TABLE OF CONTENTS (Spanish)

- HOW TO DRILL AN IRRIGATION WELL
- MODERN DESIGN TECHNIQUES FOR EFFICIENT HIGH CAPACITY IRRIGATION WELLS (Paper No. 70-732)
- HUMAN-POWERED PUMP FOR LOW-LIFT IRRIGATION (paper 85-5054)
- METODO PARA SELECCIONAR UNA BOMBA DE POZO PROFUNDO

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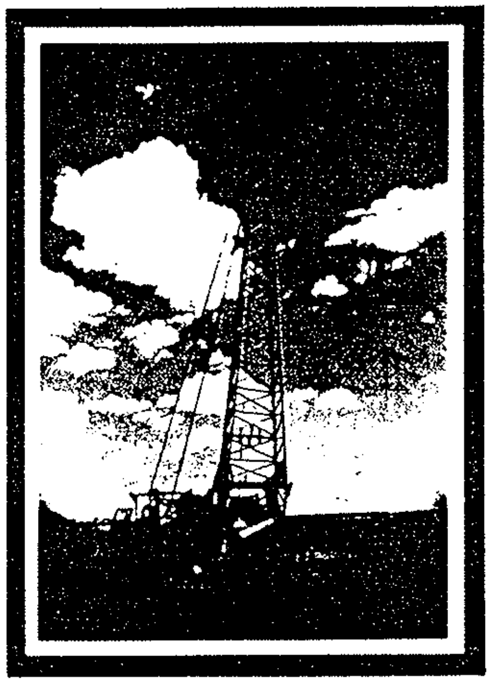
?? L. Decker

how to drill an irrigation well



An IRRIGATION AGE Special

by
Age Inc
Wall St.
Dallas, Texas

INTRODUCTION

IRRIGATION AGE published a series of four articles dealing with all of the phases of developing a dependable supply of water for irrigation from underground sources in the belief that the information will be of benefit to old and new irrigators alike. Beneficial in that the farmer may have a better understanding of the mysteries of fresh water supplies and how a substantial and sustaining amount of that water can be obtained by drilling and equipping a well. Articles published to put the farmer in a position to be able to evaluate the well drilling firm he hires, determine if he is getting in fact what he is paying to get and otherwise acquire a speaking and working knowledge of this vital and indispensable part of his irrigation system.

There is no intent in presenting this information to cast aspersions on the skill or knowledge of established, reputable well drilling firms. Nor is there intent to in effect try to make the farmer a well driller or a groundwater geologist. In fact, the opposite is our purpose. We believe this information, read, studied, digested and believed by irrigation farmers will be of benefit to the well driller, the pump manufacturer, and others involved in supplying equipment and services to the farmer who irrigates with water from underground.

For, when the farmer more nearly understands the intricacies, the problems, the limitations, etc., of developing an irrigation water supply from underground sources, the nearer, we think, he and the driller will come to establishing a rapport with one another and thereby "get a good well" if one is obtainable.

IRRIGATION AGE obtained the services of two non-journalists to prepare this series of articles. But, John H. Marsh and John S. Fryberger are professionals in their field.

Mr. Marsh has a dozen years experience in civil, and sanitary engineering, ground water development, disposal wells, irrigated agricultural systems and land development.

Mr. Fryberger has more than 14 years professional experience in ground water geology. He has worked throughout the United States in ground water development, including exploration, evaluation, design and construction.

The two men are the principals in Engineering Enterprises, Norman, Oklahoma.

TABLE OF CONTENTS

Some Important Terms to Know and Understand 5

A Little Practical Theory 7

Test Drilling 11
Analyzing the formation and aquifer performance testing

Well Design 15
Gravel packing and corrosion resistant metals

Constructing the Well 20
Setting screens and placing the gravel pack

Developing the Well 22
Air lift pumping and simultaneous pumping

Pump Testing and Equipping the Well 24
Well alignment, sand pumping and yield

Records and Maintenance 27

Drilling A Water Well

For development of a dependable water supply from wells, farmers must rely on *knowledgeable* and *experienced* ground water engineers, geologists, drillers and suppliers to have a good chance for a successful project development. This article is written specifically to help the farmer understand some facts about planning and implementing ground water development programs which will help him achieve a successful project if one can be had. Some fundamentals of a few of the important elements the farmer should know about test drilling, well design, construction, testing, inspection, equipping and maintenance of wells are presented. Understanding these discussions will help the farmer in selecting responsible, qualified and experienced ground water engineers, geologists, drillers, etc., to work for him.

Some checks and requirements are set out that the farmer should impose on those hired to carry out the work. These checks and requirements will help avoid the occurrence of costly errors that result in wells that produce sand with the water, wells that unexpectedly drop off in yield, wells that don't produce as much as they should, wells that require too much pumping power, wells that are too crooked, grossly inefficient or otherwise inferior and doomed to premature failure or undesirable operation.

Ground water evaluation and development is a complicated, technical science. Thus the limited presentations in this series of articles can only challenge the readers to make the additional study and investigations necessary to plan and execute a sound ground water development program and feel confident of a good chance for success.

Some Important Terms To Know and Understand

The following terms are used often in the ground water business and should be clearly understood by the farmer if he is to judge the potential of those he hires.

Aquifer; ground water reservoir; water bearing formation; formation; water sand — All of these terms mean a water-saturated geologic formation that will give up useful quantities of water to wells.

Alluvial — Means deposited by running water. The unconsolidated sand and gravel commonly found underlying major stream or river flood-plains form alluvial aquifers. These sand and gravel deposits are often intermingled with silt and clay as stringers and discontinuous layers. Because these deposits are usually shallow (less than 100 feet) and are spotty as far as well yields are concerned, considerable test drilling is sometimes necessary to locate good permeable layers. (The Ogallala formation is an unusually thick alluvial aquifer.) Test pumping when properly done and analyzed, will tell you if the permeable layer is big enough to support a large pump. Even when you already know that alluvium is located on your property, it is still necessary to conduct test drilling to find the best well location.

Bedrock — Means the more consolidated formations which may underly the alluvium or soil, or may crop out at land surface. These formations are usually relatively uniform in character over large areas as opposed to alluvium which is usually not at all uniform but changes from place to place. However, only a few bedrock formations are aquifers. Only those that are composed of poorly-cemented sand grains, or limestone with fractures and cracks or other rocks that have openings (porosity) that are connected (permeability) and are filled with water are aquifers. Because these formations are already extensive and generally relatively uniform in their water producing properties, less test drilling is required. Considerable information regarding bedrock formations can usually be obtained from state or U.S. Geological Survey agencies. The exact location of the well is seldom as important in a bedrock aquifer as it is in an alluvial aquifer. These terms mean a water-saturated geologic formation that will give up useful quantities of water to wells.

Permeability — The ability of a geologic material (sand for example) to transmit water. Sand is permeable, most clay is not. Water can flow through sand but cannot flow through clay. Gravel is usually more permeable than sand.

Porosity — Defines that part of a material that is pores or void spaces. Sand has porosity. Water is contained in the pores of saturated sand. The porosity occurs between the sand grains. The amount of water that can be contained in a volume of formation is the porosity times the volume.

Transmissibility — This term relates to the ability of an aquifer to transmit water to a 100 percent efficient or theoretically perfect well.

Static Water Level — The depth *to* water in a well when pumping is not in progress.

Pumping Water Level — The depth to water when the well is pumping.

Drawdown — The amount the water level is lowered in a well during pumping. It's the distance from the static water level to the pumping water level. Drawdown is greater with a greater pumping rate. It also normally increases with time of pumping at a constant rate. **Figures 1 & 2.**

Yield; Capacity — The gallons of water per minute a well or aquifer formation should or does give up. Because wells aren't perfect they won't yield all the water the aquifer will allow.

Specific Capacity — This term is very important. It is the well or aquifer yield divided by the amount of drawdown. It is the average gpm produced for each foot of drawdown. A good or efficient well produces at a specific capacity close to the specific capacity the formation would contribute to a 100 percent efficient or "theoretically" perfect well.

Well Efficiency — The amount of water a well produces compared to the amount a perfect well could produce. If an inferior well can produce only 1000 gpm but the aquifer has the ability to give up 2000 gpm to a perfect well, then the well efficiency is 1000/2000 or 50 percent. Good wells are 80 percent efficient or more. Efficiency is computed after a specified pumping time.

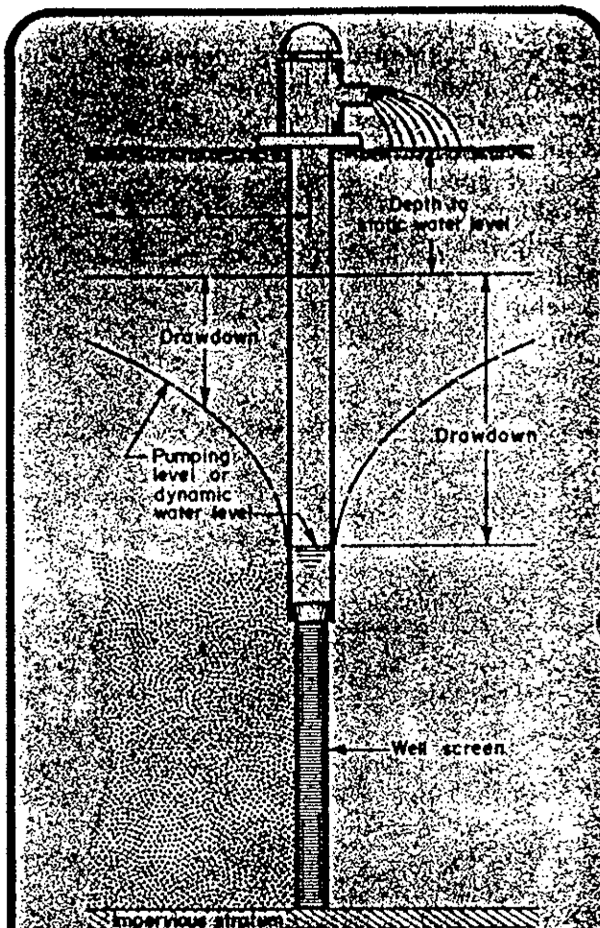


Fig. 1. Measurements related to well performance and pumping tests of wells and aquifers.

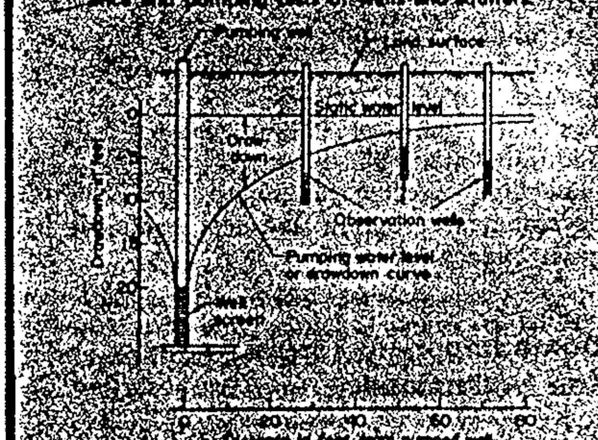
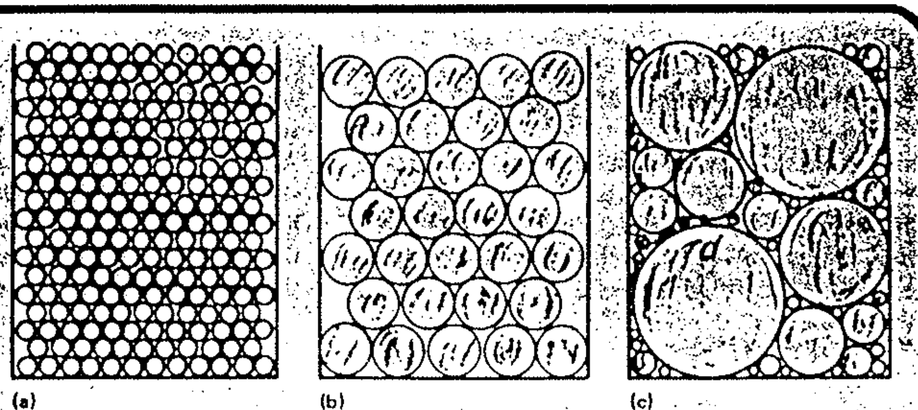


Fig. 2. Trace of half the cone of depression showing variation in drawdown with distance from the pumped well.

Fig. 3. Containers (a) & (b) each have 26% porosity, and 26% of the container volume could be water between the particles. Container (c) has a porosity much less than 26%.



Sand Pumping — Refers to wells that produce sand with the water. When wells produce sand it is an unequivocal blunder. It does not need to happen but to insure against it requires exacting work in test drilling, design and construction.

Sieve Analysis — A procedure of measuring sizes of grains in a sand sample by sifting the sample through a series of different sized sieves. It is an inexpensive, simple but rather exact procedure, to insure high efficiency and sand-free water, all wells must be designed from sieve analysis of samples — even gravel packed wells.

A Little Practical Theory

Ground water is stored in aquifers which are large underground reservoirs composed of geologic formations that have become saturated with water. The water occupies the pore spaces (porosity) between the individual geologic particles of sand, clay, gravel, etc. Even in hard rock or dense formations water can occur in cracks, fractures or crevices. Like surface water lakes, ground-water reservoirs have dimension of length, width and depth. They also have inflow and outflow (recharge and discharge). In general, water moves constantly but slowly into, through and out of ground-water reservoirs.

The amount of water that is contained in aquifers is measurable and can be large. It is equal to the width times length times depth of the aquifer times the porosity of the material. Porosity of fine sand may be as high as 25 percent. Porosity of gravel and coarse sand may or may not be as high as fine sand. For example, Figure 3 shows three one-gallon cans of spheres exemplifying sand and gravel. Container (a) of small particles (but all the same size) has 26 percent porosity. It could contain .26 gallons of water. Container (b) of larger particles could contain *only the same precise .26 gallons of water.* However, container (c) a mixture of sizes has much less volume that could be occupied by water.

Point No. 1 — Fine sand can and often does contain as much water as coarse gravel and sand mixed. Experienced and knowledgeable ground water engineers, geologists, and drillers know how to measure the amount of water stored in an aquifer, and the amount that can be withdrawn.

The amount of water stored in the aquifer is related to how much can be withdrawn or how dependable a water source is. The rate water flows into the aquifer from recharging precipitation also bears on the dependability. However, this isn't the whole story by a long shot. The rate water will flow through the formation and into wells is very important. It is related to the permeability of the sand or the transmissibility of the aquifer. Using Figure 3 again, we can form a concept. If water were poured in on top of the spheres to fill all the pores and then the bottom of the cans were perforated with an ice pick, the water would drip out. The water would drip from container (b) faster than container (a). However, if container (c) had a mixture of enough different sizes of particles it would be dense like concrete and not pass water as fast as the others. It would have a lower permeability. Likewise an aquifer composed of particles such as in container (b) would transmit water to a well faster than one composed of material as in container (a) or (c). It would have a higher transmissibility.

Now think hard a minute and answer the following questions as you go.

Point 2 — Will the number of ice pick holes in the bottom of the cans have anything to do with how fast the water would drip out?

*Yes*______________ *No*______________

Point 3 — Do you suppose there would be a maximum rate the water could drip out if the bottom of the containers were no obstacle or restriction to the flow of water?

*Yes*______________ *No*______________

Point 4 — And would the size of holes in the bottom of the container be important in preventing the spheres from dropping out with the water?

*Yes*______________ *No*______________

Point 5 — Would it be possible to measure the particle size in the containers and adjust the drain holes to prevent the particles from flowing out with the water.

*Yes*______________ *No*______________

Point 6 — Since the particle size and mixture of sizes dictate the rate water can flow out of the buckets, would it follow that the same factors would control the amount of water that could flow to wells?

*Yes*______________ *No*______________

Point 7 — Would it be practical to collect aquifer samples during test drilling and measure the sizes of grains of sand and gravel?

*Yes*______________ *No*______________

Point 8 — If Point 7 were done accurately, could wells positively be designed to produce sand-free water?

*Yes*______________ *No*______________

The correct answer to all these questions is unequivocally "yes". These questions are so often mistakenly answered "no" in practical application of ground water development by inexperienced and poorly trained practitioners. Any engineers, geologists, or drillers you hire should answer the questions "yes" and know how to apply his work to insure compliance to the principles of those eight points mentioned thus far.

When wells don't yield close to as much as the formation would permit (and many don't), and when wells pump sand, it's because of misapplication of the basic principles promulgated by the questions above. Other well problems and malfunctions result from breaching other basic concepts. The principles are simple. Successful application of them, although not simple, is possible and practical in test drilling and exploration, aquifer evaluation, well design and construction. Accurate test drilling, sample analysis (grain size measurement), well design and construction procedures are straight forward, and when sufficient care, caution, and attention to detail is practiced, the procedures are nearly fool-proof.

A fool-proof program can be broken down into seven general step-by-step categories as follows.

1. Pre-drilling and planning activities.
2. Test drilling, test pumping and other geologic investigations.
3. Evaluation of testing.
4. Well design.
5. Well construction, development and testing.
6. Equipping the well.
7. Records and maintenance systems.

Step 1 — Pre-Drilling Investigation and Project Planning. A reliable exploration program is much more than just drilling test holes. If a well production system is to be efficient and dependable, all geologic and hydrologic factors plus water quality must be evaluated. Don't buy a cheap exploration and evaluation program. A 40-cent per foot test drilling program is rarely a bargain.

a. *Use Existing Information* — Governmental water and geologic agencies usually have large amounts of valuable ground water data, logs, maps of surface geology, geologic cross sections, etc. available for the asking. Extension irrigation engineers from universities can provide assistance in planning, and advice on the need and selection of technical consultants, and in selecting drillers. Don't ask just one. Ask several. That should apply all the way through your project.

Although these agencies cannot recommend a specific consultant or driller as the best, they do generally know who is and who is not competent and can supply several names of competent ones for consideration. Again don't just interview one; question and test several. Don't judge on price alone.

b. If it is important for the potential irrigator to know (not guess or speculate) how much water is available; to know the long-term yield capability of a supply, to insure that wells produce water with least power costs, etc., then it is likely important for him to secure assistance from a ground water engineer or geologist. If a consultant is to be used, extreme care should be used in the selection and then he should be brought into the project early.

With a few days of intensive search, sufficient existing geologic and hydrologic data can usually be found without drilling to allow appraisal of the probability of the presence of a suitable aquifer in a given area. From this data approximate depths and location of test holes can be planned, conclusions can be drawn on water quality sampling needs, and the "drillability" and other general characteristics of formations expected to be penetrated can be roughly determined. Sometimes, sufficient information can be gathered to allow preliminary project cost and feasibility determinations.

All sources of available information should be surveyed. Other typical sources are neighbors, drillers, City Water Superintendents, State Water Board, oil companies, oil field log libraries, ground water engineers, and geologists.

Typical useful information that should be gathered is: existing and abandoned well data, well location, name of driller, drillers logs, E-logs, etc.; design details; operating problems — sand pumping, corrosion, incrustation; static water level; pumping water levels; aquifer tests; well tests; pump tests; water samples for quality analysis; geologic maps; formation samples; sieve analysis; etc.

c. By all means take advantage of the agencies mentioned above. The knowledge they can share and information in their files can save considerable exploration drilling time and prevent costly errors. It is doubtful, however, that it will cause you to spend less on exploration and design. On the contrary, if you believe in the science of measuring instead of "guessing", "eye balling", or "feeling", you will probably demand more accurate and costly (per foot anyway) test drilling and other aquifer investigations than what is sold as adequate for 50¢ per foot in some parts of the country. Don't be afraid of price if the value is good. Cheap methods result in more frequent failures. Precise scientific methods cost more but are more successful and usually save money overall.

d. Design the test drilling program as follows to secure the required additional information.
   (1) Location and approximate depth and anticipated number test holes and test wells.
   (2) Equipment required for best results — type rig, and sampling tools and techniques, requirements for Elog or Gamma Ray log, and water sampling.
   (3) Set out the geologic characteristics which will identify the general character of formations to be penetrated.
   (4) Interview several drillers and secure quotations along with their discussions and qualifying remarks on any exceptions to the above.

Step 2 — Test Drilling, Test Pumping and Other Geologic Exploration. When a driller is selected who can perform the exacting work required for the best chance for success, the procedures should proceed as follows:

a. Drill the expected deeper holes first and spread several holes far apart. Details of geology are required to set the test drilling pattern. Your consultant can guide these activities or assistance may be secured elsewhere. But the judgment should be on a geologic basis. Some pertinent discussion previous to this is under "Some important Terms — Aquifers".

b. The driller or geologist *must* prepare a detailed permanent drilling log (record) for you. It must show the following minimum data: exact location of hole, date, type rig, type mud or fluid, type of bit, and sampling procedure; description of geologic character and thickness of each strata (This may require even one foot sampling intervals); drilling characteristics — drilled hard, smooth, fast; and mud loss and time used in drilling each major interval.

c. For sure, formation samples below the observed or expected static water level should be carefully taken to accurately represent each interval drilled. The samples should be bagged, labeled and given to the farmer for analysis by engineering (measuring) techniques.

   Formation sampling must be performed for two specific purposes: (1) to verify presence of and determine the general character and quality of an aquifer, and (2) to get specific information upon which to base the design for an efficient and sand-free producing well. Samples used in design of an efficient well must be taken with *extreme* care.

   To get good samples with a rotary rig is difficult. It takes great skill and concern on the part of the driller but it can be done successfully if the following factors are properly controlled: (1) A constant sized bore hole diameter must be maintained which requires proper drilling fluid, a constant and not excessive fluid circulation rate. (2) *All* of the cuttings must be allowed to settle out of the fluid in the sampling pit to prevent recirculation and mixing of them. (3) To know which cuttings come from where, the drilling must proceed in batches by drilling a short interval, then stopping penetration while all the cuttings from that interval are circulated out.

d. Occasionally water samples must be collected for analysis. Preliminary investigations will have set out this requirement if it exists. Also many types of formations require that electric or other geophysical logs be run. Here is another caution point. Geophysical logging is a real science — use care when selecting one to log the holes.

e. *Test Pumping — Aquifer Performance Testing* — The only way to *positively* determine the full ability of a formation is to run a closely controlled pumping test. Specific situations dictate when (1) pumpable test wells, (2) no pumpable test wells, or (3) pumpable test wells and observation wells should be a part in a given exploration program. If it is important to *know* the aquifer dependability, and full capability, then the third alternative must be followed. You should depend only on an experienced ground water engineer or geologist for advice on the need of and conducting aquifer performance testing. This is not to be confused with testing a production well to select the pump. This will be discussed later in the article.

Step 3 — Evaluation of Testing. The samples collected can be conveniently analyzed by sieve analysis. Sieve analysis is a *direct measurement* of the sizes and number of different sizes of particles that make up a sample. The analysis procedure is simple and quite inexpensive. Some well screen companies perform the sieving free of charge. It is a very important step because only when based on sieve analysis of representative formation samples, can a production well be designed to insure a certain degree of efficiency and sand-free water. Some drillers will guarantee a certain efficiency and sand-free water when the testing and design work is accurate. However, the farmer must be willing to pay more for the premium work.

Test Drilling

Direct rotary rigs, cable tools, air rotary or combination air-mud rigs are all used successfully in test drilling. Most irrigation test drilling is done by one of the rotary processes. It is faster, but not the most accurate. In rotary drilling the formation samples are cut loose by rotary action of the bit and carried to the surface by a flow of fluid. Consequently the samples are extremely mixed.

Cable tool drilling is preferable for testing, but cable tools usually are not economically available. It is more accurate; water samples can be conveniently acquired; water levels are easily determined; and bail testing can be performed conveniently for approximations of yield.

Test drilling is performed for two specific purposes: (1) to verify presence of and determine the general character and quality of an aquifer, and (2) to get specific information upon which to base the well design, particularly formation samples. Formation samples used in design of an efficient well must be taken with *extreme* care. They must be *representative* of the formation.

A key point — Insist that careful and accurate sampling procedures be used and that samples of the entire saturated formation be collected, logged, bagged and sent to a laboratory for analysis.

Ground water exploration is like detective work. One must rely on clues and bits of information, which when all put together and interpreted, form evidence that a suitable aquifer is present. The more bits of information that are acquired, the more valid the evidence. Therefore all details, even minor ones, must be recorded on the log when performing test drilling. The log should contain any remarks that even might possibly be pertinent.

When little is known about the formation or if sand pumping or other problems have been known to exist, special exploration techniques may be warranted. A core barrel can be used for more accurate sampling. This technique consists of pushing or drilling a hollow tube into the formation, forcing the sample up into the tube. The tube is then brought out of the hole and the relatively undisturbed sample extracted. Core drilling is accurate and very useful but it is fairly expensive and is therefore used only selectively.

Occasionally electric and/or gamma ray-neutron (geophysical) logging is required, especially in deep holes that have been drilled fast and where formation samples and their locations of origin are questionable. The information recorded in geophysical logging is only relative and doesn't actually measure the characteristics that are looked for. Therefore interpretation is necessary and a novice may give erroneous results. Your consultant or a U. S. Geological Survey geologist can offer advice on the need for geophysical logging in conjunction with test drilling.

Analyzing the Formation Samples

We studied earlier how the particle size and number of sizes affect the porosity and ability of a material to transmit water (transmissibility) of a formation. Sieve analysis of unconsolidated formation samples gives a most important clue to the water transmitting capability of a formation. For efficiency and positive sand control the well must be designed on the basis of sieve analysis. *Remember, however, that for the sieve analysis to have meaning, the samples must be carefully collected so they actually represent what is in the formation.*

Sieve analysis is so important to helping insure a successful well that it is worth discussing in depth. Sieve analysis is a *direct measurement* of the sizes and number of different sizes of particles that make up a sample. The procedure is simple and inexpensive. Some well screen companies commonly perform sieve analysis free of charge. It is logical that any procedure of direct measurement will reduce error. When one measures two feet from one point to another, there is less chance for error than by estimating. If the size of sand and gravel is described by measured dimensions, then interpretation again is easy, and designs, gravel packs and screen slots can be intelligently selected.

Figure 4 shows a well or test hole section. The samples are bagged and sent to a laboratory for analysis. Figure 5 illustrates the sieving process and Figure 6 shows graphs of sieve analysis. The graphs are records of the *measured* characteristics of the samples.

Transmitting ability and other factors are reflected in the specific shape of the graph. These graphs provide the technician a much more accurate technique for estimating yield ability from samples than by simple inspection of the samples laid out on the ground.

"Sieve analysis graphs" may be like a new language to the reader. *The main thing is to remember that ways do exist to measure characteristics which permanently and discretely describe samples and that sieve analysis is an absolute prerequisite to positive design of efficient and sand-free wells.* Sieve analyses are required regardless of whether the well is to be gravel packed or direct screened and naturally developed.

Aquifer Performance Testing

Although test holes are essential to verify the presence of water-bearing formation and to get samples, test holes alone permit only an estimate of well yield. Test holes present very little evidence of how much total water can be withdrawn over long-term pumping, or how one well will affect the yield of another well. These questions can only be answered after sophisticated aquifer performance pump testing. To understand the requirements for this type testing one must know the theory of ground water hydraulics (how water flows through aquifers and into wells).

Flow into a well comes from all directions like water moving from the rim of a wagon

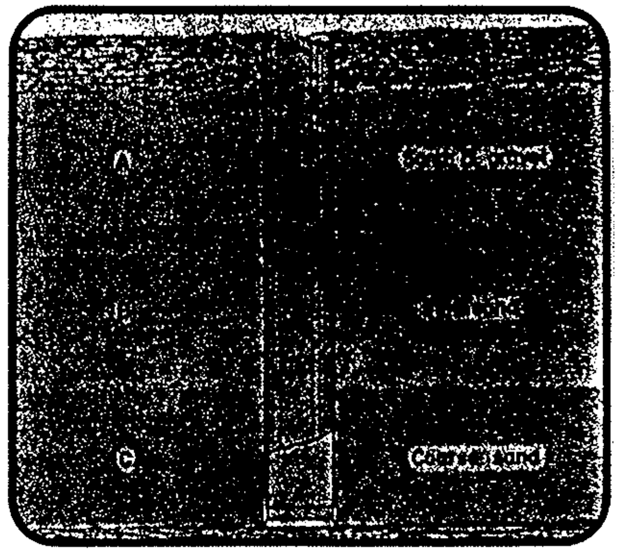


Figure 4

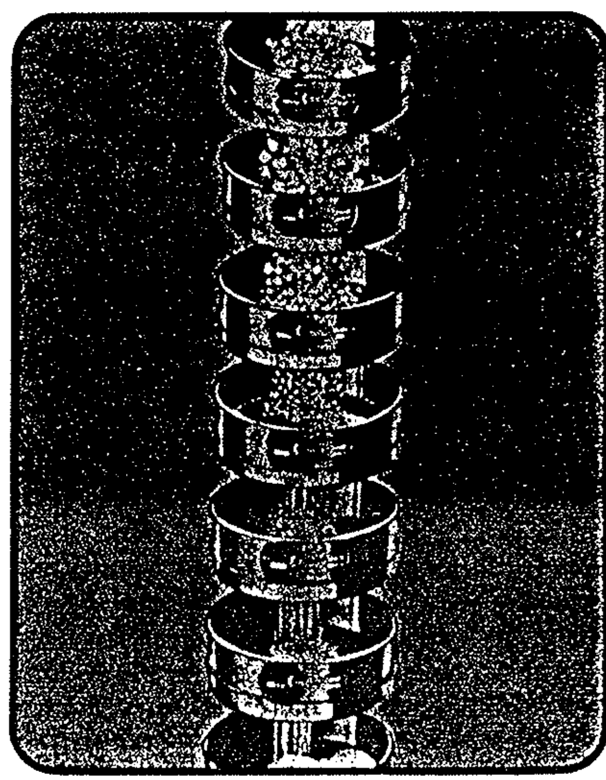


Figure 5

wheel along the direction of the spokes and into the hub. Before the pump is started, water stands in the well at the static water level.

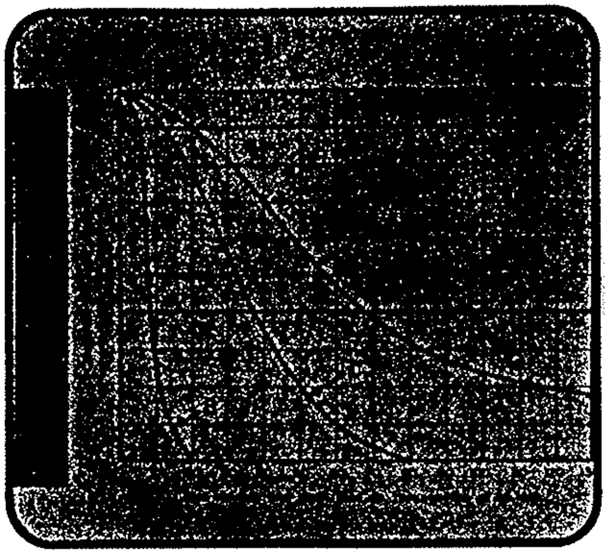


Figure 6

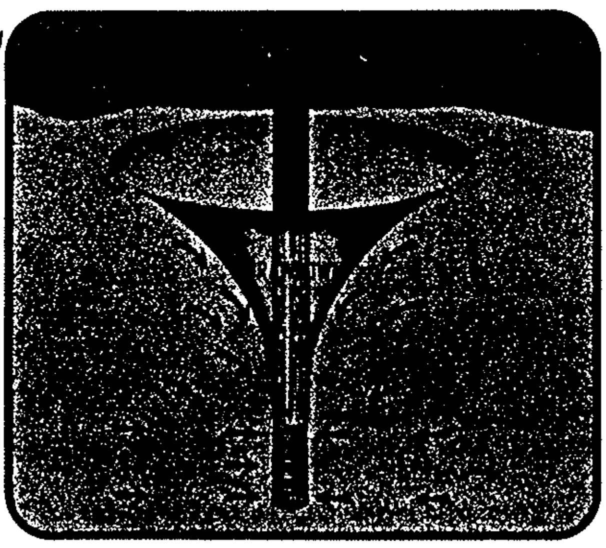


Figure 7

When pumping starts water is removed from inside the well lowering the water surface. The amount of lowering is called "drawdown." With the water level inside the well lower than at a point just outside, water will move into the well causing drawdown at that point. Accordingly water further away moves nearer the well to replace the water that was formerly there. The greatest amount of drawdown is at the well. The amount of drawdown decreases at points further away from the well until at some distance the water surface is unaffected. The water surface slopes where water is moving toward the well. It slopes from all directions downward toward the well. The water moves downhill, so to speak.

The shape of the water surface in the area where water is moving toward the well is like a cone or funnel. It is called the cone of depression. *(See Figure 7.)*

The shape, diameter, width and depth of the cone of depression for a given well depends primarily on four things: the pumping rate, the time since pumping began, and the two measurable aquifer characteristics of transmissibility (rate water can flow through the formation into a perfect well), and the storage coefficient (the storage coefficient is related to the amount of water an area of the formation can release). Each of these four things have a separate and distinct effect on the depth and areal extent of the cone of depression.

Effect of the Storage Coefficient — When pumping begins the water comes out of storage close to the well. An aquifer with a high storage coefficient will release more water than one with a low storage coefficient. Thus the higher the storage coefficient the less area of aquifer that must be affected to give up a certain amount of water.

Effect of Time of Pumping — As pumping continues and more water comes from storage, it must come from greater and greater distances away from the well, causing the cone of depression to grow as pumping continues. Figure 8 illustrates how the cone of depression expands during equal intervals of time. The longer the pumping time the larger the area of effect.

Effect of Pumping Rate — Strangely enough the rate water is removed from a well doesn't significantly affect the extent or area of the cone of depression, but it has a tremendous effect on the depth. Figure 9 shows this effect. The higher the pumping rate, the deeper the

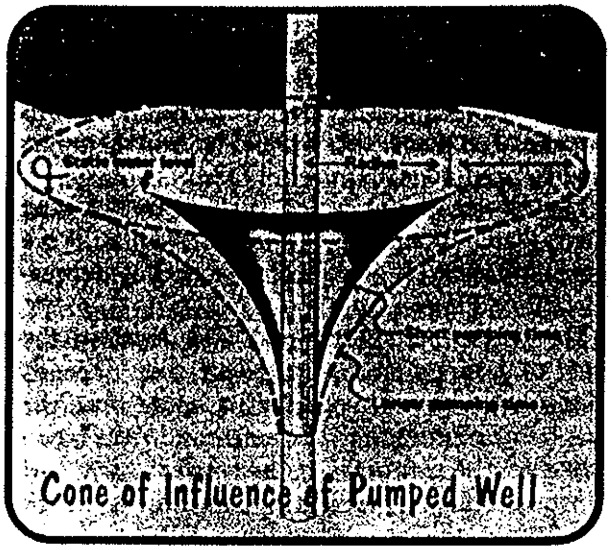


Figure 8

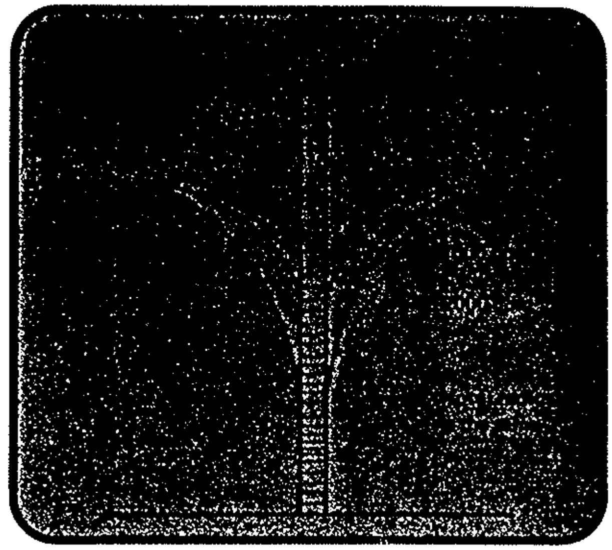


Figure 9

cone of depression. Notice that the slope or "hill must be steeper" to make water flow faster toward the well.

