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THE STOVEPIPE OR CALIFORNIA METHOD OF WELL DRILLING AS PRACTICED IN ARIZONA

By Harold C. Schwalen

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CONTENTS

ILLUSTRATIONS

TABLES

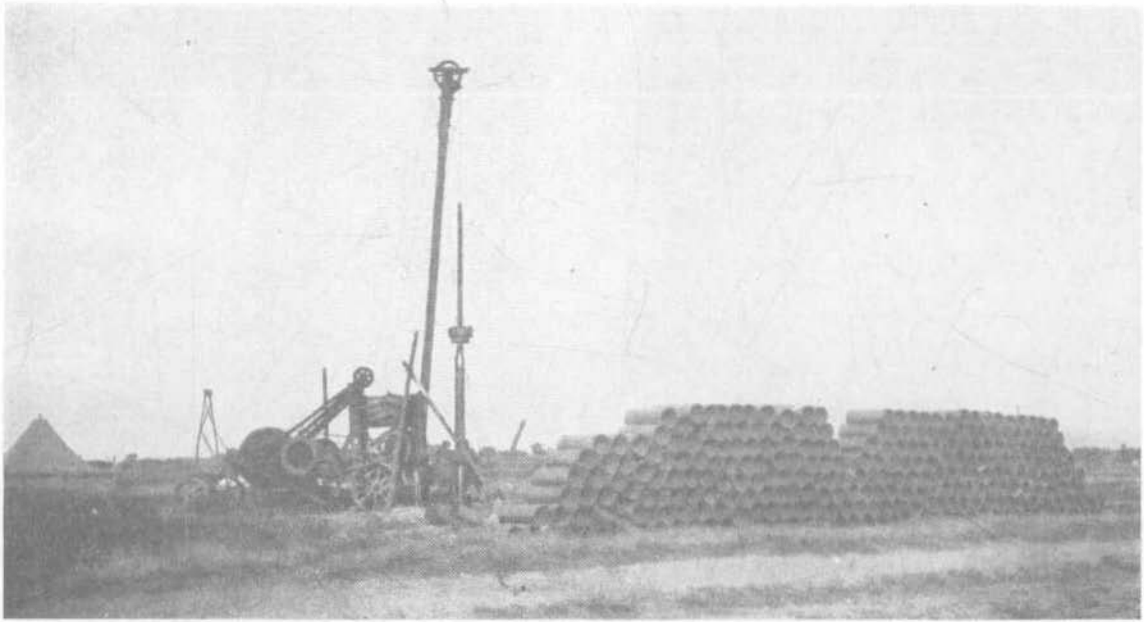

Fig. 1.—A churn-drilling rig specially equipped to handle stovepipe casing and for drilling with a mud-scow. A single string of 16-inch stovepipe casing was carried to a depth of 1,218 feet, with this rig, in a well near Yuma, Arizona.

THE STOVEPIPE OR CALIFORNIA METHOD OF WELL DRILLING AS PRACTICED IN ARIZONA*

By Harold C. Schwalen

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INTRODUCTION

The shallow groundwaters in Arizona available for irrigation are found in the unconsolidated valley fills of the Quarternary Period, consisting of alternate strata of clays, sands, and gravels with some boulders. It is by tapping the more porous of these water-bearing strata of sands and gravels that a supply of water sufficient for irrigation purposes is secured.

The first types of wells put down were the ordinary dug wells or pits, sometimes as large as 10 feet in width *by* 30 feet in length, with plank curbing and framed with heavy timbers. In most cases it was found almost impossible to get these wells deep enough into the water-bearing strata to furnish sufficient water for irrigating. Sinee 1908 a number of wells have been sunk using reinforced-concrete cassions as curbs. This type of well has proved to be very satisfactory where the first water stratum furnishes sufficient water, but its use is limited by this condition.

The drilled well that may be driven to any desired depth, properly perforated to tap the water-bearing strata, has proved to be satisfactory. It has the additional advantage that alkaline or other undesirable water-bearing strata may be cut off.

The well for irrigation purposes is ordinarily from 16 to 20 inches in diameter and from 150 to 300 feet in depth. To drill a well of this type, in material consisting of loose boulders, gravels, running sands, and clays, it has been found that the California or stovepipe method of well-drilling is the most successful. This method was originated in California somewhat over 30 years ago, where conditions, similar to those in Arizona, had to be met.

*Presented as a thesis as a partial requirement for the degree of Master of Science in Civil Engineering, and later revised for publication as a bulletin of the Arizona Agricultural Experiment Station

Strictly speaking, the California or stovepipe method of well-drilling is the drilling of wells with a mud-scow using the stovepipe casing which is forced down with hydraulic jacks. The mud-scow is a drilling tool, similar to the ordinary sand bucket or bailer, but it is made extra heavy and is equipped with a heavy, steel cutting-shoe. It serves both as a drilling tool and as a bailer for cleaning out the hole. In Arizona the drilling is often done with solid tools or a combination of both solid tools and the mud-scow.

CASING

STOVEPIPE CASING

Stovepipe casing, or double stovepipe casing as it is sometimes called, is made of double-thickness, sheet steel, of from 8-guage to 16-guage, made up into inside and outside joints. The steel from which stovepipe casing is made, is known as hard, red steel, containing a relatively high percentage of carbon. This makes a rigid, stiff casing which will stand without collapsing, the high pressures required to force it into the hole. The joints are made in 2, 3, and 4-foot lengths, from 4 to 36 inches in diameter, rolled into shape and with vertical, single-riveted, lap joints.

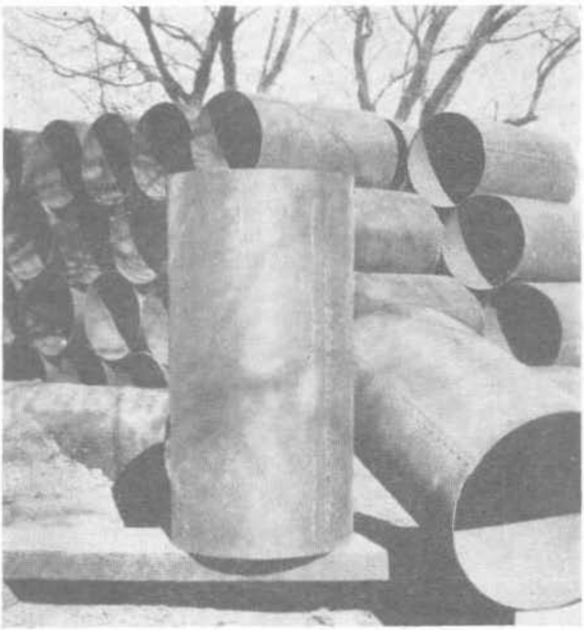

Fig. 2.—An inside and an outside joint of 18-inch, 10-guage stovepipe casing with a pile of casing in the rear.

The rivets in the inside joints are countersunk on the outside while those in the outside joints are countersunk on the inside; this affords a ready means of distinguishing them, besides providing a smooth surface of contact. The inside joints are made just small enough to telescope into the outside joints and fit snugly.

The inside and outside joints are put together over-lapping each other by one-half the length of a joint; thus, two inside joints butt together midway from the ends of an outside joint. In figure 2 an inside and an outside joint are shown with a pile of casing in the background.

The proper weight of casing depends theoretically upon the diameter of the well and the depth to which it is to be drilled. The character of the formation in which the well is drilled must also be taken into consideration. If the material is hard and cemented, or full of large boulders, or consists of loose, caving gravel, the chances are that a very great pressure will be required to force the casing down, in which case heavier casing than that ordinarily used is desirable. Practical experience has shown that for wells 18 inches and larger, in diameter, or wells 250 feet or more in depth, 10-guage casing should be used. For wells 16 inches in diameter and less, up to 250 feet deep, the 12-guage casing has been found satisfactory. Where the life of the casing must be taken into consideration, it may be cheaper to use the 10-guage, although drilling conditions will permit the use of lighter weight casing. For small-diameter wells the 14-guage casing is sometimes used.

In general, wells put down for irrigation purposes are not less than 12 inches in diameter. High-capacity, turbine, centrifugal pumps are, as a rule, more efficient in types with large-diameter bowls, and for this reason wells of 24-inch and 26-inch diameters in many cases are put clown. Mention should be made here that several large pump manufacturers are now building high-capacity, propeller pumps which require no larger than 14-inch casing. Another system is to use 24-inch casing down to the depth at which the bowls of the pump are to be set, and from there use only a 12 or 16-inch casing. Oftentimes when starting a well in new territory, where it is not known how far a single string of casing can be carried, the hole is started with a large casing so that it may be reduced later on to a smaller size. In some territory it is known that a single string of casing can be forced only to a certain depth, so the starting size is always large enough that it may be reduced later on.

In describing stovepipe casing, the weight or thickness is specified by the guage of the sheet steel; the inside diameter and also the length of joint desired are given. Table I gives the weights per foot of stovepipe casing of various diameters and thicknesses.

TABLE I.—WEIGHTS PER FOOT OF DOUBLE STOVEPIPE CASING

Diameter of casing*	Gauge of Casing				
	16	14	12	10	8
Inches	Pounds	Pounds	Pounds	Pounds	Pounds
6	8.6	10.7	15.1	193	.
8	11.2	14.0	19.6	25.3	
10	13.9	17.4	24.4	31.3	-
12	16.3	20.7	29.0	37.3	-
14	19 2	24.1	33.7	43 3	55 0
16	21.9	27.4	38.3	49.3	62.0
18	24 7	30.9	43.2	55 5	70.0
20	27.3	34.1	47.8	61 5	78.0
22	29.9	37.4	52.3	67.3	85 6
24	32.5	40.7	57.0	73 2	93 0
26	---	---	62.5	80.5	98 5

If additional casing is needed to complete a well it should be secured from the same manufacturer as that already in the hole. It is found sometimes that there is enough difference in size between the cabings of two manufacturers that they will not fit together. For this reason, also, the weights of stovepipe casing may van somewhat from those given in Table I.

Stovepipe casing is not water-tight when first put together, but after standing in a hole for some time rust is formed and silt and clay also gradually work into any openings, so that it does become practically water-tight.

SPECIALS

Specials are inside or outside joints made either longer or shorter than regular joints. They are often called "longs" or "shorts" and are used when a difference in length of the inside and outside casing joints causes the horizontal butt joints between the casing to creep together. They are often made in the field by cutting off 5 or 6 inches of the end of a regular joint with a cold chisel and then finishing off the edge with a file.

SECTIONS

Built-up lengths of stovepipe casing in which the inside and outside joints are riveted together are called sections, They are made to order in any length specified and the cost is about 10 percent more than for ordinary casing. The use of sections effects a saving of time in putting together the string of casing when starting a hole in the bottom of a pit, for the casing must reach up to the ground surface. They are used for the same purpose when the size of the hole is reduced in starting the second (smaller) string of casing inside the first.

ADAPTERS

In wells in which two sizes of casing are used, an adapter can he set down in the well over the top of the inside casing when it has been cut off. Often in the process of cutting off the inside casing the top joint left in the well springs out of shape or is knocked to one side. The adapter helps to keep it in shape and albo to center it and, in addition, it serves as a funnel to direct the tools or the suction pipe of a pump into the lower casing.

A type commonly seen in Arizona is made of single-thickness, riveted, sheet metal of the same guage as the casing. It is made in the shape of a double funnel with a short, straight section in the center about one foot long, and of the same diameter as the inside casing. The two ends are slightly less in diameter than the large casing and taper down to the short

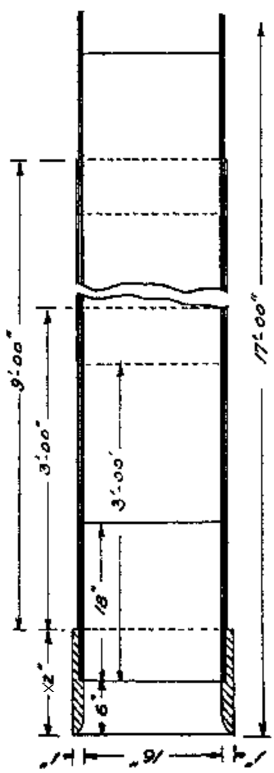

Fig. 3.—Design of a 3-ply starter for 16-inch casing with a 12-inch shoe or well ring. This starter has proved to be very satisfactory for use in the Santa Cruz Valley,

center section in about three feet. The overall length of an adapter of this type is approximately seven feet.

Adapters are often made up according to the ideas of the individual driller to fit special conditions.

