**US Army Corps**
**of Engineers**
**Afghanistan Engineer District**

# AED Design Requirements:
## Well Pumps & Well Design

Various Locations,
Afghanistan

July 2012, Version 2.1

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AED DESIGN REQUIREMENTS
FOR
WELL PUMPS & WELL DESIGN
VARIOUS LOCATIONS, AFGHANISTAN

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## 1. GENERAL

This document is available online at http://www.aed.usace.army.mil/Design.asp . Its purpose is to provide an overview of the information needed by Contractors to design and construct wells for the Afghanistan Engineering District (AED). Even under the best of conditions, building a successful well requires many scientific disciplines, access to supplies and equipment, experienced personnel, and a bit of luck. Building wells in Afghanistan necessarily requires some unique approaches and simplifications.

The document is organized in the following manner. The main body of the document provides information, concepts and guidelines related to site planning, design processes and construction methods. Appendix A provides information on acceptable and unacceptable construction techniques and materials used on AED projects. Photographs are provided to help Contractors understand what AED will and will not accept during a well construction project. Appendix B contains procedures on well screen and filter pack design when depth-dependent gradation curves are available. Appendix C provides information to be used when sizing and selecting pumps for wells on AED projects. Appendix D includes the actual textbook pages for selected references. Appendix E contains the Water Well Summary Sheet and instructions.

The primary goal is to find a suitable water supply at the shallowest depth. In most cases, this will be an alluvial or unconsolidated aquifer. Fractured bedrock wells represent a high-cost, high-risk exploration target. To facilitate the goal of finding shallowest water, AED has structured the payment schedule to create a financial incentive for finding the shallowest water, and a financial disincentive for finding the deepest water.

Wells must extend at least 40 meters below the static (non-pumping) water level (except in areas where salinity or total dissolved solids concentrations increase with depth) and must not extend deeper than 120 meters without modification to the contract. The contract will only be modified when AED is convinced that the shallow, unconsolidated aquifer was thoroughly and accurately tested for both water quantity and quality.

The Contractor will be paid based upon contract requirements and specifications. The standard contract requirement is a lump-sum depth of 120m. If a contractor constructs an acceptable production well at a shallower depth than specified in the contract, he will still be paid the full lump-sum amount.

All drilling and well construction materials will be on site before drilling commences. This may require that some materials be supplied in quantities so that design and placement decisions can be made in the field. These supplies include, but are not limited to, drilling mud, casing, well screen, and filter packing. AED has experienced problems with wells constructed over the past few years. One of the common problems has been with PVC well screens; therefore we now require stainless-steel screens.

Water quantity requirements including the design population, usage per capita, capacity factor and pumping day will be specified in the 1010 and 1015 documents. Nevertheless, it is understood that despite the best efforts of the contractor, adequate water may not be found. Well reports will be required as explained in this document. All submissions should identify the site by coordinates.

It is an AED requirement that a qualified Geologist or Hydrogeologist be present on the drilling rig for all phases of drilling. This Geologist must have at least 3 years experience in soil and rock logging, and water-supply well installation. Qualifications of the Geologist will be available for AED approval. Duties of the Geologist will include, but are not limited to the following:

- Ensure that the Driller's Log is completed.
- Preparation of the Geologic Log (lithologic descriptions from rock samples or chips).
- Determination of the water table (first water).
- Ensure proper configuration of test well.
- Conduct the pumping tests and report preparation.
- Preparation of the Final Well Design Proposal.
- Supervise the construction, development, and disinfection of the permanent well.
- Perform the final performance testing of the permanent well.
- Prepare the Water Well Summary Sheet (Appendix E)
- Prepare the Final Well Completion Report.

## 2. WELL CONSTRUCTION SEQUENCING

The sequence to be followed for AED well construction projects is as follows. Details about each of these steps are found in subsequent sections.

Section 3.0 Required Reporting
Section 4.0 Select Well Site
Section 5.0 Drill Well Borehole
Section 6.0 Preliminary Well Testing
Section 7.0 Propose Final Well Design
Section 8.0 Receive AED Approval
Section 9.0 Construct Permanent Well
Section 10.0 Develop and Disinfect Well
Section 11.0 Test Well Performance
Section 12.0 Submit Final Well Completion Report

## 3. REQUIRED REPORTING

Contractor must construct water well(s) as specified in the contract to provide sufficient supply for the population of the facility. The well construction and water well capacity shall be based on the allowable safe yield of the new well, determined by a well pumping test as described in the following sections. The contractor will provide documentation for approval at the planning and design stages. The Contractor shall submit all required information listed below and take the following steps:

1. Well Test and Construction Plan – Prepare and submit a customized Well Test and Construction Plan PRIOR to any well drilling activities and include procedures for decommissioning dry wells in the event water is not encountered.
2. Approval of Well Test and Construction Plan – Obtain approval of the Well Test and Construction Plan before starting to drill.
3. Well Drilling – After government approves the Well Test and Construction Plan, drill a test well.
4. Pumping Test – Conduct step-drawdown test to determine yields.
5. Water Quality Test – Sample and test the quality of water in the test well.
6. Well Design – Design a permanent well, based upon lithologic and groundwater data of test well.
7. Water Well Test and Permanent Well Design Report – Provide water-quality lab results, pumping-test results, driller's log, lithologic log, and a well construction design for approval PRIOR to the start of final well construction.
8. Government Approval – Final well construction cannot start until government approves the Water Well Test Report and Permanent Well Design with proposed construction details.
9. Well Construction – Build final well in accordance with approved well construction details and contract specifications. The final well construction details must be provided in the post-construction as-builts.
10. As Builts – The completed well including lithology should be part of the As-Built Drawings.

## 3.1 WELL TEST AND CONSTRUCTION PLAN

The Contractor shall submit a site-specific Well Test and Construction Plan PRIOR to any well drilling activities for each well. The plan will include coordinates for the well. The plan will also plan for decommissioning a dry well in the event water is not encountered. After approval of the well construction and test plan by the government, site mobilization can proceed. One plan per site will be required if more than one well of the approximate same depth is planned for the same site, the contractor will be reimbursed for one plan.

## 3.2 WATER QUALITY TESTING AND REPORTING

The Contractor shall drill the wells in an attempt to find potable water meeting all World Health Organization (WHO) water quality requirements. Upon completion of drilling of the well borehole and testing of the well, the contractor must conduct water quality sampling of the water in the well and analytical testing must be conducted by an approved analytical laboratory. Analytical testing must be conducted on each well drilled. The results of the testing must be provided to the Government and final well construction cannot be started without review and approval of the water quality test results. If water cannot be found meeting WHO standards, the Contractor shall immediately notify the Contracting Officer's Representative (COR).

## 3.3 TEST RESULTS AND PERMANENT WELL DESIGN REPORT

Contractor must provide well pumping test results, drillers log, lithology log, and submit a well construction design for approval PRIOR to the start of final well construction (submit prior to installing any features of the well that cannot be removed without destruction of the well). This information is required for each well drilled under AED contract. The contractor must design a permanent well based upon initial testing of well based upon lithology, groundwater data, pumping test(s), and recovery test(s) (Capacity test of well yield). Final well construction cannot start until government approval of Water Well Test and Permanent Well Design Report with proposed final construction details. Upon approval of the design and report by the Government, the contractor shall build final well in accordance with approved well construction detail and contract specifications. The final well construction details must be provided in the post-construction as-builts.

### 3.4 AS-BUILT DRAWINGS

The As-Built drawings item shall consist of all labor, equipment and supplies required to produce as-build drawings of the constructed well and appurtenances. This will include the Water Well Summary Sheet.

## 4. SELECT WELL SITE

If the well location is not specified in the contract, the contractor may be required to select a location for the well. Prior to selecting the well location, a thorough survey of the area should be undertaken. The following information should be obtained and considered:

- Local hydrogeology such as terrain, soil type, depth, and thickness of water bearing zone.
- Location of nearby karezes (qanats) and wells, both drilled and hand dug, particularly those that may limit the well yield or be impacted by the new well.Location, construction, and disposal practices of nearby sewage and industrial facilities.
- Locations of sewers, septic tanks, cesspools, leach fields, pastures and irrigated fields.
- Chemical and bacteriological quality of ground water, especially the quality of water from nearby wells.
- Histories of water, oil, and gas well exploration and development in area.
- Location and operating practices of nearby industrial and municipal landfills and dumps.
- Direction and rate of travel of ground water if studies have been conducted.

The existing facilities such as building structures, utilities, walks, trees, etc., shall be protected from damage during construction of the wells, and if damaged, shall be repaired by the Contractor at his expense. Water pumped from the well shall be conveyed via piping to a place where it will not damage property or create a nuisance.

Recommended minimum distances for well sites from commonly encountered potential sources of pollution are shown in Table 1. It is emphasized that these are minimum distances which can serve as rough guides for locating a well from a potential source of groundwater contamination. The distance may be greater, depending on the geology of the area. In general, very fine sand and silt filter contaminants in groundwater better than limestone, fractured rock, coarse sand and gravel. Chemical contaminants may persist indefinitely in untreated groundwater. If at all possible, a well should be located up-gradient of any known nearby or potential sources of contamination.

**Table 1. Minimum Distance from Pollution Sources.**

| Source | Minimum Horizontal Distance |
|---|---|
| Building Sewer | 15m (50ft) |
| Disposal Field / Septic Tank | 30m (100ft) |
| Seepage Pit | 30m (100ft) |
| Dry Well, Abandoned Well | 15m (50ft) |
| Cesspool / Leaching Pits | 45m (150ft) |
| Note: *The above minimum horizontal distances apply to wells at all depths. Greater distances are recommended when feasible.* | |

Well-site planning should also consider the proximity to existing wells both on the project site and in the local community. Distance must be a minimum of 60m from an active well. A full discussion on the mathematics of well hydraulics is beyond the purview of this document; however, Section 11, Multi-Well Fields, shows a simplified method of estimating the radius of influence for an unconfined aquifer at steady state.

The Driller shall take all necessary precautions during construction to prevent contaminated water, gasoline or other contaminated materials from entering the well either through the opening or by seepage through the ground surface. The Driller shall exercise extreme care in performance of his work in order to prevent the breakdown or caving of the strata overlying that from which the water is to be drawn.

## 5. DRILL WELL BOREHOLE

After the Government approves the Well Construction and Testing Plan, the contractor shall drill the well borehole, collect lithologic and aquifer data, install temporary casing and screen, conduct pumping tests, and collect and analyze groundwater samples for laboratory analysis. The borehole shall be drilled, using minimum borehole diameter and depth specifications listed in the contract, into the water bearing stratum or bedrock. These tests must be completed before permanent well construction. This well shall be located as shown on the drawings, or where directed by the Contracting Officer (CO) or his representative (COR).

A GPS instrument will be used to determine the geographic coordinates of the well. This information shall meet requirements of the World Geodetic System 1984 (WGS 84 and the correct UTM Zone – 41, 42, or 43) in decimal degrees. The test hole shall be used to determine the location and character of the water-bearing strata and to obtain samples of the various formations. Samples of drilling cuttings shall be taken at every change of strata and at depth intervals not to exceed 1.5 meters. A driller's log shall be made based on the cuttings obtained. The drill cuttings shall be divided, put into suitable containers and labeled. These samples shall be approximately half a liter each. If the test hole fails to indicate the presence of water-bearing strata or is abandoned for any other reason, the test hole shall be plugged in conformance to UFGS-33 20 00 (April, 2008) Section 1.3.2. At the completion of the test hole, a drillers log shall be prepared containing the following information:

- Depth of water strata
- Depth of different material strata contacts
- Color, size, and soil description of cuttings
- Penetration rate (meters per day)
- Types and amount of drilling fluid gain or loss
- Type schedule and length of well casing

AED requires that the alluvial or unconsolidated zone be thoroughly tested for water before bedrock drilling can commence. Results of this testing will be documented in the Final Well Design Report. Failure to prove that the unconsolidated aquifer was tested for water will result in no modifications for drilling deeper than the depth stipulated in the contract. This provides a financial incentive to thoroughly test the water bearing characteristics of the alluvial or unconsolidated zone.

## 6. PRELIMINARY WELL TESTING

### 6.1 PUMPING TESTS

To determine the expected yield from the well and to assure acceptable water quality, a pumping test shall be performed in the candidate test well. Three types of tests can be performed.

1) Step-drawdown Test. This 3-step test measures the non-steady state drawdown curves which result from increasing the pumping rates at 75%, 100% and 150% of the design flow. Each pumping step will be allowed to continue to steady state before proceeding to the next step. This test establishes the maximum pumping rate that is sustainable by this well, and is required for every test well. These data can also be used to calculate Specific Capacity.

2) Specific Capacity Test. This is the simplest of the three tests and measures the productivity of a well. It is defined by discharge divided by drawdown at steady-state conditions. This test is required only if a Step-drawdown test was not feasible.

3) Pumping test. This test measures the hydraulic conductivity or transmissivity of the aquifer and is required for major municipal supply wells, or in areas where well- interference is suspected. This test requires at least one observation well and may require long pumping times in order to effectively stress the aquifer. Please refer to Driscoll (1986, page 534) for detailed information on collecting and analyzing pumping test data.

A temporary casing and screen may be used to construct the test well for execution of a 3 phase step-drawdown test. The 3 phase step-drawdown test shall test the well at 75%, 100% and 150% of the design flow required for the well. A temporary pump with the capacity to pump at the rates may be used for this test. The static water level in the well will be measured prior to installing the pump and the water level at the end of the pumping period will be measured. The temporary casing shall be a minimum diameter of 150mm and extend to the top of the water bearing strata being tested in unconsolidated formations. The Contractor shall not let pumped water infiltrate near the pumping test. Doing so invalidates the required assumptions and invalidates the test. After completion of the test well, all data pertaining to the construction of the well shall be reported as described in Section 3.3.

## 6.2 WATER QUALITY TESTING

Water quality must also be established in the test well. During the testing of the test well and again during the yield and drawdown test in the permanent well, the Contractor shall schedule to obtain a preliminary sample of the water in suitable containers and of sufficient quantity to have bacterial, physical and chemical analyses made. The word "potable" for purpose of this contract is further defined as water that is suitable for drinking by the public, i.e., good, clear water -- free from objectionable amounts of harmful bacteria and with acceptable chemical and physical properties. Sampling shall be performed by qualified personnel who must obtain sampling kits and obtain the samples as directed. The coordination with the COR for the sampling and analysis should start at the beginning of the contractual period.

As a goal, AED suggests water quality testing contained in the U.S. Department of Defense drinking water standards (see DOD TB MED 577, 2005, UFC 3 230 08a Water Supply Water Treatment, January 2004, and TM 5-813-3/AFM 88-10, Vol. 3). Another goal is that wells supplying water to Afghanistan installations will meet the World Health Organization drinking water standards (WHO, 2006). In certain cases, some of these goals may not be feasible. At a minimum, the parameters shown in Table 2 will be tested.

**Table 2. Water Quality Testing Parameters**

| Physical and Biological Characteristics: | Chemical Characteristics (Expressed as mg/L): |
|---|---|
| • Turbidity | • Arsenic |
| • Conductivity | • Chromium $^{+6}$ |
| • Total Dissolved Solids | • Lead |
| • pH | • Cadmium |
| • Total/fecal coliform | • Selenium |
| • Total Hardness (as $CaCO_3$) | • Copper |
| | • Silica |
| | • Sodium |
| | • Potassium |
| | • Magnesium |
| | • Fluoride as F |
| | • Manganese as Mn (Dissolved and total) |
| | • Iron as Fe (Dissolved and total) |
| | • Sulphates as $SO_4$ |
| | • Chlorides as Cl |
| | • Nitrites as $NO_2$ |
| | • Nitrates as $NO_3$ |
| | • Ammonia |
| | • Bicarbonate |
| | • Carbonate |

## 7. PROPOSE FINAL WELL DESIGN

Test wells and permanent wells should be at least 40 meters below the static water table, unless groundwater quality decreases with depth or site conditions dictate otherwise. The pump, at actual capacity, should have a minimum of four meters of submergence at the lowest drawdown depth reached during the pumping tests described later in this guide. Well screens shall have a minimum of four meters submergence at the lowest drawdown depth occurring during well testing. Permanent wells shall not operate with any portion of the well screen above the lowest drawdown level.

