Draft

WATER WELL DESIGN AND CONSTRUCTION

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DEPARTMENT OF STATE
AGENCY FOR INTERNATIONAL DEVELOPMENT
OFFICE OF ENGINEERING
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1. PURPOSE AND SCOPE

a. This Manual was prepared to aid the Missions in obtaining better water-well construction. It is designed to furnish step-by-step instructions in preparing well-drilling specifications, supervising well-drilling work and preparing completion and evaluation reports. There are no other AID published criteria, or standards available for reference in compiling and preparing well drilling, sampling, developing, testing, records and reports.

b. The information contained herein has been prepared to guide the ground water engineers engaged in water well exploration and construction within the Agency for International Development. The information in this Manual should not be misconstrued to allow the inexperienced inspector or engineer to make design analyses for well, screens, certify completeness of developing, or evaluate the results of pumping tests. The manual consists of twelve paragraphs on general aspects of water well drilling work. Details are included in four appendices. Various limitations, standards and guides have been carefully seleced and developed. The guides and standards are not hard and fixed laws but reasonable limits furnished for liberal interpretation by experienced personnel.

c. It is the desire of AID/W that full information from all aquifers that appear to require artificial (sand) packing be forwarded to the AID/W for independent concurrence before completing the design and selection of well screens. For design, and selection of any well screen, it is necessary to know, the gradation analysis for the water-bearing layers (each foot of aquifer is preferable), have a detailed log showing the materials above and below the aquifers and knowledge of hydrostatics of the aquifers based on bailing-tests.

d. It is also the desire of AID/W that upon competion of pump-testing work and acceptance of the well, a full report on the construction of the well, similar to the outline and report-form given in Paragraph 11 of this Manual, be prepared and forwarded to AID/W for information and review. It is intended that copies of the report, complete with an engineering appraisal of the well and full operating instructions be furnished to the Missions for records and guidance.

2. GENERAL

a. Successful wells can be obtained by a combination of two efforts; (1) a careful review of the qualifications of the prospective drilling contractors in order to select those companies with proven ability; and (2) the furnishing of impartial technical supervision (trained and experienced ground-water engineers and geohydrologists) to observe, measure and record well construction operations and prepare reports that will evaluate the finished structure.

b. Standard Guide Specifications for Construction of Water Wells, and for furnishing Engineering Supervision of Water-Well Construction, are given in Appendices 2 and 3. In adapting these specifications to any project, the form and phraseology must be changed as necessary to properly specify the work contemplated. A separate unit price schedule is generally made for each well, whether exploratory or permanent, that is to be constructed. Identification of each well should be shown using both Schedule and Well No., for example: Schedule A, Well No. 1, Schedule B, Well No. 2.

c. Copies of all specifications and bidding documents will be reviewed and approved by AID/W prior to advertising.

d. Upon completion of the testing work in each successful water-well, a report will be prepared which will completely evaluate the well and record the drilling and testing data for future reference. Copies of the report will be furnished to the Mission and AID/W for information and guidance.

e. It is not possible to set standards for the construction of all water-wells. For example, a well built to produce 20gpm for a remote site will not be constructed to the same precise standards as a well built at a permanent installation where more than a thousand gallons per minute are required. The following general limitations are given for guidance in constructing the average well:

(1) The screen-opening capacities for wells built in alluvial (clastic) deposits shall not be greater than that shown in Table 2.

(2) The permanent pumping rate shall not exceed one-half the ultimate potential yield of the well.

(3) After surging and developing, the amount of sand or sediment raised shall be less than one gram for each 1,000 gallons of water pumped. The tests must include several periods of pump-cycling, and the pumping rate, during the cycling, shall result in at least 50 per cent drawdown of the total potential water column, or twice the anticipated pumping rate, whichever is applicable. The quantity of sand and silt, if any, can be determined by pumping into a large tank that contains a system or set of baffles located to trap fine-grained material.

(4) The turbidity of the water (after surging and sand extraction) shall be less than five (5) ppm on the silica scale as described in "Standard Methods for the Examination of Water and Sewage," A.P.H.A. and A.W.W.A. and referred to in A.S.T.M specifications D 859-55T.

(5) The presumptive coliform organism count shall be less than one per cent in all of the standard ten-milliter portions planted in

lactose broth. If the count is more than one per cent, a full examination should be made to differentiate the pathogenic organisms.

(6) If chemical analysis (partial) on samples of water from the well(s) shows that the water does not meet the standards set forth in Paragraph 10 (b), water treatment facilities must be provided to the release of the project by the Contractor.

3. RESPONSIBILITY

a. At least one trained and experienced technical person (referred to hereinafter as "Ground-Water Engineer") will be responsible for all water-well construction work in each Mission. The Ground-Water Engineer should be a Geologist or Engineer qualified by virtue of education, training and experience. It will be the Ground-Water Engineer's responsibility to:

(1) Program all test-well and permanent water well drilling, (and associated technical supervision, when this part of the work is done by architect-engineer service contract).

(2) Prepare or edit specifications, plans and bidding documents for drilling work, analyze bids and recommend drilling contractors, and maintain lists of competent companies with adequate equipment and know-how.

(3) Interpret the intent of specifications and coordinate all sampling and testing work with the contractor.

(4) Provide continuous professional engineering representation during drilling work to obtain, classify and log (in accordance with standards set forth in this Manual) all materials recovered during exploratory drilling work.

(5) Select the well screens to best fit aquifer conditions and determine the position in the well that will yield efficiently the maximum amount of water.

(6) Supervise installation of well screens and coordinate surging and developing operations with contractors.

(7) Supervise, or provide qualified personnel to observe, measure and report pump-testing work.

(8) Supervise, or provide qualified personnel to prepare final well-evaluation reports in accordance with paragraph 11 of this Manual.

b. In the absence of other information and instructions, and after receipt of this Manual, the following policies and regualtions shall apply for all wells drilled.

(1) Modern, industrial type water wells using well screens designed to fit the particular aquifer conditions shall be specified. Wells using perforated or slotted casing will not be designed or constructed without prior written approval of AID/W. Open-pit shallow wells will not be designed or constructed without the prior written approval of AID/W.

(2) All permanent water wells in plastic materials shall be completely surged and developed prior to pump testing, using techniques and methods similar and equal in all respects to those described in Bulletin No. 1033, "The Principles and Practical Methods of Developing Water Wells" by Edward E. Johnson, Inc. and as described in Paragraph 8.

(3) Artificial packed wells will not be designed or constructed in aquifers where 20 per cent or more of the total number of particles are 0.25 millimeters or coarser in size. See Plates 5, A & B. Designs for artificial packed wells will be submitted to AID/W for approval prior to installing well screen, and will include log of aquifer and gradation analysis (No. 20 sieve size and finer sizes) for each foot of material for the aquifer under consideration.

(4) No well drilling, sampling or testing work shall be

done without continuous technical supervision.*

(5) A complete report, prepared in accordance with the instructions and outline of this Manual shall be compiled for each well drilled and accepted by the Supervising Engineer.

c. Responsibilities for test hole and permanent water-well construction work (including all ground-water development and water supply facilities) will be under the direct supervision of the Supervising Engineer.

4. CONSTRUCTION OF WATER WELLS

a. A description of various kinds of water-wells can be found in the Bibliography references in U.S.G.S. Water Supply Paper 257, "Well Drilling Methods"; and in U.S. Department of Agriculture Circular 546, "Putting Down and Developing Wells for Irrigation."

b. Some wells are constructed to allow all the water to enter through the bottom end of the well pipe without using a screen or strainer. In coarse gravel or cobble formation, this arrangement can work satisfactorily for a time, especially for small capacity pumps. But in wells where sand is present, this arrangement is improper because the flow of water gradually disrupts the water-bearing formation and sand damages the pump. Frequently, attempts are made to build a cheap water well by using perforated casing that consists of pipe drilled with small holes or cut slots. In some instances, an attempt is made to get a satisfactory well by covering the perforated pipe with brass, or galvanized iron gauze, but this make-shift arrangement, retards the flow of water and increases the possibility of corrosion because dissimilar metals are used. The results of all these attempts are most indefinite and unsatisfactory.

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*NOTE: Technical supervision - "The professional engineering control by qualified and experienced personnel in the logging, sampling, testing, evaluating and daily shift reporting operations."

c. There are no clearly defined and accepted standards for water-well construction work. The quality of results depends in large measure on the class of equipment used, the training and previous experience of the driller (and ground-water engineer or other technical personnel supevising the work) and uniformity of subsurface conditions. The guide specifications and technical instructions furnished herein have been prepared on the basis that the Contracting Officer, or his representative the Engineer, will exercise continuous supervision over well drilling work. This supervision starts with review of the qualifications of the drillers and ends with the well-acceptance pump test. Appendix Four Page gives USAID personnel guidance in what is considered good well construction and some standards to check by.

d. There is generally no difficulty in getting straight holes, properly cased to depths of 200 feet or less. Below this depth, alignment and casing joints have to be more carefully checked. Deep-well turbine pumps installed in crooked holes will operate inefficiently and eventually give trouble. Actual drilling operations should not concern the ground-water engineer or inspector, if the provisions and intent of the Specifications for Construction of Water-Wells are closely followed. It is intended that the ability of the contractor to satisfactorily do the work be proven, in so far as possible, prior to starting by including the paragraph in the job specifications entitled: "Qualifications of the Contractor."

e. The following list of items selected from the standard Guide Specifications for Construction of Water Wells, Appendix 2, are among those that should be checked with the contractor and approved in writing by the Contracting Officer prior to the initiation of drilling work:

(1) A list of the number of pieces, outside diameter and

size of opening inlet (slot) for well screens (strainers) that will be furnished by the Contractor for testing purposes with date screens will be delivered to the job site. The Contractor should furnish a detailed description how he proposes to install the screens. This list of various sizes of screen openings (slot) can be stocked by the Contractor in order to have screens available and avoid delays in ordering and shipping after drilling has started. In general the pullback or standard system of well construction should be specified in preference to any other method.

(2) The method the Contractor proposes to use for aquifer-sampling, the kind of sampling equipment to be used, and frequency of sampling, especially the method to be used to recover the fine-grained materials (silt and clay) in the aquifers, transportation and storage of samples, final disposition of samples and other items required by the paragraph in the Guide Specifications entitled: "Samples and Records."

(3) A complete description of the steps the Contractor will use to surge and develop the well and remove the sand, to meet the standards set forth in Paragraph 2, "GENERAL."

(4) A detailed plan and schedule for pump-testing, including information on equipment, capacities, rates, metering and gaging devices, disposal of pumped water and similar requirements.

(5) Appendix Four, Guides of Inspection on Water Well Construction, describes the other features of the work to be checked before and during sampling and testing operations.

f. The ground-water engineer preparing the job specifications should make sure that all data on geology and hydrology available to the Mission from previous investigations are made available to the Contractor in the paragraphs of the Guide Specifications entitled: "General" and "Locations." Particular effort should be made to try to anticipate, and include in the specifications provisions for dealing with problems that might arise during the construction work, such as: the possibility of dry holes, rock drilling, disposal of pumped water, real estate action and clearances, accessibility to site during wet weather, delays caused by the Contracting Officer and similar impeding and costly factors.

g. The Guide Specifications given in Appendix 2 will have to be adapted to each well drilling project. The specifications were prepared for wells in unconsolidated clastic sediments and must be materially changed for rock wells. The provisions for well screens will probably not be required, for example, in most rock-wells; however, the type of rock and its structural conditions should be thoroughly explored before this provision is deleted. One satisfactory way to advertise for exploratory well drilling where there are many unknown factors is to provide for optional bid items and indicate in the specifications that because of the unknown factors involved this method of advertising is necessary and the decision as to application is reserved to the Contracting Officer.

h. Guide Specifications for Engineering Supervision of Water-Well Construction Work, Appendix 3, Page include most of the important technical aspects of well construction that are to be observed and reported, whether by Government personnel or by engineer service contract. The engineer supervisor, ground-water engineer and other Government personnel should never act as drilling superintendents or give instructions to the Contractor as to how he should drill the well. Engineering supervision should be limited to observing and reporting operations, and recording tests such as: alignment, welding, sampling, pumping and the like.

i. The size of the well to be constructed is usually based upon the quantity of water required. It is wise practice to first determine what diameter of well would be necessary for installtion of a pump of proper size to deliver the maximum required amount of water with best pumping efficiency. A commonly accepted practice is to specify the next larger size of well at the pump level than the diameter of the pump bowls required to produce the maximum amount of water desired. As a general rule, it is better to design for two or more wells whenever the quantity required from one well exceeds 500 gallons per minute in coarse-grained aquifers and 300 gallons per minute in fine-grained aquifers. This figure will vary for each individual area depending on the permeability of the aquifers, available land, expected life of project, radius of influence and other factors.

j. In the absence of other criteria, it is well to anticipate future expansion for all projects and water wells should be designed and constructed to produce two or more times the current requirements. In other words, wells should be constructed to yield all the potential water available in the ground that can be economically and efficiently recovered without materially changing the drawdown in adjoining wells, inducing salt-water encroachment or causing similar hydrological factors.

k. Water well drilling normally includes exploratory or test holes to locate and test all potential water-bearing beds (aquifers) underlying the surface of the ground. This is the first order of business in well construction work in unexplored areas, or in areas where reliable test-drilling has not been previously accomplished. Generally speaking and depending upon the quantities of water required, the programming of test wells hould be done to answer the following questions:

(1) How many aquifers are present underlying the surface of the ground?

(2) What are their depths; top and bottom of each aquifer?

(3) What are their potential quantities and qualities?

(4) What are the physical properties of the water bearing layers?

(5) What are the hydraulic characteristics of the aquifers?

(6) What is the practical and economical depth-limit to investigate, based on the geological conditions present in the region and the projected water supply requirements?

1. Test wells or test holes do not differ materially from permanent wells except that they are smaller. The term pilot hole applies to a smaller test hole that is drilled below and before the main well to locate aquifers and for reconnaissance sampling and logging purposes. The selection of screen sizes and final well design is best based on samples taken from the larger-size permanent well rather than from a test or pilot hole. If samples from the pilot or test hole are used for design, then the design should be checked by close sampling and logging in the permanent well. Test wells, when successful, are generally converted to permanent wells by reaming to a larger diameter and installing a permanent screen. Test wells are drilled to locate positions for permanent wells, to determine whether a site will yield the required quantity of water and investigate the general ground-water conditions in the area. The test well can frequently be used later as an observation well to measure the radius of drawdown-influence whem pumping the permanent water well. Observation wells are built to measure the static level, rate of drawdown and recovery in the water-table when pump testing a nearby well. From these measurements it is possible to determine the hydraulic characteristics of aquifers; coefficient of permeability, coefficient of transmissibility and coefficient of storage. The spacing of observation wells should be based upon geological and hydrological information. In general, from two to four observation wells, located on a line through the discharge wells are usually constructed upgradient from the well and an equal number constructed on the same line down-gradient. The distance from the discharge well to each up-gradient observation well should be equal to the distance from the discharge well to a corresponding down-gradient observation well.

m. In water-wells constructed in clastic sediments, an envelope of uniformly graded, relatively coarse sand and gravel surrounding the well screen is generally provided in one of two ways, referred to as "sand packing" or "gravel packing." A naturally-developed "gravel" envelope can be produced by removing the fine sand and silt from the water-bearing beds (aquifer) thru the well screen openings by surging and bailing. An artificial packed (gravel wall) envelope can be provided by drilling the well somewhat larger than the well screen, centering the screen in the hole and then filling the annular space around the screen with properly selected sand to fit the gradation of the aquifer soils. The materials used for the artificial envelope must be carefully sized in relation to the grading of the water-bearing formation in order to function properly. Plates 5A and 5B show the steps in selecting an artificial pack. In either of the two methods of well construction in clastic sediments, the important benefit of the sand and gravel envelope is to increase the effective diameter of the well. Also, if either type of well is correctly designed, using the grading of the aquifer materials as the starting point, proper development will usually insure a sand free well. When samples from the test well are found to be extremely fine-grained throughout and the size of 80 per cent or more of the particles is less than 0.254 millimeters, an artificial pack is indicated. The selection of the proper pack-size, thickness of pack and screen inlet opening (slot) should be based on privious experience. Plates No. 5A and 5B show screen inlet and pack gradation foruniformly graded, well graded and poorly graded aquifers. Medium and coarse grained sand within the gradation limits shown on Plates No. 5A and 5B will satisfy practically all aquifer conditions requiring an artificial pack. There follows a discussion on the steps involved in designing, and constructing artifical-packed wells. Most of the steps apply equally well to natural-pack wells.

(1) Sample carefully each foot of the water-bearing material

and measure depth to the top and bottom of each zone sampled. The amount of fine-grained silt and clay in the aquifer is most important and must be recovered and measured, or carefully estimated, if a true representation of the aquifer is to be obtained. When fine-grained soil is washed away in rotary and reverse-circulation drilling, or when the soil is not collected by sand-pump or bailer, a more favorable impression as to the coarseness and permeability of the aquifer may result. The presence of impermeable silt and clay layers should be observed and recorded. Experienced and conscientious drillers can recognize, from the action of the drill, layers two inches or more in thickness, depending upon the depth of drilling. Bail-testing should be done frequently to confirm the presence of impermeable layers.

(2) The potential aquifer should be bail-tested often to get some idea of the variation in yield of water with depth, (every five feet in coarse-grained, free yielding aquifers and as often as every foot in fine-grained material that may have to be artifically packed). This is one way to determine how impermeable (relatively) are the finer-grained layers.

(3) Make gradation analysis on the samples. A gradation curve for each foot of aquifer-depth should be obtained. Prepare a composite curve for the total aquifer, showing the range of sizes and average gradation curve.

(4) Select the portion of the aquifer that contains the coarsest graded materials for first consideration in screenings. As a rule it is mor economical in the long run to build two wells using the natural-pack system than one well using the artificial-pack method, all other things being equal. It is always better to practice to build two wells and operate them at lower yield per well than run the risk of losing a single well by over-pumping.

(5) If 80 per cent or more of the potential aquifer, foot by foot, is smaller in particle size than 0.254 millimeter (0.010 inches, 1/100 inch) then artifical-pack must be selected and installed.

(6) Determine the uniformity coefficient (D_{60}/D_{10}) of the aquifer materials. The uniformity coefficient is used in judging gradation and permeability. It is defined as to ratio between the grain diameter corresponding to 60 per cent and 10 per cent on the gradation curve, referred to as D_{60} and D_{10}. The size of material in aquifers requiring artificial-pack is fine-grained (0.254 mm to 0.02 mm) and the permeability is more or less directly related to the uniformityof gradation. The uniformity coefficient should be calculated from the average curve made from a composite of gradation curves from samples from each foot (or less) of the aquifer. The shape and mineral compostion of the individual grains exert some influence over the hydrological characteristics of the aquifer, but ways to measure this influence are not yet known.

(7) The lower limit for the pack-size depends upon the screen opening size selected. The screen opening size in turn depends upon the average gradation analysis of the aquifer. The four screen opening sizes given in Plates No. 5A and 5B will be found to be satisfactory for most aquifers, requiring artificial packs. In selecting the gradation for the pack material keep in mind the fact that the finer-grained aquifer materials have to be pulled through the pack by surging to develop the aquifer.

n. In order to be of benefit, the artificial pack must have a much higher permeability than the natural formation which it is designed to control. Higher permeability is insured by keeping the uniformity coefficient low and by making the material as uniformly graded as practicable. For example, permeability tests on three gradings of sand were considered for a well in fine-grained sand and gave the following resutls. Sand "A" with a uniformity coefficient of 1.5 was 84 times more permeable than the natural formation; sand "B" with uniformity coefficient of 2.0 was 63 times more permeable and sand "C" with uniformity coefficient of 3.0 was 34 times more permeable. The average grain size of all three sands was 2 mm (0.080 inches). For the particular design under discussion medium-grain-sand grading from 1.2 mm to 2.4 mm with uniformity coefficient not greater than 1.7 was specified. Four things must be included in the design of artificial packs: the limits of gradation, the required uniformity coefficient, the maximum thickness, and the screen opening size.

o. One of the most important factors to consider in choosing the thickness of the pack is the development work that must be done to complete the well after the sand pack has been placed around the screen. When the hole for an artificial-packed well is drilled, a thin skin of relatively impervious material is plastered on the wall of the hole. When the sand-pack has been placed around the screen, this skin or wall cake becomes sandwiched between the sand-pack and the face of the natural deposit. One of the objects of the development work is to break up and remove this material. The thicker the sand-pack, the more difficult it is to insure complete removal of the "skin" or wall cake. One of the reasons for this is that a properly designed sand-pack is highly permeable, offering little resistance to the flow of water. There is much more tendency for surging operations to slosh the water up and down in the sand-pack envelope than to cause movement into or out of the aquifer at points where it may be partially clogged. The thinner the pack, the better are the chances of removing all of the undesirable fine silt, clay and drilling muds in developing the well. Polyphosphate dispesing agents such as Calgon, plus a little calcium hypochlorite will often help remove the undesirable material. Ordinary detergent soaps will work if commercial well products are not available.

p. Three factors must be weighed in choosing the diameter for an artificial-packed well; cost, effective-diameter, and thickness of sand-pack. Cost is the first factor to consider since cost increases more than proportional to increase in well diameter. Larger effective diameter is beneficial, but only if development work can undo any damage to the permeability of the aquifer resulting from the drilling operations. The thickness of sand-packs should not be less than three inches nor more than seven inches.