STARTERS

The starter consists of a specially built-up section of 2, 3, or 4-ply casing which is meted to a properly recessed, steel, drive shoe (Fig. 3). The built-up section is made of the same guage sheet steel as the casing and may consist of only 2-ply casing, or of both the 3-ply and the 2-ply casing. For shallow wells and where no particular trouble is expected in forcing the casing down, light starters are used, made up of only 10 or 12 feet of 2-ply casing. On the other hand, if considerable difficulty is expected in putting down the casing, or if the well is to go down 400 or 500 feet or more, a heavy starter is required. It may be made up of from 9 to 15 feet of 3-ply, and from 6 to 9 feet of 2-ply casing. Sometimes no starter is used, but the casing is started on the drive shoe. However, in most cases the starter is used as its use makes it much easier to start and keep a well straight and plumb.

WELL RINGS

Steel drive shoes, or well rings, are made in sizes from 3 to 20 inches in length and from ½ to 1½ inches in thickness, the size depending partly upon the diameter. The sizes most commonly used in irrigation wells are those 10 or 12 inches in length and 1 or 1¼ inches thick. The inside of the shoe is recessed for a distance of 6 or 8 inches, and to a depth of two or three thicknesses of casing, depending upon the thickness of the starter used, so that the inside of the starter and shoe form a smooth surface. The starter and shoe are securely riveted together.

Starters built up as the one shown in figure 3 have been used in a large number of wells, near Tucson, Arizona. The wells were drilled in the Quarternary valley fills consisting of strata of clays, gravels, sands, and boulders, which are in some cases cemented with calcareous material.

OTHER CASING

In a few cases, single, stovepipe casing is used in wells. The joints are then put together with single, strap-riveted, butt joints or with single-riveted, lap joints. However, where the expression "stovepipe casing" is used, the double stovepipe casing is always referred to.

For small wells new or second-hand, screw casing or standard pipe is sometimes used when it can be secured at low cost.

DRILLING RIGS

GENERAL FEATURES

In Arizona there are in general two types of drilling rigs used in putting down stovepipe casing. The first type includes those rigs similar to the regular California mud-scrow rig, and the second type the ordinary churn drills put out by many manufacturers. Only portable drilling rigs are considered here, for as a rule, they are the kind used for water-well work.

The drilling machinery of all portable rigs is mounted upon a heavy bed frame which is supported on trucks. It is important that this frame be designed correctly and that the sills and crosspieces be of ample size, straight-grained and clear timber. The rig itself should be so designed that excessive stress is not developed in any of its members while drilling. The drilling rig is subjected to the racking strain of alternately picking up and dropping, from 30 to 50 times a minute, a heavy string of tools weighing between 1 and 2 tons.

In the case of steam rigs the engine is usually mounted on the same frame as the rig, as is also the boiler, except on very large rigs where the boiler is mounted separately. The running of the engine alone is sufficient to impart a continuous vibration to the rig. Practically all the manufacturers of portable drilling rigs now put out machines equipped with gasoline or oil engines. It has been the aim of manufacturers to design a gasoline or oil engine which can be operated under varying loads with a wide range of speed, and which is under the immediate control of the operator. Some manufacturers now claim that their rigs are equipped with oil engines which fulfill these requirements.

So far as drilling alone is concerned most drillers prefer the steam engine to the internal combustion engine. The speed of a steam engine is under the absolute control of the operator. It is more flexible and will carry loads under which the gas engine would at once stall. The steam engines used on drilling rigs are all of the reversible type, so that their direction of rotation may be almost instantly reversed.

Under Arizona conditions, however, where the cost of boiler fuel together with the haulage charges on both fuel and water would "in many cases be prohibitive, the rig with the gasoline or oil engine is preferred.

CALIFORNIA RIGS

The machine shown in figure 4 is one similar to those usually seen in Arizona, of the California portable type, and it is referred to in the following description, unless some other figure is designated. The front running gear Is easily detached so that the rig may be lowered onto heavy mud-sills, 14 inches by 14 inches or larger and the rear wheels are also

Fig. 4.—A large California or mud-scow rig of the type most commonly seen in Arizona. Note the heavy construction of the A-frame mast and rear braces.

lowered to level up the machine. This has the advantage of lowering the center of gravity of the whole rig. Other drillers support the front end of the machine on two screw jacks taking the weight off the wheels.

The mast is made in the shape of an "A" frame of 3½ by 11-inch timbers strongly laced and braced, and stands about thirty-six feet high. In drilling position it is held vertical by two diagonal, 3 by 5-inch braces from the rear end of the rig frame and by guy wires to the sides.

In moving position the mast rests in a horizontal position on its hinged supports in front, and upon uprights in the rear.

The distinguishing feature of the California type of rig is the walking beam, which may be of either wood or steel and is pivoted on the top of the mast. The walking beam on this rig is made of two 10-inch, 20-pound, channel irons 10 feet long. The pivot bearing is supported by a car spring to take part of the jar and strain off the rig when drilling. The crown pulley is placed on the front end of the walking beam,

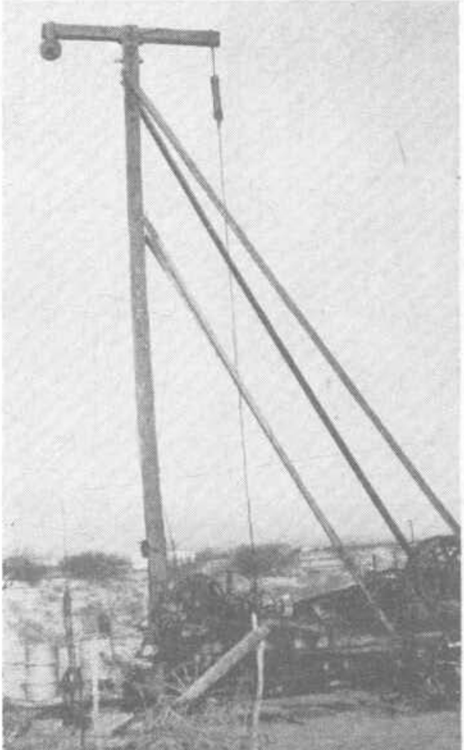

Fig. 5.—A small drilling rig of the California type which is equipped with a drilling line only and without either a sand line or hydraulic pumps.

and the rear end is connected to the rig irons by the tail rod. In this case the tail rods are double-strength, 2-inch pipe, both ends fitted with pin bearings. A reciprocating motion is given the walking beam by the crank to which the lower end of the tail rod is fastened. A stroke of 12, 18, or 24 inches is secured by changing the position of the crank pin.

Fig. 6.—A large tractor rig of the California type. The framework to the right of the rig was used in testing the well with an air lift.

Tail rods of pipe or wood are most commonly used, but sometimes steel cable is used for this purpose as is seen in figure 5. The large rig shown in figure 6 has wooden tail rods.

All except the small California or mud-scow rigs are equipped with a light, steel line, about ½-inch in diameter, in addition to the drilling line. This cable is used to lower a bailer or sand pump when necessary, and has by common usage become known as the sand line. The sand-line pulley is hung from the front end of the walking beam, below the crown pulley (Fig. 4).

The rig irons are located on the front end of the rig and the power is transmitted from the band-wheel shaft by spur gearing and chain drive. The sand-line reel is above the frame on the back of the vertical mast braces, and just below is the drilling-line reel. Back of this is the crank shaft with its gearing and then the band wheel and shaft. The clutches are all of the internal-expanding, drum type, each with composition brake lining. The arrangement of the rig irons on practically all the California rigs is very similar to that in figure 7 which shows their arrangement on one of the larger rigs. The driller has complete control of his tools and of the various parts of the machine from his position in front of the rig, the sand-line and drilling-line clutch handles being on the right side, the drilling and pump-clutch handles on the left side, and the pressure gage and valves to the hydraulic jacks in the center. The governor of the engine is also controlled by a lever at the front of the rig, enabling the driller to adjust the speed of the engine without leaving his position.

The hydraulic, pressure pump is seen on the near side of the rig placed on a shelf and is chain-driven direct from the band-wheel shaft.

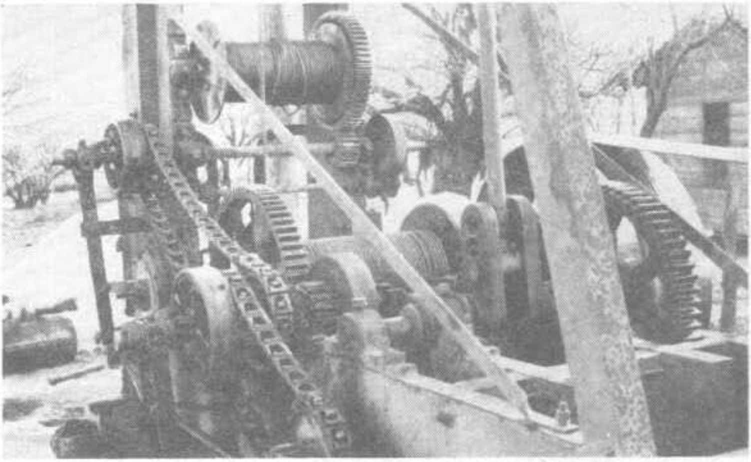

Fig. 7.—Arrangement of the rig irons on a large drilling rig of the California type. Note that gear and chain drive is used throughout, with the exception of the belt drive from the engine to the band wheel.

The hydraulic, pressure pumps are all of the double-acting, solid-plunger type. The cylinders and frames are made of semi-steel castings and the valves and seats of special bronze. The crank shaft is made of special steel and the plungers of steel or bronze. They may be either chain-driven, direct gear-driven, or belt and gear-driven. The pumps are all tested under a very high, hydraulic pressure before they leave the factory, one company testing their pumps to 4000 pounds pressure, although they are assumed to be operated at about 2000 pounds pressure per square inch. The size of the pump is designated by the diameter of the plungers and the length of the stroke. The table given below shows the different sizes of pumps made by one manufacturing firm, and the size jacks each will handle.

TABLE II.—HYDRAULIC PRESSURE PUMPS AND THE CORRESPONDING SIZE HYDRAULIC JACK

Hydraulic pumps					Hydraulic jacks	
Diameter of plunger	Length of stroke	Capacity	Speed	Pressure in pounds per sq in	Diameter of cylinder	Approximate weight
In.	In	G P M.	R P.M.	Lb	In	Lb
1¼	7	8	110	2000	6 or 7	500
1%	7	9½	110	2000	7 or 8	550
1%	7	11%	no	2000	2 pr 7	600
1⅝	7	13	110	2000	2 pr 8	650

The power on the rig shown m figure 4 is supplied by a 20 h.p. horizontal oil engine mounted on the rear of the frame. The engine is of the electric ignition type, equipped with a high-tension magneto and uses tops, a fuel oil of between 38° and 42° B. gravity. The cooling water is circulated by a 1-inch, centrifugal pump belted to the engine. The California type of rigs used in Arizona are all equipped with internal-combustion engines, the larger si/es burning tops, the smaller ones burning distillate or gasoline. In California the first rigs of this type were operated with steam power, probably because they were modified from the standard rigs to meet special conditions encountered in water-well drilling. In "Water-Supply and Irrigation Paper" No. 140,* are some excellent plates showing the earlier types of these rigs which are similar to the rigs used at present, except that they are equipped to use steam power.

Practically all the so-called California or mud-scow rigs are built along lines similar to the rig which has been described. Because of the high freight rates many rigs are built up by the individual drillers who order their rig irons and mount them according to their own ideas. This results in some changes in the minor details of the rigs but it does not result in any radical departure from the ordinary type.

The small rig in figure 5 is not equipped with either hydraulic pumps or sand line. This rig is used on small-diameter and shallow holes, only an 8 h. p. gasoline engine being used for power. This rig has steel cable in place of tail rods and has shock absorber springs connected in the cable near the top. Figure 6 showb one of the heaviest of the California, traction-type rigs ever used in this State. It is equipped with a 25 h. p. engine and ib rated as capable of drilling a 24-inch well to 1000 feet. The tail rods on this machine are of wood.

Few tractor drilling rigs of any type are seen in Arizona, partly because of the increased first cost but also because of the added weight, which increases the difficulty and expense of moving.

*Charles S. Slichter, 1905. Field Measurements of the Rate of Movement of Underground Water

CHURN-DRILLING RIGS

This includes other rigs than those having a walking beam at the top of the mast, or tower. There may be a walking beam built in, as an integral part of the rig, about ten feet above the ground, or in the case of small rigs there may be no walking beam, all the drilling being done over the crown pulley, in the top of the mast.

Churn-drilling rigs, when used in putting down large stovepipe wells, are equipped with hydraulic pumps as auxiliary equipment. The churn-drilling rig, as a rule, is not as efficient in the use of the mud-scow and stovepipe casing as is the California rig, for it has been developed essentially for the use of solid-drop tools. However, at least one of the large companies manufacturing churn-drilling rigs puts out a gasoline rig specially equipped and adapted to the use of a mud-scow and stovepipe casing.