Well design methods and construction techniques are different for water wells constructed in consolidated vs. unconsolidated formations. Typically, wells constructed in an unconsolidated formation require a screen to line the lower portion of the borehole. An artificial gravel pack will be required. A diagrammatic section of a gravel-packed well is shown in Figure 1. Wells constructed in sandstone, limestone or other fractured rock formations can often utilize an uncased borehole in the aquifer, and do not normally require screens or gravel pack. A well in bedrock is shown in Figure 2. The contents of the Final Well Design Proposal are outlined in Section 8.0.

**Figure 1. Diagrammatic Section of Gravel-Packed Well**

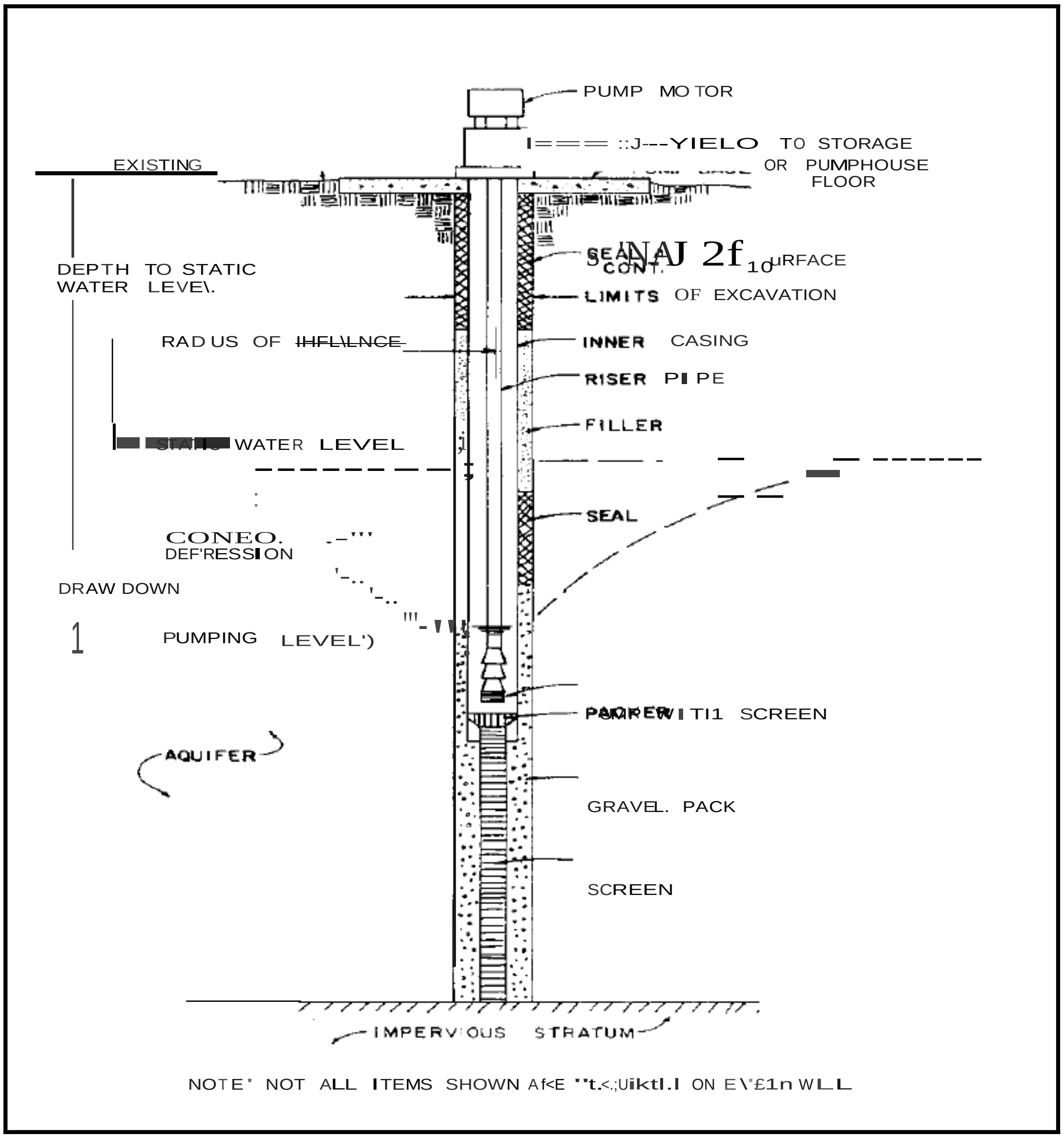
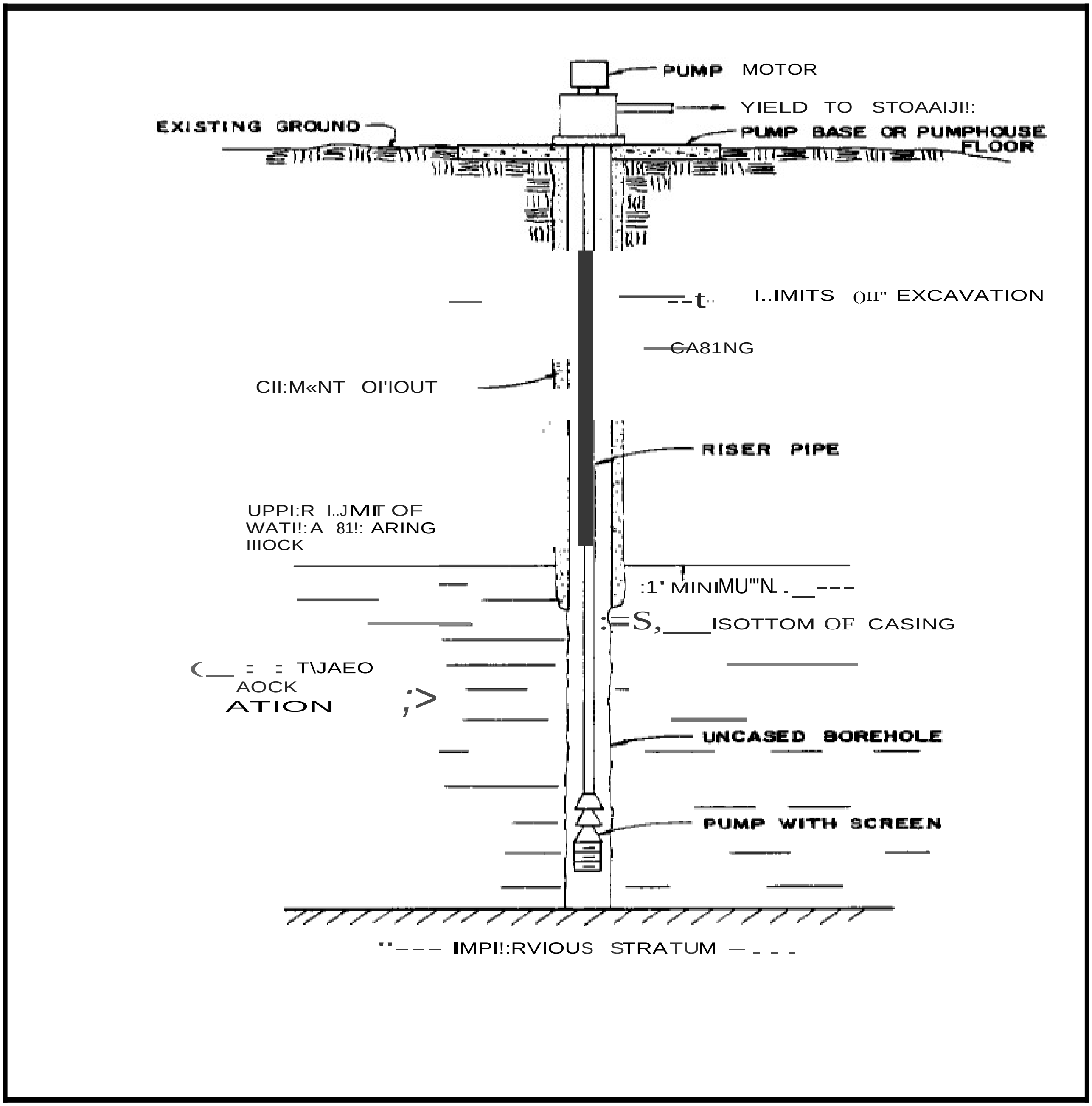


**Figure 2. Well in Bedrock**




## 7.1 WELL CASING

**7.1.1 SURFACE CASING.** Steel surface casing shall be used at the driller's discretion. This casing may be left in place or removed at the option of the driller. Steel casing should be driven 0.50 m into bedrock and cemented in place for its full depth, if it is to be left in place. All well surface casing shall be extended 0.5 meters above grade.

**7.1.2 WELL CASING DIAMETER.** The inside diameter for well casings shall be selected based on information provided in Table 3. The minimum diameter for any well casing shall be 150mm (6 in). Larger diameters shall be installed based on required well yield and the potential for future expansion. The diameter of a well has a significant effect on the well's construction cost. The diameter shall be uniform from top to bottom. In rare circumstances, construction may be initiated with a certain diameter casing, but drilling conditions may make it desirable to reduce the casing size at some depth. However, the diameter must be large enough to accommodate the pump. In addition, the diameter of the intake section must be sufficient to assure that the upward velocity of the flow in the pump discharge pipe is 1.5 m/sec or less. The well shall be constructed to be straight and plumb. Other factors that control diameter are (1) yield of the well, 2) screen intake entrance velocity, and (3) construction method. The pump size, which is related to yield, usually dominates.

Approximate well diameters for various yields are shown in Table 3. Well diameter affects well yield but not to a major degree. Doubling the diameter of the well diameter will produce only about 10 to15 percent more water. Table 4 gives the theoretical changes in yield that result from changing from one well diameter to a new well diameter. For artesian wells, the yield increase resulting from diameter doubling is generally less than 10 percent. Consideration should be given to future expansion and installation of a larger pump. This may be likely in cases where the capacity of the aquifer material (such as coarse-grained gravels and unconsolidated conglomerate) is greater than well yield required for the current project.

The values in Table 4 are valid only for wells in unconfined aquifers (water table wells) and are based on the following equation:

$$Y_2/Y_1=(\log R/r_1)/(\log R/r_2) \qquad \text{Eq. 1}$$

Where:

$Y_2$=yield of new well
$Y_1$=yield of original well
R=Radius of cone of depression (mm)
$r_2$=diameter of new well (mm)
$r_1$=diameter of original well (mm)

**Table 3. Well Diameter vs. Expected Yield**
**(In SI and U.S. Customary Units)**

| Expected Well Yield | Nominal Size of Pump Bowls | Optimum Size of Well Casing | Smallest Size Well Casing |
|---|---|---|---|
| | | | |
| (lpm) | (mm) | (mm) | (mm) |
| | | | |
| <380 | 100 | 150 ID | 125 ID |
| 285-660 | 125 | 200 ID | 150 ID |
| 570-1515 | 150 | 250 ID | 200 ID |
| 1325-2460 | 200 | 300 ID | 250 ID |
| 2270-3400 | 250 | 350 OD | 300 ID |
| 3200-4900 | 300 | 400 OD | 350 OD |
| 4550-6800 | 350 | 500 OD | 400 OD |
| 6050-11400 | 400 | 600 OD | 500 OD |
| | | | |
| (gpm) | (in) | (in) | (in) |
| | | | |
| <100 | 4 | 6 ID | 5 ID |
| 75-175 | 5 | 8 ID | 6 ID |
| 150-400 | 6 | 10 ID | 8 ID |
| 350-650 | 8 | 12 ID | 10 ID |
| 600-900 | 10 | 14 OD | 12 ID |
| 850-1300 | 12 | 16 OD | 14 OD |
| 1200-1800 | 14 | 20 OD | 16 OD |
| 1600-3000 | 16 | 24 OD | 20 OD |
| 3000-6000 | 20 | 30 OD | 24 OD |

Note: *If provided, contract section 01015 technical requirements shall supersede the minimum diameters suggested in this table.*

**Table 4. Change in Yield for Variation in Well Diameter**

| Original Well Diameter | New Well Diameter 150 mm (6") | 300 mm (12") | 450 mm (18") | 600 mm (24") | 750 mm (30") | 900 mm (36") | 1200 mm (48") |
|---|---|---|---|---|---|---|---|
| 150 mm (6") | 100% | 110% | 117% | 122% | 127% | 131% | 137% |
| 300 mm (12") | 90 | 100 | 106 | 111 | 116 | 119 | 125 |
| 450 mm (18") | 84 | 93 | 100 | 104 | 108 | 112 | 117 |
| 600 mm (24") | 79 | 88 | 95 | 100 | 104 | 107 | 112 |
| 750 mm (30") | 76 | 85 | 91 | 96 | 100 | 103 | 108 |
| 900 mm (36") | 73 | 82 | 88 | 92 | 96 | 100 | 105 |
| 1200 mm (48") | 69 | 77 | 82 | 87 | 91 | 94 | 100 |

Note: *The above gives the theoretical increase or decrease in yield that result from changing the original well diameter to the new well diameter. For example, if a 300 mm well is enlarged to a 900mm well, the yield will be increased by 19 percent.*

**7.2 WELL AND CASING DEPTH.** Depth of a well is usually determined from the logs of test holes or from logs of other nearby wells that utilize the same aquifer. However for contract purposes, a minimum depth is usually specified in either the contract 01015 (Technical Requirements) or in the water well guide specification. A well that is screened the full length of the water bearing stratum has a potential for greater discharge than a unit that is not fully screened. Where the water-bearing formations are thick, cost may be the deciding factor in how deep the wells are installed. Cost, however, is normally balanced by the savings from a potentially long-term source of water. Well casing should not be founded on bedrock, since the weight of the casing and any other loads transferred to the casing from the construction features may exceed the buckling strength of the casing. The wall friction of the casing after sealing, grouting and well gravel packing should be designed to bear the vertical load on the casing.

**7.3 CASING MATERIAL.** The allowable casing material is steel (ASTM A53 Grade B or ASTM A139 Grade B). Use of PVC is not authorized. The casing in a well developed in a sand and gravel formation should extend a minimum of 4 m below the lowest estimated pumping level. In the percussion method of drilling, and where sloughing is a problem, it is customary to drill and jack the casing to the lower extremity of the aquifer, install the appropriate size screen inside the casing, and then pull the casing back, exposing the screen to the water-bearing formation. The wall thickness and pipe strength for the casing material depend on the hydraulic collapse and buckling strengths required for the well. Substitution of other pipe material shall first be approved by providing a shop submittal (Form 4025) with material specifications sufficient to evaluate the pipe strength for the proposed well application. The minimum wall thickness for steel pipe used for casing is 8 mm. Table 5 provides minimum pipe wall thicknesses for various diameters:

**Table 5. Minimum Steel Pipe Casing Wall Thicknesses By Well Diameter**

| Nominal Diameter, mm (in) | Wall Thickness, mm (in) |
|---|---|
| 150 (6) | 8 (.250) |
| 200 (8) | 8 (.250) |
| 250 (10) | 8 (.279) |
| 300 (12) | 9 (.330) |
| 350 (14) | 10 (.375) |
| 400 (16) | 10 (.375) |
| 450 (18) | 10 (.375) |
| 500 (20) | 10 (.375) |

**7.4 WELL SCREENS.** Well screen shall be 304 stainless steel, wire-wrapped, and with a slot size between 0.7 and 1.0 mm (unless specified differently by the COR). Ideally well screens are designed based on the type of aquifer material encountered during drilling. This requires accurate depth information correlated to samples of the material at various depths and changes in strata. It is often not practical or feasible to perform these tests, because it is a requirement that all equipment and supplies be acquired, and located at the well site before drilling can commence. This includes the well screen and gravel pack material.

There will be situations (high pumping rates or large design populations) when the well screen and filter pack must be designed to match the geologic materials. If specified by the COR, the

Contractor will perform the appropriate design calculations (Appendix B) and supply the specified well screen and filter pack.