5. WELL LOGS

a. Water-well logs can be divided into three general classes: stratigraphic log, drilling log or record of drilling operations, and casing log. This part of the Manual is primarily concerned with obtaining information for and recording and reporting the sequence of sediments, rocks and water-bearing beds; that is, the stratigraphic log or well log. The recording of drilling operations and related functions are of concern only as they contribute to the construction record of the heart of the well (the aquifer and well screen) and the ultimate use of the well as a water producing source. The form recommended for use in the field to obtain basic data for the drilling and casing logs is shown in Plate 1, "Well Drilling Operations Daily Shift Report." Most of the items necessary for the history of construction section of the Evaluation and Completion Report, see Paragraph No. 11, are shown on this form. It is important that the actual hours of time for the various operations during each shift be observed, distributed and concurred in by the contractor (generally the driller) and the U.S. Government representative. The daily shift report, if properly prepared, can prevent disagreement later between the contracting parties and will serve as evidence of actual work completed. The form and procedures to be used in logging the stratigraphic materials encountered are outlined in the following pages and described in detail in Appendix Four.

b. The logging form entitled "Log of Materials Penetrated," records (1) information that is required in making the design analysis for the well screen, (2) data needed to determine the proper method and approximate period of time required forsurging and developing the well, and (3) serves as the official record of subsurface data needed for evaluation upon completion of well construction. In most cases, full information for completing this form can be obtained by planning each step of the sampling and testing work prior to the start of drilling work. The Contractor should be fully informed as to what is expected in the way of samples, how to collect the samples, the approved method for measuring the depth of sample, marking the sample and similar operations. The ground-water engineer should be present for the first sampling work in every new well that is started in order to make decisions as to when and how samples should be taken and where to store the samples. As a general rule, it is good practice always to start taking continuous samples after once entering a potential aquifer below the zone of saturation.

c. The amount of water obtainable from a well can be indirectly known by measuring properties of the sediments (or rock openings) that comprise the water bearing beds (aquifer). In alluvial deposits one of the most important physical characteristics is the effective porosity or open spaces in the material. Porosity is the ratio of volume of voids to the total volume of the aggregate and is also known as per cent voids. Effective porosity is the ratio of the pore space, occupied by water that can be recovered by dewatering in a pumping well, to the total volume of aggregate. In addition to porosity there are other physical factors that control the quantity(and to a certain extent the quality) of water that can be recovered. Among these factors are density of the deposit, shape of particles, smoothness of the surfaces of individual grains, and the hydraulic head pushing the water to the well opening. The size of the individual grain is not an important factor in determining porosity. Theoretically, porosity is independent of size for spheres; and similar-shaped particles, with a given packing and a given degree of gradation should have the same porosity regardless of average grain size. In practice, it is generally found that fine grained sediments have higher porosities than coarse but this is partly a function of differences in density and orientation. Porosity is usually expressed in per cent by volume. In the densest possible arrangement of equal-size or uniformly graded sand particles, the porosity is seldom below 25 per cent and in the loosest state it is equal to 47 per cent. Clean natural sands vary in porosity from 20 per cent to 47 per cent. The porosity of a natural sand deposit then depends mainly on the shape of the grain, the uniformity of grain size and the density or compactness of the deposit. Aquifers that have a porosity of 20 per cent or less are slow in responding to surging and developing work and require considerably more time and work to build up a natural pack around the well screen. As a general rule, if the maximum size of grain in the water bearing formation is 0.40 millimeters or less (fine sand and silt sizes) and the porosity is less than 20 per cent, a large producing water well yielding 200 gpm or more cannot be satisfactorily constructed.

d. Porosity alone is not enough to determine the quantity of water that can be obtained from a well. It is helpful however in estimating potential yield, using representative samples that have been carefully collected and graded. The permeability, or ability to transmit water under pressure, is the name given to measurement of rate (quantity) at which water can be obtained from sediments. In soils engineering work permeability (coefficient) is measured in terms of velocity; centimeters per second, feet per day, etc. In ground-water engineering permeability is measured in terms of discharge, quantity per unit area under unit hydraulic gradient (pressure). Permeability can be determined for soils engineering purposes in the laboratory. For ground-water purposes permeability is almost always determined in the field by pumping one well and observing the change in ground-water level with time and distance. Attempts have been made to calculate permeability from gradation analysis and some success has been obtained, however, no formula or procedure has been derived that will give reasonably accurate values. One important reason for failure of such formulas or procedures is that a given sand can be packed to different densities. Plate No. 4 shows the extreme range of permeability that has been found in various grain-size sediments with approximately the same density. Permeability estimated from sand analysis or measured directly by a laboratory flow test can be used as a rough guide in some cases for estimating the potential yield of a well. However, the estimates should be made by a person familiar with the technology of wells and ground water and a person with wide field experience in well construction and well testing. The calculated figures should never be used without advice and judgement based on considerable experience.

e. The form to be used for logging stratigraphy is shown on Plate No. 2, "Log of Materials Penetrated." Generally, the upper 30 to 50 feet of holes in unconsolidated clastic sediments are carefully sampled, graded and logged for subsurface information for any structures that may be built in the nearby vicinity and for design of foundations under the pump house. Occasionally, drive samples and penetration tests are taken in this range of depth. The requirements for such work must be anticipated and the well drilling specifications include provisions for obtaining the samples and tests. Samples are not often taken below the depth of foundation load influence, other than for classification purposes, until water-bearing materials are encountered. As a rule, continuous sampling should be done after entering the zone of saturation. The material encountered during the drilling operations should be carefully examined, graded where necessary to determine classification and entered in Column 3. Each change in material size, or composition requires an entry. Method and rate of sampling are discussed in Paragraph 6 and in Appendix 4. The classification and description of material (Column 3) should be made in accordance with Appendix 4. The following key for examining well samples is adapted in part from U.S.G.S. Water Supply Paper No. 489. The sample whould be examined by direct visual inspection and with the aid of a hand lens. If the sample consists of sand, sandstone, gravel or conglomerate sized particles, note adherence, grain size, grain form and shape, polish or etching of surfaces and mineral characteristics of grains or pebbles. Note nature of cementing material, whether abundant or scarce, whether calcareous, siliceous, ferruginous, etc. For this purpose it may be convenient to place a small fragment of the rock in a drop of dilute hydrochloric acid on a glass slide and examine. It must be remembered that coarse dolomite will not respond to dilute acid, unless heated or unless the material to be tested is pulverized. A close approximation of the acutal percentage of fine grained materials (silts and clays) must be made. It is good practice to have settling tank or pit that can be used to receive all of the bailings, cutting, etc., from a definite, controlled interval in the well and allow them to settle out. The fine-grained soils thus collected should be included in the samples that are to have laboratory gradation analysis. It is poor practice to try to estimate the amount of fines present in a water-bearing horizon by the color of the return-water, bailer samples and the like. The color and texture will frequently indicate the physical conditions present in the deposit and should be carefully noted. As a general ruel in unconsolidated sediments, the first test well should be drilled through the deepest water bearing horizon to sample and test all aquifers prior to making a decision as to which aquifers are to be utilized. No firm, final figures can be given as to "just how deep" a test well should go. A separate decision must be made for each new area as the work progresses. In rock wells, when the relative compactness of the materials cannot be readily determined by surface mapping of the geological conditions in the area or observing the action of the drill in the testing work, core-sampling should be done to obtain representative rocks for examination.

f. Column No. 4. Plate No. 2 is to be filled in from a study of the gradation analysis on the aquifer sediments. It is an aid to be used in selecting the screen size openings. After the gradations have been completed, two or three nominal-size screen openings should be selected that cover the average range of the aquifer soils between 20 per cent and 50 per cent coarser by weight. These two (or three) size openings are tabulated as headings in Column 4 and the percentage of each size coarser by weight is shown under the size opening for each foot of depth of aquifer. The following, extracted from the design analysis of a large producing water well, will serve to illustrate the use of Column 4:

Interval (Feet)	Thick (Feet)	Material Description	Gradation Summary Size Openings 0.040"	0.060"	0.080"	Porosity Per Cent
0-122	122	Deleted for simplification	(Percent coarser)			
122-125	3	Silty Sand, with scat gr, entered hydrostatic water at 123', rose to 11' in 30 sec. S.W.L. @ 8' not screenable, runny				
125-126	1	Gravelly Sand, rel Clean, H_2O bearing, sharp ang pcs, max size 3", tight, combined samples 127-130 and 130-134 as similar, igneous, greenstone and quartz.	52	38	20	38
126-127	1		48	35	18	33
127-130	3		50	35	20	35
130-134	4		44	38	12	30
134-135	1		30	17	11	24
135-136	1	Sandy Gravel, similar to above, coarser, with 2"-3" layers of tight impervious blue clay binding gravel, required drilling, interval will have to be specially developed.	70	55	43	42
136-137	1		72	53	44	40
137-138	1		68	54	41	38
138-143	5	Clay, sandy, tight impervious, blue-gray.				10
143		Deleted				

(NOTE: Fractions of a foot dropped for simplification).

g. The water-bearing horizon in the log given above extends from 125' to 138' or 13 feet. By leaving two feet at the top to hold the loose roof and one foot at the bottom a standard 10 foot well screen was used. The material is exceptionally well graded throughout and quite uniform in size so a screen opening of 0.060 inch was ordered which could yield, for the 10 inch diameter screen, 430 gallons per minute without danger of sand packing. The screen opening area for various screen sizes is shown on Plate 11 The quantity of water that can be obtained from a formation without danger of sand packing is given in Table No. 2. An additonal 18 gallons per minute could have been obtained by ordering a screen having the bottom 2 feet with 0.080 inch openings and the upper 8 feet at 0.060 inch openings.

6. FORMATION SAMPLES

a. Good representative samples from water bearing beds are the key to successful well construction. The purpose for taking samples is to determine closely the natural conditions that exist inplace in the water-bearing materials. By knowing accurately what these conditions are in sediments then it is possible to select the proper screen sizes and to the surging and developing work in the most effective manner. It ispossible to deduce from action of the drill the relative density of the materials, from the way the water level responds to bailing the degree of permeability, and similar indirect facts without ever seeing the samples. The contract specifications usually place responsibility for taking samples and measuring sample thickness on the drilling contractor. The mechanical operations of taking samples must be the contractor's responsibility, but where to sample must always be the Contracting Officer's responsibility.

b. The use of the percussion drill (churn, cable-tool, spudder, etc.) can be stipulated in the Guide Specifications, Appendix 2. This particular type of drilling is frequently chosen in preference to others when it is necessary to get accurate samples and time is not too important. There follows a list of advantages in using the percussion drill:

(1) Accurate samples can be obtained, the degree of accuracy

need be limited only to the kind of samples and amount of time that can be spent.

(2) Each stratum can be tested for quantity and quality of water as drilling proceeds.

(3) Lower quality and contaminated waters can be sealed off by casing as the hole advances.

(4) Less water is required for drilling operations.

(5) Less damange results to the water bearing material because drilling muds are not used.

(6) Any encounter with water-bearing beds is noticed at once and testing in unknown regions, or developing border line cases can be easily and positively accomplished.

(7) As a general rule the first hole in any new area should be drilled with a percussion drill. After the aquifer limits have been determined any kind of a drill can be used to construct the permanent wells. Electric well logs are no substitute for actual samples of materials that have been graded, tested, and described.

c. Whenever possible, formation samples should be taken from cased holes (the larger the size hole the better) by sand or suction pump, core-barrel, auger, or special samplers that will recover the material in as undisturbed a condition as possible. Washed, jetted, or rotary samples are not representative of the sediments from which they are taken and therefore are not reliable as samples for screen analysis. Samples from rotary or reverse circulation drills should not be used for screen design. Samples taken directly from a rotary, jet, reverse circulation and other open-hole drills are generally contaminated by drilling muds and by loose material from the walls of the hole. Further, particles in the samples are always segregated and washed in being carried to the surface in drilling-water.

d. The following from Bulletin No. 638-S "Instructions for

Taking Formation Samples," Edward E. Johnson, Inc., will aid in obtaining samples in unconsolidated formations: "The best method to secure a representative sample is to drive a loose plug part of which may be removed by bailing carefully and at the same time taking care to prevent heaving. Formation samples should never be taken 'on the heave or rise'* as the finer particles and the coarser particles are separated giving a false picture of the true grading of the formation. To overcome heaving and obtain accurate formation samples is sometimes a problem. The usual procedure is to fill the hole with water to balance the hydrostatic pressures on the inside and outside of the casing. Another method is to drive the casing as far ahead as possible in order to cut off the outside pressure thus allowing the heaved material to be removed. It should be remembered that material that has heaved has been disturbed and therefore is not representative of the formation." It is good practice to have the driller save all materials recovered during drilling operations from potential aquifers. It can be stockpiled on boards or canvas laid on the ground near the well and visually graded and classified in the field. Representative samples can then be combined and selected for laboratory gradation analysis. The larger the sample examined and graded the greater the accuracy. As a general rule all the material from holes smaller than 10 inches in diameter from potential aquifers should be quartered and graded for the best results. Samples from the first fifty (50) feet or so of wells can often serve for foundation exploration purposes and this dual usage should be anticipated and included in the bidding documents and specifications. Hydrometer analysis should not be made on aquifer samples.

7. DESIGN AND USE OF WELL SCREENS

a. Most of the wells to be constructed by AID Missions will be in

* When hydrostatic pressures in the drill hole become greater than the weight of the column of water, it frequently happens that sandy material is heaved or forced up the drill pipe.

unconsolidated clastic sediments and will require the use of well-screens, designed to fit the gradation and thickness of individual aquifers. Table 1, lists the types of well screens that are available in the United States and Europe. Modern, industrial wells in clasitc sediments fall in two classes, the natural pack wells and artificial-pack wells. In order to insure satisfactory results the latter type well requires the services of a specialist, both in the design and construction and should not be attempted without detailed knowledge of the aquifer conditions, including gradation analysis and permeability tests on each foot (or less) of material from the aquifer(s). In the developed, natural-pack well, no provision is made or needed for the insertion of sand or gravel artificailly; the entire method is dependent upon the withdrawal of the finer grained sand and silt from the water bearing formation around the screen. The particles are pulled through the screen openings by surging and then removed by bailing until a stabilized envelope, or zone of coarser grained particles, too large to pass through the screen openings, remains around the screen. This envelope or developed zone has a much higher permeability and greater porosity than the original formation material. This serves two purposes: it removes the fine grained sand and silt that could block the well and plug the pump, and removes the material that fills the voids and hinders the free-flow of water into the well. If the ground water contains dissolved minerals that may deposit out in the formation, the higher porosity developed in the formation retards this tendency and increases well life. The fundamental considerations necessary to determine what type of well construction to use are:

(1) Ordinary fine sand with reasonable premeability and good uniformity is usually best screened without packing and with the use of a screen with small openings, between 0.010 inch and 0.020 inch openings. The use of screens with openings smaller than 0.010 inch should not be attempted. See Plate No. 11 for decimal and millimeter equivalents. The installation

of screens with small openings requires extra care in the surging and developing work to insure satisfactory results.

(2) Aquifers in very fine and uniform sand (smaller than 0.254 mm) can be best developed using artificial packing. The design, development and use of thiskind of a well is very critical and should be constructed only as the last resort and in accordance with paragraph 4, "Construction of Water Wells," by a driller that has had proven prior experience.

(3) Under practically all conditions a mixture of coarse and fine sand or gravel is best finished with developed natural pack, using as coarse a slot of screen as an accurate analysis of the material shows to be advisable. The screen-opening size should fit the gradation curve of the aquifer materials. It is the common practice to select a size opening somewhere between the 60 per cent and 80 per cent finer by weight size. The actual size depends upon the natural gradation curve of the materials throughout the aquifer, the average porosity of the section of the well being studied, the quantity of water desired and the gradation of the materials that lie over the aquifer. It is necessary to know the nature of fine-grained silts and clays when present above, below or interbedded with water bearing formations, including the extent of plasticity and degree of cementation. The size of the screen opening often determines the amount of work required to loosen clay-bound particles by surging action. It is sometimes necessary to use polyphosphate dispersing agents and other forms of agitation to assist in the removal of silt and clay. The size of the screen openings should meet the gradation of the material throughout the entire section of the aquifer(s) to be developed. As a general rule water bearing formations become coarser with depth and it is often possible to have larger screen openings in the bottom part of a well. This is one reason why it is so important to have the accuracy of the well log measurements to 0.1 of a foot or closer. Where

loose fine-grained soils occur above an aquifer, sufficient material (at least one foot) should be left between the bottom of the fine grained soils and the top openings in the screen. The upper portion of the aquifer may also be left undeveloped as a filter. The materials under the aquifer should be solid enough to prevent settlement of the screen and coarse enough not to be sucked in and block the lower part of the screen during surging operations. In the ideal condition, one or two feet of the aquifer will be left unscreened below and aboce the top of the screen. This all adds up to several feet of unused or blank screen section. The pull-back or standard system of well construction should be specified, if at all possible in preference to any other method.

b. In the case where exploratory drilling has opened a hole below the aquifer selected to be screened and developed and it becomes necessary to plug back (back-fill) the hole, extreme caution must be used so as not to construct a situation where later development and pumping will cause settlement in the materials used to backfill the hole with a resulting settlement in the well screen. It is a good practice to compact backfill material in four or five inch layers under water with the bit and tool string before installing the screen and thus have insurance against it "floating away." Before installing a new screen it should be thoroughly examined to see that it meets specifications as to the type metal desired for the quality of the ground-water present, that the size openings are correct and that the lead packer is undamaged. Some drillers will expand the packer prior to installing, leaving only enough clearance to get it in the casing and finish the expanding after the casing has been pulled back and the screen set. If at any time during the surging and developing operations material coarser than the screen opening size is withdrawn, immediate action is indicated. Either the packer was not properly set or else the screen has ruptured allowing the coarser grained aquifer material to flow into the hole. To insure that the packer has sufficient casing length to seat against and to allow for a small amount of settlement it is common practice to leave at least one foot of the casing over the top of the screen when setting the packer.

c. Representative types of well screens available from manufacturers in the United States and Europe are listed in Table No. 1. Prepacked well screens are used in Europe. Aquifers cannot be surged and developed through a prepacked screen.

TYPES OF WELL SCREENS (STRAINERS)

SCREEN MANUFACTURER AND ADDRESS	TYPE OF SCREEN	RANGE OF SIZE OPENINGS	TYPE OF SCREEN OPENING
1. Edward W. Johnson, Inc. 315 N. Pierce St. Paul 14, Minn.	(1) Wire-wound, welded, continuous slot; everdur, stainless steel, brass, iron.	0.006" to 0.250"	Self cleaning, non-clogging, "V" shaped, horizontal slot.
Screens can be installed by any one of three methods; (1) screen attached directly to the casing in an open hole, (2) standard or pull-back, and (3) bail-down or wash down.			
2. Cook Well Strainer Co. 6330 Glenway Avenue Cincinnati 11, Ohio	(1) Wire-wound, continuous slot. (2) Slotted, seamless tubing. All metal listed under 1. above.	0.006" to 0.0250"	Same as above
Screens can be installed by any one of the three methods listed under 1. above.			
3. EMSCO Screen Pipe Co. 3 Ricks Road Houston 21, Texas	(1) Slotted, black or galvanized iron pipe. (2) Slotted pipe with wire-wound screen, galvanized, bronze or stainless steel. (3) Prepacked screens, sand of any gradation placed between inner and outer slotted iron pipe.	0.006" to 0.100"	Machined slots "V" shaped wire wrapped.
Screens can be installed only by open-hole method.			
4. Layne & Bowler, Inc. Memphis, Tennessee Layne-France 39 bis, Rue de Chateaudun Paris, France	Pressed-slot openings; everdur, steel, iron, stainless stell, monel.	0.020" to 0.125"	Slot with overhanging shutter.
Screens are installed only by the open hole method. Company claims success using bail-down, artificial-pack method with cone on bottom of screen. Use of this screen limited to coarse grained materials meeting the slot-opening size or artificial-pack wells.			
5. Doerr Metal Products Co. Larned, Kansas	Same as 4.	0.010" to 0.250"	Same as 4.
Screens can be installed only by the open-hole method. Trade name DOERR GRAVEL-GUARD. Screen sections are 4 foot long and joined by swaging.			

Table 1

Table 1 (Continued)

SCREEN MANUFACTURER AND ADDRESS	TYPE OF SCREEN	RANGE OF SIZE OPENINGS	TYPE OF SCREEN OPENING
6. Schonebecker Brunnen-filter Kirchroder Strasse 10 Hannover-Kleefeld, Germany	Compressed bakelized wood, Stoneware, Plastic (no metal)	0.012" to 0.080"	Slotted; smooth, flat walls, vertical for stoneware, horizontal slots for wood and plastic.

Installed by open-hole method only.

SCREEN MANUFACTURER AND ADDRESS	TYPE OF SCREEN	RANGE OF SIZE OPENINGS	TYPE OF SCREEN OPENING
7. Willersinn-Filter Mainzer Landstrasse 78 Frankfurt AM Main Germany	Prepacked, cemented sand size particles, unlined, continuous filter-pipe from bottom of hole to surface (no metal)	4 gradations 0.030" to 0.250"	Joints 3' long, joined together with resin and nylon.

Installed by open-hole method only.

SCREEN MANUFACTURER AND ADDRESS	TYPE OF SCREEN	RANGE OF SIZE OPENINGS	TYPE OF SCREEN OPENING
8. Hagusta G.M.b.H. Schaumainkai 89/91 Frankfurt AM Main Germany	Cemented sand-pack around outside of coated and slotted steel pipe.	0.030" to 0.125" in four sizes of sand-pack gradation.	Joints 8' long Screwed or flanged connection.

Installed by open-hole method only.

SCREEN MANUFACTURER AND ADDRESS	TYPE OF SCREEN	RANGE OF SIZE OPENINGS	TYPE OF SCREEN OPENING
9. J. F. Nold & Co. Stockstadt/Rhein Germany	Perforated and slotted, bridge slots similar to Layne & Bowler; in coated steel, copper, bronze, stainless steel.	Slots: 0.8" to 2" in length, and 0.04" to 0.4" wide.	Joints 6.6', 8' and 10', clamp, flanged or threaded joint connection.

Manufacturer recommends installation in artificial-packed wells only by open hole method.

SCREEN-OPENING CAPACITIES

(Capacities that can be obtained from a formation requiring the slot numbers specified below without danger of sand packing).

Sizes of Wells	Screen Openings (inches) Gals per Min. per foot of screen				
	0.008-0.010	0.014-0.020	0.030-0.040	0.050-0.060	0.080-0.100
4 Inch	3	7	10	17	20
6 Inch	5	10	15	25	30
8 Inch	7	13	20	35	40
10 Inch	9	17	25	43	52
12 Inch	12	25	37	62	75
16 Inch	15	27	40	65	80
18 Inch	18	35	53	90	105
20 Inch	20	40	60	100	120

Example: A ten foot section of 8 inch (nominal diameter of casing, actual outside diameter of screen, $7\frac{1}{2}$ inches) having slot openings of 0.050 inch would permit the free entrance of 350 gallons of water per minute without danger of plugging the screen with sand, providing the well has been completely surged and developed. There are 100 square inches of opening area per foot of screen or 1,000 square inches of openings in this particular screen.

Table 2

8. WELL DEVELOPMENT

a. Two methods are generally recognized and approved for the surging and developing phase of well construction. They are (1) using the solid-surge plunger (or the valved-surge plunger) and by (2) the use of compressed air. Ordinary pumping without the benefit of backwashing or surging is not an acceptable method for developing water wells. The Guide Specifications provide for a review by the Contracting Officer, or his representative, the Engineer, of the methods proposed by the interested well-drilling contractors during the bidding stages of work. It is important to know and concur in the system that the apparent low-bidder proposes to use and have a prior commitment on the number of pieces and type of equipment that he will employ in doing the work. Prior to the awarding of a contract it is well to find out exactly what his attitude is toward spending the time and patience that is required to fully surge and develop most wells. The common problem in well-construction is to find a contractor that has modern, industrial well-construction experience, who is willing, or able to recognize the need for high standards of work and in a position to perform the work in compliance with guide specifications.

b. Based on the percentage of fine-grained soils to be withdrawn from the aquifer, as determined from the gradation analysis and the length of the screen, it is good practice to prepare a rough estimate in advance of work as to the quantity of sand that will be (or should be) extracted during the development work. See Appendix 4 for procedure. The surging work should be started slowly and the surging pressure and rate gradually increased as the work develops. The rate should never be so rapid, or the surging cycle so long, that the amount of sand pulled into the screen between bailing operations exceeds 1/5 the length of the screen. In other words one or two feet of sand is all that should be pulled into the screen in one surging operation. The inspector should observe the rate and period of surging, the amount of sand in the screen (or withdrawn) after each cycle of surging and size of the particles recovered. Surging operations should continue, when using the plunger-type system until the amount of sand in the screen is less than six inches in depth in the bottom after surging for one hour or more using a set of new and tight plunger washers and the plunger falling freely with the full weight of the tool string less jars. An experienced well driller can tell from the "feel of the cable" on a standard cable tool percussion drill when the screen is loading-up with sand. The driller can regulate the speed and stroke of the machine to produce a wide range of effects. As in all phases of well drilling, final results depend greatly upon the skill and judgement of the driller. Surging and developing work should not be stopped once it is started, because it is difficult and impossible in some cases, to start the sand and silt flowing again into the screen once the action or cycle has been broken.

c. Any well drilling operation produces some undesirable effects in the water-bearing sediments immediately outside the bore-hole. In drilling a well by the rotary method, the drilling mud forms a coating on the wall of the hole usually referred to as the "mud cake." Also, some of the drilling fluid flows out radially into the sand formations penetrated by the well. This is called mud invasion of the formation. The mud clogs the pores in the sand for some distance in all directions around the hole. The fluid pressure due to the weight of the mud in the hole forces some of the mud out through the voids in the sand and gravel. At some critical distance (two to five inches from the wall of the hole) the flow rate slows down, the mud thickens in the pores of the sand and gravel and develops an appreciable gel strength. This increases resistance to flow and stops further mud invasion. The critical distance at which mud invasion stops is different for each situation. It will vary with the viscosity of the drilling fluid, the fluid, the fluid pressure in the hole, the gel properties of the fluid and the permeability (or in this case porosity) of the water-bearing sand. Obviously, all the mud must be removed if the well is to be brought to maximum yield and efficiency. The undesirable effects of cable tool (percussion or churn) drilling is the forming of a skin of silt and clay on the inner face of the drilled hole and the vibration of the sand around the casing resulting from driving the casing. The skin of silt and clay occurs as the well casing is forced down through the water-bearing sand and gravel and later pulled back to expose the well screen. These movements of the well casing produce a troweling action that leaves a "slick" of silt and clay on the wall of the hole. The vibration of the casing during driving tends to compact or densify the sand and gravel. Recognizing this, cable tool drillers always try to work the casing down in the water-bearing formation by bailing or sand-pumping operations rather than by driving.