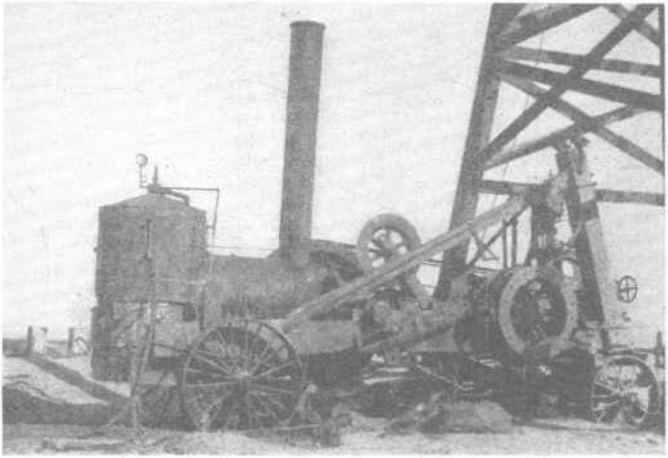

Fig. 8.—The steam rig referred to on page 131, with which four 20-inch, 500-foot wells were drilled for the City of Tucson.

Ordinarily the walking beam is a part of the churn-drilling rig and a special spudding attachment is used for spudding-in the well over the mast. The expression "spudding-in a well" is now generally accepted as meaning that the actual drilling has been started. Strictly speaking, it is the drilling of a well over the mast or derrick when the hole is first started. These various spudding attachments on the different rigs are all designed to give a reciprocating motion to the tools, so that the down-stroke is made in much less time than the upstroke. Thus, the tools are dropped quickly and picked up slowly. Except on the small rigs not equipped with walking beams, it is assumed that the spudding arrangement working over the crown pulley or the mast is to be used only to a depth of 100 or 200 feet. For this reason the masts are not made as strong as on California rigs where all the drilling is done over them.

All churn-drilling rigs are equipped with some sort of spudding arrangement to give the tools a reciprocating motion up and down when first starting a hole. The different manufacturers all give reasons why their rigs are the best in this respect, but all of them are somewhat similar in that they endeavor to give a quick drop to the tools and pick them up with a steady stroke. The constant bending of cable or rope over pulleys when drilling this way causes it to wear out rapidly, and to prevent this many of the spudding arrangements have been designed so that the pulleys run over the cable.

The portable, churn-drilling rig in figure 8 is a steam rig with a T-boiler mounted on the rear of the frame. This rig embodies several features of the standard rig in its construction. In place of the single pole mast, with which the rig is regularly equipped, a 4-post derrick has been built, and the drilling is all done over the crown pulley in the derrick, for which reason the walking beam has not been mounted. When the walking beam is in use, it is pivoted on a samson post on the right side of the rig and is connected by the p tman to the wrist pin in the crank arm of the band wheel. The bull-wheel gear is driven by a spur pinion and shaft on the other end of which is a friction pulley operating on the outside of the band wheel. The bull reel is equipped with a wooden brake wheel about three feet in diameter and a 6-inch, steel brake band. The sand reel is operated directly by a friction pulley on the end of the shaft working inside the band wheel. The spudding arm to which is attached the spudding pulley, is given a variable speed by the sliding link connection to the crank pin of the band wheel. The engine is of the vertical, reversing type, mounted on the left front of the frame where it partly balances the samson post and walking beam on the right. A large steam rig, with separately-mounted boiler, is shown in figure 9 in which the lower end of the pitman has been hooked down to the rear wheel, thus holding the front end of the walking beam out of the way while the tools are being lowered into the hole.

Most churn drills are equipped with walking beams all designed for the purpose of giving a long stroke to the tools when the hole gets deeper and to decrease the wear and tear on the cable or rope. In drilling over the mast all the parts of the rig arc subjected to greater strain than when the walking beam is used, because of the increased leverage. There are several different types of walking beams: (1) The center beam, mounted in the center and usually supported by the mast; (2) the double beam consisting of two beams, one on each side of the rig, and connected together with a crosspiece on the front end; and, (3) the side beam mounted on one side of the rig. The first two types balance the rig better than does the side beam, especially on small rigs. It cannot be said that any one rig is superior to the others. They all have some particular points that are very good or they could not continue to be sold, since a well rig is one machine that must make good or it is very soon off the market.

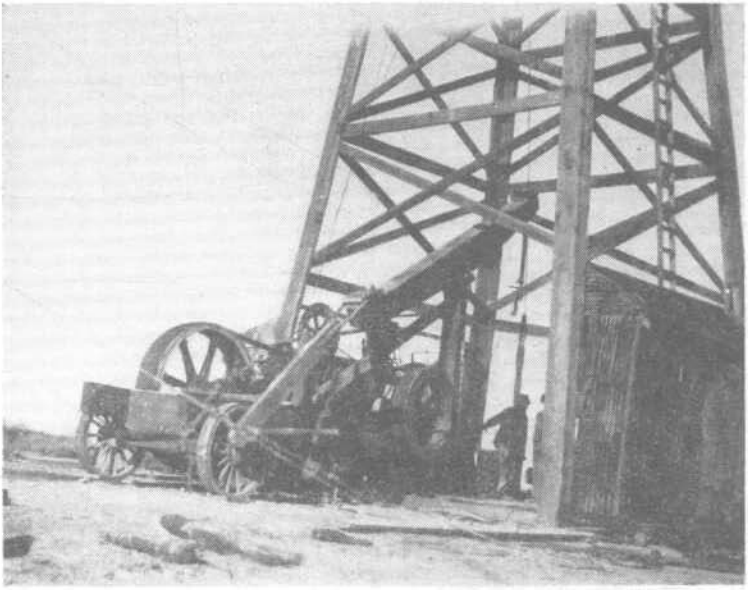

Fig. 9.—Large, portable, steam rig on State well near San Simon, Arizona. The driller has his hand on the brake lever and is lowering the tools into the well.

DRILLING TOOLS AND EQUIPMENT

DRILLING TOOLS

Practically all drop tools are made now with the tapered screw joints, A joint called the I & H joint is now recognized as standard. This joint is made with a taper of 24°, or ¼ inch to 1 inch, with either seven or eight V-threads per inch, or seven flat threads per inch. The size of a joint given, as 2 by 3 by 7 is one that has a diameter at the end of the pin of 2 inches, a diameter at the base of the pin of 3 inches, and seven threads per inch. The drilling tools are made with square sections at each end, upon which the heavy tool wrenches are

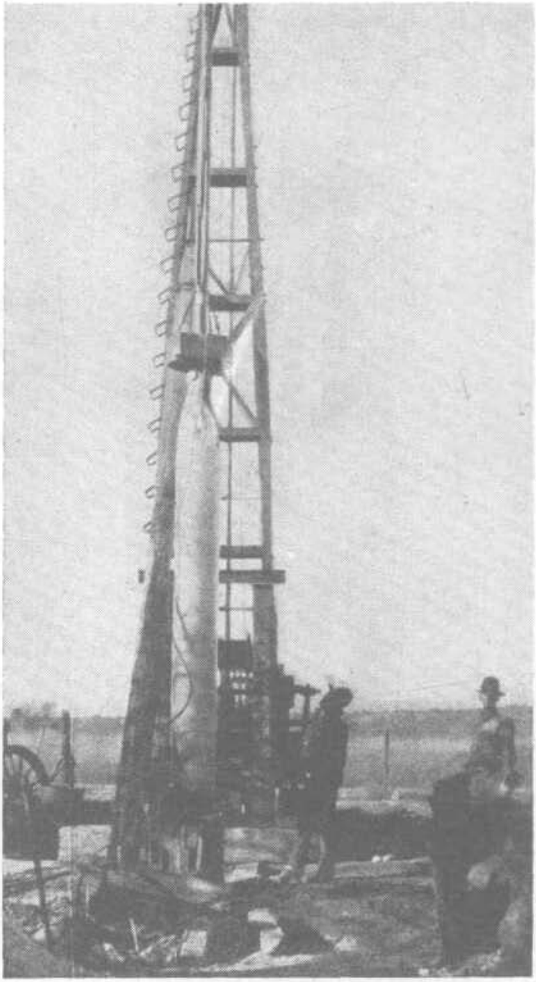

Fig. 10.—A complete string of tools used in drilling an 18-inch hole, consisting of a clevis or jaw cable socket, sub, jars, sub, and 16-inch mud-scow. The heavy casing cap is suspended from the jars by a short cable as the mud-scow is so large that it will not go up through the hole in the cap.

used in setting up the screw joints. The size of the joint is always marked on the collar, which is the round part of the tool between the joint and the wrench squares. The tapered joint has proved to be superior to other types in strength, and also has an additional advantage in that only a few turns are necessary to screw a joint up tight. Between the collar and pin a square shoulder is turned, which varies from ½ to over 1 inch in width, depending upon the size of joint. This shoulder makes a butt joint with the end of the box, which causes a wedging action to take place between the threads, resulting in a tight and rigid joint.

The string of tools ordinarily used with the California or mud-scow rig consists of a jaw or clevis cable socket, sub from cable socket to jars, jars, sub from jars to mud-scow, and the mud-scow. In figure 10 a string of tools with a mud-scow is shown hanging from the mast. The regular string used with the churn drill consists of rope or cable socket, jars, stem, and bit.

Steel cable sockets are usually made with a tapered hole drilled through them increasing in diameter towards the bottom of the hole. The end of the cable is pulled through, the strands separated, and part of them bent back. The cable is then pulled back into the socket and melted babbit poured in. This, when cool makes a joint that will not pull out. Care must be taken that babbit metal and not lead is used, for the lead will not hold. The light, steel, cable socket much used with the mud-scow is made with a jaw or clevis in place of the regular box. It is called a jaw or clevis socket and is made with a square hole and pin for connecting to a tongue and box sub. There are several patented sockets in which the cable is fastened to a swivel which fits up in the socket. During the short interval in the stroke in which the cable does not carry the weight of the tools, the twist in the cable is sufficient to turn it and the swivel in the socket. The tools are kept turning in the hole *by* this method.

Rope sockets are made in several different styles, the most common types being the Solid socket, Wing socket, and the New Era socket. In the Solid socket a hole, slightly larger than the diameter of the rope, is drilled straight Into the end of the rope socket. A piece 4 or 5 feet long is cut off the end of the rope from which loose strands are secured. The end of the rope is now tightly wrapped with some of these strands and then forced into the end of the rope socket. Through the upper end of the socket 3 or 4 holes about ½ inch in diameter have been drilled. A pointed iron rod is driven through these holes, and cut off and riveted on both ends, thus preventing the cable from pulling out. The Wing socket is made lighter than the other types, with the end split so the wings may be spread apart. After the rope has been placed in the socket, the wings are driven up tight against the rope and riveted together with rivets through the rope the same as in the Solid socket. The New Era socket has a hole, the size of the rope, drilled straight in the end of the socket and brought out on the side with a gradually increasing taper. The rope is pulled through the socket about two feet and three plies of the rope are separated up to the socket, where a number of loose strands are laid between them. They are then twisted together again and the rope wrapped tightly to the end. The rope is pulled back up into the tapered hole where it wedges fast. Any piece left projecting is cut off. The New Era rope socket may be used with steel cable also, but requires more babbit metal to fill the large hole. Both rope and cable sockets are as a rule made with a threaded box on the lower end for fastening to other tools.

A set of jars is made up of two pairs of linked bars having a play or stroke of from 6 to 36 inches. The ordinary drilling jars used with

Fig. 11.—Drill stem with drive clamps bolted on to the upper wrench squares for driving casing. Note the drive head at the lower end of the stem, used to protect the end of the casing.

solid tools have a stroke of only 6 to 12 inches, while those used with a mud-scow are long btroke or fishing jars having a stroke of about 30 inches. The jars do not help in the drilling except that one-half the weight of the jars is added to that of the drilling tools; they are used only as a safety measure in case the tools become stuck in the hole. An upward blow may then be struck with the jars which has proved much more effective in getting the tools loose than a steady pull on the drilling cable. A box joint is cut on one end of the jars and a pin joint on the other. Jars are made by hand of a special composition steel.

A sub or substitute is used to connect tools with either different sizes of joints or different types of joints. In connecting the jars to the mud-scow the sub is made with the taper pin joint on one end and a tongue on the other with a round hole in it. This is called a pin and tongue sub. A box and tongue sub is used between jars and a jaw, cable socket.

The mud-scow is made of heavy pipe, or of about ¼ inch steel plate. It is fitted on the bottom with a plain, flap valve and a heavy shoe somewhat similar to a casing or drive shoe, the cutting edge of which is tapered out slightly at the bottom to give it clearance in cutting. The upper end is fitted with two heavy ears or reins, which are fastened securely with stud bolts to the body of the scow, and extend about two feet. A round pin is used to fasten the tongue of the sub to the reins of the mud-scow forming a knuckle joint.