Effect of Transmissibility — As shown by Figure 10, the transmissibility has a significant effect on both the depth and extent of the cone of depression. For a given rate and time of pumping, a high transmissibility has a shallow but broad cone of depression. A low transmissibility has a deep and not so broad cone of depression. Large capacity wells can be constructed in aquifers that transmit water easily (high transmissibility).

Interference — Effect of One Well on Another — Each well has a cone of depression. If two wells are pumping from the same aquifer their cones of depression will overlap if they are sufficiently close together or if the time of pumping is long. When the cones overlap, the yield of both wells will decline, or the drawdown in each well will increase if the pumping rate stays the same.

The interference between wells can be significant. For example, say two wells are 2,000 feet apart in a good artesian aquifer (low storage coefficient and a high transmissibility). A typical 16-inch 1,000 gpm well pumping for 100 days could impose 17 feet of drawdown on a well 2,000 feet away. This would take away 30 percent of the yield of a like well 2,000 feet away or cause the drawdown to increase 30 percent if the pump is capable of producing the additional lift. Figure 11 illustrates the interference concept.

Accelerated drawdown from interference can be a major cause of problems if it is not anticipated in equipping a well, or planning well spacings on multiple well projects or where there is a well or two on every quarter section. Short durations of pumping won't show effects of interference.

Accelerated Drawdown — If the cone of depression extends to the edge of the aquifer, drawdown will increase just the same way as if it were caused by interference from an imaginary neighboring well. If the geology indicates an aquifer boundary may be nearby, or if a well is suspected of being inefficient and producing less than aquifer will give up, then the sophisticated aquifer performance pump testing is required.

To get full results from aquifer performance testing, observation wells must be used. The rate the cone of depression deepens (change in drawdown) and expands must be carefully measured in observation wells and the pumped

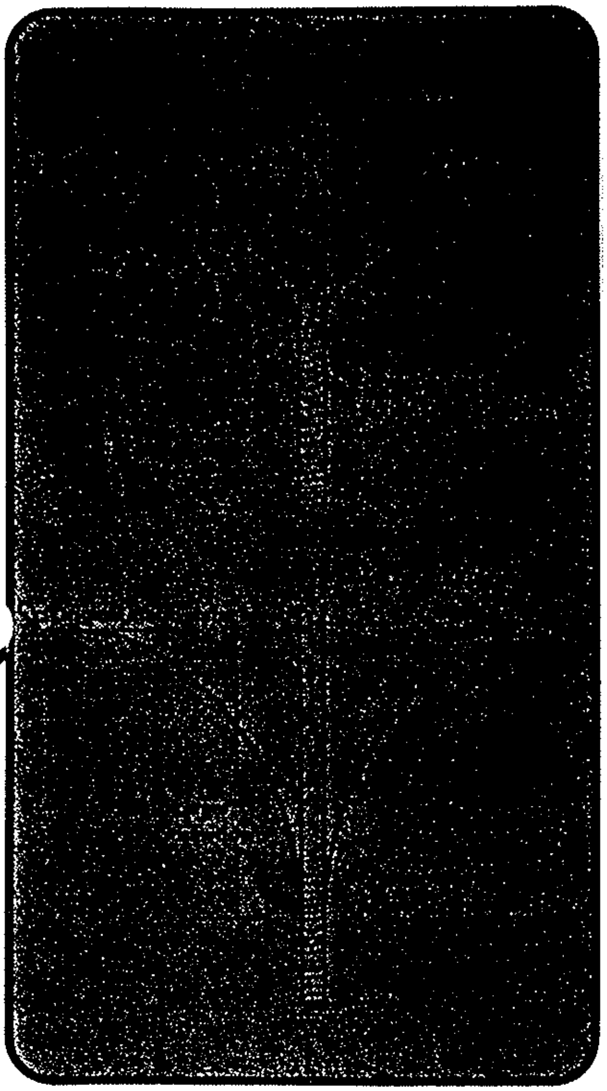


Figure 10

well. *Only an experienced ground water engineer or geologist can properly advise on the need for and conduct tests required for solving aquifer boundary and accelerated drawdown problems.*

Well Design

The well design has a tremendous effect on the success or failure of the irrigation project. The objectives of the well design procedure are to achieve a proper well that will:

1. Produce sand-free water. Just a few parts of sand per million parts of water will reduce

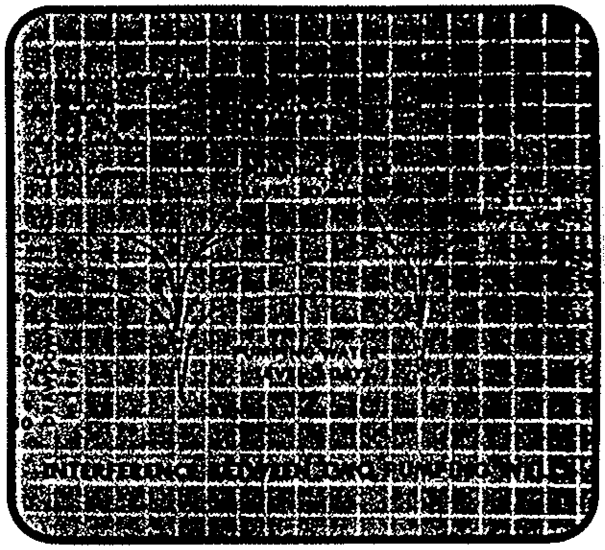


Figure 11

the useful life of the pump and sprinkler drastically.

2. Produce water economically. The cost and life of the well are factors here. A well that costs $8,000 and lasts 10 years is not economical compared to one that costs $10,000 and lasts 20 years. Wells that have a premature failure from plugging or corrosion, that produce too little water, that produce pump-eating sand, are uneconomical.

3. Allow production of at least 85 percent of the specific capacity that the formation is capable of giving up. That is to say the well should be efficient.

The term well efficiency is difficult to understand. A 100 percent efficient well is usually unobtainable. The maximum specific capacity and/or yield that a perfect well will yield depends on the aquifer's ability to transmit water to the well location. The well on the other hand usually will allow a lesser amount to be produced.

Many wells which were drilled to "produce all the water" actually yield grossly less than the ability of the aquifer. A 50 percent efficient well in a certain formation may produce 1,000 gpm with 200 feet of drawdown. A perfect well in that location would produce 2,000 gpm with 200 feet of drawdown or the same 1,000 gpm with only 100 feet of drawdown. At 1,000 gpm the extra 100 feet of drawdown would require an additional 30 hp. Few farmers or drillers know how to determine well efficiency. Unfortunately, the only way to know for sure that the well is efficient is to do enough testing to determine the theoretical ability of the aquifer.

The capability and well efficiency *cannot* be determined by simply pumping a production well. At least one observation well is required and two are preferable. Approximations, however, can be made sometimes by measuring how a well recovers after pumping. Figure 12 shows the effect of an inefficient well.

Gravel Packed Well Design — the well efficiency and tendency to produce sand are factors of both design and construction techniques. Construction techniques will be discussed later on in this article. Here we will consider the effects of design and limit discussion to gravel packed wells.

It is usually economical to design the well to produce at 85 to 90 percent efficiency. Factors that bear on the well efficiency are the length of well screen, the amount of open area in the well screen, and the permeability and thickness of the gravel pack material. The screen length should equal the total thickness of the water bearing zones of the formation. Each zone must be screened for it to contribute easily to the yield.

Some zones in nearly every formation are negligible in their ability compared to others. These zones are not economical to screen, particularly if one of the better type screens is used. The decision on whether or not to screen all or some of the sand depends on the percent of contribution from each zone. The percent contribution can be fairly accurately computed using formulas and a sieve analyses of the formation samples. *(See charts, page 17.)*

In this case there are two intervals of water sand totaling 65 feet. However, the sieve analysis and subsequent computations show the 30-feet interval from 160 to 190 feet will contribute only 11 percent of the water. It would be economical to screen only the interval

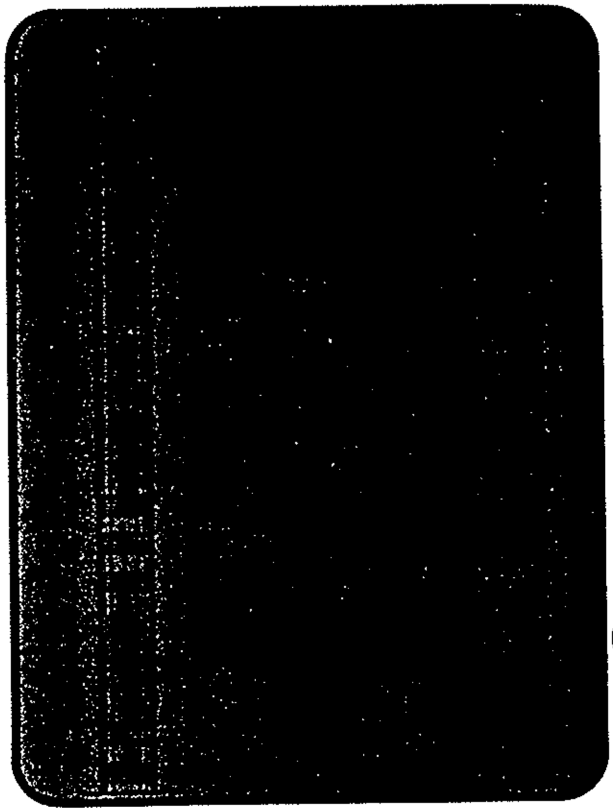
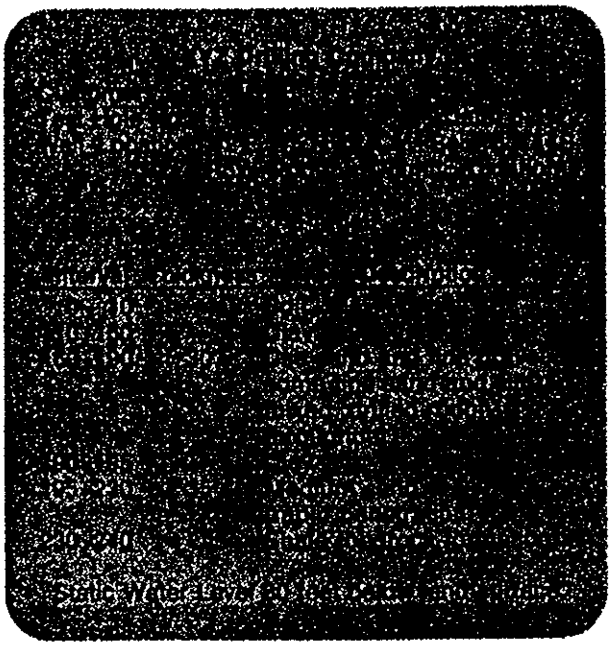
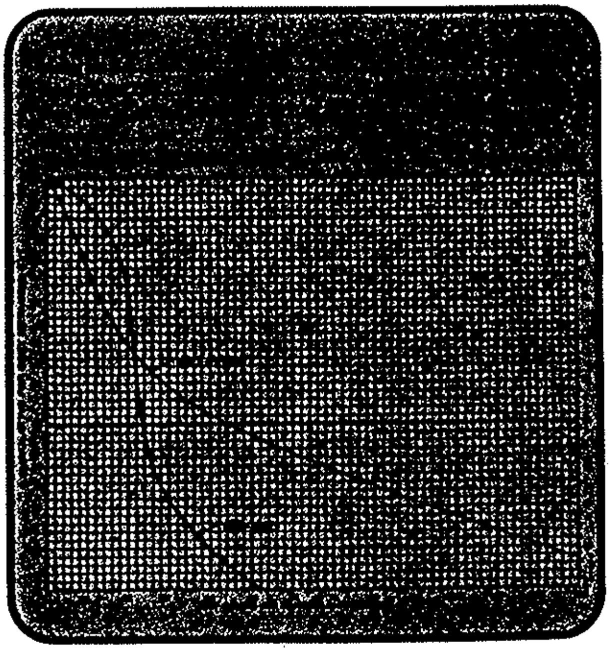


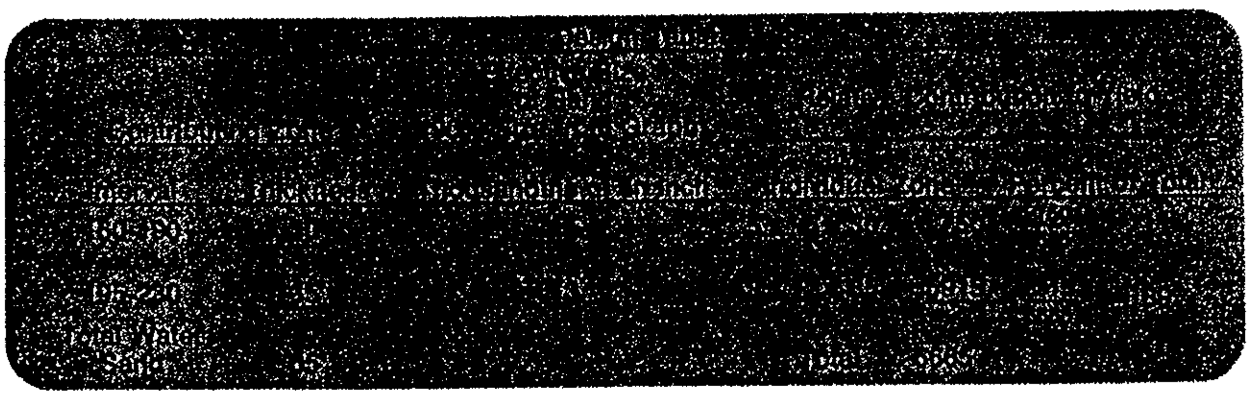
Figure 12

from 195 to 230. To screen the other 30 feet would almost double the cost of screen. This would be a significant wasted cost. For example, a commonly used type screen that is efficient is the "Johnson-type" or "wire wound" type. These screens have a maximum amount of open area. Such a screen made of mild steel in a 16-inch size would cost about $30 per foot installed. To screen both sands would cost $1,950, but about 90 percent of the water could be produced with only the lower zone screened at a cost of $1,050.

A cheaper screen such as torch slotted pipe or one with a similarly small amount of open area that extended over the entire 65 feet would be the wrong choice, because it likely would not permit the lower zone to produce its maximum. A cheaper screen would only be warranted if efficiency or maximum production was not needed.







Selection of the proper type screen is as important as selecting the correct slot opening. Oftentimes the driller doesn't think the farmer is willing to buy the premium screens when they are needed. A good rule to follow is: *Ask your driller to show you one of every type screen, wire wound, louver type, bridge type, mill slotted pipe, punched pipe and torch slotted pipe. Get the cost of each screen, the advantages, disadvantages and the amount of open area for screen with the same slot size.* In a screen it is the open area you are buying. Even the best screens that cost hundreds of dollars per foot are barriers to flow to some extent, so it's open area that counts if maximum production is desired. *Don't compare one driller's price for a well against another without knowing the design details on each well. You could ask the driller to quote on wells using several types of screen and other components, but make sure you're comparing apples to apples.*

The gravel pack has bearing on well efficiency. The purpose of the pack material is to provide the filter. Filter design is straight forward. If the filter material is all the same

Figure 13

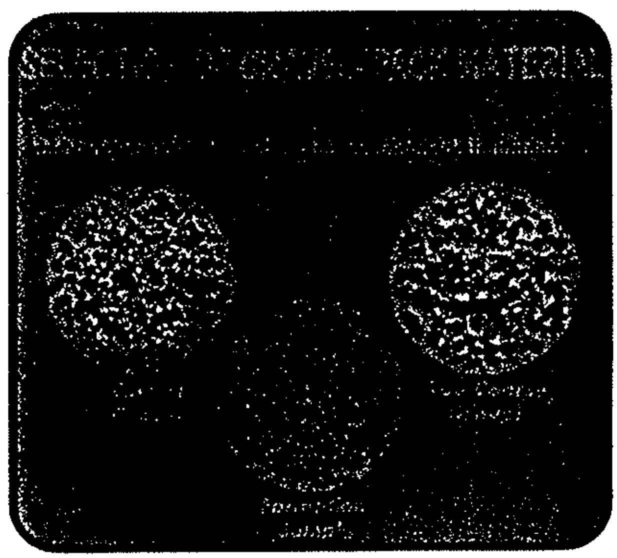


Figure 14

size spheres, the size of particles it will hold back is just over one-fifth the diameter of the particle size of the pack. Figure 13 illustrates this concept.

The filter theoretically needs only be one layer of particles thick. However, the natural gravel used will not all be perfect spheres and it would be impossible to construct a pack one gravel grain thick, so the practical rule is: *The gravel pack should be from three to five inches thick (as thin as practical to constant).*

The important thing for efficiency or maximum yield is that the gravel be very uniform in grain size. This permits the maximum porosity transmitting capacity as explained earlier. *(See Figure 3, page 7.)* This picture makes it evident that for porosity and ease of flow the pack must be near all the same size particles and to be a filter the size of the particles simply must be just less than five times the size of the sand to be filtered out. The pack must be thin so the damage or plugging of the formation by silt, clay, etc., that occurs during drilling is close to the well bore so it can be easily flushed out after the gravel is placed and the well is completed. If the pack is too thick or not highly porous then the flushing can't be as fully accomplished.

One may believe there is great advantage in having a thick pack to have a large diameter hole that will yield more water — not so. A 36-inch hole can yield only about five percent more water than a 24-inch hole if they're both perfect. The theory says *to double the well diameter will increase yield potential about 10 percent.*

The factors that must be correctly considered to prevent sand pumping are the grain size of the gravel pack and the screen slot opening. The pack particle size is discussed above. The design of the proper screen slot is easy with sieve analysis graphs — just pick the screen slot to retain the gravel pack material. The pack is sized to filter the sand, and the screen slot is sized to filter the pack. In practice actually the pack won't be absolutely uniform in size but will have a few oversized and undersized particles. Therefore, the screen slot is actually selected to retain 85 to 90 percent of the gravel material.

Figures 14 and 15 show samples and sieve analysis of a formation sand, the proper gravel pack material is also shown. The corresponding screen slot, to retain 90 percent of the gravel would be No. 20 (0.020 inches).

To emphasize again, all these exacting design

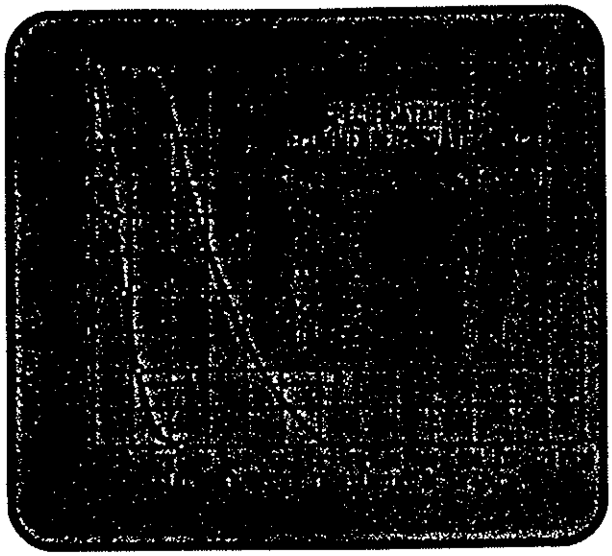


Figure 15

procedures are rather simple and inexpensive. They depend on sieve analysis which is inexpensive and usually provided free by screen companies. Take advantage of the scientific way. Depend on *measurements* and not eyeball judgement. Insist your driller or designer follow the technically correct way and you'll have a much better chance for success.

Most irrigation wells are of artificially gravel packed design as opposed to naturally developed (natural pack) design. In a gravel packed well the filter that retains the formation sand and prevents it from moving into the well is a specifically designed gradation of gravel (see page 12). The gravel pack (filter) occupies a three-to five-inch thick space between the screen and the bore hole face. The screen slot size is selected to retain the gravel pack material.

In a naturally developed well the screen with a proper slot opening is set directly against the bore hole face. Then during "development" (a cleaning and flushing process) of the well, a specific percentage of the fine sand is removed allowing the coarser particles to pack together and move forward to the screen where they are retained to form the filter. Figure 16 illustrates the two types of wells.

Because most irrigation drillers prefer them

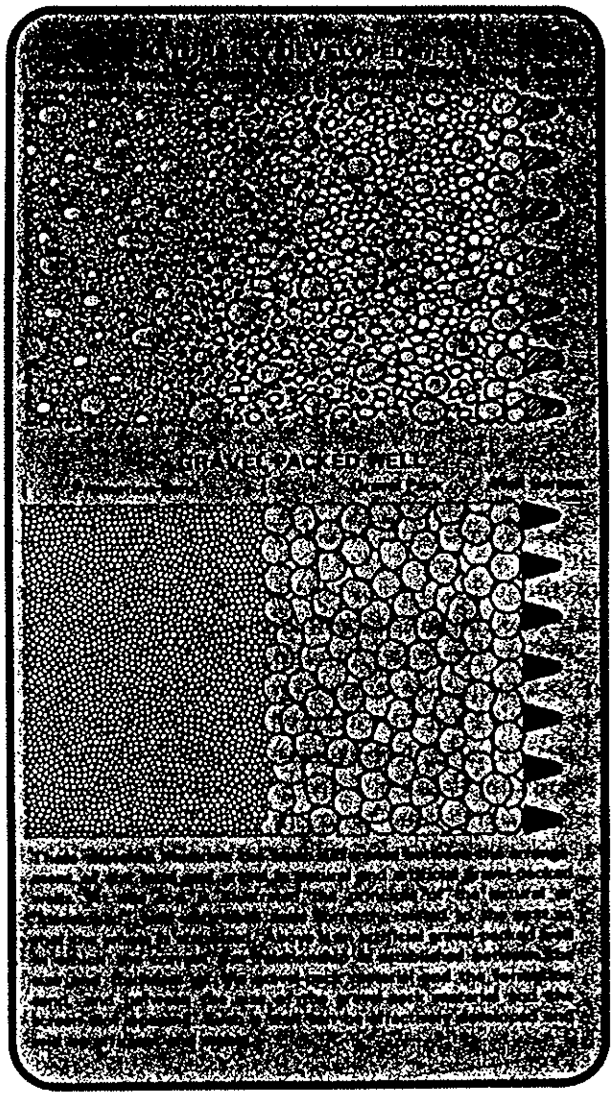


Figure 16

and because of space limitations the discussions herein are limited to artificially gravel packed wells.

The most important factors of the well design — length of the well screen, the gravel pack particle sizes and the screen slot opening size were discussed earlier. The remaining design factors are selection of the casing diameter, the screen diameter, the type of screen and the materials and strength requirements (e.g., mild steel, stainless steel, plastic and wall thickness).

Basically the casing is only a "housing" for the pump assembly. Therefore it need only be large enough to accommodate the size pump required to efficiently produce the expected yield. It should be one or two sizes larger than the pump bowl diameter.

Corrosion Resistant Metals

If the water is corrosive, corrosion resistant screens are warranted. A small corrosion rate of 0.001 inches per year by eating away from both sides of the screen slot opening can widen the slot by .002 inches per year. Obviously in five or 10 years this could cause complete failure of the well. On the other hand, it is rare that the casing would need to be of exotic metal, but casing with extra wall thickness should be used in corrosive water. The tendency of the water to corrode can be fairly well estimated from chemical analysis of water samples.

When the water is encrusting (tends to deposit minerals on screens, pipe surfaces, tea kettles, etc.) corrosion resistant metals are also required. This is because after prolonged pumping the well screen, the gravel pack and formation around it become plugged from the deposition of minerals from the water. The harder the well is pumped the faster it will become plugged if the water is very hard, has iron, manganese or certain other elements in it. To unplug the well requires that various acids be introduced into the well to dissolve the encrusting mineral deposits.

Drawdown Pipe Important

An item in the well design that often is overlooked is to provide a means so the water level in the well can be frequently and accurately measured conveniently. The best scheme is to provide a one-inch pipe running from the surface down the outside of the well casing to near the bottom of the well where it should be connected to the casing so as to reflect the water level inside the well. The pipe should enter the casing near the bottom of the well yet as close as possible to the screen to prevent sediment from plugging the drawdown tube.

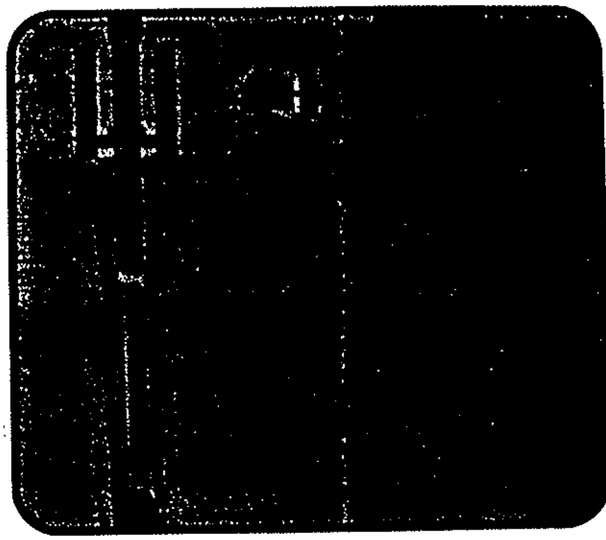


Figure 17a

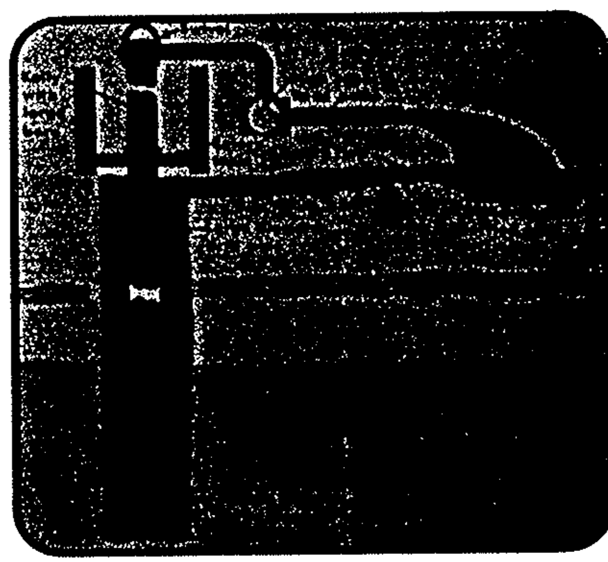


Figure 17b

Constructing the Well

Most irrigation wells are drilled by a rotary process, either direct or reverse circulation. Figure 17 illustrates the principle of direct and reverse circulation. With this type drilling, often the hole is drilled to its full depth before any casing is set into the hole. If the hole is left open and uncased for more than the absolutely necessary length of time, problems of excess

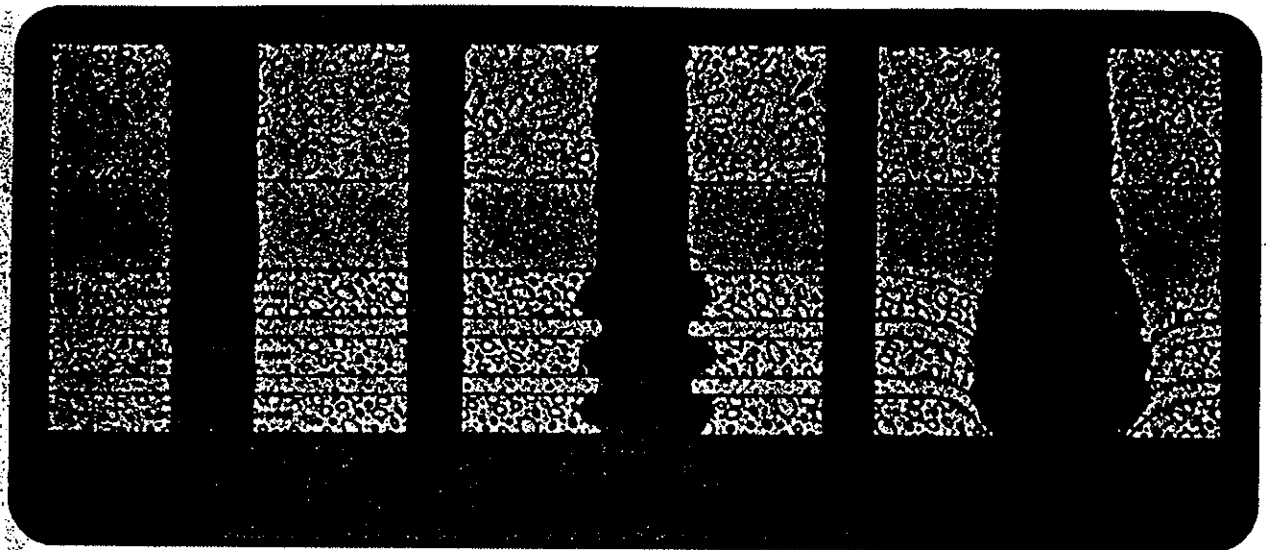


Figure 18a Figure 18b Figure 18c

caving and over-excavation have their best chance to occur. These mishaps can cause the well to yield less than it should.

In most formations the good water yielding parts of the formation are in alternating layers of fine sands, clays, etc. The coarse loose material (usually the best water sands) slough off most easily. When the loose clean material is over-excavated, the other layers (particularly clay) can fold down to partly or completely cut off the better zones. *(See Figure 18.)*

Excess time, improper drilling fluids, poor drilling and circulation procedures hasten these problems which may sometimes exist to some extent regardless. *You can help control loss of time by insisting that your driller work continuously around the clock from the time the drilling begins until the casing and screens are set and the gravel pack placed. Also insist that all materials required for the work be on hand before drilling starts.*

Setting Screens

Screens should be set as recommended by the screen manufacturer. This is important. The screens generally are most subject to collapse during installation and placement of the gravel pack. If the screen has to be strong enough to be handled and set in just any haphazard manner, then usually open area has been sacrificed. Remember it's maximum open area (with of course the proper slot) that is of primary value in the well screen. Theoretically the best screen to use would be one that has the very maximum amount of openings which conversely means the least amount of metal. Sufficient metal must of course be present to withstand the forces executed on the screen as it supports the borehole, but these forces can be computed and the screens are made of proper strength to withstand them.

Placing the Gravel Pack

The most sure-fire method of placing the gravel is to pump it down with water or place it through a small tremie pipe. However, much controversy exists over what is the proper method of placing the gravel pack. This stems from historical use of non-uniform (poor) gravel pack materials. When the gravel pack is nonuniform, the particles segregate when free-falling through water. The coarser particles collect in layers and the fines collect in layers on top of the coarse. We discussed, you will recall, why very uniform gravel pack materials should be used. If good uniform gravel is used the segregation will not be as significant a problem, and any controlled and gentle method of placing the pack should suffice.

The volume of pack material used should be computed and compared to the calculated volume required to fill the annulus. This provides a rough check that the gravel is continuous in the hole and that it hasn't bridged and left part of the hole void of gravel. Also the gravel level should be checked frequently as placement proceeds.

Developing the Well

Direct rotary drilling pastes mud, silt, debris and other particles on the side of the borehole during drilling. Reverse circulation drilling, with what is referred to as clear water vibrates and compacts the sand grains in the vicinity of the boreholes, and the so-called "clear-water" used is recirculated dirty water. It carries silt, grass and clay from stratas in the formation, along with other plugging material, into the water bearing zones of the formation being drilled. The formation is thereby damaged. Depending on how coarse the formation is, these plugging agents may be carried several inches or several feet into it. The parts of the formation that will give up the water most easily also "take" the drilling fluid and the plugging agents most easily. *(See Figure 19.)*

For the well to even approach being efficient most of these plugging agents must be removed after the well is completed. This is done by "developing" or cleaning the well.

For development to be effective, water must be flushed back and forth through the screen, gravel pack and formation around the borehole. Figure 20 shows a completely developed formation around a naturally developed "laboratory" well. The picture would be about the same for a gravel packed well . . . except the particles next to the screen would be nearer the same size. Overpumping with the test pump, without reversing flow, is not very effective. The key is to flush water at a fairly high velocity back and forth.

One effective method is air lift pumping. A common hookup for this method is illustrated

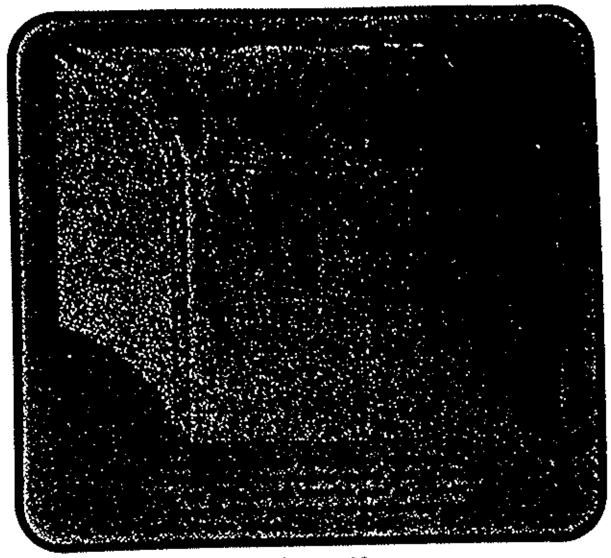


Figure 19

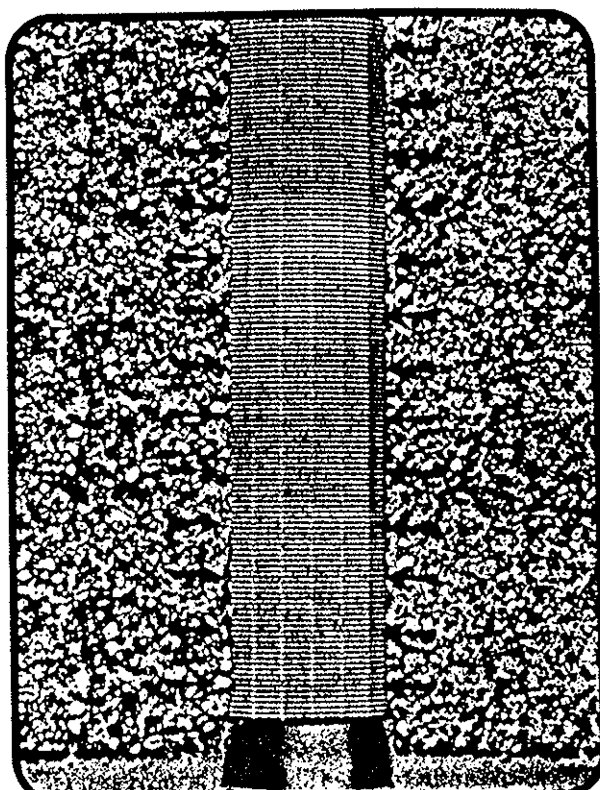


Figure 20

by Figure 21. Compressed air is introduced through the air line, it mixes with the water,

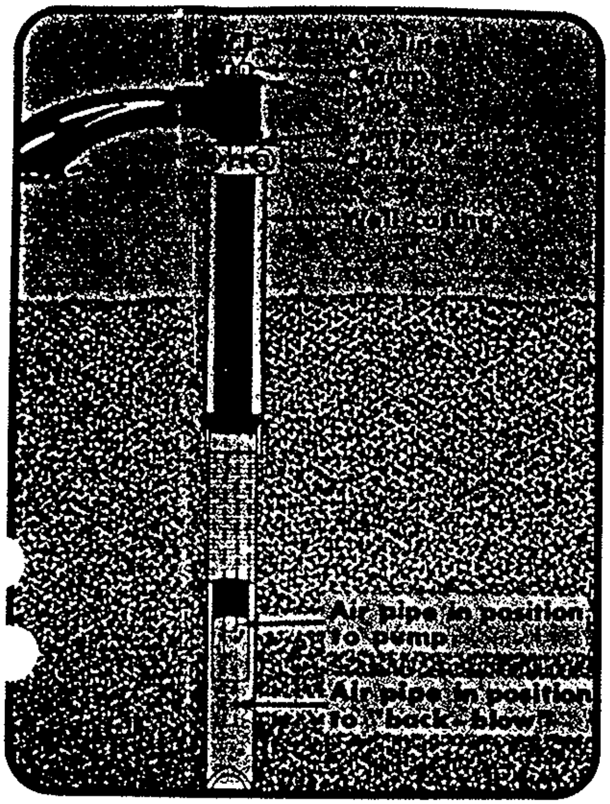


Figure 21

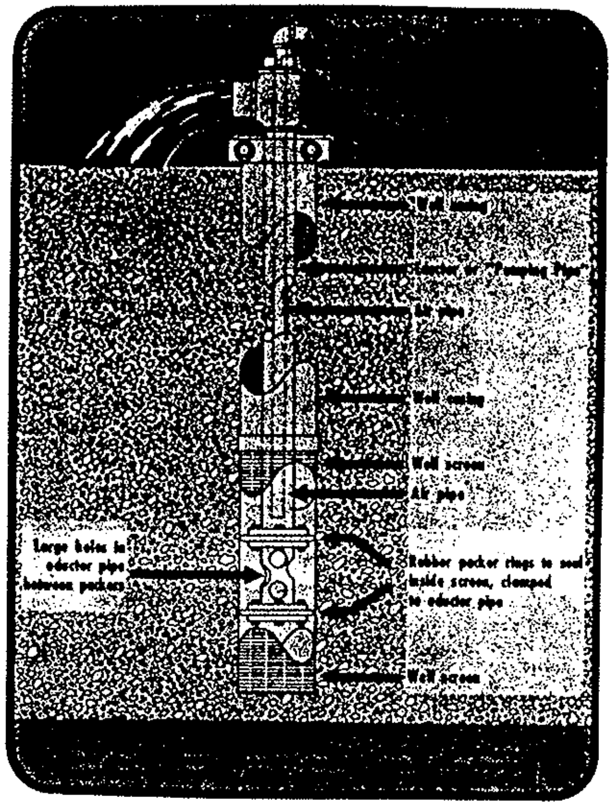


Figure 22

and the mixture of air and water is blown out the top of the eductor or "pumping" pipe. The pumping comes in explosion-like spurts causing water to move back and forth through the screen, but there is a net removal. Air development is possible when there is a sufficient depth of water in the well and the lift to the surface isn't too great.