9. DRAWDOWN AND YIELD TESTS

a. Prior to completion and acceptance of every well drilled some form of pump testing will be done to evaluate the hole, determine the extent of its usefulness and if a producing well, help fix the most efficient position for the pump-intake setting. The contract specifications should establish the responsibility for the various portions of the testing work. Generally it will be the contractor's responsibility to furnish a detailed plan as to how he proposes to test each well and to furnish, install and operate the pumping and gaging equipment.

b. It will be the USAID responsibility, in most cases, to provide qualified personnel to review the contractor's plan and make recommendations, when necessary, to insure measuring and recording controls during the testing work. USAID should arrange to have at least one trained man on the job at all times during the pump-tests to observe, measure and record the rate of pumping, drawdown in the wells being pumped and also in the observation wells, make temperature measurements, collect samples and obtain other data necessary for the evaluation and completion reports. As a gener rule the Contractor sh ... ... sh an electrical water-level measuring device, chalked- ape equipment, clip board with pump-testing recording forms, thermometer, sample jugs, and make the physical and chemical analysis on water samples. Further details for observing and measuring drawdown-yield tests are in Appendix 4. The major items of information that should be obtained in the test are shown on the form, "Pump-TestingReport," Plate No. 3, which should be used in a comparable form for all pump-testing work.

c. The quantity of water being pumped ("Pumping Rate," Column 4, on Plate No. 3) can be determined by any one, or combination of methods, such as measuring the quantity in a tank or barrel, flow-meter, orifice meter, weir, calibrated pumping curves based on the velocity of the pump and others. The pumping level can be measured by using a pressure gage, altitude gage and air line, bubbler system, electrical sounding devices and chalked-tape.

d. Perhaps the most important factor in pumping tests is the ability of the pumping equipment to maintain a continuous and constant pumpi ng rate until stabilization occurs in the drawdown of the pumped well. Quite frequently it is desirable to continue pumping at a constant rate until drawdown has ceased in observation wells. Misleading results are obtained from observation wells that are not constructed to be fully open into the pumped formation. An observation well must have permeable connection into the water-yielding formation. One test for this is to pour a quantity of water into the observation well sufficient to raise its level by a readily measurable amount. Timed readings of the water level change are then taken on the observation well to see how rapidly the water level returns to its original elevation. Observation wells that are "deaf" (do not respond to water lev fluctuations) should either be cleaned out and rehabilitated or abandoned.

e. The sequence of pumping operations for drawdown and yield testing purposes should be as follows:

(1) Cyclic pumping, in short spurts, to celan-up and test the surging and development work. It is frequently possible to increase the yield per foot of drawdown or raise the static-water level by this operation. This can also be considered part of the development work.

(2) Make the sustained pumping test required by the specifications to determine the maximum yield of water per foot of drawdown, specific capacity. Continuous pumping at a safe, constant rate should be done until the drawdown remains at a stabilized level for at least 12 hours. In large well programs pumping operations are continued until the drawdown level in one or more of the observation wells becomes stabilized.

(3) In conjunction with (2) above, or immediately following, special drawdown tests are made to obtain additional data. The type of special pumping test and duration depend upon the size and purpose of the well. These features of work are included in Appendix Four.

(4) After completion of all drawdown operations make the recovery measurements.

f. Explanation of Pump Testing Report Form - Plate 3.

(1) Column Number One; Time: During all phases of testing an accurate record of time must be kept. This is so because the hydraulic equations that describe ground water flow in an aquifer include functions of time. The way in which drawdown changes in relation to the time-duration of pumping provides data for calculating these functions. Values can also be calculated from the way water levels recover after pumping is stopped. Time-drawdown measurements and time-recovery measurements provide two distinct sets of information from a single aquifer test. The values obtained from the analysis of the recovery record serve to check the calculations based on the pumping record. The rate of receovery after

the pump is shut off is probably more accurate in demonstrating the performance of the well than the drawdown. Variations in pumping rate, loss in pump-friction, pump noise and other physical factors are absent during the recovery period. For these reasons the recovery of a well should be carefully observed until the water-level has reached or closely approached static level.

It is generally good practice to cycle the pumping-rate during the first few hours of test-pumping to test the efficiency of the surging and developing work and at the same time "finish up" any undeveloped portions of the aquifer. The pump cycling should be in ten minute intervals, five minutes on and five minutes shut off. This holds ture only where the drawdown is more than 25 per cent of the total water column when the test pump is operating at the maximum rate. The amount of sand and silt pumped, if any, should be carefully measured and reported. After cycling the well should "rest" until the water level has fully recovered before starting the acceptance pump-testing. In absence of other criteria it is suggested that the first pumping rate for the acceptance test be one-third to one-half of the anticipated operating rate or about 1/3 of the maximum drawdown possible, whichever is the greater. When first stage pumping has started, readings should be taken every minute for the first 15 minutes, every five minutes for the next one-half hour and at half-hour intervals thereafter. The first stage pumping should be continued for at least 12 hours after the drawdown has remained constant. The second stage pumping, in step-drawdown tests, (refer to Plate No. 10) is generally at twice the first stage rates, but it need not be continued until complete stabilization is obtained. The rate of stabilization-curve for the first stage pumping can be used to project the second stage drawdown curves to stabilized conditions. Step-drawdown testing is further described in Appendix Four.

(2) Columns 2 and 3. Water Level Readings and Drawdown:

The gage and air line method is the most popular method used for measuring water level. The procedure is quite simple. It is shown on Plate 7. A hand pump forces air through an airline extending from the surface to the top of the pump intake. The air under pressure displaces water that would normally fill the airline. As water is displaced, the pressure increases until air bubbles out of the bottom of the airline. The air line must be air-tight. A gage with a scale of pressure values is used to measure air-line pressure. The maximum readings on the pressure gage indicates to a first approximation the "head of water" over the bottom of the airline. When the gage is other than a direct-reading altitude gage a correction must be made to convert the unit of pressure reading to feet of water. The air line and gage should be carefully checked to see that they are operating correctly before starting the test. The length of the airline should be such that its lower end is several feet above or below the pump intake. If the airline terminates close to the place where water enters the pump the excess turbulence in the well at this point makes it difficult to get good readings on the gage.

A precise water-level reading device such as an electric sounder is used to calibrate the air line gage, take check readings from time to time and be on hand for more accurate readings. The air line system is more convenient but not always dependable. The Fisherscope Company, Palo Alto, California, manufactures an approved electrical water-level measuring device.

(3) Column 4. Pumping Rate: The rate of pumping can be measured by flow meters, venturi tubes, circular orifices, weir boxes and can be estimated from the velocity of pump and pump curves. These are all indirect methods for estimating discharge rate. Taken alone, the pumping rate figures have little meaning. It is only when discharge is compared with drawdown and time, that it takes on meaning. The rate of pumping will

always fluctuate to some degree, despite the most careful adjustments of pump controls. This uncontrollable rate fluctuation is due to flow friction, air pressure, changes in ground-water pressures, small changes in velocity of pump-driver and other physical factors. When using a channel weir, flow-meter or other device, direct readings can be entered in column four for later reference and conversion to GPM. Conversion to gallons per minute should be obtained from standard orifice and weir tables. Prior to starting a pump-test it is always good practice to check the weir tables that are on hand to see that they cover the size orifice and educator pipe that are to be used. Four large scale pumping tests of 500 GPM or more, it is best to use an orfice plate having an opening of at least three inches less in size than that of the eductor pipe. As a general rule, the head rise above the center of the pipe should be between 6 inches and 48 inches. To insure that this range is obtainable the tables should be consulted prior to selection of weir sizes and the correct sizes for the pumping rates determined. In the case of a flow meter, pumping curves or other recognized methods of gaging the pump production, the factored quantity should be entered in column four. The circular ofifice weir should be checked to see that it is level and that a control valve is located near the discharge of the pump to control the pumping rate. A straight run of pipe from the valve to the measuring device must be long enough so that any turbulence caused by partial closing of the valve will not interfere with the flow through the orifice: The distance from the orifice plate to the ell on the piezometer tube should be checked. If a weir box is used, the approach channel should be checked to be sure that it does not create turbulence just ahead of the weir.

(4) Column 5. Recovery: The rate at which the water level in the well rises (in both pumped and observation wells) after the pump is shut off should be carefully observed and measured. It normally takes two persons to obtain accurate results from pumped wells during the first few

minutes after the pump is shut off, one to measure and one to record. A good method is to set the electrical gage (when this device is at hand, otherwise the lower readings cannot be taken) at a depth equal to about one-half of the drawdown and then observe the time it takes for the well to recover to this position. The rate of recovery for the remaining one-half of the total drawdown will be at a slower rate and can usually be measured at a fairly even pace. As many readings, as can be accurately obtained during the first 15 minutes of recovery, will help to fix the recovery curve. The rate at which the well recovers will be later compared with the rate at which the static-water level was lowered when pump-testing started. The results of plotting these two rates should be closely comparable, depending upon the accuracy and frequency with which the readings were taken. The depth to water (Column No. 2) readings are taken in the same manner during the recovery as during the drawdown. Column No. 5, Recovery, is the distance that the water rises after pumping ceases. It is obtained by subtracting the water level readings at each time stage of recovery from the average maximum drawdown at the stabilized final pumping rate. There are other hydraulic features that enter into recovery calculations, however, all data necessary for later study will be available if the information required by Plate No. 3, Pump Testing Report Form is carefully obtained. The form can be modified as necessary to fit each particular pump-testing job.

10. WATER SAMPLES

a. The quality of a water supply depends on three factors: bacterial content, chemical content and physical composition. For human consumption, the first two control whether the water will spread disease or cause physiological disturbance. The last two control appearance, taste and color; the use for washing and other domestic requirements and determine the scale formation or corrosive effect on boilers, mains and plumbing. The first quality mentioned above is not of too much importance in deep water-well construction because water from this source is almost always free from harmful organisms. The annular spaces around all casings must be tightly sealed against the entrance of contaminating surface waters. The responsibility for sealing the casing is normally the drilling Contractor's. No firm depth and distance can be established for the locations of wells away from contaminating sources because of variations such as type and amount of contamination, the filtering factor of soils, temperatures and other conditions. A few minimum distances can be established however; there should be at least 50 feet of impervious clayey soil, or 100 feet of semipervious silt, or sandy silt soil over the aquifer and wells should be located in these two cases at least 250 feet away from any raw sewage surface-discharge and upstream in the direction of subsurface flow. No distance criteria can be established where coarse-grained soils or creviced rock formations occur because of potential contamination by piping. Each individual area should be studied and mapped to determine all factors involved prior to siting wells.

b. Testing for chemical content and physical composition should be done during the early design phases of work at new projects, or expanding facilities, in order that the necessary treatment, if any, can be designed into the project and included in the plans and specifications for construction. The water supply will, in general, meet the Drinking Water Standards of the U.S. Publich Health Service (Bibliography reference No. 31). The following table lists the physical and chemical limits for an acceptable water as given in the Manual of the American Water Works Association and the U.S. Public Health Service Drinking Water Standards. The A.W.W.A. standards are furnished for information purposes only.

Characteristic	A.W.W.A. Std.	U.S.P.H.S. Std. (Corps Stds, modified)
Turbidity	not over 5 ppm	10 ppm (silica scale)
Color	not over 6	20 (cobalt scale)
Objectionable tase or odor	none	none
Hydrogen Sulphide	0.2	0.2
Lead	not over 1.0 ppm	0.1 ppm
Flourides	-	1.5
Arsenic	-	0.05
Selenium	-	0.05
Copper	0.2 ppm	3.0
Chromium, hexavalent as Cr.		0.05
Iron & Manganese	0.3	0.3
Zinc	5.0	15.0
Magnesium	100.0	125.0
Chloride	250.0	250.0
Sulfate	250.0	250.0
Phenol		0.001
Total Solids	1,000.0	500.0
Total Hardness (as $CaCO_3$)	-	300.0

c. In general it will be necessary to obtain samples of water from deep wells (more than 50 feet in depth) and shallow wells and have bacterial content tests made. However, when wells are constructed in areas known or suspected to be contaminated and laboratory facilities are available for testing, samples should be obtained, the tests made and the information furnished to the Using Service as part of the well completion and evaluation reports required by this Manual. Sampling and testing should be done in accordance with Bibliography reference No. 16, Part IV.

d. Samples for chemical content and physical composition will be taken in accordance with the information contained in Appendix 1, "Recommended Practice, Water Sampling." The instructions contianed therein pertain to sampling water from permanently constructed wells. Test or pilot holes should not be sampled for water analysis unless the aquifers can be pumped for 2 or 3 hours or until stabilized flow can be obtained. The results of physical and chemical tests on water samples will be reported.

e. The end purpose of all sampling, testing, filtering and treating work is to see that the water supply for each facility is clear, pleasant to the taste, of reasonable temperature, neither corrosive nor scale-forming, free from minerals which would produce undesirable physiological effects and free from organisms capable of producing intestinal infections.

f. Generally ground waters are clear, cold, colorless and harder than the surface waters of the region in which they occur. In limestone (chemical) deposits, ground waters are very hard, tend to form deposits on water pipes and are relatively noncorrosive. In igneous deposits and clastic sediments derived therefrom, ground waters are soft, low in dissolved minerals, relatively high in free carbon dioxide and are actively corrosive. Ground water from wells is generally of uniform quality over long periods of time. The temperature of ground water 20 to 50 feet below the surface is usually the mean atmospheric temperature of the locality. Below 50 feet the temperature increases about one degree Fahrenheit for each 60 feet in depth. Ground water temperatures remain fairly constant throughout the year.

11. WELL RECORDS AND COMPLETION REPORT

a. Evaluation and Completion Reports are required in making designs of the permanent well pump, pump house, and related structures, for obtaining the necessary treatment facilities as described in Paragraph 10, WATER SAMPLES and for the information and guidance of the Using Service. The following suggested outline for the reports will be of assistance in compiling and assembling information:

(1) Abstract or Summary.

(2) Introduction: Include purpose and scope of well-construction work, description of program, number of wells, quantity of water required, etc.

(3) Description of Area and General Geology: location map showing position of all wells, water-shed and streams; precipitation records; factors that control hydrology of region, description of existing wells, description of water-shed, features that may influence use of the well as a completed structure, access, topography, surface drainage.

(4) History of Construction of Wells: Include a narrative description of the various phases of drilling, casing, surging, developing and testing, with dates, names of drillers, helpers, and supervisors. A summary prepared from the Daily Reports is one method that may be used to present this information. Rate of drilling, difficulties, sampling and materials analyzing methods, tests for alignment, tests for welding and other details as to the efficiency of construction that will help evaluate the job and provide information in case trouble should occur with the well in the future. Complete data on hydrostatic pressures, as shown by sand-heaving in the casing, should be included in the report. The position of all aquifers, gradation analysis and bailing tests should be described. The method used to locate and test each water bearing horizon is valuable information to record. Details as to the construction of all artificial-packed wells should be described, giving the procedure for determining the gradation for the pack, gradation of aquifer, and method of placement of pack.

(5) Detailed Materials Log: to be prepared in a manner similar to that shown in Plate No. 2 and in accordance with Paragraph No. 5 and Appendix 4. Graphic logs are not required.

(6) Pump Test Results: should be prepared in a manner similar to that shown on Plate No. 3 and Paragraph 9 and Appendix 4. It is good practice also to include with this part of the report a summary sheet that lists all data pertinent to the well that has not been included with materials log. For example, the amount of sand recovered in the surging and developing work as compared with the calculated amount based on the gradation analysis and screen-opening sizes. Calculations for the ultimate and safe yields should be included in this part of the report. The recommended pumping rate and depth for pump intake setting should also be included here. Other information would be, variations in static-water level, consideration of well loss and formation loss, radius of influence and description of direction of flow, well boundaries, etc.

(7) Analysis of the Physical and Chemical Composition: of the water with recommendations for the design of any water-treatment facility that may be required.

(8) The Hydraulics of the Well: based on the pumping-tests and permeability results. Depending upon the amount and nature of the information obtained during testing work, illustrations should be prepared to show the information. For example, profiles or cross-sections can be prepared where two or more wells (or holes) have been drilled. Other drawings and charts that should be prepared, if the information is obtainable are: map showing the location of all wells and holes, geologic maps, drawdown and static-water level variations, hydraulic gradient and radius of influence, geophysical logs, gradation analysis curves, permeability tests, distance-drawdown graph, time-drawdown graph, time-recovery, step-drawdown curves, hydrographs, drawdown-yield curves, efficiency curves, and head-loss constants.

(9) Miscellaneous information: such as photographs or drawings of drilling and testing equipment, aerial photographs of the surface

drainage system and water shed, electric well logs, special problems such as salt-water intrusion, artesian flows and surface sealing, references, copies of pump testing records on other wells in the area, copies of specifications and other pertinent documents.

(10) Operating Guidance For Using Service: to include a description of the water supply distribution system and a summary of all features of the system, including the wells, that may be potential sources of trouble to the Using Service.

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WELL DRILLING OPERATIONS

DAILY SHIFT REPORT NO.____

PROJECT______________________ LOCATION______________________

CONTRACTOR______________________ COORDINATES OF WELL______________________

CONTRACT NO. ______________________ ELEV. TOP OF GROUND______________________

WELL NO. ______________________ DATE______________________

TYPE OF DRILL______________________ SHIFT______________________

Time Distribution - Hours

SETTING UP______________________ SAMPLING______________________

DRILLING______________________ DEVELOPING______________________

CASING______________________ PUMPING______________________

REPAIRS______________________ OTHER______________________

Operations

SIZE OF HOLE______________________ SAMPLE NO. (Interval)______________________

CASING SIZE______________________ DEPTH OF SAMPLE______________________

DEPTH - START OF SHIFT______________________ METHOD OF SAMPLING______________________

DEPTH - END OF SHIFT______________________ CLASSIFICATION OF MATERIAL______________________

STATIC-WATER LEVEL______________________

CHANGE IN WATER LEVEL______________________

TOP OF AQUIFER______________________ HYDROSTATIC PRESSURE(SAND HEAVING)____

BOTTOM OF AQUIFER______________________

BAILING TEST______________________

DEPTH OF HOLE BELOW CASING______________________

Remarks (To be continued on reverse)

Signatures: ______________________ Driller ______________________ Ground-Water Engineer

Plate No. 1

LOG OF MATERIALS PENETRATED

Well No. .... Size of Hole...........................

Surf. Elev.......................... Aver. Uniformity Coefficient............

Date Drilled........................ Aver. Effective Size....................

Date Sampled........................ Aver. Porosity..........................

(Describe method of Sampling)

.... Total Depth of Well.....................

Static Water Level.................. Total No. of Samples....................

Thickness of Aquifers............... Hydrostatic Pressures...................
(Depth to top and bottom)

LOG

Depth		Material	*Gradation Summary	
Interval (Feet) (1)	Thickness (Feet) (2)	Description (3)	Size Opening (4)	Porosity (Percent) (5)

*NOTE: When well is constructed in rock, this space should be used to furnish information on the type of aquifer; such as joints, fractures, bedding planes, etc., and physical characteristics of the beds. The construction of water wells in consolidated formations is generally much simpler than in unconsolidated clastic sediments.

PUMP - TESTING REPORT

WELL No._____

Location: Coordinates . . . .

Surface Elev . . . .

Depth of Well . . . .

Pump Size & Make . . . .

Driver . . . .

Date Pumping Started . . . .

Date Pumping Finished . . . .

Pump Intake Setting . . . .

Depth to Top of Screen . . . .

Size of Screen Opening(s). . . . .

Length of Screen . . . .

Static Water Level . . . .

Rate of Pumping . . . .

Size of Weir (Orifice) . . . .

Size of Eductor Pipe

Method of Measuring Water Level . . . .

Aver. Drawdown . . . .

Time for Stabilization . . . .

Time for 90% Recovery . . . .

Time for 100% Recovery . . . .

Remarks (such as quality of water, maximum drawdown, personnel) . . .

Specific capacity . . . .

Amount of Sand (ounces) 1st hr. of Pumping. . . . .

Amount of Sand (ounces) 2nd hr of Pumping . . . .

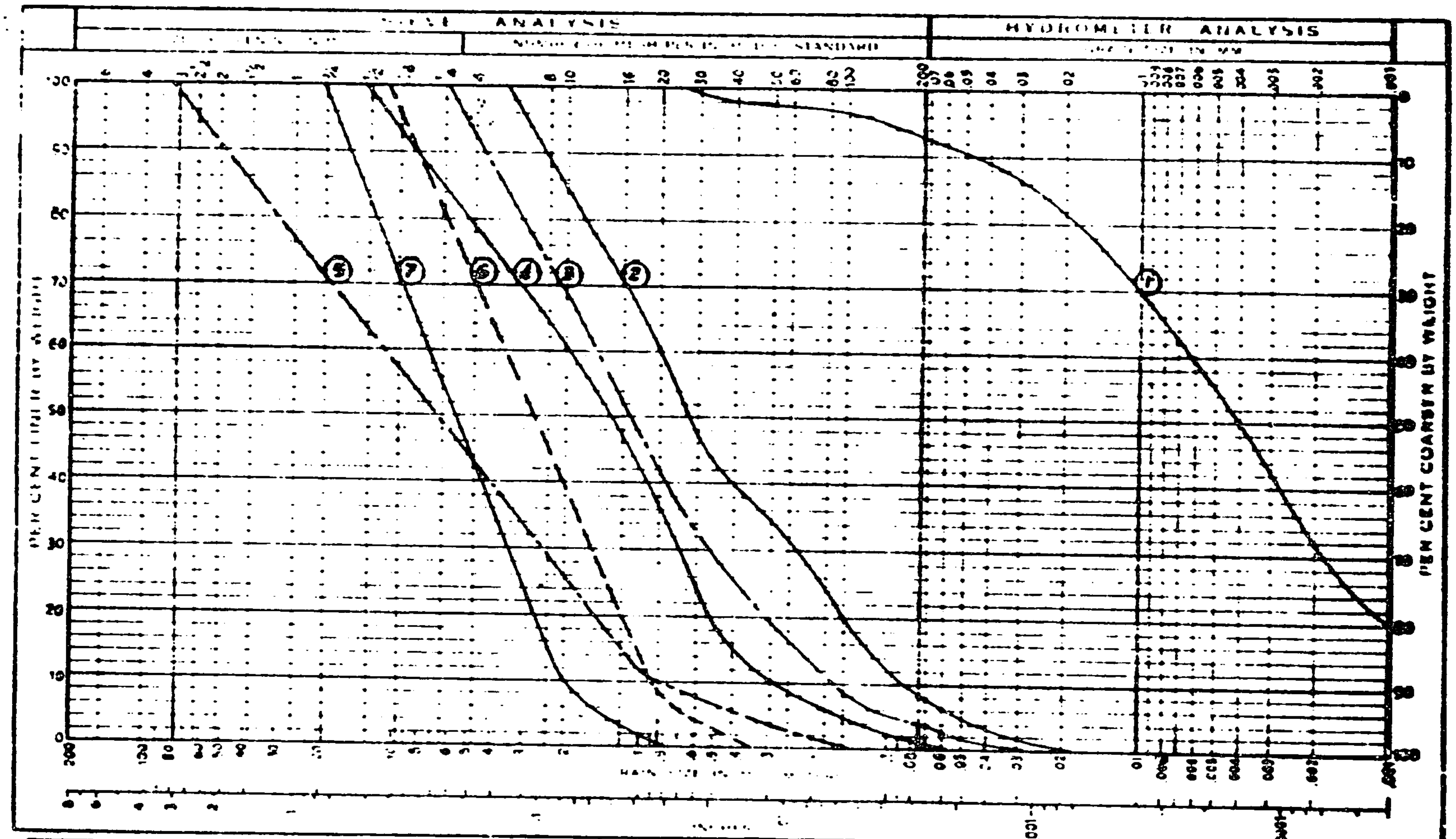
Number & Location - Observation Wells . . . .