With solid, drop tools a stem is used below the jars to give weight to the string of tools. For use with portable rigs they are usually not over 18 or 20 feet in length and about four inches in diameter, and are made with the regular box and pin joints. The length of the stem which can be used is limited by the height of the mast or derrick on most small rigs. A stem is shown in figure 11 without any jars. It has been used for driving casing only and the drive clamps may be seen bolted near the top.

The bit used with the solid, drop tools in water-well work is called a spudding bit; it is only from 3 to 4 feet long and is thinner than the regular drilling bits. This type of bit has been found satisfactory for drilling in the unconsolidated or cemented formations in which our wells are drilled. In figure 12 is shown the type of bit commonly used in well-drilling work, while in figure 13 is shown a bit used in regular drilling work in hard, fissured rock or shale. Regular drilling bits axe 5 or 6 feet in length and may be what is known as a welded bit or an all-steel bit. In the welded bit, the upper or pin end of the bit is made of soft steel which will not crystallize; the lower end is made of high-carbon tool steel which admits of taking a good temper. The all-steel bits are made of tool steel throughout, and the pin, even though annealed, has a tendency to

Fig. 12.—The type of bit ordinarily used for drilling large-diameter wells, with a 4-foot carpenter's rule standing alongside.

Fig. 13.—A Mother Hubbard, all-steel, hard-rock bit, about six feet long, used in drilling small holes.

become crystallized, due to the constant hammering which it receives from the stem, thus making a weak place in the string of tools. The regular bits are used by well drillers in Arizona for small holes 6 or 8 inches in diameter in hard formation.

A bailer or sand bucket is used for cleaning the drill cuttings out of the hole. It is usually made out of a length of pipe or casing and is fitted with a bail on one end, and either a dart or flap valve on the other. The sand bucket with the flap valve has to be up-ended to empty it, so as a rule sand buckets of this type over 16 feet in length, are not used.

FISHING TOOLS

Fishing tools are made for almost every conceivable kind of fishing job, but the number of tools used makes it practically impossible for the ordinary driller to carry a stock of them. The most common fishing

Fig. 14.—Group of fishing tools, from left to right as follows: Spud, rope or cable spear, horn socket, slip socket, and combination socket.

tools are: (1) Manila and wire-rope knives for cutting off the drilling line close to the tools; (2) horn or slip sockets for taking hold of loose tools in the hole, or to take hold of the collar of tools in the hole; (3) a combination socket to take hold of a pin or the neck of a rope socket; (4) a rope or wire-line spear for catching hold of a broken drilling line; and, (5) a spud for loosening tools fast in the hole or spudding around them. A number of fishing tools are shown in figure 14. Most fishing tools are operated on a regular string of tools with fishing or long-stroke jars.

Several companies have been organized in California which make a business of renting fishing and drilling tools. They send out a rental list and usually charge a certain amount for the first day, and a fixed sum for every day thereafter. Rental charges are computed from the time the tools leave the company until returned to them, and the user also pays freight or transportation charges. Fishing tools are costly and in many cases the rental alone is prohibitive, for it is not known that they will be successful even if tried.

MANILA AND STEEL CABLES

Both manila cable and steel cable have been used for drilling line but the steel cable being cheaper and having a longer life is now used almost exclusively. Manila drilling line is known as hawser-laid, made up of the three main plies which in turn are each made up of three other plies of

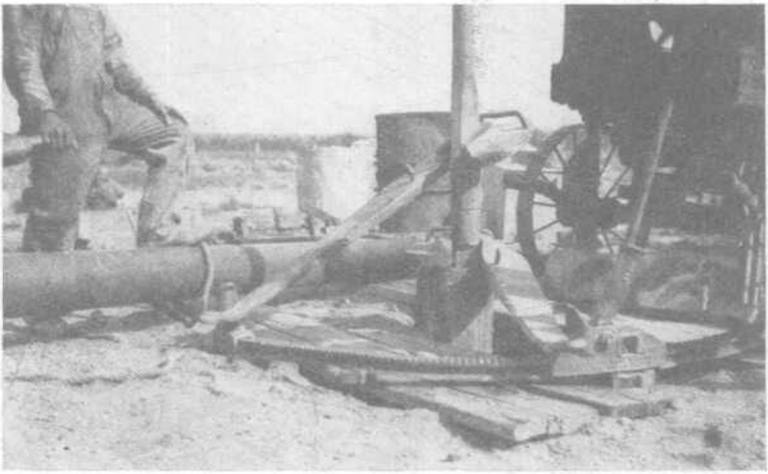

Fig. 15.—Setting up the tool joints with a jack and circular track.

the best grade manila hemp. Manila cable has more stretch and spring than steel cable and is more flexible. It puts much less strain on the drilling machine and for shallow holes has several other advantages over the steel cable. For these reasons a "cracker" or short piece of manila cable is sometimes used next to the drill tools and is spliced to the steel cable.

The sand line is a steel cable usually from ⅜ to ⅝ inch in diameter, depending upon the size of the rig.

HYDRAULIC JACKS

One of the most important parts of the equipment used in putting down stovepipe casing is the set of hydraulic jacks. They are made in sizes from 6 to 10 inches in diameter and the usual length of stroke is from 4½ to 6 feet, depending partly upon the length of the casing joints used. The jacks are made to withstand pressures of from 2000 to 4000 pounds per square inch, with semi-steel cylinders and heads, the heads being held in place with heavy, steel bolts from one end to the other. The piston rod is made of cold-drawn steel securely fastened to the piston at one end and fitted with a steel clevis on the other end.

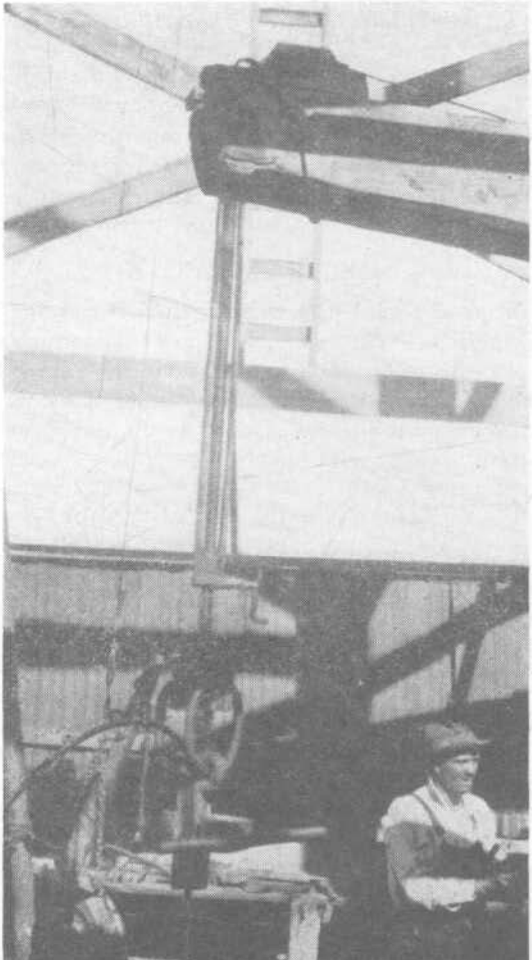

Fig. 16.—Temper screw, with cable clamps, hanging from the walking beam in drilling position.

TOOL WRENCHES

Wrench squares are provided on all tools with screw joints upon which heavy, forged, steel wrenches are placed in tightening the joints. A set of wrenches consists of a right-hand wrench and a left-hand wrench. In setting up the joints a circular track and jack are used with the wrenches as shown in figure 15. Joints 2 by 3 by 7 inches and smaller may be set up with a lever bar and chain in place of the jack and circular track.

TEMPER SCREW

The temper screw is the tool used to connect the drilling cable to the walking beam on a churn drill. There are several types but they are all made on the same general principle and consist of a frame or reins, main screw with yoke, a ball-bearing swivel, and clamps for fastening to the drilling cable. One of the types most commonly used may be seen in figure 16.

DRIVE CLAMPS

Drive clamps of forged steel weighing from 50 to 300 pounds are made for driving pipe. They are recessed to fit the wrench squares and are held in place by a heavy bolt on each side. In driving casing they are usually clamped to the upper wrench square of the stem. In figure 11 a set of drive clamps is shown attached to the upper wrench squares of the drill stem.

DRILLING OPERATIONS

SETTING UP THE RIG

Usually the rig is brought up to the well site in traveling position and placed so that the hole will be approximately where desired, that is, within 2 or 3 feet. The front end of the rig is raised with jacks and blocked up to take the weight off the running gear, or the running gear may be removed and the frame lowered upon heavy mud-sills. Sometimes the rear wheels are set on blocks and wedged or they may be lowered into small holes dug in the ground, as may be necessary to level the frame of the rig. The rig shown in figure 4 has been set on heavy blocks, both in front and rear. Placing a rig on a solid foundation saves it from much wear and tear by eliminating a great deal of the vibration, and thus increases the efficiency of it as a whole.

Raising the mast is done on many rigs by a small windlass on the front end of the machine which is either hand-operated with a crank, or with power from the engine. To save time the drilling and sand lines are threaded through their respective pulleys and the guy wires and braces are fastened to the mast before it is raised. The mast being raised, guy wires and braces are securely fastened either to stakes or to deadmen in the ground.

The tools are next strung up, the screw joints being set up with a wrenching bar and chain or with a sledge hammer used on the ends of the wrench handles. The latter method is used when the tools are put together on the ground surface, and the jack and track are used after the hole has been started and the tools can be lowered into it. Most drillers make a chisel mark across the joint after it has been set up, so that they can tell immediately on inspection whether any one of the joints has started to loosen. The tools hanging from the mast serve as a plumb bob for lining up the mast in a vertical position and at the same time the rig is given a final levelling all around. On churn drills using a walking beam it is necessary to make a final adjustment of the mast, either forward or backward, in order that the end of the walking beam and the outer end of the crown pulley will be very nearly in the same vertical line.

INSTALLATION OF THE JACKS

While the driller and helper are busy setting up the rig, a couple of laborers are usually engaged to dig a pit for the hydraulic jacks and the anchor timbers. The center of the pit is located where the drill hole is to be. This pit is usually about five feet wide by twelve feet long and about nine feet deep. The length is determined partly by the length of the anchor timbers, and the depth is made so that the tops of the jacks are just above the ground surface, A hole 2 or 3 feet deep and about two feet in diameter is dug in the center of the pit in which the starter is placed. The two anchor timbers are then placed in position, one on each side of the starter, and plank flooring is laid across them from one side of the pit to the other. When it is expected that very heavy duty will be required of the jacks, an installation such as is shown in figure 17 should be made. Ordinarily, diagonal braces are only run out to pieces of planking set against the ends of the pit, but the full capacity of the jacks can not be developed in this way. The starter is lined and plumbed up and then braced in position. The piping between the hydraulic pump and the jacks should be put together carefully and the jacks tested before the pit is covered up.

Churn-drilling rigs are sometimes at a disadvantage in setting in the jacks, for on many rigs the mast does not overhang far enough in front so that there is sufficient room to dig a pit for the jacks. Sometimes the pit is dug and the jacks are installed before bringing up the rig. A temporary, four-post derrick from 30 to 40 feet high may be

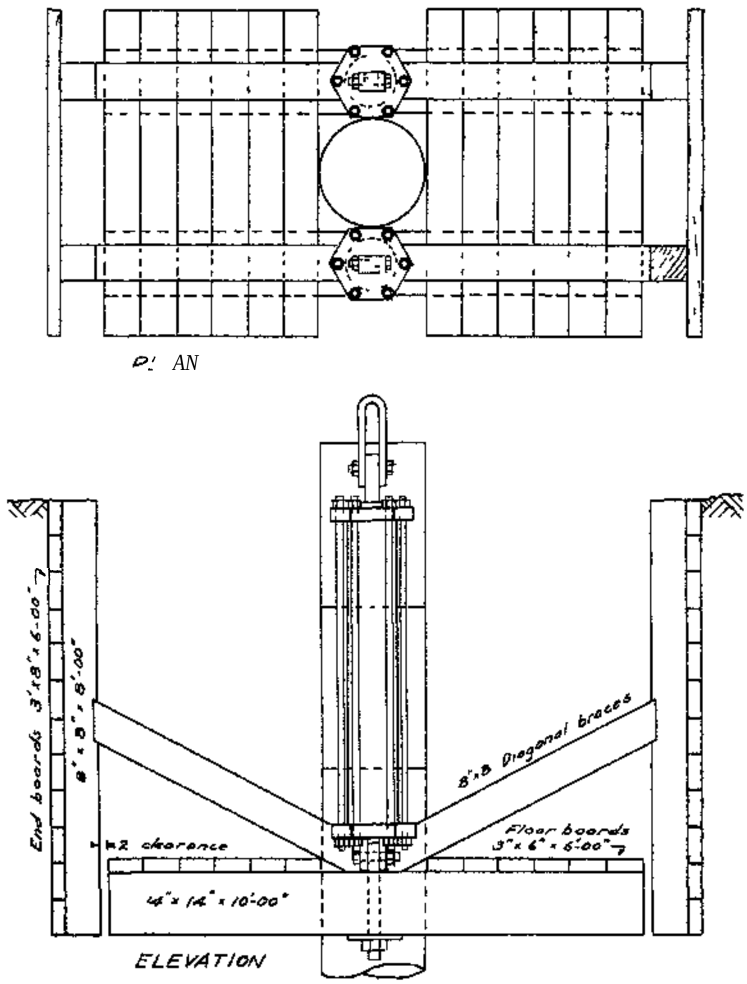

Fig 17—Installation of hydraulic jacks with end walls and diagonal bracing for heavy duty Some drillers use heavy angle irons for the diagonal or end braces

used in place of a mast and the pit dug within the derrick legs. In many cases the well is spudded-in over the crown pulley for its entire depth where a four-post derrick has been constructed.