A most effective method is the double disc packer air lift method. This uses air lift pumping but the pumping is restricted from small zones in the formation isolated between packers. Raising and lowering the assembly allows the entire aquifer section screened to be devel-·ed selectively. Figure 22 shows the arrange-nt required for this method.

Another powerful method is high pressure j ·ng with *simultaneous pumping*. With this ı. ıod, water is pumped down a pipe extending into the screen and forced out horizontally (at a very high velocity) through nozzles in a jetting tool such as illustrated by Figure 23. The jet streams of water go through the screen slots and penetrate the gravel pack and/or formation as shown in Figure 23. At the same time water is removed from the well. More water is removed than is jetted in, so the fines, clay, mud, etc., are brought into the well bore and pumped out. A primary advantage of the jetting method is that the jet streams can be directed at any part of the formation for selective development.

Other methods are available. The point to remember is that development is necessary. Good development by an experienced driller using a sound method is worth a premium price. It will get you more water longer.

The degree to which the cleaning and restoration can be done depends on how much access area (screen open area) is available.

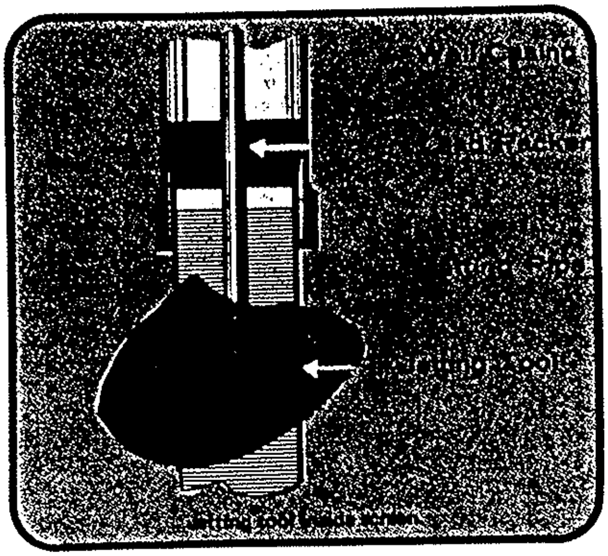


Figure 23a

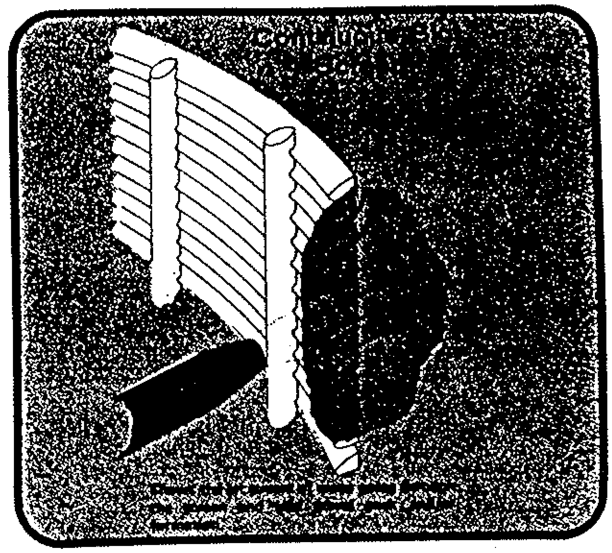


Figure 23c

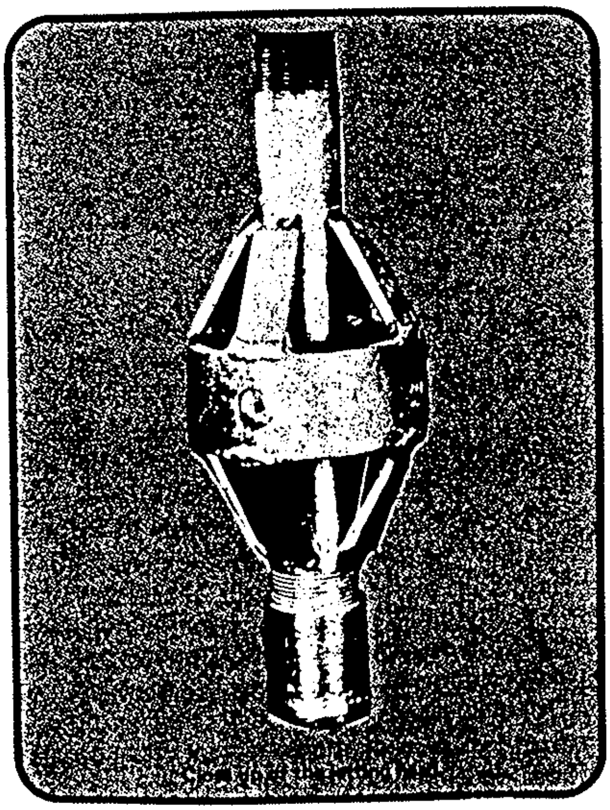


Figure 23b

Figure 24 illustrates that the screen is to a degree a barrier to the required cleaning job.

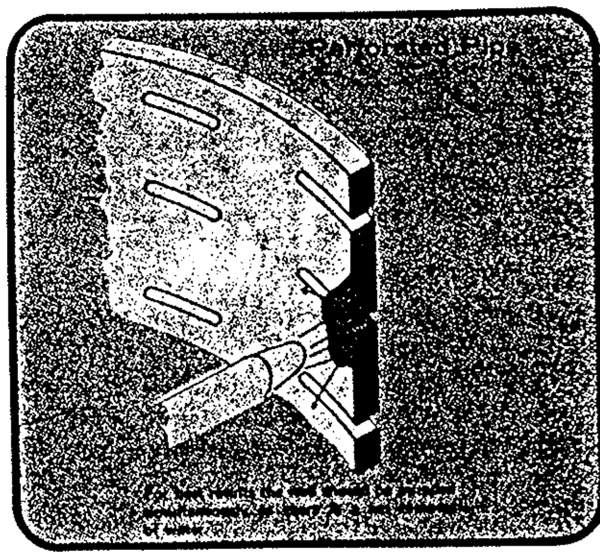
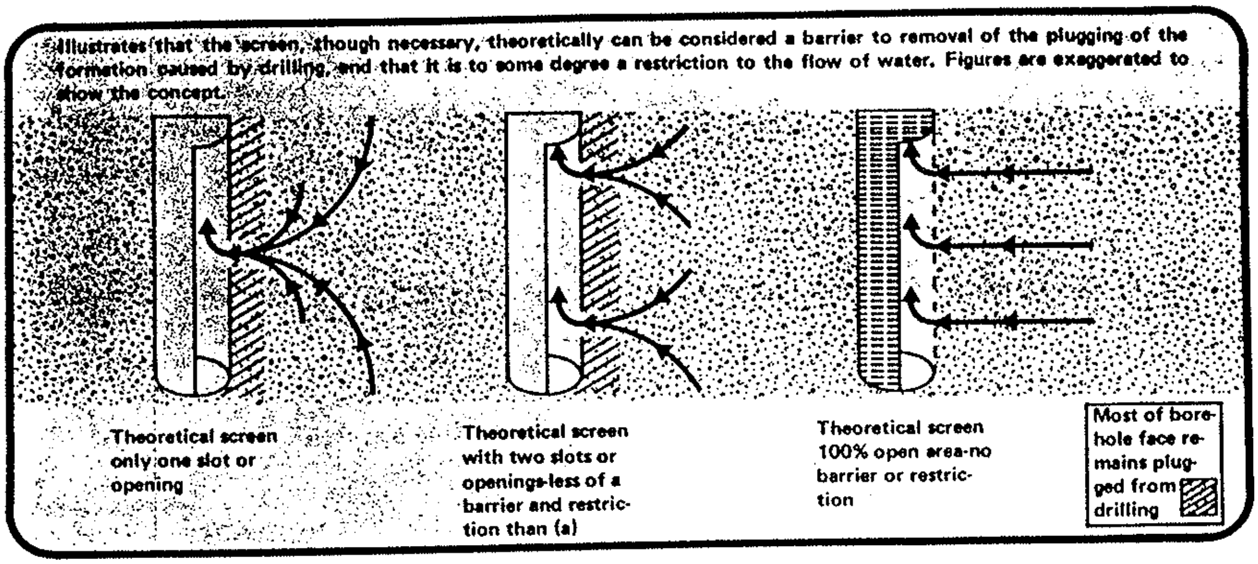


Figure 23d

Pump Testing and Equipping the Well

After the well is completed and developed, a test pump should be installed and a pumping test run in order to determine the well's yield and drawdown relationships. It is only from such a test that the pump can be properly selected. Usually, the pumping test should be run a minimum of 24 hours in artesian type aquifers and a minimum of 72 hours in water table type aquifers. If long term aquifer performance tests



Illustrates that the screen, though necessary, theoretically can be considered a barrier to removal of the plugging of the formation caused by drilling, and that it is to some degree a restriction to the flow of water. Figures are exaggerated to show the concept.

Figure 24a Figure 24b Figure 24c

e been conducted in the exploration phase, the test's length may be safely shortened.

Many times pumping tests are run "till she stabilizes", which means that the pumping water level appears to have ceased lowering. Actually what is usually the case is that either the water level is still moving down slowly and measurements aren't accurate enough to reflect the changes, or the pump discharge has dropped off.

You will recall that we have discussed some theory of ground water flow that shows that the well should continue to drawdown with time. There is very rarely an exception, and when an exception does occur and the water level does cease lowering, it happens after long, long pumping when the cone of depression has grown very large. For the water level to actually stabilize, complete recharge must be received and this is a rare occurrence in a short duration of pumping. In very shallow aquifiers, very close to surface water sources (say 100 feet or `, stabilization might be expected to occur in .e day's pumping.

The proper way to conduct a pumping test is follows:

1. Measure the static water level accurately several times.
2. Make sure the pump has the capability to pump the full expected capability of the well, or 25 percent more than the yield you desire.
3. Run a short test (30 minutes) to get a rough estimate of what short term maximum capacity is, throttle the pump back to about 70 percent capacity.
4. Let the well rest 30 minutes until the static water level is back to the original level.
5. Turn the pump on and record the *exact* time to the nearest 10 seconds. With a valve, not the throttle, maintain a constant discharge within five percent.
6. *Accurately* measure and record the pumping water level and time on the following approximate schedule. Make sure the pumping rate is correct or constant before making the measurements.

1st 15 minutes	every 1 minute ±
Next 10 minutes	every 5 minutes ±
Next 2 hours	every 10 minutes
Next 3 hours	every 30 minutes
Next 6 hours	every hour
Remainder	every 4 hours

Your driller should make and record all these measurements very accurately, and plot the data on graphs to show what is happening. A proper pump test graph (record) will appear as shown in Figure 25.

The production pump should be selected on the basis of what the pumping water level will be after long term pumping, at least 60 days and 100 is better. Therefore the data observed in a 24-hour or three-day test must be extended to estimate the water level at a longer pumping time. Figure 25 shows a plot of a pumping test from a typical water table type aquifer. Notice in the first eight to 10 minutes the water level fell from the 40-foot static level (0 drawdown) to about 83-84 feet (drawdown of 43-44 feet). Then in the next 60 minutes the water level was almost stabilized. (Usually this stabilized condition in a water table aquifer lasts at least a day.) Then the drawdown started increasing again.

By extending the graphs on to 60 days of pumping, one can get the expected pumping water level for that time. In this case if the extrapolation were made when "she first seemed to stabilize" at a pumping level of 84 feet (drawdown of 44 feet) and the pump was set 20 feet below that to be safe (at 104 feet), then the well would suck air on the 10th day. Artesian aquifers don't have such a pronounced false stabilization.

Proper pump selection involves the setting, the lift, the discharge pressure required, the yield and the friction loss getting the water to the surface. It's pretty complicated and should not be done by a novice.

Well Alignment and Plumbness

Most high capacity irrigation wells are equipped with line shaft turbine pumps. The shaft rotates at a rapid speed (1,760 rpm is common). Obviously the straighter the shaft hangs, the less the wear, vibration and power loss. For this reason the well needs to be plumb and straight. Wells which are improperly drilled sometimes are crooked enough to cause premature pump failure. Competent drillers can guarantee that the well will be plumb and straight.

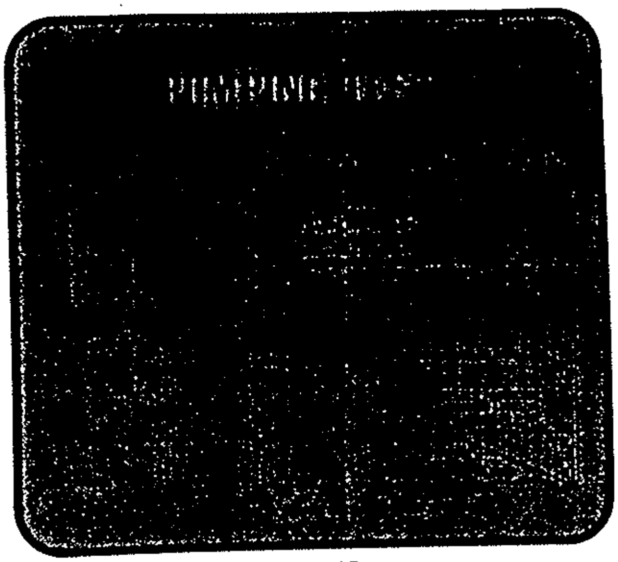


Figure 25

The farmer should insist on such a guarantee. Also, an alignment and plumbness test should sometimes be required.

The test is easily run by lowering a "dummy" into the well on a wire line. The dummy is a *rigid*, large diameter, heavy wall pipe 40 feet long with three rings (short pieces of casing one foot long) welded concentrically to the pipe, one at both ends and one in the middle. The diameter of the rings should be no less than one-half inch less than the inside diameter of the well casing. If this dummy can be lowered to the bottom of the well, then the alignment or straightness is okay.

To check the plumbness, the dummy should be lowered in five- or 10-foot increments and the distance the cable moves off center at the top of the casing measured accurately to nearest 1/16 inch. The deviation from vertical at each location can then be computed fairly easily. Plumbness is not as important as straightness but a reasonable requirement is that the well should not deviate from vertical more than a distance equal to 3/4 the casing diameter per 100 foot of depth.

Yield

One knowledgeable in ground water hydraulics knows that without prior sophisticated aquifer performance testing that well yields can only be estimated and not accurately predicted. You cannot expect a guarantee of yield without being willing to pay for a test well and a couple of observation wells. (Test wells need not be efficient or expensive structures.)

However, a driller can guarantee his workmanship, design and procedures by guaranteeing a specified well efficiency. Even this is rarely done because to determine well efficiency requires at least one observation well and some computation from the pump test. However, it isn't much expense to make a nearby test hole into an observation well by installing 1¼-inch slotted plastic pipe.

It is usually wise and economical to require at least 80 percent efficiency and 90 is usually tainable. Remember efficiency is the percent of yield you are getting from your well, to what theoretically perfect well would yield. To compute this requires determination of the true aquifer capability.

Sand Pumping

When good screens and gravel packs are used absolute zero sand pumping is possible if care is taken. However, a reasonable specification to require is that the well not produce more than one part sand per million parts water in the second minute of pumping at the rate the well is to be put into service. One part per million (1 ppm) is equivalent to one-half teaspoon sand per 1,000 gallons of water. It may sound like an infinitesimal amount. However, a well producing one ppm sand pumping 1,000 gpm for 60 days each year will produce 2.6 cubic yards of sand in 10 years. It's reasonable that this amount (1 ppm) will hurt the pump.

The irrigator should thoroughly investigate the competency of the driller before selecting him to do the work. Determine that the driller has all the equipment needed, that it is of adequate size for the job and that the personnel are experienced and have sufficient technical knowledge of ground water and well hydraulics to do an effective job. A good well is a fairly complicated operating engineering structure. It should be regarded as such. To have a good well, the irrigator should be unwilling to settle for the cheapest material, design and construction methods. In order to have a well that is efficient, sand free and sure to have the desired useful life, he must be willing to pay a premium price to a premium driller.

The best arrangement is to have one man or company be responsible for the exploration, the design, drilling, developing, testing and equipping the well. Single responsibility will afford you the best chance for complete satisfaction.

Records and Maintenance

With use, wells generally will decline in yield. The decline may be gradual, like 10 percent over 10 years, or rapid, like 50 percent over a period of months. The decline in yield can be from one or combinations of several causes. Some are:

1. Normal increase in drawdown from time of pumping.
2. Pump wear.
3. Change in pumping head conditions.
4. Lowering of *static* water level (depletion of the aquifer).
5. Interference from nearby wells.
6. Well plugging from encrustation.

The remedy for each cause is different. In order to easily and inexpensively determine the cause and design a remedy, records of well performance are absolutely necessary.

The farmer should prepare a permanent file containing the following initial data on his wells.

1. Test hole logs and location map.
2. Sieve analysis of formation samples.
3. Water analysis.
4. All geologic data collected in the exploration stage.
5. Well design drawing showing accurate finished dimensions and details.
6. Pump test records and graphs.
7. Pump specification sheets, performance curves, parts lists, etc.
8. Details of repairs, acid treatments, etc.

Then each year the following tests and measurements should be made for comparison to previous data so trouble can be detected early when it is still possible to rectify.

9. Each winter, when all wells have been at rest a long time, run a two-hour pumping test. Record the static water level, the pumping rate and frequent drawdown measurements as discussed under pump testing.
10. Every two months, all year, measure and record the static water level when pump has been off at least four days. Record details.
11. During heavy pumping season measure the yield and drawdown, and record along with length of time in hours that the pump has been running. Several measurements per summer are advisable.

When the yield has dropped no more than 25 percent remedial measures should be taken. Isolation of the cause is usually a job for a ground water engineer or other qualified technician. He may prescribe lowering the pump, acid treating the well, adding a pump bowl, polyphosphate treatment and redevelopment, or adding another well. Obviously you will want sufficient data so the right remedial measure can be prescribed.

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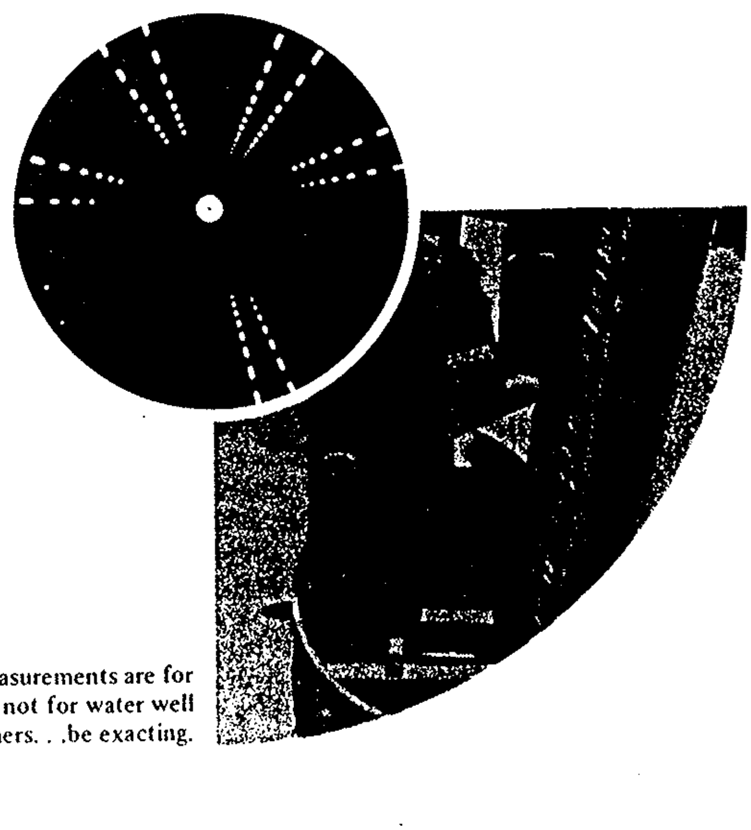

Eyeball measurements are for girl watchers, not for water well designers. . .be exacting.

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PAPER NO. 70-732

MODERN DESIGN TECHNIQUES FOR EFFICIENT HIGH CAPACITY IRRIGATION WELLS

by

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SUMMARY:

Common irrigation well design problem areas are reviewed. Modern design criteria that are presented insure sand-free water, overall high efficiency and long well life. The benefits of suggested procedures are economical, low-cost irrigation wells.

ASAE

American Society of Agricultural Engineers

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INTRODUCTION

Irrigation is a major consumptive use of water and expected to increase approximately 50 percent by the year 2020. Many irrigation systems are supplied by ground water from a high capacity water well. Traditionally, much time and money are directed to the design and purchase of the well pump and surface equipment for the purpose of efficiently and economically distributing water on the land surface. However, what most agriculturalists fail to realize is that the "heart" of the entire ground water irrigation system is the water well. Yet, little or no design considerations are given to this engineering structure to insure the same long life, efficiency and economic operation expected of the pump and surface equipment. Irrigated agriculture is often attracted by slightly lower capital costs that prohibit the use of modern materials and design techniques. This often results in the construction of irrigation wells that are expensive to operate and have a short expected life over which the components of the irrigation system can be amortized. It cannot be over emphasized that without a reliable, efficient and economical supply of abundant water the entire irrigation system, regardless of the most sophisticated surface equipment design, becomes nearly useless or generates much less profit than the system's true capability.

The purpose of this paper is to outline the most common problems of irrigation well design and construction and to present design criteria that can be used to overcome these problems so that efficient, sand-free and long lasting irrigation wells can be designed and constructed. The discussion will be limited to irrigation wells completed in unconsolidated sand and gravel water-bearing formations rather than wells completed in bedrock. Irrigated agriculture can greatly benefit from the implementation of these techniques. The savings generated from proper irrigation well design and construction can add thousands of dollars each year to the much needed profits of agriculture.

DEFINITION OF TERMS

Before it is possible to discuss major irrigation well problems and offer solutions to these problems, it is important the reader understands the terminology of ground water hydraulics and wells. The following are common terms:

Aquifer: Water saturated geologic formation (unconsolidated sand and gravel) that will yield water to a well at a sufficient rate so that the well can serve as a practical source of water supply for the intended purpose or need. In relation to irrigation wells, aquifers of importance are only those capable of yielding large quantities of water. Often the term aquifer is used interchangably with the following: formation, water-bearing material, formation material.

Water-Table Aquifer: Condition where the upper limit of the aquifer is defined by the water level in the formation. At this surface - the top of the saturated portion of the geologic formation - the water in the pores of the aquifer is at atmospheric pressure. When a well is drilled in a water-table aquifer, the water level in the well stands at the same elevation as the water level in the formation.

Artesian Aquifer: Condition where an aquifer is present between impermeable layers above and below it. Both the aquifer and the water it contains are said to be confined or under pressure. The water of the aquifer is not open to atmospheric pressure because of the presence of the upper confining layer. Thus, water occurs within the pores of the aquifer at pressures greater than atmospheric. When a well is drilled into an artesian aquifer, water rises in the well to some level above the top of the aquifer. This water level in the well represents the hydrostatic pressure in the aquifer. This hydrostatic pressure within an artesian aquifer is sometimes great enough to cause water to rise above land surface. Under these conditions, a flowing artesian well results and the formation is known as a flowing artesian formation. It is not necessary for a well to flow at the land surface to be termed artesian. An artesian well is simply one completed in an aquifer that is confined between two impermeable layers and contains water under pressure greater than atmospheric pressure.

Static or Standing Water Level: The level at which water stands in a well when no water is being removed from the well either by pumping or by natural flow. It is generally expressed as the distance from the ground surface (or from a measuring point near the ground surface) to the water level in the well. The elevation to which the water level rises in a well that taps an artesian aquifer is also referred to as the piezometric level. An imaginary surface representing the artesian pressure or hydraulic head throughout all or part of an artesian aquifer is called the piezometric surface. This imaginary surface is analogous to the real water surface or the water table in a water-table aquifer.

Pumping Water Level: This is the water level in a well when pumping is in progress. The pumping level is also known as the "dynamic water level". The distance to the pumping water level is measured from the ground surface or other selected measuring point. The pumping water level is at times erroneously referred to as drawdown.

Drawdown: The amount the water level is lowered below static level of the well when pumping is in progress. Drawdown is the difference, measured in feet of water, between the static water level and the pumping water level. This term represents the hydraulic head, in feet of water, that is needed to cause water to flow through the aquifer material toward a well and into the well at the rate that water is being removed from the well. Total "available drawdown" is the difference between static water level and the top of the screening device.

Well Capacity or Yield: The volume of water per unit of time discharged from a well. This unit is usually measured as the pumping rate in gallons per minute (gpm) or cubic feet per second (cfs).

Specific Capacity: The yield of the well per unit of drawdown, usually expressed as gallons per minute (gpm) per foot of drawdown. It is obtained by dividing the pumping rate by the drawdown each measured at some specific time after pumping began. For example, if the pumping rate is 1,000 gpm and the drawdown is 20 feet, the specific capacity of the well is 50 gpm per foot of drawdown at the time measurements are taken.

Naturally Developed Well: A well in which the intake device or well screen is placed directly opposite the water-bearing sand and gravel. The width of the openings in the screen is selected so that fine sand in the aquifer immediately surrounding the screen can be removed by development to create a highly permeable zone consisting of the coarser formation particles. See Figure 1.

Gravel Packed Well: A hole larger in diameter than the casing and well screen is drilled through the water-bearing formation and the zone immediately surrounding the well screen is made more permeable than the aquifer by filling the annulus between the face of the borehole and well screen with artificially graded sand or gravel that is coarser than the formation. See Figure 1.

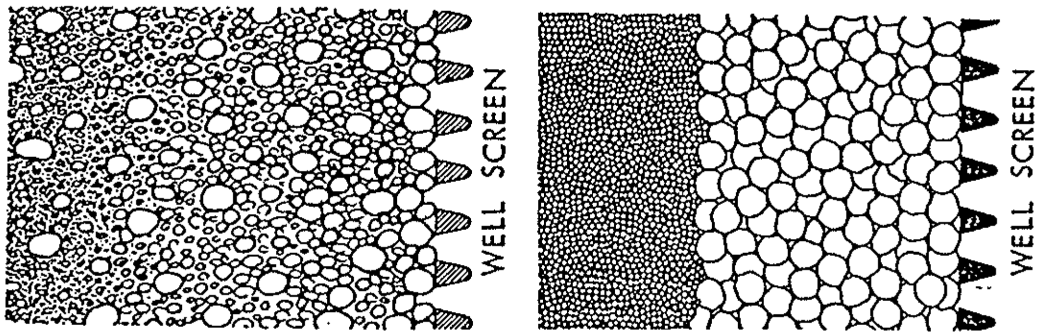

Figure 1. These sketches illustrate the basic difference between the arrangement of the sand and gravel in naturally developed and artificial gravel packed wells. At the left is illustrated the principle of the naturally developed well with the sand grains rearranged by development so that the coarsest grains remain immediately adjacent to the well screen. Beyond that zone, the formation material gradually grades back to the original character of the water-bearing formation. The right diagram shows an artificial gravel packed well in which the correct relationship is established between the grain size of the gravel pack material and that of the formation sand, and between the size of the gravel pack material and the size of opening in the screening device.

Well Efficiency: The ratio of the actual specific capacity of the pumped well at the well design yield to the maximum specific capacity possible calculated from formation hydraulic characteristics and well geometry (producing capability of the aquifer from a 100% efficient well) at a particular time after pumping began. This is the same as the ratio of the theoretical drawdown that would be required to produce the design yield from a 100% efficient well to the actual drawdown measured in the pumped well producing at the design yield. Efficiency is usually expressed as a percent. The difference (drawdown increase) between the theoretical drawdown and actual drawdown represents the head loss required to force water through the intake portion of the well. Obviously, this head loss should be a minimum. Well efficiency should not be confused with pump efficiency because pump efficiency is a characteristic of the pump only and is completely independent of well efficiency. For example, the pump efficiency may be 85% while the well efficiency of a poorly designed and constructed well may be 45%.

Well Development: A variety of mechanical and chemical methods with the aim of correcting damage to the formation which occurs during the drilling operation and removing the finer material from the aquifer adjacent to the screen or gravel pack thereby cleaning, opening or enlarging passages in the water-bearing sand and gravel so that water can enter the well more freely.

Corrosion: Chemical action upon metals which results in the metal being "eaten away" or destruction of the material. Corrosion causes the size of the slot opening to enlarge and causes deterioration of the casing to the point that the well eventually begins to pump sand and gravel or collapse structurally.

Incrustation: Deposition of undesirable materials in and about the slot openings in the screening device and in the voids of the water-bearing formation or gravel pack in the vicinity of the well bore. This plugging causes the well to fall off in yield. Incrustation should not be confused with corrosion as they are different phenomena having opposite effects.

DISCUSSION OF PROBLEM AREAS

Major irrigation well design and construction problems can be grouped in the following three catagories: (1) sand pumping; (2) well inefficiency; (3) short well life. The order in which these are listed does not imply the degree of importance or frequency of occurrence. All are major problems and one or as many as all can affect a particular well at the same time.

SAND PUMPING

Modern design methods allow the production of sand-free ground water from high capacity irrigation wells. Irrigated agriculture is still plagued with the fallacy that maximum water production is impossible without pumping fine sand from the water-bearing formation. This idea has long been refuted by the designers of municipal and industrial wells and it is time the sand-free concept become an integral part of irrigation well design.

Sand pumping is a major problem because excessive abrasion of the pump bowls and impellers, distribution pipe, sprinkler heads and other irrigation system components reduces the useful life of the entire system and significantly increases maintenance costs. In addition, unnecessary costs result when sand must be periodically cleaned from the lines, sprinkler heads and in some cases even from the well and pump. Sand pumping can create large underground cavities which collapse and cause land subsidence in the vicinity of the well bore. This eventually can cause total collapse of the well casing and the screen.

In many irrigated areas sand pumping at a rate of 20 to 40 ppm or even more is common and considered satisfactory at times. It is the contention of the authors that this sand removal is entirely unsatisfactory and unnecessary. For example: An irrigation well producing 1,000 gpm with 20 ppm sand during the irrigation season in a semi-arid area requiring 2800 hours of irrigating would remove approximately 15 tons or approximately 9 cubic yards of fine sand from the water-bearing strata. The most economical and logical place to control sand is below land surface at the screening device or gravel pack. This can be achieved while maintaining maximum water production.

In naturally developed wells sand pumping is most often caused by selecting openings in the screen device that are too large to retain the proper amount of the water-bearing formation. Improper relationship between the grain size of the gravel pack material and the size of the aquifer sand grains is the major cause of sand pumping from gravel packed wells. Too often, a slot opening in the screening device for gravel packed wells is chosen first. A gravel pack size is then selected such that it will not pass through the openings in the screening device. This method gives no consideration to the size of the sand and gravel particles of the water-bearing formation. As a result, many times the gravel pack is much too large to properly retain the water-bearing sand and the well pumps sand. A sieve analysis of formation samples is the basis for proper gravel pack and slot opening selection. The design procedure should proceed from the aquifer to the screening device rather than from the screening device to the formation.

Some designers assume sand control can be achieved by installation of a thick gravel pack. They theorize the large diameter resulting from a thick gravel pack allows water to enter at the circumference of the gravel pack at a velocity so low that it is impossible for sand to be carried toward the well by the water. It is also theorized that an added advantage of a thick gravel pack consisting of coarse particles is maximum water production. Theoretically a thick gravel envelope does not materially increase the yield of the well and thickness, in itself, does little to reduce the possibility of sand pumping because the controlling factor is the ratio of the grain size of the gravel pack material to the aquifer material.

WELL INEFFICIENCY

Practical application of modern design methods has proven that irrigation well efficiency should be at least 80%. This efficiency, or even greater, can be attained by a relatively small additional capital expenditure at the time of construction and by the implementation of a relatively small number of design and construction procedures that can be easily carried out. Unfortunately, there are hundreds of irrigation wells in many areas having efficiencies as low as 35 to 50%. Ironically, a great deal of effort is generally directed toward proper selection of a highly efficient pump and power unit but yet little effort is directed toward maximizing well efficiency. For example, many vertical turbine pumps (used widely in irrigation wells) are carefully designed to achieve 85 to 90% efficiency whereas the well in which this pump is installed may only be 40% efficient. This is even more ironic when one considers that this peak efficiency of the pump is often reduced shortly after installation by the ills of air and sand pumping which are commonly associated with inefficient wells.

Efficiency is important because irrigation wells with poor efficiency result in high pumping costs due to excessive drawdown. Often this added operating cost through one pumping season can off-set the slightly greater initial cost required for the design and construction of an efficient irrigation well by modern methods. For example: Assume the example well discussed previously is 90% efficient when producing 1,000 gpm with 20 feet of drawdown. The specific capacity is then 50 gpm per foot. If this would be a 45% efficient well the specific capacity would only be 25 gpm per foot. The drawdown required to produce the 1,000 gpm would then be 40 feet rather than 20 feet. The cost of lifting the 1,000 gpm the extra 20 feet by electric power can be calculated by the following formula.