Naturally-developed wells are not allowed because they do not allow for the installation of the bentonite seal. The minimum inside diameter of the well screen shall be 150mm. A properly designed screen allows the permeability of the water bearing materials around the screen to be utilized. The screen and filter pack function to restrain sand and gravel from entering the well, which would diminish yield, damage pumping equipment, and deteriorate the quality of the water produced. Wells developed in fractured bedrock areas do not need screens if the wall is sufficiently stable and sand pumping is not a problem. Appendix A shows examples of acceptable and unacceptable well screens.

Screen length depends on aquifer characteristics, aquifer thickness, and available drawdown. The minimum screen length of stainless steel screens shall be two (2) meters. For a homogeneous, confined, artesian aquifer, 70 to 80 percent of the aquifer should be screened and the maximum drawdown should not exceed the distance from the static water level to the top of the aquifer. For a non-homogeneous, artesian aquifer, it is usually best to screen the most permeable strata. The top of the screen will be at least 4m below the lowest drawdown level reached during the testing.

Homogeneous, unconfined (water-table) aquifers shall be equipped with screens covering the lower one-third to one-half of the aquifer. A water-table well is usually operated so that the pumping water level is at least 4 meters above the top of the pump. Screens for non-homogeneous water table aquifers are positioned in the lower portions of the most permeable strata in order to permit maximum available drawdown. The following equation shall be used to determine if a screen length greater than the minimum screen length stated above is required:

$$L=Q/(AV(7.48)) \qquad \text{Eq. 2}$$

Where,

L=length of screen (ft)

Q=discharge (gpm)

A=effective open area per foot of screen length ($ft^2/ft$). Approximately ½ of the actual open area which can be obtained from screen manufacturers.

V=velocity (fpm) above which a sand particle is transported; is related to hydraulic conductivity as shown in Table 6.

Centralizers will be placed at the top and bottom of each section, and at intervals of 8 meters of screen to maintain the screen position in the center of the hole. If the screen length is greater than 8 meters, a 1 meter length of blank casing shall be placed in the middle of the screen interval for placement of centering devices. Centering devices will not be placed on the screened interval.

**Table 6. Estimated Sand Transport Velocities**

| Hydraulic conductivity | | Velocity sand transport | |
|---|---|---|---|
| m/day | gpd/ft^2 | m/min | ft/min |
| 204 | 5,000 | 3.05 | 10 |
| 163 | 4,000 | 2.74 | 9 |
| 122 | 3,000 | 2.44 | 8 |
| 102 | 2,500 | 2.13 | 7 |
| 82 | 2,000 | 1.83 | 6 |
| 61 | 1,500 | 1.52 | 5 |
| 41 | 1,000 | 1.22 | 4 |
| 20 | 500 | 0.91 | 3 |
| 10 | 250 | 0.61 | 2 |

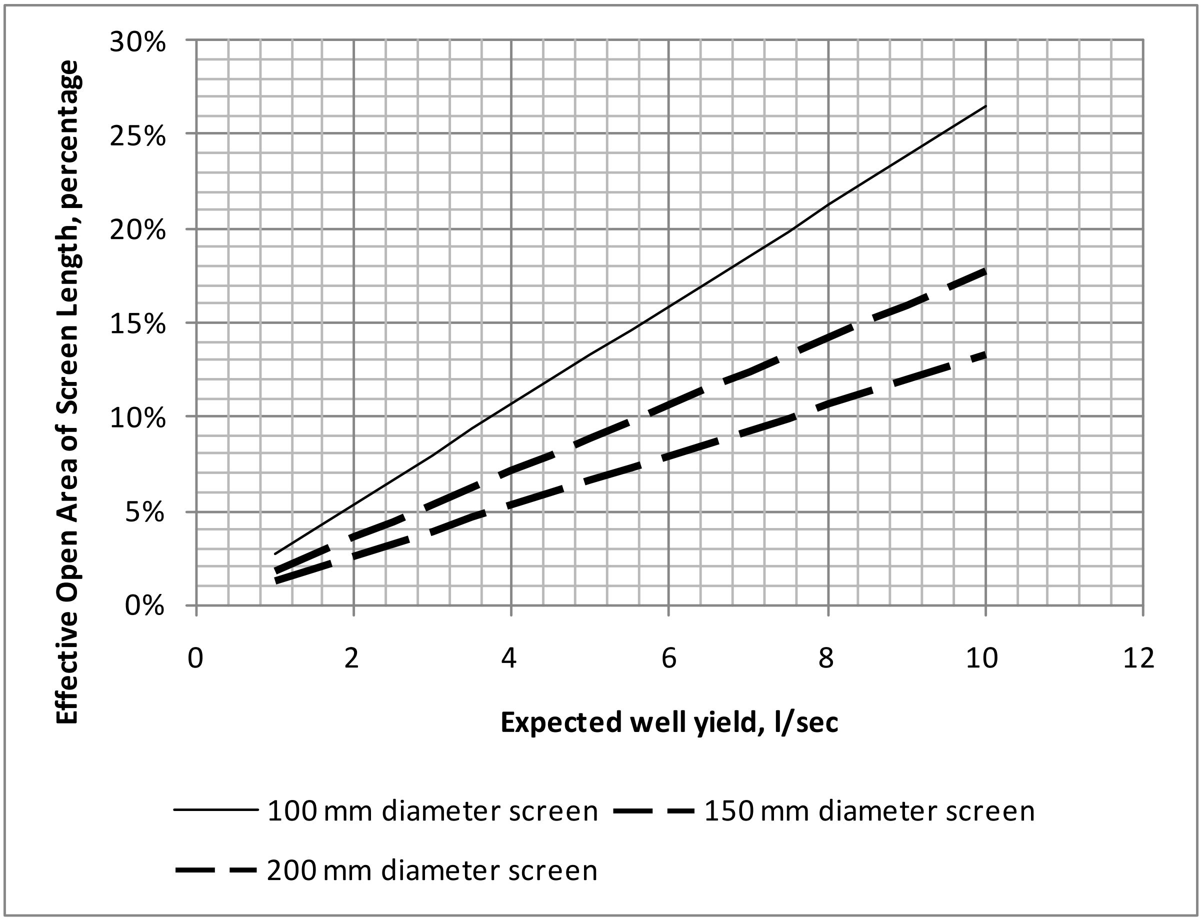
The screen diameter shall be selected so that the entrance velocity through the screen openings will not exceed 0.03 m/s (0.1 foot per second). The entrance velocity is calculated by dividing the well yield in cubic feet per second by the total area of the screen openings in square feet. This will ensure the following:

- The hydraulic losses in the screen opening will be negligible.
- The effect of incrustation will be minimal.
- The effect of corrosion will be minimal.

**Table 7. The relative open space in the screen as a function of screen diameter and slot size.**

| Relative Open Space vs. Diameter and Slot Size | | | | |
|---|---|---|---|---|
| **Nominal Well Screen Diameter** | **Screen Slot Size** | | **Steel Continuous Slot** | |
| ***mm*** | ***No*** | ***mm*** | ***cm2/m*** | ***%*** |
| | | | | |
| 100 | 20 | 0.508 | 931 | 25 |
| 100 | 60 | 1.524 | 1,905 | 52 |
| 150 | 30 | 0.762 | 1,693 | 25 |
| 150 | 60 | 1.524 | 2,857 | 41 |
| 150 | 95 | 2.413 | 3,492 | 51 |
| 200 | 30 | 0.762 | 1,629 | 16 |
| 200 | 60 | 1.524 | 2,857 | 28 |
| 200 | 95 | 2.413 | 3,851 | 38 |

**Figure 3. Minimum Effective Open Area versus Well Yield**




**7.5 FILTER PACKING.** Filter packing (sometimes referred to as gravel packing) is sand and gravel placed around the well screen to stabilize the aquifer and provide an annulus of high permeability around the screen. This differs from the naturally-developed well in that the zone around the screen is made more permeable by the addition of coarse material. Grain size of the filter pack is ideally selected on the basis of information obtained from sieve analyses of the material in the aquifer. Information on how to make these calculations is included in Appendix B.

Filter pack material shall be a product of a commercial sand and gravel supplier, shall be properly sized and graded for the surrounding soil encountered, and shall be composed of clean, round, hard, water-worn siliceous material, free of flat or elongated pieces, organic matter, or other foreign matter. It must conform to the following criteria:

- The well-screen aperture size will be selected so that between 90 and 100 percent of the filter pack is larger than the screen openings. Refer to Table 8 for slot size and corresponding sieve size. For example, if the well screen has a slot size of 0.7 mm, between 90 and 100 percent of the material cannot pass through a size 25 sieve.

- A uniformity coefficient of less than 2.5 for the filter pack is required. The uniformity coefficient is defined as 40 percent of the retained grain size divided by 90 percent of the retained grain size.

- Filter pack material should be composed of clean rounded sand or gravel. Angular grains reduce pumpage and increase the drawdown. Pure silica sands are preferred because there is no loss of material due to solution effects.

- It is important that the filter used for packing be clean. If composed of local materials, it must be disinfected by immersion in strong chlorine solution (50 mg/L or greater available chlorine concentration, prepared by dissolving fresh chlorinated lime or other chlorine compound in water) just prior to placement. Dirty filter pack must be thoroughly washed with clean water prior to disinfection and then handled in a manner that will maintain it in as clean a state as possible.

**Table 8. ASTM Standard Sieve Sizes**

| Opening size | | ASTM Sieve |
|---|---|---|
| *mm* | *in* | *No* |
| 4.76 | 0.187 | 4 |
| 2 | 0.079 | 10 |
| 1.2 | 0.05 | 16 |
| 1.0 | 0.0394 | 18 |
| 0.707 | 0.0278 | 25 |
| 0.5 | 0.0197 | 35 |
| 0.25 | 0.01 | 60 |
| 0.1 | 0.004 | 140 |

The thickness of the filter pack will range from a minimum of 75 mm (3 in) to approximately 200 mm (8 in). A filter envelope thicker than about 200 mm (8 in) will not greatly improve yield and can adversely affect removal of fines, at the aquifer-filter pack interface, during well development. Filter pack should extend one meter above the screen but not above the top of the aquifer. A tremie pipe will be used to evenly distribute the filter material around the screen and also to prevent bridging of the sand grains.

The Well Completion Submittal shall include:
(a) Number of screens and depth of setting in the well.
(b) Size of well screen inside and outside diameters and length.
(c) Pipe material (material schedule and specification).
(d) Standard slot opening, mm
(e) Effective open area of screen (sq cm per meter)
(f) Transmitting capacity (liters/meter)
(g) Sieve analysis of the material to be screened
(h) Calculations supporting screen slot size
(i) Photo of screen slot pattern
(j) Results of Gravel Pack selection analysis.

**7.6 GROUTING AND SEALING.** Wells must be constructed to prevent water that is polluted or of otherwise unsuitable quality from entering the well. Grouting and sealing of wells are necessary to protect the water supply from pollution, to seal out water of unsatisfactory chemical quality, to protect the casing from exterior corrosion and to stabilize soil, sand or rock formations that tend to cave.

**7.6.1 BENTONITE SEAL**. A bentonite seal with a minimum thickness of three meters shall be placed directly above the filter pack to prevent vertical infiltration of contaminants through filter material into the well. If the bentonite is installed in dry form, such as chips or pellets, there must be sufficient time given so that the bentonite can hydrate and form the seal. Allow three hours for hydration times, or per manufacturer's guidelines.

**7.6.2 NEAT CEMENT/GROUT**. Neat cement or grout must be placed from the top of the bentonite seal and extends from the bentonite seal to approximately 2 meters from the ground surface. This seal is continuously placed from the bentonite seal to the surface. The annular space between the well casing and the walls of the hole shall be filled with cement-bentonite grout mix as hereinafter specified. The cement-bentonite grout mix shall be proportioned of Portland Cement conforming to ASTM Specification C150, Type I or II and bentonite (either sodium bentonite or calcium type morillonite or opalite). The cement-bentonite mix shall be proportioned, by weight, as follows; 6.6 : 1 : 0.4 (water : portland cement : bentonite). The water-cement (w/c) ratio shall not exceed 7. The mix shall be prepared as follows: the cement shall be mixed with the water first at the w/c ratio prescribed above. At this stage, the mix is like grey water. Next, bentonite powder shall be slowly added such that clumps of bentonite do not form. This should be constantly checked by scraping the bottom of the mixer with a shovel. When clumps form, slow down and do not add any more powder until they are dissolved. Bentonite shall be added until the watery mix transitions to an oily/slimy consistency. Observe the consistency while mixing and allow the grout to thicken for another five to ten minutes. Generally, the mix thickens with added mixing time. Bentonite shall be added as required. The mixture should form craters at the surface when it is the proper consistency for placing down the tremie pipe.

The cement-bentonite grout shall be forced from the bottom of the space to be grouted towards the surface by use of a tremie pipe. The minimum depth of grouting shall be three meters unless approved in writing by the COR. The grout shall also seal off any other water-bearing strata above the zone providing water to the well. The grouting shall be done continuously and in a manner that will insure the entire filling of the annular space in one operation, without damaging the well casing. No drilling operations or other work in the well will be permitted within 24 hours after the grouting operation to allow the grout to properly set.

Establishment of good circulation of water through the annular space to be grouted is a highly desirable initial step toward a good grouting job. This assures that the space is open and provides for the removal of foreign material.

If a deeper, confined aquifer contains undesirable water, care should be taken during drilling so as not to penetrate or breach the confining unit separating the two aquifers. Any portion of the confining unit that is breached should be replaced with grout.

**7.6.3 CEMENT SURFACE SEAL**. The well annulus must be filled with cement from the top of the neat cement/grout seal to the land surface. The cement supplies structural support for the well casing and above-grade piping and parts and keeps fluids out of the well.

**7.7 ACCESSIBILITY.** The well location shall be readily accessible for pump repair, cleaning, disinfection, testing and inspection. The top of the well shall never be below surface grade. At least 600 mm (2 ft) of clearance beyond any building projection shall be provided.

**7.8 DETAILS RELATING TO WATER QUALITY.** In addition to grouting and sealing, features that are related to water quality protection are:

**7.8.1 LOCATION.** The well or wells should be located on the highest ground practicable, certainly on ground higher than nearby potential sources of surface pollution. The surface near the site should be built up, by fill if necessary, so that surface drainage will be away from the well in all directions. Where flooding is a problem, special design will be necessary to insure protection of wells and pumping equipment from contamination and damage during flood periods and to facilitate operation during a flood.

**7.8.2 CONCRETE COVER.** The well casing should be surrounded at the surface by a concrete slab having a minimum thickness of 100 mm (4 in) and extending outward from the casing a minimum of 600 mm (2 ft) in all directions. The slab should be finished a little above ground level and slope slightly to provide drainage away from the casing in all directions.

**7.8.3 CASING HEIGHT.** The well casing should extend at least 500 mm (20 in) above the level of the concrete surface slab in order to provide ample space for a tight surface seal at the top of the casing. The type of seal to be employed depends on the pumping equipment specified.

**7.8.4 WELL HOUSE.** A permanent well house is required, the floor of which can be an enlarged version of the surface slab. The floor of the well house should slope away from the casing toward a floor drain at the rate of about 1 mm per 50 mm (1/8 inch per foot). Floor drains should discharge through carefully jointed 100 mm (4 in) or larger pipe of durable water-tight material to the ground surface 6 m (20 ft) or more from the well. The end of the drain should be fitted with a coarse screen. Well-house floor drains ordinarily should not be connected to storm or sanitary sewers to prevent contamination from backup.

The well house should have a large entry door that opens outward and extends to the floor. The door should be equipped with a good quality lock. The well house design should be such that the well pump and drop-pipe can be removed readily. Any structure built over the well must have a large door in the roof that allows for easy removal of the pump piping and pump using an overhead crane. The well house protects valves and pumping equipment and also provides freeze protection for the pump discharge piping beyond the check valve. Where freezing is a problem, the well house should be insulated and a heating unit installed.