SIZE OF DRILLING TOOLS

If a mud-scow is to be used in drilling, it should be about 2 inches less in diameter than the casing. Smaller mud-scows can be used, but they are not quite so satisfactory. If a bit is used, the size will depend to a great extent upon the character of the formation. If the formation is hard the hole cut may be but little larger than the size of the bit, in which case the bit should be just small enough to clear the inside of the casing. In loose, caving material and in sonic clays the bit may be several inches smaller than the casing. In one case where it was desired to reduce from 16-inch stovepipe casing at a depth of 120 feet, in clay formation, the 16-inch casing continued to follow to a depth of 170 feet, although only a 10-inch bit was used in drilling.

DRILLING

The expression which ib commonly used to designate that the drilling has just commenced on a well is to say that it has been spudded-in. To spud-in the well the tools are lowered to the bottom of the starter, which has previously been set and braced in position, and the clutch to the spudding attachment is thrown in, putting the tools in motion. The position of the tools in the hole is controlled by the clutch to the drilling line or bull reel, by which they can be either raised or lowered at the will of the operator, and as drilling progresses they are gradually lowered a little at a time as the hole goes down.

Water is necessary for mixing with the material drilled in with either the mud-scow or solid, drop tools. The water for drilling purposes is supplied from the surface and is poured into the top of the well as needed until the groundwater table is reached. Where a well is not cased it is sometimes necessary to lower the water into the well m a dart-bottom bailer, which is emptied by setting it on the bottom of the hole. This is done to eliminate any chance of the water running down the side of the hole, causing it to cave.

In drilling, the mud-scow is operated more slowly than are the solid, drop tools, between 30 and 40 strokes per minute being made with the former and between 50 and 60 with the latter. In spudding-in, however, until the tools are below the surface, they are run more slowly than this, as it is difficult to control the movement of the tools above the ground and prevent them from swinging sidewise.

The heavy, steel shoe on the bottom of the mud-scow may cut the material in fairly large chunks, small pieces, or even churn it into a thin mud, according to the character of the material being drilled m. On the beginning of the upstroke of the mud-scow the flap valve closes, creating a suction as the mud-scow moves upward. The loose material is thus pulled up from the bottom of the hole, and on the downstroke the flap valve is forced open and the suspended material enters the mud-scow through it. As the drilling progresses and the mud-scow gradually fills up, it no longer drops quickly, for the load in it prevents the flap from opening freely and in this way the drilling is slowed up. The closing of the flap is clearly heard when the mud-scow is empty, but as it picks up a load the sound becomes more or less muffled. The mud-scow must be withdrawn from the hole from time to time and emptied. It must be up-ended to empty it and several methods are used, one of which is shown in figure 18. Another method is to raise the bottom end of the mud-scow with the sand line, and still another common method is to use the weight of the heavy casing cap, as shown in figure 10, suspended from the lower half of the jars, in up-ending the mud-scow after it has been lowered with the shoe on the floor and balanced over a low crotch.

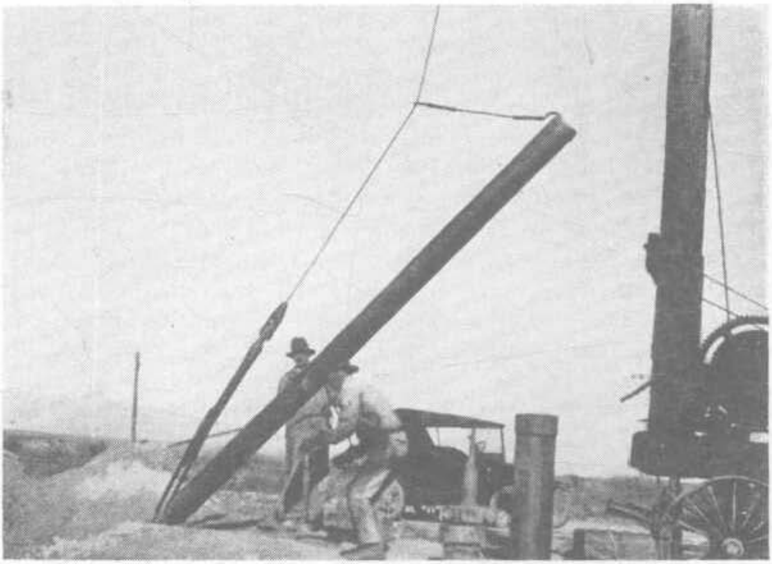

Fig. 18.—One method of up-ending a mud-scow with only one line and a short piece of cable with two hooks.

The length of the stroke in drilling with a mud-scow is varied according to the character of the material being drilled in. In clay or in hard formation, the long stroke may be used, but in loose sand or gravel with boulders, the short stroke of not over 18 inches is used. If the long stroke is used in loose formation, rocks or small boulders may be thrown up through the mud-scow and fall between it and the casing, wedging them tightly together. This happened in a 24-inch well near Tucson, Arizona, where the driller, an experienced man, spent 6 weeks' time with different tools before he finally pulled the mud-scow loose. He was able to take hold of the mud-scow with several different tools, but on pulling they all broke until at last he had a special, forged-steel hook made and using double-strength, 4-inch, standard pipe and pulling with the hydraulic jacks, he was able to free it.

When the solid, drop tools, that is, a bit and stem are used in drilling, the cuttings are usually fine enough to form a thin mud in the bottom of the hole. As more cuttings are formed, the mud becomes thicker, until the movement of the tools is slowed down to such an extent that very little progress in drilling is made. The tools are then withdrawn from the hole and a bailer or sand bucket is lowered to the bottom and worked up and down, thus being filled in much the same manner that the mud-scow is filled. It is necessary to lower the bailer to the bottom of the hole, two or three times in order to clean out all the cuttings. The number of feet that are made without bailing out the hole is called a run. Runs of 5 feet or more are made in material that mixes well, but in sand, gravel or boulders, which settle quickly to the bottom of the hole, it is necessary sometimes to bail out every 6 inches.

The solid, drop tools can be used in almost any formation for drilling, but in unconsolidated material more footage as a rule can be made with the mud-scow. This is particularly true in band, gravel, and small boulders, which do not mix but settle immediately to the bottom of the hole. A large part of the wells in Arizona are drilled in formations of this character and as the mud-scow is? particularly adapted for this kind of drilling, it has met with much favor.

When drilling in sticky clay or gumbo, both the mud-scow and solid, drill tools have their disadvantages. The mud-scow can be equipped with one or two heavy knife blades welded across the diameter of the cutting shoe to help keep the clay from balling up in it. With the solid, drop tools, the clay, not mixing readily acts somewhat like putty, so that if a solid blow is struck the bit sticks and must be jarred loose.

If, in drilling, rock or hard, cemented formation is encountered, the mud-scow should be replaced with the drill stem and bit. The mud-scow or California rig is at a disadvantage in this kind of drilling, since it is not designed for use with solid tools, and since the stroke is too short and slow and hence does not give the necessary snap to the tools which permits of rapid drilling with solid, drop tools. The City of Tucson had four 20-inch stovepipe wells drilled to a depth of 500 feet in a formation consisting of some sand, gravel, and clay strata, but mostly of hard, cemented sand and gravel or caliche. In the competitive bidding for the drilling, a contractor using a churn-drilling rig equipped with a hydraulic pump, and using solid, drop tools was awarded the contract. The drilling was even harder than was expected and sometimes only 2 or 3 ieet per day were made. At times it was necessary to use the drive clamps on the drill stem, in addition to the hydraulic jacks, to move the casing.

Wells which have been drilled vertical and perfectly straight are extremely rare. A well, however, should be straight enough and near enough to the true vertical so that any of the standard makes of deep-well pumps will operate satisfactorily in it, Certain precautions should always be taken by the driller to insure a hole as nearly straight and vertical as possible. In starting the well, particular care should be taken that the starter is set in a vertical position and well braced there. The drilling tools should hang over the center of the hole at all times; very often tightening one of the guy wires on the mast slightly too much, will throw the crown pulley to one side, or one side of the rig may settle a little, thus throwing the drilling line to one side. There is more danger of getting a crooked hole with the mud-scow than with the solid, drop tools, the reason being that the combined length of the bit and stem is greater than that of the mud-scow. In drilling with solid, drop tools, the drilling line should he kept tight and the tools or cable should be turned by hand until a depth of a 100 feet or more is leached. Drilling with a bit when the tools are not turning is one of the most common ways in which crooked holes are started. Crooked holes are often the result of carelessness on the driller's part, particularly when he is trying to "make hole" too fast. Inclined strata of alternately hard and soft materials may start the tools off at an angle or a large boulder at the edge of the hole may deflect them and cause the hole to go crooked.

The weight of the casing in most cases is sufficient to cause it to follow the drilling tools for the first 40 or 50 feet without using hydraulic jacks or driving it. The common practice is to put on two joints of casing at a time, denting each joint in a dozen or more places with a heavy, casing pick, although some drillers dent each joint deeply in only three places around the circumference. Picking the casing in this way unites the inside and outside joints and thus prevents the casing from separating in case the upper part is tight in the hole and the lower part is hanging loose. Except in clay or cemented formation, where there is no danger of caving material falling into the hole, an open hole is seldom carried the length of the mud-scow ahead of the casing, or If solid, drop tools are used, not more than 10 or 15 feet ahead.

When the stovepipe casing will no longer move down by its own weight, it becomes necessary either to drive it or force it down with the hydraulic jacks. Casing can be forced much deeper with the hydraulic jacks than by driving it, and it is never safe to depend upon driving stovepipe casing except in very shallow holes. In figure 19 the clevises on the upper end of the jacks are shown hooked over the prongs of the casing or well cap, in position to pull the casing down. With the California type of rig and with some churn drills, that are fitted specially for the use of hydraulic and mud-scow drilling, the hydraulic jacks are operated by simply throwing in the clutch to the pump and operating the proper valves. In action the jacks move slowly and steadily either up or down as desired. It is an added advantage to be able to drill at the same time the jacks are being operated, as it is sometimes possible to

Fig. 19.—Forcing the stovepipe casing down with hydraulic jacks.

move casing in this manner that cannot be moved by the jacks alone. Most churn drill manufacturers do not equip their machines with hydraulic pumps, as they are not designed for handling stovepipe casing or for drilling with a mud-scow. Hydraulic pumps added as extra equipment are not usually so convenient to operate as when furnished with a rig designed for their use.

One of the great advantages in using stovepipe casing and hydraulic jacks is that in some materials the casing may be forced several feet ahead of the bottom of the hole. Sometimes a stratum of running sand or gravel Is encountered which runs into the hole as fast as it is taken out and the only way to get through it is *by* forcing the casing ahead.

The casing in small-diameter or shallow wells may be put down without hydraulic jacks. Drive-clamps are bolted to the upper wrench squares of the drill stem and the casing driven down. The top of the casing should be protected with a heavy drive-head. A drilling stem with drive-clamps attached is shown in figure 11 hanging from the mast with the lower end setting in the drive-head, which has just been taken off the top of the casing. A mud-scow was used for drilling so that when it was necessary to move the casing, a change to the drill stem had to be made.

Large-diameter, that is 24 or 26-inch holes, are often put down to a depth of 80 feet or more and the remainder of the hole finished up with 12 or 16-inch casing. High-capacity, turbine pumps with large bowls may then be installed. By reducing the size of the casing, below where the pump bowls are set, the cost of drilling and casing may be decreased.

In reducing to the smaller size casing, it is necessary to start it from the ground surface with a starter. In order that the inside string of casing may be started in the center of the drilled hole, the starter is sometimes blocked out to almost the size of the large casing. Instead of adding one joint of casing at a time, sections 20 to 25 feet long are used. They are put on in the same manner as single joints but are picked more deeply to keep the sections from pulling apart, as they are lowered. As soon as the shoe reaches the bottom the drilling proceeds as before.