Extra Cost per Hour of Operation =

$$= \frac{\text{GPM X Additional Feet of Lift X .746 X Rate per KWHr.}}{\text{3960 X Overall Pump Efficiency X Motor Efficiency}}$$

Calculation of extra operating cost:

Pumping Rate	1,000 gpm
Additional Lift	20 feet
Overall Pump Efficiency	85% *
Motor Efficiency	90% *
Power Cost	2 cents per KWHr. *

* Assumed values known to be realistic. Variations from region to region are possible.

$$\text{Extra Cost} = \frac{1{,}000 \times 20 \times .746 \times .02}{3960 \times .85 \times .90} = \text{10 cents per hour}$$

Thus, the owner of an efficient well would save $280 (2800 hours of operation at a saving of 10 cents per hour) per pumping season. At the end of just four pumping seasons he would have saved more than $1,000!

Many times well inefficiency is related to the improper selection of the gravel pack size and size of slot openings in the screening device of the well. The most common error is that the ratio of the gravel pack particle size to the formation particle size is too large which allows migration of formation particles into the artificial gravel pack. As this migration proceeds for a period of time, successively smaller and smaller particles become lodged in the gravel pack and eventually the permeability is drastically reduced which makes movement of water to the well difficult.

Low efficiency is also related to the fact that agriculturalists tend to be attracted by lowest capital cost possible and therefore the screening device in irrigation wells is often a cheap, make-shift device. These include various types of perforated, punched, sawed or cut casing or pipe. All of these screening devices have some very serious limitations such as the following: (1) percent open area is low; (2) poor distribution of slot openings; (3) openings cannot be closely spaced while maintaining adequate strength; (4) openings are inaccurate and vary in size; (5) openings small enough to control fine sand or retain finely graded gravel packs (sand pack) are difficult or impossible to produce.

In reference to the first limitation, thousands of irrigation wells are completed with slotted or perforated pipe having 5% or often less of the total surface area as openings or passageways for water to enter the well. A few slotted screening devices provide as much as 10% open area but these are not widely used. Hand perforated or torch slotted casing provides exceptionally low open area (2 to 3%). Furthermore, the shape of the openings in punched or slotted pipe is such that the openings lend themselves to rapid plugging by sand particles. Due to these factors, the porosity of the formation is greater than the amount of open area provided by perforated or punched pipe thus flow into the well is restricted. Therefore, additional hydraulic head is required to force the water into the well which makes the well inefficient.

In reference to the second limitation, because perforated pipe contains only a small number of holes, only a small percentage of the water approaching the well has direct access into the well. This means that excessive convergence of flow occurs near the individual slot openings as shown in the left diagram of Figure 2. This is a common cause of well inefficiency. In some cases this has caused twice as much drawdown as there should have been. The right diagram of Figure 2 shows how this problem can be eliminated by a quality continuous slot well screen which provides good slot opening distribution. A well screen of this design allows radial and horizontal flow to the entire well screen.

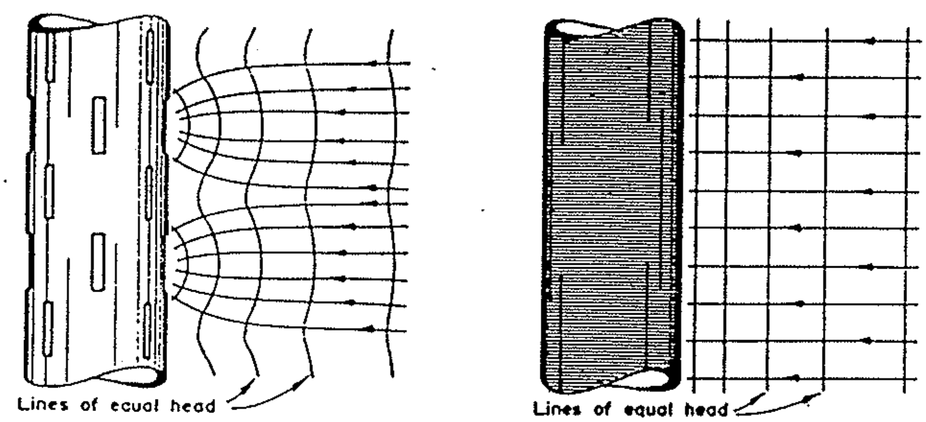

Figure 2. Flow nets around screening devices. Water approaches openings along lines indicated by arrows. Flow to slotted pipe converges to individual slots whereas flow to continuous slot well screen is not distorted.

The lack of irrigation well development upon completion of drilling is another factor causing well inefficiency. Traditionally designers, agriculturalists and well owners have refused to make the necessary capital outlays to thoroughly develop wells because they theorize development is of little value. Some suggest that simple over-pumping with a test pump is all the development that is necessary, but this simply isn't true. This absence of development prevents maximum utilization of many aquifers tapped by irrigation wells which robs irrigated agriculture of thousands of dollars each year. It is important to first properly design and construct the well with quality materials utilizing modern techniques but it is equally as important to follow through with thorough development.

SHORT WELL LIFE

Irrigation wells should be constructed for an expected useful life of at least 25 years. This is a realistic design expectation and under most conditions can be easily attained with small additional capital expenditure. Unfortunately, many poorly designed irrigation wells have a useful life of as little as 5 to 10 years and in some cases only 2 or 3 years. The cost of drilling two or perhaps even three wells during a 25-year period that would be necessary to replace the service of one properly designed and constructed well is much greater than the one-time construction cost of a good well capable of 25 years of service. In addition, maintenance costs are higher for poorly designed wells.

Early irrigation well failure is related to the improper selection of gravel pack and size of slot openings as discussed under the section entitled, "Sand Pumping". Complete collapse of a well is not uncommon because of excessive sand pumping. However, more well failures occur as a result of installing low quality screening devices such as perforated or slotted pipe. These devices provide little open area and poor distribution of the open area which causes the water to enter the well at excessively high velocities. It is known that as velocity increases the rate of corrosion and/or incrustation is accelerated at the screening device and within the formation or gravel pack near the borehole. Incrustation can cause premature decrease of yield while corrosion can cause early structural failure of the well.

In some irrigated areas the natural waters are either corrosive or incrusting even when the entrance velocity is minimal. Unfortunately, in these areas thin wall casing and other devices are often used with poor corrosion resistance to water or strong acids that are needed to remove the products of incrustation.

Perhaps the most common design error affecting well life is the placement of the screening device at elevations in the drilled hole too near the static water level. In fact, in some areas it is standard practice to set screening devices from the static water level to total depth. This excess screening device length serves little purpose because it is often placed opposite impermeable or low permeability materials. In many areas, 50 to 75% of the total screening device length could be eliminated while still maintaining adequate penetration of the good water-bearing sands and gravels that actually produce the water for maximum production.

Placing the screening device near the static water level also results in pumping water levels below the top of the perforated section. This allows cascading water which is water entering the well above the pumping level and free-falling to the pumping water surface. Cascading water seriously affects the life of an irrigation well because it accelerates corrosion and/or incrustation. In addition, cascading water causes air entrainment which results in the following: pumping of air, reduction in well yield and severe erosion of pump components. All of the preceding factors reduce the economic value of the irrigation well.

The importance of long well life is obvious. A reliable ground water supply for 25 years will allow the well owner to obtain more favorable financing from financial institutions that are concerned with quality and reliability of financed projects. This reduces the financial burden of the well owner because amortization can be extended to a more realistic time period. Short amortization periods have historically plagued irrigated agriculture thereby adding another restriction to the already unfavorable profit structure. If a system is designed for a 25-year life it would be feasible to obtain 25-year financing rather than 15-year financing which is the general practice at the present time.

DESIGN CRITERIA

PRELIMINARY INVESTIGATION

The preliminary investigation is the foundation upon which much of well design depends. Preliminary investigation involves one or as many as all of the following:

1. An examination of records from existing wells in the area should be made to determine yield, depth and characteristics of the aquifers presently being used.

2. Consultation should be made with the U. S. Geological Survey, the State Geological Survey or any other agency which may have geologic information about the area in question. Progressive, reputable local well drillers are also an important source of useful information.

3. If sufficient records are not available, planned test holes should be drilled to allow selection of the site with the best water production potential and to help formulate the production well design for the selected site. Agriculturalists often do little test hole drilling in the interest of economy but experience shows this is false economy. The information gained from test holes usually justifies the investment.

   In drilling test holes, samples of the aquifer should be collected so that sieve analyses and permeability tests can be made. If equipment is available, electric logging and gamma ray logging should be done when test holes are drilled. From the completed test hole, the well designer should determine aquifer thickness, aquifer depth, static water level of the aquifer and estimate the yield and specific capacity of a full-sized production well.

4. In some cases, geophysical prospecting such as electrical resistivity and seismic refraction may be helpful to the designer.

5. A water sample should be collected and analyzed to determine the corrosion and/or incrustation characteristics of the water.

DESIGN PROCEDURE

After the preliminary investigation and well site selection is complete, a well design can be selected which best utilizes the hydrogeological conditions present at the site. Successful well design is best accomplished by first developing the design of the cased portion of the well and then developing the design of the intake portion of the well. The design criteria presented here are primarily for screened wells in unconsolidated sand and gravel aquifers. In comparison to wells in rock formations, screened wells require consideration of more design details. The basic principles, however, apply to both types of wells.

Cased Portion

The cased portion of the well consists of the well casing which serves as a housing for the pump and as a vertical conduit through which water flows upward from the intake portion of the well to the level where it enters the pump. The cased portion of the well should:

1. Be of sufficient diameter to accommodate the pump. In selecting the size of the casing, the controlling factor is usually the size of the pump that is required for the potential yield of the well. Table 1 shows casing sizes recommended for various ranges in well yield (pumping rate).

Table 1 - Recommended Well Diameters

Anticipated Well Yield (gpm)	Nominal Size of Pump Bowls (inches)	Optimum Size of Well Casing (inches)	Smallest Size of Well Casing (inches)
150 to 400	6	10 ID	8 ID
350 to 650	8	12 ID	10 ID
600 to 900	10	14 OD	12 ID
850 to 1300	12	16 OD	14 OD
1200 to 1800	14	20 OD	16 OD
1600 to 3000	16	24 OD	20 OD

2. Be of sufficient diameter to allow the ascending water to move at a velocity of 5.0 feet per second or less up the well casing. For the pipe sizes and pumping rates shown in Table 1, the head loss due to vertical movement of water is minimal.

3. Be of sufficient strength to withstand the column and collapse loads of installation. These requirements are usually best satisfied by new mild steel pipe specified by the ASTM number, design wall thickness and pounds per foot.

4. Be of sufficient wall thickness to resist rapid deterioration and failure. Data from the preliminary investigation and chemical analysis of water samples should be reviewed to determine if the water tends to be corrosive or incrusting. When necessary, extra heavy mild steel casing should be installed and in severe cases stainless steel or fiberglass casing should be used. It is false economy to over-design a well for conditions at a particular site just as it is to under-design by using low quality materials. For example, fiberglass casing has been used in areas where ground water is known not to be corrosive or incrusting and where the useful life of mild steel casing has proven to be in excess

of 25 years. For these conditions, the added cost of fiberglass casing is not justified. Instead, it is wise to direct this money toward improving the quality of other well components such as the well screen or gravel pack.

Intake Portion or Screening Device

The intake portion of the well has been called the "business end" and this component is the most important consideration of well design. This is where ground water irrigation "all begins" because this is where water enters the well from the aquifer. Thus, careful consideration must be given to the hydraulic factors that influence the efficiency of the screening device. It has already been demonstrated how short-sighted design in this part of the well structure results in sand pumping, inefficiency and short well life. These problems can be minimized if careful design consideration is given to the following:

A. Type of Screening Device

The screening device should be a commercially manufactured quality well screen. To accomplish its intended purposes, the well screen must be of efficient design. A well screen is adequate only when it is capable of letting sand-free water flow into the well in ample quantity and with minimum hydraulic head loss.

The desirable features of a properly designed well screen are: (1) close spacing of slot openings to provide uniform open area distribution; (2) maximum open area; (3) V-shaped slot openings that widen inwardly; (4) adaptability to different ground water environments by the use of various metals; (5) ample strength to resist the forces to which the screen may be subjected during and after installation.

The most effective product satisfying these requirements is the welded, wire wound continuous slot screen. These screens are manufactured by welding cold-drawn triangular shaped wrapping wire spirally around longitudinal rods. By welding the triangular shaped wrapping wire with its apex on the longitudinal rods, a continuous opening is provided which enlarges inwardly. This tapered aperture provides hydraulic efficiency and has unique self-cleaning properties. Sand grains smaller than the aperture are easily brought into the well in the development process, while large grains are retained outside.

Commercial well screens and their advantageous design features are sometimes ignored. In their place, make-shift substitutes such as perforated or punched pipe are employed. The inadequacies of the make-shift substitutes have been discussed previously.

Because of the problems associated with perforated pipe and the other make-shift screen substitutes some manufacturers have developed a low cost premium well screen specifically designed for gravel packed irrigation wells. This specially designed irrigation screen combines many of the above desirable features with economy.

B. Screen Length

The optimum length of well screen is chosen with relation to the thickness of the aquifer, available drawdown and stratification of the aquifer.

In an artesian aquifer, 70 to 80% of the thickness of the water-bearing sand should be screened, assuming the pumping level is not expected to be below the top of the aquifer. It is generally not advisable to screen the entire thickness of artesian aquifers. For example, about 90% of the maximum specific capacity can be obtained by screening only 75% of an artesian aquifer. An exception to this rule should be made when the aquifer is highly stratified and interbedded with low permeability layers. In this case more of the aquifer should be screened.

Optimum design practice dictates that the maximum available drawdown in an artesian well should be the distance from the static water level to the top of the aquifer. If it is necessary to lower the pumping level below the top of the aquifer in the interest of greater yield, the screen length should be shortened and the screen should be set in the bottom of the aquifer. All attempts should be made to design and construct the well so that the pumping level stays above the top of the uppermost well screen.

For water-table wells, selection of screen length is something of a compromise between two factors. High specific capacity is obtained by using as long a screen as possible. On the other hand, more available drawdown results from using as short a screen as possible. These two conflicting aims are satisfied, in part, by using an efficient well screen.

In a water-table aquifer, screening the bottom 1/3 to 1/2 of the aquifer provides the optimum design because maximum yield is obtained. For example, if the lower 1/3 of a water-table aquifer is screened and the pumping level is lowered to the top of the screen, the well will theoretically produce 88% of maximum yield. If the drawdown were increased to 95% of the possible, almost to the bottom of the screen, the well yield would theoretically increase to 99% of its maximum. This represents only an 11% increase in yield for almost an additional 32% more drawdown!

Available drawdown in a water-table well is the distance between the static water level and the top of the screen. The pumping water level should be maintained at or above the top of the well screen. The screen should be positioned in the lower portion or bottom of the aquifer, since the upper part of the aquifer is necessarily dewatered to cause water to move into the well.

Screen length is an important design consideration because a screen that is too short seriously affects the efficiency of the well whereas a well screen that is too long causes problems such as cascading water, entrained air and accelerated corrosion and/or incrustation.

C. <u>Gravel Pack</u>

In the gravel packed well the zone immediately surrounding the well screen is made more permeable by removing the formation material and replacing it with artificially graded coarser material. The size of this artificially graded gravel is chosen so that it will retain essentially all the formation particles. The well screen slot opening size is then selected to retain the gravel pack.

Gravel packed wells are particularly well suited to some geologic environments but gravel packing is not a cure-all for every sand condition, as many people believe. The following conditions tend to favor gravel pack construction: (1) where fine sand constitutes the aquifer; (2) in thick artesian aquifers; (3) in loosely cemented sandstone formations; (4) in extensively laminated formations consisting of alternating layers of fine and coarse sediments or thin silt and clay layers.

Modern gravel pack design includes specification of gradation, thickness and quality of the gravel pack material. The following are logical steps in designing an artificial gravel pack:

1. All samples collected during the test hole drilling representing that part of the borehole that may <u>possibly</u> be screened should be examined. It is good design practice to completely disregard the most unfavorable strata of the aquifer, such as the finest sands. Plain casing should be set opposite these intervals. This means it may be necessary to space plain casing between screen sections which are positioned in the best strata of the aquifer. One advantage of placing blank casing opposite strata composed of the finest sands and low permeability intervals is that a coarser gravel pack can be utilized. The coarser pack will allow the coarser strata of the water-bearing formation to yield maximum water. It is likely little potential yield is lost by setting blank casing opposite the finest sands and other low permeability strata because these unfavorable intervals generally produce little water.

2. After the intervals where plain casing will be set have

been selected, the samples representing these can be set aside. It is not necessary to analyze these samples further. A sieve analysis graph representing the gradation of all remaining samples from the strata comprising the aquifer where the screen will be set should be prepared. This graph is prepared by plotting cumulative percent retained versus sand particle size such as shown in Figure 3. The sieve analysis graph representing the finest stratum of those tested should be selected and the grading of the gravel pack should be designed on the basis of this graph.

3. To begin the gravel pack gradation design, the 70% retained size of the selected graph should be multiplied by a factor ranging between 4 and 8. This product represents the 70% retained size of the proper gravel pack gradation to retain the formation particles. A multiplier of 4 should be used if the formation is fine and uniform whereas 8 should be used if the aquifer is coarser and non-uniform. A factor as high as 10 may be used if the formation sand and gravel is highly non-uniform and contains silt, as commonly occurs in portions of the western United States and in other semi-arid or arid areas of the world. The calculated 70% size determines the first point on the sieve analysis curve representing the artificial gravel pack material. Figure 3 shows an example of this procedure using a multiplier of 5. Note the design was made on the basis of the finest formation material to be screened (75-90 feet).

4. A smooth curve representing material with a uniformity coefficient (40% retained size divided by 90% retained size) of 2.5 or less should be drawn through the initial point on the gravel pack curve. This must be done by trial and error. Figure 3 shows the grading of two water-bearing formation samples determined by mechanical analysis and constructed gravel pack curves. The gravel pack curve drawn as a solid line has a uniformity coefficient of about 1.75. A line could have been drawn somewhat differently, as shown by the dashed line, which has a uniformity coefficient of 2.47. It is best to design the gravel pack as uniform (low uniformity coefficient) as practical because a more uniform gravel pack has significantly greater permeability and is easier to install without segregation. The material indicated by the solid line curve is more desirable than the material indicated by the dashed line curve because the former is more uniform.

5. The gradation of the gravel pack actually installed should approximate the designed gravel pack gradation. Because gravel pack design is not precise and is based on empirical considerations, a permissible range of 8 percentage points larger and smaller than the percent retained at any point on

the design curve can be allowed. This range also permits practical approximation of the designed pack in the field. The tabulation in Figure 3 shows the permissible range for various points on the example curve.

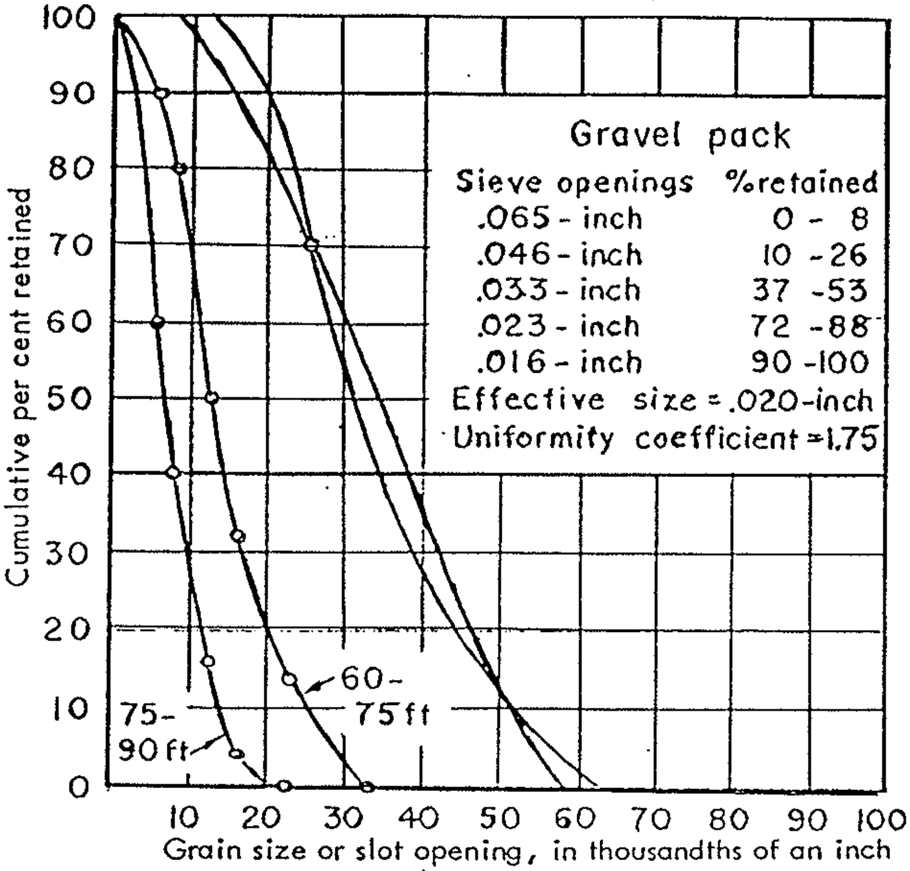

Figure 3. Sieve analysis curves for aquifer sands and corresponding curve for properly selected gravel pack material.

6. The gravel pack material should be as uniform in gradation as possible, clean and consist of well rounded grains that are smooth. These characteristics increase the permeability and porosity of the pack material. In addition, the particles should consist of mostly siliceous, rather than calcareous material. Five percent calcareous material is a practical allowable limit.

7. Laboratory tests show that a gravel pack with a thickness of only a fraction of an inch successfully retains formation particles regardless of how high the water velocity is tending to carry the particles through the gravel pack. However, it is recognized that it is impossible to place in a well a proper gravel pack only a fraction of an inch thick. Therefore, to insure that an envelope of gravel will surround the entire screen, a thickness of 3 inches is considered the practical minimum for field installation. The

upper limit of gravel pack thickness should be 8 inches. When more than 8 inches of gravel pack is provided, development of the aquifer is hampered. A thicker envelope does not materially increase the yield of the well and does little to control sand pumping because the controlling factor is the ratio of the grain size of the pack material to the formation material.

To insure that the envelope of gravel completely surrounds the entire screen, centering guides should be used to center the string of casing and screen in the borehole. Furthermore, the pack material should be placed continuously but slowly to avoid bridging and sorting of the particles. If the screen is not centered in the borehole and is in direct contact with the formation material (no gravel pack between the well screen and formation) sand pumping results.

In summary, if the well designer follows all of the foregoing steps carefully, sand pumping wells can be avoided.

D. Screen Slot Openings

In a gravel packed well, the size of the screen slot opening is selected to retain 90% or more of the gravel pack material. In the example of Figure 3, the correct size of slot opening is 0.020-inch. The retention of water-bearing formation is accomplished by the proper selection of the gravel pack and the well screen retains the gravel pack particles.

For naturally developed wells, the size or sizes of well screen slot openings depend on the gradation of the sand and are selected from a study of sieve analysis data of samples representing the water-bearing formation. A sand analysis curve, such as shown in Figure 4, is plotted for each sand sample. The size of the screen opening is selected such that the screen will retain from 40 to 50% of the sand. Or, stated in another way, 50 to 60% of the formation sand particles will pass through the openings in the screen during development. If the formation is non-homogeneous it may be necessary to select various sizes of slot openings for different sections of the well screen. The use of a multiple-slot screen to custom fit the gradation of each stratum will assist in attaining the highest specific capacity possible and will greatly reduce the possibility of pumping sand with the water.

The 40% size is usually chosen when the ground water is not particularly corrosive and when there is little doubt as to the reliability of the formation samples. The 50% size is chosen if the water is corrosive or if the reliability of the sample is in question. If the water is corrosive, enlargement of the openings of only a few thousandths of an inch due to corrosion could cause the well to pump sand. If the water is incrusting a 30% retained size may be selected. When this larger slot opening is selected, longer well life can be expected before plugging reduces the well yield.

Large slot size also makes it possible to develop a larger area of the formation surrounding the screen. This generally increases the specific capacity of the well by making the well more efficient.

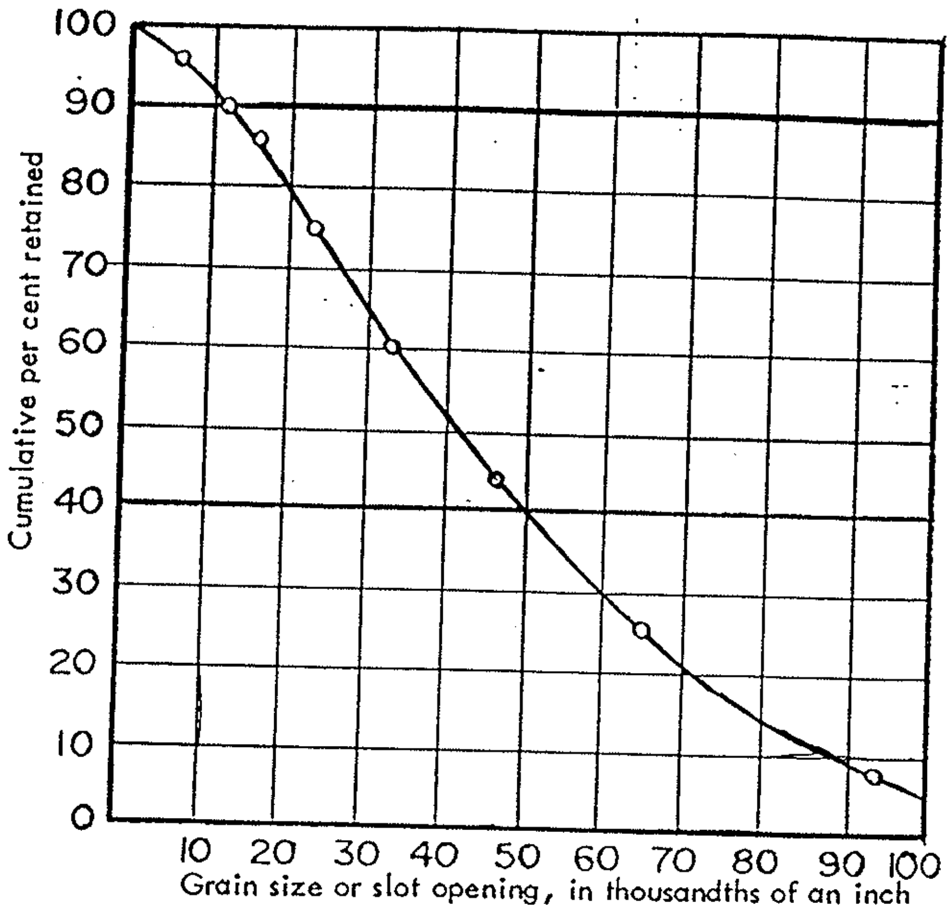

Figure 4. Sieve analysis graph showing gradation of a sample representing a water-bearing formation. In a naturally developed well, a No. 50 (0.050-inch) slot opening would be selected for a well screen.

E. Screen Diameter

Screen diameter can be varied after the length of the screen and size of the screen openings have been selected. Screen diameter is selected to provide enough total area of screen openings so that the average entrance velocity of the water through the slot openings does not exceed the design standard of 0.1 feet per second. A quality well screen with maximum open area offers a decided cost advantage when different types of screening devices are compared at this entrance velocity.

The entrance velocity is calculated by dividing the expected or desired yield of the well by the total area of openings in the screen. If the velocity is greater than 0.1 feet per second, the diameter should be increased. If the calculated entrance velocity is less than 0.1 feet per second, the screen diameter may be reduced somewhat. However, the screen diameter should not be reduced to the point that the velocity of vertical water flow to the pump exceeds 5.0 feet per second. This was discussed earlier in relation to ascending velocity in the casing.

Laboratory tests and field experience show that if the screen entrance velocity is equal to or less than 0.1 feet per second, (1) the friction loss through the screen openings is negligible, resulting in a higher well efficiency; (2) the rate of incrustation will be a minimum; (3) the rate of corrosion will be a minimum. Minimum corrosion and incrustation are both important to long well life.

One important consideration that must be kept in mind when selecting the screen diameter is that the diameter can be varied without greatly affecting the well yield. Doubling the diameter of the well screen can be expected to increase the well yield only about 10%. This fact has been demonstrated by field experience and can be shown theoretically by basic ground water hydraulics relationships.

F. Open Area

The percent open area of the screen should be equal to or greater than the porosity of the sand and gravel water-bearing formation and the artificial gravel pack supported by the screen. Where the irrigation well screening device provides only 2 to 5% open area as in perforated pipe, flow restrictions are unavoidable. This is one of the most common reasons for typically low efficiencies of irrigation wells. Suppose that the water-bearing sand has 30% voids or porosity, and the screening device installed has only 5% open area. This constriction of flow causes unnecessary drawdown because additional head loss occurs in the movement of water toward and into the well.

Secondly, adequate open area should be provided by the well screen to allow the desired or design yield to enter the well at an entrance velocity through the screen openings of 0.1 feet per second. This hydraulic characteristic of the screen is known as transmitting capacity. If the amount of open area of a screen is known and the recommended entrance velocity of 0.1 feet per second is used, the transmitting capacity of that screen can be readily calculated. For example, a 16" diameter quality well screen of continuous slot construction with 175 square inches (1.22 square feet) of open area per lineal foot of screen can transmit 55 gpm per foot of screen body at an entrance velocity of 0.1 feet per second. The calculated transmitting capacity of a screen is a hydraulic characteristic of that screen and not a measure of the yielding capability of the water-bearing formation in which the screen is installed. A quality well screen which provides maximum open area is usually necessary to furnish sufficient transmitting capacity to meet this important requirement.

G. Screen Material

The well screen should be fabricated of materials that are as corrosion resistant as necessary, as determined from analysis of data collected during the preliminary investigation. If the screen corrodes, sand and/or gravel enters the well. Thus, the screen must be replaced or often a new well must be drilled.

Corrosion of screens can occur from bi-metallic corrosion if two metals have been used in the fabrication and therefore this type of bi-metallic screen should always be avoided. Water with high total dissolved solids accelerates this type of corrosion because the water is a more effective electrolyte. Corrosion can also occur from dissolved gases in the water such as oxygen, carbon dioxide and hydrogen sulfide.

Irrigation wells are also commonly troubled with plugging by the deposits of incrustation. Such deposits plug the screen openings and the formation and/or gravel pack immediately surrounding the well screen. When incrustation is a problem, acid treatments must be anticipated. Therefore, corrosion resistant material should always be employed to resist the attack of strong acids introduced into the well screen during treatment.

It is not commonly understood that corrosion and incrustation can occur simultaneously in some ground water environments. The products of corrosion can re-locate themselves on the screen and form incrustation which plugs the screen openings much like waters which are naturally incrusting. Removal of those deposits also often requires strong acids.

Choice of the well screen material sometimes is based on strength requirements. The two loads imposed on the screen which should be considered are column load and collapse pressure. When a long screen supports a considerable weight of pipe, it functions as a slender column. Where earth pressure and caving materials squeeze the screen, it must have good collapse resistance. It is impossible to accurately determine or calculate earth pressures with depth but generally greater strength is needed at greater depths. The rugged construction of an all-welded, continuous slot well screen meets these strength requirements adequately for all irrigation well applications.

Well development includes those steps in completion of a well that aim to clean, open and enlarge passages in the formation near the borehole so that water can enter the well more freely. Three beneficial results of development are: (1) correction of any damage or clogging of the water-bearing formation which occurs as a result of the drilling operation; (2) increase in porosity and permeability of the natural formation in the vicinity of the well; (3) stabilization of the sand formation around the screen or artificial gravel pack so that the well will yield sand-free water. All these benefits can be obtained for wells in unconsolidated aquifers if the wells are properly screened and development procedures are properly applied.

The key to successful development is to cause vigorous reversals of water flow through the screen openings that will re-arrange the formation particles. This action, provided that adequate energy is applied to the formation, breaks down bridging of groups of fine sand particles. Better results can be obtained if development begins slowly and increases in vigor with time and when the well is pumped during the development procedure. When the development method makes simultaneous pumping impractical, the well should be at least pump occasionally. At times, it may be wise to incorporate chemical development with the mechanical methods. This is particularly true when silt and clay plugging of the formation is suspected.

The design of the well screen is one of the most important factors controlling success of the development procedure. The screen must provide maximum open area and even distribution of that open area to allow maximum energy to be applied to the aquifer. The continuous slot well screen best meets these requirements. The left diagram of Figure 5 shows how a continuous slot screen permits maximum access of the water-bearing formation to the development energy. If a screening device with a very small amount of open area is used as shown in Figure 5 (right diagram), much of the aquifer remains un-touched by the development procedure because energy can only affect that portion of the aquifer directly opposite the few widely spaced openings.

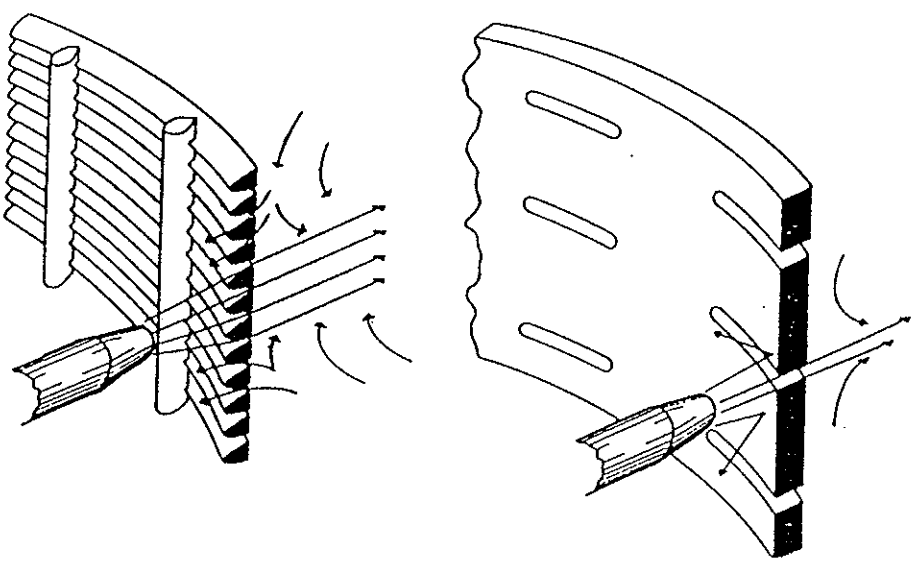

Figure 5. High-velocity jet working through the openings of a continuous slot well screen produces vigorous agitation of formation surrounding the screen. Development is much less effective when a well is completed with slotted pipe where open area is only about 5%, since jet impinges on metal surface 95% of the time. The comparison shown is applicable to all development methods.

No one particular development procedure is the best method for all geologic formations or types of well construction. Some methods are more adaptable to the particular type of drilling equipment used to construct the well but other factors such as availability of water, air compressor or pump may also dictate which development procedure is the most practical to use. The selection of the best method should be made on evaluation of the hydrogeologic conditions at the well site and past experience with similar irrigation wells in the same geologic formation. Once a method has been selected the designer should specify the details of the procedure.

It is beyond the scope of this paper to thoroughly discuss the details of each common development method along with its advantages and disadvantages. However, the following is a list of the most common techniques in use. They are not listed in any order of importance or effectiveness. These are: (1) Surging with compressed air. This method conveniently allows pumping from the well while development is in progress; (2) Mechanical surging by operation of a plunger in the casing like a piston in a cylinder. This procedure is particularly adaptable with the use of cable tool drilling equipment; (3) Mechanical surging with the use of a bailer. This method is adaptable to both cable tool and rotary drilling; (4) Back flushing the well with the use of a test pump. Starting and stopping of a pump to produce such action is often called "rawhiding" the well. This is the simplest method of development but is usually the least effective. The surging effect created is simply not vigorous enough to obtain maximum results; (5) High velocity horizontal jetting with water. This is the most effective method of well development in most cases and is especially useful for development of gravel packed wells.