The well house should be of fireproof construction. The well house also protects other essential items. These include:

- Flow meter (totalizer)
- Backflow prevention devices on the above-ground well discharge piping;

- Manual aboveground shutoff valve downstream of backflow device;
- Pressure gage
- Screened casing vent
- Sampling tap
- Commercial submersible pump protector
- Water treatment equipment (if required)
- Well operating records

**7.8.5 SECURITY.** The well building shall be protected from unauthorized use by a security fence having a lockable gate.

## 7.9 WELL PUMPS

**7.9.1 PUMP TYPE.** Many types of well pumps are on the market to suit the wide variety of capacity requirements, depth to water and power source. Electric power is used for the majority of pumping installations. Where power failure would be serious, the design should permit at least one pump to be driven by an auxiliary engine, usually gasoline, diesel or propane. The most appropriate type is dictated by many factors for each specific well. Factors that should be considered for installation are:

- Capacity of well
- Capacity of system
- Size of well
- Depth of water
- Type of well
- Power source
- Standby equipment
- Well drawdown
- Total dynamic head

There are several types of well pumps. The most common are line shaft turbine, submersible turbine, or jet pumps. The first two operate on exactly the same principal; the difference being where the motor is located. Line shaft turbine pumps have the motor mounted above the waterline of the well and submersible turbine pumps have the motor mounted below the water line of the well.

ANA and ANP projects commonly employ small submersible turbine pumps; however, there may be projects where other types are preferable. For deep wells with high capacity requirements, submersible or line shaft turbine pumps are usually used and are driven by electric motors. A number of pump bowls may be mounted in series, one above the other to provide the necessary discharge pressure. A partial listing of pumps commonly used in water-supply wells are listed in Table 9.

Depending upon the depth of the static water level (<100m), a standard hand pump with seal and air gap shall be installed on the permanent well discharge piping to discharge at concrete pad around well. Hand pump components will be stainless steel. The hand pump shall be capable of pumping at a minimum pressure head of 138 Kpa (20 psi) in the event there is either a loss of power supply or a pump failure in the water well system.

**Table 9. Characteristics of Pumps Used in Water Supply Systems**

| Type of Pump | Practical suction lift | Usual well-pumping depths | Usual pressure heads | Advantages | Disadvantages | Remarks |
|---|---|---|---|---|---|---|
| Reciprocating:<br>1. Shallow well . . .<br>2. Deep well . . . | 22–26 ft.<br>22–25 ft. | 22–26 ft.<br>Up to 600 feet | 100–200 ft.<br>Up to 600 feet above cylinder. | 1. Positive action.<br>2. Discharge against variable heads.<br>3. Pumps water containing sand and silt.<br>4. Especially adapted to low capacity and high lifts. | 1. Pulsating discharge.<br>2. Subject to vibration and noise.<br>3. Maintenance cost may be high.<br>4. May cause destructive pressure if operated against closed valve. | 1. Best suited for capacities of 5–25 gpm against moderate to high heads.<br>2. Adaptable to hand operation.<br>3. Can be installed in very small diameter wells (2" casing).<br>4. Pump must be set directly over well (deep well only). |
| Centrifugal:<br>1. Shallow well<br>a. straight centrifugal (single stage) | 20 ft. maximum | 10–20 ft. | 100–150 ft. | 1. Smooth, even, flow.<br>2. Pumps water containing sand and silt.<br>3. Pressure on system is even & free from shock.<br>4. Low–starting torque.<br>5. Usually reliable and good service life. | 1. Loses prime easily.<br>2. Efficiency depends on operating under design heads & speed | 1. Very efficient pump for capacities above 50 gpm & heads up to about 150 feet. |
| b. Regenerative vane turbine type (single impeller) | 28 ft. maximum | 28 ft. | 100–200 ft. | 1. Same as straight centrifugal except not suitable for pumping water containing sand or silt.<br>2. They are self–priming. | 1. Same as straight centrifugal except maintains priming easily. | 1. Reduction in pressure w/increased capacity not as severe as straight centrifugal. |
| 2. Deep well<br>a. Vertical line shaft turbine (multi–stage) | Impellers submerged | 50–300 ft. | 100–800 ft. | 1. Same as shallow well turbine. | 1. Efficiency depends on operating under design head & speed.<br>2. Requires straight well large enough for turbine bowls and housing.<br>3. Lubrication & alignment of shaft critical.<br>4. Abrasion from sand. | |

**7.9.2 PUMP CAPACITY_ –** The design capacity of the pump must equal the system requirements. The design goal is for the well pump capacity to be capable of supplying one average day flow (ADF) in a time period specified in the contract documents. **However the capacity of the pump must never exceed the capacity of the well.** There are many situations in which the aquifer can supply water, but at a rate which is less than the desired flow rate. For example, some facilities may only supply electricity for 6 hours per day. In these cases, it is not feasible to simply install a large pump to compensate for a higher required flow rate. The aquifer formation will only supply water at the rate it is able, and a larger pump will simply burn out. There are several alternatives:

- Install a well field instead of a single well. Multiple wells may be able to supply the desired pumpage.
- Rely on the hand pump for periods when the well pump is without electricity and storage is depleted.
- Supplement water storage with hauled water.
- Increase the time which the generator operates so that water needs can be met.

Pump manufacturers publish charts giving the pump discharge capacity for their particular pumps at various operating pressures. The total dynamic head (TDH) of the system must be calculated accurately from the physical arrangement and is represented by the following:

$$TDH=H_S+H_D+H_F+(V^2/2g) \qquad \text{Eq. 3}$$

Where:

$H_s$=suction lift; vertical distance from the waterline at drawdown under full capacity to the pump centerline, m
$H_D$=discharge head; vertical distance from the pump centerline to the pressure level of the discharge pipe system, m
$H_F$=friction head; loss of head on pipe lines and fittings, m
$V^2/2g$=velocity head; head necessary to maintain flow, m

The brake horsepower (engine horsepower with no power loss from associated components) of the motor used to drive the pump may be calculated from the following equation:

$$P=(HQ)/(102*e) \qquad \text{Eq. 4}$$

Where:

P=break power required, kW
H=total dynamic head, m
Q=volume of water discharged, L/s
e=Combined efficiency of pump and motor, from manufacturer's data

Appendix C contains information for designers selecting of water well pumps.

## 8. RECEIVE AED APPROVAL

CONSTRUCTION OF THE FINAL WELL CANNOT START AND SHALL STOP until receipt of AED Approval. Before any final well construction, AED shall receive, review and approve the Test Well Approval Submittal and shall authorize construction of the permanent well. Failure to follow the construction and submittal procedures outlined, may at AED's discretion, result in rejection of the well and, the contractor having to remove the well casing and screen, re-drill the well and reinstall the proper features per the approved design. The contents of the Final Well Design Proposal shall include:

1. Proposed pumping rate.
2. Location and coordinates of well on site plan.
3. Size of well diameter and depth.
4. Driller's Log Submittal.
5. Geology Log Submittal.
6. Water Well Summary Sheet (Appendix E)
7. Pump Selection Design.
8. Static and dynamic water table depths and elevations.
9. Casing and screen diameters and lengths installed in the test well.
10. Proposed permanent casing diameter and material.
11. Proposed permanent screen design and supporting calculations.
12. Proposed permanent grouting and sealing.
13. Proposed permanent gravel/filter pack design and materials and supporting calculations.
14. Step-test results, including Specific Capacity, Max Sustained Yield, and Radius of Influence. (Hydraulic Conductivity will be reported if full pumping test was performed.)
15. Water quality results.

## 9. CONSTRUCT PERMANENT WELL

After receipt of AED concurrence, the permanent well can be constructed. If AED rejects the Well Design document or Report, then the contractor will amend or revise subject reports to achieve approval before final well construction can begin.

A stainless steel check valve (if not on the pump discharge piping), isolation valve, sampling port, and well-discharge totalizer shall be installed on the pump discharge pipe line, as minimum appurtenances, between the well head and the water storage treatment tanks. A water level measurement port shall be provided at the well head. Additional appurtenances such as flow meter, air release valve, and chlorination treatment piping may be required depending upon the contract technical requirements.

Upon completion of the well and other incidentals, all debris and surplus materials resulting from the work shall be removed from the job site. The drilling fluid shall be pumped out and properly disposed of and the excavation for the sump backfilled suitable to the site COR.

## 10. DEVELOP AND DISINFECT WELL

After the structure of the well is installed, there remain two very important operations to be performed before the well can be put into service. Well development is the process of removing the finer material from the aquifer around the well screen, thereby cleaning out and opening up passages in the formation so that water can enter the well more freely. Disinfection is the process of cleaning and decontaminating the well of bacteria that may be present due to the drilling action.

**10.1 WELL DEVELOPMENT.** After construction is complete, the well shall be thoroughly developed. The developing equipment shall be of sufficient capacity to remove all drilling fluids, sand, rock cuttings or any other foreign matter. The wells shall be thoroughly cleaned from top to bottom before beginning the well tests. Three beneficial aspects of well development are to correct any damage or clogging of the water bearing formation which occurred as a side effect of drilling, to increase the permeability of the formation in the vicinity of the well and to stabilize the formation around a screened well so that the well will yield sand-free water.

Development is necessary because many drilling methods cause increases in the density of the formation around the hole. Methods utilizing drilling fluids tend to form a mud cake. Good development will eliminate this "skin effect" and loosen up the sand around a screen. Removal of fines leaves a zone of high porosity and high permeability around the well. Water can then move through this zone with negligible head loss.

Methods of development in unconsolidated formations include the following:

- Mechanical surging is the vigorous operation of a plunger up and down in the well, like a piston in a cylinder. This causes rapid movement of water which loosen the fines around the well and they can be removed by pumping. This may be unsatisfactory where the aquifer contains clay streaks or balls. The plunger should only be operated when a free flow of water has been established so that the tool runs freely. Swabbing is a type of surging utilizing a specialized plunger.

- Air surging involves injecting air into a well under high pressure. Air is pumped into a well below the water level causing water to flow out. The flow is continued until it is free of sand. The air flow is stopped and pressure in an air tank builds to 700 to 1,000 kilopascals (100 to 150 psi). Then the air is released into the well causing water to surge outward through the screen openings.

- Back washing involves reversal of flow. Water is pumped up in the well and then is allowed to flow back into the aquifer. This usually does not supply the vigorous action which can be obtained through mechanical surging.

- High velocity jetting utilizes nozzles to direct a stream of high pressure water outward through the screen openings to rearrange the sand and gravel surrounding the screen. The jetting tool is slowly rotated and raised and lowered to get the action to all parts of the screen. This method works better on continuous slot well screens better than perforated types of screens.

The well must be developed using surge methods and the overpumping development method is not permitted. Development in rock wells can be accomplished by one of the surging methods listed above or by one of the following aquifer stimulation methods.

- Acidizing can be used in wells in limestone formations. Fractures and crevices are opened up in the aquifer surrounding the well hole by the action of the acid dissolving the limestone.

- Sand fracturing is the action of forcing high pressure water containing sand or plastic beads in to the fractures surrounding a well. This serves to force the crevices open.

Development using explosives is prohibited. The recommended type of development for stainless steel screened wells is hydro-jetting; however surge blocks, air-development or other development techniques are permissible at the option of the Contractor. The well shall be disinfected before removing the test pump and collecting samples for determining the water quality.

**10.1.1 WELL DEVELOPMENT REQUIREMENTS --** A well development record shall be prepared. Development is complete when both of the following criteria are met:

1. Well water is clear to the unaided eye and/or turbidity is less than or equal to 5 Nephelometric Turbidity Units (NTUs) and no sand is visible at the bottom of the sample container.
2. Sediment thickness in the well is less than 1% of the screen length.

If the Contractor has the appropriate instrumentation, then the following alternative development metric can be used. A minimum of three times the standing water volume in the well is removed plus three times the volume of all added water and drilling fluid lost during drilling and installation of the well is removed, and Temperature, specific conductivity, pH, oxidation-reduction potential (ORP), dissolved oxygen (DO), and turbidity readings, measured before, twice during and after development operations, have stabilized. Stabilization shall mean variation of less than 0.2 pH units, variation of ± 0.5 degrees C (1 degree F), ± 3 percent change in specific conductance; and less than a ± 10mV for ORP; and ± 10 percent for DO, and turbidity, measured between three consecutive readings with one casing volume of water removed between each reading. ORP shall be determined in accordance with AWWA 10084. Temperature, specific conductance, DO, turbidity and pH readings shall be conducted in accordance with EPA 600/4-79/020.

Whichever development metric is used, at completion of well development, approximately 0.5 liter of well water shall be collected in a clear glass jar. The jar shall be labeled with project name, well number and date; and photographed using digital photography. The photograph (minimally 125 x 174 mm or 5 x 7 inch) shall be a suitably backlit close-up which shows the clarity of the water and any suspended sediment. The photograph and .jpg file shall become a part of the well development record.

**10.2 WELL DISINFECTION**. The well shall be disinfected to remove bacteriological contamination that may cause the well-water supply to be unsafe for human consumption. The chlorine solution used for disinfecting the well shall be of such volume and strength and shall be so applied that a concentration of at least 50 mg/L of available chlorine shall be obtained for the entire water depth of the well, and this solution shall remain in the well for a period of at least 12 hr.

If the samples collected after disinfection show bacteriological contamination, the contractor shall prepare and apply to the entire depth of the well a total volume of the chlorine solution of at least 100 mg/L of available chlorine equal to at least four times the volume of water in the well. The contractor shall allow this solution to remain in the well for a period of at least 24 hr. Driscoll (1986, page 619, Appendix D) offers an excellent summary of disinfection procedures.

## 11. TEST WELL PERFORMANCE

Upon completion of the permanent production well, the Driller shall conduct a continuous 6-hour pumping test at the designed flow rate. Drawdown will be recorded from time-zero at the following time intervals:

***First 5 minutes – every 30 seconds***
***Next 5 minutes – every minute***
***Next 50 minutes – every 10 minutes***
***Next 2 hours – every 20 minutes***
***Next 2 hours – every 40 minutes***
***Last hour – one sample at end***

If water levels are recorded digitally with a transducer, smaller time intervals are often programmed into the software. This is acceptable. The above guidance serves as minimum time intervals.

After the 6-hour pumping test has been finished, but before the pumps are shut off, a second round of water-quality samples will be taken and tested for the same parameters as outlined in Section 5.2.

Recovery data will also be recorded at intervals described above. Recovery data will be recorded until drawdown reaches 90% of pre-pumping levels.

## 12. SUBMIT WELL COMPLETION REPORT

The design and construction documents must provide a permanent record of the well construction. Without this documentation, later attempts to evaluate the potential long term yield of a well, well pump problems, water quality, expected / actual yield, and the potential to increase production will be meaningless. Reporting requirements include the following:

- Drillers log
- Geology or Lithology log
- Geophysical logs (if performed)
- Water Well Summary Sheet
- Performance Pumping Test Report and Analysis
- Well Screen and Gravel Pack Design
- As-Built drawings

The Contractor shall submit editable CAD format As-Built drawings. The drawing shall show the final product as it was installed in the field, with the exact dimensions, locations, materials used, logs and any other changes made to the original drawings. Refer to Contract Sections 01335 and 01780A of the specific project for additional details.

## 13. MULTI-WELL FIELDS

The grouping of wells must be carefully considered because of mutual interference between wells when their cones of depression overlap. In this case, a full pumping test, with observation well(s), will be performed. Minimum well spacing shall be 75 m (250 ft). The total interference effect at a well is a function of the following:

- Number of wells being pumped.
- Distance from point of measurement to pumping wells.
- Volume of discharge at each well.
- Penetration of each well into aquifer.

For simple systems of 2 or 3 wells, the method of super position may be used to estimate well interference. The procedure is to calculate the drawdown at the point (well) of consideration and then to add the drawdown for each well in the field. For multiple wells, the discharge must be recalculated for each combination of wells, since multiple wells have the effect of changing the depth of water. For large systems the following conditions should be noted:

- Boundary conditions may change.
- Change in recharge could occur.
- Computer analysis (numerical modeling) may be helpful to recalculate the combinations.