When the drilling is completed, if two sizes of casing are used, the inside casing is cut off a few feet above the bottom of the outside casing. Ordinarily some type of ripper or a perforator with which a long cut can be made, is used for this purpose. A single cut 3 or 4 feet long is made and as this is as long or longer than a single joint, the casing may then be pulled apart. To straighten out and center the top joint of an inside string of casing, where it has been cut off, an adapter is very often used. It also serves as a funnel into the smaller casing.

After the casing has been cut off and withdrawn, the top of the inside casing is sometimes left in such shape that tools cannot be lowered into it. To straighten out a place of this kind, or a place where the casing has been dented in by a large boulder, or where the casing has collapsed, a swage is used. The swage is a large, heavy piece of cast-iron or cast-steel, shaped like a huge plumb bob, about two feet in length and slightly smaller than the casing in diameter. The swage is lowered on the tools with long-stroke jars and also with a sinker bar or short stem above the jars.

In a 26-inch well in the Salt River Valley it was found impossible to get the pump suction pipe into the inside casing. Repeated attempts were made and finally an impression block of hard soap was lowered on the bottom of the tools. When pulled out it was found that the Inside casing was leaning over to the side, just enough to keep the long, pump suction, which hung vertically, from entering, while at the same time the comparatively short mud-scow entered without difficulty. After the trouble wab located the pump was put in by slanting it at just the proper angle to enter the inside casing.

Another case is reported in the same valley where after all other means had failed, a diver was sent down into a well to locate the trouble.

The depth to which a hole is to be drilled in many cases is decided before the work is started. This is only safe, however, when the well is drilled in proved territory and where the water strata are known to lie fairly uniformly. Most wells are contracted for a certain depth with a provision in the contract, that if sufficient water-bearing strata are not encountered in this depth, the well is to be drilled deeper at the option of the owner.

It is always desirable to stop drilling either in clay or some cemented formation so that sand or gravel has no opportunity to come in from the bottom and fill up part of the hole. In case there is a possibility of this happening, the bottom of the hole should be cemented or filled up with coarse gravel and then boulders, for a distance of 8 or 10 feet.

Economizing in the drilling of a well by using inexperienced drillers, inadequate equipment, or not casing the well properly, almost invariably proves more costly in the end.

LOG OR RECORD OF THE WELL

The importance of keeping a careful and accurate log of a well cannot be emphasized too strongly, and it should be considered just as much a part of the driller's contract as the drilling of the well. The driller in too many instances makes note only of the depth to water and probably the principal water-bearing strata. Later, if the owner asks for it, he makes up the rest of the log from memory and as a result it is usually inaccurate and unreliable.

The owner should insist that the driller keep a careful log, made up from day to day of the material passed through, describing it as best he can. In addition, samples of each change in formation should be preserved in tin cans and plainly labeled. This daily log should also include the progress made with the casing, any variations in water level, size, number, and location of all perforations, and a record of the developing of the well, if done by the driller. To this should be added any additional information that the owner may have concerning the well.

In an article on the Construction of Driven Wells,* Mr. John Oliphant, probably the ranking authority on pneumatic pumping, says, "A driller should be required to furnish a complete log and this should be as carefully preserved as a deed to the property." In many instances in this State the value of the well is equal to and sometimes exceeds that of the land which is to be irrigated by it.

The Irrigation Section of the University of Arizona has from year to year been adding to its collection of well logs and miscellaneous data on wells. These records are now considered among the most valuable of those kept on file in this office. They are needed in any study of underground waters, and are also of considerable value to individual owners of wells. This is attested by some of the inquiries received, of which the following may be considered fair samples: How deep was my well when first drilled, and how far was it cased? Was the casing in my well perforated? Can you furnish me with a log of the formations in my well? Most of these inquiries have been from owners of land which has changed hands since the wells were drilled, but they serve to indicate the value of preserving complete and accurate well logs.

PERFORATING

IMPORTANCE OF PROPERLY PERFORATING THE CASING

The perforating of the casing is the cutting of a sufficient number of holes in it of the proper size opposite the water-bearing strata, and for several feet above and below, to allow the water to enter the casing without an excessive loss of head due to friction.

The number of holes depends upon the amount of water which is expected to be developed in a stratum. And this is determined by the water-bearing capacity of the stratum. If the material is open or porous, provision should be made for the entrance of a large amount of water and the perforations can be put close together, care being taken, however, not to materially weaken the casing. In tight formations, in which no definite water strata are located, it may be assumed that the water will seep in all along the casing and an average of four holes per foot would be sufficient.

In water-bearing material containing some coarse gravel or boulders large perforations may be made. This is the condition found in most of the wells in the Santa Cruz and Rillito valleys near Tucson, and also in the Salt River Valley. Some of the wells producing the largest yields

*Oliphant, John Construction of Driven Wells. Engineering and Contracting 58.259, S. 13, 22.

have been perforated with holes ½ Inch in width by 3½ inches in length. As many as 10 holes equally spaced in a ring around the casing and the rings 10 or 12 inches apart, are made. The logs of the wells put down in the northeast section of Tucson for municipal purposes show that almost all the material from the ground surface to the bottom of the wells was tightly cemented together. Few, definite, water strata were detected by the drillers and it was thought that some water was making its way into the well at all points from the water surface to the bottom, For this reason the casing was perforated with large holes as described above, but only six holes per lineal foot of casing were put in. Where the water is found in sand and comparatively small gravel, smaller perforations must be made,

As a rule it is not advisable to perforate in quicksand. It usually carries little water and in many cases it is almost impossible to keep the sand out of the well. Several patented screens with very fine perforations are on the market, for use in fine sand. But because of their high cost and the uncertainty as to whether their use will be satisfactory, as a rule they have been little used in Arizona,

From the preceding paragraphs it may be been that in perforating the well a complete and accurate log is indispensable, for upon if depend the size, number, and location of the perforations. In perforating, holes should be cut for several feet both above and below the water stratum.

Most of the perforators in general use today will be found satisfactory if properly handled. However, certain precautions should always be taken before using any perforator. Several test holes for inspection purposes should be made close to the surface, both before and after perforating. Before lowering the perforator into the hole, it should be gone over carefully, all badly worn parts replaced, nuts tightened, and cotter pins put in where needed. The experience of the operator in the use of a particular type of perforator, and also the adaptability of the drilling rig for its use should be considered. It is only in the last few years that the importance of having a well casing properly perforated has been recognized by drillers. Now, if a well does not develop the expected capacity, the perforating is the first thing to be checked up. One of the last wells put down by the Pima Farms Company near Tucson supplied only a comparatively small amount of water when tested. The well was re-perforated at once, although there was no reason to suspect that the work was not done properly in the first place. No increased supply of water was secured, which was taken as proof that the fault was not in the perforating. Several wells which were drilled a number of years ago have been re-perforated recently and in several instances their capacities have been increased.

Fig. 20.—Four samples of perforated casing in which the holes all were made after the casing had been set in the hole.

In figure 20 are shown four field samples of perforated casing. The casing on the extreme right was perforated with a Mills knife, the lower center one with a perforator designed by the Reclamation Service, the one on the extreme left with a Star Four-Way perforator run twice, and the one on top of the preceding two by a Mackey Four-Way perforator. In all four specimens it may be noted that any beads formed by the knife blades on going through the casing are left on the outside which results in the holes all being larger on the inside than on the outside of the casing. Thus any particle that starts into the hole goes right on through without sticking and plugging up the hole.

Many types of perforators have been patented and still more home-made ones may be found in use. A few of those which have met with favor in this State are described in the following paragraphs.

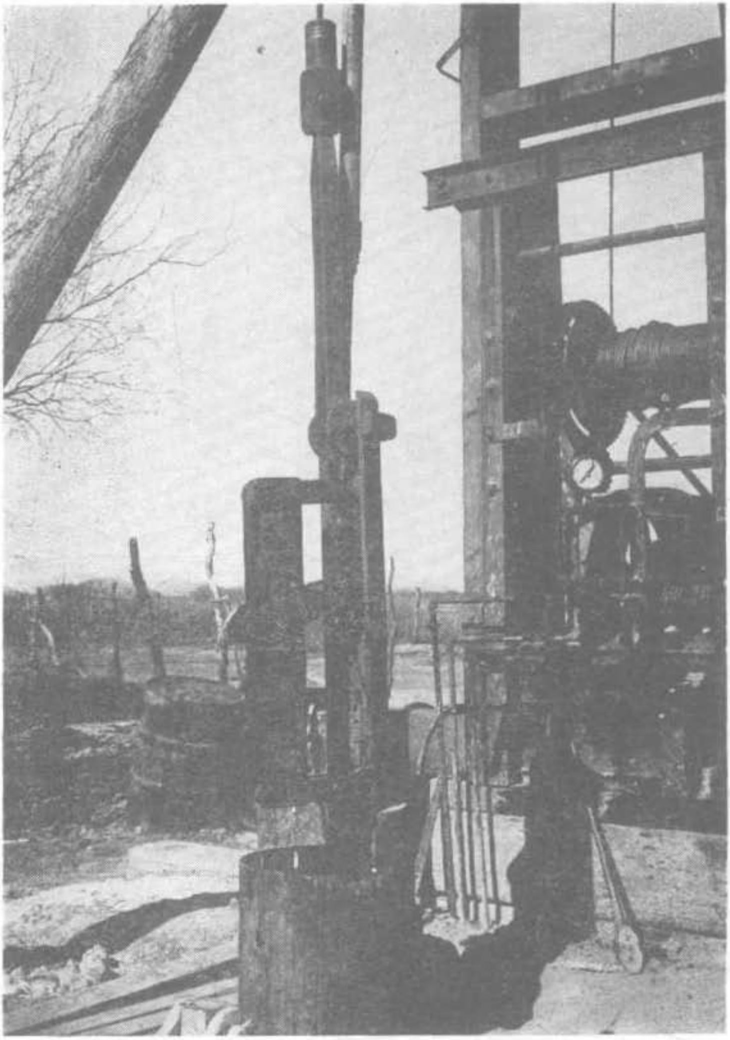

Fig. 21.—A 16-inch Mills knife perforator backed up to use in 18-inch casing. Note the pressure gage with arrangement of piping and valves for the operation of the hydraulic jacks in the background.

THE MILLS KNIFE

In figure 21 is shown a patented perforator known as the Mills knife. It cuts only one hole at a time and is made in sizes to perforate from 6-inch to 26-inch casing inclusive. The perforator is held in place or suspended on the sand line. The knife blade or cutter is made of a

Fig. 22.—The Star Four-Way perforator only partly assembled but showing how the roller knives work in the grooved slots.

single piece of flat, tool steel, held in place by a pin upon which it pivots. It is operated by a lever action with a 2-inch pipe from the top of the well. To secure sufficient pull to force the knife blade through the casing, the drilling line or sand line is strung through a set of blocks, one of which is attached to the 2-inch pipe. The weight of the 2-inch pipe is sufficient to pull the knife blade back out of the hole and the position of the knife blade may then be changed by turning the 2-inch pipe. This perforator cuts a good, clean hole and is reliable. It has an advantage over most perforators, for it may be worked upward from the bottom of the hole, thus eliminating any danger from running sand coming in on the perforator from holes cut above. Each hole can be located accurately with respect to the preceding holes and the spacing of the holes may be varied at the will of the operator.

THE STAR FOUR-WAY PERFORATOR

A Star Four-Way perforator is shown in figure 21 which is operated on the regular drilling tools. It is fastened below the jars and a sinker bar or short stem is used above to give weight to the tools in driving. A trip is provided so that it may be operated at any desired depth from the surface. It has four sets of cutters mounted on discs which revolve on pins, whose ends are engaged in slanting slots. In operation the releasing of the trip allows the lower part of the perforator to expand sufficiently to hold it in place by friction against the sides of the casing. The weight of the tools is used in driving the main body of the perforator downward, causing the revolving discs and cutters to be forced outward by the slanting slots which serve as guides. Further driving forces the cutters to punch through the casing, the discs revolving as the perforator moves down.

In using the Star perforator it is the common practice to start near the bottom, run down, and then come back further up and run down again, rather than to start at the top and run to the bottom and take chances on sand coming in on the perforator from above. If not enough openings are provided by running once, it may be run twice, as was done in the sample shown in figure 20. An objection to running twice is that no control over the position of the perforator is had, and the second row may be right along the side of the first row and the casing greatly weakened and forced out of round. This is probably the reason why one of the rows of perforations shown in the figure is not as good as the other. This perforator was used in the East Well of the University of Arizona where screw casing was used. It proved very satisfactory in this well and it is believed that the Star perforator is better suited for use *in* screw casing than in stovepipe casing.