Well development methods are always needed and are generally economical regardless of the type of drilling methods used to construct the well. Proper development will improve almost any well. Some persons claim that development work is unnecessary when a well is artificially gravel packed but experience has shown that development of these wells is important. Well development is not expensive in terms of the results in the form of high efficiency and lower operating costs.

Following completion of development the well should be test pumped. This test, however, should consist of more than simply finding our "what she'll do" or simply pumping the well at a number of different production rates for a short period of time and measuring the drawdown at these rates. The varying pumping rate test can be conducted but in addition, the well should be pumped for a long period of time (at least 12 hours) at a constant pumping rate during which time-drawdown measurements are taken within the pumped well and any nearby observation wells, if available. It is best to conduct the constant rate test first so that the drawdown measurements will not be influenced by any prior pumping which occurred as part of the varying rate test.

The primary objectives of the pumping test are to obtain information about the performance and efficiency of the well plus collect data which are used to select the permanent pumping equipment to insure maximum pump efficiency. The information is used to evaluate the success of the design and development procedures and provides the basis to make other performance judgements and evaluations. In some cases, this information indicates that further development is necessary.

The second objective of well testing is to obtain data from which the hydraulic characteristics of the aquifer can be evaluated. This is more aptly called an "aquifer test" that requires a more sophisticated technique than suggested above.

Field experience has proven that recovery data collected at the end of a pumping test are also extremely beneficial in evaluating performance of irrigation wells. Recovery data indicate the rate at which the water level in the pumped well and/or observation well recovers after the pump is stopped. This data can also be used to make calculations of the aquifer hydraulic characteristics. The recovery method is not widely known or used in the irrigation well industry which is unfortunate because this data can be easily obtained at low cost.

CONCLUSIONS

The design criteria presented should be a standard because they are the basis for the construction of sand-free, efficient irrigation wells that provide many years of trouble-free service. It should not be misconstrued that the design criteria are sophisticated suggestions for use in municipal and industrial well design only, with no application in irrigated agriculture.

The initial cost of the suggested procedures and quality materials is greater than traditional completion methods but is the best investment the irrigation farmer can make. The construction, operation and maintenance costs of an efficient, sand-free irrigation well amortized over a 25-year period will be the cheapest well possible. The long-term economics of modern irrigation well design is in the interest of adding much needed profits to agriculture.

REFERENCES

Ground Water and Wells, Johnson Division, Universal Oil Products, 315 North Pierce Street, St. Paul, Minnesota 55104.

Irrigation Principles and Practices, Israelsen and Hansen. John Wiley & Sons, New York.

Study and Interpretation of the Chemical Characteristics of Natural Water, U. S. Geological Survey Water Supply Paper No. 1473, U. S. Government Printing Office, Washington, D. C.

Sprinkler Irrigation, Third Edition, 1969, Sprinkler Irrigation Association.

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PAPER NO. 85-5054

HUMAN-POWERED PUMP FOR LOW-LIFT IRRIGATION

by

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MAF-IRRI Industrial Extension Program for
Small-Farm Equipment
Philippines

For presentation at the 1985 Summer Meeting
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

Michigan State University, East Lansing
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SUMMARY:

A foot-operated pump developed by RDRS/Bangladesh has been adapted to the Philippines for irrigation of vegetables and other crops grown in rice fields during the dry season. This report describes the features of the pump and the initial extension efforts.

American Society of Agricultural Engineers

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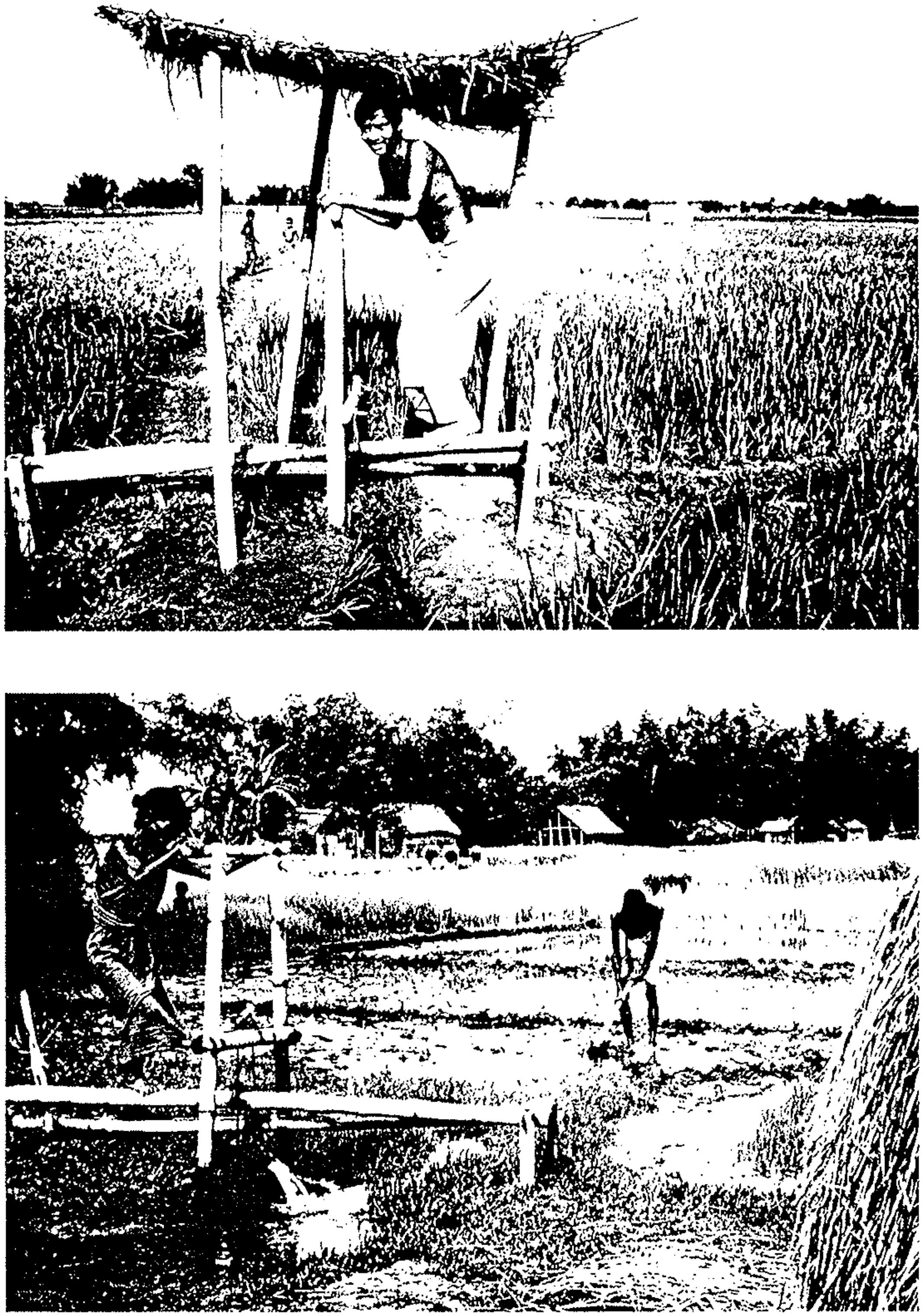

Figure 1. Installations of T-T pumps on shallow tubewells in Bangladesh. (Photo of RDRS/Bangladesh).

INTRODUCTION

Water is a major constraint to food production in developing countries, particularly among the majority of the poorest farmers who have to rely on rainfall due to the lack of all-year irrigation systems. Consequently, there are continuing efforts to develop low-cost irrigation technologies which would enable farmers to grow additional crops during the dry season, while also providing supplemental irrigation in the wet season at times when rainfall is insufficient.

As a result of an intensive effort to find a suitable irrigation technology for small farms in northern Bangladesh, the Rangpur Dinajpur Rehabilitation Service (RDRS)* developed the twin treadle pump ("T-T pump") shown in Fig. 1. The outstanding features of the pump are its low cost (US $10) and ease of fabrication, operation, and repair. Over 20,000 units of the T-T pump were manufactured and installed in northern Bangladesh during 1981-84. (RDRS, 1984.)

This paper describes the adaptation and initial promotion of the T-T pump in the Philippines by the MAF-IRRI Industrial Extension Program for Small Farm Equipment.** In the Philippines the pump has been given the name "Tapak-Tapak" ("step-step") pump because it is powered by the

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**The MAF-IRRI Program is a collaborative effort of the Ministry of Agriculture and Food (MAF) of the Philippines and the International Rice Research Institute (IRRI). See Stickney, Gonzalo, and Bockhop, 1983.

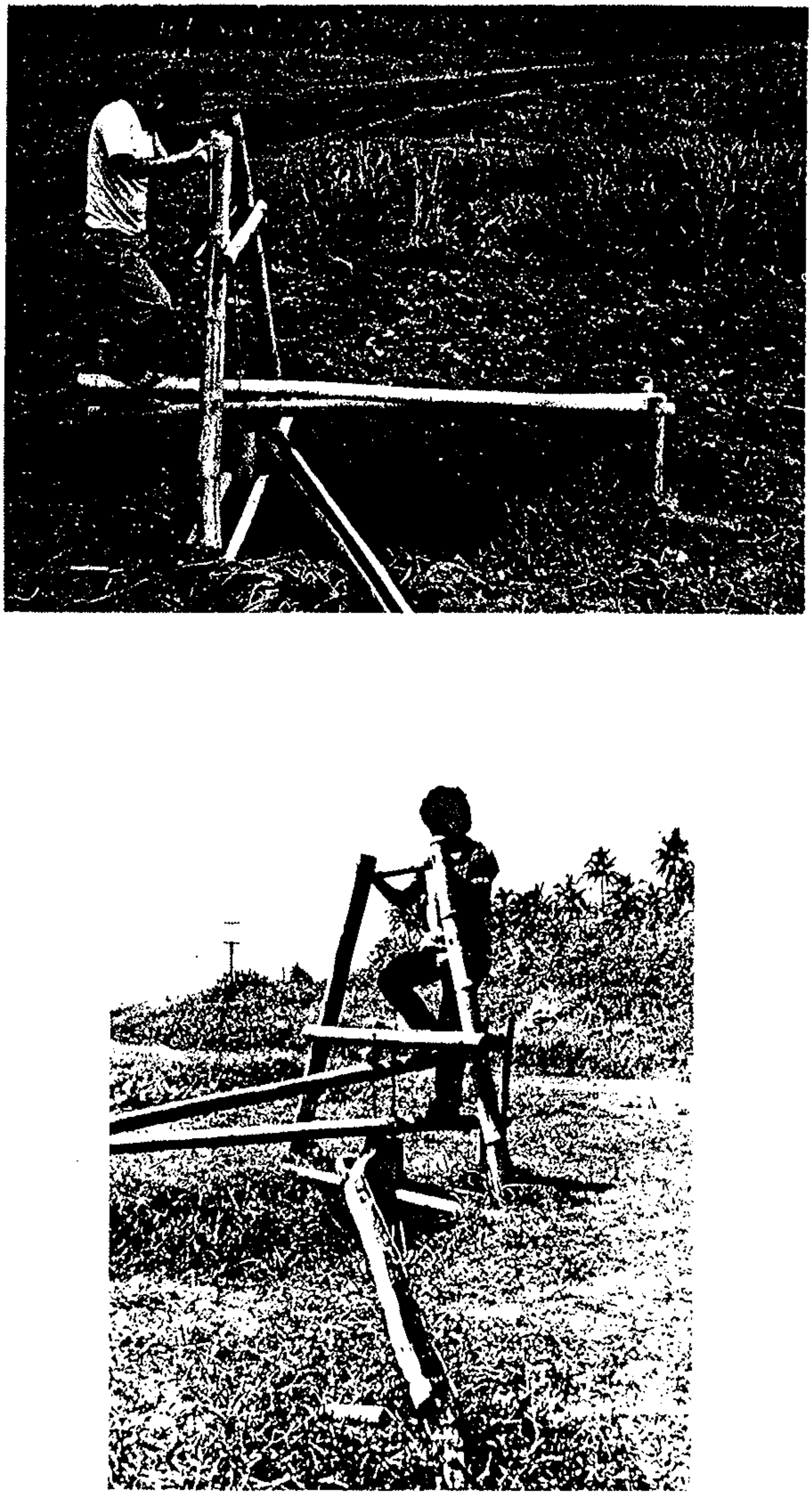


Figure 2. Installations of T-T pumps in the Philippines.

stepping action of the operator's feet. (Figure 2.) The principal features of the pump are:

EASY TO OPERATE: Uses the body weight and leg muscles, and therefore is less tiring than conventional pumps which use arm and back muscles.

LOW COST: About US $20 for the (pump alone (excluding the metal or bamboo framework and the cost of digging or drilling the well).

SIMPLE CONSTRUCTION: Can be fabricated from locally available materials using common shop tools, thereby reducing cost and simplifying maintenance and repair.

ADAPTABLE: Can be portable or stationary; suitable for shallow tubewells, open-pit wells, canals, lakes, and rivers; no priming required for depths as great as 4 meters.

HIGH CAPACITY: Due to the effective use of the body weight and the twin pump cylinders, the capacity is higher than for most manual pumps. Approximate capacities are:

3 liters/second (48 gallons/minute) for a 2-meter lift.

2 liters/second (32 gallons/minute) for a 4-meter lift.

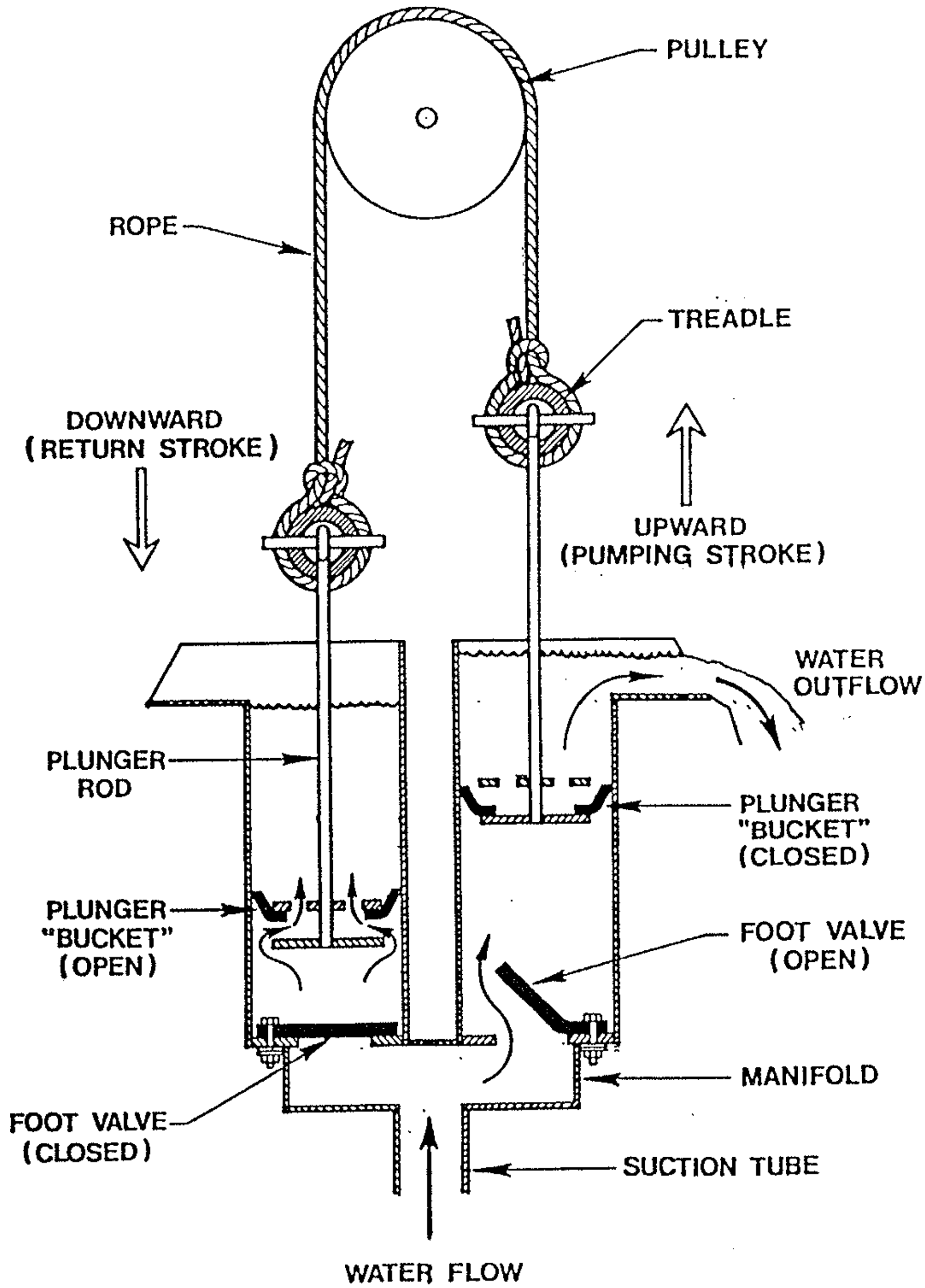


FIG. 3. SCHEMATIC OF T-T PUMP COMPONENTS AND OPERATION.

DESCRIPTION OF PUMP

The components and operation of the pump may be explained by referring to the schematic sketch in Fig. 3. The suction tube at the bottom of the pump is connected to the water source, which may be a tube well or an open-water source, such as an open-pit well, stream, or pond. The pump "sucks" water up the suction tube and into a manifold that is connected to the two pump cylinders. Each cylinder is equipped with a footvalve that prevents the back-flow of water from the cylinder to the suction tube during the return stroke of the pump. The footvalve is a simple rubber flap made from a used innertube of a truck tire.

The main reason for having two cylinders is that pumping will be smoother than the highly pulsating flow of a single-cylinder pump. Since frictional and inertial losses are reduced by smoothing out the pulsating flow, the work required to pump a given amount of water is lower for a two-cylinder pump than for an equivalent single-cylinder unit.

The pump plunger consists of two round disks fastened to a rod, plus a molded rubber cup or "bucket". The upper disk has holes that allow water to pass through the plunger during the downward return-stroke when, as illustrated in Fig. 3, the bucket moves off the lower disk and provides a water passage. On the upward pumping stroke, the bucket is pressed against both the lower disk and the cylinder wall, thereby providing a seal that prevents water from passing by the piston and creates a partial vacuum that sucks water into the cylinder from the manifold and suction tube. In this way, the bucket serves both as a flow valve and as the conventional seal against the cylinder wall.

The plunger assembly is easy to fabricate with simple tools, and it utilizes the buckets of standard domestic water handpumps which are widely used in developing countries. In the Philippines, buckets for 100mm (4 inch) pumps are readily available throughout the country at approximately US $0.25 per piece.

The plunger rods are connected to the treadles (generally bamboo poles) by means of a hinged joint (see Fig. 4). The two treadles are connected together by a rope which passes over a pulley (Fig. 3). This simple arrangement has an important function: when one treadle is forced downwards, the rope pulls the other treadle upwards, causing the attached plunger to move upwards and thereby pump water from the cylinder. Since a larger force is required to move a plunger upwards (pumping stroke) than downwards (return stroke), the rope is always under tension and therefore acts as if it were a rigid linkage between the two plungers. (Note: several existing designs of two-cylinder pumps

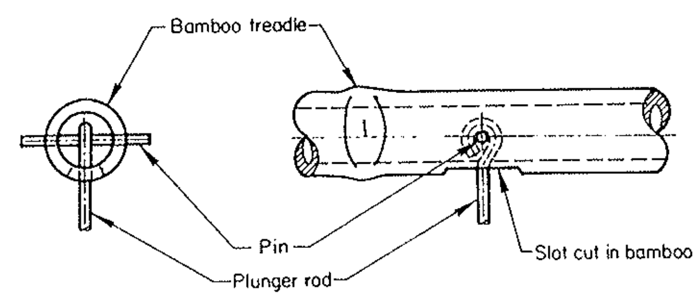


Figure 4. Hinged connection of plunger rod to bamboo treadle.

have rigid linkages which are more expensive and more difficult to fabricate than the rope and pulley arrangement.)

By placing the pivot point of the treadles at a considerable distance (about 1 meter) from the pump cylinders, the motion of the plunger will not deviate significantly from the centerline of the cylinder, thereby avoiding problems of poor sealing and rapid wear of the bucket. The length of the treadle is sufficient to enable the operator to vary the position of his feet to achieve comfortable and efficient operation. A hand rail is provided to allow the operator to balance himself (Figs. 1 and 2).

FABRICATION

Pump cylinders are generally made from standard sizes of pipe or tubes, or from cast iron. Since these pipes, tubes, and castings are rather expensive and/or of limited availability in rural areas of developing countries, RDRS decided to fabricate the pump cylinders from readily available sheet metal (gage 16), using a conventional sheet metal roller. The seam of the round cylinder is welded by means of an oxy-acetylene torch. The seam is then hammered to smoothen the weld, and the cylinder is re-rolled to ensure that it will be sufficiently round. Our experience shows that this technique can easily be utilized by small shops to produce satisfactory cylinders at very low cost using available tools and materials. The second advantage of the technique is that it enables manufacturers to produce cylinders having the most appropriate diameter with regard to local conditions in terms of lift, body weight, and available size of plunger buckets.

The manifold, suction tube, and plunger components are all fabricated from metal sheet, plate, and bars which are commonly available throughout the Philippines. Fabrication requires cutting and welding equipment that are available in most small-scale metalcraft shops. A lathe machine is not necessary but does facilitate cutting the round disks for the plunger and the cylinder bottom plates.

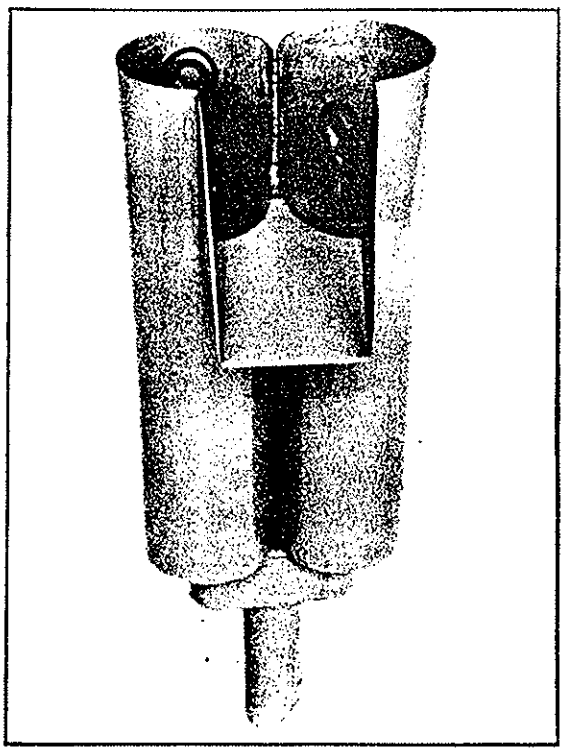
The pulley (see Fig. 3) is made from hardwood, and most of our manufacturers obtain these pulleys by contracting the services of a nearby carpentry shop having a woodworking lathe. The pump framework may be fabricated either from wood or metal bars, depending upon local preference, cost, and availability.

RDRS published a simple manual for interested manufacturers to help them learn to fabricate the pump. They found that the manual is more appropriate than engineering drawings because metalcraft workers in north Bangladesh seldom know how to read and interpret technical drawings. In the Philippines we have found that simplified engineering drawings are generally understood by metalcraft workers, and we have therefore prepared such drawings and provided sets to interested cooperating manufacturers of the MAF-IRRI Program. These drawings include full-size patterns for most of the pump components. Copies of the drawings may be obtained from the International Rice Research Institute, P.O. Box 933, Manila, Philippines.

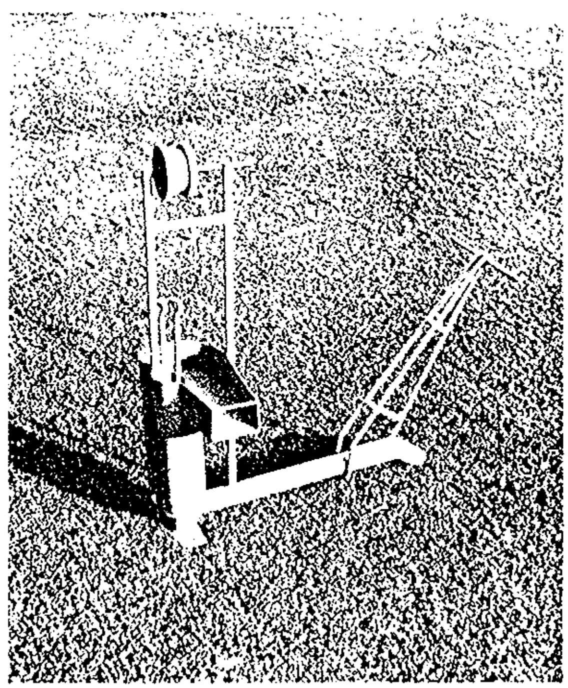
The MAF-IRRI Program provides technical assistance to cooperating manufacturers who intend to fabricate the tapak-tapak pump. This assistance includes loaning a pump to the manufacturers because this simplifies understanding the engineering drawing, thereby facilitating fabrication of the first unit.

DESIGN VARIATIONS

The basic pump design has been modified to suit different types of water sources, irrigation applications, and farmer preferences with respect to materials and operation. In north Bangladesh, the most popular design is the tubewell pump similar to that shown in Fig. 5a but often without a spout. We have found that farmers in the Philippines generally prefer to have a spout on the pump to facilitate filling buckets which are then carried to the field to apply water to individual vegetable plants. Since shallow tubewells are less common than open wells in many areas of the Philippines, our initial experience is that the open well design shown in Fig. 5b appears to be the most appropriate



a. Tubewell model



b. Open-well model

Figure 5. Tubewell and open-well models of the T-T pump.

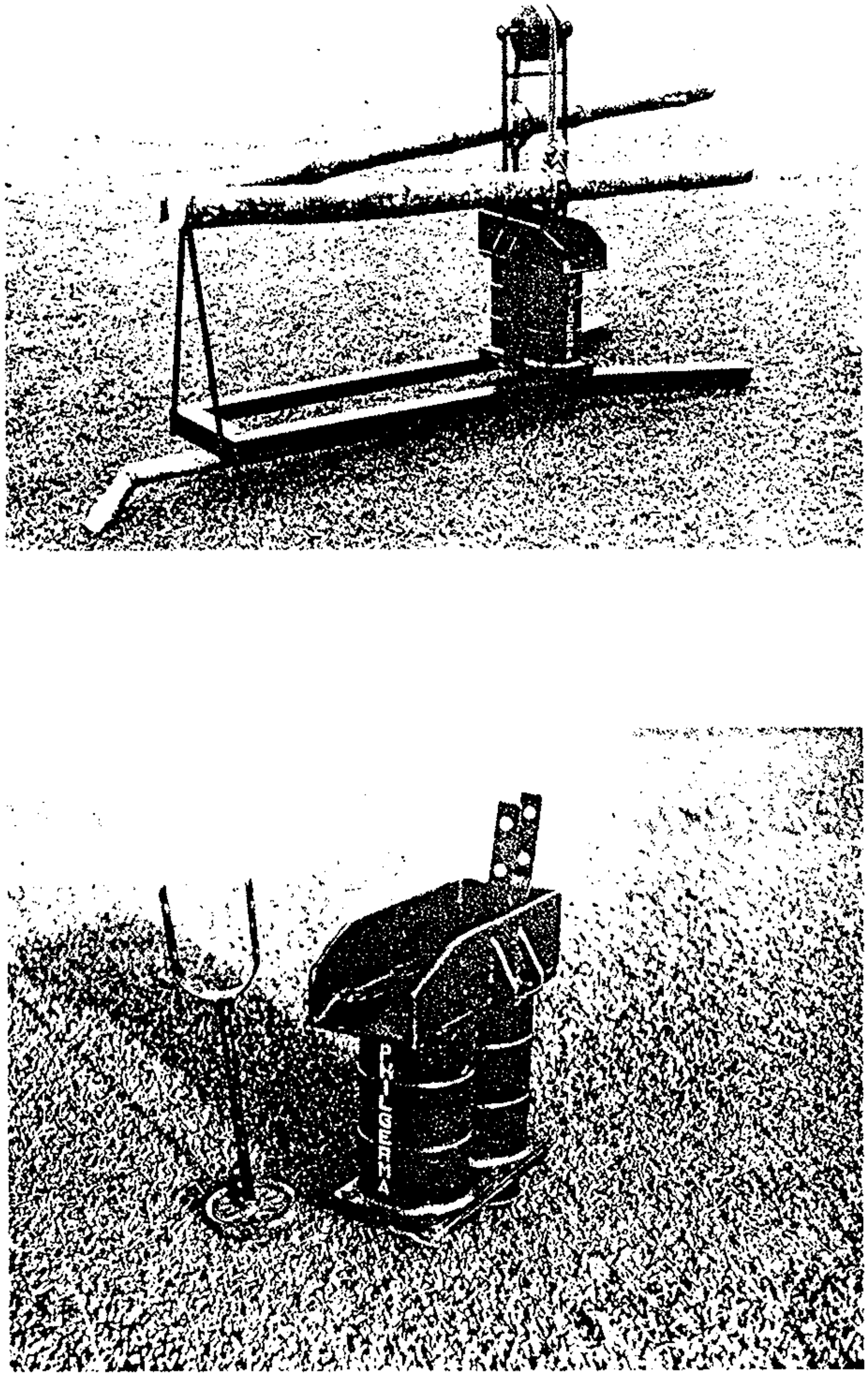


Figure 6. Cast iron version of the T-T pump.

configuration. This design is also advantageous with respect to portability, since the pivot for the treadles is an integral part of the pump assembly. On the other hand, this design is more expensive to produce than the simple tubewell design, - a factor which limits sales, but not to the same degree as in Bangladesh.

One of the cooperating manufacturers of the MAF-IRRI Program has a foundry and was producing cast iron handpumps for domestic use. After seeing the tapak-tapak pump, he decided to produce a cast iron version by mounting two of his standard cast iron cylinders on a common manifold and with a common spout as shown in Fig. 6. The advantage of this pump is that it uses many parts which are already available for domestic water handpumps, thereby taking advantage of the use of mass-produced components. The pump is expected to be more durable than the one fabricated from sheet metal, but its weight is a detriment for applications requiring a portable pump. At present, the cost is equal to or only slightly higher than that of the sheet metal pump.

INSTALLATION

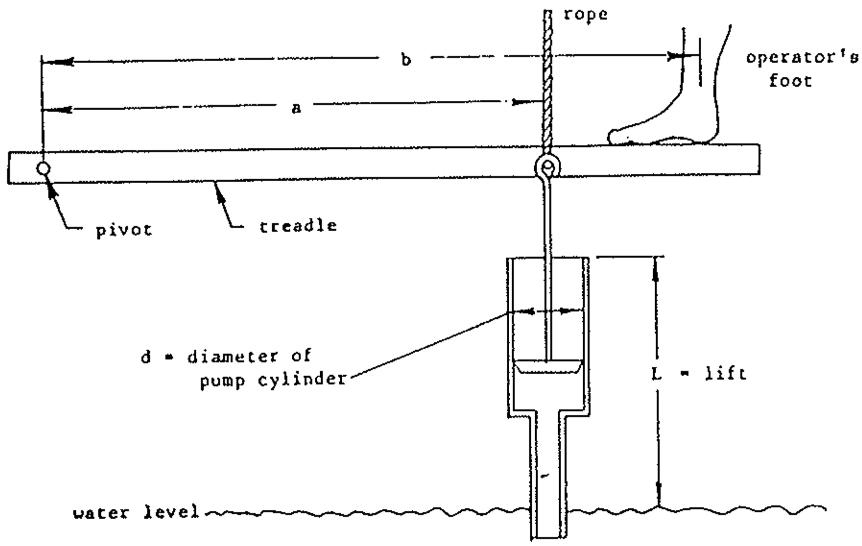
The pump framework and installation may be varied according to type of water source, availability of materials, and application. In north Bangladesh, most of the pumps are permanent installations on tubewells utilizing bamboo as the suction tube and the strainer (screen). Bamboo is also used for the treadles and handrail, as shown in Fig. 1.

In the Philippines, the open-well pump is connected to a PVC suction pipe by means of a strip or band of rubber cut from a used tire

TABLE 1. Dependence of force exerted by pump operator on lift and pump diameter.

$$\text{Force exerted by operator} = \frac{a}{b} \times \text{Force required by pump}$$
$$= \frac{a}{b} \times \rho \times \frac{1}{4} \pi d^2 \times L$$

where a, b, d, and L are defined in the sketch and ρ is the density of water (1000 kg/m^3).



Lift (L) (meters)	Force (F) exerted by operator,* kilograms (pounds) d = 76 mm (3 in)	d = 102 mm (4 in)	d = 127 mm (5 in)	d = 152 mm (6 in)
1	3.63 (8)	6.53 (14)	10.1 (22)	14.5 (32)
2	7.25 (16)	13.1 (29)	20.3 (45)	29.0 (64)
3	10.9 (24)	19.6 (43)	30.4 (67)	43.5 (96)
4	14.5 (32)	26.1 (58)	40.5 (89)	58.0 (128)
5	18.1 (40)	32.7 (72)	50.7 (112)	72.6 (160)
6	21.8 (48)	39.2 (87)	60.8 (134)	87.1 (192)
7	25.4 (56)	45.7 (101)	70.9 (156)	101 (222)
8	29.0 (64)	52.2 (116)	81.0 (178)	116 (255)
9	32.6 (72)	58.8 (130)	91.2 (201)	131 (288)
10	36.3 (80)	65.3 (144)	101 (222)	145 (319)

A

B

*Notes:

1. It is assumed that $\frac{a}{b} = 0.8$.
2. Since the calculation neglects friction and other non-ideal aspects of pump operation, the computed forces are the minimum (ideal) values rather than the actual values.
3. The region between the dashed lines, A and B, is the comfortable operating range where the force exerted by the pump operator is between 15 and 45 kg (33 and 100 lbs.).

innertube. This provides a portable unit which may be easily moved from one well to another.

APPLICATIONS

Since the T-T pump is a suction-type pump, it is suitable only for low-lift applications (i.e., cases where the source of water is no more than approximately 7 meters below the pump). Although a suction-type pump has a theoretical maximum lift of approximately 11 meters, practical pumps are generally limited to lifts of no more than 7 meters. In fact, irrigation applications requiring considerable volumes of water are often viable only for lifts of no more than 5 meters because the force required to pump water increases with lift. This point is illustrated in Table 1 where the theoretical pumping force is tabulated for a range of values of lift and pump cylinder diameter.

In Bangladesh, suction-type pumps are applicable in widespread areas where the water table is close to the soil surface even during the dry season. The principal applications of T-T pumps have been to enable farmers to irrigate wheat during the dry season, while some farmers are also using the pump for small plots of paddy.

In the Philippines, our initial objective was to promote the pump to small farmers who grow vegetables in their rice fields during the dry season. At present, these crops are irrigated either by lifting buckets of water from open wells or by engine-driven centrifugal pumps on shallow tubewells. The T-T pump offers an intermediate level of technology which reduces the labor of bucket lifting and avoids the high initial and operating costs of engine-driven centrifugal pumps.

A preliminary evaluation was made by surveying 24 farmers who purchased pumps during the first extension effort. Over half of the pumps had not yet been utilized either because the owners encountered difficulties in installing the pumps and/or because the units were purchased late in the dry season. We plan to reduce these problems during the next dry season by providing more technical assistance on installation and ensuring that pump promotion and commercialization will be initiated earlier in the season. Our experience indicates that pumps should be available for sale at the time and place of promotional field demonstrations, thereby taking advantage of the farmers' interest and presence.