It is seldom practicable to eliminate interference entirely because of pipeline and other costs, but it can be reduced to manageable proportions by careful well field design. When an aquifer is recharged in roughly equal amounts from all directions, the cone of depression is nearly symmetrical about the well and is about the same in all directions. If, however, substantially more recharge is obtained from one direction; e.g., a stream, then the surface elevation of the water table is distorted, being considerable higher in the direction of the stream. The surface of the cone of depression will be depressed in the direction of an impermeable boundary because little or no recharge is obtained from the direction of the impermeable boundary.

Where a source of recharge such as a stream, exists near the proposed well field, the best location for the wells is spaced out along a line as close as practicable to and roughly parallel to the stream. On the other hand, multiple water-supply wells should be located parallel to and as far as possible from an impermeable boundary. Where the field is located over a valley, the wells should be located along and as close to the valley's center as possible. In hard rock country, wells are best located along fault zones and lineaments in the landscape where recharge is greatest. These are often visible using aerial photographs. Special care should be exercised to avoid contamination in these terrains since natural filtration is limited. Wastewater is commonly recharging groundwater at these sites, and consideration should be given to expected flow patterns.

**13.1 RADIUS OF INFLUENCE CALCULATIONS --** The following definitions are necessary to an understanding of radius of influence calculations:

- *Static Water Level* – The distance from the ground surface to the water level in a well when no water is being pumped.

- *Pumping Level* – The distance from the ground surface to the water level in a well when water is being pumped – also called dynamic water level.

- *Drawdown* – The difference between static water level and pumping water level.

- *Cone of Depression* – The funnel shape of the water surface or piezometric level which is formed as water is withdrawn from the well.

- *Radius of Influence* – The distance from the well to the edge of the cone of depression.

- *Hydraulic Conductivity* – The rate at which water moves through the formation. Units are expressed in length/time or gallons per day per square foot. It is governed by the size, shape, and interconnectedness of the pore spaces.

The well discharge equation (Eq. 5, also known as the Thiem equation) below is used to determine the amount of water that can be expected from a well or the radius of influence. The formula assumes certain simplifying conditions. However, these assumptions do not severely limit the use of the formulas. The assumptions are as follows: 1) the aquifer is unconfined (water table), of constant thickness, is not stratified and is of uniform hydraulic conductivity (i.e. homogeneous); 2) the piezometric surface is level, laminar flow exists and the cone of depression has reached equilibrium (i.e. steady state); and 3) the pumping well reaches the bottom of the aquifer and is 100 percent efficient.

The following equation is used to calculate the discharge:

$$Q = (1.366K(H^2-h^2))/(\log(R/r)) \qquad \text{Eq. 5}$$

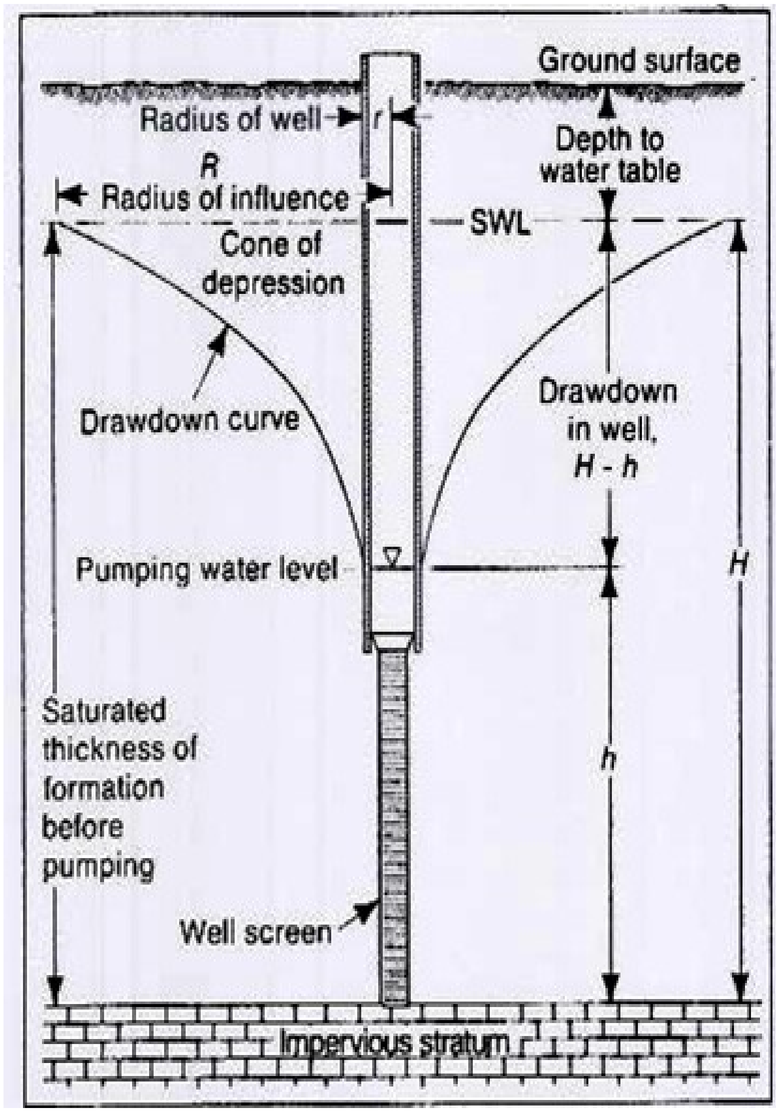
Where:

$Q$ = pumping rate ($m^3$/day)
$K$ = hydraulic conductivity of water-bearing unit (m/day)
$H$ = Static head from bottom of aquifer (m)
$h$ = pumping head from bottom of aquifer (m)
$R$ = Radius of influence (m)
$r$ = Radius of well (m)

Hydraulic conductivity (K) is equal to the aquifer transmissivity divided by the saturated aquifer depth. (Or $T = Kb$)

Figure 4 shows the relationship of the terms used in Equation 5 for available yield from a water table well. An existing well or monitoring well must be used to estimate the radius of influence of the proposed production well.

**Figure 4. Diagram of Water Table Well**



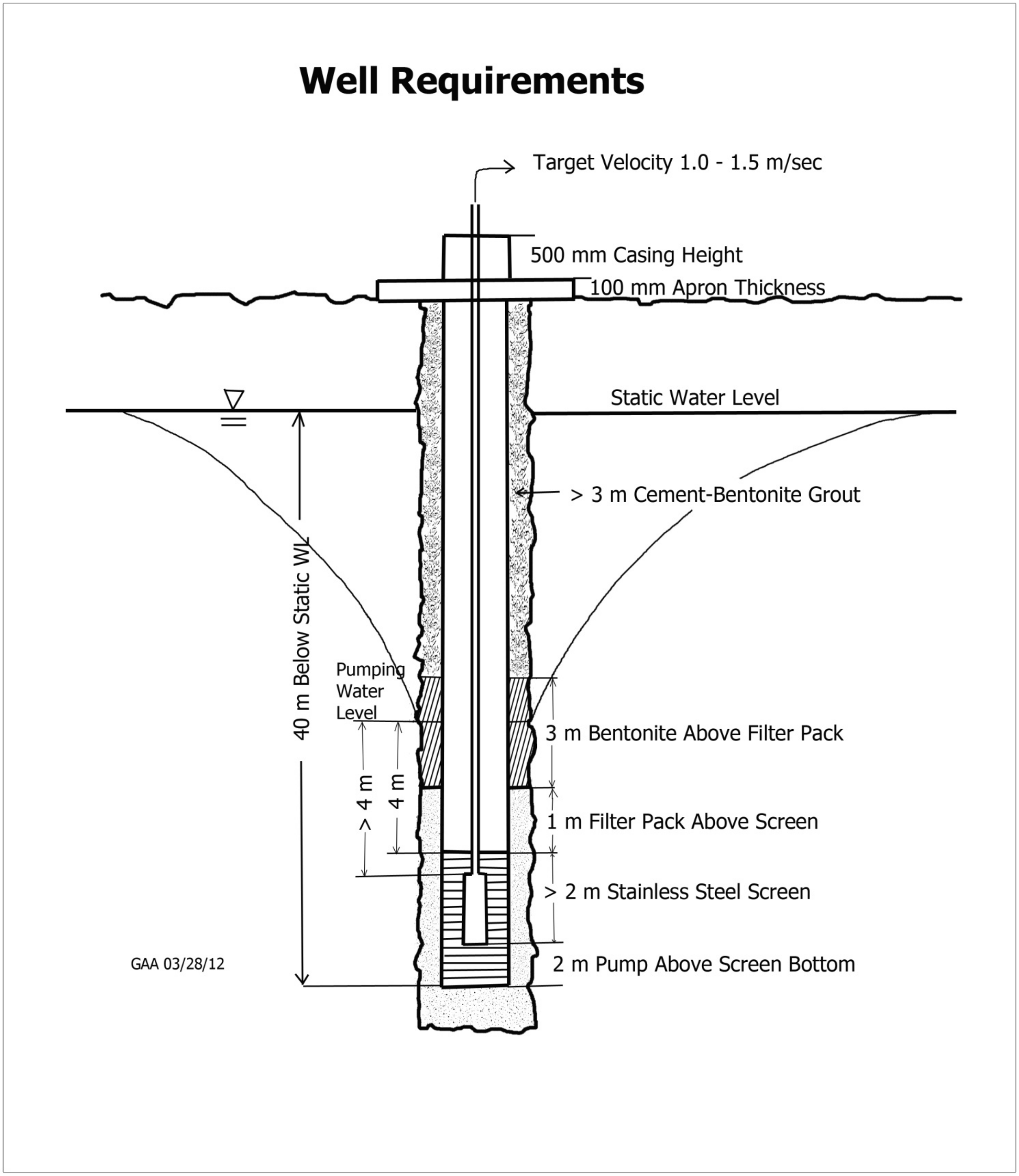



**Figure 5. AED Well Requirements**

## 14. REFERENCES

1. *Groundwater and Wells*, Fletcher Driscoll, Johnson Division, 1986.
2. UFC 3 230 07a, *Water Supply Sources General Considerations*, 2004
3. ASTM F480-06b *Standard Specification for Thermoplastic well Casing Pipe and Couplings Made in Standard Dimension Ratios, SCH 40 and SCH 80*
4. ASTM D 1785-06 *Standard Specification for PVC Plastic Pipe, Schedules 40, 80 and 120*
5. ASTM A 53 *Pipe, Steel, Black and Hot-dipped, Zinc-coated, Welded and Seamless*
6. *Inventory of Ground-Water Resources in the Kabul Basin, Afghanistan, U.S.* Geological Survey, Scientific Investigations Report, 2005-5090.
7. *Guidelines for Sustainable Use of Groundwater in Afghanistan, Norwegian Church Aid*, 2002
8. *Sanitary Control and Surveillance of Field Water Supplies*, TB MED 577, Department of Defense 2005
9. World Health Organization, *Guidelines for Drinking Water Quality*, 2006
10. AWWA A-100-06 *Water Wells*
11. AWWA, C200, *Steel Water Pipe 6 Inches & Larger*
12. AWWA, C206, *Field Welding of Steel Water Pipe*
13. *Water Wells and Pumps*, Michale, A.M.; Khepar, S.D., and Sondhi, S.K., McGraw Hill, 2008
14. UFGS 33 20 00, *WATER WELLS*, Prep. by USACE, April 2008
15. ASTM, C-150, *Portland Cement*
16. TM 5-813-3 (UFC 3 230 08a Water Supply Water Treatment, January 2004).AWWA 10084, *STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 21ST EDITION*, 2005
17. EPA 600/4 - 79/020, *Methods for Chemical Analysis of Water and Wastes*, March 1979
18. DoD 4715.05-G, 2007, *Overseas Environmental Baseline Guidance Document*

# Appendix A

## Examples of Unacceptable and Acceptable Well Construction (Source: Statement of work Military Water Well Construction, Testing and Completion, United States Forces, Afghanistan, 2009)

Figure 4. Example of unacceptable, locally fabricated well screen. Slots were cut into the steel casing using a cutoff wheel or grinder (yellow ovals), creating 0.05% openings per foot. Folded knife is 4-in long.

**Figure 5. Example of approved stainless steel slotted screen with threaded connections (folded knife is 4-in long). Minimum opening area is 15% of the screen surface per foot.**

**Figure 6. Unacceptable wellhead completion examples. Upper panel - casing sticks up <1-inch above the floor, has an inadequate sanitary seal, and has inadequate well pad slope and floor drainage. Lower panel – no sanitary seal or well house over well, and the well pad has no slope Both examples are missing totalizers, water sampling ports, water level measuring ports.**

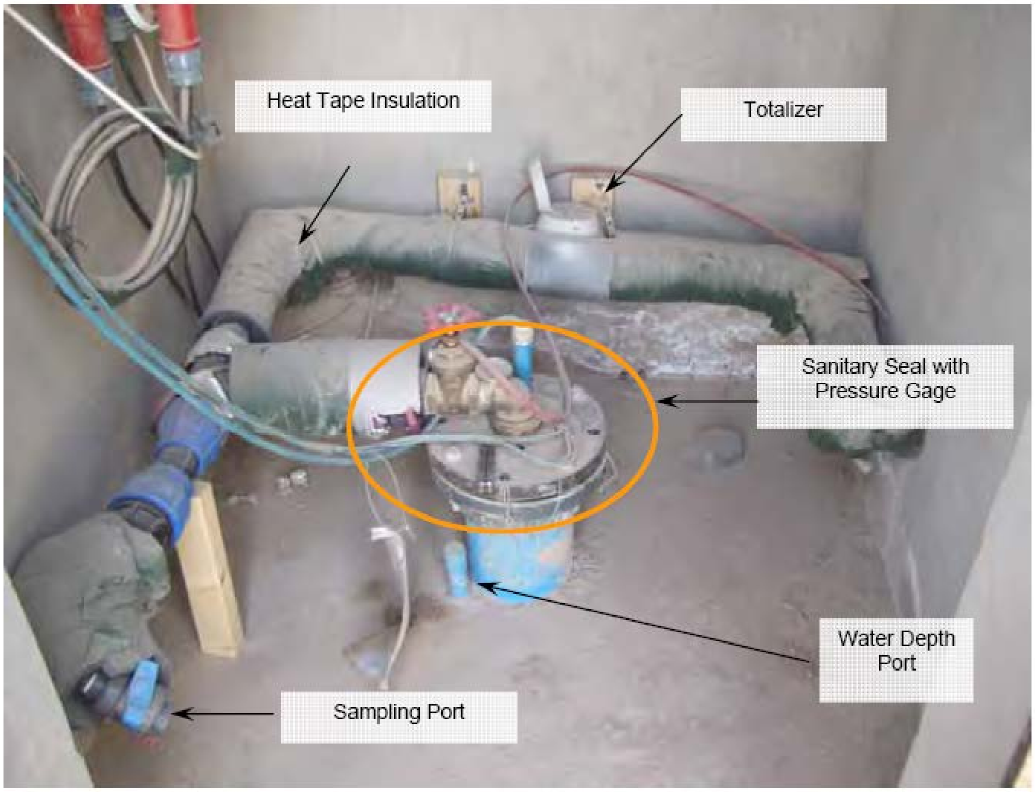



**Figure 7. Acceptable wellhead completion, with totalizer (rear center), raw water sample port (lower left), sanitary port for measuring water level (left of 8-in blue well casing), and adequate sanitary seal on well casing (center).**

# Appendix B

## Theoretical Well Screen and Filter Pack Design

This section, and referenced text, will provide more information well screen and filter pack design. This is predicated upon depth-dependent data on aquifer materials, i.e. gradation curves for each aquifer zone which is to be screened.

The results of the analysis of any particular aquifer sample should be recorded as the percent (by weight) of the sample retained on each sieve and the cumulative percent retained on each sieve (i.e., the total of the percentages for that sieve and all larger sieve sizes). Based on these sieve analyses, determine the aquifer stratum which is composed of the finest material. Driscoll, page 409 (Appendix D), gives more information on determining grain-size distributions.

Using the results of the sieve analysis for the finest aquifer material, plot the cumulative percent of the aquifer material retained versus the size of the mesh for each sieve. Fit a smooth curve to these points. Find the size corresponding to a 70 percent cumulative retention of aquifer material. This size should be multiplied by a factor between 4 and 6, 4 if the formation is fine and uniform and 6 if the formation is coarse and non-uniform. Use 9 if the formation includes silt. The product is the 70 percent retained size (i.e., the sieve size on which a cumulative 70 percent of the sample would be retained) of the material to be used in the packing.

