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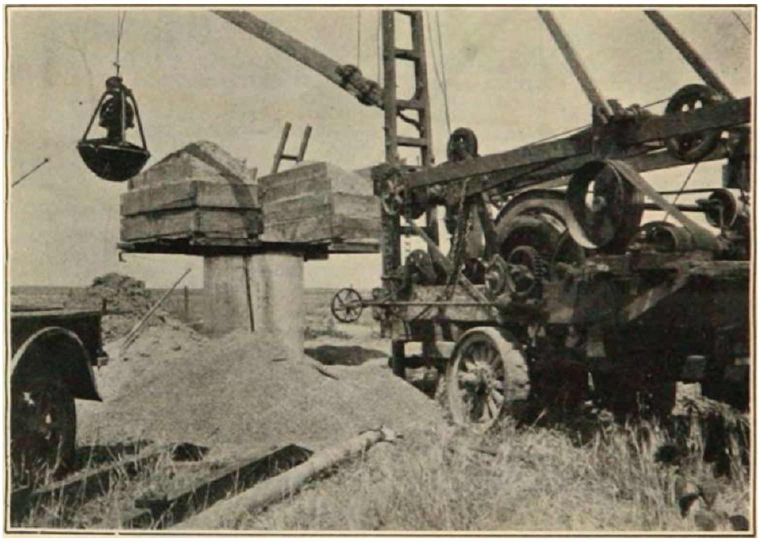
CONSTRUCTION OF IRRIGATION WELLS IN COLORADO

By W. E. Code



Sinking an irrigation well with orange-peel bucket equipment. Boxes loaded with soil provide the weight for forcing casing.

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Colorado Experiment Station
Fort Collins

The Colorado State College
FORT COLLINS, COLORADO

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Construction of Irrigation Wells in Colorado

By W. E. Code

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CONSTRUCTION OF IRRIGATION WELLS IN COLORADO

By W. E. Code

The earliest recorded use of ground water for irrigation in Colorado was in 1885 when a large well was excavated near Baton. Little attention was paid to the early efforts of sinking irrigation wells because they were considered of slight economic importance, and the water so obtained proved to be too costly. Growth of ground-water development was retarded for a long time because of the handicaps in the use of steam and unreliable oil engines for power, by pumps that were inefficient or not suited for well work, and because of the lack of knowledge needed for successfully obtaining good irrigation wells. These causes, together with the lack of understanding of the principles involved, inadequate capital and high lifts, resulted in many failures during this period, not only in Colorado, but in many other states.

Through the improvement in methods of well construction, the perfection of pumping equipment, the availability of electric power, and more widespread information on the subject, there has been a tremendous increase, since 1910, in the number of farmers who have successfully developed ground-water supplies by means of wells. There are now in excess of 1100 pumping plants in use in the state, producing water mainly to supplement surface flows. It is a matter of interest that about one-third of this number were installed during the drouth of 1934. Such an emergency water supply could have been obtained in no other manner in so short a time or at so reasonable a cost.

To obtain water in sufficient quantities for irrigation, it is necessary that good water-bearing gravels be available, and if the development is to be economically feasible, the lift, while pumping, must be reasonably low. While there are numerous cases where water is being pumped against a lift exceeding 40 feet, it is generally conceded that this figure should be about the maximum in general farming. Low operation cost, due in part to very efficient power units or favorable electric rates, substantial crop yields or, under some circumstances, the pumping of relatively small supplemental supplies to insure successful crop production, permit an exception to this limit.

The amount of lowering of the water surface in a well by pumping, called drawdown, plays an important part in the total lift. It may be so great that, with the water table but a few feet from the surface, the total recommended lift will be exceeded. The depth or thickness and the character of the water-bearing gravel, method of construction, perforations, and the diameter are important factors which determine the yield of a well.

Although gravels occur widely in the state, they are found in greatest depth along the main drainage streams and in old channels which are now covered and not recognizable or associated with present drainage. Nearly all the irrigation wells of the state are located along these channels, not only because the gravels exist there, but also because of the reasonable depth to water. It is usual to find either shale or sandstone underlying the gravels, and it is quite useless to penetrate these formations in further search of water. In a few cases, a small yield has been obtained from a well passing through a considerable depth of water-bearing sandstone, but ordinarily such efforts are not worth while. In many localities, because of the widely varying conditions, it is decidedly advisable to explore with test holes before the site of the well is selected.

There are three principal sources of ground water occurring in gravels near the surface: Seepage losses from streams and canals; percolation losses from the application of irrigation water; and the escape of deep water at sandstone outcroppings. A change in the height of the water table is indicative of a change in the relation between the amount of recharge from the various sources and the outflow. As most sources of recharge have somewhat definite limits, it is apparent that pumping may disturb the normal balance and cause a continuous lowering of the water table. The fallacy that ground water is inexhaustible is believed by many of the uninformed. The opposite, however, is too well proved by the alarming rate at which the water table has receded in a number of districts in the Southwest. Where irrigation water from other sources is applied, recharge will probably be adequate for moderate pumping demands; but where such is not the case, development should proceed with caution.

The use of wells in conjunction with canal water is of considerable importance to a great many farmers. In some cases a well is needed because of occasional insufficient natural flow, or as a supplement to, or replacement of, inadequate reservoir supplies. Reservoir supplies replaced by well water may be rented or sold to advantage in some localities. The availability of well water at all times gives it an enhanced value over canal water for the timely irrigation of crops.

In the northern part of the state, water is not turned into canals as early as is necessary for some crops, and reservoir water is run only on the demand of a sufficient number of shareholders. In certain areas, wells are extremely beneficial in keeping down the water table when seepage conditions threaten. As a means of further economic use of water after diversion, the irrigation well is an important factor, and is of state-wide importance in the beneficial use of a natural resource.

The legal aspect of diverting ground water for irrigation in Colorado is frequently a subject of discussion. There is no specific statute covering its use, but by implication the laws governing appropriations from surface streams hold, inasmuch as ground waters are considered tributary to such streams. As yet no court decision has been rendered which clearly defines the status of ground water use for irrigation in this state.

Kinds of Irrigation Wells

Irrigation wells in Colorado may be divided into two main classes according to materials used for the curb, and methods of construction. The first is the large excavated well, curbed with various materials, and sunk either with hand tools or powered machinery. It is adapted to shallow ground-water conditions, and offers an advantage in that it may be sunk without the aid of expensive equipment. The second is the metal-cased well nearly always sunk by machine methods. It is applicable to nearly all ground-water conditions, but requires the services of an experienced well driller.

Large Excavated Wells

Curbs.—The principal points for consideration in building a well curb are durability, strength against lateral pressure and weight to facilitate sinking. It should have strength or coherence enough to withstand slight uneven settling, and be of a shape to be sunk with certainty and a minimum of effort. A square shape presents greater resistance to sinking than a circular or many-sided one. Wood above the water surface will not last many years, and below the water surface the construction should not depend entirely on nails for strength. Bricks should be hard burned and laid in mortar when placed above a strainer, or through loose gravel, if the well diameter is greater than 6 feet. Probably the strongest construction is that of solid concrete, or connected precast concrete rings. Old steam boilers and water tanks perforated with an acetylene torch have also been used.

If the curb is of brick or concrete blocks, a timber shoe is first laid in the bottom of the excavated dry pit. This shoe should be of reasonable stiffness in order to bridge over short distances of unequal support. It is built up of short pieces of 2-inch lumber over- lapping in rings, with the narrowest size on the bottom, spiked together, and set level. A suggested arrangement is a 2 by 4, a 2 by 6 and a number of 2 by 8-inch pieces, to make up about 1 foot of thickness for light construction. Depending on the curb diameter, the segments should be as long as possible yet present a reasonably uniform exterior after the corners are chopped off. Great care should be exercised in keeping the brick work perfectly round by using a template because the entire strength of the curb depends on this shape. No mortar is used near the bottom, and for smaller sizes of wells, one inside corner of each brick should be chipped off to allow easy entrance of water. An 8-inch wall has been used successfully on wells up to 10 feet in diameter, but this should be considered the minimum thickness for such diameter. Only in wells under 5 feet in diameter should the bricks be laid so as to form a 4-inch wall and then only above the water line. Arc-shaped concrete blocks are safer than bricks in that they produce a stronger wall and are less likely to be forced out of round.

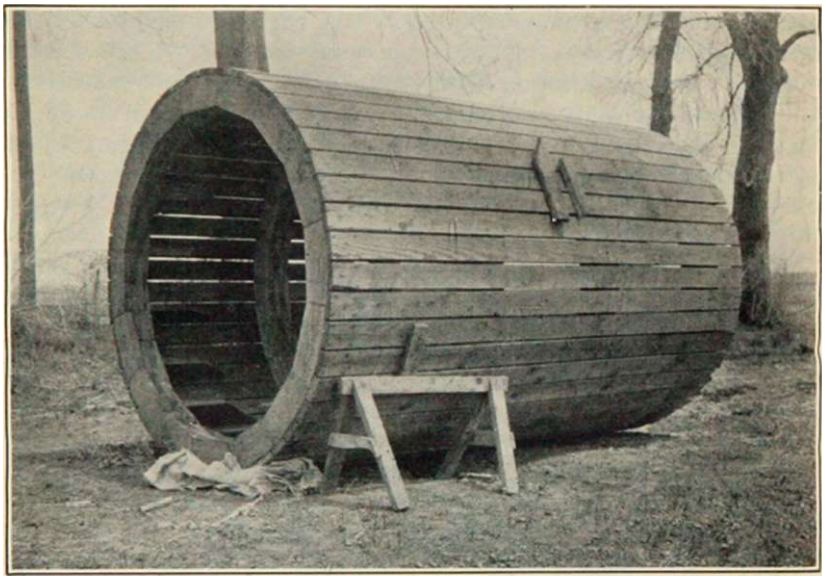

Fig. 1.—A timber shoe and strainer 8 feet in diameter and 10 feet long.

Figure 1 is an illustration of a type of shoe and strainer used by a well contractor near Fort Collins. The shoe is built up of vertical 2 by 6-inch lumber from 6 to 10 feet long, beveled at the bottom and so spaced that after swelling occurs, cracks about one-fourth to three-eighths inch wide remain on the inside. Although these vertical planks are not beveled on the edges, so doing would produce an opening smaller on the outside instead of on the inside, and the effectiveness of the opening would be greatly increased. The hoops consist of four thicknesses of short segments cut out of 2 by 8-inch lumber and all spiked together. Four of these hoops are used on a 10-foot length. In sinking, the inside is temporarily lined with bricks resting on the hoops, and as extra weight is needed, the brick work is started on the top hoop which has bracket supports beneath.

Concrete curbs, sometimes reinforced, require special forms that will produce a cylinder which is smooth inside and out. Silo forms have been used, but they are usually too large. Forms should be about 4 feet long and built so as to be easily loosened and moved to a new position. The wall thickness will vary from 4 to 8 inches, depending on the diameter and depth below the surface, because the upper sections do not have to be as thick as those near the bottom.

In casting the lower sections, some provision must be made for the entrance of water. Among the various materials used for openings are pieces of garden hose, rolled sheet iron, and old pipe not larger than 1 inch in diameter. These tubes are placed as the concrete is being poured, and after removal of forms, they must be punched clean. Openings should be numerous near the bottom, 4 to 6 to the square foot. A hole smaller outside than inside is to be preferred as it will be non-clogging. Such a hole can be obtained by using a shingle as a form, pressing it down into the fresh concrete, and then filling the depression with clay which can be dug out subsequently.