Many of the first persons to buy pumps were extension workers of the Ministry of Agriculture who quickly recognized the pump's potential usefulness on their own farms. We expect that their pumps will help promote future acceptance by neighboring farmers.

Many small farmers who attended our demonstrations wanted to buy a pump but did not have sufficient cash available at that time. Others preferred to wait for a season in order to see if the first persons to purchase pumps were satisfied with the unit's performance and durability.

Although most of the pumps are being used to fill buckets for hand-watering of vegetables, several are used to fill or drain fishponds or azolla ponds. Only two are installed for providing water for furrow irrigation. One of these cases demonstrates that family labor is sufficient to irrigate a 1/3 ha field containing corn, bush sitao, mungbean, onion, and native fodder crop. This case and three others are now being evaluated in detail by IRRI economists to estimate the economic benefits and costs of T-T pumps for several different small-farm applications.

Acknowledgment

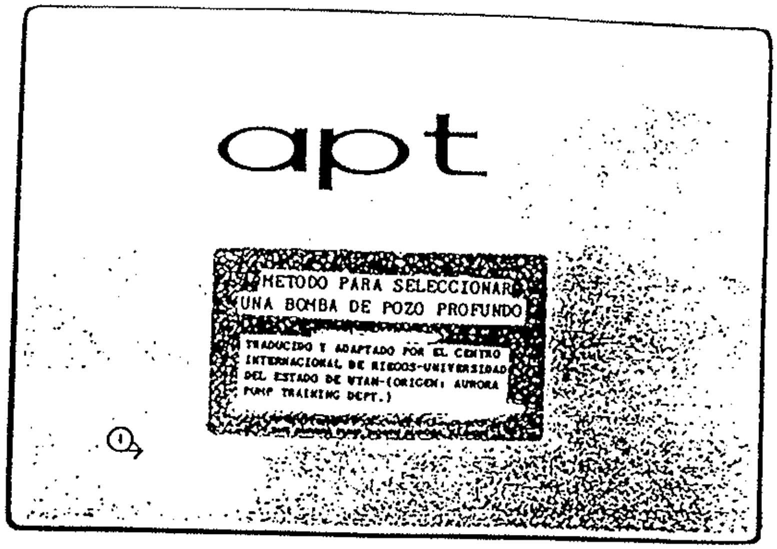
We are grateful to RDRS/Bangladesh for generously sharing the T-T pump technology.

REFERENCES

Stickney, R. E., B. C. Gonzalo and C. W. Bockhop. 1984. Philippine agricultural engineering extension of small farm equipment. Paper presented at the American Society of Agricultural Engineers, University of Tennessee, Knoxville, June 24-27.

RDRS, 1984. Annual Report, Rangpur Dinajpur Rehabilitation Service/Lutheran World Federation, Dhaka, Bangladesh.

METODO PARA SELECCIONAR UNA BOMBA DE POZO PROFUNDO



2

Los datos básicos de una unidad de bombeo son determinados generalmente por el comprador asistido por un ingeniero de venta, un perforista, ingeniero consultor o alguna otra persona con la experiencia y conocimientos necesarios para proveer al cliente con toda la información necesaria.

3

Hay una serie de datos que deben considerarse si se va a seleccionar una bomba vertical en forma adecuada. Estos son: diámetro y profundidad del pozo, nivel estático, depresión, elevación, presión disponible, carga total dinámica, caudal deseado o pronosticado, instalación, impurezas en el agua, tipo de descarga y tubería a utilizar, tipo de accionamiento, régimen de la bomba y sobrecarga admisible del motor.

INFORMACION NECESARIA

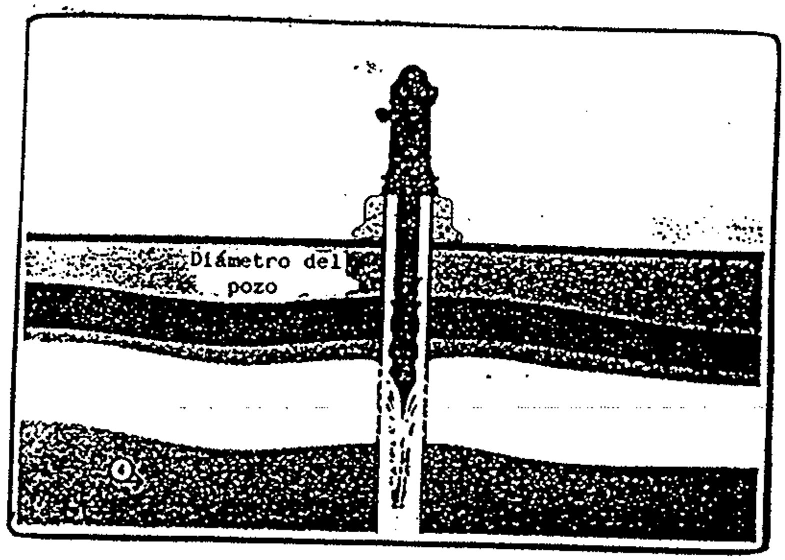
1. Diámetro del del pozo
2. Profundidad del pozo
3. Nivel estático
4. Depresión
5. Elevación
6. Altura ó presión
7. Carga total de bombeo en condiciones de servicio
8. Caudal del pozo deseado ó esperado
9. Longitud de la columna
10. Impurezas químicas
11. Tipo de descarga y tamaño de la tubería
12. Tipo de accionamiento
13. Velocidad permisible de la bomba
14. Sobrecarga permisible

Se examinan a continuación todas estas caracteristicas.

4

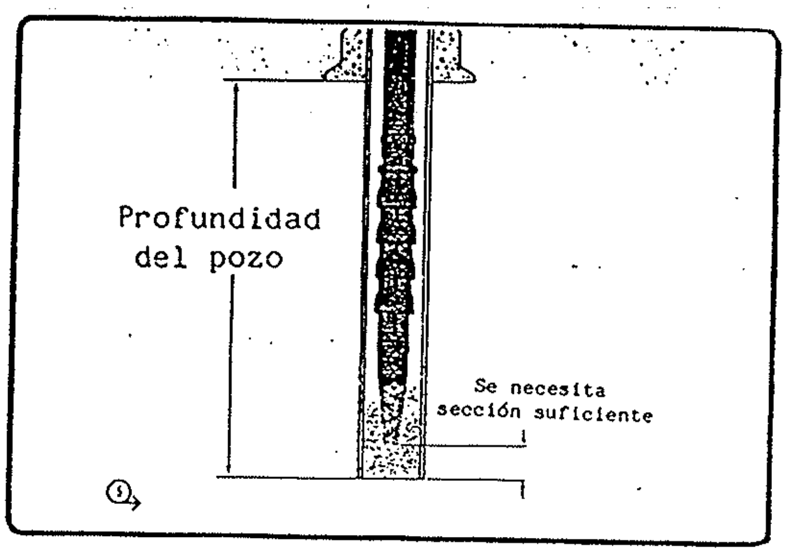
El diámetro del pozo es importante, ya que determina que tamaño de bomba se puede instalar. Dependiendo del tamaño de la misma y del diámetro del pozo, el agua entrando al pozo en forma de cascada desde arriba de la bomba puede crear un problema si cae lo suficiente para captar demasiado aire. Como se puede ver en la ilustración #4, el aire en el agua afectará el funcionamiento de la bomba.

Otra consideración importante es el espacio entre la bomba y el diámetro interior del pozo. Si el espacio fuera insuficiente, el agua entrando al pozo desde arriba del cuerpo de la bomba puede que no lo haga con un caudal igual a la capacidad de diseño de la bomba.



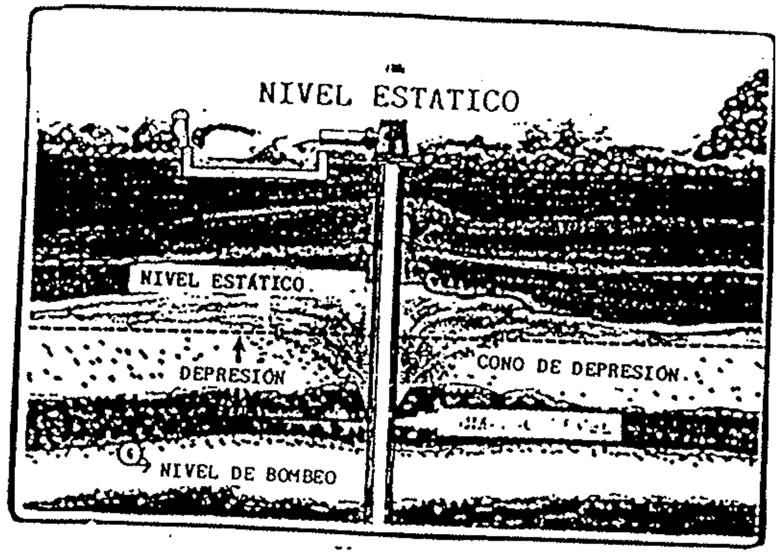
5

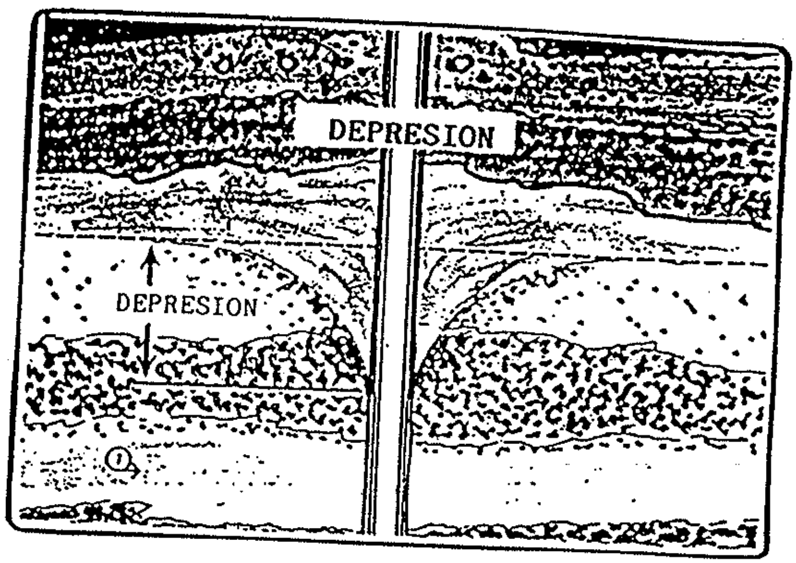
La profundidad del pozo también es importante si el cuerpo de la bomba se va a colocar cerca del fondo del mismo. Se necesita suficiente espacio alrededor de la entrada de succión para permitir un flujo apropiado del agua. Es necesario saber si hay alguna limitación en la profundidad del pozo, o si hay alguna obstrucción, por ejemplo, la camisa del pozo. Esta información se necesita para seleccionar apropiadamente el equipo que funcionará mejor en estas condiciones. Siempre se debe sondear el pozo antes de instalar la bomba. Es posible que el pozo se haya llenado de arena y deba limpiarse antes de instalar la bomba. El equipo se puede dañar y por lo tanto puede resultar muy caro, tanto para el usuario como para el instalador el hecho de bajar una bomba en fondo barroso



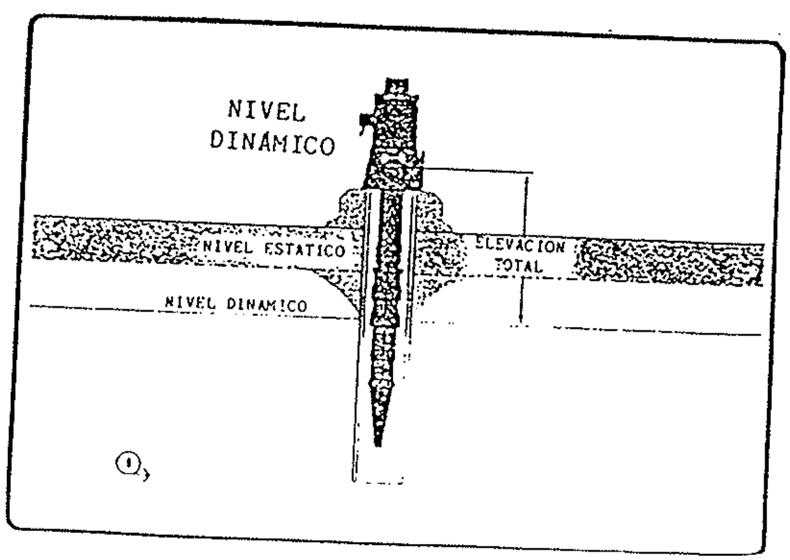
o arenoso. Al hacer ésto se puede ahogar la entrada de la bomba causando que ésta se seque o que se llene con material abrasivo. También es posible que se dañen los impulsores y los cojinetes.

6
Es útil saber la profundidad hasta el nivel del agua cuando la bomba no está operando. Esta distancia se conoce como nivel estático del agua. Se puede usar para determinar donde colocar el cuerpo de la bomba y si un eje descubierto es aconsejable. También ayuda a conocer las características de las condiciones del agua en las cercanías del pozo. El nivel estático del agua, en conjunto con una depresión conocida a un caudal determinado aportan un rango de valores y una buena base para determinar la depresión y la elevación que resultan con la variación del caudal.





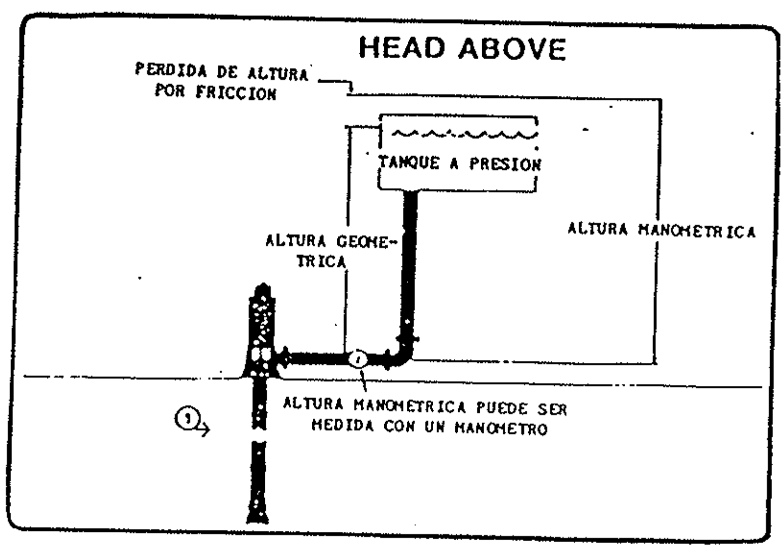
7
"Depresión" se refiere a la "carga" de agua que se necesita para hacer que el flujo que entra al pozo sea igual a la corriente que está saliendo por la bomba. La depresión a veces varía de una estación a otra y de un año a otro a medida que la existencia de agua disminuye. El nivel estático del agua usualmente baja a medida que hay menos existencia de agua en el acuífero y la depresión aumenta en forma correspondiente. Si se conoce el nivel estático del agua y la depresión para un caudal determinado, se asume que las depresiones correspondientes a un rango de caudales están en relación directa con estos.



8
La elevación es la suma del

nivel estático del agua medido desde el punto medio de descarga en el cabezal mas la depresión. Al seleccionar el equipo de bombeo, se tiene que saber el valor máximo que se espera de elevación. Con ésta información, es posible determinar el largo de la columna suficiente para mantener la bomba funcionando durante toda la temporada. Un pozo puede estar un poco fuera de la vertical y una bomba aún funcionará apropiadamente mientras que el pozo esté recto y libre de torceduras. Se ha sabido de pozos que estaban fuera de nivel hasta cinco grados y la bomba aún funcionó en una manera satisfactoria. Sin embargo, el peligro está en una situación donde el pozo está tan torcido que ejerce una trabazón sobre el eje, o donde los cambios de tensiones causan el fracaso del eje por fatiga de materiales a esta condición se la denomina a menudo erroneamente como cristalización. También la presencia de arena puede ser crítica. Interesa no solamente si está presente, sino también cual es la causa. Está ahí debido al desarrollo del nuevo pozo? Es ésta una condición ineludible? O tal vez la bomba está sacando el agua del pozo a un ritmo mayor que el pozo puede proveer? No se debe usar una bomba nueva para desarrollar un pozo. A menudo es como tirar partes de la misma a la basura. Cuando se ha terminado el desarrollo, si se ha usado una bomba centrífuga vertical con un eje descubierto (o lubricado por agua) ésta puede que necesite un cambio total de eje y cojinetes.

9
Se tiene que saber la altura (por encima del cabezal de descarga) si se quiere determinar la carga total de bombeo. Al estudiar



la ilustración #9, se puede ver que constituye la altura.

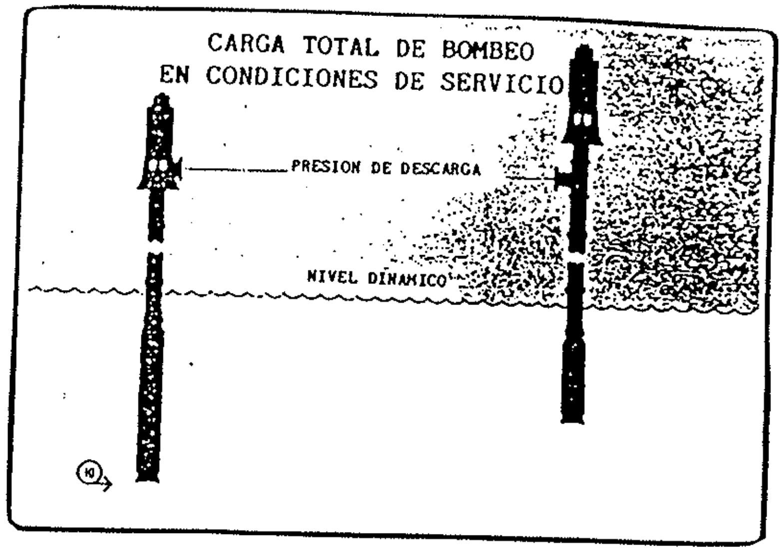
10
Cuando se selecciona una bomba se debe considerar la altura o carga total que se usará para seleccionar la bomba. La carga total de bombeo en las condiciones de servicio mas las pérdidas por fricción dentro de la bomba determinan esta carga. Las pérdidas dentro de la bomba consisten de una pérdida en la columna y una pérdida en el cabezal de descarga. Otra característica a considerar es que la distancia entre el punto medio del cabezal y el nivel dinámico varía de una instalación a otra; y la pérdida de carga producida en dicho tramo debe ser considerada al totalizar el desempeño de la bomba.

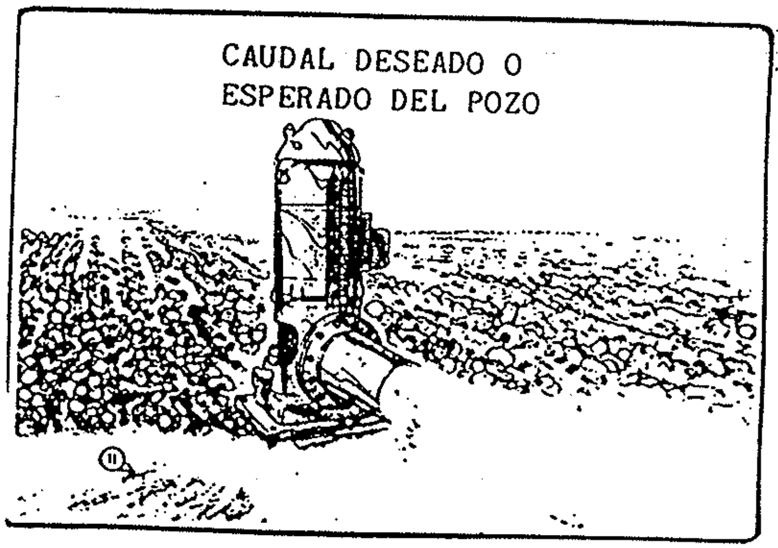
11
El usuario tiene que saber cuanto produce un pozo y cuanto él necesita del mismo, antes de tomar cualquier decisión acerca del tamaño de la bomba. Se tiene que saber el caudal deseado o el que se espera del pozo.

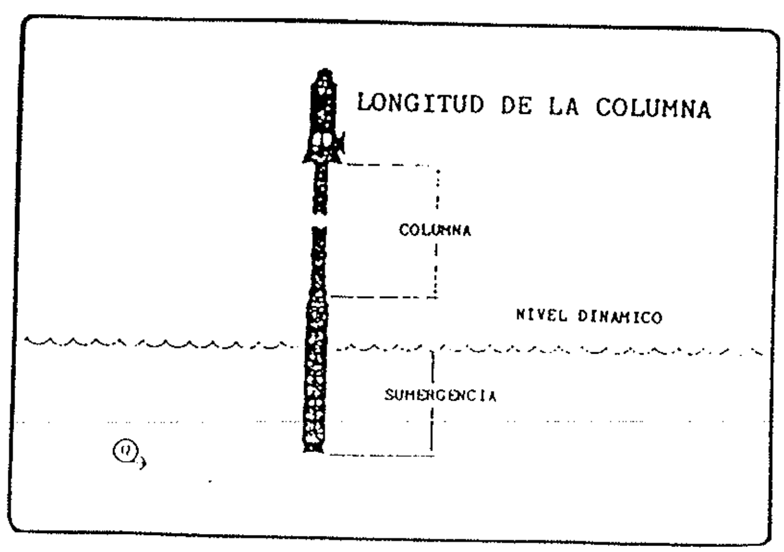
12
Es importante una buena sumergencia de la bomba. Para lograr ésto el largo de la columna de la bomba debe ser adecuado para que el agua no baje mas de la entrada de succión y esta deje de bombear.
El término columna significa el tubo que va desde el cabezal al cuerpo.

13

Impurezas químicas de varios orígenes pueden existir en el agua. Estas a menudo hacen necesario el uso de materiales especiales en la manufactura de



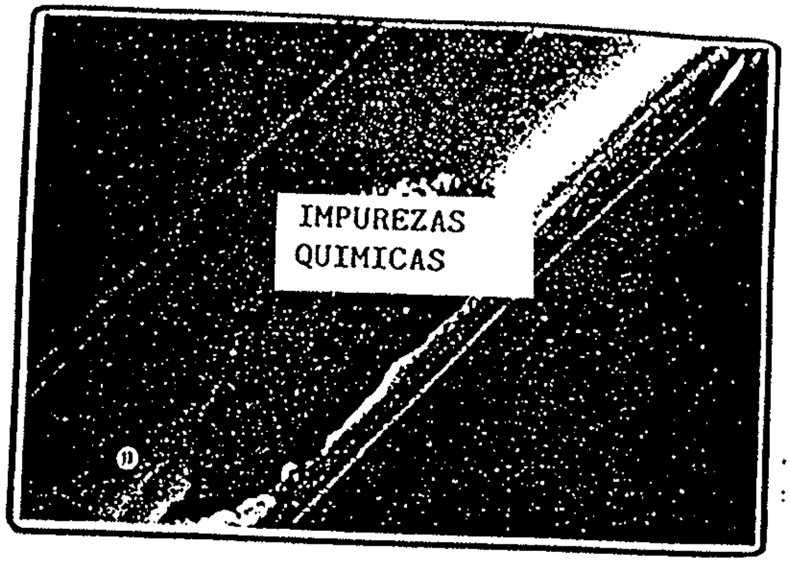




bombas. Algunas sustancias atacan los materiales básicos en sí; mientras que otros hacen un electrolito del agua y provocan una acción galvánica entre las partes de la bomba hechas de diferentes materiales. Consultar las normas correspondientes (Hydraulic Institute Standards), que contienen una lista bastante completa de materiales recomendados para impurezas específicas.

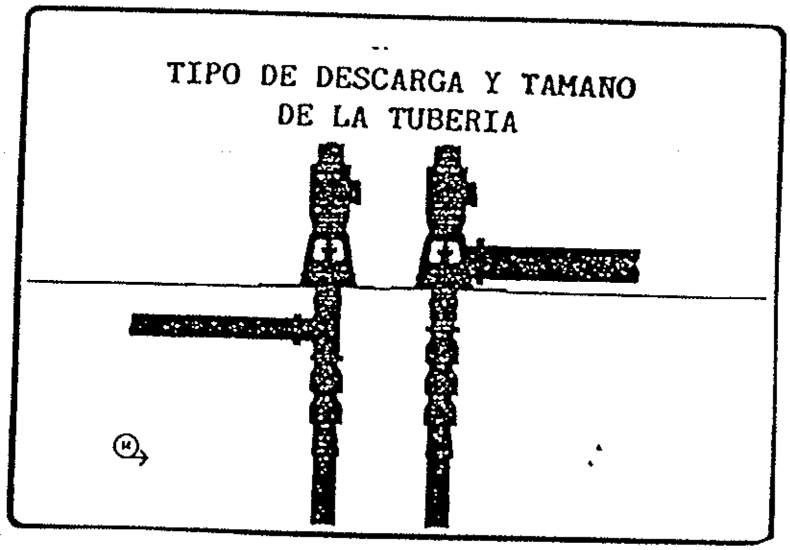
En general, los pozos son imfluenciados por un número de factores:

- Formaciones geológicas
- Cuerpos de agua naturales o artificiales en las cercanías
- El tamaño, caudal y número de pozos que se están bombeando en el área.
- Y el tamaño y condición general del pozo en cuestión.



14

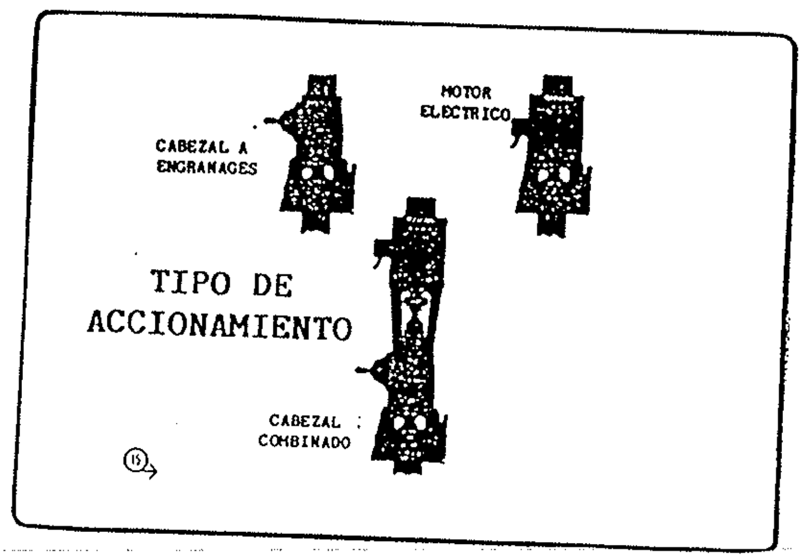
Para ayudar a hacer la selección apropiada del cabezal de descarga, se debe saber el tamaño de la tubería a servir y su ubicación, ya sea por encima o debajo de la tierra.



15

Si se debe hacer una conección apropiada del cabezal al accionamiento, se necesita cierta información con respecto al tipo de transmisión requerida. Se ven cuatro tipos de trasmisiones aquí en la ilustración #15. Si se tuviera un accionamiento con motor eléctrico, se deben especificar, las características de la potencia disponible en el lugar de bombeo tales como:

- Voltaje
- Fases
- Ciclaje, o número de Hertzs



16

La velocidad permisible de la bomba no se puede ignorar ya que el usuario puede tener restricciones y también puede que haya limitaciones técnicas por parte del fabricante del motor tanto como de la bomba.

17 El otro asunto para recordar es la sobrecarga permitida sobre el motor por el usuario, por supuesto siempre dentro de las limitaciones del fabricante.

En algunas áreas se encontrará que la sobrecarga del motor es una práctica común. Sin embargo en otras se insiste que la potencia requerida no exceda la clasificación en la placa del motor.

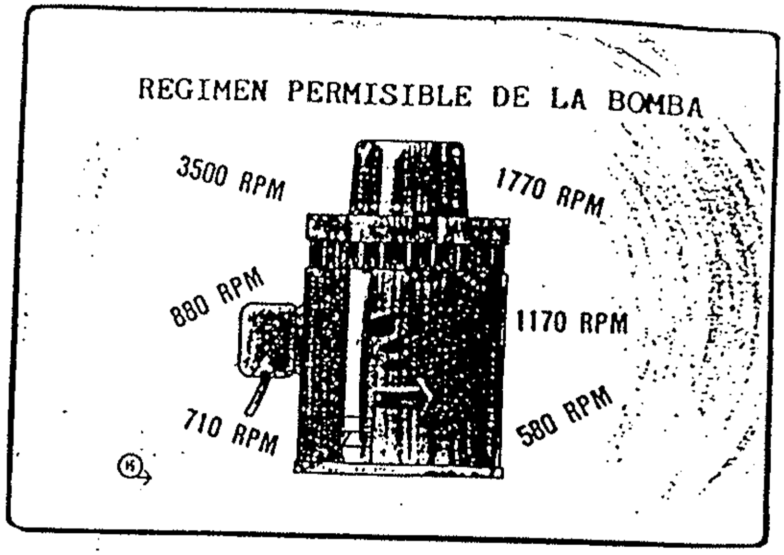
18

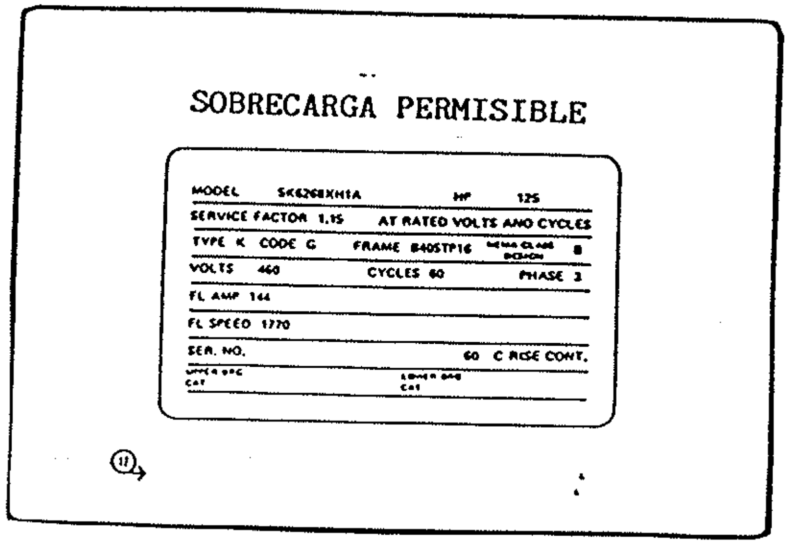
La selección del equipo y los cálculos asociados están basados en la información especificada en ilustraciones previas. Ahora se convertirá esa información a los pasos necesarios para realizar la selección:

1. Se puede hacer una preselección del cuerpo de la bomba por medio de una revisión de las curvas de ensayo.
2. Estimar la potencia efectiva requerida.
3. Hacer una selección preliminar del tamaño del eje.
4. También se puede hacer una selección preliminar del diámetro de columna y determinar la pérdida de carga de la misma
5. Se puede seleccionar el cabezal de descarga tanto como la.....
6. Pérdida por fricción del cabezal de descarga, si es que existe

19

7. La presión o altura por etapa, determinada en el laboratorio
8. Eficiencia de ensayo
9. Potencia de ensayo



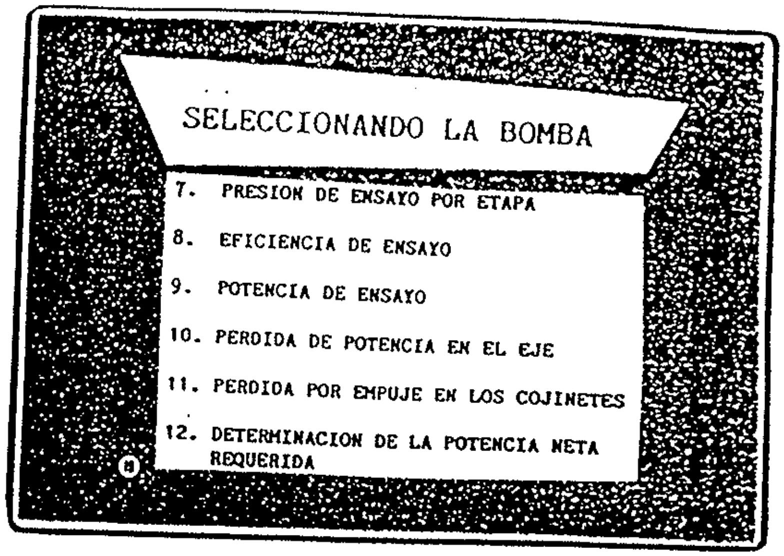


SELECCIONANDO LA BOMBA

1. SE PUEDE HACER UNA PRESELECCION DEL CUERPO DE LA BOMBA POR MEDIO DE UNA REVISION DE LAS CURVAS DE ENSAYO
2. ESTIMAR LA POTENCIA EFECTIVA REQUERIDA
3. HACER UNA SELECCION PRELIMINAR DEL TAMAÑO DEL EJE
4. SELECCION PRELIMINAR DEL TAMAÑO DE COLUMNA Y DETERMINACION DE SU PERDIDA DE CARGA
5. SELECCION DEL CABEZAL DE DESCARGA
6. PERDIDA DE CARGA ORIGINADA POR EL CABEZAL (SI EXISTE).

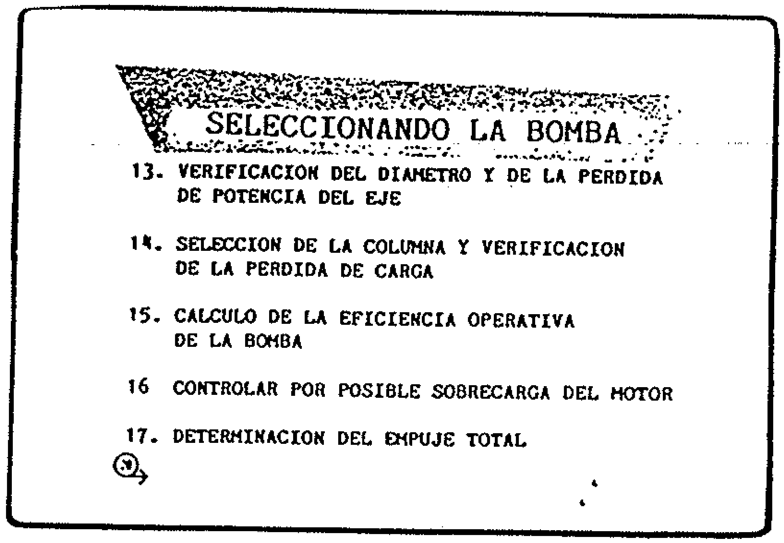
18

10. Pérdida de potencia en el eje
11. Pérdida de potencia por empuje en los cojinetes y....
12. Determinación de la potencia neta requerida



20

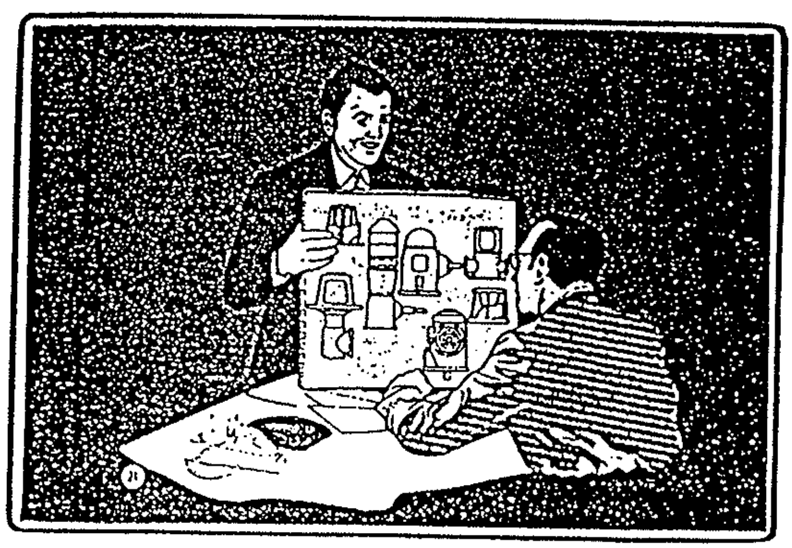
13. Verificación del diámetro y de la pérdida de potencia del eje
14. Selección de la columna y verificación de la pérdida de carga
15. Cálculo de la eficiencia operativa de la bomba
16. Controlar por posible sobrecarga del motor
17. Determinación del empuje total



21

Se seguirá la secuencia indicada para seleccionar y especificar una bomba centrífuga vertical para pozo profundo.