Time Since Pumping Started - Stopped (minutes) (1)	Water Level Readings (2)	Drawdown feet (3)	Pumping Rate(GPM) (4)	Recovery (feet) (5)

NOTE: Data from observation wells should be included in separate report. Physical analysis results (color, odor, turbidity, temperature) and field tests for free carbon dioxide and dissolved oxygen will be reported.

Plate No. 3

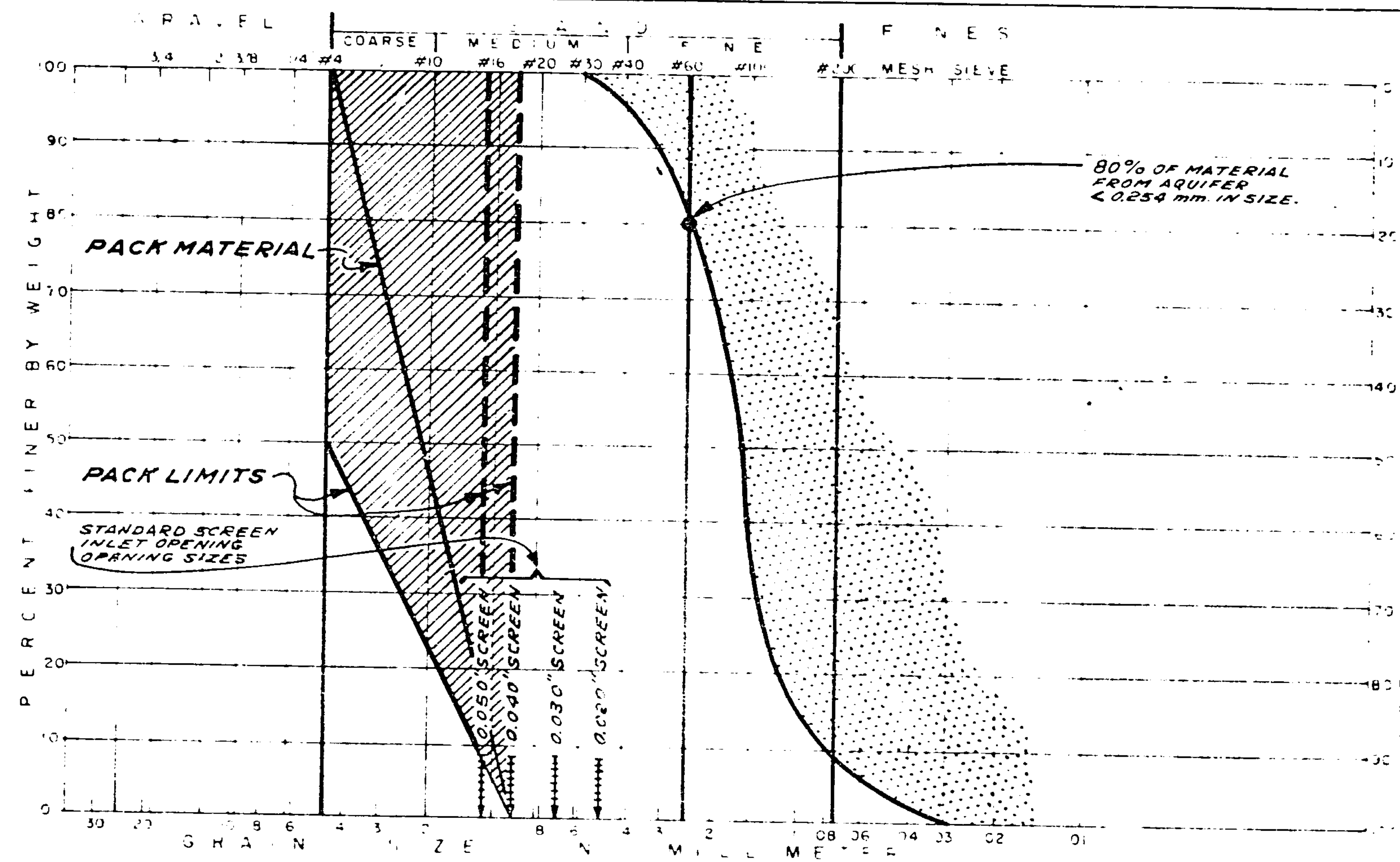
PLATE No. 4



SAMPLE No.	POROSITY	COEF. PERMEABILITY (GALS/DAY PER SQ.FT)	UNIFORMITY COEFFICIENT
1	55.5	0.2	10
2	26.3	150	10
3	27.1	480	10
4	27.2	2,000	7
5	28.4	4,800	15
6	26.6	12,800	4
7	28.0	90,000	3

RELATION OF GRAIN SIZE TO PERMEABILITY

PERMEABILITY INCREASES WITH INCREASING GRAIN SIZE, SINCE THE SIZE OF THE VOID SPACES ALSO INCREASES. STEEPER CURVE = GREATER PERMEABILITY.

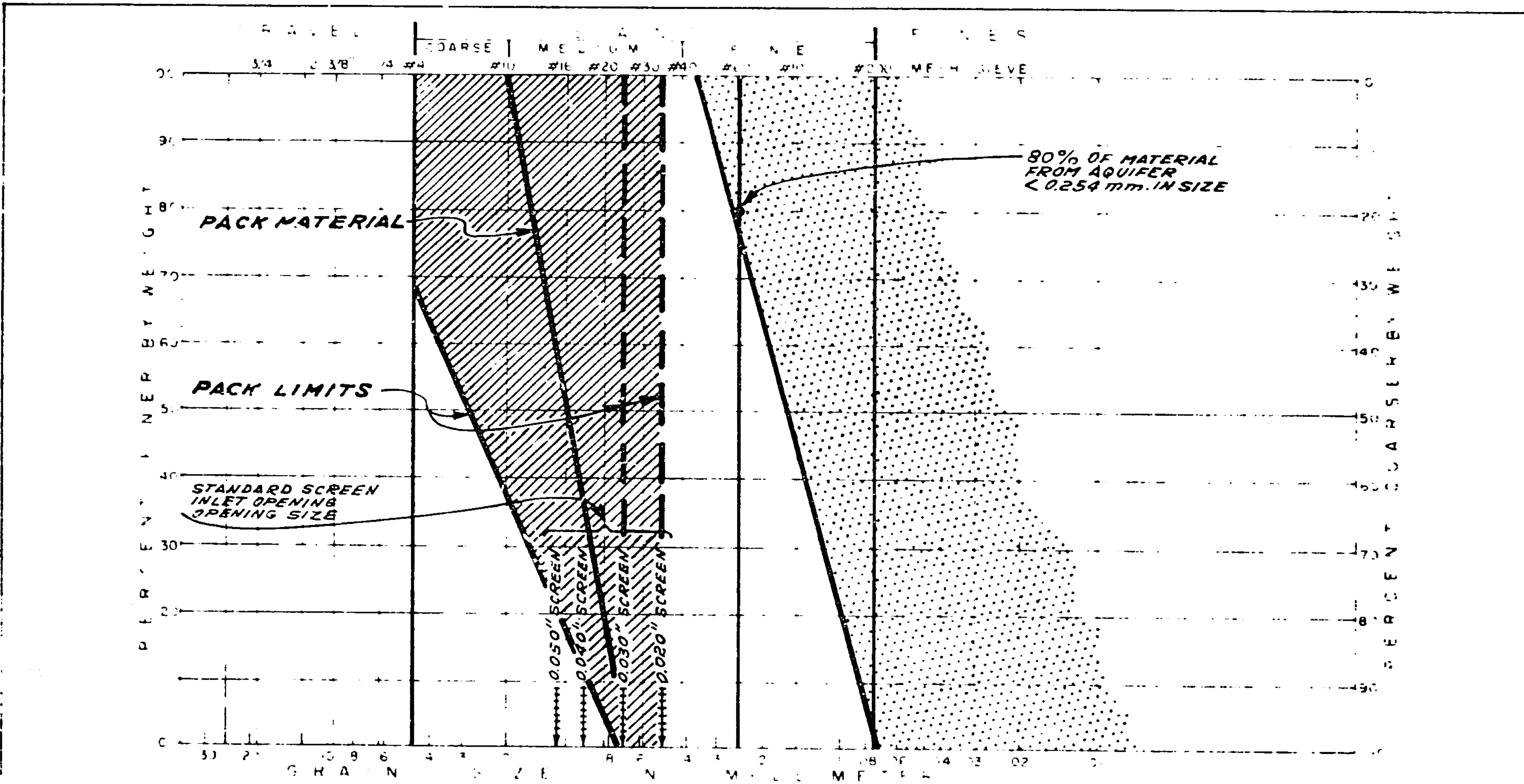


NOTES:

1. DETERMINE AVERAGE UNIFORMITY COEFFICENT OF AQUIFER MATERIAL : $Cu = \frac{D60}{D10}$
2. FOR Cu < 6 USE 0.040" SCREEN OPENING SIZE.
3. FOR Cu > 7 USE 0.050" SCREEN OPENING SIZE.
4. SIZE OF SCREEN OPENING DETERMINES LOWER LIMITS OF PACK SIZE IN ALL CASES.
5. THICKNESS OF PACK: NOT MORE THAN 7 INCHES.

SCREEN INLET AND
PACK GRADATION FO
UNIFORM OR WELL GRADE
FINE GRAINED AQUIFER

PLATE 5-A

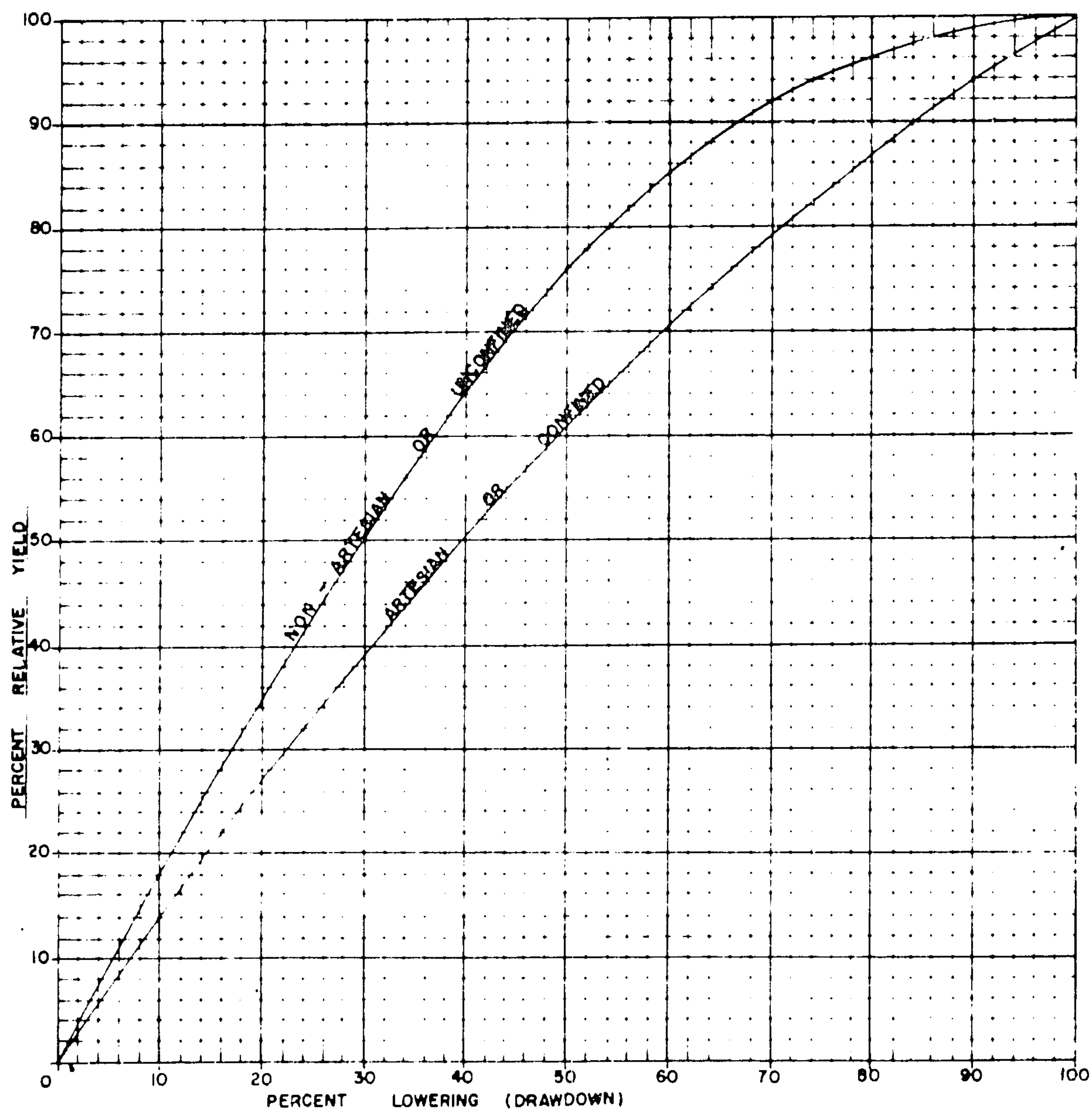


NOTES:

1. USE 0.030" OPENING SCREEN FOR AQUIFERS HAVING MORE THAN 50% MATERIAL COARSER THAN 0.07 mm. SIZED PARTICLES.
2. USE 0.020" OPENING FOR AQUIFERS HAVING LESS THAN 50% MATERIAL COARSER THAN 0.07 mm. SIZED PARTICLES.
3. SIZE OF SCREEN OPENING DETERMINES LOWER LIMITS OF PACK SIZE IN ALL CASES.
4. THICKNESS OF PACK: NOT MORE THAN 5 INCHES.

SCREEN INLET AND PACK GRADATION FOR POORLY-GRADED FINE GRAINED AQUIFERS

PLATE 5-8



RELATION OF DRAWDOWN TO YIELD

(ADAPTED FROM BUL 1243 - JOHNSON INC.)

EXPLANATION :

1. $\frac{\text{DRAWDOWN (FEET)}}{\text{*WATER COLUMN (FEET)}}$ = % LOWERING (AT CONSTANT PUMPING RATE)

   * ALSO KNOWN AS STANDING ...R

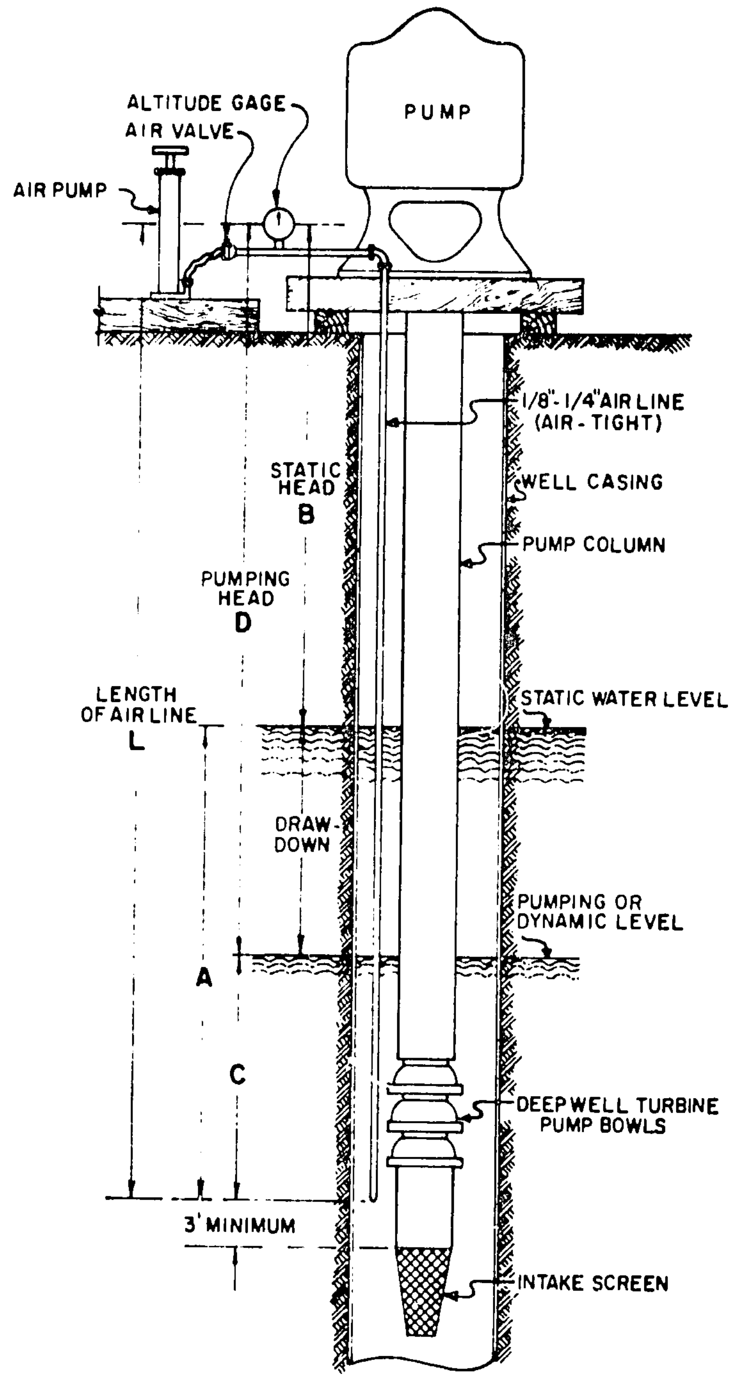
2. ENTER TABLE (AXIS OF ABSCISSA) AND READ PERCENT RELATIVE YIELD (AXIS OF ORDINATE), ARTESIAN OR CONFINED GROUND WATER - WATER RISES IN NON PUMPING WELL ABOVE THE UPPER LIMIT OF AQUIFER

3. $\frac{\text{PRODUCTION (G.P.M AT CONSTANT PUMPING LEVEL)}}{\text{\% RELATIVE YIELD}}$ = MAXIMUM POTENTIAL YIELD (G.P.M.) (ALL OF THE WATER COLUMN)

4. THE CAPACITY OF WELLS INCREASE IN DIRECT PROPORTION TO LENGTH OF SCREEN AND DEPTH TO WHICH THE WATER BEARING FORMATION IS PENETRATED.

5. THE LOSS OF HEAD IN A WATER-BEARING FORMATION DECREASES AS THE VELOCITY THROUGH A SCREEN IS REDUCED BY INCREASING ITS SLOT-OPENING AREA. FRICTIONAL LOSSES THROUGH A WELL SCREEN ARE ALSO REDUCED BY INCREASING THE AMOUNT OF SLOT-OPENING AREA.

PLATE N° 6



NOTES :

1 - AIR LINE MUST BE ACCURATELY MEASURED (L).

2 - AIR LINE MUST BE AIR-TIGHT

3 - AN ALTITUDE GAGE GRADUATED IN FEET SHOWS DIRECTLY THE AMOUNT OF SUBMERGENCE OF THE BOTTOM OF LINE

4 - USE ELECTRIC SOUNDER TO CALIBRATE GAGE AND FOR MICRO READING.

5 - REFER TO PAGES 58 AND 64 OF MED. DIV. MANUAL № 7

6 - FOR STATIC WATER LEVEL B = L - A

7 - FOR DYNAMIC (PUMPING) WATER LEVEL: D = L - C.

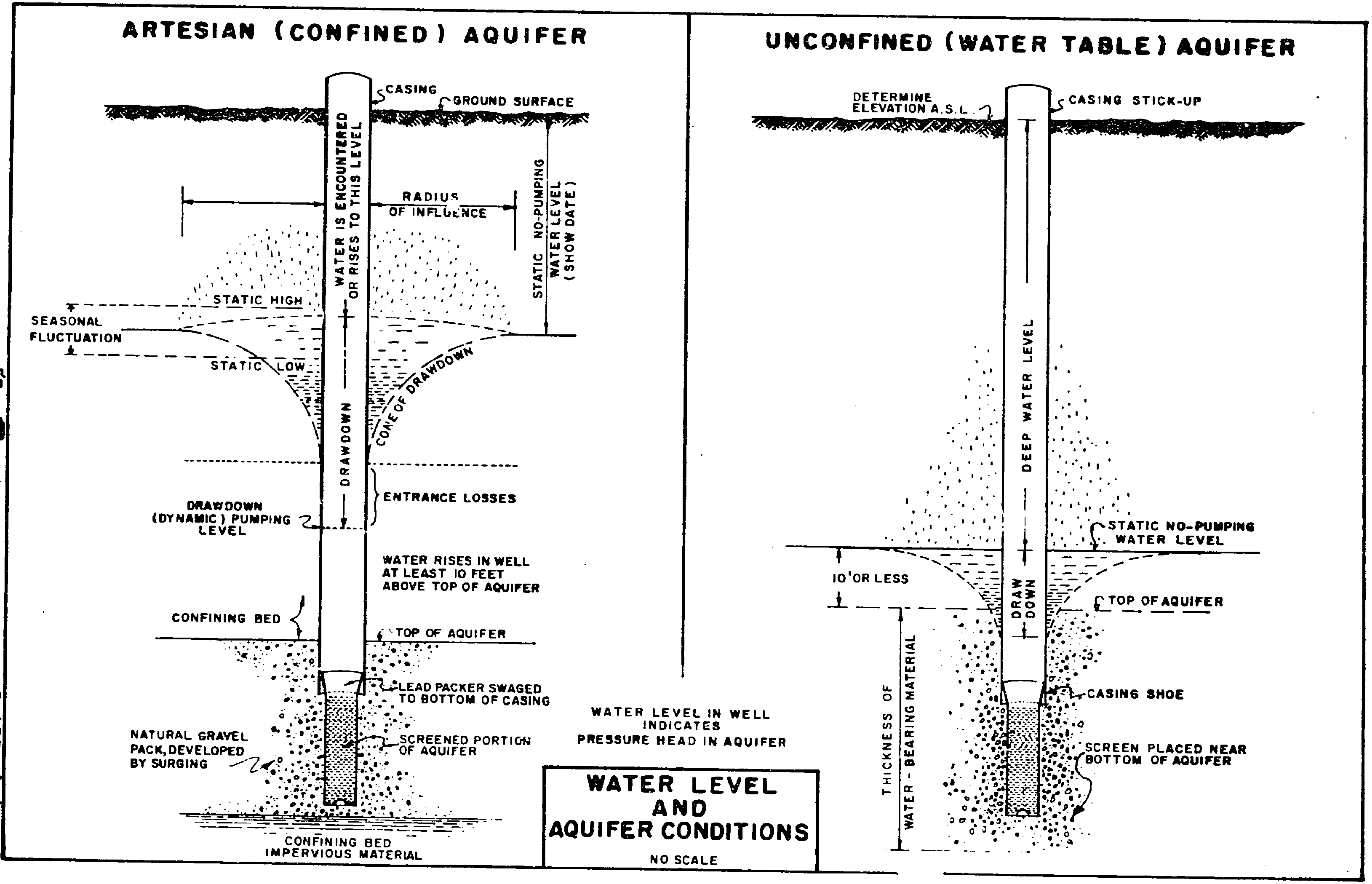
8 - DRAWDOWN: D - B

9 - IF GAGE READS IN POUNDS PER SQUARE INCH MULTIPLY BY 2.31 TO CONVERT TO FEET

AIR LINE INSTALLATION FOR MEASURING:

STATIC WATER LEVEL,
PUMPING LEVEL
AND
DRAWDOWN

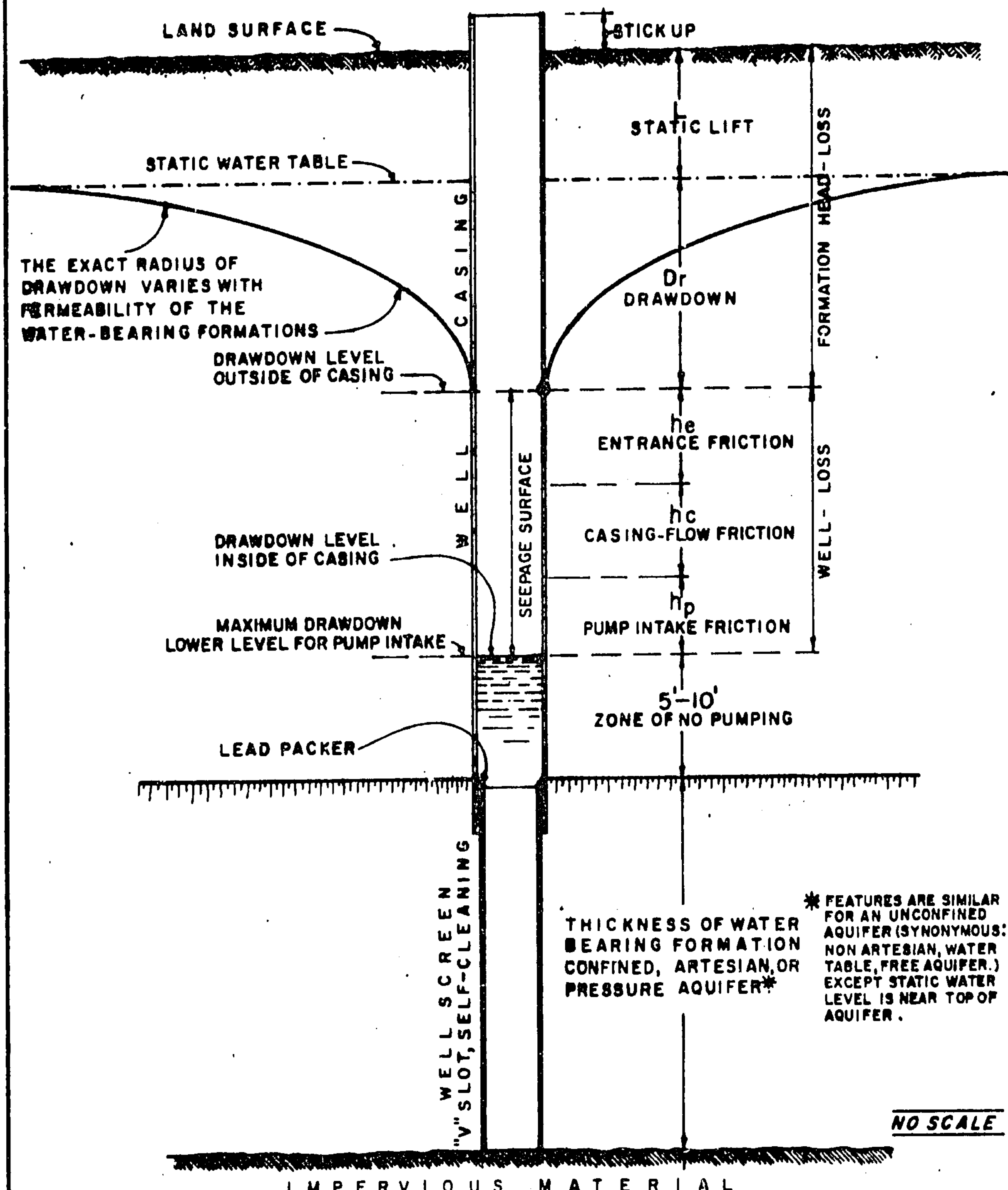
PLATE № 7



WATER LEVEL AND AQUIFER CONDITIONS

NO SCALE

PLATE Nº 8



NOTES:

Entrance and turbulent flow-losses that occur in pumping-wells, resulting in a lower water level in the well than outside the casing.

In properly constructed and properly operated wells, the casing flow-friction (hc) and entrance friction (he) should be negligible.

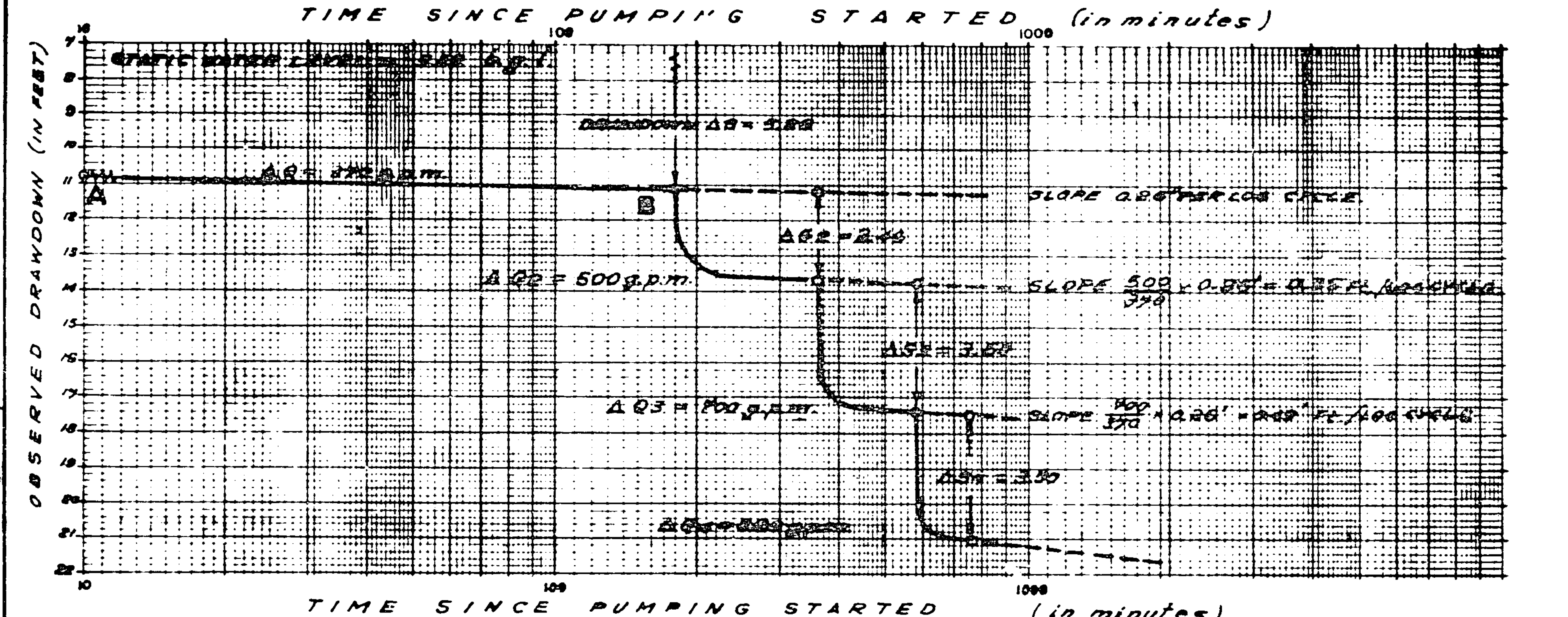
he = Entrance-friction loss related to effective radius of well and permeability of aquifer <u>after</u> development work.

hc = Casing flow-friction loss while flowing to the pump intake.

hp = Pump intake-friction loss.

FEATURES OF A PUMPING WATER-WELL

65



SUMMARY OF STEP DRAWDOWN ANALYSIS (180 MINUTE STEPS)					
RATE g.p.m.	INCREASE IN RATE g.p.m.	DRAWDOWN EACH STEP ΔS	SUM OF DRAWDOWN	SPECIFIC DRAWDOWN ft./g.p.m.	SPECIFIC CAPACITY g.p.m./ft.
370	370	5.28	5.28	0.0143	70.08
500	130	2.46	7.74	0.0155	64.60
700	200	3.60	11.34	0.0162	61.73
880	180	3.50	14.84	0.0169	59.30

LEGEND:

Q = PUMPING RATE

t = 180 MINUTE STEPS

S = FEET OF DRAWDOWN

NOTES:

1). - OBTAIN SLOPE A-B FROM AVERAGE SLOPE OF RECESSION CURVE DURING THE FIRST STAGE OF PUMPING TO REACH STABILIZATION REQUIRED BY APPENDIX 2, MANUAL 7.

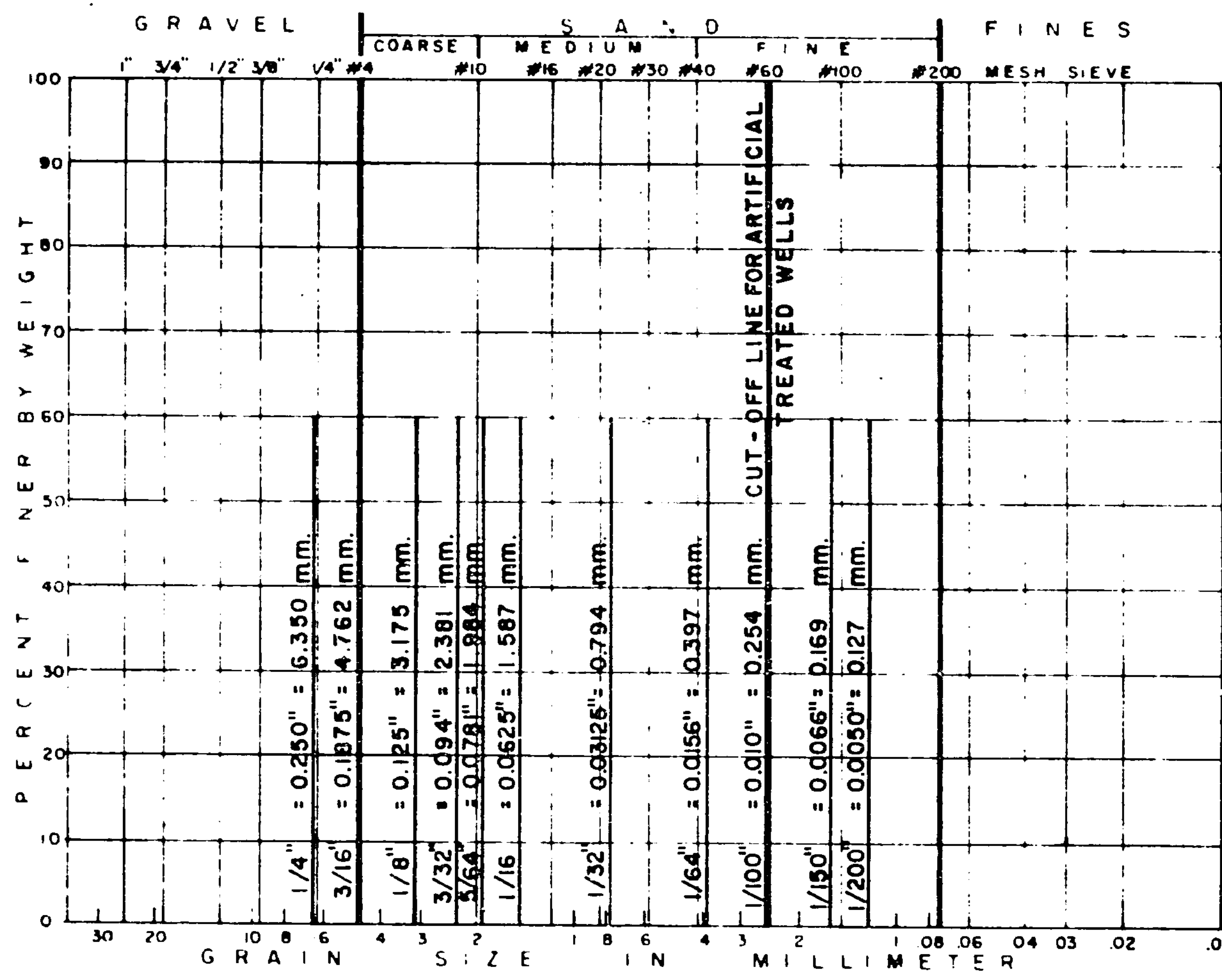
2) - INCREASE PUMPING RATE FOR TWO OR THREE STEPS AT EQUAL PUMPING TIME FOR EACH STEP.

3) - TAKE WATER LEVEL READINGS EVERY 5 MINUTES FOR FIRST ONE HALF HOUR AND EVERY 10 MINUTES FOR DURATION OF EACH STEP.

STEP-DRAWDOWN TEST

COMPARISON OF TIME-DRAWDOWN CURVES UNDER ARTESIAN CONDITIONS

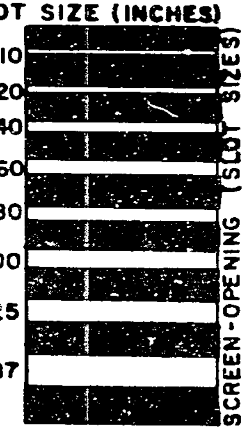
PLATE Nº 10



SCREEN OPENING AREA

SQUARE INCHES/FOOT OF SCREEN

CASING SIZES 8"	10"	12"	SLOT SIZE (INCHES)
28	36	42	0.010
51	65	77	0.020
87	110	130	0.040
113	143	170	0.060
116	147	174	0.080
131	166	180	0.100
145	164	202	0.125
180	230	252	0.187



CONVERSION SCALE

PLATE 11

60

RECOMMENDED PRACTICE IN WATER SAMPLING

APPENDIX ONE

RECOMMENDED PRACTICE FOR WATER SAMPLING

(The folliwing is taken from ASTM Standards, D 510-55T, D1129-55, D1192-51T; "Methods for collection and Analysis of Water Samples, U.S.G.S.W.S. 1454 and Examination of Water and Sewage," A.P.H.A. and A.W.W.A., 11th Edition).

1. Samples of water for testing must be taken by trained personnel. Unless samples are representative and carefully taken, the test results can be erroneous and misleading. The field analysis section, and all identifying entries in the Form, "Physical and Chemical Analysis of Water," should be completed and copies of the Form furnished by the Contractor or USAID representative to the Laboratory with the sample.

2. Water sampling in well construction work is normally done for one of two purposes: tests for bacterial (sanitation and potability) and tests for physical and chemical determinations.

3. Bacteriological analysis is normally not required for deep wells. When samples for bacteriological testing are taken, special sterilized bottles should be obtained from the testing laboratory. The cover and neck of the bottle must be covered with a square of wrapping paper or other guard to protect against dust and handling. The Form, "Bacteriological Examination of Water," should be completed by the Contractor or USAID representative and submitted with samples: Chlorinated water supplies require special handling to neutralize chlorine residual in water. Biological changes occur rapidly. Therefore, tests should be made within one hour after collection, otherwise the sample should be refrigerated. Bacterial tests made after 48 hours have questionable value.

4. Physical and chemical analysis will be made on water from all permanent water wells. The physical features: temperature, color, turbidity, PH gases (when possible) and odor should be determined at the well by the sampler and the information furnished to the laboratory with the

request for testing.

5. Sample containers for physical and chemical tests may consist of any of the following approved types:

a. Ployethylene bottles, 1/2 gallon capacity (Note: This is the preferred container, since it is unbreakable).

b. Chemically resistant 2-liter glass bottles (Pyrex or Jena) with ground glass stoppers or tight-fitting rubber stoppers. Usually such bottles are fitted within a special container, to guard against damage in shipment.

c. Chemically resistant 4-liter glass bottles (Pyres or Jena) with rubber stoppers, in carrying case.

Ordinary "soft glass" or soda lime bottles are not recommended, since appreciable amounts of sodium will dissolve in natural waters. Such containers as glass jugs, fruit-jars, medicine bottles, etc., should not be used, since the resulting analyses are usually inaccurate.

d. Stoppers, caps and plugs should be chosen to resist the attack of water. Metal screw caps are a poor choice for any sample that will cause them to corrode. Glass stoppers are unsatisfactory for strongly alkaline liquids because of their tendency to stick fast. Rubber stoppers are excellent for alkaline liquids but very poor for organic solvents in which they swell or disintegrate.

6. Sample bottles must be carefully cleaned before each use. Glass bottles may be rinsed with a chromic acid cleaning mixture, made by adding one liter of concentrated H_2SO_4 slowly, with stirring, to 35 ml saturated sodium dichromate, or with an alkaline permanganate solution followed by an oxalic acid solution. Dodium dichromate is extremely caustic and must be handled with extreme care, preferably using protective gloves. Detergents or concentrated HCl acid can be used for cleaning hard rubber and polyethylene bottles. After having been cleaned, bottles must be rinsed at least three times with tap water and then with distilled water.

Rinsing to be accomplished by half-filling the bottle and shaking vigorously for 10-15 seconds and draining.

7. The bottle should be filled completely with sample-water from the well, exercising caution not to contaminate the water by touching the lip of the bottle to casing, etc. Polyethylene and hard rubber bottles that will withstand some expansion and contraction should be sealed with little or no air space left at the top of the sample. Eliminating air space helps to retard oxidation and chemical change in the composition of the water. Sample collected in pyrex or glass bottles must have a small air space (about one inch below stopper) for expansion due to temperature changes. One-half gallon sample sizes will be ample for routine physical and chemical determinations. If special tests, such as boron, radium, phenol and heavy metals are required, then two-one half gallon samples are required.

8. The shorter the time elapsing between collection and physical and chemical analysis of a sample, the more reliable will be the analytical results. Under some conditions, analysis in the field is necessary to secure accurate results because the composition of the water will change before an analysis can be made in the laboratory. Determination of dissolved gases, especially oxygen, hydrogen sulfide, and carbon dioxide whould be made at the well in order to be reasonably accurate. When time elapse between collection and testing for physical and chemical properties will exceed 48 hours, particular care should be made to note on the Form for analysis of water the exact time of sampling and the amount of dissolved gases, iron pH, organic material and odors indicative of oxidizing elements.

9. Samples for physical and chemical analyses should not be taken until after completion of surging and developing work. The preferred time to take record samples is during the yield and drawdown tests. The analysis from samples taken during the early stages of pumping and compared with the analysis from samples taken just before completion of the yield and drawdown

tests will often give an excellent picture of what chemical variation may be expected, if any, in the water from the well with future operations. Samples taken during the first few minutes of the yield and drawdown tests, particularly if the pump is operated at maximum capacity, will indicate the successfulness of the surging and developing work. If sand in quantity, continues with operation of the pump, the testing should be discontinued and the faulty condition corrected. Samples of water taken with a bailer or a bucket are generally of little or no value and are not recommended for accurate control samples on which the design of treatment facilities would be based.

10. Every sample should be accompanied by a copy of the Form for water analysis and bear the following information:

a. Sample Number

b. Name of Sampler

c. Date and time of sampling

d. Method of sampling

e. Location of well with number and coordinates or surveyed location

f. Odor, color, turbidity, temperature, depth of aquifer and other pertinent physical data

g. Results of field tests made on the sample, (free CO_2, hydrogen sulfide, iron, and dissolved oxygen), if performed

h. Indicate on the Form for water analysis whether a partial, complete, or special analysis is desired:

<u>Partial</u>: Total Dissolved Solids
Sodium + Potassium
Odor, Color and Turbidity
Iron and Manganese
Total Hardness
Non-Carbonate Hardness
Alkalinity (or Acidity)
Chloride
Sulfate
Nitrate
pH
Specific Conductance

Complete: Odor, Color and Turbidity
Total Dissolved Solids
Loss on Ignition
Iron and Manganese
Sodium and Potassium as Na
Calcium as Ca
Magnesium as Mg
Fluoride
Total Hardness
Alkalinity (Methyl-Orange)
Alkalinity (Phenolphthalein)
Non-Carbonate Hardness
Carbonates as CO_3
Bicarbonates as HCO_3
Chlorides as Cl
Sulfates as SO_4
Nitrates as NO_3
Silica as SiO_2
pH
Specific Conductance

Special: Complete analysis plus any or all of the following as requested:

Boron
Heavy Metals (Lead, Arsenic, Copper, Etc.)
Phosphate
Bromide
Iodine
Chromium
Aluminum
Oxygen-consumed
Radium
Phenolic compounds

11. Samples should be shipped in containers, protected against breakage, and handled as expeditiously as possible. If slow transit (exceeding 72 hours) under unrefrigerated conditions is the only means of transport, samples will be taken as information only, since the results will be approximately correct; in particular, relative to the actual water, the percentage of sodium will be high, total solids and total hardness low, alkalinity either high or low, etc. No means of computing how these effects will arise is available, since they depend on temperature, composition of water, and biological activity. The longer the time between sampling and analysis, the greater the inaccuracy. Complete analysis should not be requested if shipment will require longer than 72 hours.

GUIDE SPECIFICATIONS

FOR THE

CONSTRUCTION OF WATER WELLS

APPENDIX TWO

APPENDIX TWO

GUIDE SPECIFICATIONS FOR THE CONSTRUCTION OF WATER WELLS

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GUIDE SPECIFICATION FOR THE CONSTRUCTION OF

WATER WELLS AT ____________________

UNIT PRICE SCHEDULE

SCHEDULE__________WELL NO. ________

ITEM NO.	DESCRIPTION	EST QTY	UNIT	UNIT PRICE	AMT
1.	Lump sum bid for all work in connection with mobilization and demobilization of equipment and materials.		Lump Sum		
2.	Cost for drilling and casing _____" minimum diameter hole from surface to any depth down to _____feet.		Lin. Ft.		
3.	Cost for drilling and casing _____" minimum diameter hole from _______ feet to any depth down to_____feet.		Lin. Ft.		
4.	Cost for drilling and casing _____" minimum diameter hole from _______ feet to any depth down to _____feet.		Lin. Ft.		
5.	Cost per lineal foot for furnishing well screen.		Lin. Ft.		
6.	Cost per hour for setting screen and withdrawing casing to expose screen to aquifer and for the work involved in surging and developing well to extract sand and form a natural pack around the screen.		Hour	$	$
7.	Cost per hour for making yield and drawdown tests. This is to include setting and removing pump by Contractor, and will be paid for on the basis of hours that well is pumped.		Hour	$	$
8.	Cost per day (24 hours) for delays incurred by Contractor standing by at direction of Contracting Officer (Time to start after _____days).		Days	$	$

TOTAL $____________

The quantities listed in the Unit Price Schedule are only estimates. The Contractor will be required to complete the work specified herein in accordance with the contract and at the contract price or prices, whether it involves quantities greater or less than those given in the Estimated Quantities.

NOTES:

a. Specifications must be modified for "rock" water-wells.

b. Special and General condition paragraphs are to be added.

c. Additional pay items marked as "OPTIONAL TO THE CONTRACTING OFFICER" can be included where it is suspected that artificial packed wells, rock core-drilling, extraction of casing, additional sampling work, additional surging and developing time and similar specialty items may be required, and will not result in undue hardship to the Contractor or additional hidden costs to the U.S. Government. Paragraphs describing these special phases of work should be included in the specifications.

d. A Unit Price Schedule is prepared for each well (either exploratory or permanent) that is to be drilled. Identification of the well is shown by both the Schedule and Well Number, for example, Schedule A, Well No. 3TW; Schedule B, Well No. 4TW, etc.

e. Separate unit price items for 'Drilling' and for 'Casing' should be established when it appears from the geology of the region, that uncased holes can be drilled.

f. Projects involving many wells sometimes require the Contractor to standby, or remain idle for the convenience of the Contracting Officer. Unit Price Bid Item per day may be indluded for this contingency.