No special shoe is required, but the bottom should be beveled outward. The curb is usually started when the excavation has reached the water table, or a loose stratum that will not stand alone, and should be built then to the ground surface where subsequent rings of concrete are added.

Plain concrete rings are available commercially in sizes from 24 to 48-inch in 2-foot lengths which are designed for well construction. The rings are tongued and grooved at the ends, and holes

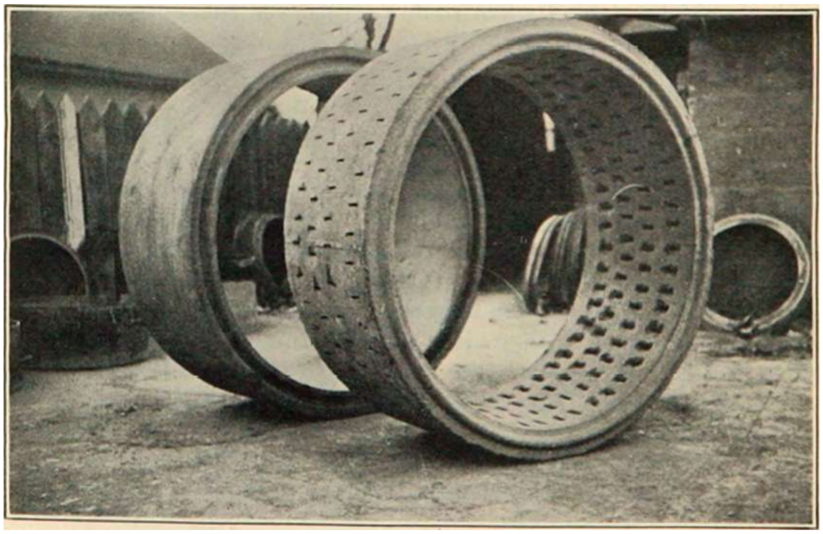

Fig. 2.—Plain and perforated concrete rings 4 feet in diameter and 2 feet long.

are provided for bolting and strapping the rings together. Perforated sections are obtainable as shown in Figure 2.

Perhaps the least satisfactory type of curb is that of loose vertical planks which are driven down with a sledge hammer behind supporting horizontal beams. Small cave-ins cause the lower ends of the planks to bend in and drive with difficulty. The top ends become battered and split, and unless the formation will stand readily, no great depth can be attained.

Sinking Methods.—The large excavated well seldom is sunk very far below the water table unless an orange-peel or clam-shell bucket is used in conjunction with a reinforced concrete curb. Otherwise, the usual maximum depth attained is about 15 feet below the water table.

Excavation of the dry material is effected ordinarily without difficulty. After spading down about 7 feet and throwing out the soil by hand, a boom derrick is rigged with a. rope and bucket for hoisting out materials. Usually a horse furnishes the power, but trucks or automobiles are also used either by driving them, or by a power take-off to a winch. Hand hoisting is usually done by turning a small wooden drum equipped with two handles and set over the pit. Two hoisting buckets should be available, one bucket being filled while the other is being hoisted. In place of a bucket, a wheelbarrow may be used which has the advantage of allowing the load to be wheeled away, in case no boom is used.

Excavation is continued without a curb so long as no caving formation is encountered. Narrow seams of soft sand or running gravel may be held back temporarily, but if this is not possible the curb should be started when such a stratum is encountered. If an impervious formation that will stand is found at the water table, then it too should be excavated as deeply as possible, removing the water by bailing or pumping.

After 5 or more feet of curb have been built, excavation may proceed, starting along the edge of the shoe, care being taken that the rate of digging is the same at all points along the ring. It is essential that the curb settle level and the walls remain plumb. If it does not settle slowly and uniformly, more curb should be built, as large, sudden movements are decidedly dangerous to the work. In cutting through impervious material, the spade must be worked far enough under to more than clear the outside edge of the shoe. It is important that there be a space between the curb and the earth wall which is kept full of gravel to a point as high as the first gravel stratum above the normal water table. The object of this is to prevent material from caving back of the well curb. An impervious formation above a cave-in is quite likely to break down and seal off the water flow to the well. This type of well construction is always attended with a flow of gravel from the formation behind the curb

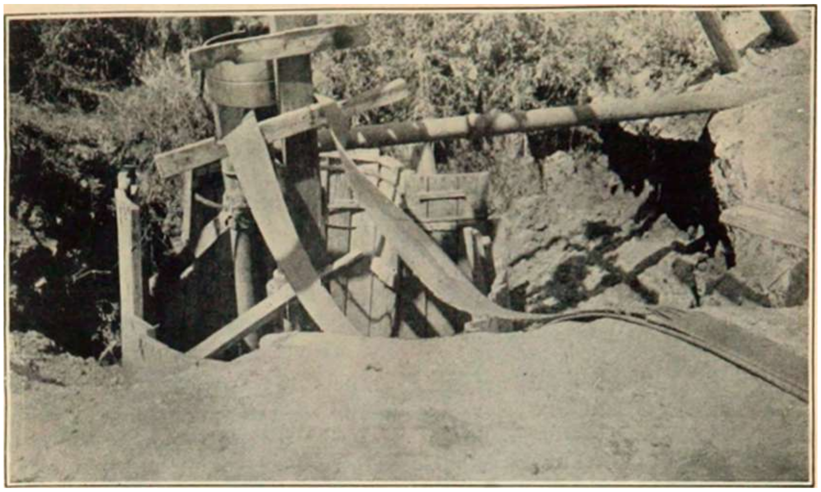

Fig. 2.—Caving around top of large dug well due to taking out excess material from under the shoe.

which, if not replaced, undermines the adjacent ground and often causes the breaking down of materials all the way to the surface. Figure 3 shows the crater-like result where caving has occurred.

When the water depth approaches 2 feet, little progress can be made with shovels, and it becomes necessary to install a pump. An old pump is preferable since a considerable amount of sand will be handled. The vertical centrifugal or pit pump is best suited for this purpose, because it will prime itself and take care of the water as fast as it comes in. It should have a very short suction piece and be protected with a half-inch mesh screen. If placed in a short piece of perforated well casing, a low place can always be maintained and excavation can proceed with the workers standing in but a few inches of water. Since the vertical position of the pump has to be changed frequently, a wide-faced pulley secured with a set screw, or a split pulley with a compression hub, should be used. These can be moved easily along the shaft to any desired position. A supporting idler pulley on the belt obviates the necessity of frequent small changes. A horizontal centrifugal pump can also be used, but requires a suction hose, and must be placed within 15 feet of the water surface while pumping—the closer the better. The discharge pipe must be equipped with a gate valve to permit priming and to adjust the flow to that of the incoming water. This valve should be opened occasionally to permit trapped gravel to pass out. Precaution should be observed not to stop the pump while much sand is being conveyed by the water, for sand in the discharge pipe will settle back into the pump case and around the impeller and may cause locking. The suction hose also should be equipped with a foot valve to prevent the entire system from being drained when prime is lost. Figure 4 shows sinking-pump equipment being used on this class of well.

Fig. 4.—Sinking-pump equipment for large shallow wells in use.

The curb should be stopped on a solid clay or rock foundation and then backfilled about 2 feet with gravel, unless other means are taken to prevent runs of gravel under the shoe. This sometimes can be effected by driving a very short inner curb. Should the curb be stopped in gravel, a few lengths of perforated metal casing may be sunk in the bottom without much difficulty, increasing the well depth, and providing a sump for the suction pipe. The top of this casing should be left a couple of feet higher than the bottom of the curb, and the intervening space backfilled with gravel.

It will be seen in the foregoing description that there are many factors that prevent sinking to a very great depth, but there is one which is most important of all. As the depth is increased and the water level inside the curb is kept down, the difference in pressure becomes so great that the gravel will not stand and flows under the curb in great slides. This is sometimes called bottom heaving, and as much as 2 or 3 feet depth of gravel may come in at one time, bringing about a serious condition and usually ending the sinking operations. Curbs out of plumb or distorted, often prevent the completion of a well to the desired depth.

Excavation by means of power operated orange-peel buckets permits the removal of material under water. By this method, bottom heaving is less probable because of the supporting water inside the curb, and greater depths are attainable.

Large Pits.—Open pits 20 to 25 feet wide and 50 to 200 feet long, usually dug with a drag-line machine, appeal to some because of the tremendous infiltration area. They are feasible only where water is close to the surface and in gravel. Their yield is usually disappointing, and there are many objections to them. With a water depth seldom over 8 feet when made, they become rapidly shallower as the sides slough in on being pumped. By installing a collecting box or perforated casing in a trench in the bottom leading to a sump at one end, the depth can be maintained, and after backfilling, there is no unsightly trap for tumble weeds.

Metal Well Casing

The well casing used in irrigation wells in Colorado is almost exclusively of the riveted galvanized iron or steel type in sizes from 12 to 48 inches. Up to 24-inch diameter, sometimes larger, the joints are lapped and riveted, but usually, in the larger sizes, a butt-joint is made by riveting to an overlapping inside iron band. This band serves as a stiffener and permits the use of lighter material for the casing.

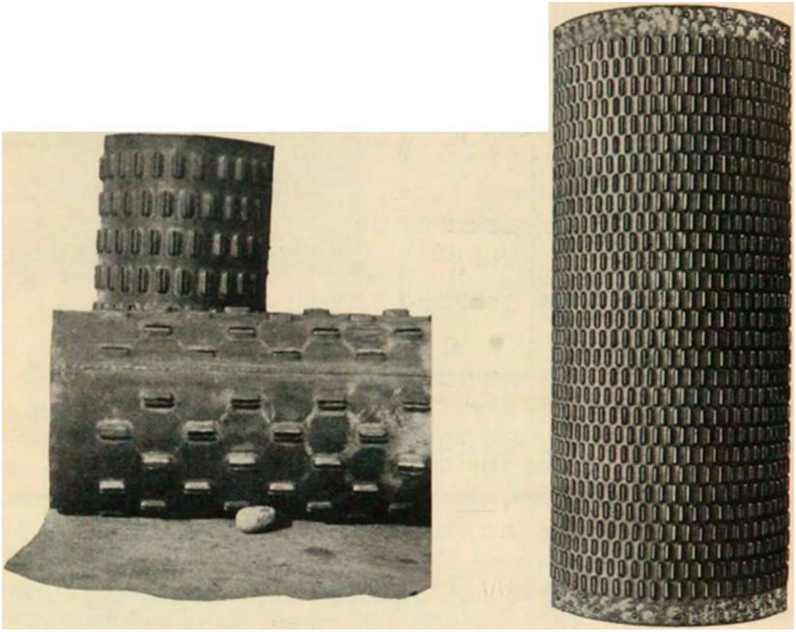

Fig. 5.—Sections of perforated well casings.

The sheet steel used is 16, 14, 12 or 10 gage according to well diameter and depth, and iron bands vary from 3/8 inch by 3 inches to 1/2 inch by 4 inches. The weight of the casing to be used is determined largely from experience, and Table 1 is offered as a guide. It is based on the opinion of manufacturers and drillers and is for ordinary conditions. If great pressure is required to force the casing down as through clay and large boulders, the next heavier weight should be used. Perforated casing is made by shearing a slot through the metal leaving the burr on the outside. This "chisel" type of perforation is non-clogging, and much to be preferred over punched holes, either round or oblong. Usually the slots are made either one row or a double row at a time in such a manner as to be staggered. They are 1 to 1 1/4 inches long and 1/32 to 1/4 inch in width according to specification. Most machines perforate the plates flat, but others, after the plate has been rolled. Figure 5 shows samples of such perforations. Perforated casing will usually be found a little undersized except at the joints as the perforating tends to draw up the metal slightly.