A uniformity coefficient of 2.5 for the filter pack is desirable. The uniformity coefficient is defined as 40 percent of the retained grain size divided by 90 percent retained size. Lower size represents a more uniform material and is more meaningful for values less than 5.

The plot of cumulative percent retention versus grain size for the filter pack should be approximately parallel to same plot for the aquifer material, should pass through the 70 percent retention value, and should have 40 and 90 percent retention values such that the uniformity coefficient is less than 2.5. Filter pack material will be specified by determining the sieve sizes that cover the range of the curve and then defining an allowable range for the percent retention on each sieve. The contractor shall verify these gradations are suitable for the specific well as not all aquifers are the same. Driscoll, pg 441 (Appendix D), gives more information on filter pack design.

## APPENDIX C

# WELL PUMP SELECTION EXAMPLE

### 1.0 GENERAL

The purpose of this appendix is to assist the contractor to fulfill the design and submittal requirements for projects requiring well pump selection and installation. Selecting the correct pump for a project is important for the sustainability of well operation and the efficient use of power to run the pump over time. In recent years, there have been a large number of pumps that required replacement at the ANA and ANP facilities. One of the reasons has been the incorrect selection of submersible pumps.

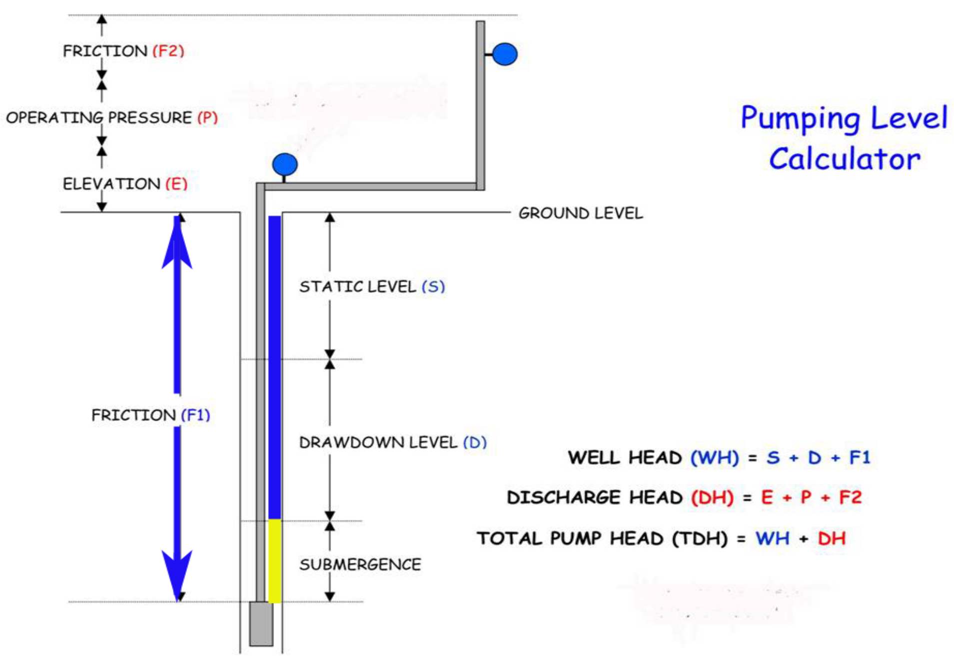
### 2.0 DESIGN FLOW

The first step is to determine the water demand and the amount of flow required of the pump per unit time. But remember **"The Capacity of the Pump Must Never Exceed the Capacity of the Well".** The design flow is one of the first determinations for the site and it depends upon the design population x usage per day / hours of pumping per day. That result is multiplied times the capacity factor. The final number is a flow rate in quantity per unit time.

### 3.0 HEAD REQUIREMENT

The second step is to calculate the total head that the pump has to push against and overcome. There are different components contributing to flow resistance that can all be expressed in terms of head. But the head changes depending on the flow rate. So the objective is to determine total dynamic head based on the design flow.

modified from www.pumped101.com



### 3.1 Well Head

The well head consists of heads that are below ground surface (bgs) and must be overcome to pump water to the surface. It includes overcoming friction in the pump discharge pipe as well as elevation heads.

3.1.1 Dynamic Water Level **--** The most common misunderstanding is in determining the water level for the "Well Head". It is based on the difference in elevation between the ground surface and the dynamic water level. The dynamic water level equals the drawdown added to the static water level. The dynamic water level should be determined during the step-drawdown pumping test when pumping at 100% of the design flow.

3.1.2 Friction Head (bgs) **--**The friction head depends upon several factors including the length of the pump discharge pipe, its diameter, the velocity of flow and the roughness of the pipe, reflected by the type of material from which it is made.

### 3.2 Discharge Head

The discharge head is a combination of heads that must be overcome once the water has been pumped to the ground surface. They include: the elevation head, the operating pressure and the friction head from piping at or above the ground surface.

Elevation Head – The most common elevation head at ANA and ANP sites is the 20m height of the elevated storage tank.

Pressure Head **–** There is commonly little or no pressure required for the ANSF systems.

Friction Head **–** There is the friction head from any pipelines that transmit water to the storage tank. Also there are fixtures such as elbows, Ts, flow meters etc. that should be determined and their contribution to head added to the total discharge head.

### 3.3 Total Pump Head

The total pump head is the well head and discharge head combined. There is also the velocity head but it is negligible.

## 4.0 SELECT FAMILY OF PUMPS

The third step is to select a general category or family of pump curves. The primary determination is based on the design flow rate but the total head is also a factor. Select a pump family that is in the range of design flow needed.

From: [www.pedrollo.com](http://www.pedrollo.com)

[Family of Performance Ranges](#)

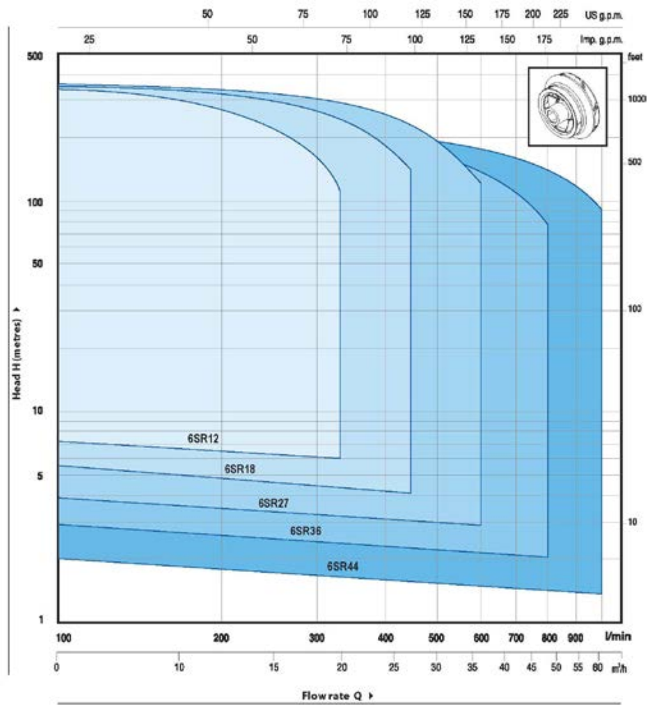
Pump Design is Based on Flow Rate and Head.

6-inch Pump

Water Requirement = 43,594 L/h

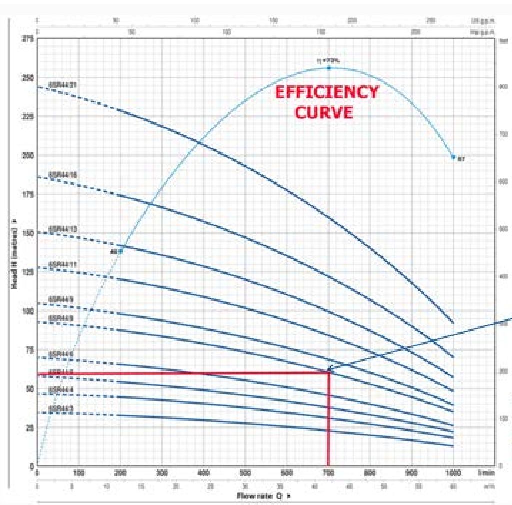
44 m³/h = 44,000 L/h

Select 6SR44 for example




## 5.0 SELECT PUMP

Look at the pump curves from the family of pumps selected. Based on the total head that was calculated, select that point on the y-axis. Then look along the x-axis for that point and find the curve that is nearest to the peak of the efficiency curve. The point where that line crosses the pump curve is the "Duty Point." Look down to the x-axis and that is the flow rate that can be expected. If that is inappropriate one may need to try another family of pumps or another manufacturer.



# Appendix D.

## Sited References from Driscoll, *Groundwater and Wells*, 1986

and the cumulative amount of material measured. These volumes can then be plotted in a manner similar to the procedure discussed above. It is assumed all the material has essentially the same density. This method is not as accurate as a laboratory sieve analysis or sedimentation procedure.

### Grain-Size Distribution Curve

The grain-size distribution curve shows at a glance how much of the sample material is smaller or larger than a given particle size. For example, the curve in Figure 12.16 shows that 90 percent of the sample consists of sand grains larger than 0.009 in (0.23 mm) and 10 percent is smaller than this size. Reading the curve in another way, the 40-percent sand size is 0.026 in (0.66 mm); or 40 percent of the sample is coarser than 0.026 in and 60 percent is finer than 0.026 in.

Grain-size distribution curves have many applications other than in the water well industry. They are used to represent the grading of concrete sand, foundry sand, earth materials for embankments and dams, filter sands, and many other types of granular materials. Engineers in these different fields use several variations in plotting the curves. Attention is called to this fact because there may be occasion to use grain-size distribution curves that are plotted differently than those discussed here.

In the most common variation, percent of material passing a given sieve is plotted on the vertical scale instead of percent retained. This has the effect of reversing the curve so it slopes upward from left to right instead of downward. However, plotting percent retained on the vertical scale is the logical procedure because this permits using the cumulative weights in the same manner that they are recorded in the laboratory. To permit plotting percent passing, on the other hand, the percent retained must be subtracted from 100.

A second variation is the use of a logarithmic scale for the particle size or sieve opening. This has the effect of elongating the part of the curve that represents the finer fraction, and squeezing that part of the curve representing the coarser material.

No single term or word can be used to give an overall description of a sand or sand and gravel mixture, because the material consists of the whole range of particle sizes. Between the limits of the smallest and largest particle sizes, the intermediate sizes can be distributed in many different ways, and each distribution changes the shape of the curve.

There are three elements essential to a complete description of a grain-size distribution curve: (1) sediment size (fineness or coarseness); (2) slope of the curve; and (3) shape of the curve. Any of these elements can change independently of the others, and this makes it necessary to use all three for a complete description of the material grading.

### Sediment Size

In describing the fineness or coarseness of a granular material, the terms fine sand, coarse sand, fine gravel, and other similar terms are used. Unfortunately, these terms do not apply to specific particle sizes, which results in various scientific and engineering specialties using different terms for sediments of the same size. Therefore, several different grain-size classifications have been developed to define each descriptive term. Each of these systems has been adopted in the special field where it seems to fit the best.



**Table 12.6. Grain-Size Classification**

| Wentworth Classification | Size Range |
|---|---|
| Boulder | 10.08 in & above (256 mm & above) |
| Cobble | 2.52 to 10.08 in (64 to 256 mm) |
| Pebble* | 0.16 to 2.52 in (4 to 64 mm) |
| Granule (very fine gravel) | 0.08 to 0.16 in (2 to 4 mm) |
| Very coarse sand | 0.04 to 0.08 in (1 to 2 mm) |
| Coarse sand | 0.02 to 0.04 in (0.5 to 1 mm) |
| Medium sand | 0.01 to 0.02 in (0.25 to 0.5 mm) |
| Fine sand | 0.005 to 0.01 in (0.125 to 0.25 mm) |
| Very fine sand | 0.002 to 0.005 in (0.063 to 0.125 mm) |
| Silt | 0.0002 to 0.002 in (0.004 to 0.063 mm) |
| Clay | Below 0.0002 in (Below 0.004 mm) |
| *The USGS has subdivided this category as follows: | |
| Very coarse gravel | 1.26 to 2.52 in (32 to 64 mm) |
| Coarse gravel | 0.63 to 1.26 in (16 to 32 mm) |
| Medium gravel | 0.31 to 0.63 in (8 to 16 mm) |
| Fine gravel | 0.16 to 0.31 in (4 to 8 mm) |

*(Krumbein & Pettijohn, 1938)*

The Wentworth scale, developed in 1922, is still the basic particle size classification used in the groundwater field. The United States Geological Survey (USGS) uses this classification but has taken one size range, 0.16 to 2.5 in (4 to 64 mm), and subdivided it into groups. The Wentworth scale and USGS amendments are shown in Table 12.6.

The curve in Figure 12.16 shows that the sample tested consists of medium and coarse sand, according to the USGS classification. Applying the same system to the four curves in Figures 12.19 to 12.22 gives the following descriptions:

Class A curve — fine sand
Class B curve — fine and very coarse sand
Class C curve — coarse and very coarse sand
Class D curve — coarse sand and very fine gravel

### Other Ways to Describe Sediment Size

Often, a specific point on a grain-size distribution curve is used as a general index of fineness. An attempt is then made to correlate this size with the hydraulic conductivity of the sediment. Several selected sizes have been used by various researchers.

The term "effective size" was developed by Allen Hazen in his studies of filter sand in 1893. He defined it as the particle size where 10 percent of the sand is finer and 90 percent is coarser. On all the curves shown here, the effective size is the 90-percent retained size. The effective size of the Class A curve in Figure 12.19 is 0.003 in (0.08 mm). In Figure 12.21, the effective size of the sand is 0.010 in (0.25 mm).

Another curve point often used as an index of fineness is the 50-percent size, which for the curve in Figure 12.16 is 0.022 in (0.56 mm). For the Class A and Class B curves, the 50-percent size is 0.007 inch (0.18 mm) in both cases. The 50-percent size may be referred to as the mean or average particle size for uniform (steep slope) sediments. However, when the general slope of the curve is flatter, such as the Class D curve in Figure 12.22, the 50-percent size is inaccurate as an indicator of fineness or coarseness.

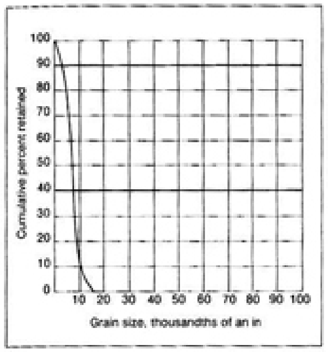



**Figure 12.19. Class A curve for fine sand.**

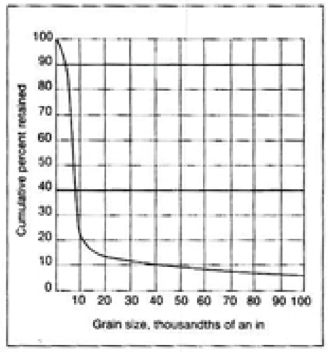



**Figure 12.20. Class B curve for fine and very coarse sand.**

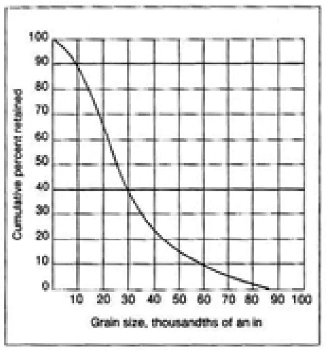



**Figure 12.21. Class C curve for coarse and very coarse sand.**

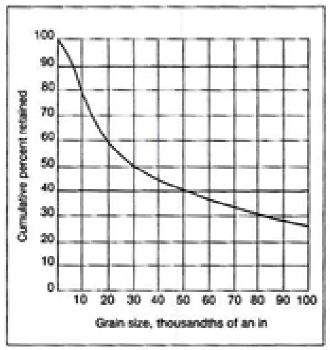



**Figure 12.22. Class D curve for coarse sand and very fine gravel.**

### Slope and Shape of Curve

The slope of the major portion of a grain-size distribution curve can be described in several ways. One term that is used extensively is the uniformity coefficient, which was developed by Hazen at the same time he adopted the idea of effective size.Uniformity coefficient is defined as the 40-percent retained size of the sediment divided by the 90-percent retained size. The lower its value, the more uniform is the grading of the sample between these limits. Larger values represent less uniform grading. The uniformity coefficient is limited in practical application to materials that are rather uniformly graded. It is meaningful only when its value is less than 5. It is well suited for describing the desired uniformity of filter-pack materials. The uniformity coefficient for the sample in Figure 12.16 is 2.9 [0.026 in (0.66 mm) divided



by 0.009 in (0.23 mm)]. For the Class B curve, the uniformity coefficient is 2; for the Class C curve, its value is 3.