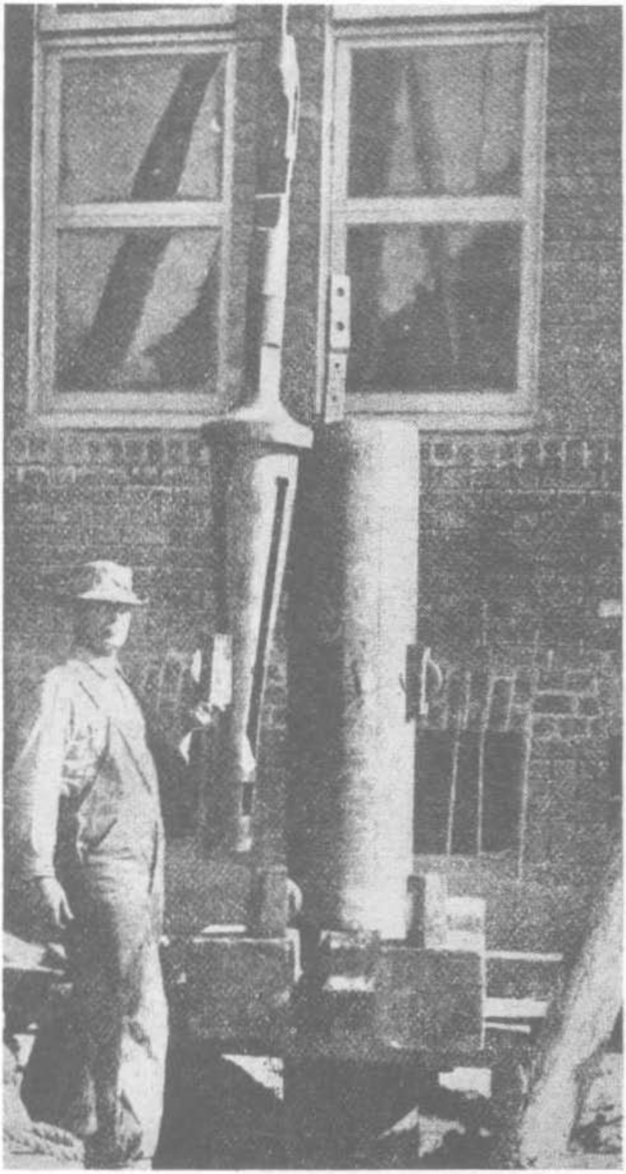

Fig. 23.—The Mackey Four-Way perforator, showing the four roller knives and the grooved knife-frame removed from its shell.

THE MACKEY FOUR-WAY PERFORATOR

The Mackey Four-Way perforator is shown in figure 23 where it was used in perforating the 12-inch stovepipe casing used in the Agriculture Building well of the University of Arizona. Tests of this well showed that a discharge of 705 gallons per minute was secured with a 10.6 foot draw-down which is the highest specific capacity of any well in this section, showing that the cross-sectional area of the perforations was at least sufficient. The perforator is hung on either the sand line or

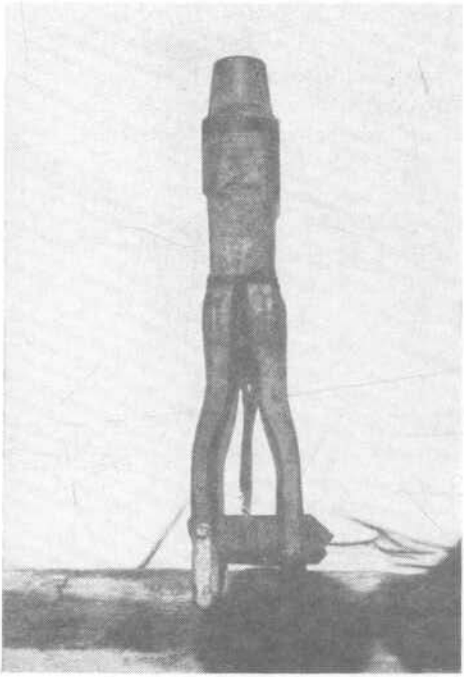

Fig. 24.—A home-made ripper or perforator made out of a set of worn-out jars.

drilling line and thus the position of the holes vertically can be regulated. The roller knives are set in steel blocks which are held in place in the main shell by rectangular holes in the shell. The heavy, grooved knife-frame is shown removed from the frame. In use it is operated on the tools and when driven downward the wedge-shaped knife-frame forces the roller knives through the casing.

OTHER PERFORATORS

The Reclamation Service perforator is also designed to cut four holes at once, but evidently is not to be depended upon at all times. The specimen casing shown in figure 19 shows a perfect cut on the front side but out of the four there were two good holes, one fairly good, and the fourth was only dented and not cut through.

A home-made perforator or ripper for small casing is shown in figuie 24. It was made out of a pair of old jars and is operated on the tools. To lower the perforator into the hole, the knife is tied down, but in such a manner that when lowered to the desired position in the hole a very slight jarring releases the knife. It can be pulled up to any point desired but cannot be lowered except by driving and cutting *A* hole in the casing. A spring holds the knife blade out against the casing and the blows of the tools first force it through the casing and then the whole perforator is driven downward cutting a vertical hole or blot. The casing is perforated by alternately pulling the perforator up and driving it down. Each time the perforator is brought up higher than the preceding time in order that the holes made will not run together. If a second row of holes is desired the process is repeated. The objections to using this perforator are that only one series of vertical holes can be cut at a time and the tendency is to make the holes too long. It is advisable to use perforators of this type only in small casing, that is not over 8 inches in diameter.

DEVELOPMENT OF THE WELL

OBJECT OF DEVELOPING THE WELL

The object in developing a well is to provide a path of the least resistance for the water to enter the well casing from the water-bearing strata. This object is accomplished by cleaning out the perforations and opening up the water-bearing strata. All the fine material, not only adjacent to the casing but for several feet away, should be brought into the well where it can be bailed or pumped out leaving only the coarser material around the casing. It can be truly said that the efficiency of a well depends upon the thoroughness with which it has been developed, as well as upon the perforating.

The most common methods of developing wells are by means of a mud-scow, pumping with a deep-well pump, and using an air-lift.

DEVELOPING WITH A MUD-SCOW

Because the rig is already on the ground and no additional equipment is required, the mud-scow method of developing the well is the one most generally used. Usually the same mud-scow is used as in drilling, although some drillers prefer to use one that will give a little more clearance between it and the casing. A long stroke is used and the mud-scow is worked up and down in front of the perforations, usually starting from the top of the hole and gradually working down. It is necessary to bail out the hole from time to time, for in some cases more material is taken out of the well in developing than when it was drilled. When sand and gravel are no longer brought in by the action of the mud-scow there is no further use in continuing with it. On seven wells, varying in depth between 230 and 360 feet, put down by the Continental Rubber Company in the Santa Cruz Valley, an average of 45 hours was spent on each well in developing with a mud-scow.* Ordinarily 2 or 3 days' time spent in developing the well is sufficient but occasionally more time than this is required to get all the loose material out.

Some drillers always use a plugged mud-scow in developing, that is, one in which the flap valve is fastened down. For this purpose, a pole may be wedged in between the valve and the knuckle joint on the bailer or a specially shaped hook which fastens from the bottom of the bailer can be used. The action of a plugged mud-scow is similar to that of a plunger working up and down in the casing. It develops a suction on the upstroke, pulling sand into the well, and on the downstroke a pressure is created, forcing the water out through the perforations.

DEVELOPING WITH A DEEP-WELL PUMP

The propeller and turbine types of deep-well pumps have been found the best adapted for developing wells. Propeller pumps are made that can be installed in a 7-inch casing while the smaller-size, turbine pumps require a 12-inch casing. These pumps are not equipped with a priming device of any kind, so they are set deep enough that they will be covered with water at all times. A very long suction is used which causes the water to be in motion for practically the entire depth of the well when pumping. By using this long suction, practically all of the sand that enters the casing through the perforations is pumped out with the water. At first the pump is started and stopped repeatedly. Thus the direction of the water is first upward and then downward as the water from the discharge column surges back into the well. This is called rawhiding a well and is used for about half a day before the pump is run steadily. The well should be pumped continuously for from 48 to 72 hours and at intervals during this time the process of rawhiding should be repeated. This method has the advantage over the mud-scow method in that all the information required for properly designing the pumping plant is secured at the same time.

*From records of G E, P. Smith, Consulting Engineer for Agricultural Products Corporation.

The method as outlined in the preceding paragraph was used by a local machinery company in testing out and developing a well near Tucson, Arizona. On first starting the pump a discharge of only 320 gallons per minute was secured, but at the end of 72 hours the pump was throwing over 800 gallons per minute. Continued pumping on this well brought the discharge to over 1000 gallons per minute without increasing the drawdown. If the discharge at the end of the first day had been taken as the capacity of the well, and the well had been equipped accordingly, the owner would have been utilizing less than one-half of his investment in the well.

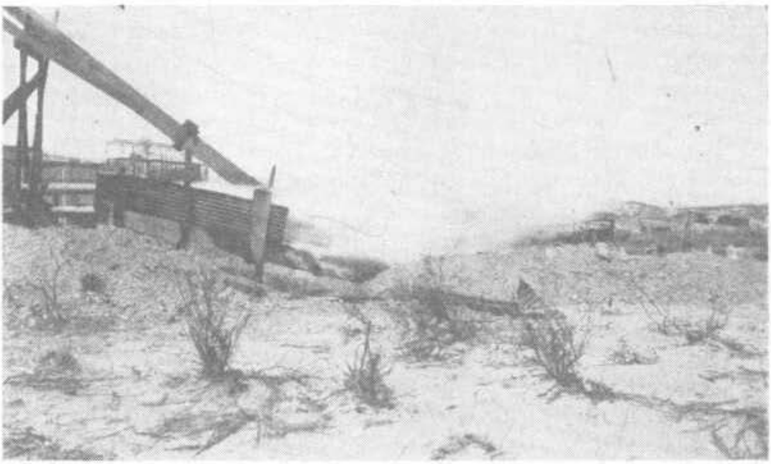

Fig. 25.—Developing and testing a well with an air lift. The air valve was opened quickly, throwing a spray of water from 75 to 100 feet horizontally.

DEVELOPING THE WELL WITH COMPRESSED AIR

A third method of developing a well where an air compressor is available is by pumping with compressed air. This method is particularly adapted for use in very deep wells of small diameter. The air line consists of small pipe usually not over an inch in diameter which extends down several hundred feet in the well. The water can be pumped from much greater depth than with the ordinary pumps. The air can be turned on or off at the will of the operator by merely opening or closing a valve. In this manner the entire column of water can be instantly started or stopped.

In figure 25 is shown a 760-foot well in the San Pedro Valley being developed with the air lift. In the figure, the air has just been turned on and the high velocity and force with which the water comes out of the eduction pipe is clearly shown. The water mixed with air is thrown horizontally a distance of between 75 and 100 feet. This well is owned by the Apache Powder Company and is in the artesian belt, the water standing within 5 feet of the ground surface. When pumping steadily, a discharge of 200 gallons per minute was secured with a 100-foot drawdown.

Another method of using compressed air for developing wells is to cap the well and then turn the compressed air into the casing. This forces the water back out through the perforations and by alternately

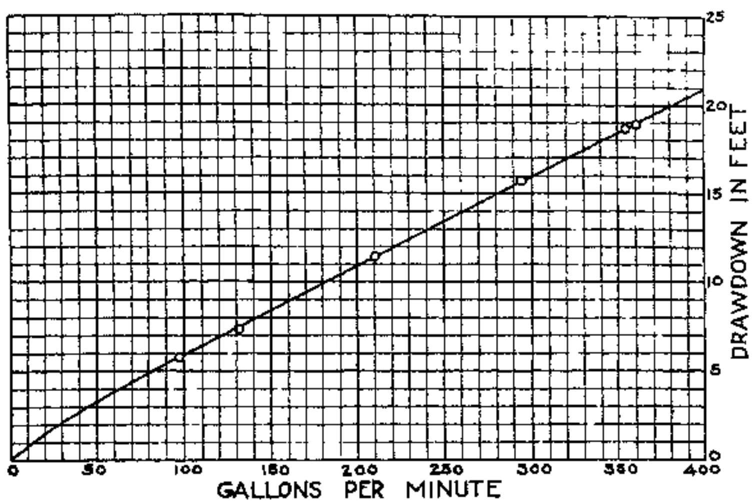

Fig. 26—Drawdown-capacity curve of the University of Arizona Well No. 2

taking the air pressure off and on, practically the same results are obtained as with the other methods.