Table 1.—Recommended Minimum Well-Casing Thickness for Shallow Wells.

U. S. Standard Gage

Depth of Well	Diameter of well casing in inches																
	8	10	12	14	16	18	20	24	26	30	36	42*	48*	54*	60*	66*	72*
20 Feet	16	16	16	16	16	16	14	14	14	12	10	16	16	14	12	12	10
30 Feet	16	16	16	16	16	14	14	14	14	12	10	16	14	12	12	10	10
40 Feet	16	16	16	16	14	14	14	14	12	12	10	14	14	12	10	10	10
50 Feet	16	16	16	14	14	14	14	12	12	12	10	14	14	12	10	10	10
60 Feet	16	16	14	14	14	14	14	12	12	10	10	12	12	10	10		
70 Feet	16	14	14	14	14	14	12	12	10	10	10	12	12	10			
80 Feet	14	14	14	14	14	12	12	10	10	10	10	12	12				
90 Feet	14	14	14	14	12	12	12	10	10	10	10	12					
100 Feet	14	14	14	14	12	12	10	10	10	10	10						
†Band Thickness in inches	¼	¼	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8	3/8	½	½	½	½	½	½
†Band Width in inches	1	1	1½	1½	1½	1½	2	3	3	0	3	2		4	5	5	5

* Reinforcing bands placed on inside of casing at 3-foot intervals and on outside at top and bottom.

†Thickness and width of top and bottom reinforcing bands and intermediate bands for casing over 42 inches in diameter.

Gage thickness of casing to be the same for entire depth of well.

Casing may come in single joints, or in any number of joints riveted together, as ordered. The overlap between joints runs from 1 inch to 1 ½ inches, and must be taken into consideration in ordering, for with a 1 ½-inch overlap, a foot is lost every 8 joints. The quoted price on casing does not include the overlap.

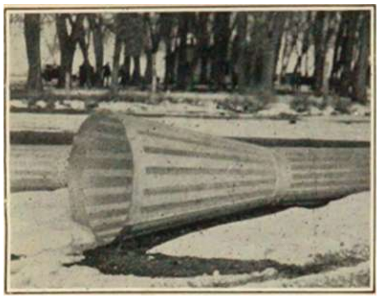
Fig. 6.—Shutter-screen perforation. Bell-bottom used only in gravel.

Another kind of casing used to a small extent in Colorado is that illustrated in Figure 6. This is made up of 6 or 8-gage plain steel plates with butted joints held together by wide, outside bands. The perforation is a patented feature, and is made by shearing the metal and forcing one edge out as are louvers on an automobile hood, except that the openings are horizontal.

The use of the bell bottom, as shown in Figure 6, is limited to certain conditions. If all of the well is in gravel, the bell bottom may be bailed down without trouble, but if a thick clay stratum is encountered, there being no way to cut to the edges, progress will be stopped. The bell bottom provides an enlarged hole for the application of a gravel wall the entire length of the casing.

Casing shoes, as used in Colorado practice, are comparatively light, and consist only of an iron band as indicated in Table 1. There is seldom a shoe failure when the casing is of proper thickness, because of the light loads generally used in forcing the casing.

Tools and Methods Used in Sinking Metal-Cased Wells

Types of Wells.—There are two main types of metal-cased wells when viewed from the standpoint of the manner of construction and not from the type of tools used. The first involves the sinking of a blank casing to the ultimate depth, at which time the perforated casing is set, and the blank withdrawn. As the blank casing is being pulled up, screened gravel is put into the space between the two. The second type of construction, that of sinking the final casing directly, is the more common. With either type of well, the procedure in actual drilling is much the same. One difference, however, is noted in that because of heavier first casing in the two-casing well, a drilling bit can be used, while with the second type a bit is avoided because of possible damage to the lighter metal.

Drilling Machines.—The outline diagram, Figure 7, shows the essential parts of a drilling machine for the usual Colorado irrigation-well work. Variations in details are many because drillers often

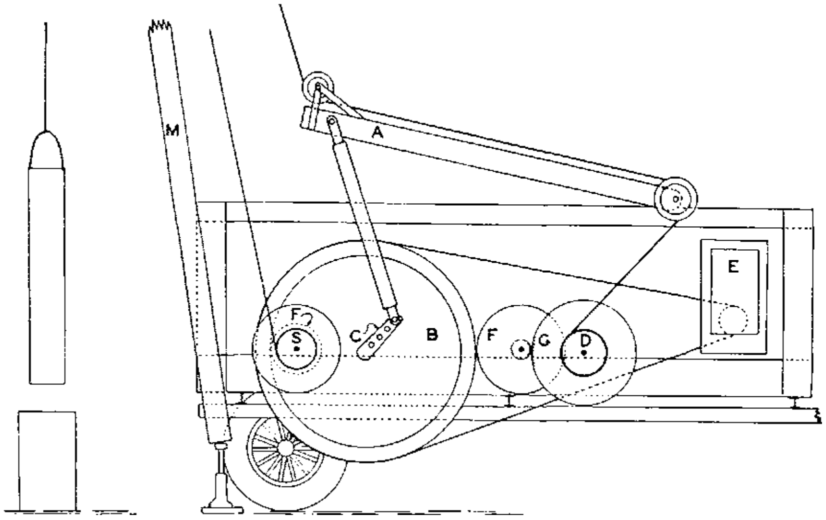

Fig. 7.—Diagram of well-machine action. E, engine; B, band wheel, D. drilling line; S, sand line; A, spudder arm; M, mast.

build their own equipment. Most machines with their engines are mounted on motor trucks, while others are trailed and powered by tractors.

Power from a high-speed engine, E, of about 10 to 15 horsepower, is transmitted to the band wheel, B, by belt. By means of a movable shaft bearing, controlled at the front of the machine by a rod and lever, rotation is transmitted to the shaft by holding a pulley, P, against the rim or other circular part of the band wheel. This motion, reduced, is transmitted by sprocket and chain or gear. G, to the spool, D, holding the drilling line. A similar independent arrangement drives the sand-line spool, S, but at higher speed. Each spool is provided with its own brake for stopping and holding the tools. The drilling-line spool may be hand operated through a worm-and-gear reduction for handling the tools without the aid of the engine. The spudder arm, A, is given an up-and-down motion from a crank, C, on the band-wheel shaft through a clutch.

The length of the up-and-down stroke may be varied from 6 to 30 inches by setting the crank pin in one of the several holes in the crank arm. A machine with this equipment can be used for test- hole drilling, operation of large buckets and surge blocks, as well as for deep well work. Some machines are provided with a third reel for use in operating an orange-peel bucket, and a boom hinged to the derrick to facilitate its use. Others may have a power take-off for rotating an auger stem.

Where wells are to be put down with a sand-pump bucket only, in sand and gravel, a power hoist and a mast may be all that is re-

Fig. 8a.—Soil auger operated by hand.

quired. This has been further simplified, in some instances, by omitting the hoist and attaching the drilling line to an automobile axle—a somewhat awkward procedure lacking flexibility.

Augers.—The well is often started by excavating as far down as a man can work with a spade. Because of the necessity of hauling water when working in dry material with drop tools, augers are often used to as great a depth as possible. Augers may be hand operated, or of the horse, or power-driven type. The hand auger, Figure 8-A. is turned by two men and the load lifted by the hand winch on the machine. The horsepower rig shown in Figure 10

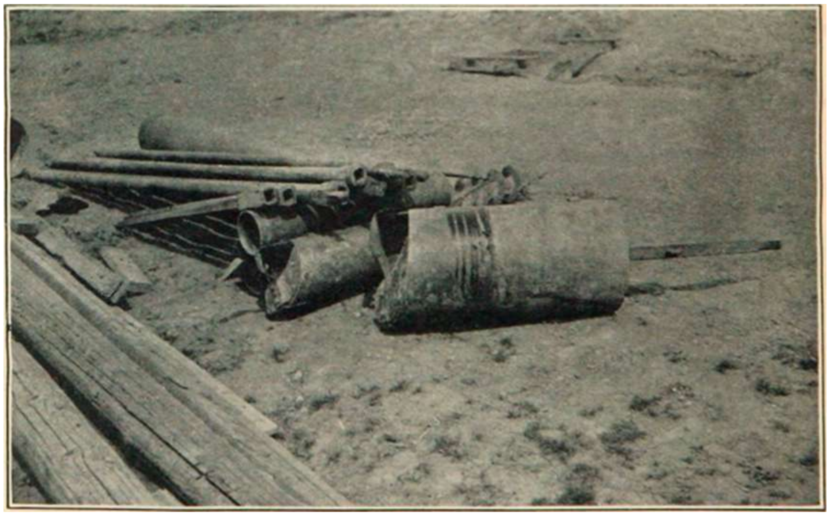

Fig. 8b.—Soil auger operated by horses.

Fig. 9. —Engine-driven soil auger. Side opening bucket with reamer attached.

turns the auger, and by shifting a gear, hoists the load as well. A power take-off turns the table shown in Figure 11, the cross-bar imparting rotation to the square hoisting bar. The hoisting-bar joints are of the square box and pin type for fast handling, and permitting power to be applied in either direction.

For making holes larger than the bucket size, and up to 32 inches in diameter, an ear is bolted to the upper edge, which acts as a reamer. Augers equipped with a bucket above the cutting blades make it possible to cut through any clayey material that will stand in the hole, and progress is much faster than with any other method now in use except the rotary. Up to a 30-foot depth in ordinary hard soil, from 5 to 10 feet of 30-inch hole can be made per hour with a power-driven auger, and the operation can be continued until loose gravel is encountered.

The regular drilling operations are started when no further progress can be made with spade or auger. If the materials will stand, casing is not set until it appears dangerous to go on without it. The casing should be at least 5 or 6 inches less in diameter than the starter hole, and after being set in position and plumbed, the outside space is backfilled with gravel. The gravel, as ordinarily used, is obtained by taking the cut between ¼ and 1-inch screens.

Sand Buckets.—Two kinds of sand buckets or bailers are in general use; the churn bucket, equipped only with a flat valve at the bottom, and the other, a sand-pump bucket or bailer which has a close-fitting piston on a long stem running through the bail in addition to the bottom valve.

The churn, or common sand bucket is usually made of ordinary standard pipe, the weight, size and length depending on the service imposed on it, and should have a chilled-steel shoe. The valve seat is located from 2 to 5 inches above the bottom of the shoe and is from ¾ inch to 1 ¼ inches wide. The valve flap is often made of a heavy wrought-iron plate, to which a piece of rubber-fabric belting is sometimes bolted. At one point on the rim of the plate, curved arms with holes at the end meet similar arms welded to the seat ring, which, with a short bolt, form the hinge. It may also be of cast steel with a beveled bottom in which case the seat is made slightly rounded on the edges and contact is on a line, rather than on a flat surface. Another type, quite different from the preceding, is that formed by a loose cast-iron ball fitting against a square-edged seat. The valve opening should be as large as the bucket will permit in order that large stones may be picked up. The loose ball valve does not permit as large a clear opening as the flap-valve type.