The grain-size distribution curves for most granular materials deposited by running water and wave action are referred to as S-shaped curves, although this term is properly applied only to the percent-passing curves. The S-shape of the curve becomes distorted when gravel constitutes 15 percent or more of a mixture of sand and gravel. The curve in Figure 12.16 and the Class A and Class C curves are typical S-shaped distributions. The Class D curve has a "tail" of coarse material. Size distributions that result in S-shaped curves usually represent samples having higher porosities than are found in samples with a "tail"-type configuration.

There is yet no accurate way to calculate hydraulic conductivity directly from the grain-size distribution curve. Many tests and research studies have been performed to find a simple relationship between the grading of a sediment and its hydraulic conductivity, but no dependable correlation that may be applied generally has yet been discovered. Nevertheless, with practical experience, it is possible to estimate the relative yields of different sand and sand and gravel mixtures by careful consideration of the three factors described in this section.

of a test hole, sample logs of other nearby wells in the same aquifer, geophysical analysis of the formation, and data taken during the drilling of the production well. Generally, a well should be completed to the bottom of the aquifer because:

1. More of the aquifer thickness can be utilized as the intake portion of the well, resulting in higher specific capacity.

2. More drawdown can be made available, permitting greater well yield.

3. Sufficient drawdown is available to maintain well yield even during periods of severe drought or overpumping.

An exception to this rule is made when the well screen is centered between the top and bottom of the aquifer, a practice sometimes followed to make more efficient use of a given length of screen in a uniform, confined aquifer. Furthermore, the extreme upper and lower parts of any aquifer commonly consist of materials that are less uniform than those forming the major part of the aquifer. All pilot holes should penetrate the entire aquifer so that the most productive zones can be identified. Another exception is in extremely thick aquifers, such as the Navajo Sandstone and the sand and gravel deposits along the Rio Grande River in New Mexico, where it may not be economical to drill to the bottom of the aquifer.

A third exception is made when poor-quality water is found in part of an aquifer. In this case, the well should be completed to a depth that will avoid the undesirable water. Any part of the hole drilled into a portion of the aquifer containing poorer quality water should be isolated. Although low-quality water may appear anywhere in an aquifer, it is likely that any gases such as hydrogen sulfide or contaminants having low molecular weight will be concentrated near the top. Heavy ions such as iron and manganese move toward the bottom.

## WELL SCREEN LENGTH

The optimum length of well screen is based on the thickness of the aquifer, available drawdown, and nature of the stratification of the aquifer. In virtually every aquifer, certain zones (horizons) will transmit more water than others. Thus, the intake part of the well must be placed in those zones having the highest hydraulic conductivity. Determination of the most productive layers can be made by one or more of the following techniques:

1. Interpretation of the driller's log and comments on drilling characteristics such as fluid loss, penetration rate, and pulldown and chatter.

2. Visual inspection and comparison can be made of samples representing each sediment layer. The relative transmissivity of each layer is estimated from the observed coarseness, lack of silt and clay, and thickness of the layer.

3. Sieve analyses can be made from samples taken from the various layers in the aquifer. Comparison of grain-size curves can indicate the relative hydraulic conductivity of each sample. It is highly recommended that sieve analyses be performed on selected formation samples from any industrial, municipal, or irrigation well. The curves presented in Figure 13.4 indicate the relationship between the grain-size distribution of aquifer materials and the resulting hydraulic conductivity.

4. Laboratory hydraulic conductivity tests can be performed on samples that represent individual layers of the water-bearing formation. In this test, water is caused to flow through a sample of the material. Measurements of the area through which flow occurs, the rate of flow, and the corresponding head loss provide data for calculating the hydraulic conductivity. Aquifer transmissivity can then be determined by adding the individual transmissivity values for all layers of the aquifer (transmissivity equals the hydraulic conductivity times the thickness for each layer).

5. Borehole geophysical logging techniques can help locate zones having the highest hydraulic conductivity. Velocity-meter surveys also are extremely useful. See Chapter 8 for an analysis of the various exploration methods.

Each technique listed above provides useful information on the zones that should be exploited. As many of these techniques should be used as possible. Economic factors governing a well project dictate the cost that can be justified in determining most accurately the productive zones of the aquifer.

Recommended screen lengths for four typical hydrogeological situations are given below.

1. *Homogeneous Unconfined Aquifer.* Theoretical considerations and experience have shown that screening of the bottom one-third to one-half of an aquifer less than 150 ft (45.7 m) thick provides the optimum design for homogeneous unconfined aquifers. In some cases, however, particularly in thick, deep aquifers, as much as 80 percent of the aquifer may be screened to obtain higher specific capacity and greater efficiency, even though the total yield is less.

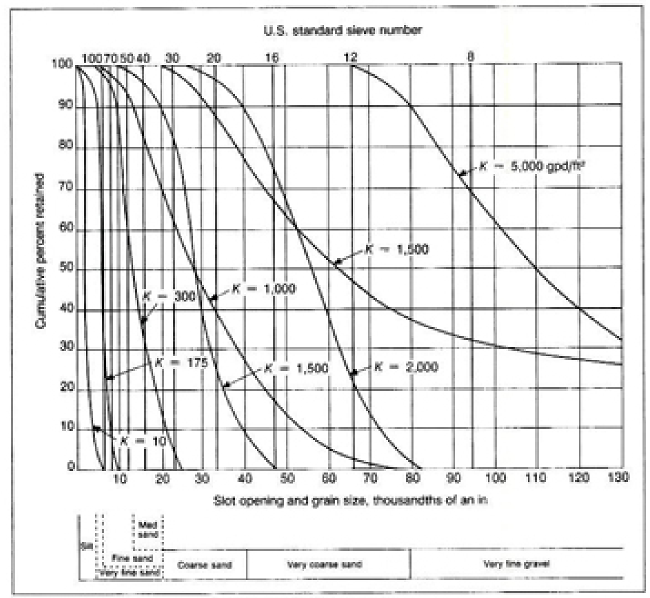



**Figure 13.4. Hydraulic conductivity can be estimated on the basis of grain-size-distribution curves.**

A well in an unconfined aquifer is usually pumped so that, at maximum capacity, the pumping water level is maintained slightly above the top of the pump intake or screen. The well screen is positioned in the lower portion of the aquifer because the upper part is dewatered during pumping.

For wells in unconfined aquifers, selection of screen length is a compromise between two factors. On the one hand, higher specific capacity is obtained by using the longest screen possible. This reduces convergence of flow and entrance velocity, thereby increasing specific capacity. On the other hand, more available drawdown results from using the shortest screen possible. These two conflicting aims are satisfied, in part, by using an efficient well screen that minimizes the loss in specific capacity as drawdown increases.

As shown in Chapter 9, Figure 9.13, it is impractical from a theoretical (hydraulic) standpoint to pump a well in an unconfined aquifer at a drawdown that exceeds two-thirds the thickness of the water-bearing sediment. Figure 9.13 shows that the well produces 88 percent of maximum yield at 65 percent of the maximum drawdown. If the drawdown were increased to 95 percent of the amount possible, the well yield would increase to 99 percent of its maximum. Thus, 46 percent greater drawdown results in only 12.5 percent greater yield.

2. *Nonhomogeneous Unconfined Aquifer.* The basic principles of well design for homogeneous unconfined aquifers also apply to this type of aquifer. The only variation is that the screen or screen sections are positioned in the most permeable layers of the lower portions of the aquifer so that maximum drawdown is available. If possible, the total screen length should be approximately one-third of the aquifer thickness.

3. *Homogeneous Confined Aquifer.* In this type of aquifer, 80 to 90 percent of the thickness of the water-bearing sediment should be screened, assuming that the pumping water level is not expected to be below the top of the aquifer. Maximum available drawdown for wells in confined conditions should be the distance from the potentiometric surface to the top of the aquifer. If the available drawdown is limited, however, it may be necessary to draw the well down below the bottom of the upper confining layer. When this occurs, the aquifer will respond like an unconfined aquifer during pumping.

Screen lengths chosen according to these rules make it possible to obtain about 90 to 95 percent of the specific capacity that could be obtained by screening the entire aquifer. Best results are obtained by centering the screen section in the aquifer. In the past, screens were often interspaced with blank casing placed in the less permeable zones of the formation. Today, however, higher water demands and lower screen costs have resulted in completely screening most deep wells.

4. *Nonhomogeneous Confined Aquifer.* In this type of aquifer, 80 to 90 percent of the most permeable layers should be screened.

## WELL SCREEN SLOT OPENINGS

Screen slot openings for the same formation can differ depending on whether the well is naturally developed or filter packed. Either design is satisfactory and the choice for a particular well will depend primarily on the nature of the grain-size-distribution curve for the aquifer materials. Coarse-grained nonhomogeneous material can be developed naturally, whereas fine-grained homogeneous materials are best developed



using a filter pack. Well screen slot openings for either method are selected from a study of sieve-analysis data for samples representing the water-bearing formation.

The design for the slot openings must be based on accurate samples if maximum yields and sand-free water are to be obtained. In rotary drilling, clay added to the drilling fluid can contaminate samples and lead to recommended slot sizes that are smaller than necessary. The log of the well should show if natural clays are present and should be considered in the screen design. In some cases, fine material from formations overlying the aquifer may be kept in suspension in the drilling fluid while the aquifer is being drilled. These fine materials may then be included in the cuttings from the aquifer, although they originate in the overburden. The drilling method may also affect the accuracy of the sample. In air drilling, samples collected at the surface tend to be finer in texture than the materials in the formation. As the bit advances, formation water entering the borehole may pull in finer material differentially, resulting in a higher proportion of fine particles in samples taken at the surface.

On the other hand, highly viscous drilling fluids made with clay additives may entrain fine aquifer materials and prevent them from settling out in the mud pit. Thus, the sample will be coarser than the actual formation materials. The use of a polymeric drilling fluid that has little or no gel strength will minimize these sampling problems. Sampling procedures are discussed in Chapter 8.

### Screen Slot Selection for Naturally Developed Wells

In a naturally developed well, the screen slot size is selected so that most of the finer formation materials near the borehole are brought into the screen and pumped from the well during development. This practice results in creating a zone of graded formation materials extending 1 to 2 ft (0.3 to 0.6 m) outward from the screen. The increased porosity and hydraulic conductivity of the graded materials reduces the drawdown near the well during pumping.

To determine the correct slot openings for nonhomogeneous sediments, the typical approach is to select a slot through which 60 percent of the material will pass and 40 percent will be retained. This is usually done when the groundwater is not particularly corrosive and when there is little doubt about the reliability of the sample. On the other hand, the 50-percent-retained size is chosen if the water is extremely corrosive or if there is some doubt about the reliability of the sample. Selecting a smaller slot size is wiser if the water is corrosive or if low-carbon steel screens are used, because enlargement of the openings of only a few thousandths of an inch caused by corrosion could allow the well to pump sand. If the screen is stainless steel, slot enlargement from corrosion is generally not a problem. A conservative slot opening is used in calcareous formations (shell fragments) which dissolve readily if the well is acid treated. Removal of the calcareous materials reduces the amount of bridging material and allows fine clastic material to enter the well.

A more conservative slot selection may be advisable when (1) there is some doubt about the reliability of the samples, (2) the aquifer is thin and overlain by fine-grained loose material, (3) development time is at a premium, and (4) the formation is well sorted. Under these conditions, slot sizes that will retain 40 to 50 percent of the aquifer material are preferred.

When the formation consists of coarse sand and gravel, the designer has greater latitude in selecting the slot openings (Figure 13.5). An increase of a few thousandths of an inch in the slot size allows only a small amount of additional material to pass through the well screen during development. The slot size selected, therefore, may retain from 30 and 50 percent of the aquifer material. If the openings chosen retain only 30 percent, more material is brought through the screen during the development process. This will increase the time required to develop the well.

Offsetting the cost of extra development work, however, are the advantages gained from the larger slot sizes that increase the screen open area. For example, when the water is incrusting, longer service life can be expected before plugging reduces the well yield. Larger slot size and open area permit the development of a thicker, more permeable zone around the screen. This generally increases the specific capacity of the well, making the well more efficient and therefore less expensive to operate.

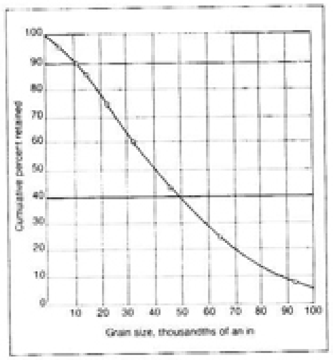



**Figure 13.5. A 0.040- to 0.058-in (1.0- to 1.5-mm) slot opening is selected from this grain-size-distribution curve for a naturally developed well. For the larger slot size, the development time will be greater.**

Nonhomogeneous formations occur most commonly because the strength of the forces responsible for erosion and deposition of earth materials tend to vary over relatively short periods of time. When designing screens for these formations, slot openings for different sections of the well screen may be chosen according to the gradation of materials in the different layers, if the layers are at least 4 ft (1.2 m) thick and their depths have been determined accurately. Two additional recommendations should be followed, however, when selecting slot openings for a multiple-slot screen:

1. If fine material overlies coarse material, extend at least 3 ft (0.9 m) of the screen designed for the fine material into the coarse layer below.

2. If fine material overlies coarse material, the slot size for the screen section installed in the coarse layer 3 ft (0.9 m) beneath the formation contact should not be more than double the slot size for the overlying finer material. Doubling of the slot size should be done over screen increments of 2 ft (0.6 m) or more.

Application of these two recommendations reduces the possibility that the well may pump sand if the location of each layer has not been determined accurately or if the samples are not reliable. The guide for slot-size selection indicates that about 60 percent of the formation material near the screen will come through the screen during the development process. Removal of this fraction results in some settlement of material around the screen. Thus, the position of the overlying finer layer moves downward slightly as settling occurs.

Figure 13.6 illustrates what can happen if the first of the above recommendations is not followed. Here the section of the screen with openings selected to fit the coarser sand begins at the boundary between the two layers. As the finer fraction of the coarser material is removed during development, slumping of the overlying fine-sand layer may occur. This can easily permit the top section of the screen, which has the larger



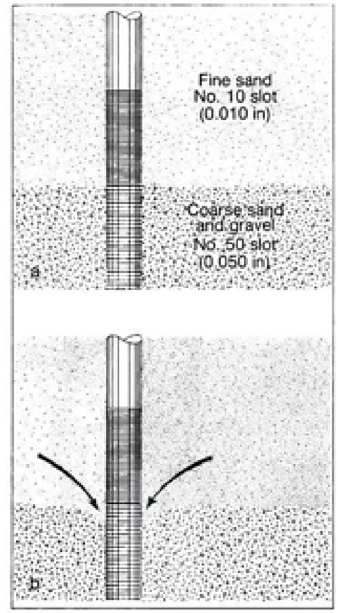



**Figure 13.6. Screen in lower part of stratified aquifer (a) should be shorter than the total thickness of the coarser sand, to avoid situation (b) which shows possibility of fine sand entering upper part of the screen after development.**

openings, to come into contact with the fine sand; sand pumping would then occur.