SCOPE: The work covered by this section of the specifications consists of furnishing all plant, labor, equipment and materials and performing all perations necessary to drill, sample and test a minimim of ________ and a maximum of ______ inches and a maximum depth of _____feet each at the location shown on the accompanying drawing, in strict accordance.

with these specifications, as may be required by the Contracting Officer and subject to the terms and conditions of the contract. The exact depth of the wells will be determined by the Contracting Officer based on an analysis of the material samples obtained by the Contractor and quantities and qualities of water encountered. It is the intent of this contract to drill wells to locate and test any and all subsurface waters that exist at the location of the wells shown on the accompanying drawing. In the event suitable water supplies are available for developing, the Contractor will be directed in writing to proceed with the permanent water well construction work as described in these specifications and required by the Contracting Officer. Every effort shall be made to obtain the maximum amount of information and complete the drilling and testing work covered by these specifications in the most expeditious and efficient manner possible using modern and approved methods. In the event suitable subsurface water supplies cannot be located in exploratory wells _____ and ______ (Schedules______) the Contractor may be directed by the Contracting Officer to drill ______ or possibly ______ additional holes in the vicinity at locations to be selected by the Contracting Officer. Depending upon the nature, thickness and location of the aquifer(s) encountered, the Contractor may be required to install a well screen in order to construct a permanent water well to industrial standards capable of efficiently and economically producing all potential subsurface waters. Artificial packed wells will be designed and constructed in fine sand and silt aquifers only when 80 per cent or more of the total number of particles in water bearing formations are 0.250 millimeters or smaller in size and when the Contractors written procedure for operations has been approved in writing by the Contracting Officer. Upon completion of the drilling and testing work in each well the Contractor may be given permission by the Contracting Officer to extract the casing at no cost to the U.S. Government. Ownership of the casing extracted will revert to the Contractor in lieu of compensation, and casing may be reused in subsequent wells, provided it meets the requirements of these specifications and is approved for use by the Contracting Officer's representative.

GENERAL: The wells are to be drilled in an area known to be underlain by

(Description of Subsurface Conditions)

Samples from each foot-of-depth in the aquifers shall be carefully obtained by the Contractor in the wells to be constructed under the terms of this contract. Based on laboratory gradation analysis of the samples, the Contractor shall furnish (except when GFM) and install, subject to the direction and approval of the Contracting Officer, industrial well screens with 'V' shaped, continuous, self-cleaning inlet (slot) openings of such length and inlet openings as will permit withdrawal of the maximum amount of water from each completed well, free from sand and with the highest degree of pumping efficiency obtainable. The Contractor shall schedule his work so that the minimum amount of delay will be experienced in ordering and obtaining well screens. No additional payment will be made because of delays or standby time incurred by the Contractor in ordering and receiving the well screens.

*QUALIFICATIONS OF THE CONTRACTOR:

"The Contractor shall have ______ years previous experience as a water-well drilling company in the construction of large-yield water wells including experience in setting well screens with 'V' shaped, wire-wound, self-cleaning openings, and surging, developing and pump-testing natural in-situ and artificial-packed wells. The Contractor shall employ a minimum of ______ American drillers on each drill. Each driller shall

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*Paragraphs that may be included in the GENERAL CONDITIONS when drilling work is included with other construction.

have had at least ______ years previous experience at a responsible level in drilling, sampling, surging, and developing work using the same methods and techniques as are set forth in these specifications, and utilizing standard cable tool (percussion) drilling equipment in the work. Subsequent to the opening of bids and for the purpose of determining the responsibility factor in selecting the lowest responsible bidder, the Contracting Officer will (may) require of any bidder the following:

(1) Evidence of previous experience as a well-drilling company in drilling test and permanent water wells with standard cable tool (percussion) equipment, in installing 'V' shaped, self-cleaning, wire-wound well screens and in all features of surging and developing work to construct natural-packed water wells.

(2) Names and addresses of American drillers that will be employed on the work with statements as to their qualifications and experience record, including a listing, with references, of the recent wells on which they were employed in the capacity of Driller. The statements shall also describe the size and depth of wells, the kind of well screens used, methods of development and ultimate potential yields, as determined by a supervised pumping test.

(3) List and description of equipment that will be used in the work including the make, model and condition of standard cable tool (percussion) drill, size and capacity of air compressors, test-pumps, welding machines and all other equipment proposed. The list and description furnished will be used by the Contracting Officer to determine the qualifications and capability of the subcontractor (or element of prime contractor) to satisfactorily accomplish the exploratory and permanent water-well construction work described in these specifications, drawings and contract.

(4) Date when each of the following items required by the Technical Provisions paragraph of the specifications will be submitted for review and

approval of the Contracting Officer: program and proposed work progress schedule, certification of welders, method proposed for sampling and handling of samples, pump-testing method to be used, surging and developing procedures and plumbness and alignment testing, and details as to shifts, hours of work and other operation data.

LOCATION:

(Description of project and general information such as accessibility, previous work in the area, geology, hydrology).

LOCAL CONDITIONS: The Contractor shall satisfy himself regarding all local conditions affecting his work by personal investigation. This investigation should include access to the working area, terrain and weather conditions and rrequirements of military security. Other information derived from maps, logs, the Government, or its employees shall not act to relieve the Contractor of any responsibility hereunder or from fulfilling any and all of the terms and requirements of this contract. The Contractor acknowledges that he has satisfied himself as to the character, quality, and quantity of surface and subsurface material to be encountered, insofar as this information is reasonably ascertainable from an inspection of the site, including all exploration work done by others as well as information presented by the published logs and drawings. Any failure by the Contractor to acquaint himself with all available information will not relieve him from responsibility for estimating properly the difficulties or costs of successfully performing the work.

PLUMBNESS AND ALIGNMENT:

a. General: The well shall be constructed with all casing set round, plumb and true to line. The well shall not vary from the vertical in excess of two-thirds the inside diameter of that part of the well being tested per 100 feet of depth. The plumbness and alignment of the well shall be corrected by the Contractor at his own expense and should he fail to correct such faulty alignment of the plumbness the Contracting Officer may refuse to accept the well.

b. Description of Tests: Variations that would affect the operation of the pumping installation will not be accepted, and therefore to demonstrate the compliance of his work with the requirements, the Contractor shall furnish all labor, tools and equipment and make tests (select either example A or B) as directed by the Contracting Officer, to prove the plumbness and alignment of the well.

Example A:

A piece of pipe 1/2 inch smaller in diameter than the inside of the section of the well casing being tested and 40 feet in length shall be lowered into the casing, and it shall move freely throughout the entire length of the section of casing being tested when lowered and raised. Should the pipe not move freely, proper corrections shall be made in the casing alignment until it does move freely. At the Contractor's option, in lieu of the pipe section hereinbefore mentioned, a dummy may be used, consisting of a rigid spindle 40 feet in length with three rings, spaced one at each end of the dummy and one ring in the center. The rings shall be truly cylindrical and 1/2 inch less in diameter than the casing. The central member of the dummy shall be rigid so that it will maintain the alignment of the axis of the rings. The rings shall be 12 inches longer in length.

Example B:

Suspend a guide pulley from a tripod with the horizontal center of the guide plley exactly 10 feet above the top of the well casing and the vertical center of the pulley located so that a plumb line suspended from the side of the pulley will come off the pulley exactly over the center of the top of the well casing. A plumb ring or plummet is attached to the end of the plumb line. The plumb ring or plummet is a short cylinder with outside diameter 1/4 inch smaller than the inside diameter of the well casing. The plumb ring or plummet shall be heavy enough to keep the plumb line tightly drawn and yet must be open so water can pass through it as it is lowered inside the well casing. The plumb line shall be attached to the exact center of the plumb ring. The plumb ring (plummet) is lowered into the well and a measurement is taken at the top of the well casing and at each 10 foot intervals of the plumb line depth. At each 10 foot depth, if the plumb line remains at the exact center of the well casing, the well is plumb to the depth of the plumb ring (plummet). If the plumb line is not in the center at a given depth, then at that depth the well is out of plumb the distance the plumb line varies from the well center, plus an equal distance for each 10 feet the plumb ring is below the top of the casing. In wells requiring long pump columns readings taken may be plotted on cross section paper preferably on E-W and N-S planes to determine plumbness.

SAMPLES AND RECORDS: The Contractor shall keep an accurate record of the location of the top and bottom of each stratum penetrated and shall save and deliver to the Contracting Officer a sample (at least 30 pounds) of material taken from every change in sediment gradation from potential water-bearing formations. The sample containers to be furnished by the Contractor shall be heavy cotton bags (at least 7 ounce weight) or approved equal. A label designating the exact top and bottom depth (measured within 0.1 feet) at which the sample was taken and a description of the material and how it was collected shall be attached to the sample bag. Samples shall be taken with a sand-pump, similar and approved equal to SOILTEST Model DR-63, in a manner that results in little or no disturbance to the aquifer material.

Samples directly from rotary drilling will not be acceptable for sampling under the terms of the contract. An accurate record of the grade, size and length of the individual pieces of casing as assembled and installed, shall be kept and the exact position of the casing shall be measured and reported. The Contractor shall submit a daily report on a form entitled, "Well Drilling Operations: Daily Shift Report," copies of which will be furnished by the Contracting Officer. The report shall cover the well drilling operations, describing the drilling as easy, difficult, or whatever type of drilling it may be, the nature of the material encountered, the type work accomplished each day, including items such as depths drilled, casing set, amount of sand removed during surging and developing work, the water level in the well at the beginning and end of each shift, the depth at which water was lost at any time during drilling and such pertinent data as is required by the forms furnished by the Contracting Officer.

DRILLING AND CASING:

a. Drilling: The well shall be of tubular form. The Contractor shall elect the method best suited to the kind and condition of material encountered, for obtaining the results required in the most expeditious manner. The method selected, however, shall obtain the information described under Paragraph ______ "Samples and Records," and locate any and all potential aquifers. The use of drilling muds will not be permitted without the prior approval of the Contracting Officer. The Contractor shall have the necessary equipment and experience to cope with any and all drilling problems that may arise; for example, he shall be able to bring under control and fully utilize and develop flowing (artesian) wells, case caving and/or heaving ground and case a straight hole in cobbley and bouldery soils. The U.S. Government makes no guarantee as to the lineal footage that will be directed to be drilled in any of the ______ wells or the total lineal footage that will be drilled.

b. Casing: The Contractor shall furnish and install new casings, with the exception of the provision for reusing casing as stated in ______ conforming to the requirements of the latest American Water Works Association Specifications for pipe. ______ inch casing shall have a minimum weight of ______ pounds per foot. The casing shall be cut off square and smooth at the height above existing grade directed by the Contracting Officer and shall be capped by tack-welding a 1/4 inch thick steel plate over the top, all as approved by the Contracting Officer.

c. Joints: All well casing joints shall be made up tight, with welded joints or threaded couplings from above ground surface to the bottom of the well, so as to exclude all surface drainage and ground water not included in the well supply. Welded joint casing shall have one side 45 degree, bevel-butt, joint-weld with 3/32 inch root opening and 1/8 inch reinforcing bead on outer side. Full penetration shall be obtained and the welding shall be performed by a certified welder in accordance with the provisions of the American Welding Society Code. Welding rod shall meet the requirements of the A.W.S. for welding metal of the composition represented by the casing furnished by the Contractor.

WELL SCREEN, SURGING AND DEVELOPING WORK: During the testing work the Contractor may be directed to furnish and install a wire-wound well screen and surge, develop, and pump test the well(s) in order to obtain an accurate measurement on the potential productivity of the aquifer(s). Samples of the aquifer to be screened will be submitted by the Contractor to the ___(Name)___ Laboratory for gradation analysis and selection of screen-size opening. The Contracting Officer will furnish to the Contractor (upon his written request), the results of the analysis and a recommendation for screen-size opening and length. The size of the opening will be determined in accordance with the effective size and uniformity coefficient of the sands found in the water-bearing strata. The Contractor shall furnish and install self-cleaning, non clogging, wire-wound well screen having horizontal, "V" shaped continuous slot. (Include type metal, Everdur, Stainless steel, etc.). The screen shall be set by withdrawing the casing with an approved lead packer designed and recommended by the manufacturer of the screen. The screen will be withdrawn by the Contractor upon completion of each test well and its acceptance by the U.S. Government and may be used, at the discretion of the Contractor and subject to the approval of the Contracting Officer in other test wells described herein. The test well screen will become the property of the Contractor in the event the Contracting Officer determines the test-well to be nonproductive or otherwise concludes not to permanently use the test-well screen. The Contractor shall build the well in such a way that the full yield of the formation can be transmitted into the well, free from sand and without undue friction loss through the well screen. The maximum practical quantity of such sand as may, during the life of the well, be drawn through the screen when the well is pumped under maximum conditions of drawdown shall be extracted from the well. The Contractor may extract the sand by any approved method he proposes to use. The Contractor shall submit in writing (prior to the commencement of work) for the approval of the Contracting Officer, a detailed plan on how he proposes to develop and test each well. The Contractor shall exercise extreme care in the performance of his work in order to prevent the breakdown or caving-in of strata overlying that from which the water is to be drawn. The screen shall have no change of alignment at any of its points after installation. The Contractor shall develop and bail the well by such methods as may be approved by the Contracting Officer until the water pumped from the well is free from sand and until the turbidity is less than five (5) on the silica scale described in "Standard Methods of Water Analysis," American Publich Health Association and A.W.W.A. Since it is impossible to predict the number of hours that may be required to properly develop the well, the number of hours given in the Unit Price Schedule is an estimate only and the actual number of hours will be determined by the results as development proceeds. Upon completion of development and sand extraction work, the well shall be tested in accordance with the requirements of these specifications. Artificial gravel (sand) packed wells shall not be designed and constructed in aquifers where 20 per cent or more of the total number of particles is 0.25 millimeters or coarser in size. When in the opinion of the Contracting Officer, it is necessary to construct artificial packed wells in order to obtain efficient

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and satisfactory wells in fine grained sand and silt aquifers, the Contractor shall submit for the approval and acceptance of the Contracting Officer upon his request, a complete program for construction of artificial packed wells together with his proposal. This additional work may be made the subject of a change order.

GROUTING AND SEALING: The Contractor shall perform all drilling and casing work under the terms of these specifications in such a manner that a tight seal is obtained between the outside of the casing (the outside of the outer casing where applicable) and natural, undisturbed ground. When the Contractor by his drilling operations disturbs or otherwise breaks a potential seal by drilling an over-sized hole, under-reaming, or other reason associated with standard well drilling practices, then the Contractor shall seal by pumping a cement-sand-water (or cement-water) mixture from the bottom of the hole upward around the outside of the casing. Grout shall consist of not more than 5.5 gallons of water per cubic foot of cement (or cubic foot of cement and sand in 70-30 proportions). No grouting shall be permitted or attempted within 50 feet of a potential aquifer or an installed well screen. No additional payment will be made for grouting and sealing work.

YIELD AND DRAWDOWN: After each well has been completely constructed, developed and cleaned out and the depth accurately measured, the Contractor shall notify the Contracting Officer to that effect and then shall make all necessary arrangements for conducting the final yield and drawdown test. Yield and drawdown tests shall be made in each well prior to acceptance by the U.S. Government unless the Contracting Officer determines that sufficient information can be obtained by test pumping alternate wells. The Contractor shall furnish all necessary pumps, compressors, plungers or other needed equipment and shall test the well by a method approved by the Contracting Officer, to determine the maximum yield of water per foot of drawdown. The Contractor shall also furnish, install, and maintain equipment of approved size and type for measuring the flow of water such as weir box, orifice or water meter and an air line complete with gage, handpump and check valve to measure the depth of water in the well at any time. The Contractor shall submit in writing (prior to commencement of work), for the approval of the Contracting Officer, a detailed plan on how he proposes to develop and test each well. The yield at the beginning of any test will not be considered the true yield if the water level is dropping. For estimating the actual flow of water the yield shall be measured after the water level in the well has become practically stationary. Observations shall also be made of returning water levels after pumping has ceased. The estimated yield of the well shall be determined by the average output in gallons per minute when drawdown has ceased and stabilization of the water table has existed for at least 12 continuous hours at the decision and direction of the Contracting officer. The Contractor shall furnish a pump with accessory equipment capable of producing _____ gallons per minute at a pump setting and lift from _____ to _____ feet. After completion of the final acceptance test, the Contractor shall remove any sand or other objectionable material that may have accumulated in the well during the testing operations. The water pumped from the well may be disposed of in nearby drainage ditches or natural drains as approved by the Contracting Officer. It will be the responsibility of the Contractor to dispose of all water in a manner that will not create a hazard to roads, buildings or other property. Water shall be conducted far enough away from the well so that it will not be recirculated.

<u>PROTECTION OF QUALITY OF WATER:</u> The Contractor shall take such precautions as are necessary or as may be required to permanently prevent contaminated water, or water having undesirable physical or chemical characteristics, from entering through the opening made in drilling the well or the stratum from which the well is to draw its supply. He shall also take all necessary precautions during the construction period to prevent contaminated water, gasoline, etc., from entering the well either

through the opening or by seepage through the ground surface. In the event the well becomes contaminated, or that water having undesirable physical or chemical characteristics, does enter the well due to the neglect of the Contractor, he shall, at his own expense, perform such work, including the redrilling of the well, or supply such casings, seals, sterilizing agents or other material as may be necessary to eliminate the contamination or to shut off the undesirable water.

*PROTECTION AND CLEAN-UP OF SITE: The Contractor shall at all times protect and preserve all materials, supplies and equipment of every description and all work performed. All reasonable requests of the Contracting Officer to enclose or sepcially protect such property shall be complied with. If, as determined by the Contracting Officer, material, equipment, supplies and work performed are not adequately protected by the Contractor, such property may be protected by the Government and the cost thereof may be charged to the Contractor or deducted from any payments due him. The Contractor shall protect all drainage ditches, structures, embankments, or other property during the progress of his work. Cuttings, drillings, or other debris shall not be washed into drainage structures that might cause clogging of drainage in any way. Upon completion of the well, and any tests that may be required, the Contractor shall remove by bailing, sand pumping, or any other approved method, any sand, stone, or other foreign material that may become deposited in any well, and shall leave the surrounding areas clear and ready for installation of permanent pumping equipment and appurtenant structures.

*INSPECTION: The work will be conducted under the general direction of the Contracting Officer and is subject to inspection by his appointed ground-water engineer to insure strict compliance with the terms of the contract.

*Paragraphs that may be included in GENERAL CONDITIONS during all drilling, developing and testing work. No engineer is authorized to change any provision of the contract without written authorization of the Contracting Officer, nor shall the presence or absence of an engineer relieve the Contractor from any requirements of the contract. The period of time to be spent in the surging and developing and testing work will be determined by the Contracting Officer and will be based on the results of the work and recommendations of the Contractor.

*MOBILIZATION AND DEMOBILIZATION:

a. The Contractor shall furnish all materials and equipment required to compete this contract. The transportation of all material and equipment from the point of origin to the jobsite and upon completion of the work, the removal of all material and equipment not required in the construction shall be by and at the expense of the Contractor.

b. One half (1/2) of the contract price for the above mentioned mobilization and demobilization, exclusive of the cost for those materials to be paid for under any other item as shown on the Bid Schedule, shall be due and payable upon arrival and commencement of work at the jobsite and the remainder shall be due and payable at the completion of all work as required under the terms of this contract.

OPTIONAL TESTING WORK: Upon completion of drilling and testing work in wells ______ and as specified hereinbefore the Contracting Officer may (at his discretion and option, based on the requirements for additional subsurface information) direct the Contractor to drill, sample and test _____ and possibly ______ additional holes. The holes will be located and drilled in strict compliance with the requirements of this contract and specifications. Payment for any and all directed optional work will be made at the unit price in Schedule ______ and ______. In no event will the number of such optional holes exceed ______.

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*Paragraphs that may be included in GENERAL CONDITIONS

PAYMENT:

a. Item No. 1, Mobilization and Demobilization: Payment under this item will be at the contract lump sum price and include the costs for transportation of all materials, equipment, and labor from the point of origin to the job-site; and transportation between well sites, the erection and dismantling of equipment; overhead and any and all delays incurred in completing the work; the removal of all materials and equipment not required upon completion and acceptance of the wells and all other costs incurred by the Contractor in performing the work covered by these specifications or shown on the drawings and not included in Items 2 through _____ inclusive.

b. Item 2: Payment under this item will be at the contract unit price per linear foot and shall be for the actual unit of footage drilled, cased and accepted. The costs shall include all equipment, material, and labor required to complete the items of work as described or intended by these specifications and shown on the drawings. The U.S. Government makes no guarantee as to the lineal footage that will be directed to be drilled in any of the wells or in the total lineal footage that will be drilled.

c. Item _____ and Item _____: Payment under this(these) item(s) will be at the contract unit price per linear foot and shall be for the actual unit of footage drilled, cased, tested and accepted. The exact variation in the stratigraphic section of the area is not known and for this reason the U.S. Government can make no guarantee as to the lineal footage.

d. Item _____: Payment under this item will be at the contract unit price per linear foot and will include all fittings, for the actual size and length of screen installed and accepted by the Contracting Officer. The length, diameter, and screen opening size will be determined by the Contracting Officer, based on the thickness of aquifer(s), and the effective size and uniformity coefficient of the sands and gravels in the water bearing strata.

e. Item ______: Payment under this item will be at the contract unit price per hour for all material, equipment, and labor to set screen(s), withdraw casing to expose screen(s) to aquifer; surge and develop well by approved methods to provide a stable gravel pack around the screen(s), and to bring well to highest possible production as specified in paragraph "Well Screen, Surging and Development Work."

f. Item ______: Payment under this item will be at the contract unit price per hour for all material, equipment and labor required to make yield and drawdown pumping tests as specified in paragraph "Yield and Drawdown," when, and as directed by the Contracting Officer. This unit price item is to include the setting and removal of pump by Contractor, and will be paid for on the basis of the number of hours that well is pumped.

Note: Additional payment clauses will have to be added and the ones shown above (a to f incl.) revised for special wells, such as rock-wells, artificial-pack, etc. See notes on the Unit Price Schedule.

GUIDE SPECIFICATIONS FOR ENGINEERING SUPERVISION OF WATER-WELL CONSTRUCTION

APPENDIX THREE

APPENDIX THREE

GUIDE SPECIFICATIONS FOR ENGINEERING SUPERVISION OF WATER-WELL CONSTRUCTION

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GUIDE SPECIFICATIONS

Engineering Supervision of Water-Well Construction

General and Scope:

The U.S. Government intends to drill under the terms of another contract ______ test wells and ______ permanent-producting water-wells at ____, all in accordance with the accompanying copy of contract number ______ and specifications ______ titled "Specifications for the Construction of Water-Wells at ____________________ ________________________________." It is the purpose and intent of this contract to provide for expert engineering services during both the exploratory drilling and permanent-producing well construction work. the Supervising Engineer shall furnish the necessary and sufficient man-months of inspection services as required by the Contracting Officer, described herein and listed in the Unit Price Schedule. Without additional compensation, the Supervising Engineer or any members of its organization in __________, when requested, shall consult and advise with the Contracting Officer on any questions which may arise in connection with the work under this contract. The work includes, but is not limited to, furnishing all technical equipment, materials and qualified personnel and performing all engineering services necessary to accomplish the following:

a. Interpret the requirements of contract number ______ and specifications ______ entitled "Specifications for the Construction of Water-Wells at ______________________________" for the benefit of the well-drilling Contractor and on behalf of the Contracting Officer.

b. Furnish at least ______ qualified Ground-Water Engineer(s) for inspection services at each well during all drilling, testing and sampling operations.

c. Make all measurements, observations and recordings necessary to determine exactly what items of work have been accomplished under the Unit Price Schedule for contract number ______ and certify to the Contracting Officer the exact quantities of work that were completed, or partially completed in fulfillment of the requirements of the specifications.

d. Order the performance of and observe and report on all evaluation tests, such as plumbness and alignment, welding, bailing, hydrostatic-pressure, sand-extraction, yield and drawdown and other tests required by the specifications and as may be necessary to certify to the acceptability and successfulness of the drilling and well-construction work.

e. Establish, with the drilling constructor, the exact policy and procedure for taking samples and collect, prepare, examine, describe and classify all soil and rock materials, with particular attention given to potential aquifer deposits. It shall be the Supervising Engineer's responsibility to make the field and laboratory tests to accurately determine the chemical and physical composition of the water from each aquifer.

f. Make the observation, tests, and measurements necessary to prepare the well records and completion reports required by "Water-Well Construction Manual," dated November 1, 1964.