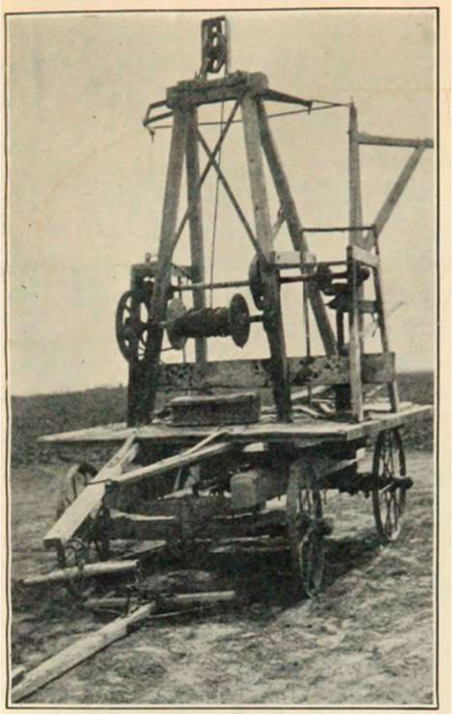

Fig. 10.—Horse-driven soil-auger machine.

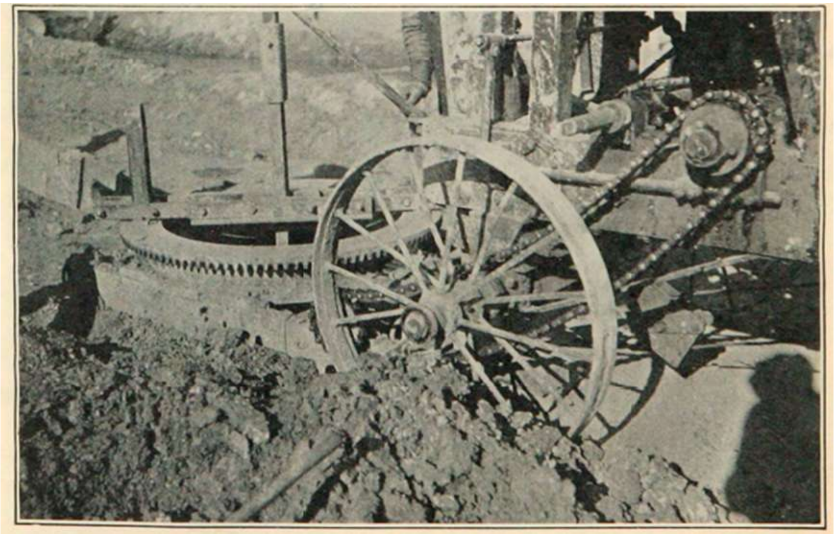

Fig. 11.—Power take-off from well machine to drive soil auger.

The bucket should be as large as can be operated safely in the casing used. The larger and heavier it is within the limit of power of the well-drilling machine, the faster and better the work that can be done.

In operation, the bucket is placed on the drilling line and an up-and-down motion imparted to it by the spudder arm. It is handled about the same as in regular drilling with cable tools when working in clay, but with probably a shorter stroke in sand or gravel. The bucket is brought up and dumped when it will not pick up more drillings, generally after 2 feet or more of material have accumulated. The dumping is accomplished in an easy manner after upsetting by connecting the bottom of the bucket and the drilling line by a short piece of cable, or rod with a hook at each end, as shown in Figure 12.

Fig. 12.—Dumping a churn bucket. Steel billets being used to load casing.

The sand-pump bucket is operated on the drilling line, but with the spudder arm tied down or on the sand line if the bucket is small. This bucket may be either top or bottom dump, and although usually 5 or 6 feet long, may be as much as 10 feet long. The piston should fit closely but not so tight as to tend to raise the bucket on withdrawal. The smaller-sized pistons may be fitted with leathers but these are not necessary on the large ones. The piston shown in Figure 13-B has no leathers nor valve as do most pistons. The valve is necessary to allow the water to escape as the piston settles to the bottom position. Without the valve, more clearance is necessary around the piston and greater withdrawal speed is required.

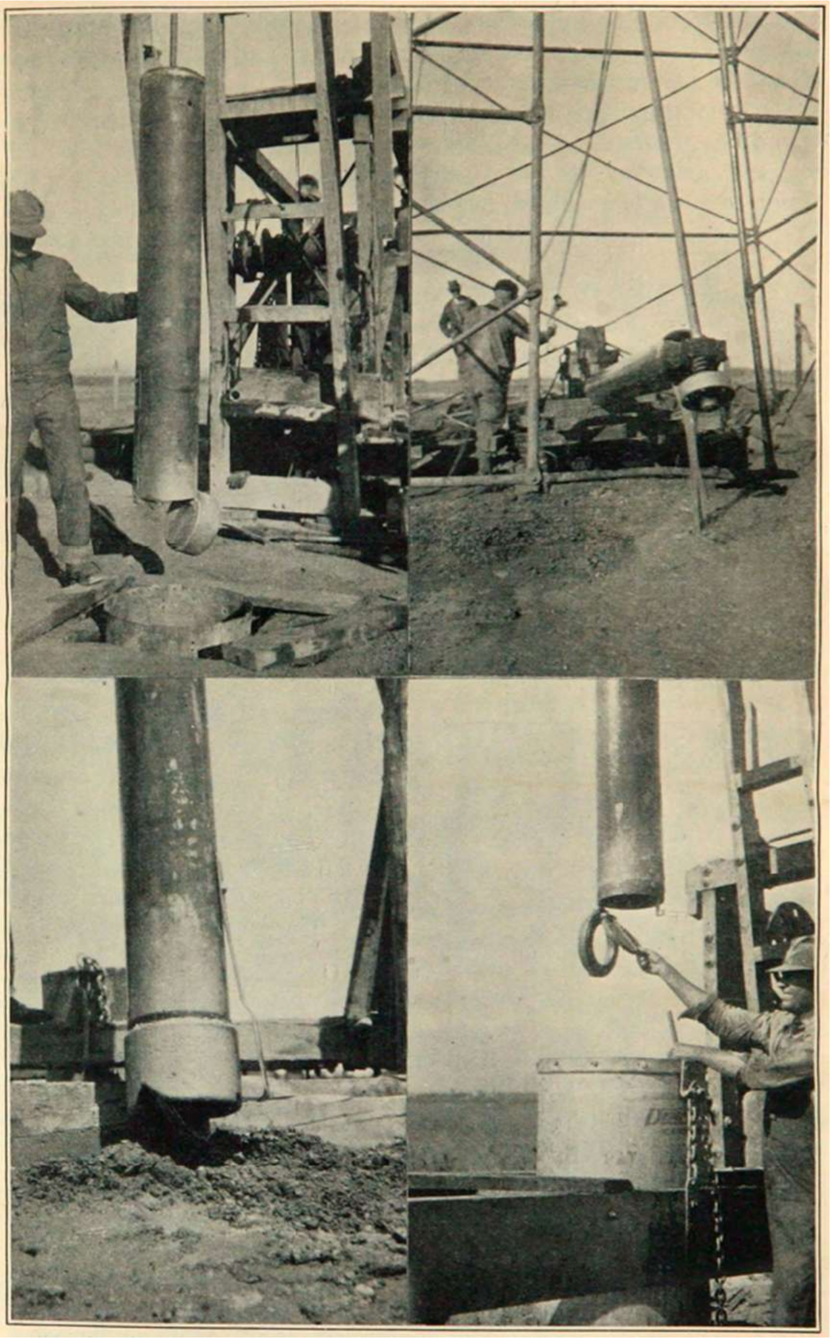

Fig. 13.—Sand pumps or vacuum buckets. Upper left, bottom dump, hinged shoe; upper right, top dump: lower left, bottom dump, hinged valve seat; lower right, bottom dump, hinged shoe.

The top dump bucket requires either a hole in the side near the top and a hinge in the rod, or a hinge at the bail, high enough up to allow the piston to swing out.

The bottom dump bucket requires a hinging mechanism which will allow the bottom valve to swing down when unlocked. Either the seat alone or the entire shoe may be so hinged. The bottom dump is more convenient, but the operator must be protected from the splash on opening. It is generally more leaky when not loaded and not quite so substantial as the top dump type.

In operation, the bucket is lowered to the bottom and time allowed for the piston to sink its full stroke. The engine is then accelerated, and the piston pulled up rapidly the full length of the rod and a little more. Sometimes this one pull will fill the bucket, but more often two to four pulls are required. It is essential that the bucket does not lift before the piston reaches the top, for in successful operation, the bucket sinks as it loads. The usefulness of the sand-pump bucket, it will be seen, is limited practically to sand and gravel or flowing material, but can cut through clay when used as a churn bucket. Figures 13-A, B, C and D illustrate a number of sand-pump buckets. The one in Figure 13-C is open to the objection of having an outside band which might catch under the well-casing shoe. One of the photographs shows the upstroke bumper-spring just above the piston.

Orange-Peel Buckets. — Wells, 36 inches or over in diameter, are usually sunk by using an orange-peel bucket. Although such buckets are made small enough to go into a 12-inch hole, they are used only to pick up large stones or lost tools. The smallest practical size is the 22-inch, and under some circumstances, it is not as efficient as a sand-pump bucket. They do not work very well in hard clay as it is not safe to drop them fast in open position in a well having inside hoops. To increase their efficiency in cutting clay, the hammer type can be obtained, shown in Figure 14. The hammer has a throw of about 8 inches and is worked by the holding line. As ordinarily operated, two lines are required, the holding or lowering line and the closing or hoisting

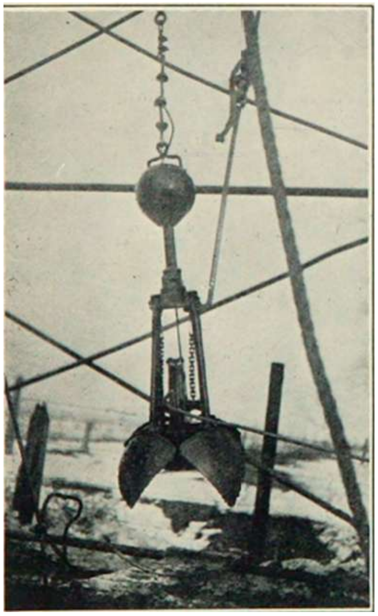
Fig. 14.—Hammer type of orange-peel bucket rigged with one line.

line. By arranging a spring hook inserted in a ring on the hoisting line, which will hold the bucket open until released when the leaves touch bottom, only one line is required for its operation. (Figure 14.) One driller, unable to cut through a thick layer of clay with the orange-peel, made up a clay cutter shown in Figure 15 from an old drill stem and some ½ by 6-inch band-iron.

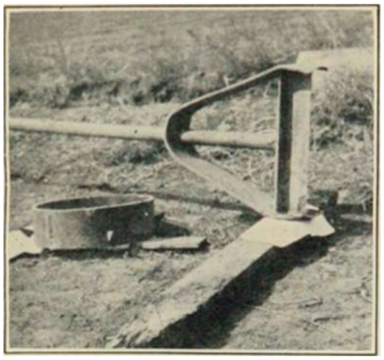
Fig. 15.—An improvised clay cutter.

In using an orange-peel with a regular drilling rig, a boom should be attached to the mast so that loads may be swung sideways. Either a single or double-drum hoist can be used with a boom-mast or temporary tripod. In a few instances, a boom hay-stacker has been used. The cover illustration shows orange-peel bucket equipment being used.