The Tucson Farms Company in developing a series of 18 wells in a cross-cut in the Santa Cruz Valley, used a combination of the two previously described methods of developing with air.* The wells were capped and then equipped with air and discharge lines. The pressure in the casing could be run up in this way to 35 or 40 pounds per square inch, which would force the water out through the perforations into the water-bearing strata. By alternately opening and closing the discharge valve the water is kept moving back and forth through the perforations, thus washing them out. This constant ramming back and forth was continued until no more sand could be pulled into the well. It was found

*Hinderlider, M. C., Irrigation of the Santa Cruz Valley, Engineering Record Vol 68, No. 8, August 23, 1923.

that by this method the capacity of the wells was increased about fifty percent.

Developing a well by any of these methods should be followed as soon as possible by continuous pumping for several days. In almost all cases the capacity of the wells will be found to increase. It is very probable that many wells throughout the State were never properly developed, for many of them, after having been pumped for some time, are found to be filled up with sand almost to the suction pipe. This may be attributed to failure to properly develop the well when drilled.

TESTING OF WELLS

Before an efficient and properly balanced pumping plant can be designed it is necessary that the specific capacity of a well, that is, the yield per foot of drawdown, be determined. The pump used in testing does not necessarily have to be as large as that which is permanently installed afterwards. To be on the safe side it is probably best to test the well for at least 25 percent of the desired capacity. Within ordinary limits it has been found that the capacity of a well varies almost directly as the drawdown. The drawdown-capacity curve in figure 26 shows this very clearly. It is taken from the data secured in testing the University of Arizona Well No. 2, March, 1922. There are special cases where this is not true; for instance, if most of the water comes from one thin, water-bearing stratum and this is uncovered, an increase in the drawdown does not materially affect the capacity, or if a large percentage of the water-bearing strata are uncovered, it does not hold true.

Sometimes permanent plants are installed without first testing the well, in which cases it is assumed that sufficient water will be secured because of the number of feet of water strata encountered, or because other wells in the vicinity have yielded large supplies. However, when it is taken into consideration that the efficiency of the poorly-designed, pumping plant not only affects the cost of pumping for the first year but for the entire life of the plant as well, it may be seen that the comparatively small, additional expense required for testing the well is a very profitable investment.

COST OF DRILLED WELLS

The cost of the completed well may be separated into the following items; the cost of casing, of drilling and perforating, and of developing.

CASING

The cost of the casing constitutes about fifty percent of the cost of the completed well so the owner can well afford to spend some time in its consideration. For points in the Southwest, casing is quoted f. o. b. Phoenix, Arizona, El Paso, Texas, and Los Angeles, California.

In less than carload lots, stovepipe casing 12 inches and under in diameter takes the third-class freight rate, while stovepipe casing, over 12 inches in diameter takes one and one-half times the first-class freight rate. Because of the very high freight rate on large-size, stovepipe casing, it is important in comparing prices from different dealers, that the freight rates be considered also. Sometimes to take advantage of the lower freight rate, the casing is only rolled and punched at the factory and then nested for shipment, in which case it takes a fourth-class rate. The difficulty of riveting the casing in the field is so great that it is a question whether there is any real saving.

There is but little difference between the cost of shipping casing over 12 inches in diameter, by freight and by express. For instance the freight rate from Phoenix to Tucson is $1.48 per hundred pounds, and the express rate is $1.55 per hundred pounds. Casing is usually furnished by the owner and most contracts stipulate that any delays due to lack of material, to be furnished by the owner, shall be paid for at a fixed sum per day, usually from $20 to $30 per day. For this reason casing may often be shipped by express or by truck, to avoid such delays.

Price quotations on stovepipe casing are subject to market changes at all times. List prices on stovepipe casing f. o. b. Phoenix, Arizona, are given below. In October 1, 1925 this list was subject to a 25 percent discount.

TABLE III.—LIST PRICES PER FOOT OF STOVEPIPE CASING.

Diameter of casing in inches	Guage of casing				
	16	14	12	10	8
6	$1.27	$1.52	$2.02	$ 2.57	$
8	1.54	1.85	2.49	3.14	
10	1.83	2.20	3.12	3.89	–
12	2.13	2.57	3.62	4.58	---
14	2.45	2.94	4.14	5.27	6.64
16	2.77	3.33	4.68	5.92	7.58
18	3.10	3.70	5.25	6.64	8.29
20	3.44	4.13	5.82	7.32	9.14
22	3.79	4.54	6.37	8.02	10.00
24	4.10	4.93	6.98	8.62	10.79
26	———	———	7.54	10.17	12.67

Stovepipe casing ordered in sections costs about 10 percent more than the regular joints. The cost of 2-ply starters is approximately 25 percent more than casing, and 3-ply starters are about twice the cost of casing.

The list price of well rings or drive shoes f. o. b. Phoenix, Arizona, is given in Table IV. These prices were not subject to any discount on October 1, 1925.

PRICES OF DRILLING AND PERFORATING

Practically all well drilling is contracted for at a certain price per foot; in case the exact depth desired is not known, both a minimum and maximum depth which will be drilled at this rate are stated. Sometimes an increasing rate per foot is made for each additional 100 feet after a certain depth has been reached. The common practice is to include the perforating in the price paid for drilling, but the developing is usually an extra charge. Ordinarily the rate for extra work, such as developing or setting in a pump, is between $25 and $30 per day. Where material, such as casing, is to be furnished by the owner and delays are occasioned through material not being on hand, the same charge as for extra work is sometimes made by the contractor.

In general, the price of drilling increases both as the diameter and depth of the hole. The footage which can be made per day depends upon the character of the material or the formation in which the well is drilled. For this reason drilling prices are as a rule from 20 to 25 percent lower in the Casa Grande Valley and the lower Gila Valley than in the Santa Cruz Valley or in Pima County. In the Salt River Valley they are approximately the same as in Pima County. Strong competition for drilling jobs results in a lowering of drilling prices to a certain extent. The actual prices paid and their variation are shown by the following cases.

The contract price for three of the wells put down by the City of Tucson and referred to on page 131 was $5 per foot. Perforating and developing were to be paid for extra at $40 per day. These Wells were each 20 inches in diameter and 500 feet deep in a partly-cemented formation of sand, gravel, and clay, of Pleistocene Age.

The contract price on an 18-inch well, drilled to a depth of 208 feet in the unconsolidated, valley fill of the Santa Cruz Valley was $4 per foot and included the perforating of the well. This well was completed in February, 1924.

A 16-inch well in the Casa Grande Valley, recently completed, was drilled to a depth of 227 feet for $3 per foot, including the perforating.

The Apache Powder Company's well previously referred to, which was drilled 760 feet deep and cased with 16-inch stovepipe casing to 698 feet, was contracted for at $5.50 per foot for the first 500 feet and $6.50 per foot for the balance of the hole, including the perforating. Except

TABLE IV.—PRICES OF STEEL WELL RINGS OR DRIVE SHOES—JANUARY, 1925.

Size in inches	Diameter of casing										
	6	8	10	12	14	16	18	20	22	24	26
6 by ¾	$10.00	$13.00	$15.00	$20.00	$23.00	$26.00	$ 28.00	$ 31.00	$ 35.00	$ 37.00	......
8 by ¾	16.00	17.50	19.00	25.00	27.00	33.00	36.00	42.00	47.00	51.00	......
8 by 1	......	20.00	25.00	30.00	32.00	37.00	42.00	48.00	55.00	60.00	......
10 by 1	......	......	29.00	32.00	34.00	39.00	48.00	61.00	67.00	74.00	......
10 by 1¼	......	......	......		46.00	51.00	59.00	73.00	80.00	88.00	......
12 by 1	......	......	......	36.00	38.50	45.00	58.00	68.00	83.00	90.00	$ 99.00
12 by 1¼	......	......	......	42.00	48.00	54.00	62.00	80.50	94.50	112.50	121.50
16 by 1	......	......	......	......			84.25	93.00	102.00	114.00	125.00
16 by 1¼	......	......	......	......	......	......	102.75	118.25	130.50	145.00	154.75

for a little sand in the first 50 feet of the well, the formation consisted almost entirely of a sticky clay which made the drilling slow.

In 1922, a 12-inch well 151 feet deep was contracted for by the University of Arizona at $3.50 per foot including the perforating. The well was in cemented sand, gravel, and clay from the surface practically to the bottom.

Several wells cased with 16-inch, 12-gauge stovepipe casing have recently been drilled on the mesa land near Wellton, Arizona, at a price of $7.50 per foot including the casing.

The approximate prices for drilling of various sizes and depths of holes in January, 1925, are given in Table V and represent an average of prices paid. Since this date the Salt River Valley Water Users' Association has entered into an extensive program of well drilling which has resulted in at least a temporary increase over the prices given. It was assumed that the moving charge on the drilling rig would not be over $50 or $60. The table has been submitted to three of the leading drilling contractors in the State and their criticisms and corrections have been incorporated.

TABLE V.—APPROXIMATE COST OF DRILLING PER FOOT.

Diameter of hole	Depth of hole in feet						
Inches	100	200	300	400	500	600	800
6	$2.25	$2.25	$2.25	$2.50	$2.50	$2.50	$2.75
8 10	2.50	2.50	2.50	2.75	2.75	3.00	3.25
12 14	3.50	3.50	3.75	4.00	4.25	4.50	--
16 18	4.00	4.00	4.25	4.50	4.75	5.00	--
20 22	4.50	4.50	4.75	5.00	5.25	----	----
24 26	5.00	5.00	5.00	5.25	----	----	----

Note: Prices include perforating but not developing of well.

It is common practice to include the perforating in the contract price for the drilling; however, if it is to be paid for extra, the prices paid usually average around $25 or $30 per day. The number of feet that can be perforated in a day will vary with the different perforators. Some of the four-way perforators will finish up a hole in a day, while with the Mills knife for example probably 50 feet per day of 12 holes per foot should be considered a good average day's work.

COST OF DEVELOPING

In figuring the cost of developing a well by the use of either a deep-well pump or the air lift, the local facilities for securing the necessary equipment and installing it constitute the major portion of the expense. For this reason no general costs can be given for these methods.

The developing of a well with a mud-scow will ordinarily take between 2 and 3 days for wells of about 150 feet of perforated casing, the time spent depending partly upon how thoroughly the work is done. In a very loose formation with running sand, several days may be spent in pulling this sand into the hole and bailing it out, until large cavities are formed outside the casing. On the other hand, when the gravels and sand are partly cemented very little material is pulled into the hole and one day is probably sufficient. In most cases it is desirable to supplement the mud-scow in developing the well by pumping for several days.

FUTURE DEVELOPMENT

The California or stovepipe method has proved to be the most satisfactory one of drilling wells for irrigation in the unconsolidated, valley fills found in most of our valleys. Indications are that this same method should prove very successful in betting in the first string of large-diameter casing in deep wells. Several attempts to put down deep wells in the State have met with failure in getting a first btring of screw casing down to the desired depth. In such valleys as the San Simon, Sulphur Spring, San Pedro, and the Gila, it is probable that a single btring of stovepipe casing can be carried to a depth of 1000 feet.

Even in gravity irrigation systems, the drilled well has found a place, as 5b evidenced by the increasing number of wells put down by the Salt River Valley Water Users' Association for drainage purposes. The buccess attending the pumping from drilled wells for drainage in the Salt River Valley in 1918-1919, has led to the adoption of the same method in the San Joaquin Valley, California,* to the extent that there were 137 drainage pumping plants in operation in 1924.

On February 10, 1925, the Board of Governors of the Salt River Valley Water Users' Association authorized the immediate expenditure of $100,000 for wells and pumping equipment as insurance against a water shortage the coming summer. At the annual election, held on April 7, 1925, it was voted to increase this sum to $450,000. The total number of pumping plants completely equipped on November 1, 1925, was 133 with 25 additional plants in the process of construction.

Construction work is now under way on the canals and pumping

*Walter W. Weir, 1925, Pumping for Drainage in the San Joaquin Valley, California.

stations for the Roosevelt Conservation District. This district comprises 37,000 acres of irrigable land for which a water supply is to be secured in part from the canals of the Salt River Valley Water Users' Association and the balance from wells.

The slump in agricultural products following the year 1920 resulted in almost a complete cessation in the drilling of irrigation wells. Conditions have now improved to the extent that a considerable addition to the number of drilled wells may be looked for in the next few years.

The advent of cheap hydroelectric power would mean that thousands of acres of virgin soil will be reclaimed by pump irrigation. Even with the present price of power the last year has witnessed the completion of power lines and substations by the lower Gila Valley Power District and the Casa Grande Electrical District. The former secures power from the Yuma Ice, Electric, and Manufacturing Company, while the latter secures its power from the Salt River Valley Water Users' Association. A number of new wells have been put down in both districts and it is expected that more will soon be drilled.

Within the State of Arizona lie several million acres of land for which no adequate surface water supply is available. Thousands of acres of this land can be reclaimed by the development of underground waters by means of drilled wells, and with cheap hydroelectric power for pumping from the Roosevelt Project or the Colorado River.

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