<u>References:</u>

The following documents of the U.S. Government pertain to the work covered by this contract and are hereby made a part of the work and contract.

a. Contract number ______ with specifications numbered ______ entitled "Specifications For the Construction of Water-Wells at ____________ ______________________________."

b. Inspector's Manual for Water-Well Construction Work, ([illegible] manual).

Personnel to be Furnished by the Supervising Engineer:

The Ground-Water Engineers furnished for work under this contract shall be graduate Ground-Water Geologists, Geological Engineers or Hydrological Engineers with at least five years of experience at a responsible level in water-well construction work. Graduate Civil and Mechanical Engineers with equivalent training and experience may be employed on the work required by the contract provided the Supervising Engineer submits for the approval of the Contracting Officer certified records attesting to the competency of the individuals. The Supervising Engineer shall submit with the bidding documents a written certification covering the Engineers that he will use in performing the work under this contract. Any bidder who fails to comply with the provision of this paragraph and neglects to furnish written certification of the qualifications and experience requirements listed above, his bid will be considered non-responsive. The Supervising Engineer shall at all times maintain a sufficient number of fully qualified personnel of the categories specified in the Unit Price Schedule at the well sites to insure full performance of this contract. All personnel of the Supervising Engineer employed for the performance of this service shall be subject to approval of the Contracting Officer. In addition, the Contracting Officer reserves the right to refuse to approve any proposed employee without explanation.

Interpreting the Well-Construction Specifications:

The Supervising Engineer shall thoroughly familiarize himself with the provisions of the well-construction specifications referred to in paragraph ______ above, including the requirements for sampling, testing, quality of work specified and the standards established for the completed well structure. Any questions or unresolved differences of opinion or fact between the construction contractor and the Supervising Engineer on policies, operating procedure and/or suitability and adequacy of equipment and/or materials will be resolved by the Contracting Officer.

The Supervising Engineer shall review all aspects of the drilling, testing and sampling work with the well-construction contractor and assure himself that the equipment and methods proposed by the contractor are satisfactory and capable of accomplishing the specified work.

The Supervising Engineer shall prepare monthly progress reports for the information and use of the Contracting Officer, presenting the quality and quantity of the work accomplished and data sufficient to certify payment to the well-construction contractor. The reports shall be forwarded to the Contracting Officer not later than the 10th of the month for the preceeding months work. The monthly progress reports are in addition to the well records and evaluation and completion reports to be prepared and submitted by the Supervising Engineer as required under the terms of this contract. All reports shall be in the English language.

Making Measurements, Observations and Recordings:

The Supervising Engineer shall furnish all labor, equipment and materials and perform all operations necessary to make the measurements, operations and recordings required by the Inspectors Manual referred to in paragraph ______ above and as specified herein and as may otherwise be required to completely evaluate and report the well-construction work to be done under contract ______ and referred to in paragraph ______ above. All measurements, and observations shall be recorded and reported on forms similar to those given in the Inspector's Manual. The accuracy of measurements shall be equal to or better than standards established in the Inspector's Manual. The log of aquifer samples shall be complete and include microscopic examination and laboratory tests. Every effort shall be made to determine, as closely as possible, the physical and chemical properties of the potential aquifers, furnish an interpretation of subsurface samples in terms of sources of sedimentary materials and explain the conditions of transportation and deposition, all to help evaluate the ultimate potential

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of the subsurface ground-water reservoir at the well sites. The Supervising Engineer shall furnish and use equipment such as the following: electrical water-level measuring devices, slide, disk or block comparators for chemical analysis of water samples in the field, binocular microscope, sieves and balance for making grain-size distribution tests, porosity and permeability (permeameters) testing equipment, fluorescein dye and fluoroscope for direct measurement of ground-water velocity and similar other materials and equipment as may be required to fully and adequately measure and observe the well construction work. The Supervising Engineer may be required to make chemical field tests on water samples for CO_2 and dissolved oxygen if water-bearing formations are located and developed within fifty feet of the ground surface in any of the wells to be constructed under the terms of this contract. The Supervising Engineer shall either have (or have ready access to) the necessary equipment and knowledge to perform chemical field tests for CO_2, dissolved oxygen, color, turbidity, odor, chlorides and iron on samples that he is required to collect under the terms of this contract.

Evaluation and Completion Reports:

Upon completion of drilling and testing work in each of the wells constructed under the terms of contract number ______, the Supervising Engineer shall prepare, for the information and records of the Contracting Officer, a comprehensive water-well evaluation and completion report. The report shall be submitted in one reproducible and ______ copies and delivered to the Contracting Officer within thirty (30) days after completion of the field work for each well. In addition to the information required by paragraph eleven (11) of the Inspector's Manual referred to in paragraph ______ above, the Supervising Engineer shall make recommendations as to the efficient pumping level for each well, the maximum safe pumping rate to protect the life of the well, information on any and all chemical treatment and filtering that may be required to obtain a potable water supply meeting health and safety standards, and detailed instructions for the operation and maintenance of the well to insure maximum efficiency and satisfactory production. In cases where inadequate water supplies are located during the test drilling at the locations selected, it shall be the Supervising Engineer's responsibility to make the necessary hydrological and geological studies of the region and present, for the information and guidance of the Contracting Officer, a full report on the water resources and potentialities with studied recommendations as to the nearst likely source or sources that should receive further investigation.

NOTES:

(1) Payment paragraphs to be added. (Lump Sum Contracts)

(2) A full description of any special problems that are to be expected, such as salt-water encroachment, rock-wells, low-yield wells, artificial gravel pack wells, etc., should be presented in separage paragraphs.

(3) Personnel facilities (Government or otherwise) that can be made available to Supervising Engineer, such as housing, meals, office space, equipment, transportation, etc., should be listed.

(4) Since some of the bidders may be unfamiliar with conditions in the region, a full description of the working environment, difficulties of transportation, availability of accomodations for personnel, access to communications, commercial testing facilities, and the like, should be included in a separate paragraph.

(5) Copies of previous investigations, drilling and studies can be either included with bidding documents or referenced in the specifications as to their availability for review in the USAID Mission.

UNIT PRICE SCHEDULE

FOR

Engineering Supervision of Water-Well Construction

ITEM	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	AMT
1	Cost for furnishing ______ qualified Ground Water Engineers	(number of months and cost per month)			
2	*Lump sum bid for transportation of ______ Ground-Water Engineers to job site and return		do		
3	Cost for furnishing one qualified Engineer Assistant		do		
4	Cost for furnishing ____ additional qualified Ground-Water Engineers		do		
	(Optional Work)				
5	Per Diem (Travel Expense Account) bid per Engineer per day		do		

Total Bid Price __________

*Can be deleted and the following included in the specifications "all personnel of the contractor employed for and actually engaged in performing work under this contract are authorized transportation at U.S. Government expense as follows:

1. From the contractor's home office in ____________ to the work sites and return.

2. Between the work sites, however, prior written approval of the Contracting Officer is required before travel is undertaken.

GUIDE FOR INSPECTION

OF

WATER-WELL CONSTRUCTION

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GUIDE FOR INSPECTION OF WATER-WELL CONSTRUCTION

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GUIDES FOR INSPECTION OF WATER-WELL CONSTRUCTION:

1. Introduction: Test wells are drilled to obtain information on the physical and hydraulic characteristics of underlying aquifer(s), nature of confining strata, water levels and quality of the ground water. From information gathered during test drilling operations, permanent water wells can be properly engineered and constructed to meet the existing physical conditions. Without reliable information that has been accurately interpreted, drillers and ground-water engineers must work blindly. There follows a list of some of the things to do, with suggestions for doing them, before and during sampling and testing work. These Inspection Guides are for the use of Government personnel assigned to water supply investigations and for the guidance of technical personnel employed by A/E firms under contract with the U.S. Government. Refer to Appendix 3, Engineering Supervision of Water-Well Construction.

2. Before Drilling Work Starts: The location for each well should be visited with the Contractor's drilling superintendent. The limits or real-estate clearance should be marked, the routes for an access road selected, the storage area for equipment and materials chosen, and disposal stream or pond for water during pump-testing located. Other similar items that will help make proper and efficient use of the surface of the land at the well site are to be pointed out to the drilling superintendent. It is best to go over with the driller all phases of contract work before starting work and resolve any items that may not be clearly understood. The Standard Guide Specifications in well construction and ground water development work specify certain actions to be taken and information to be exchanged between the Contractor and Contracting Officer prior to starting work, or soon thereafter. There follows a list of these actions:

Description of Action	Action by
a. Date drilling work will start.	Contractor
b. Number of personnel to be employed on project.	"
c. Key personnel by name, title and qualifications, such as drilling superintendents, drillers, welders, etc.	"
d. Complete list of drilling, testing and developing equipment by make, model, capacity and condition.	"
e. Number of rigs and shifts per rig per day.	"
f. Plan of operations proposed for each project, particularly as it will affect the logging and sampling work.	"
g. Detailed plan showing how the wells are to be surged, developed and sand removed from screen.	"
h. Detailed plan showing how the yield draw-down pump test for each well is to be made.	"
i. Obtain permission and location for storage of materials upon Government premises.	"
j. Use of established roads or temporary roadways.	"
k. Progress charts showing actual progress at end of each week and scheduled completion date for each well.	"
l. List of well screens to be stockpiled (when this procedure is used) with description such as size openings, diameter and length, grade, type and kind of fittings and date screens will be on job-site.	"
m. Safety program with records and reports.	"
n. Furnish location for wells, obtain real estate clearance and water right, furnish inspection and field direction by ground-water engineer, and provide geohydrological data and guidance.	Contracting Officer
o. Furnish plans, specifications, interpretations for test-well drilling and necessary guidance for well location and permanent well design.	"

The Supervising Engineer or Inspector should make sure that the following listed operations are clearly understood by the contractor and that proper steps will be taken to obtain desired results. (It will be assumed that the qualifications of the contractor and his drillers have been previously examined and approved).

a. Records: Obtain a supply of the Form for "Well Drilling Operations" and go over the various entries with the driller. Normally the inspector will fill out the report form in triplicate, with one copy for the contractor. The report should be made out near the close of each shift and signed by both the driller and the inspector. This is the only official record to be kept by the Contracting Offiers' representative. Personal note books and unsigned report forms are of little value in preparing the Completion and Evaluation Report.

All data pertinent to the contract work should be reported. Other items of work are to be added as they occur or develop, for example: depth of open hole below casing, record of casing sizes and lengths in hole, use of any drilling muds, (types, amounts, losses in circulation, etc.) and dispersing agents (polyphosphate), use of special tools or samplers, rate of drilling, tests for plumbness and alignment, and pertinent well construction information. Technical information especially obtained for the Completion Report, such as water-shed data, precipitation records, description of existing wells, aerial photographs, topographic maps, etc., may be compiled on separate sheets and attached to the Form on "Well Drilling Operations" as part of the permanent records. Copies of all basic information should be furnished to the Mission and AID/W. Basic geologic and hydrologic information need not be attested to by signature of driller and inspector. The subdivision, "Time Distribution" on the From will be the basis for payment for Unit Bid Items on an hourly basis. This is one reason why the daily shift report must be approved by both parties to the Contract. The total hours worked should be subdivided into the major operations listed on the basis of the nearest one-half hour. It is normally impractical to keep track of separate operations any closer than one-half hour because of repetition and alternation in drilling work.

b. Sampling Procedure: The procedure proposed for sampling by the contractor to comply with the specifications should be discussed, item by item, with the drilling superintendent. The sand-pump is the key to good sampling and it should be carefully examined in the field and compared with the requirements of the specifications. Under no condition should samples for record purposes be taken with a bailer. The piston on the sand-pump to be used for sampling should be checked to determine the condition of the washer seals and the valve for releasing the material from the pump should be tested. Close sampling need not be considered until potential water-bearing materials are encountered. Three steps for sampling must be followed: take precise measurements (on the drilling line) at the horizon where sampling is started, collect ALL material from the sand-pump, and measure the bottom of sampling with the drill line after sampling. Examine at least one of the sample bags to be furnished by the contractor to see that it complies with the specifications and check to see if a label is attached to the bag. See that the contractor has a supply of acceptable labels. As an average, at least twenty (20) bags should be on hand for each hole before drilling starts. The inspector should make arrangements to make, or have made, full gradation analysis. Hydrometer tests are never made for aquifer soil classification. The inspector should have some kind of wooden-boxes, troughs or drums that samples can be emptied into directly from the sand-pump. Selected samples for laboratory gradation analysis can be taken from the boxes later, after the inspector has had a chance to examine and study the material at well site and select the record samples. Samples should never be put directly from the well into sample bags.

During drilling, and to a lesser extent in the sampling operations, finer grained materials will be segregated and "float" on top of the material to be sampled and coarser grained particles will lie beneath. It is not enough, to take one sample load from each horizon; continuous sampling must be done to get the true average gradation for each foot, as well as the change in gradation throughout the aquifer. Frequently a larger screen opening size can be specified for installation in that part of an aquifer which may consist of coarser material. To avoid loss of recovered material, considerable care must be exercised in dumping or emptying the sand-pump to prevent loss of finer grained material. The details of and reasons for sampling should be explained to the driller before work starts and his cooperation definitely obtained. The quantities of silt and clay held in colloidal suspension in the drilling water and recovered by the sand-pump must be closely accounted for. There is little purpose in drilling the hole unless good, representative soil samples (including all fine grained materials) are obtained. For the purpose of visual identification, description of materials, and logging, the inspector should have in the field at least: one No. 60 and one No. 16 (or thereabouts) standard U.S. Sieves, (Complete gradation analysis should be made later, preferably in a Soil Laboratory), small bottle of dilute hydrochloric acid, thermometer (for measuring temperature of water at casing head), 8 or 10-power hand lens, knife, flash light, plastic sample bottles for water, water-level indicator with extra battery and electrodes, 50 foot cloth tape, clip-board with supply of forms, litmus paper, bar of soap for checking hardness of water in field, rolls of adhesive and drafting tape, watch with sweel second hand, orifice and weir tables, conversion charts, 100 foot steel tape for accurately measuring length of drilling cable, 6 foot steel folding rule, and similar other items. After a little experience, each inspector will be able to add his own personal time-saving gadgets that he has discovered to make measuring and record-keeping easier.

c. Continuous accurate measurements: of hole depth, length(s) of casing in hole and amount of hole below lowest casing should be planned with the drilling superintendent before drilling work starts so the contractor can schedule his work to make these measurements. All measurements should be referenced to the same measuring point, a steel pin, or two-inch wooden hub driven into the ground almost flush, are the commonly used reference points. The points should be located far enough away from the hole so not to be disturbed by drilling work. The elevation of the point should be determined. This is one feature of work where the Supervising Engineer takes the initiative and informs the contractor exactly how the depth of hole, amount of casing, screen settings, etc., are to be determined, with the Supervising Engineer making or supervising the taking of measurements. Suggested procedures are:

(1) First measure the overall length of assembled drilling tools from top of rope socket to bottom of bit. This length will vary, depending on component pieces and length of the particular bit used. The driller can be asked to inform the inspector when he changes bits, or tool-string length, but it is wise to practice to check this particular measurement whenever the tools are out of the hole and in the rack, or to mark in some way the individual components and record their measurements to a total overall length is known without physically having to measure the tool-string, When drilling jars are to be used in the tool-string an agreement must be made with the contractor on whether to measure with the jars open or closed.

(2) The cable length can be measured in advance, if the contractor so elects, by unspooling and marking 25 ft. and 50 ft. lengths with paint (luminous paint is good for this purpose), or in some other way permanently marking the cable. The cable length can also be measured (the common method) by measuring the cable from the top of the mast to the top of the casing, as the tools are lowered into or raised from the hole. One

way to semi-permanently mark the cable is to wrap adhesive tape around the cable, after first cleaning the section of cable to be marked to remove grease and dirt.

(3) It is recommended that all casing delivered to the job site, irrespective of sizes, be measured and permanently marked with paint, or marking crayon, to show a consecutive number and overall length of each piece. In this way the inspector can always check what casing has gone into the hole by making an inventory of what is left on the ground. A record should be kept of the length and number of each piece of casing placed in the hole. Measure made-up casing going into the hole from the bottom of the threads (on threaded and coupled pipe) on the lower joint, this gives a definitive location for each measurement. The weld on welded-joint pipe makes a good line to measure from.

(4) In shallow wells and some deep wells (more than 200 feet in depth) where it is necessary to shut off surface or shallow waters that are contaminated, it will be necessary to cement-in or in some other way seal off upper waters. There are published standard procedures for doing this kind of work. The inspector should refer to AWWA Standard Specifications for Deep Wells, A100-52. The driller's plans for doing the sealing should be reviewed and approved prior to starting sealing work. Where there are impermeable layers (clay or plastic silts), the bottom of the outer casing can often be sealed into one of them. The layers should be at least 25 feet thick, impermeable, and act as an effective seal both laterally and vertically. A good way to check the effectiveness of a potential well seal is to bail the hole frequently when drilling through the layers to measure just how much water will seep into the hole. If possible leave the hole for several hours and observe the rate of rise in the water level. For a good seal there should be practically no rise. No special provisions are included in the Guide Specifications for this feature of well construction

because it is considered to be a problem that must be solved in the field by the drilling contractor and is directly related to the methods used in drilling. For example, if the contractor drills an over-sized hole for convenience in installing casing, or for some other reason, it is then his responsibility to obtain a tight seal around the outside and bottom of the outer casing. The Contracting Officer should always reserve the right to approve the method the Contractor proposes to use. Where the producing aquifer is more than 50 feet below ground surface there is little chance for contamination from shallow waters if: (a) the casing is tight in the hole and 25 per cent or more of the overlying strata contains plastic silt or clay, and (b) the casing joints are tight, or (c) the contractor elects to grout around the casing. No grouting should be permitted within 50 feet of a well screen, or where there is a chance that grout may be carried to the screen.

(5) The terms pipe and casing are interchangeably used, frequently incorrectly. The inspector should know the main difference between the various kinds of pipe (standard, line, drive, extra heavy, and A.P.I. American Petroleum Institute) and water-well casing. A.P.I. line pipe is the most commonly used material for casing water wells drilled by the percussion tool method at the present time. Pipe differs from casing in weight per foot, bevel of threads, wall thickness, inside and outside diameter, type of thread, and size and weight of couplings. In considering welded-joint casing for use in water wells, these factors make little or no difference. In considering threaded or coupled casing, they do make a difference. Because its ends do not butt when joints are tight and its threads are fine (except for API casing), casing is not generally considered acceptable for water wells.

Experience has shown that when the taper end on pipe threads is too small and when the ends of the pipe butt, or nearly butt in the coupling, the joint is much more apt to become loose during driving than where a greater taper is used and where there is sufficient clearance between the ends of the pipe in the coupling so that the joints can be progressively tightened as driving proceeds. If the trouble is experienced in making pipe joints tight, threaded ends can be cut off and either of two actions taken: (a) bevel the ends and weld, or (b) turn out the coupling threads in a lathe to provide slip couplings so that pipe ends will butt. A coupling should be welded on end end of the pipe in such a way that half its length will extend from the pipe end. For installing, the coupling is placed end up so that when the pipe section has been driven, the piece of pipe foloowing it can be slipped into the top half of the coupling and welded into place with pipe ends butting together.

3. After Drilling Work Starts: Inspectors assigned to well drilling work should have a working knowledge of drills, equipment and drilling methods. The inspector should never try to give the driller instructions on how to operate equipment. The inspector should know enough about drilling to be able to tell whether a certain operation will bring about desired results or not. Hand books prepared by the Bucyrus-Erie Co., South Milwaukee, Wisconsin and the Star-Keystone Co., Beaver Falls, Penn. are suggested as good references. It is necessary for the inspectors to know about well drilling equipment and drilling operations in so far as knowledge of these subjects will assist in the interpretation of subsurface conditions, the design of permanent water wells, and the preparation of the Completion and Evaluation Reports. The inspector can obtain a good deal of information about the subsurface conditions by watching and recording the rate of progress in drilling. Assuming a constant drilling effort, the rate of hole progress is directly proportional to the hardness and strength of the beds penetrated. If there is need for subsurface data for foundation design of some structure to be located in the vicintiy of the test, the inspector should closely examine the materials recovered (to a depth of

50 feet) during the drilling operations and keep a record of the number of drilling strokes per minute and the number of minutes required to drill an average foot per ten foot of hole depth. Normal drilling operations will average 60 strokes per minute, with 22 inch stroke at the top of the hole, decreasing to around 50 strokes in the first hundred feet of depth. The use of standard drive sampling equipment can be considered if more than two subsurface investigation holes are in the program. Refer to ASTM Specification Designation D1586058T, "Penetration Test and Split Barrel Sampling." In most instances it will be necessary to design a floor slab, pump base and pumping station for every permanent well. The inspector should furnish the following work: detailed stratigraphic log of hole to 50 feet showing the changes in gradation (and moisture content if undisturbed samples can be obtained) measured to a depth accuracy of 0.1 foot, depth water was first encountered, static water level in hole, (when hole depth is at 50 feet), rate of rise of water in hole, presence of hydrostatic pressures (evidenced by sand heaving, flowing well, gas, odors), plasticity (non-plastic, high LL 50, medium LL35-50, low LL 35) and structural properties of the strata that would influence design.

a. Drilling: There follows a few rules for the inspector in guiding the drilling operations:

(1) In areas where holes have not been drilled, the first hole should be considered as exploratory and drilled to the bottom of the lowest aquifer. The final decision as to what is the "lowest aquifer" will be made by the Supervising Engineer. In general the potential yield of an aquifer is directly proportional to its thickness and the depth from static water level to the bottom of the aquifer, other conditions being equal.

(2) Clay (or shale) beds more than 100 feet in thickness are good indications that deper drilling will not be rewarding.

(3) Sample below the casing whenever possible (open-hole drilling) and never go more than three feet in fine-grained, or one foot in coarse grained material without sampling. The selection of material for laboratory gradations should depend upon variation in the size of the particles with depth especially in the sizes between the No. 40 mesh sieve (0.4 mm) and No. 80 mesh sieve (0.2 mm). It is very easy to seal off and go past a potential water bearing horizon simply by carrying a plug of material in the bottom of the casing. Measure the length of casing and depth of hole frequently and look out for the possibility of by-passing aquifers.

(4) The easiest method for quickly testing the yield of a potential horizon is by using a large dart-valve bailer. A few simple preparations should be made before the actual test. The contractor should furnish a trough to carry the water away from the drilling platform. Measure and mark the static-water level (after determining the rate of rise). Calculate the capacity of the bailer based on the following gallons per lineal foor for:

4" N.D. pipe - 0.66	7" N.D. pipe - 2.20
5" N.D. pipe - 1.84	8" N.D. pipe - 2.66
6" N.D. pipe - 1.50	10" N.D. pipe - 4.20

Measure and record the number of bailers removed per period of time in order to compute the yield in gallons per minute, and measure and record the change in dynamic level of water in the well during the test. After completion of bailing, observe, measure and record the rate of recovery. Samples for chemical analysis should never be taken from the bailer and care should be exercised in drawing any conclusion concerning the quality of the water during bail testing.