Methods of Forcing Casing.— Pressure to force down the casing is obtained usually in one of two ways, namely, by lever arms or by direct application of weight. Lever arms are more convenient for casings up to the 24-inch size, but above that size, direct weight is generally used. The lever arms consist of a pair of beams, usually timber, but sometimes steel, from 16 to 24 feet long, cross braced for rigidity. Usually the wide end is placed over the well, but some drillers reverse this, thus reducing the rigidity of the frame. One end, the fulcrum, is placed under the frame of the well rig or fastened to a dead man with the casing between the arms at a distance of about 5 feet. At this point chains are fastened which lead to pull-down ears hooked directly over the casing or attached to a pull-down head. A box, built at the far end of the arms containing sand or spare tools, provides the weight. Usually the maximum force exerted, using long arms, is about 4 tons and is ample for the type of work involved as frequently a 1-ton load is sufficient to force 24-inch casing 80 feet when gravel only is encountered. If clay strata are penetrated, a greater load is needed. In applying the load, the drilling cable is attached to the ends of the arms and they are hoisted 6 or 8 feet. The pull-down chains are then attached to the casing and the cable line slacked away, leaving the weight on the casing. See Figure 16.

Direct application of weight may be effected by loaded sand boxes which are supported on timber or steel beams laid across the top of the casing. With such an arrangement it is necessary to unload the boxes each time a length of casing is added.

The illustration on the cover shows sand-box loading while Figure 12 shows steel ingots being used. Detachable loaded boxes and oil barrels are shown in Figures 17 and 18.

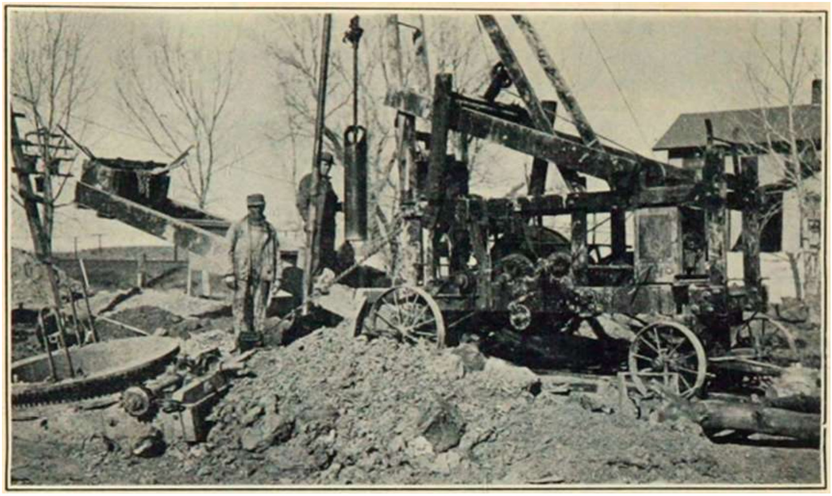

Fig. 16.—Lever-arm method of forcing casing. Ten-inch sand pump on drilling line. At lower left is turntable for soil auger

Fig. 17.—Detachable sand boxes used for forcing casing. Orange-peel bucket equipment being used.

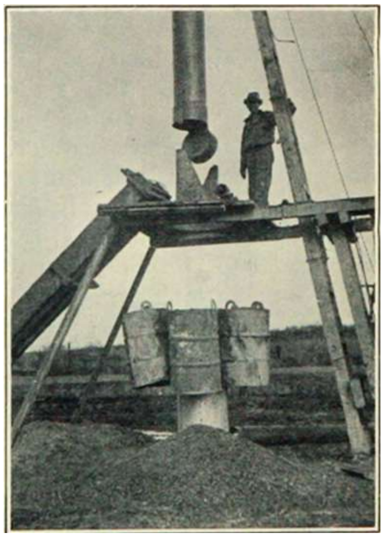

Fig. 18.—Detachable steel barrels used for loading casing. Fifteen-inch sand pump on drilling line. Note location of helper. Platform also carries drive head for auger.

A jacking arrangement is shown in Figure 19 which is very convenient and a time saver on deep holes. However, it must be continuously operated, and a third man on the work is almost necessary. It is simple to construct, the ratchet gear being about the only part requiring machine work. The foundation timbers are anchored to dead men which must have ample resistance to the large upward forces exerted. A cable on each side of the casing is fastened to the foundation timbers and passed over a pulley on the pull-down ears to the jacking shaft. The arm carrying the ratchet engaging-hook can be loaded or not, according to whether it is to be hand or power operated.

Fig. 19.—Jacking arrangement for forcing casing.

Very often the casing does not keep up with the drilling in spite of heavy loading. This occurs especially when clay strata are penetrated. One very effective method of starting a "hung up" casing is that of dropping a large, loaded bucket as far and as fast as the drilling line will permit, in order to strike a heavy blow on the water surface in the well. A free-running drilling line is very desirable in this connection. Under-reaming in clay with a special tool on a string of pipe is sometimes necessary when other methods fail. Rather than to spend too much time and effort on forcing a casing through clay, the alternative of starting a smaller casing with the assurance of a gravel wall below the clay, is often desirable.

Seating of Casing.—The seating of light casing in hard material to prevent a flow of gravel under the shoe, is somewhat difficult. With double-casing construction, the trouble is easily disposed of by riveting a bottom on to the inside string before it is lowered. Little or no trouble is experienced with the 12-inch size in open bottom construction, but the difficulties increase with the size so that with the 48-inch size it becomes impossible to set the casing into clay with any assurance of a uniform and adequate seal. It is, therefore, an established practice to seal the bottom of all wells over 14 inches in diameter with a concrete plug or by backfilling with gravel. The former is to be preferred where the well does not have to be put into service immediately.

In setting a concrete plug, several things must be kept in mind to insure success. Concrete poured under water, especially cold water, requires a longer time to set than under ordinary conditions, and secondly, it must necessarily be poor concrete because no matter how carefully dumped, some of the cement is washed out. Two weeks should be allowed for ordinary Portland cement and 10 days for quick-setting cement before any pumping is done.

The bottom of the well first should be cleaned thoroughly of mud because this is certain to mix with the concrete. A wet mixture of about 3 to 1 of gravel and cement is made and placed in a bottom- dump bailer and lowered to the bottom, the entire charge being placed at once if possible. If such a bailer is not available, then a cement sack can be used which has two ropes attached, one to lower with and one on a slip-knot over the mouth of the bag. Dumping must be done without any undue disturbance of the water at the bottom.

A variation of this method is used by placing less concrete and carefully setting a precast concrete plug on top of the grout. These methods are preferred to lowering a number of filled sacks to be subsequently broken with a sharp tool. The thickness of the plug will vary from 8 to 16 inches depending on conditions and quality of concrete.

A backfill of gravel should be 2 or 3 feet deep to be effective, and in shallow wells becomes a large percentage of the total depth. It prevents a free inflow of water near the bottom and may unnecessarily limit the setting of a turbine pump.

Rotary Method of Drilling.—A few wells have been put down in Colorado by the hydraulic rotary process. In this, water containing a large percentage of clay is forced down a rotating hollow tube to which a cutting bit is attached. As the materials are dislodged by the bit and mud stream, they are carried to the top and floated out into basins. The work is carried on without casing in the well, the heavy clay solution supporting the walls and mudding up sand and gravel strata, preventing their caving. When the boring work is completed, the perforated casing is set and the intervening space filled with screened gravel. The well is now backwashed by directing a strong stream of water against the perforations under a movable plug. After this operation, the well is immediately pumped and the clay solution removed from the well and surrounding gravel strata. It is essential that a thorough job of backwashing and pumping be done promptly, because of the difficulty of cleaning the mud-filled sand and gravel.

Development of Metal-Cased Wells

The development of a well after drilling consists of flushing the fine sand which lies adjacent, through the perforated casing into the well. Upon the removal of this fine sand from the formation, the water passes through the gravel with greater ease, and the well will yield more water with the same drawdown than it would if this fine material were allowed to remain. By decreasing the drawdown in a well, a direct saving in the cost of pumping is made since the power required is directly proportional to the lift.

Surge Blocks.—Development by means of a surge block is the process of moving a piston of approximately casing size, up and down in the well. A surge block may be made of several pieces of 2-inch lumber bolted together on the upper side of which a flange, with bolts extending through the block, forms the attachment for a string of pipe. Other devices may be attached for use with a drill stem. The diameter of the block should be as great as possible for the casing in which it is to work. The power required for operating large surge blocks is great, often beyond the capacity of the engine on some machines, and a compromise is then necessary by reducing their size or by the use of valves, with accompanying reduction in effectiveness.

Most machines can handle a surge block for a 12-inch well with the weight of an ordinary drill stem. Such a block should be about 11 ¼ inches in diameter so that it will just pass through perforated sections*. For a 24-inch well the block should be about 22 inches in diameter. A block of this size, with wire scratchers to aid in dislodging sand particles from the perforations, is shown in Figure 20. It has been found that a block of this size should weigh at least 500 pounds when immersed in order to sink promptly on the down

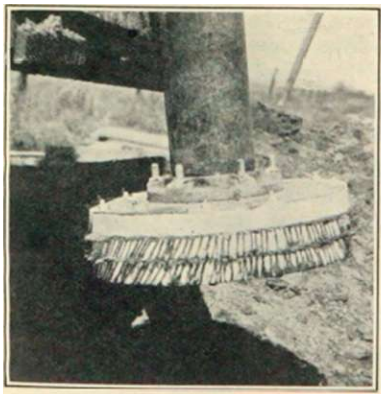

Fig. 20.—Twenty-two-inch surge block with wire scratchers.

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* Plans for making surge blocks and complete descriptions of methods of developing wells are discussed by H. O. Williams in Nos. 10, 11. and 12 of Vol. 2 and Nos. 1, 2. 3. of Vol. 3 of Johnsons' National Drillers Journal. St. Paul. Minn. Certain precautions necessary when special screens are used, are not needed for the type of perforated casings used in irrigation practice.

stroke. In operation, the block is lowered to the upper (or lower) perforations, and the machine set on the long stroke. The speed is then adjusted as fast as possible without undue slap of the cable. If the tool will not fall fast enough more weight must be added or the less desirable expedient of shortening the stroke must be resorted to. After running from 15 to 30 minutes at one position, the block is dropped to the next lower position and so on to the bottom of the well.

The well should now be sounded to ascertain the effectiveness of the work and then cleaned out. Repetition of this procedure should be carried on until no appreciable amount of sand is being brought in. With rigs having no spudding motion, good work can be done by rapidly raising the block from bottom to top on one pull. Not less than a half-day of development work should be considered sufficient and in some cases a second day's work might be profitable.

A surge block is not always necessary for the smaller wells as very effective work can be done with a heavy sand bucket filled with gravel. The bucket must be nearly the size of the casing or enlarged by wrapping belting or part, of an old automobile tire around the bottom. Development of the 48-inch well presents the most difficult problem and it has not been satisfactorily solved as yet. Besides the great size of block and the corresponding power required, the work is very much complicated by the projecting inside bands. Perhaps the most satisfactory block used is one fitted with a large, truck tire which practically eliminates the danger of dislodging these bands. Such a block should weigh no less than 1200 pounds.

Air.—Under certain conditions, development by means of compressed air is very effective. It must of necessity be confined to the smaller-sized wells, and to those where the perforations start below the water surface. A tight fitting cap is necessary at the top, and air is first forced into the casing, depressing the water surface, and then released to allow the water to return.