Lo primero que se tiene que saber al seleccionar una de éstas son las condiciones del proyecto, las cuales se encuentran descriptas en las dos próximas ilustraciones. Se aconseja escribir tales condiciones; a fin de usarlas como referencia a medida que se ensaya el ejemplo.



22

Las condiciones de servicio que se deben considerar son:

1. Un diámetro del pozo de 12" (30.48 cm)
2. Una profundidad de 250' (76.20m)
3. Un nivel estático del agua de 130' (39.62m), que ha sido el mismo por mas de 10 años
4. Una depresión maxima de 60' (28.29 m), con un caudal de 1500 GPM (93 l/seg)
5. La elevación es de 190' (57.91m)
6. La altura es de 110'(33.53m) y consiste de una presión de 40

PSI (2.8 Kg/cm^2) en un sistema a presión; mas una pérdida de fricción del tubo de 2.1' (0.64m), mas una altura vertical de 15.5' (4.72m) desde la descarga de la bomba hasta la entrada del tanque

7. Tal como se ve aquí la carga total de bombeo es de 300' (91.44m).

23

8. El caudal deseado es de 1300 GPM (80.6 l/seg), y el líquido a bombear tiene una densidad de uno
9. Se ha adoptado una columna de 190' (57.91m), que es igual a la elevación, lo que es suficiente; ya que el nivel estático no ha bajado por muchos años.
10. Cabezal de descarga requerido. El cabezal debe conectarse a una brida de 10" (25.4 cm) de diámetro, que resista una presión de 125 PSI (8.5 kg/cm^2)
11. El accionamiento es con motor eléctrico, de eje hueco, con una potencia eléctrica disponible de 460 voltios, 3 fases, 60 hertz
12. El regimen necesario es de 1770 revoluciones por minuto. Esto es aproximadamente la velocidad a plena carga de un motor de 4 polos
13. El motor puede estar sobrecargado en un 10 por ciento. Ahora ya se han establecido las condiciones de servicio; asi que es posible seleccionar una bomba centrífuga vertical para pozo profundo que está especificada en forma adecuada, la cual está manufacturada de materiales standard, usando el procedimiento expuesto en las ilustraciones #18, #19 y #20.

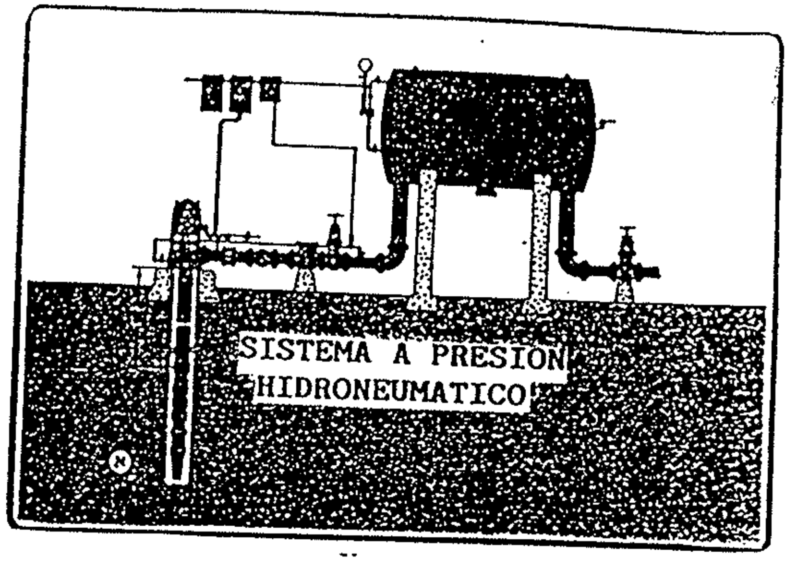
CONDICIONES DE SERVICIO

1. DIAMETRO DEL POZO - 12" (30.48 cm)
2. PROFUNDIDAD DEL POZO - 250' (76.20 m)
3. NIVEL ESTATICO - 130' (39.62m) (DURANTE MAS DE 10 AÑOS)
4. DEPRESION - 60' (18.29 m) A UN CAUDAL DE 1500 GPM (93 l/seg) (MAXIMO CAUDAL MEDIDO)
5. ELEVACION - 190' (57.91 m)
6. ALTURA - 110' (33.53m)
7. CARGA TOTAL DE BOMBEO - 300' (91.44m)

FIELD CONDITIONS

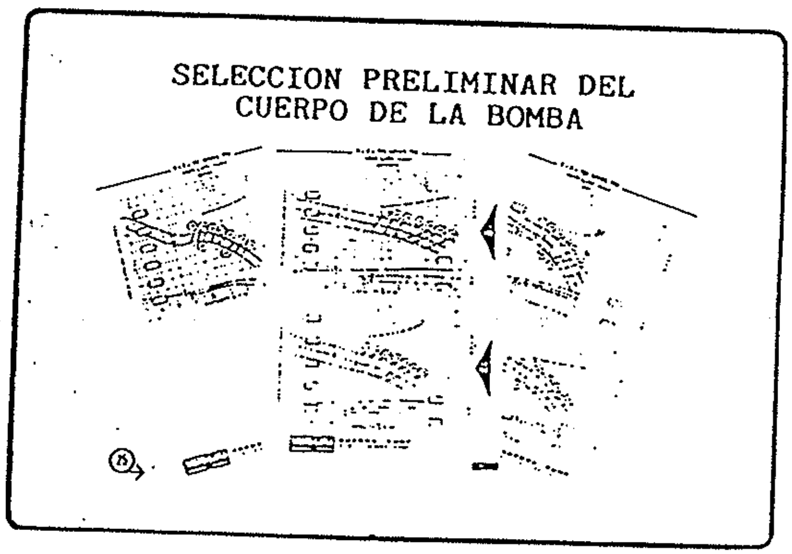
8. CAUDAL DESEADO - 1300 GPM (80.6 l/seg) DENSIDAD - 1
9. LONGITUD DE LA COLUMNA - 190' (57.91 m)
10. CABEZAL DE DESCARGA REQUERIDO
11. TIPO DE ACCIONAMIENTO
12. REGIMEN NECESARIO
13. SOBRECARGA ADMISIBLE

24
Aquí se ve un esquema de la instalación mencionada en nuestro problema de ejemplo.



25
Selección Preliminar del Cuerpo de la Bomba.

Consultando a la Sección del Catálogo Correspondiente, se localiza una bomba con una velocidad compatible con el ciclaje de 60 hertz. Revisando las curvas de 1750-1770 rpm, se encuentra un número de bombas capaces de bombear el caudal requerido. Ahora, se debe escoger una de varias bombas, basando la decisión en la máxima eficiencia o el precio mas bajo para el usuario. Usualmente la decisión está basada en el precio mas bajo, al menos que el consumidor esté conciente de la eficiencia o que la eficiencia de la bomba en general se deba considerar antes que el bajo precio. Es seguro que el lector puede ver cual sería la selección ideal para ciertas condiciones de bombeo - una bomba con la mayor eficiencia, sin embargo al precio mas bajo para el consumidor. Otros factores para ayudar a seleccionar una bomba incluyen el factor "K" de impulso de los tazones; cuando la carga de empuje de la bomba sobre el cojinete del motor debe mantenerse dentro de la capacidad admisible, o posiblemente se puede seleccionar una bomba con eficiencia mayor sobre una de bajo precio; para absorber menos potencia del motor. La selección correcta sería la siguiente como selección preliminar: 12 etapas, modelo 10 FHM, 84.5 por ciento de eficiencia del cuerpo, caudal de diseño a eficiencia máxima.



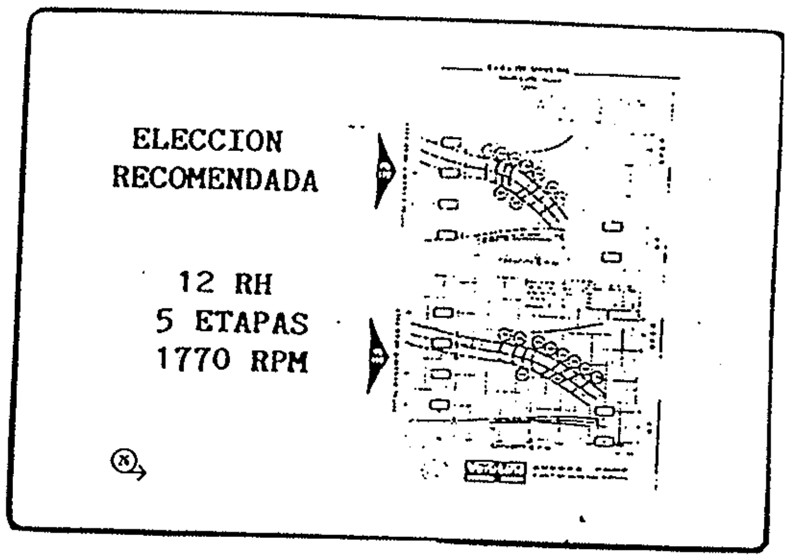
O bien: 5 etapas, modelo 12 RH, 84.0 por ciento de eficiencia del cuerpo, caudal de diseño a la eficiencia máxima.

O bien: 7 etapas, modelo 12, KHMM, 84.0 por ciento de eficiencia del cuerpo, caudal de diseño a eficiencia máxima.

Estas selecciones indican el caudal deseado de 1300 GPM (80.6 litro/seg) a la eficiencia máxima.

26

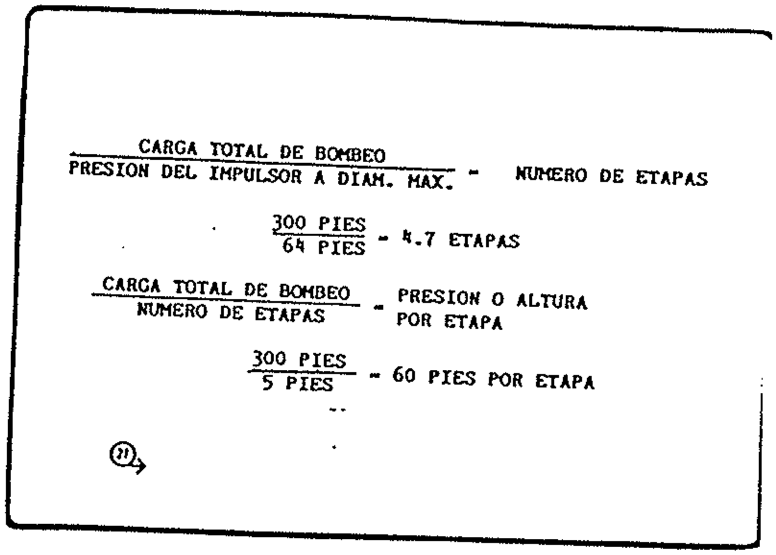
La bomba 12RH, de 5 etapas tiene buena eficiencia, entonces tomemos ésta para nuestro propósito; tiene el precio mas bajo en la lista de todas las selecciones de 1770 RPM que pudieramos hacer. Y aún de mas interés, el caudal deseado está al punto de eficiencia máxima de la bomba. Recuerdese que tan estable ha sido el nivel de bombeo del pozo por mas de una década, y no parece que bajará durante los próximos años. Por ésta razón se eligió una bomba con el punto de eficiencia máxima. Además se recomienda muy especialmente el uso de un tubo de succión de 10' (3.05m) con la bomba. Si se previera un aumento en el nivel estático del agua y en la correspondiente elevación, se aconseja seleccionar una bomba en la cual el caudal requerido esté a la derecha del máximo. Así, cualquier baja en el nivel del agua, movería el caudal resultante a través del punto de mayor eficiencia antes de caer demasiado. Además la bomba entrega el agua a un sistema a presión y, por lo tanto ésta operará dentro de una escala de presión desde un mínimo de 1.70 Kg/cm^2 hasta un máximo de 2.70 Kg/cm^2. La bomba funcionará a una presión máxima solamente durante breves períodos. Normalmente funcionará a menos



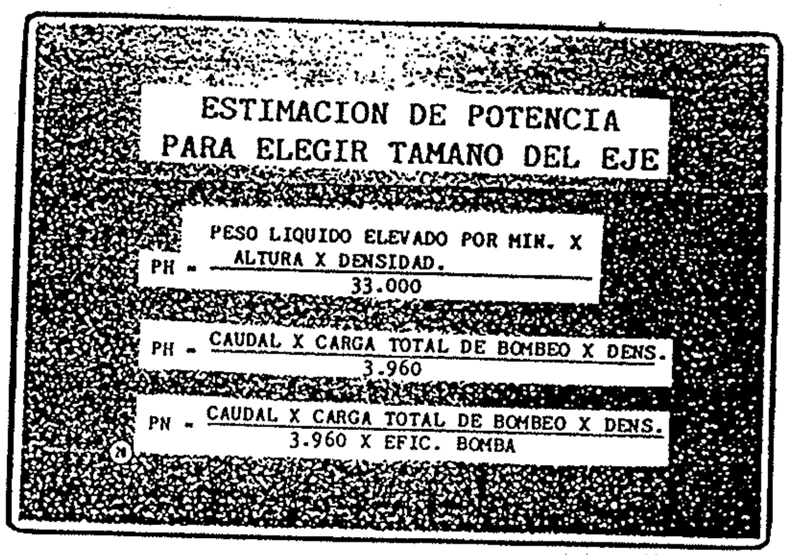
de 300' (91.44m) y variará a través del rango de eficiencia máxima durante cada ciclo de operación.

27
En la ilustración #27 se observa como se calcula el número de etapas necesarias. Se tiene que encontrar la respuesta a ésta pregunta: Que número de etapas se requiere en el punto de servicio (Caudal y carga total de bombeo de proyecto). Para encontrar la solución, se toma la carga total de bombeo, la cual, como se podrá recordar es de 300' (91.44m), estos se dividen por la presión máxima del impulsor que en éste caso es 64' (19.51m). De ésta información se obtiene una respuesta de 4,7. Esto resulta en 5 etapas. Por suerte, éste no fué un ejercicio tan difícil.

Para obtener una estimación de la altura por etapa, se toman las 5 etapas y se dividen dentro de 300' (91.44m) de carga total de bombeo. Esto da 60' (18.29m) de altura por etapa.



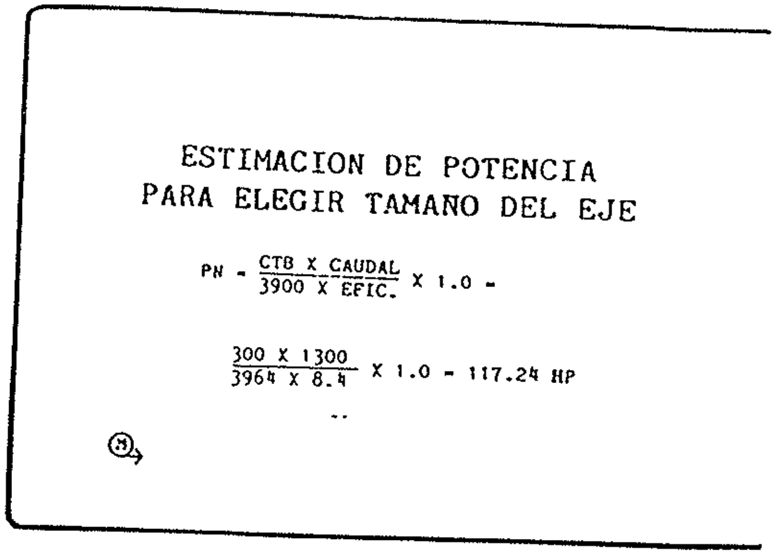
28
Para seleccionar el tamaño del eje apropiadamente se debe tener una estimación de la potencia que transmitirá. Como siempre se confía en un par de fórmulas ya conocidas para mostrar el camino. El trabajo útil hecho por una bomba se denomina Potencia Hidráulica, la potencia hidráulica es igual a las libras (Kg) de líquido elevadas por minuto, multiplicado por la altura en pies (metros) multiplicados por la densidad y dividido por 33,000 libras-pie/min HP (4500 Kgm/min. CV). Para simplificar el cálculo se expresa el caudal en GPM (l/seg) y se divide por la constante 3960 (75). La potencia neta necesaria para accionar una bomba resulta de



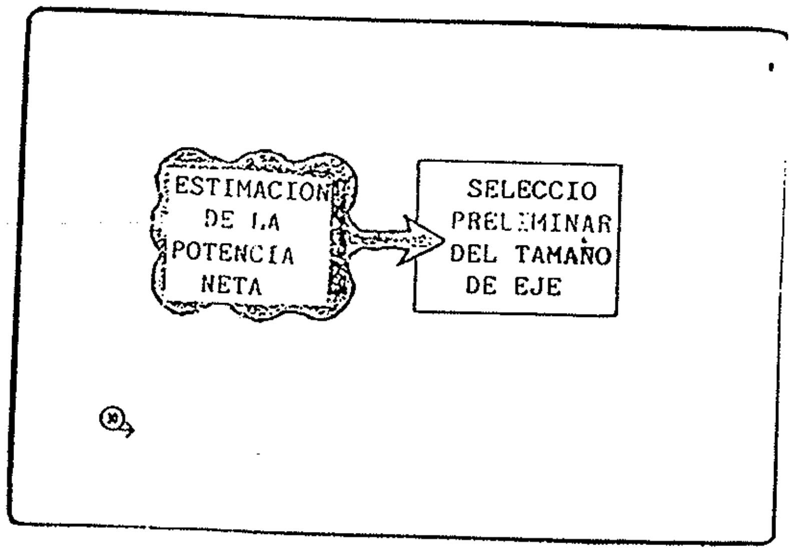
afectar a esta ultima fórmula con la eficiencia de servicio de la misma.

29

Apliquemos ésta fórmula. La altura en pies (metros) de la cual se habló en la ilustración #27 también se conoce como la carga total de bombeo. Se usa en la fórmula de la manera siguiente: la carga total de bombeo es de 300 pies (91.44m). Se tomaran estos 300 pies (91.44m) multiplicados por 1300 GPM (80.6 l/seg), multiplicado por uno, que es la densidad del agua. Se dividen los resultados por la constante 3960 (75) multiplicada por 84 por ciento, el nivel de eficiencia de la bomba. Esto nos da una potencia neta de 117.24HP (116.98 CV).

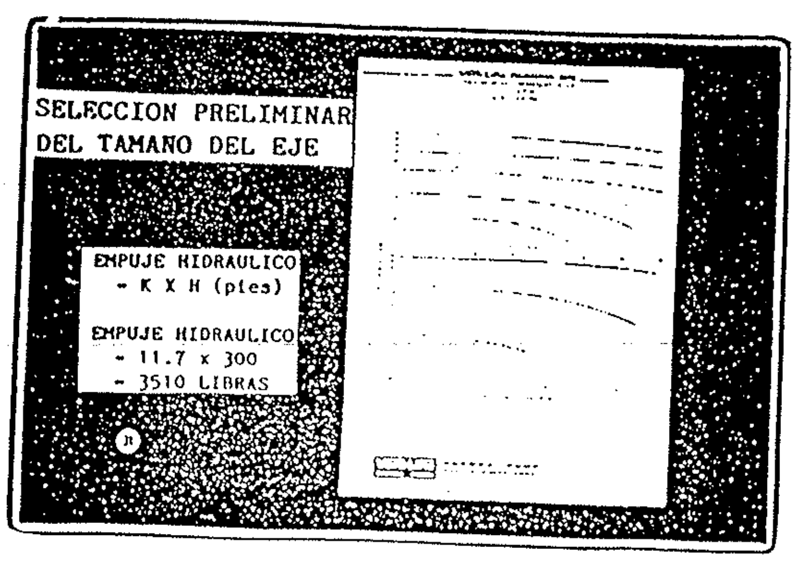


30
Ahora que se tiene la estimación de la potencia neta, se puede avanzar al siguiente paso y hacer la selección preliminar del tamaño del eje.



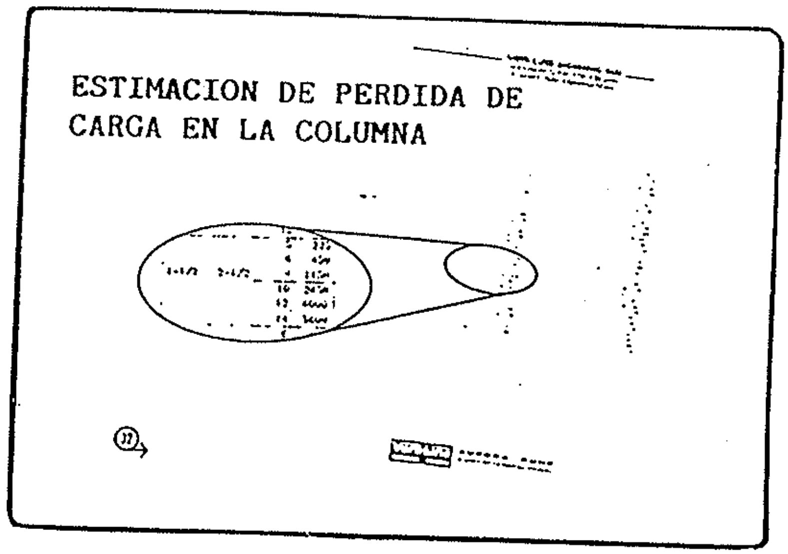
31

Otras consideraciones que se deben tomar en cuenta incluyen 300 pies (91.44 metros) de carga total dinámica o de bombeo y 1770 RPM. Con todos los hechos en mano se puede calcular el empuje hidráulico usando esta fórmula: el empuje hidráulico es igual a "K" multiplicado por la altura en pies, donde "K" se obtiene del tope de la curva de la bomba seleccionada. Así que el impulso hidráulico es igual a 11.7 multiplicado por 300, lo que es igual a 3510 libras de empuje. Una vez que se hayan completado estos cálculos, se debe examinar en el diagrama de selección del tamaño del eje, para 60 hertz, 1770 RPM. El diagrama indica que se puede

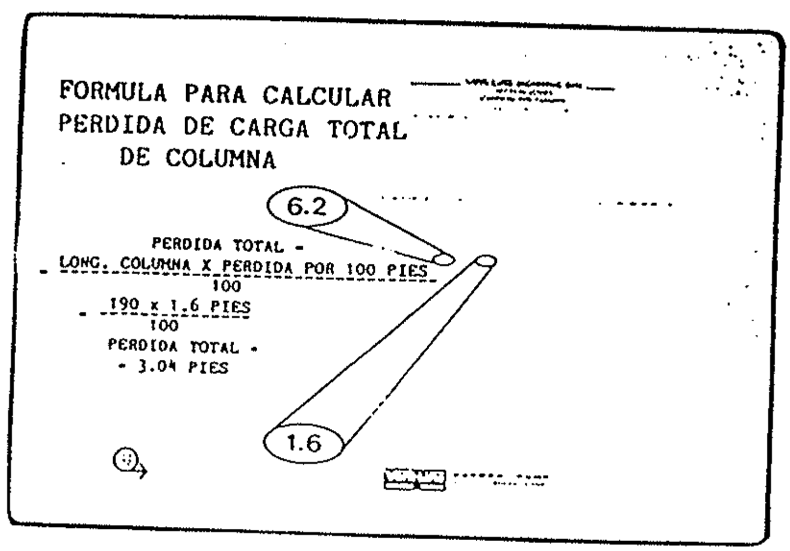


transmitir casi 210 HP de potencia a través de un eje con un diámetro de 1.5 pulgada (38.1 mm) y con una carga de empuje de 3510 libras. Como la carga excede la máxima permisible para el tamaño inferior inmediato de eje, que tiene un diámetro de 1-3/16" (30.2 mm), se tendrá que usar el eje de 1.5".

32
Para estimar la pérdida en la columna, se debe conocer el caudal, en éste caso es de 1300 GPM (80.6 l/seg); la columna es de 190 pies (57.91m), y el eje de 1.5" (38.1mm) que se acaba de determinar. Al revisar el diagrama de selección para columnas y ejes, se ve que se requiere un tubo de cobertura de 2.5" (63.5mm) para el eje de 1.5". No solo eso, sino que la columna de 8" (20.32 cm) tiene una capacidad máxima de 1150 GPM (71.30 l/seg), por lo tanto, se debe usar una columna de 10" (25.40 cm) que tiene una capacidad máxima de 2450 GPM (157.5 l/seg).

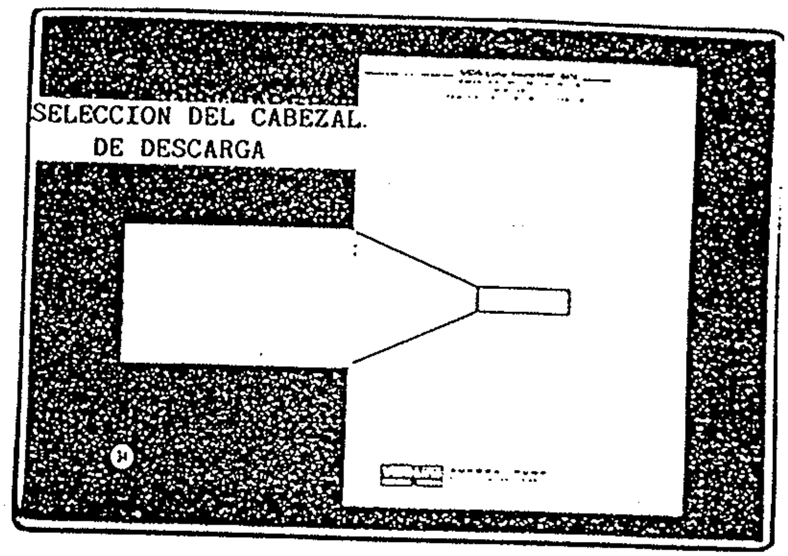


33
El próximo paso lógico en el proceso de selección es evaluar la pérdida total en la columna y existe una formula para ésto. El largo de columna dividido por 100 y multiplicado por la pérdida por cada 100 pies es igual a la pérdida total en la columna. Observando la gráfica de pérdida por fricción para una columna de tubo corriente, se deduce que la pérdida por fricción para 1300 GPM es de 1.6' por cada 100' para una columna con tubo de 10", mientras que la pérdida en la columna de 8" (20.32 cm) es de 6.2' por cada 100'. Esta última lectura es excesiva para una bomba de columna muy larga. Se repetirá la formula y luego se convertirá. La pérdida total de la

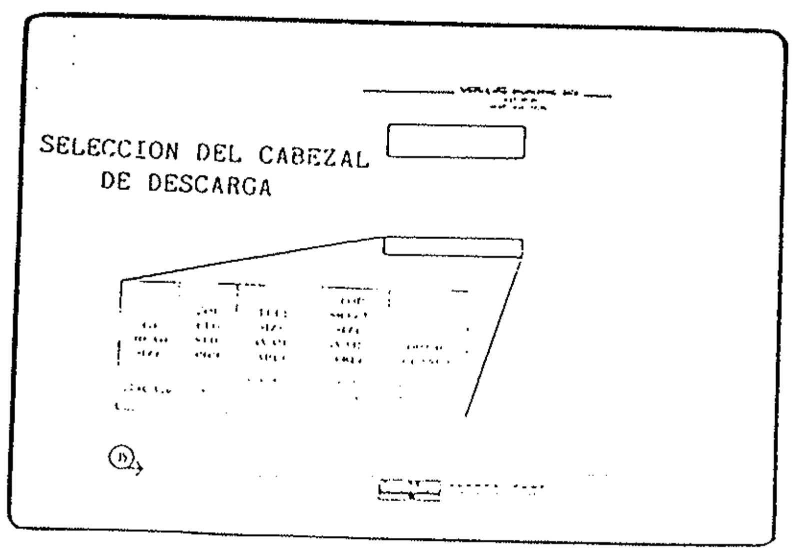


columna se computa al dividir el largo de la columna por 100 y multiplicar el resultado por la pérdida por cada 100'. La columna es de 190' (57.91M), lo cual se divide por 100 y luego se multiplica por 1.6' (45.72 cm) que es la pérdida por fricción para 1300 GPM (80.6 litros por segundo) por cada 100' (30.48 m) con un tubo de una columna de 10" (25.4cm). Lo que resulta en una Pérdida Total en la Columna de 3.04' (92.66cm).

34
Ciertas condiciones afectan la selección del cabezal de descarga: un motor de 125HP de potencia, 1800 RPM; una presión de descarga de 110' (33.53m), un caudal de 1300 GPM (80.61/seg) y la brida de descarga de 10" (25.4cm) que se necesita en el cabezal. Al referirse a la sección de motores en el catálogo, tal como se ve en la ilustración 34, se determina que el motor eléctrico de eje hueco con 125 HP de potencia, 1800 RPM, tiene un diámetro de base de 16.5" (41.91 cm). El catálogo del motor especifica un mínimo calibre del vano para el eje de 1-7/16" (36.5 mm) a 1-15/16" (49.2mm) de diámetro máximo.



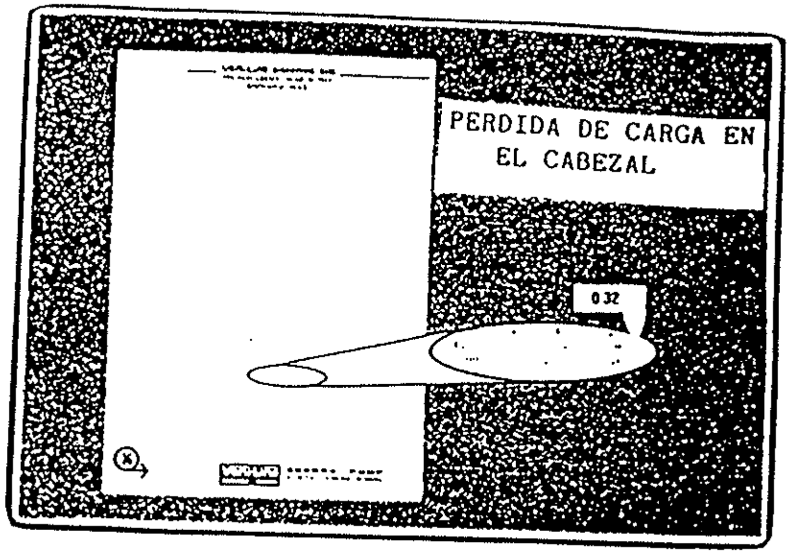
35
Usando la gráfica de selección del cabezal en el catálogo como guía, se selecciona un cabezal de descarga 17ACA10 para usar con el motor, de 16.5" (41.9cm) de base. La columna de 10" (25.4 cm), el tubo de cobertura de 2.5" (63.5mm) y el eje de 1.5" (38.1 mm). Este cabezal es apto para una presión máxima de trabajo de 200 PSI (13.6 kg/cm^2).



36

Para determinar la carga total dinámica apropiadamente, se debe saber cual es la pérdida del cabezal de descarga. Las condiciones pertinentes que se deben recordar son el caudal de 1300 GPM (80.6 l/seg) y el cabezal de descarga seleccionado el cual es 17ACA10.

Para calcular la pérdida por fricción del cabezal de descarga en bombas centrífugas verticales, se debe usar la gráfica de pérdida en el cabezal del catálogo. Al tener 1300 GPM (80.6 l/seg) fluyendo a través de un cabezal AC de 10" (25.4 cm) resulta una perdida de carga de 0.32' (9.8cm)

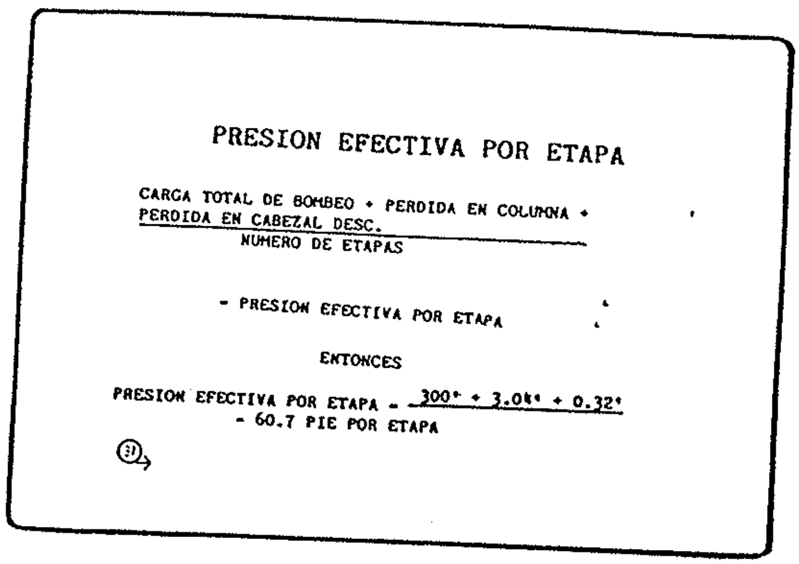


37

La presión (o altura) efectiva por etapa es igual a la carga total de bombeo para las condiciones de servicio, mas la pérdida en la columna, mas la pérdida del cabezal de descarga, dividida por el número de etapas en la bomba.

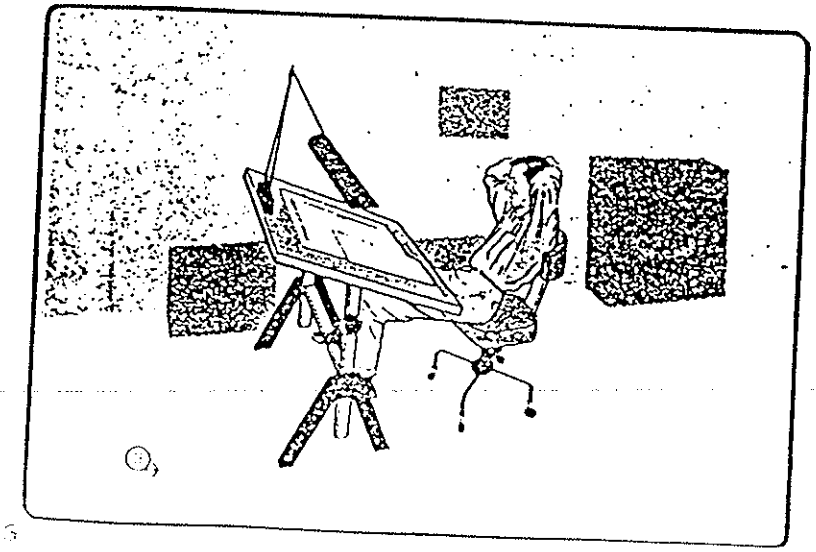
Ponganse algunos valores en la fórmula. La altura de bombeo es de 300' (91.44 m). A ésto se sumará la pérdida en la columna que es de 3.04' (92.6cm) así como los 0.32' (9.7 cm) de pérdida en el cabezal de descarga.