(6) Watch the way the bailer and tool-string go down the hole. Any sticking, draging or bumping are indications that the hole is not plumb or the inside of the welds in the casing are poor. The standard test

given in the job specification should be made for holes less than 200 feet in depth if there is any question of hole plumbness or alignment and at least one test should be made in the lower one-half of the well in all wells over 200 feet. If the water table is deep, a flash light or mirror to reflect the sun's light can be used to visually inspect alignment and the inside of casing welds.

(7) Inspect each joint of casing before it is welded or made-up. Observe the inside for bumps or protrusions that might prevent a pump from being lowered into the well. Measure closely and record the wall thickness and condition of each joint of pipe. For welded pipe, the welder must either be certified by the American Welding Society, or otherwise satisfy the requirements of the specifications by passing a welding test.

b. Sampling: The churn-drill is normally specified in test-well drilling because of the precision in sampling that can be obtained. Rotary, reverse-circulation and combination drills may be used under certain restricted condtions <u>AFTER</u> a test-hole has been drilled with the churn-drill. In churn-drilling there is no contaminants from overlaying material because the hole is (or should be) cased; muds and other potential contaminants are not allowed to be used; the samples are a true representation of in-situ material which can be physically and chemical tested; and immediate information can be obtained by bailing or pump-testing when the potential aquifer is exposed druing drilling. It is not necessary to use electric logging, bore-hole photography and other indirect methods with churn-drilling because the natual, in-situ material can be recovered in sampling and then graded and tested in the laboratory.

The material obtained by the driller from the sand pump should be gathered in piles for each foot of depth. Samples that are obviously alike can then be combined by the inspector, quartered and sacked for delivery to the laboratory. The first step in logging and field-classifying is to closely estamate the total percentage (for each individual stratum) of material smaller than the 200 mesh screen. A large part of the fine material will be lost in decanting the sample, left in the hole, held in suspension in the drilling water or for some other reason not collected. It is important to estimate as closely as possible the percentage of fines present in the water-bearing beds by observing the water in the hole, samples recovered, etc., during bailing operations. This estimate is important in order to help determine the porosity of the aquifer and to know something about the problems that will have to be faced in the surging and developing work. For example, if the material is plastic and clings to the gravel-sized particles a poor aquifer may be indicated and it will take much more surging effort to remove the fines. The plasticity of fine material is the key to many well-construction problems. The plasticity index is inversely proportional to permeability.

c. Logging: A stratigraphic log of materials shall be prepared. The description will include in order, the following items for each change in gradation, or change in kind of material: anme or classification (based on size) for alluvial (clastic) deposits, color (wet), plasticity, minerals, grain shape and roundness, polish or etching on surface of grains, degree of cementation or relative density, secondary material such as iron oxide or manganese staining, organic material, and correlation with surface outcrops (exposures) and logs of other wells in the region. Logging rock follows a very similar pattern, but should also include (from core samples) the thickness and description of layers, partings, fractures and other breaks in the rock. The log should show whether the natural openings are open or sealed. Attention should be given to evidence of shearing, chrushing or faulting and degree of alternation or weathering. The approximate amounts of silt, clay and fine sand can be easily determined by placing a handful of the sample in a bottle of water (a quarter milk bottle or a 1000 ml. cylinder jar) and note the comparative time for the various size materials to settle out.

PARTICLE SETTLEMENT RATES

(For well rounded particles with specific gravity of 2.6 and quiet water at 50°F.)

Size of Particle (mm)	Equivalent Sieve Size (US Std)	Settling rate (mm per sec)	Time to settle one foot (Seconds)
0.84	20	87	3.5
0.59	30	62	5
0.42	40	44	7
0.25	60	26	10
0.18	80	18	16
0.074	200	5	60
0.02	--	0.62	1.4×10^4
0.001	--	0.0015	1.7×10^5

The Inspector should make at least two US Standard sieve (No. 16 and No. 60 preferred) separations in the field for comparison of samples for combining purposes. It is much easier to describe the minerals, grain shape and roundness, etc. after making the sieve separations and removing the fines. It is difficult to recover cobbles and coarse gravel with the sand pump in 10" or smaller diameter holes. If the driller breaks up the larger particles with the drill bit, the size of the material covered will not be representative of the natural size and gradation of material. The inspector should be on the lookout for broken pieces of sand and gravel particles. When this takes place experience and judgment must replace actual gradation analysis. It is almost impossible to recover unbroken pieces of gravel larger than three inches in size. This is not too important in sampling coarse grained materials (cobbles or gravels) because the largest screen size opening normally used is 0.250 inches (1/4 inch opening). It is important, however, in sampling coarse grained material to determine how much material, smaller in size than 0.250 inch is in the potential aquifer that will have to be pulled through the openings during surging and developing work.

d. Water Samples: The chemical composition of minerals in alluvial deposits is one of the keys to the quality of ground waters. Refer to U.S. Geological Survey Water-Supply Paper No. 1473 for a comprehensive treatment on this subject. The inspector should include the following information in the Log of Materials Penetrated, and on the Form when sending water samples to the laboratory for testing: temperature of ground-water, presence of gas, odor, color (after pumping long enough for turbidity to reach a constant), color and amount of sediment on standing open overnight, taste, hardness with soap, depth of water source, time of sampling after completion of development work and similar information required by the Form.

In general, the shorter the time that elapses between collection of a sample of water and its analysis, the more reliable will be the analytical results. For certain constituents and physical values, immediate analysis in the field is required in order to obtain dependable results, because the composition of the sample may change before it arrives at the laboratory. It is impossible to state unequivocally how much time may be allowed to elapse between collection of a sample and its analysis; this depends upon the character of the sample, the particular analysis to be made, and the conditons of storage. Changes caused by the growth of organisms may be greatly retarded by keeping the sample in the dark and at a low temperature until it can be analyzed. The following maximum limits are suggested as reasonable for samples for physical and chemical analysis (after "Standard Methods for the Examination of Water and Waste Water, 11th Edition, APHA, AWWA and WPCF).

Unpolluted waters . . . . 72 hours

Slightly polluted waters. . . . . 48 hours

Polluted waters. . . . . 12 hours

4. Well Development: This is the most important item of work in well drilling. Proper development can make a poor well into a good one, and, lacking proper development, an otherwise excellent well may never be satisfactory. All water wells in alluvial deposits require developing to obtain full potential yield and to eliminate damaging silt and sand. Velocities are higher and backwash is stronger during development than will ever be experienced during service operation of the permanent well. Any material not moved by developing velocities will be stable under normal pumping operations. There are two well development methods, by surge-block and by using compressed air. Both methods provide a surging action to the water, moving it back and forth in the aquifer and in doing so moving fine grained silt and sand into the screen. There follows a summary of the more important rules that apply to surging and development work:

(a) Development work once started should not be stopped until completed.

(b) Jars should not be used in the tool string when surging.

(c) One of the points often overlooked in rigging up the surge block for development is the need for adequate weight in order to make the block drop rapidly enough on the down-stroke. Considerable weight is required. The tighter the surge block fits in the casing the greater the required weight to get the proper action. From a practical standpoint, it is more important to have enough weight to make the block drop at a good speed than it is to have the block really tight in the casing. A loose surge block operated at the proper speed will be much more effective than a tight block which is operated slowly.

(d) The rubber belting discs (surge block should have at least two) must fit tightly in the casing. Closely inspect the discs for wear each time the surge block is removed from the hole. Running the block up and down in the hole with worn-out discs serves little purpose.

(e) Surging should be done very slowly at first. After ten or fifteen minutes of surging, the tools should be withdrawn and the amount of sand pulled into the screen measured and removed by means of the sand pump. As the sand pump is first lowered into the hole, it will invariably strike the lead packer before it enters the screen. This point should be accurately marked on the sand line and the pump lowered very slowly past this point in all further work. The driller should be cautioned if he persists in dropping the pump (or bailer) past the top of screen. The bottom of the screen should be accurately measured and marked on the sand line. With these two control points, the lead packer and bottom of screen, the exact amount of sand pulled into the screen during each cycle of surging can be measured. The outside diameter of the sand pump should be measured to be sure that it can easily clear the inside diameter of the well screen.

(f) The inspector should keep an accurate record of the cycles of surging and record: total time spent in each cycle, rate of surging (number of strokes) per minute, feet of sand pulled into the screen each cycle (information required to determine rate at which sand recovery dropped off when plotted against time) and total cubic feet of sand recovered during development work. A comparative estimate should be made, prior to starting development work, of the cubic feet of sand that can and should be recovered. An approximation may be made by computing the volume of fine material (assuming 50% solid-volume) in a circular cylinder having a diameter four times the screen diameter and equal in length to the exposed screen. The average percentage of material smaller than the screen slot opening size is determined from the gradation analysis. The formula is: Volume (cubic feet)= K x length of screen in feet x % of material smaller in size than screen opening expressed as decimal x 0.50 (for pore-space reduction in volume)

Screen Size: D (Nominal Diameter)	K (Constant)
8"	8.5
10"	13.3
12"	19.1
16"	34.0

The constant K is from: $\frac{3.14}{4} \times \frac{(4D)^2 - D^2}{144}$

The quantity of sand silt that should be recovered during surging and development from a normal 8 inch screened well in sandy material will range from one cubic foot to three cubic feet per foot of exposed screen. With a little experience the inspector will be able to closely estimate the quantity of material that should be recovered by development work. The material can be measured in the screen before removing, or can be measured by dumping the sand pump into a box of known volume and shaking the material to get maximum density, until a known volume is thus obtained. The box can then be emptied and the process repeated until all sand is recovered and development work completed. This serves two purposes: to accumulate material for measuring the developed zone (lateral distance away from screen or developed envelope) and to be able to closely examine the particle sizes to be sure that material larger in size than the screen opening size is not being recovered. If material larger in size than the screen opening is pumped out of the screen, either the packer is not properly set or the screen has collapsed or otherwise failed. After successive periods of surging at set time intervals, the quantity of sand entering the screen will gradually become less. Surging time intervals should then be lengthened, until no sand (less than one-half foot) is recovered during an entire hour of surging. The total time required to develop a well to a point where no sand enters after an hour of surging, varies with the formation, the diameter of the well and surging effort. Some small diameter wells in coarse grained materials may be developed in a few hours, while larger wells in finer grained materials may take days to bring to a clean, stabilized state.

(g) Developing with air: follow the same pattern of instruction as given above but with the addition of pumping action. Aircan only be used where the depth of water over the top of the screen permits 50-70 percent submergence. There follows a list of air lift submergence and yield for best operating conditions:

Lift (feet)	Submergence (Feet)	(%)	Lift %	Starting Air Pressure (lbs/sq.in.)	Gallons Water per cubic ft. air	Cubic feet of air per gallon of water
25	53	68	32	23	8.34	0.12
50	93	65	35	40	4.35	0.23
100	150	60	40	65	2.70	0.37
150	183	55	40	79	2.04	0.49
200	216	52	48	94	1.54	0.65
250	240	49	51	104	1.21	0.83
300	266	47	53	115	0.96	1.04
350	287	45	55	124	0.80	1.25
400	302	43	57	130	0.69	1.45
450	326	42	58	141	0.61	1.65
500	348	41	59	150	0.54	1.85
600	400	40	60	173	0.45	2.25
700	448	39	61	194	0.39	2.55

There is little chance of over developing or sand-blocking a well using air. Because of limitations in the size of pipe that can be used in air developing and pumping and the amount of surging-effort that can be produced, air is normally only used to start development work. The surge block or plunger can exert a much stronger force and will accordingly develop a much larger area around the screen. The ideal system is using both air and surge block, provided the requirements of submergence are met.

5. Pump Testing: Prior to acceptance by the inspector, all permanent water wells will be evaluated by yield-drawdown and recovery tests to: (a) determine relationship between pumping (dynamic) water level and yield, and rate of recovery, (b) measure changes in physical and chemical properties of the ground water during pump-test, and (c) measure the amount of sand and sediment raised. The minimum capacity and head for the pump to be furnished by the contractor for yield-drawdown tests is usually given in the job specifications. The ability of pumping equipment to operate continuously (except for one or two short shutdowns of less than 5 to 10 minutes to add oil, make adjustments, etc.) is important. Tests that have to be discontinued without reaching stabilization are of little value and can be misleading. There follows a check list of some of the most important things to do before and during the pumping test.

(a) Verify that there is sufficient clearance for an electric sounding device to be lowered into the well between the pump column and inside of casing. A small diameter string of pipe ($\frac{1}{2}$"-3/4") installed with the pump column (in addition to the air line) will insure being able to get the electrode down the well.

(b) Check the depth of pump-intake setting proposed by contractor. It should not be lower than five feet above the top of the uppermost screen and must be submerged enough not to break suction at the pumping rate to be used.

(c) The water pumped during the test must be disposed of so that it cannot return to the aquifer and be repumped.

(d) The capacity of the pump is less important than the ability of the pumping equipment to operate continuously for a long period of time at a set, constant rate.

(e) It is the duty of the Contracting Officer to inform the contractor of the pumping-rates to use, change in pumping-rate to be made for the step-drawdown stage, and duration for the pump-test.

(f) Once started, the pump-test should not be stopped until the following listed data have been obtained: (1) stabilized (a reasonable lowering rate) drawdown in pumped well at constant pumping rate, (2) relative efficiency of the well as determined by a step-drawdown test, (3) comparative (with Theis' type curve) size, shape, and rate of growth of the cone of depression around the pumped well, as measured in observation holes, (4) the degree of compliance with normal standards.

(g) The pumping rate should not be decreased because it results in local recovery overlapping drawdown and creates a condition that cannot be interpreted.

(h) Any one pumping rate should not vary throughout by more than five percent.

(i) The static water level must be accurately determined before starting the pump-test. If possible determine any small seasonal or diurnal trend by measuring the level for several days prior to the test. This is especially applicable to observation wells.

(j) The water level before and after cyclic pumping (if used prior to acceptance pump-testing as part of the development work to try to raise the dynamic level) must be carefully measured. Cyclic pumping should be closely watched and discontinued if there is an appreciable lowering (two feet), until the cause is ascertained.

(k) Measure the size of orifice plate, weir box, or what ever device is furnished by contractor, to measure the pumping rate, and be sure that conversion tables are at hand for the size and kind of device used.

(l) Check the amount of sand and sediment raised during the pump test. This can be done by pumping into a tank or barrel where settling will occur. Two barrels connected together near the top will provide a simple way to collect sand. The sediment in suspension (turbidity) can be judged by casting a beam of light into the barrel. Field turbidity can be reported as the maximum depth in inches that newspaper print can be read below the surface of water using a two cell flash light. Turbidity of less than five is visibility to a depth of about three feet.

(m) Arrange to read drawdown (and recovery) levels every minute for the first 15 minutes, every 5 minutes for the next one-half hour and at half-hour intervals thereafter for the duration of each stage of the pumping test. The rate of recovery will determine the spacing of readings after the first hour. First stage pumping should continue until stabilization, as required by the specifications has been reached. The guide specifications read, "The estimated yield of the well shall be determined by the average output in gallons per minute when drawdown has ceased and stabilization of the water table has existed for at least 12 continuous hours ad directed by the Contracting Officer". This may be considered to be not more than 0.2 foot change in pumping level per any one hour period and no more than 0.5 foot lowering of pumping level in 12 hours of continuous pumping with all control measurements made with an accurately calibrated electrical sounding device and at least one measurement taken every hour during this time.

(n) Determine what lowering will take place in the general water table and what effects future pumping may have on nearby wells. Static-water level should be determined in wells (deep and shallow) within a radius of one mile (about) for a period of several days prior to starting the pump test. This is done to get the trend in the water level for the period of the pump-testing. The water level in the wells (observation) should be measured at frequent intervals during the pump test. The duration of the pumping test should be based, to some extent, upon the rate of lowering of the water level in the observation wells. Inspectors assigned to well construction work are not required to know the theory of ground-water hydraulics. Certain fundamentals are necessary so the inspector will understand and appreciate the measurements and field operations outlined herein. The fundamental hydraulic principles associated with a pumped well are: (a) water flows faster the closer it approaches the well screen; (b) the yield of a well is directly proportional to the drawdown as long as the flow of water in the aquifer to the well and in the well is steady, laminar flow; (c) the shape and slope of the cone of depression is directly related to the permeability of the deposits and the pumping rate, (d) the drawdown within a given distance increases approximately in proportion to the logarithm of the time since pumping began and decreases in proportion to the logarithm of the distance from the well. Water wells are separated into two categories depending upon the level of water in the hole. If the water level rises noticeably above the top of the aquifer it is said to be under 'artesian' conditions, or under 'pressure', or 'confined' by the overlaying and underlying beds. If the water level is at, or only a few feet above, the top of the water-bearing strata it is referred to as 'unconfined', or 'non-artesian', or 'water-table', or 'free-aquifer' conditions. These terms are found in various publications on ground-water and hydraulics. Plate No.8 shows the two conditions of water level as compared with aquifer position. In each of the two categories of wells the water level indicates the pressure head in the aquifer at the edge of the well for all elevations below that water level. As a well is being pumped the static water level is drawn downward, forming an inverted cone around the well. The cone of drawdown in artesian aquifers grows at a rate 50 to 100 times as fast as it does in unconfined aquifers. The relationship of drawdown to pumping rate (yield) is used to measure the effectiveness (evaluation) of well construction and to determine how much water can be safely withdrawn without overpumping the well. The relationship is used to check indirectly, the extent of surging and developing work and to help determine the relative permeability of the water-bearing beds that the well taps. The ratio of drawdown to pumping rate (yield) is not quite a direct proportion, except for the first few feet of lowering, after which the drawdown increases more rapidly than the yield. This is shown in Plate No.6. The maximum potential yield from a well is the drawdown from static low-water level to a point five feet above the top of the uppermost well screen. The distance of five feet is arbitrarily selected to prevent drawing the water level below the top of the screen which would expose the aquifer and screen to oxidation and result in overpumping. Turbulence in flow and movement of fine-grained material can also result from drawing the cone of depression into the well screen. The curves on Plate No.6 are used to estimate the safe pumping level, usually taken as one-half the potential water column. The estimated yield of a well is expressed in terms of gallons per minute produced for each foot of drawdown based on the calculated maximum potential yield. This way of expressing yield is referred to as the specific capacity. This relationship, discharge/drawdown decreases with increasing discharge and time and for this reason the relationship can only be used for estimating purposes and is most accurate when based on the calculated maximum potential yield basis (see Plate No.6). Drawdown is the difference between the static and pumping-water (dynamic) levels, or the amount the water level drops in the well during pumping. The total drawdown in a screened well represents the sum of two elements of head loss. Refer to Plate 9. One of these is the head loss associated with the well itself and is called the "well loss". It includes the head loss caused by the well screen, the extra head loss in the zine of higher velocities very close to the well and the head loss inside the well as the water flows upward to the pump intake. The formation head-loss is the larger of these two. It is the head that pushes the water through the aquifer within the area of influence of the well. Except for the zine very close to the well, the water moves slowly through the water bearing sand slowly enough to obey what is called the principle of laminar flow. This means the absence of turbulence. By careful examination of the specific capacity at various pumping rates the overall efficiency and whether the well has been developed to the highest efficiency can be determined. This is the principle behind the Step-Drawdown Testing Method shown on Plate No.10. Under laminar flow conditions, water moves through a given type of aquifer at a velocity directly proportional to head loss. If the head loss between any two points is doubled, the velocity is doubled. The component of the total drawdown represented by the formation head loss is directly proportioned to the well yield.

The capacities of water-bearing materials to transmit water under a hydraulic gradient and to yield water from storage when the water table or artesian pressure declines, are generally expressed, respectively, in terms of a coefficient of transmissibility and a coefficient of storage.

The quantity of water that will percolate through a given formation, is directly proportional to the hydraulic gradient, the cross-sectional area, and the permeability of the material. In most areas the hydraulic gradient can be determined from contour maps of the water table or the piezometic surface, and the cross-sectional area can be approximately ascertained from the logs of wells. The permeability of the water-bearing material, however, is usually more difficult to determine. The step-drawdown method of testing wells (example given on Plate No.10) is used to determine the well-construction efficiency, condition of well and the most effective pumping rate. The step-drawdown method is based on a study of the variations that occur in the specific capacity. The actual test of the well using the step-drawdown method involves pumping it at three or four different rates. The test is started with a pumping rate about 1/3 the capacity of the pump or well. This is held constant for three hours. The pumping rate is then suddenly stepped up to about 1/2 of the capacity and again held constant for three hours. This procedure is repeated for the third and fourth steps. Water level readings must be taken every five minutes for the first 30 minutes of each step and then every ten minutes for the duration of each step-test. The pumping rate must be accurately controlled and the test continuous from start to finish. If an observation well is available within a reasonable distance from the pumped well, the water level measurements in it should be made at the same time intervals as in the pumped well. Drawdown effect in observation wells can be analyzed in exactly the same way as in the well being pumped. An important detail in analyzing a step-drawdown test is to cancel out the effect of time of pumping. Normally, the drawdown increases slowly with time as a well is pumped. This change in drawdown is not related to the condition of the well so its effect on the specific capacity at different pumping rates has to be eliminated. The step-drawdown test shown on Plate 10 can be analyzed as follows:

GPM	Drawdown (each step)	Specific Capacity	% decrease
370	5.28	70.08	--
500	2.46	64.60	8.48
700	3.60	61.73	4.65
880	3.50	59.30	4.10

The specific capacity dropped from 70.08 GPM per foot of drawdown to 59.30 GPM as the pumping rate was stepped up from 370 GPM to 880 GPM. This is a decrease of 15.38 percent in specific capacity and is directly attributed to the well-loss element shown on Plate 9. Table 2 gives the gallons of water that can be obtained per lineal foot of screen length without danger of inducing turbulent flow or moving sand. These figures are conservative. By comparing the pumping rate with this table and with the step-drawdown test results, a fairly good appraisal of the well efficiency can be made. The permanent pumping rate should not exceed the capacity per foot given in Table 2, and the specific capacity should not excedd 20% well-loss when the pumping rate is doubled. These are comparable figures and must be interpreted in terms of elements such as the type of well, intended usage, life expectancy, number of wells in the field, demand, safety factor, hydraulic features of area, and others. The calculatic plotting of data and other phases of work required for the Well Completion and Evaluation Report should be done by the Supervising Engineer. The inspect is required to plan the pump-tests, make all measurements and observations and report the field data in accordance with the requirements of this Manual.

6. Completion and Evaluation Reports:

Paragraph 11 of the Manual provides for a Completion and Evaluation Report for each well, or well field. A determination should be made by the Mission as to whether individual well reports, or combined report will be prepared. The final report will be assembled and distributed by the Mission. The field inspector will plan all tests and make all observations and measurements to obtain the basic field data for the Report. There follows a check-list of the information to be furnished by the inspector. Refer also to Paragraph 11. It will not be possible in many cases to supply all of the information listed below and the inspector will often have to be satisfied with the data that can be obtained.

a. A description of all wells within one mile, including logs, screen data, history of construction, records of operation, pump-test records, quality of water, etc.

b. Description of terrain and contributing watershed near the well site from the standpoint of water recharge and storage. Information such as annual and monthly precipitation, type of soil cover, slope of ground in watershe size of water watershed, relative relief, drainage density, mean annual runoff,et

c. History of contract well construction. This can be best done by summarizing the operations in a chronological order for each well. The information should come from the "Well Drilling Operations" forms. Any construction problems experienced that may affect the life or use of the well as an efficient structure are to be included, items such as: alignment and plumbness tests, installation of well screens, settlement around casing, use of muds, detergents or acid, etc.

d. Completed copies of the form, "Log of Materials Penetrated", shown on Plage 2. (Graphic strip logs need not be prepared.)

e. Completed copies of the form, "Pump-Testing Report", shown on Plate No.3. (Curves need not be plotted or calculations made.)

f. Physical test data on samples of water, temperature, presence of gas, color, odor, turbidity, etc.

g. Miscellaneous information such as, aerial photographs, copies of topographic and real estate maps, geologic maps, soil maps, copies of reports that contain related information, climatological records, etc.

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