To increase the efficiency in the use of air by preventing its escape at casing joints, and to obviate the compressing of the large volume of air in the well, a tight fitting plug can be set just above the water surface. The piping should be arranged as in Figure 21 with two valves, one to control the air from the compressor, and the other to effect a release of pressure from the well. A combination of surging and pumping is still more effective, and can be obtained by extending an eduction pipe, with the air pipe inside, through the block to near the well bottom. The air pipe should stop about a foot or two above the bottom of the eduction pipe. Pipe sizes will depend on capacities, but for 400 to 500 gallons per minute, a 6-inch eduction pipe and a 2-inch air pipe can be used.

In order to pump with air, it must be remembered that at least 50 percent submergence of the eduction pipe is necessary. Therefore, if the lift is to be 35 feet, the eduction pipe must extend 35 feet into the water while pumping.

In order to be certain as to what is occurring in the well, a pressure gage is a necessary part of the equipment. If such a gage is calibrated in pounds, then by multiplying by 2.31, the approximate distance in feet is obtained that the water surface has been depressed during surging operations.

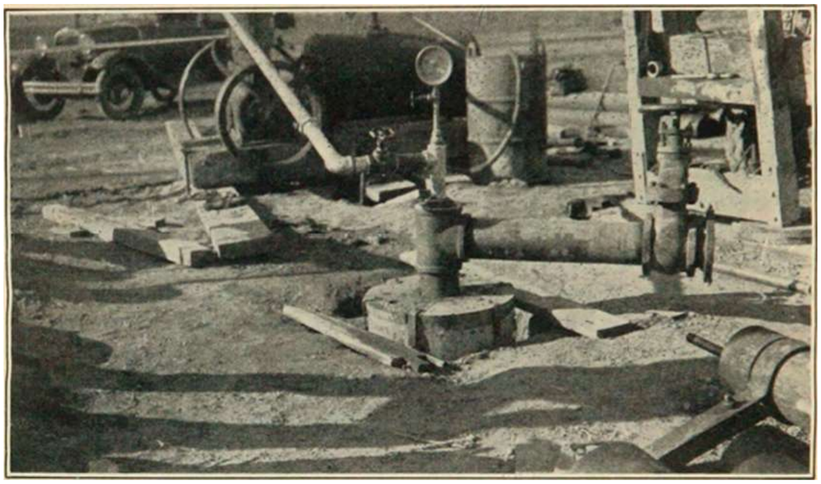

Fig. 21.—Compressed air being used for well development.

Dry Ice.—Solid carbon dioxide or dry ice liberates gas rapidly on immersion in water and may be used to build up pressure within a well casing. The rate at which gas is liberated is dependent on the size of the pieces of ice; the action being quite violent if applied in powdered form, whereas pieces weighing 2 or 3 pounds require 10 to 15 minutes to dissolve.

For economical use, dry ice should be introduced below a tight plug at the water surface, and valves and a gage provided, as described under air development. The use of dry ice can be considered only an emergency method because of the short time that development work is possible even with large quantities. Two hundred pounds would be required for 4 or 5 runs of 15 minutes each on a 24-inch well, and each run would yield perhaps 10 surges.

Pumping.—A considerable development occurs when a well is first pumped, and most wells receive no other treatment. In order to obtain the maximum benefit, a pump should be installed which has a capacity at least as great as the anticipated yield of the well, and the discharge pipe must be equipped with some type of valve for controlling the flow. Before any attempt is made to start pumping, it is essential that everything- be in readiness for a full day's run, as pumping should be continuous so long as sand is being produced. At the start, only a small amount of water should be pumped and this rate should be continued until the stream is nearly clear of sand. The valve is then opened a little, and the process repeated until, in three or four stages, the maximum discharge is attained. It will be found that each successive increase will start a new run of sand. Should the maximum quantity be pumped at the start, there would be such a sudden rush of sand that all of the fine particles possible would not come in, but a portion would be "bridged" off. After the maximum discharge has been reached, the pump should be stopped and the well allowed to fill up. When the water surface has reached about its original point, the pump should be started again at full capacity. This should be repeated frequently (every 15 minutes perhaps) until but little sand comes in.

Results from Developing.—The beneficial effect of development work is not known to or appreciated by many well drillers and owners. It has proved of such great value that it should always be included in a well contract either as extra work, or for a stipulated number of hours of work. The yield of many wells has been increased from one third to one half by development.

The difference between no development and 6 hours of surge- block work was demonstrated recently near Eaton, Colorado. After pumping, during the latter part of the summer season from a new well, a test was made. The pump was removed, and the surge block used. The next day, another test was made, and it was found that, the discharge had increased from 345 to 450 gallons per minute and the drawdown had decreased from 24 to 13 feet.

Test-Hole Drilling

Exploratory work preceding actual well construction has been justified so often that it should be considered as part of the plan in nearly all irrigation-well work. It has been demonstrated so many times that conditions may exist under a farmer's land varying from poor to good, that he runs a considerable hazard in selecting an arbitrary site. The information gathered by test drilling is not only valuable to the farmer, but to the driller as well, because he is informed in advance as to what difficulties may arise and can plan accordingly. Some drillers will not put down a well 24 or more inches in diameter without test-hole information.

The test hole is ordinarily 5 or 6 inches in diameter and is put down with cable tools. Standard pipe, which can be driven and pulled, is used for casing. Samples of the formations obtained from the sand buckets, if carefully taken, are generally considered good and as giving a first-class log of the hole. Because of their superiority in speed over cable tools, rotary test rigs are also used. A hole 21/, or 3 inches in diameter is drilled without casing by forcing down a mud-laden stream of water through hollow drill pipes. As the material floats up on the outside in the mud stream, samples are taken at definite intervals with a shovel and placed in little piles on the ground to dry out or be washed. Reliable information can be obtained only by experienced operators who interpret the log, not only from the samples, but by the feel and progress of the tools in the hole.

Under some circumstances exploratory work by hand methods may be carried on quite satisfactorily. Holes 30 feet or more in depth are possible with post-hole augers providing the formation will stand without caving. Two or more sizes are advisable for such a depth, the start being made with the largest. It is not possible to maintain a hole in loose gravel, and an auger is useless in such material, but %-inch or V2-inch rods can be driven through it to considerable depths. Driving becomes more difficult in clay, and if a hammer, not over 3 pounds in weight, is used, and the rod turned constantly, it is possible to determine approximately at what point the rod leaves the gravel. It is almost impossible to drive such a rod into shale or sandstone, and often the location of these strata is the information desired. The full depth of gravel cannot be proved on one trial because of the possibility of encountering a boulder and a. proof trial should be made near by. Soil augers may be used instead of post-hole augers, but they are more easily stopped by small stones.

Since rod exploration yields no information on the quality of gravel, it may be desirable to sink a hole with a sand bucket to obtain samples. Such a bucket can be made of 3 or -i-inch pipe to weigh about 50 pounds and worked by hand inside of light casing to a moderate depth.

Design of Metal-Cased Wells

It has been aptly said that 110 two wells are alike. Since most irrigation wells are sunk in recent alluvium, it is to be expected that even within very short distances, there will be considerable variation in formation. Only suggestions can be given here in the way of general plans for accomplishing the best results.

The simplest condition is one where the gravel is continuous below the water table, and above that, there is a continuous column of soil and clay. The upper portion may be excavated without casing, at least in part, and should be from 6 to 8 inches greater in diameter than the casing in order that fine gravel applied at the top will have an opportunity to flow down around it. As soon as the removal of gravel is begun in water, excess material is naturally taken out, and the screened gravel flows down on the outside to take its place. The gravel will follow the casing down a considerable distance, easily 40 feet, but gradually becoming dispersed and not so effective.

A second condition may be assumed to be the same as in the preceding case, but with two gravel layers separated by a 6-foot stratum of clay. Because of the probability that gravel would not go past this clay, since the casing would have to be forced through it leaving no space on the outside, a second casing is recommended. The second string of casing should be not less than 4 inches smaller than the first in order to provide space for gravel between them. After the first casing is landed on the clay, operations are begun on a hole of ample size through it. When this is accomplished, the second string of casing is inserted and the space between kept filled with gravel *up to* some point above the top of the clay. From previous test-hole information, it will be possible to locate a slip joint so that, when the second casing is landed it will separate, on being pulled, at a point 2 or 3 feet above the shoe of the first casing. In this manner, screened gravel can be applied with assurance to the lower water-bearing stratum.

Should the formation include a number of clay strata in the water-bearing portion, or should there be dangerous quicksand strata, then the type of construction involving the sinking of blank casing should be adopted. Since the blank casing must be withdrawn, it must be of heavy weight and the joint separation strongly constructed yet easily taken apart. Bolts and lock-lugs are both used for this purpose. The casing should be started in the usual manner, gravel being used on the outside. Since it will be improbable that the gravel will follow down past the various clay strata, the casing should be heavily weighted and precaution taken that the hole not be drilled ahead of the shoe except in clay. This will reduce the tendency to take out excess material which may cause caving below the clay strata. It is necessary to go only to the last clay stratum with the blank casing, penetrating it with an open hole, then bailing down the perforated casing through the lowest gravel stratum. As this casing is going down, gravel is fed in at the top in such a manner that when landed, the top of the gravel is not much above the shoe of the blank casing. The blank casing is now jacked or pulled out, and as it is raised, gravel is continually fed in between the two and kept just a little above the shoe. The reason for keeping a minimum of gravel between the casings is to prevent unnecessary friction being developed, as the outer one is being withdrawn.

Screened gravel, fed into a well around the well casing while it is being sunk and developed, has two particular uses. It holds back the fine sand and allows a free movement of water into the well. If the gravel wall is thick enough, even quicksand may be held back from flowing into the well, because of the reduction in velocity near the casing. The second use is in preventing the formation of cavities which would allow cave-ins to occur. A cave-in often results in the deformation of the casing or the shutting off of a water-bearing formation.

The width of perforation is governed somewhat by the character of sand and gravel encountered. The largest permissible size should be used, the maximum being one-fourth inch, in order to facilitate development work and to prolong the useful life of the casing. The addition of gravel outside the casing allows the use of wider perforations, as a rule, whereas if none is used the opening must not be so large as to permit a continuous run of sand into the well. The average- sized small gravel must be depended upon to stop at the perforation. Perforations less than one-eighth inch are not recommended; those over one-fourth inch are not necessary and may be dangerous. The common widths in use are one-eighth and three-sixteenths inch. Many casings put in 16 to 20 years ago with one-sixteenth-inch perforations have had to be pulled out because of rusting shut. It is believed that the wider perforation will not rust so easily.

Well Contracts and Cost of Wells

Well-drilling price schedules vary somewhat according to locality and general conditions. Fair practice codes have been adopted in several areas, but have not always been adhered to as the industry, up to this writing, does not have a nationally approved code. It is to be expected that the driller with complete equipment and contracting for a completed well, must necessarily charge more per foot of well than the contractor who possesses but a few dollars worth of inadequate equipment, and whose only guarantee is that he will go as far as he can. Very often the "go as far as he can" guarantee means stopping at the first tough spot, or consuming an unreasonably long time.