Al dividir los resultados por 5, o sea el número de etapas, se establece una altura por etapa efectiva de 60.7' (18.5 m).



38

Recuerda como se obtuvieron éstos números previamente? Puede Ud. ver como emerge el patrón de interrelación entre todos éstos valores? Seleccionar una bomba no es la tarea más fácil del mundo, pero sí se efectua con cuidado y correctamente, le proveerá con mucha satisfacción por muchos años, y lo habrá logrado a un



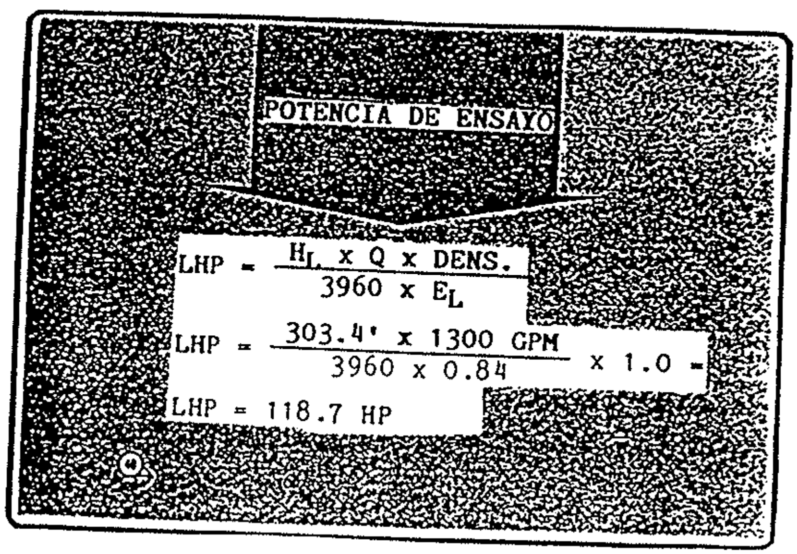
precio razonable. Se debe tomar el tiempo necesario al hacer la selección; y evaluar todos los parámetros con prudente previsión.

39
Tomando la curva del catálogo para una bomba 12RH se interpola una eficiencia de ensayo de 84 porciento al usar los siguientes valores: 1300 GPM (80.6 l/seg), 60.7' (18.50m) de altura por etapa, 5 etapas con tazones standard a 1770 RPM. La curva se determina por medio de una prueba en el laboratorio. Esta curva de desempeño muestra las características de la altura-caudal- eficiencia-potencia para cualquier punto en particular.

Si Ud nota, la esquina superior derecha de la hoja lleva correcciones de eficiencia para varios números de etapas. Ya que el requisito de 5 etapas no está en la lista, uno debe referirse a la página del catálogo que corresponde a "Ajustes del Punto de Eficiencia para Etapas solamente". Al usar la información que está marcada "12R" la corrección de eficiencia para 5 etapas es "0".

Los tazones de hierro fundido o de materiales especiales requieren una reducción de eficiencia tal como se indica en el catálogo en la página titulada "Ajustes para el Punto de Eficiencia para materiales que no son de hierro vidriado"

Ya que se ha seleccionado una bomba de construcción corriente con tazones vidriados, los factores que se acaban de mencionar no se aplican aquí y la eficiencia determinada en el laboratorio que se debe usar permanece a 84 por ciento.



40
Empecemos éste segmento del

programa con la definición de la potencia de ensayo (se determina con datos de laboratorio). No es una formula muy difícil de entender al definir que la potencia de ensayo es simplemente la potencia necesaria para accionar el cuerpo de la bomba. Esta potencia en particular se calcula usando la siguiente formula: LHP igual a H_L multiplicada por Q multiplicada por la densidad; sobre la constante 3960, multiplicada por E_L.

LHP es la potencia de ensayo que se debe calcular, H_L es la altura total en pies (metros) ensayada en el laboratorio, la cual a su vez se divide en altura total de servicio mas todas las pérdidas.

Q es el caudal en galones por minuto, GPM (l/seg). Dens es la densidad del fluido que se bombeará el cual es agua y E_L, la eficiencia determinada en el laboratorio.

Bien, pongamos ésta fórmula a trabajar LHP es igual a H_L multiplicada por Q multiplicada por la densidad; dividida por 3960 que multiplica a E_L; o sea 303.4' (92.48m) de altura determinada en el laboratorio, multiplicada por 1300 GPM (80.6 l/seg) multiplicada por una densidad de uno; dividida por la constante 3960 (75), multiplicada por 0.84, la eficiencia determinada en el laboratorio; lo cual nos da una respuesta de 118.57 HP (118.32CV) de potencia.

41 Se deben considerar tres condiciones al determinar la pérdida de potencia del eje: tamaño del eje, velocidad de la bomba y longitud de columna. Digamos que el diámetro del eje es de 1.5" (38.1 mm), la velocidad de la bomba es 1770 RPM y la columna es de 190' (57.91 m)

En la ilustración #41 se ve una

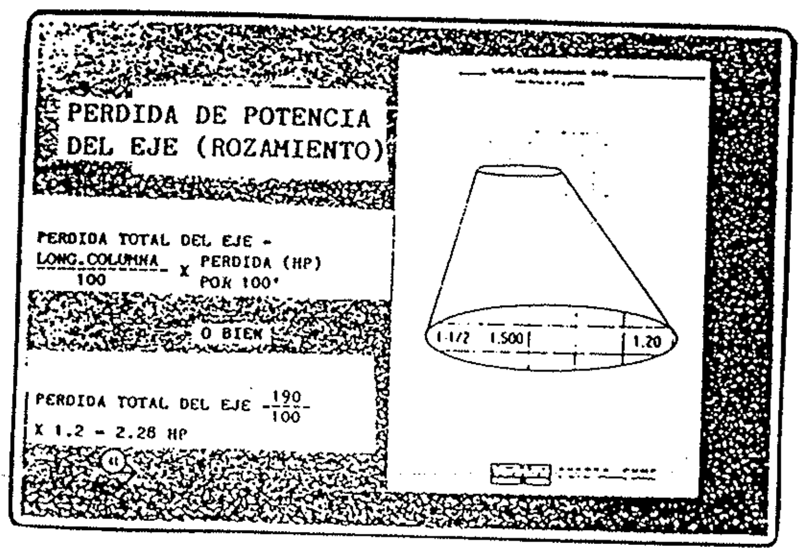


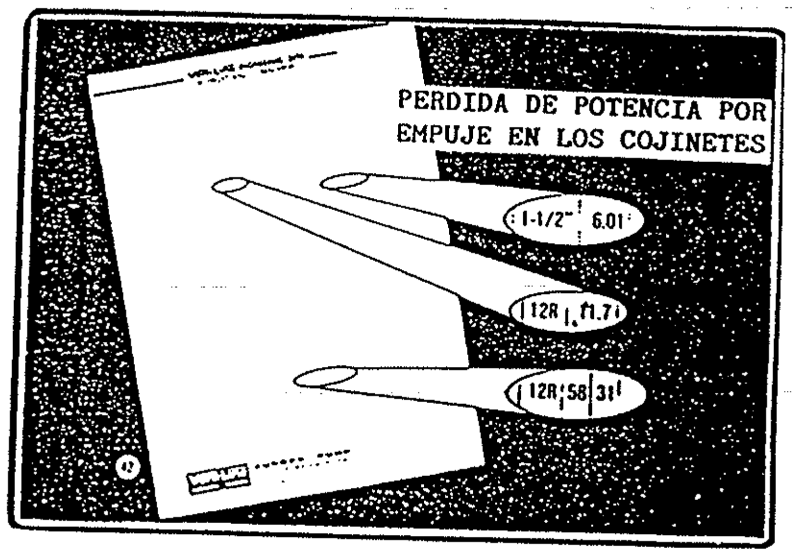
diagrama de pérdida de fricción en el eje similar a la que se encuentra en la sección técnica del catálogo. Al referirse a ésta se encuentra que la pérdida por cada 100' (30.48 m) de un eje de 1.5" (38.1 mm) de diámetro a 1770 RPM es de 1.2 HP de potencia. Por lo tanto....

La Pérdida Total del Eje es igual al largo de columna multiplicado por la pérdida de potencia por cada 100' (30.48m), dividido por 100.. o sea 190' (57.91m), multiplicado por 1.2 HP dividido por 100' (30.48m), lo cual nos da una pérdida total de potencia en el eje de 2.28 HP.

42

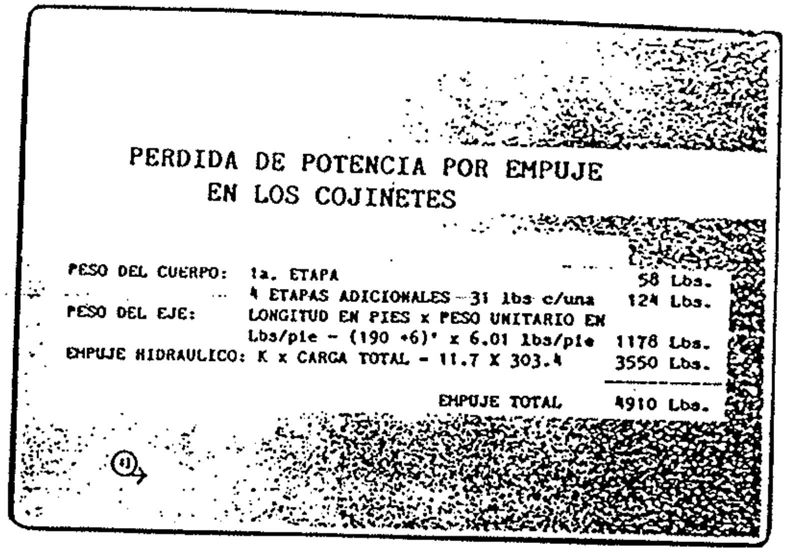
Se desea señalar en ésta etapa de la selección que es que probable que haya algunos para quienes todo esto sea elemental. Mientras que para otros algo de ésto puede ser nuevo. Estamos deleitados de poder ayudar a ambos grupos. Solo tengan un poco de paciencia con los que estamos en el medio.

Ahora queremos determinar la pérdida de potencia por empuje (en sentido axial) en los cojinetes. Que se debe hacer? Se debe calcular la carga total de empuje que actuará sobre el cojinete del motor. Al ponerlo en una fórmula resulta: Empuje Total es igual al peso de los elementos rotatorios del cuerpo mas el peso del eje, el que a menudo es llamado empuje mecánico; más el empuje hidráulico del cuerpo de la bomba (producido por reacción) esta información se puede obtener del diagrama de empujes en la sección técnica del catálogo correspondiente. En éste caso el peso de los elementos rotatorios del tazón 12R es de 58 libras (26.3 Kg) para la primera etapa y de 31 lb (14 Kgs) para las



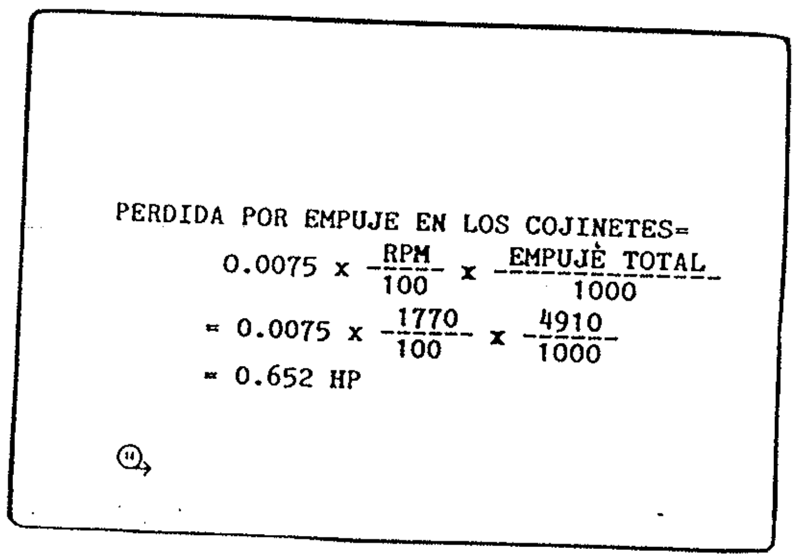
etapas adicionales. El empuje hidráulico de los tazones 12R es de 11.7 lb (5.3 Kg) por pie de carga total y el peso del eje de 1.5" es de 6.01 libras por pie.

43
Luego de una vista general a la pérdida de potencia por empuje en los cojinetes, analicemos el concepto en forma funcional. Hay condiciones que se deben considerar en el cálculo tales como 303.4' (92.48m) de altura, 190' (57.91 m) de eje de 1.5" (38.1mm) de diámetro y 5 etapas de una bomba 12RH. Ahora se puede aplicar la información, obtenida en la ilustración #12. El peso de la primera etapa es de 58 lb y cada etapa adicional pesa 31 lb. 190' de largo del eje mas casi 6' de altura de cabezal y motor multiplicado por el peso unitario del eje (libras por pie) da el peso total del mismo. El empuje hidráulico se obtiene al multiplicar el factor "K" por la carga total de bombeo. Un factor "K" de 11.7 multiplicado por 303.4' es igual a 3550 lb. Al sumar ésto nos da un empuje total de 4910 lb. La pérdida total por empuje (o esfuerzo axial) en los cojinetes se puede calcular a partir de la relación siguiente ......

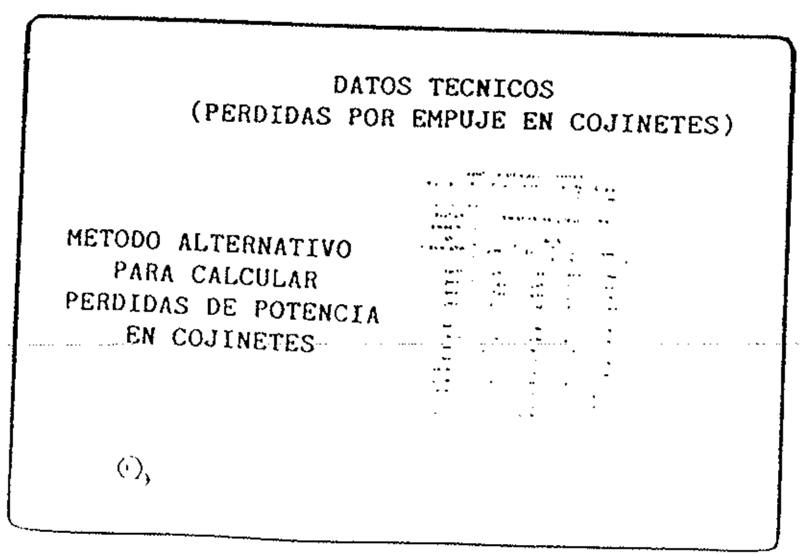


44
La pérdida por empuje en los cojinetes es igual a 0.0075 multiplicado por las RPM necesarias divididas por 100; multiplicado por el empuje total dividido por 1000.

En nuestro ejemplo la pérdida de impulso en los cojinetes es de 0.652 HP; el cual, en honor a la simplicidad, puede redondearse a 0.65.



45
No siempre es necesario calcu-



lar la pérdida por empuje de los cojinetes. La página titulada "Pérdida de Impulso de los Cojinetes", en el catálogo, contiene esta información en forma tabulada. Pero se debe interpolar para obtener los valores intermedios. Esta tabla provee una pérdida de impulso de 0.653 ó 0.65 HP, lo que verifica el cálculo original. Al comprar cualquier clase de motor, para ésta función, la capacidad de los cojinetes debe exceder el requerimiento de 4910 lb de empuje de la bomba.

POTENCIA TOTAL DE SERVICIO
(BHP)

BHP = LHP + PERD. POTENCIA EJE + PERD. POTENCIA COJINETES

BHP = 118.7 + 2.28 + .65

BHP = 121.63 HP POTENCIA TOTAL DE SERVICIO

46
Como se nota en la fórmula de la ilustración #46; la potencia total de servicio es simplemente otro término para determinar la potencia neta absorbida. Por lo tanto, al calcular la potencia total de servicio, se colocará el acrónimo (BHP). Con ésto en mente, lleguemos a la conclusión de la fórmula BHP o potencia neta, que es igual a la potencia determinada en el laboratorio, mas las pérdidas de potencia del eje y los cojinetes.

Al interpretarla precisamente, Potencia Neta es igual a 118.7 mas 2.28 mas 0.65HP. Lo cual da una Potencia Neta Total o potencia de servicio total de 121.63 HP.

Recuerdese que ésto no incluye ninguna pérdida en el motor o transmisión ya que éstas pérdidas se producen en otra parte y no se pueden incluir en los cálculos de desempeño de la bomba.

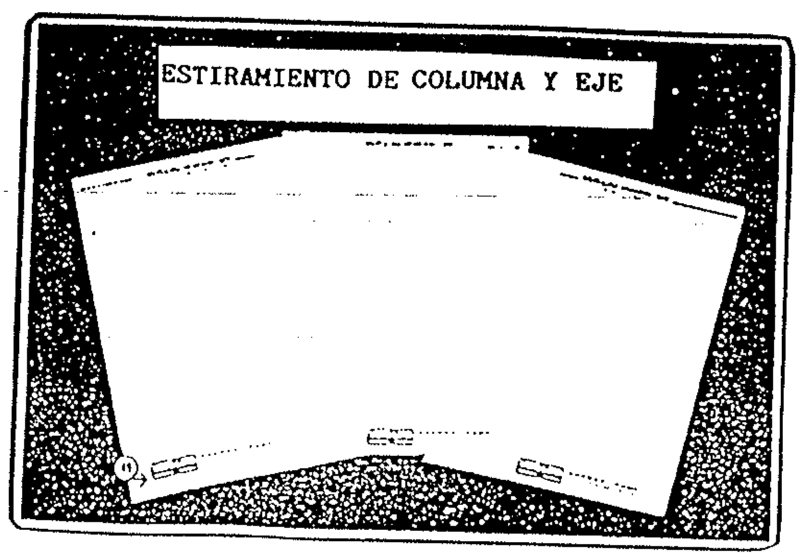
47
Ahora estamos en la posición de confirmar nuestra selección de tamaño del eje y la pérdida de potencia del mismo. Los datos para esta verificación incluyen una potencia neta de 121.63 HP, una altura ensayada en el laboratorio

de 303.4' un régimen de 1770 RPM un eje de 1.5" y una columna de 190'.

Primero se deberá revisar la selección del tamaño de eje, la cual está basada en una potencia neta absorbida de 121.63 HP y un empuje total de 4910 lb, tal como fué calculado para la pérdida de empuje de los cojinetes en la ilustración número 43.

Al usar el diagrama para la selección del tamaño de eje, se encuentra que la carga máxima para un eje de 1.5" es casi 210 HP de potencia, con una carga de empuje de 5000 lb, lo cual nos pone dentro de límites tolerables. Siempre se debe verificar éste valor, ya que la suma del peso del eje y la pérdida por fricción del mismo pueden causar que la selección preliminar del eje exceda la carga máxima. Es mas posible que tal situación ocurra con bombas de columnas de gran longitud.

48 El próximo paso es confirmar la selección apropiada del tamaño de columna y la pérdida de carga por fricción. Las condiciones de servicio son: un caudal de 1300 GPM, un eje de 1.5" y un tubo cubierta de 2.5". Ya que la selección original de tamaño del eje no cambió, las pérdidas de la columna permanecen con los mismos valores usados en los cálculos previos.



49 Cuando se suma el empuje hidráulico producido por una bomba en funcionamiento al peso del eje y de los elementos rotatorios del cuerpo de la bomba, se impone una tensión axial sobre el eje, la que causa que estiren el eje y la columna. Por causa de ésto, se debe determinar la magnitud neta de

la elongación y si ésta excede el espacio provisto en los tazones de la bomba. Insuficiente espacio libre causará que los bordes del impulsor friccionen contra las juntas que sellan el tazón lo cual resultará en excesivo desgaste y consumo de energía.

En este caso hay 3 cuadros de interés en el catálogo:

- El cuadro de alargamiento del eje
- El cuadro de alargamiento de la columna y el tubo, y
- El cuadro del huelgo del tazón.

Las condiciones que rigen son: tazones 12RH, 190' de columna de 10", un eje de 1.5" y un empuje hidráulico de 3550 lb.

Con ésta información a mano se calculará cada uno de los alargamientos.

50
El huelgo lateral o standard para 12RH es 0.560". Las tolerancias de ensamble reducen éste valor por 0.010" por etapa. Por lo tanto, el huelgo del tazón que resulta es 0.560 menos 0.050 que es igual a 0.510".

HUELGO DEL TAZON

HUELGO STANDARD DEL 12RH = 0.560 (0.010 POR ETAPA)
= 0.560 – (0.010 x 5)
= 0.510 PULGADAS

51
El alargamiento para un eje de 1.5" se puede encontrar en el cuadro de Alargamiento del Eje en el catálogo. Tal como se calculó previamente el empuje hidráulico es de 3550 lb. Ya que éste número no aparece en el cuadro, entraremos en el cuadro con el valor inmediato superior de impulso que es de 3600 lb. El alargamiento se especifica como 0.085" por cada 100' del eje. Así que, el alargamiento total del eje es igual a 0.085" multiplicado por 190 dividido por 100 ó sea 0.162".

ALARGAMIENTO DEL EJE

1-1/2 PULGADA

EMPUJE HIDRAULICO 3600 LBS
ALARGAMIENTO DEL EJE = 0.085 PULG. x 100 PIE
$= 0.085 \times \frac{190}{100}$
ALARGAMIENTO DEL EJE = 0.162 PULG.

52

Entrando al cuadro de alargamiento de la columna y tubo con 3600 lb de empuje hidráulico, se averigua que el alargamiento para una columna de 10" es de 0.012" por cada 100' de largo. Se multiplica 0.012 por 190 y se divide por 100. Esto da un total de elongación de 0.023" en la columna y tubo.

53

Esta pregunta es algo retórica pero, que fue lo que aprendimos de las ilustraciones 49 a 52?

Aprendimos como calcular la elongación del eje y la columna, el valor del huelgo del tazón en nuestro caso particular, y de cuanto resulta la elongación del eje y la columna usando nuestros factores.

También aprendimos que cuando se resta la elongación de la columna, que es 0.023", de la elongación del eje o sea 0.162", tenemos una elongación neta de 0.139". Habiendo determinado que el huelgo del tazón es igual a 0.510", sabemos que hemos escogido el eje correcto. Como sabemos ésto? Ya que la elongación neta del eje y de la columna es menor que el huelgo del tazón de 0.510", estamos seguros que hemos provisto suficiente espacio para la elongación del eje y la columna.

Si se encuentra una situación donde la elongación del eje excede cierto huelgo máximo del tazón, se tendrá que escoger un eje mas grande para obtener una menor elongación neta.

Si sus cálculos son bastante críticos, no dude en consultar con la fábrica ya que otros factores que afectan la elección se procesan en la computadora.

54

Existe un índice por medio del

ALARGAMIENTO DE COLUMNA
Y TUBO

ALARGAMIENTO DE COLUMNA
Y TUBO

COLUMNA DE 10 PULG.   EMPUJE HIDRAULICO 3600 LBS

ALARGAMIENTO DE COLUMNA Y TUBO

$= 0.012$ PULG. POR 100 PIES

$= 0.012 \times \frac{190}{100}$

52

ALARGAMIENTO EJE	−	ALARGAMIENTO COLUMNA	=	ALARGAMIENTO NETO
0.162	−	0.023	=	0.139

HUELGO DEL TAZON = 0.510

LA ELECCION DEL EJE ES CORRECTA
SI EL ALARGAMIENTO NETO ES MENOR
QUE EL HUELGO DEL TAZON

53

EFICIENCIA DE SERVICIO
DE LA BOMBA

$$\frac{\text{CARGA TOTAL DE BOMBEO} \times \text{CAUDAL} \times \text{DENS.}}{3960 \times \text{POTENCIA TOTAL DE SEVICIO}}$$

= EFICIENCIA DE SERVICIO

$$\frac{300 \times 1300 \text{ GPM}}{3960 \times 121.63 \text{ HP}} \times 1.0$$

54

cual se evalúa el desempeño de toda bomba. Es la potencia téorica para una bomba que es eficiente un 100 por ciento, en donde no hay pérdida en la columna o cualquier otra pérdida que se pueda atribuir a la bomba directamente. Lo que nos trae a la eficiencia de servicio de la bomba que es definida como la relación entre la potencia hidráulica con la potencia de servicio. Examinemos las fórmulas. La eficiencia de servicio de la bomba se determina multiplicando la altura total efectiva de bombeo por la capacidad y dividiendo el resultado por 3960 multiplicado por la potencia efectiva total, luego se multiplica el resultado por la densidad del fluído. Al substituir valores, multiplicamos la altura de bombeo de 300'; por un caudal de 1300 GPM y se divide por 3960 multiplicado por 121.63 HP de potencia multiplicado por la densidad del agua, o sea 1, que nos da un 81 por ciento de eficiencia de servicio.

55 La peor cosa que se pueda hacer con el motor de una bomba es sobrecargarlo en extremo, lo cual causa que éste recaliente y se queme. Entonces tenemos que revisar por posible sobrecarga en nuestro motor que tiene 125 HP de potencia.

Ya que tenemos un sistema donde la presión varía de 25 a 40 PSI; tenemos que revisar el punto de mínima carga donde la bomba funciona a un caudal mayor y posiblemente absorbe una potencia neta mayor. La condición bajo la cual se desarrolla el punto de menor carga posible es a 25 PSI. Entonces, la carga es igual a 190' mas 25 PSI convertida a pies, mas 3.04' de pérdida en la columna, mas 15.5,' que es la distancia

CONTROLAR POR POSIBLE SOBRECARGA

MINIMA CARGA POSIBLE

$$190' + (25 \text{ PSI} \times 2.31) + 15.5' + 3.04' = 266.3'$$

$$\frac{266.3}{5} = 53.3 \text{ PIE POR ETAPA}$$

$$\text{POTENCIA NETA} = \frac{266.3 \times 1530}{3960 \times .823} \times 1.0 = 125.02 \text{ HP}$$

PERD. POTENCIA EJE = 2.28 HP

$$\text{POTENCIA NETA} = 125.02 + 2.28 = 127.3 \text{ HP}$$

55

desde la descarga de la bomba hasta la entrada del tanque.

La altura por etapa es igual a 266.3' dividido por 5 que nos da 53.3'.

Si nos referimos a la curva 12RH del catálogo con 1770 RPM, con un diámetro de impulsor recortado para llegar a 60.7' con 1300 GPM, producirá casi 1530 GPM con 53.3' por etapa. Entonces la potencia neta requerida es igual a 266.3' multiplicado por 1530 dividido por 3960 multiplicado por 82.3 por ciento multiplicado por 1; que es 125.02 HP. Al sumarle la pérdida de potencia en el eje tenemos una potencia efectiva de 127.3 HP.

Es obvio que ésta carga o aún la máxima carga posible con menor altura está dentro del 10 por ciento de sobrecarga permitida sobre el motor con 125 HP de potencia. El caudal bombeado bajo estas condiciones de menor altura estaría dentro del caudal máximo de producción del pozo, así que la columna de 190' es satisfactoria.

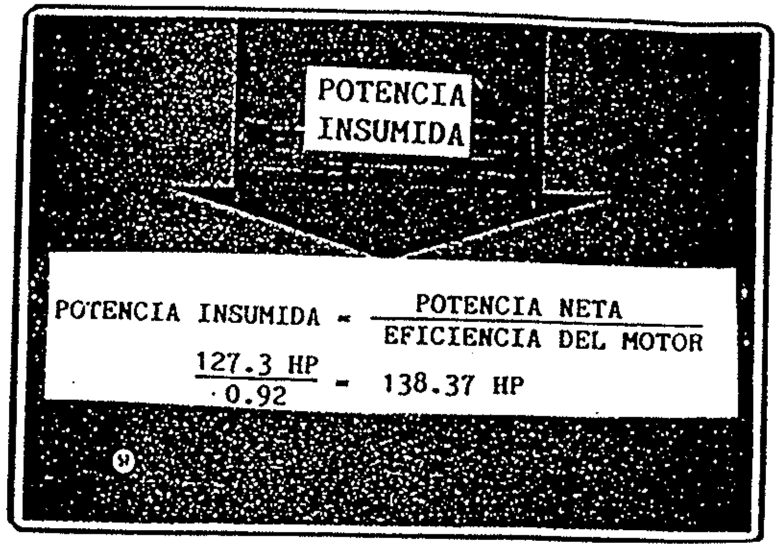
56

La eficiencia total de una bomba instalada, a veces llamada eficiencia de cable a agua, es decir la medida de energía eléctrica que entra y la medida de energía mecánica producida, medida por medio de un freno de Prony u otro medio aceptable, es la razón de la energía obtenida sobre la energía entregada en función de la carga total, caudal y potencia insumida. Esta se puede determinar multiplicando la eficiencia del motor por la eficiencia de servicio de la bomba. La eficiencia del motor, para motores normales, se muestra en el catálogo. Si se usa un cabezal a engranajes también se debe multiplicar por las eficiencias de este y del eje transmisor.

EFICIENCIA TOTAL

EFICIENCIA TOTAL = EFICIENCIA DE SERVICIO x EFICIENCIA DEL MOTOR
= 81 % x 92%
= 74.5%

57
La potencia insumida, a veces llamada potencia de cable a agua, es la potencia provista al accionamiento motríz de una bomba. Determinamos la potencia insumida al dividir la potencia neta (o potencia al freno) por la eficiencia del motor. Las eficiencias de los motores normales se muestran en la sección técnica del catálogo.

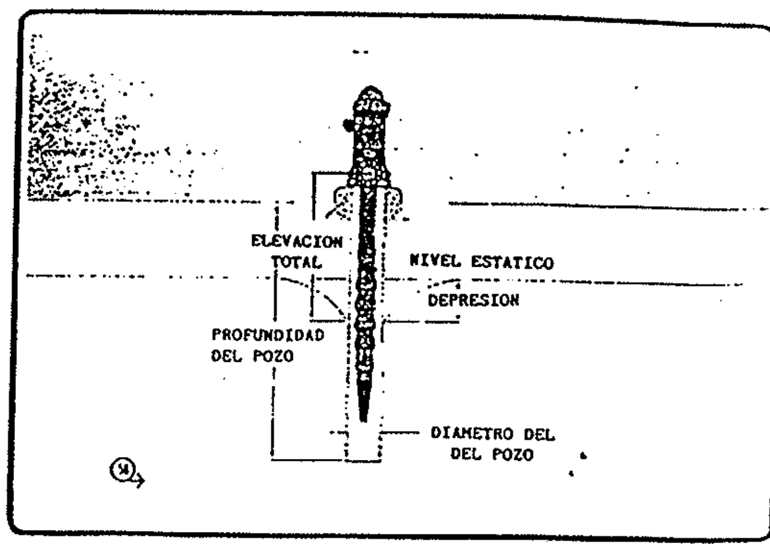


58
Al recapitular, que hemos aprendido?

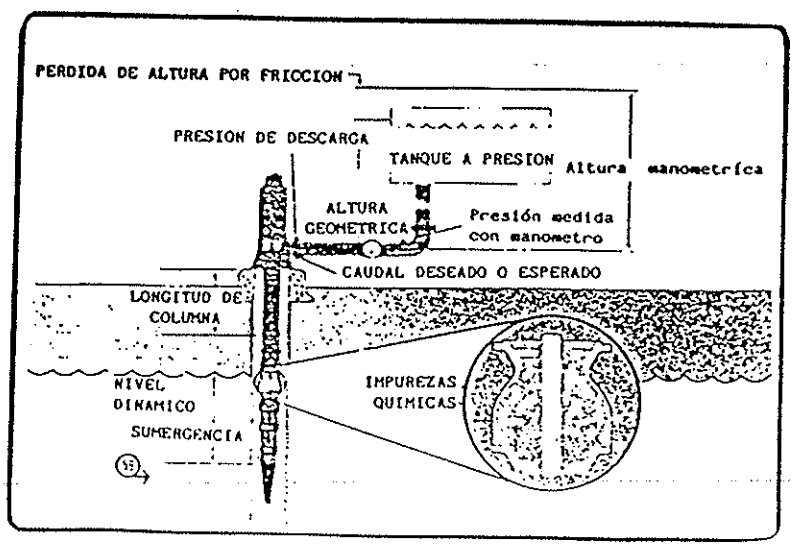
El diámetro del pozo es importante ya que determina el tamaño de la bomba que se puede instalar. La profundidad también es importante si el cuerpo de la bomba se va a colocar cerca del fondo.

Es útil saber la profundidad hasta el nivel del agua cuando la bomba no está funcionando. Esta distancia conocida como nivel estático se puede usar para determinar donde colocar el cuerpo de la bomba y si se necesita un eje descubierto. La depresión se refiere a la altura del agua necesaria para hacer que el caudal producido por el pozo sea igual al que está sacando la bomba.

La elevación o nivel dinámico como es llamado, es la suma del nivel estático del agua debajo del punto medio de descarga en el cabezal mas la depresión. Esta es usada para escoger el largo de la columna, que sea suficiente para mantener la bomba funcionando durante toda la temporada (o sea que el cuerpo trabaje siempre sumergido)



59
La altura o presión disponible nos permite calcular la carga total de bombeo.



Cuando se escoge una bomba se tiene que considerar la carga total. La carga total de bombeo en las condiciones de servicio mas las pérdidas dentro de la bomba determina esta carga total de bombeo (también llamada altura manométrica total dinámica).

El caudal que se desea o se espera del pozo permite tomar una decisión acerca del tamaño.

Se debe conocer el nivel dinámico para determinar un largo de columna que provea sumergencia amplia de la bomba.

Un conocimiento de las impurezas químicas presentes en el agua permite escoger los materiales que evitarán el daño a las partes de la bomba.

60

Para una selección apropiada del cabezal de descarga se tiene que saber:

- El tipo de descarga requerido para la bomba
- Ya sea bajo tierra o en la superficie
- El tamaño de la tubería al cual se debe conectar el cabezal.

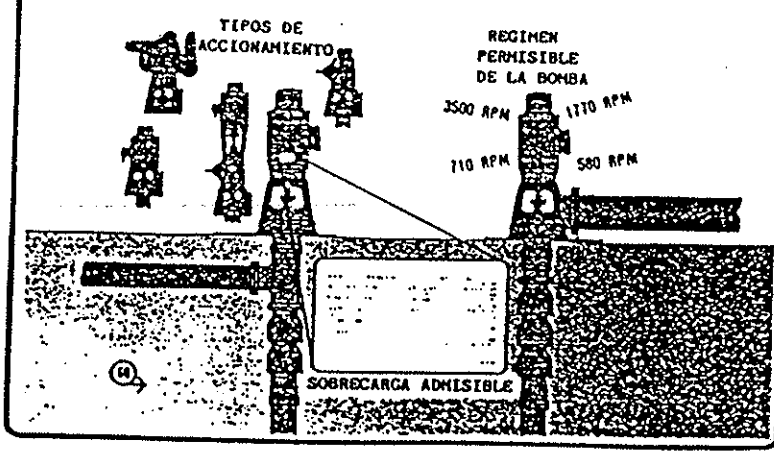
Para conectar apropiadamente cabezal y motor, se tiene que tener cierta información concerniente al tipo de transmisión necesaria. Puede que existan restricciones técnicas o por parte del usuario en la velocidad permisible de la bomba. Présteles atención!

En algunas áreas se puede sobrecargar el motor. En otras áreas no es permitido. Nuestro consejo es que se evite tal práctica.

Esto es todo, al ver el gran proceso de selección a través de la gran lente de un telescopio.

Buena suerte al seleccionar su bomba centrífuga vertical para pozo

TIPO DE DESCARGA Y TAMAÑO DE LA TUBERIA



profundo.

Pero por favor, -- no dependa tan solo de la suerte.