A contract for a well should be in writing, and should contain, besides the price terms, the size and weight of casing to be used, size of perforation, the amount of perforated and blank casing and the agreed depth. If the depth is not known in advance, the contract should provide for a minimum payment to protect the driller, and for stopping the work at the owner's option for the latter's protection. The contractor should guarantee that the well will be sufficiently straight, true and plumb, that a turbine type of pump can be installed and operated according to the manufacturer's guarantee. It is desirable to have the method of sinking described, and the amount of intended development work or charge per hour, also included in the contract. It is common practice for the customer to furnish all necessary gravel, but the contract should so state. The amount of gravel to be used may vary from a few to 15 or 20 cubic yards and hence, if furnished by the contractor, must be agreed to on a unit price basis. The contract should state definitely who shall furnish fuel or other supplies, and contain also any agreements as to furnishing board and lodging to drilling crews. Pinal payment should not be made until the well has been tested, and in justice to the contractor, the cost of casing should be advanced at the time drilling operations are started. A contract that involves the well only is most desirable, as the inclusion of pumping equipment may lead to confusion.

The cost of steel or iron well casing is fairly well established, varying only with the price of steel. The following table gives the approximate cost of well casing at Denver, and drilling prices which do not include development work, nor the furnishing of gravel.

Table 2—Approximate Cost per Foot of Well Drilling and Riveted Galvanized Steel Well Casing.

		Casing Cost							
Size	Drilling Cost	16 gage		14 gage		12 gage		10 gage	
		Plain	Perf.	Plain	Perf.	Plain	Perf.	Plain	Perf.
Inches	Dollars	Dollars		Dollars		Dollars		Dollars	
6[1]	1.00								
12	2.50	.85	1.05	1.05	1.30	1.45	1.85	1.85	2.35
14	3.25	1.00	1.20	1.20	1.50	1.70	2.10	2.10	2.65
16	3.75	1.10	1.40	1.40	1.75	1.90	2.35	2.40	3.00
18	4.50	1.25	1.55	1.55	1.95	2.10	2.65	2.70	3.35
24	6.50	1.65	2.05	2.10	2.60	2.80	3 50	3.50	4.40
30	7.50	1.90	2.35	2.35	2 90	3.15	3.95	4.00	4.95
36	8.50	2.25	2.80	2.80	3.50	3.85	4.75	4.80	6.00
48	10.00	3.00	3.75	3.75	4.65	5.05	0.30	6.60	8.20

[1] Test hole. For more than one, a reduction in price is usually made. Iron bands required at each joint and at top and bottom for values below heavy line. See Table 1. The cost of these bands may be computed from the following-approximate prices per foot: 3/8 by 3 inches, $0.44; ½ by 3 inches, $0.50; ½ by 4 inches, $0.66.

The cost of excavation of large wells near Fort Collins is approximately $1.00 per foot, per foot of diameter, power not included, for depths up to 30 feet. The cost of material can be computed from the kind and quantities required. With lumber at $40 per thousand board feet, and bricks at $13 per thousand, a 6-foot brick well, 30 feet deep with a 10-foot wood shoe, would cost from $10 to $12 per foot and an 8-foot well from $13 to $16 per foot.

Near Denver, many wells have been put down using concrete rings similar to those in Figure 2. One firm manufacturing these rings charges $1.25, $2.50 and $4.00 per foot for the 24, 36 and 48-

inch sizes respectively, plain, and about one-third more perforated. A popular method used in sinking these rings, after digging by hand to water, is to hire an orange-peel bucket machine that would finish the excavation under water. Such a machine with its operator could he procured for $7.00 per hour plus a moving charge of $3.50 per hour in 1934. Many of these shallow wells lacking but 10 or 15 feet of the finished depth were completed in from 2 to 4 hours.

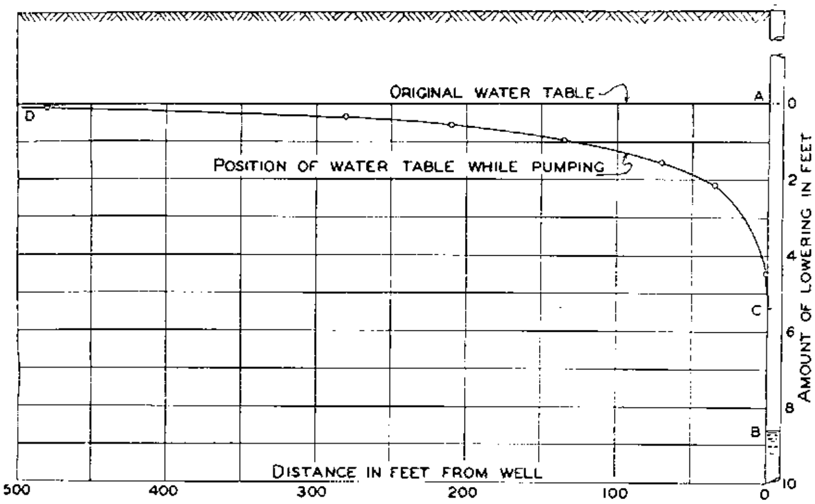

Fig-. 22.—Well drawdown curve taken from Experiment C. AB drawdown, CB casing head loss, AD radius of influence.

Well Characteristics

When a well is being pumped, the water surface inside lowers to a more or less definite point very quickly after which the rate of lowering becomes less and less, reaching practically equilibrium in 4 or 5 days. This lowering is called the drawdown. Because of it, water flows toward and into the well. A typical example taken from actual observation is shown in Figure 22. The distance AB is the drawdown, while outside the well the water table takes a curved form in all directions shown as DC. The distance from the well at which the curve DC intersects the original water table, is called the radius of influence. It is to be noted that the curve intersects the well at a point above the water surface inside. This distance, CB, is called the head loss at the casing, and is composed of two parts, the first being the resistance offered by the partially blocked perforations, and the second, the resistance offered by the sand to the high velocities adjacent to the well. This condition is recognized upon observation with a mirror or a light lowered into the well, by water spurting through the perforations above the water surface. Especially in shallow wells, this head loss increases as the drawdown increases, and is further influenced by the size of the perforation. The better the well, the less this distance will be, and it is a condition that is partly within control of the well driller's technique and well treatment. In a good free-acting well in coarse gravel or one with a good gravel wall, this loss of head is inconsequential and all that can be seen in a well is a slight disturbance around the edge of the casing.

A curve can be drawn by taking measurements of the drawdown corresponding to various rates of discharge. Such a curve is nearly a straight line for small drawdowns in deep wells, while for a shallow well, as for instance one only 40 feet into water-bearing gravel, there will be a distinct tendency to fall off in production per foot of drawdown as the drawdown increases. One of the causes of this falling off in production is the head loss at the casing. A study of a discharge-drawdown curve will assist in selecting the most economical rate at which a well should be pumped[*]. It is always recommended that a new well be so tested before a pump is purchased in order to prevent an installation unsuited to the conditions, which may result in an operation efficiency much lower than could be easily attained.

Should the test pump prove to be of inadequate capacity to reach the desired pumping rate, then knowing something about the characteristics of such a curve, it can be prolonged a reasonable distance with fair safety to reach this point, At least three points should be obtained for drawing any discharge-drawdown curve.

With the character of the gravel remaining the same, the theoretical increase in the capacity of a well will vary approximately as the water depth. Laboratory experiments, however, seem to indicate a somewhat less advantage, but nevertheless a very important one. An increase in capacity is more economically obtained by increased depth than by increased well diameter.

The question of diameter is of great importance, not so much from the standpoint of increasing capacity, but of increasing the cost. The size of well casing is often determined by the size of turbine pump to be installed, and should be at least 2 inches greater in diameter than the nominal pump-bowl size. This is necessary because of the danger of sticking when the two are the same nominal size. Although the number 12 pump bowl is about HV2 inches in diameter, it is to be remembered that perforated 12-inch casing is practically 11% inches in the clear. Any slight distortion of the casing may cause the pump to wedge. This fact, and the ever present danger of small gravel being dropped from above, causing effective locking, are ample reasons for selecting the next size larger casing.

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[*] Page 4, Bulletin 387, "Cost of Pumping for Irrigation in Colorado."

The increase in capacity of a well with increased diameter is not as great as generally supposed. Where the water depth is shallow and the formation is of fine material, the large well is distinctly advantageous. This is due largely to the increased infiltration area. Where the formation permits the construction of a deep well, size is of much less importance. A similar but greater increase is gained by sinking a group of wells, called a battery, within reasonable distance of a central pumping unit.

Referring again to the drawing, Figure 22, the radius of influence, AD, is dependent on three things: The discharge, drawdown and the nature of the gravel or sand. These quantities are interdependent and cause the problem of well hydraulics to be quite complex. The factor of greatest consequence is the nature of the material ; the finer it is, the shorter the radius of influence. This means that where fine materials exist, wells may be placed closer together without seriously affecting each other. The battery system is more effective in locations where the water-bearing materials are fine. No definite distance for spacing wells in a battery can be stated because of the many influencing factors, but 30 feet should be about the minimum and 75 feet about the maximum. Cost of pipe and its installation enter largely into the problem and the greater the distance between wells the larger the pipe must be to keep down friction losses. Wells should be in a straight line to obtain the least mutual interference. The direction of this line is of little consequence unless the underflow is confined to a narrow channel, when the line should be at right angles to the flow.

Table 3 shows the relative increase in capacity for increase in diameter using the 12-inch size as a base. The table is computed from a theoretical formula* assuming a constant drawdown, and that the radius of influence remains constant or nearly so. This latter quantity, however, will change somewhat with the discharge.

$$^{*}\ Q_2 = Q_1 \frac{\log_e \frac{R}{r_1}}{\log_e \frac{R}{r_2}}$$

in which R is the radius of influence, r_2 the radius of the larger well, and r_1 the radius of the smaller well. It is derived from the basic non-artesian formula—

$Q = \frac{k \pi (H^2 - D^2)}{\log_e \frac{R}{r}}$ which may be found in any text book or treatise on wells.

Table 3.—Theoretical Relative Increase in the Capacity of Wells for Increases in Diameter from the 12-Inch Size.

Well size in inches	Values of radius of influence in feet				
	100	200	500	1000	2000
12	100	100	100	100	100
18	108	107	106	106	105
24	115	113	111	110	109
36	126	123	119	117	115
48	135	130	125	122	120
72	151	143	135	131	128
120	177	162	150	143	139
240	230	200	177	165	157

From the experience of other investigators on wells, and from experimental data gathered by this office on shallow wells, the increases in Table 3 appear to be too low by 50 to 100 percent. The formula does not take into consideration the reduction of the casing head-loss in the larger sizes and hence the data would give results less than that actually found in the field.

Work of the Station

In an endeavor to obtain information on the effect of diameter on discharge, several experiments were made at different places. In each case, wells of more than one size were involved, and in order to correlate results, many gravel samples were taken. Mechanical analyses were made of all the samples, and each was subjected to a percolation test. Due to uncontrollable circumstances and conditions, results from these tests both in field and laboratory were not very satisfactory.

Experiment A.—The experiment made on the Arkansas River, 25 miles east of Pueblo, consisted of tests on three wells, 12, 18 and 24 inches in diameter. These were spaced 25 feet apart, and encountered practically the same conditions and materials in each instance—that is, 20 feet of soil and 26 feet of gravel. Unfortunately, the 12-inch well could not be sunk to the full depth on account of boulders and was finished off 3 feet shorter than the others. The normal water table stood at about 9 feet below the ground surface, affording a depth of water of about 37 feet above the shale. Besides measuring the discharge and drawdown, the location of the water table was obtained by means of a number of observation wells in a line 600 feet long, each way from the main wells. Testing of each well occupied about a week's time.

The results of the experiment are plotted in Figure 23. A depth correction from the ratio 3 : 34 has been added to the 12-inch well curve to make all comparable. This adjustment is based on the theory that capacity is proportional to depth. These curves show the 18-inch well to have an advantage of about 5 percent, and the

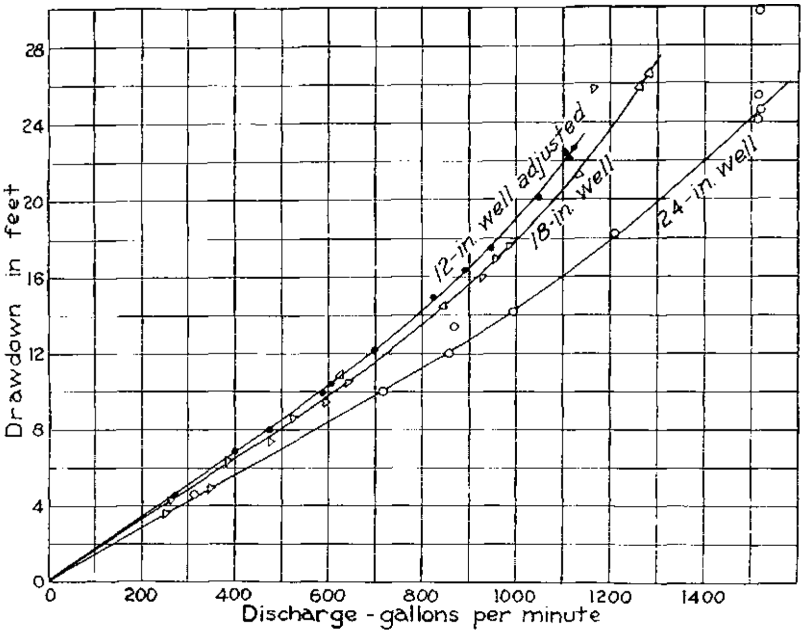

Fig. 23.—Discharge-drawdown carves for wells in Experiment A.

24-inch well, 24 percent over the adjusted 12-inch curve for drawdowns up to 20 feet. At a drawdown of 26 feet, the 18-inc.h well shows no change, but the 24-inch well increased to 30 percent above the 12-inch. Such an increase in rate for the larger well can be explained by the relatively larger strainer area as the water surface approached the bottom of the well.

All of these wells were put down with a 10-inch sand-pump bucket, after sand was encountered, and no development work was done with tools. The sand bucket had ample clearance in both the 24 and 18-inch wells, but in the 12-inch, it practically filled the casing. Due to the difficulty in sinking the well, the bucket was run more often than ordinarily, and it was easily recognized by the accumulations of sand on top of the plunger that considerable development work was in progress. When pumping began, both the 18 and 24-inch wells improved considerably, which was not the case with the 12-inch well, indicating that development of the latter was complete. The performance of the 12-inch well, therefore, is not comparable with the others for it is quite probable that there would have been a greater percentage of difference had it received no such development with tools. The result demonstrates again the value of such work.

Experiment B.—This experiment was carried out on an 11-inch and a 24-inch well on the St. Charles mesa, 7 miles east of Pueblo.

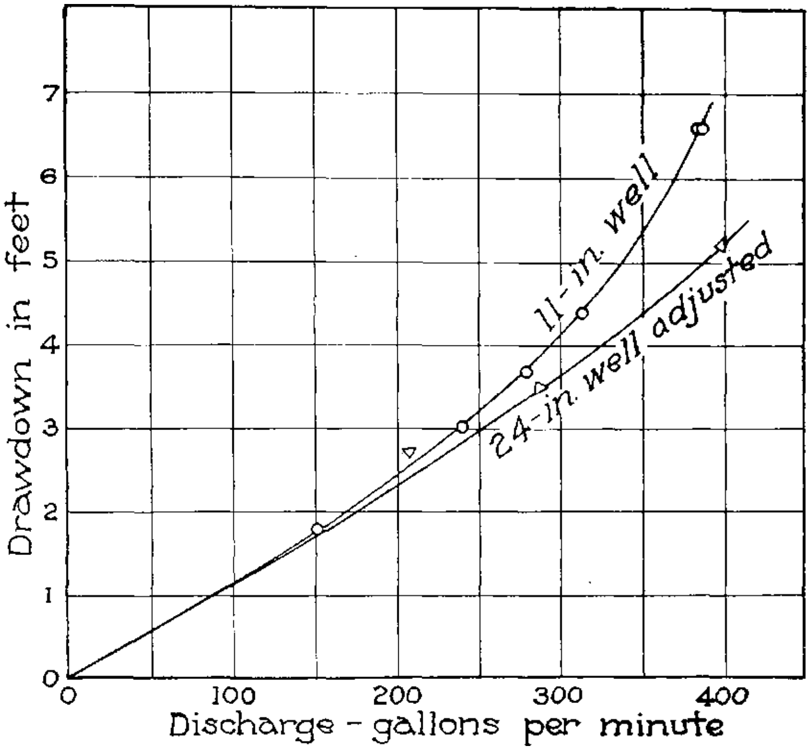

Fig. 24.—Discharge-drawdown curves for wells in Experiment B.

The two wells were 9 feet apart, and the water depth was 12 feet in coarse gravel. The 11-inch well had been in use about 300 hours the preceding season and hence final tests were not made on the 24-inch until a similar pumping time had elapsed. The water depth during the test of the 11-inch well was 11.5 feet, and during the tests on the 24-inch, 10.9 and 10.0 feet. Figure 24 shows the discharge- drawdown curve for these two wells after plus 5 and 13-percent adjustments had been made on the 24-inch. Little difference is to be noted with drawdowns up to 3 feet; at 4 feet, the discharge is 6 percent, and at 5 feet, 12 percent greater for the larger casing. Here again the effect of the increased percolation area is evident, but the experiment can hardly be regarded as a success.

Both of the well casings used in this experiment had the same width and spacing of perforations, but were put down a year apart by different drillers using different methods. The 11-inch casing was set inside of a 12-inch blank casing which had been bailed down to shale with a 10-inch flat-valve sand bucket. No gravel was used during the sinking. The 24-inch casing was sunk, using a 22- inch orange-peel bucket and also a 10-inch sand pump, and coarse gravel containing no sand was applied on the outside during the sinking operations. Neither well received development work other than pumping. It would appear that the 24-inch well should have been of greater capacity than the 11-inch well at all stages of drawdown.

Experiment C.—This experiment was conducted on a battery of five wells located on Crow Creek near Barnesville, 12 miles north and east from Greeley. The battery consisted of one 40-inch, two 30-inch, and two 24-inch wells, all 39 feet deep, and spaced 70 feet apart. From a study standpoint, the location was a very poor one and the results far from satisfactory. The formation consisted of about 8 feet of soil and clay, 17 feet of fine gravel, 3 feet of clay, then more gravel separated by two thin strata of clay. The water table stood at about 9 feet. To remove the effect of the clay strata, it was decided to backfill the wells to the top of the first clay, and tests were made of all the wells in this condition. The backfilling was then removed and tests made on the full depth.

It was found that the largest well was the poorest in the group, and that a 30-inch well was the best. There was some peculiarity about the 40-inch well that was not clearly understood, and which was more evident when tested at full depth, when little or no gain in capacity was obtained over the part depth tests. These wells were all put down with a 22-inch orange-peel bucket, and, therefore, the

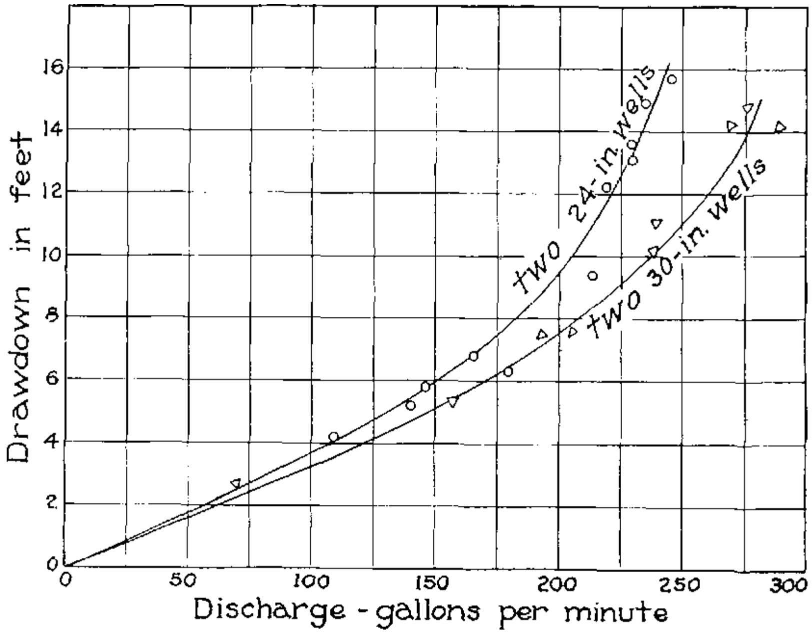

Fig. 25.—Discharge-drawdown curves for wells in Experiment C.

smaller wells received more development work. There is also the possibility that the lower clay strata were bent during the drilling, causing the blocking off of the gravel. As would be expected, the wells gave better results on the partial depth tests as the results from the two 24-inch and the two 30-inch wells respectively were much the same. The mean drawdown curves are shown in Figure 25. The larger wells show an increase of 10 percent at a drawdown of 6 feet, 15 percent at 10 feet and 21 percent at 14 feet over the 24-inch wells. The theoretical difference is about 4 percent. As in experiments A and B, the greater the drawdown, the greater the relative increase of capacity became for the larger well.

Gravel Analysis.—Forty samples of gravel, each weighing about 28 pounds, were gathered during the course of drilling the wells in experiments A, B, and C. A portion of each sample was passed through a nest of screens and a mechanical analysis made. The percolation test consisted of measuring the rate at which water passed through a column of gravel, 4 inches in diameter and 24 inches long, under a pressure head of 24 inches.

Only very general conclusions are possible from the data obtained. No relation could be discovered between sand size, porosity and percolation rate that was at all satisfactory. It was recognizable that, in general, the gravel was coarsest and the percolation rates highest in the B samples. The finest sand and the lowest percolation rates were found in the C samples while the A samples lay between the two. This coincides with actual field conditions qualitatively if not quantitatively.

Summary

In anticipation of plans for an irrigation well, the first considerations necessary are the adequacy and permanency of the groundwater supply. The best information on the adequacy of such a supply is to be obtained through test-hole drilling, either by hand or machine methods. Permanency is to be based on the probable source of the ground water and the demands upon it.

A contract between owner and well driller should be in writing in order to safeguard the interests of both parties. The contractor who has adequate equipment for such work, and who has a reputation of rendering good service and of finishing his wells properly, should be given the greatest consideration.

Large excavated wells are adapted to shallow water depth conditions, but, if considerable depth is attainable, the smaller metal- cased well is the more economical. The larger the casing size, the greater will be the well capacity; not in a direct ratio of the sizes, but considerably less than this. The true relationship between diameter and capacity has not been proved, and theoretical formulas do not agree with most field experiments.

All metal-cased wells should receive development work other than that from pumping. Pumping alone does not produce as good results as surge-block work in increasing the capacity of a well. After the development work, the well should be tested for capacity: the information so obtained is very necessary for the selection of a pump to fit the conditions.

It has been observed in a number of instances that metal-cased wells, not having been pumped for several years, have deteriorated greatly in capacity—some becoming complete failures. While the cause is not entirely understood, it is urged that every metal-cased well be pumped for a short time each year.