Application of the two recommendations is best illustrated by an example. The curves in Figure 13.7 represent the grain-size distribution for the four layers that make up the lower 65 ft (19.8 m) of an unconfined aquifer 200 ft (61 m) thick. The grain size of the material immediately overlying the aquifer should also be determined. Good design calls for screening of the lower 65 ft of the formation, which means that approximately one-third of the aquifer will be screened. To evaluate the situation, sketch the stratigraphic section and record the information in a design table (Figure 13.8 and Table 13.11). Slot sizes for a screen to be used in a formation of only two layers can be selected readily without a design table. The table is extremely useful, however, for comparing a large number of samples.

The depth and thickness of each layer, for 50-, 40-, and 30-percent-retained sizes of each sample, are recorded. The hydraulic conductivity can then be estimated from the curves in Figure 13.4. A range of slot sizes, above and below the 40-percent size, is then determined. These should be values that could be considered for a screen in each isolated layer without considering the other layers.

If a 65-ft screen* is installed in the lower part of the aquifer, the top of the screen is at 350 ft. Average water quality and development conditions are assumed in this example, so the design is based on slot sizes that retain 40 percent of the material. Selection of the slot openings begins at the top of the screen. In this example, the sediments lying just above 350

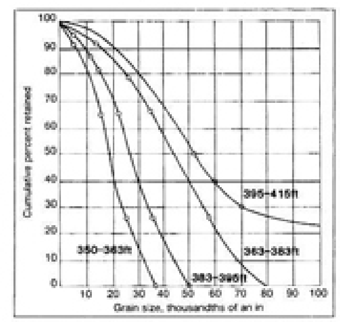



**Figure 13.7. Grain-size-distribution curves representing the various layers in a stratified sand aquifer.**

*Most continuous-slot screens are built in lengths of 20 ft (6.1 m) or less that can have many slot sizes. These sections are assembled at the well site by the drilling contractor.

ft can be retained by a screen with 0.020-in slots; that is, the overlying sediments have the same size distribution as those that exist from 350 to 363 ft. Thus, the screen section for the upper layer should have 0.020-in slot openings, the next layer, 0.050 in, the next layer, 0.030 in, and the last layer, 0.060 in.

Applying the first recommendation, the finer openings for the top screen section (350 to 363 ft) must extend at least 3 ft into the underlying coarser material. This puts the lower limit of the section with 0.020-in slot openings at 366 ft. Application of the second recommendation suggests that the slot size can be no more than doubled (0.040 in) from 366 to 368 ft. From 368 to 383 ft, the slot size again follows the 40-percent-retained size. The sediment from 383 to 395 ft is finer and should have a 0.030-in slot size. Even though the grain size becomes larger at 395 ft, 3 ft of 0.030-in-slot screen is dictated for 395 to 398 ft. From 398 to 415 ft, the screen has a 0.060-in slot size. The completed selection of screen openings is shown in Figure 13.8.

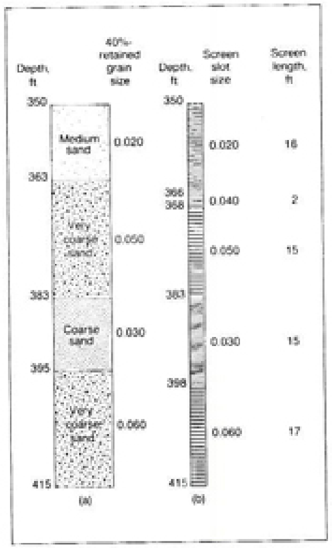



**Figure 13.8. (a) Stratigraphic section that will be screened with slot sizes corresponding to various layers. (b) Sketch of screen showing the slot sizes selected based on rules 1 and 2.**

If accurate samples from known depths are available, the well designer should custom design the screen to fit the aquifer conditions at the well site, because it costs no more to use a multiple-slot screen. Use of the proper screen openings to fit each sediment layer will help achieve the highest possible specific capacity and will greatly reduce the possibility of pumping sand with the water.

### Filter Pack Design

The second primary method for completing wells is by filter packing. In filter-

**Table 13.11. Design Table for Screen Slot Size**

| Depth (ft) | Thickness (ft) | Hydraulic Conductivity (gpd/ft²) | Transmissivity (gpd/ft) | Screen Openings (in) | | |
|---|---|---|---|---|---|---|
| | | | | 50% Retained | 40% Retained | 30% Retained |
| 350-363 | 13 | 500 | 6,500 | 0.019 | 0.020 | 0.024 |
| 363-383 | 20 | 2,000 | 40,000 | 0.045 | 0.050 | 0.056 |
| 383-395 | 12 | 1,000 | 12,000 | 0.026 | 0.030 | 0.034 |
| 395-415 | 20 | 1,500 | 30,000 | 0.052 | 0.060 | 0.070 |
| Aquifer Transmissivity | | | 88,500 | | | |



packed wells, the zone immediately around the well screen is made more permeable by removing some formation material and replacing it with specially graded material. This relatively thin zone separates the screen from the formation material and increases the effective hydraulic diameter of the well. A filter pack is chosen to retain most of the formation material; a well screen opening is then selected to retain about 90 percent of the filter pack after development. Filter pack materials should be well sorted to assure good porosity and hydraulic conductivity of the materials near the screen. Most commercial filter packs have uniformity coefficients of approximately 2. In certain areas, however, filter packs with uniformity coefficients of 4 to 5 are used occasionally with good results.

Filter packing is especially advantageous when the sediments are highly uniform and fine grained, when the sediments are highly laminated, or when all the materials to be used in the well construction must be on site before drilling begins. A filter pack is also advantageous when the small slot size dictated by natural development limits the transmitting capacity of the screen so that the desired yield cannot be obtained. Moreover, the use of certain drilling rigs may require the installation of a filter pack. For example, reverse rotary rigs will rarely complete a borehole that is less than 14 to 16 inches (356 to 406 mm) in diameter. Thus, the borehole diameter may be much larger than required for the installation of a screen.

Some geologic environments in which filter packs should be considered include:

*Fine, uniform sand [glaciofluvial, alluvial, and aeolian (wind blown) aquifers].* In these formations, filter packing should be considered so that larger slot openings can be used to increase the hydraulic efficiency of the well. In general, if a slot opening based on natural development is smaller than 0.010 in (0.25 mm), filter packing may be more desirable because the screen's transmitting capacity may not be great enough to supply the desired yield. If the water is extremely incrusting, a lower limit of 0.015 in (0.38 mm) or 0.020 in (0.51 mm) may be used instead of 0.010. Some deviation from this limit is possible, usually depending on the mineral content of the water. For example, in some areas of the Gulf Coastal Plain of the southern United States, naturally developed wells with screen openings as small as 0.006 in (0.15 mm) are used because experience has shown this to be the best design.

In other situations, filter pack design is dictated by the physical nature of the aquifer. In certain fine-grained, uniformly sorted formations, a naturally developed well may lead either to low yields because screen slot sizes must be reduced, or to high rates of sand pumping. Filter packing of these same wells would generally lead to higher sand-free yields.

Examples of fine-grained formations in which wells are ordinarily filter packed include the Tertiary sands of the Gulf Coastal Plain; the Ogallala Formation in West Texas, Kansas, and Nebraska; the Raritan sand in New Jersey; the Sparta sand in Louisiana; and aquifers of the Indus Plains in West Pakistan.

*Semiconsolidated (friable) sandstone.* Many productive sandstone aquifers are poorly cemented. The Dakota Sandstone in North and South Dakota, the Jordan Sandstone in some areas of Minnesota, and the Garber and Elk City Sandstones in Oklahoma are examples of this type of formation. If a well is finished as an open hole in these aquifers, some sand particles continually slough from the walls of the hole, resulting in a sand-pumping well. The sloughing may begin immediately after the well is completed or after several months have elapsed, depending on the pumping rate and the amount of cement holding the sand grains together. The higher the pumping rate, the more quickly sloughing will begin. The potential for sand sloughing prompts many well-design engineers to use a well screen. Because most sandstones are fine grained, screen openings of 0.010 in (0.25 mm), or smaller, may be required to screen them correctly as naturally developed wells (based on 50-percent retention). Even screening at the 50-percent retention level may require a long development time, and large amounts of sediment may have to be removed from around the screen. For such formations, therefore, it is good design practice to use specially graded filter packs so that larger screen openings can be used. It is important to recognize, however, that the installation of a filter pack and screen usually reduces the specific capacity of a previously open-hole well. Nevertheless, the reduction in yield is preferable to an unending maintenance problem created by sand pumping.

Another reason for filter packing a sandstone aquifer is that the formation material usually provides little or no lateral support for the screen. Also, the formation does not readily slump against the screen during development, in contrast to unconsolidated sediments. After setting the screen in the open borehole, some void spaces remain between the screen and the borehole wall. It is possible that a section of the formation could break off, fall against the screen, and cause damage. Loose, granular material inserted between the screen and the borehole wall accommodates itself to all the irregularities of the borehole, supporting both the wall and the screen.

Figure 13.9 shows the construction details of a filter-packed well finished in semiconsolidated sandstone. The larger space around the screen is created by an underreamer that increases the borehole diameter only where required. The oversized borehole provides sufficient annular area for a filter pack.

*Extensively laminated formations.* Some aquifers consist of alternating thin layers of fine, medium, and coarse sediment. Examples include the Magothy Formation of Long Island, New York; the alluvial deposits of the San Joaquin Valley of California; the Santa Fe Formation of central New Mexico; some coastal plain deposits of North Carolina; the Ogallala Formation of the High Plains region; and some highly stratified glacial aquifers. It is often difficult to determine precisely the position and thickness of each individual layer and to design a multiple-slot screen corresponding to the stratification. Therefore, filter packing should be specified for wells in these types of formations to avoid screen placement problems.

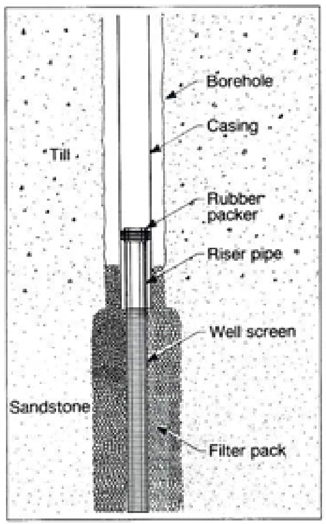



**Figure 13.9. Filter pack design is usually preferred for wells completed in semiconsolidated sandstone aquifers such as the Dakota and Lakota Sandstones in South Dakota.**



The grading of the filter pack should be based on the grain size of the finest layer to be screened. A filter pack selected in this manner ordinarily does not restrict the flow from the layers of coarsest material. The hydraulic conductivity of the pack is generally several times greater than that of the coarsest layers because the pack is cleaner and more uniform.

Filter pack material should consist of clean, well-rounded grains of a uniform size. These characteristics increase the permeability and porosity of the pack material. Pit-run or crushed materials are usually not satisfactory for filter packs. The chemical nature of the filter pack is as important as its physical characteristics. Filter pack material consisting mostly of siliceous, rather than calcareous, particles is preferred. Up to 5 percent calcareous material is a common allowable limit. This is important because acid treatment of the well might be required later, and most of the acid could be spent in dissolving calcareous particles of the filter pack rather than in removing incrusting deposits of calcium or iron. Similarily, if the groundwater is slightly acidic, partial dissolution of the pack may occur over time. Particles of shale, anhydrite, and gypsum in the filter pack material also are undesirable. Table 13.12 lists the desirable physical and chemical characteristics for a filter pack and the advantages of using these materials.

The steps outlined below are followed in designing a filter pack:

1. Choose the layers to be screened and construct sieve-analysis curves for these formations. Select the grading of the filter pack on the basis of the sieve analysis for the layer of finest material. Figure 13.10 shows the grading of two samples of typical water-bearing material from an aquifer 30 ft (9.1 m) thick. The finest material lies between 75 and 90 ft (22.9 and 27.4 m). The design of the filter pack in this example will be based on this layer. In some instances, it is good practice to ignore unfavorable portions of an aquifer and to use blank pipe between sections of screen positioned in the more permeable sections of the aquifer.

2. Multiply the 70-percent size of the sediment by a factor between 4 and 10. Use 4 to 6 as the multiplier if the formation is uniform and the 40-percent-retained size

**Table 13.12. Desirable Filter Pack Characteristics and Derived Advantages**

| Characteristic | Advantage |
|---|---|
| Clean | Little loss of material during development<br>Less development time |
| Well-rounded grains | Higher hydraulic conductivity and porosity<br>Reduced drawdown<br>Higher yield<br>More effective development |
| 90 to 95% quartz grains | No loss of volume caused by dissolution of minerals |
| Uniformity coefficient of 2.5 or less | Less separation during installation<br>Lower head loss through filter pack |

is 0.010 (0.25 mm) or less. Use a multiplier between 6 and 10 for semiconsolidated or unconsolidated aquifers when formation sediment has highly nonuniform gradation and includes silt or thin clay stringers, as commonly found in arid or semiarid areas. Using multipliers greater than 10 may result in a sand-pumping well. Place the result of this multiplication on the graph as the 70-percent size of the filter material. In Figure 13.10, 0.005 in (0.13 mm) is the 70-percent size of the sand between 75 and 90 ft. Using 5 as the multiplier, the 70-percent size of the filter material is 5 × 0.005 = 0.025 in (5 × 0.13 = 0.65 mm). This is the first point on a curve that represents the grading for the filter pack material.

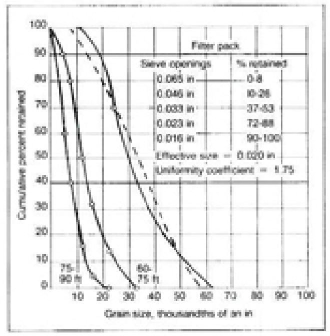



**Figure 13.10 Grain-size curves for aquifer sand and corresponding curve for properly selected filter pack material.**

3. Through the initial point on the filter pack curve, draw a smooth curve representing material with a uniformity coefficient of approximately 2.5 or less. In Figure 13.10, the curve drawn as a solid line has a uniformity coefficient of about 1.8. It could have been drawn somewhat differently, as shown by the dashed line which has a uniformity coefficient of 2.5. It is good practice to draw the filter pack curve so that the pack is as uniform as practicable. Thus, the material indicated by the solid-line curve is more desirable than the material indicated by the dashed-line curve.

4. Select a commercial filter pack that fulfills the dimensional and chemical requirements listed in Table 13.12. If a proper commercial pack cannot be purchased, but a local source of sand and gravel is available, the following procedure can be used to construct a suitable filter pack.

Prepare specifications for the filter pack material by first selecting four or five sieve sizes that cover the range of values for the curve, and then set down a permissible range for the percentage retained on each of the selected sieves. This range may be eight percentage points below and above the percentage retained at any point on the curve. In the example, the largest sieve would have an opening of 0.065 in (1.7 mm). The curve shows zero percent retained on this sieve, so up to 8 percent of the filter pack may contain 0.065-in material. The next smaller opening in the most commonly used series of sieves is 0.046 in (1.2 mm). The curve, as drawn, shows 18 percent retained on this sieve; 8 percent is added and subtracted to obtain the permissible range. Thus, on the 0.046-in sieve, the range is from 10 to 26 percent. This procedure is repeated until each of the sieves previously selected has been assigned a permissible range. In Figure 13.10, five sizes of sieve openings are shown to cover the desired gradation of the pack material. Giving the filter pack supplier an acceptable range at each of these points makes it possible to produce the desired material at reasonable cost. When designing filter pack material, the designer should keep in mind local sources of filter sand used for rapid sand filters*. Firms that produce these materials

*Rapid sand filters consist of sand beds used to filter drinking water supplies in water treatment plants.



have large stocks of clean, uniformly graded sands and gravels that readily fit the requirements for filter packing of water wells. Some firms supply sand materials to oil and gas companies for use as propping materials in hydraulic fracturing of formations. These materials are also suitable for filter packing of water wells. Drilling contractors should obtain grain-size-distribution curves for all local sources of potential filter pack materials. For economic reasons, these packs should be specified if possible.

5. As a final step, select a screen slot size that will retain 90 percent or more of the filter pack material. In our example, the correct slot size is 0.018 in (0.46 mm).

6. Calculate the volume of filter pack required from Table 13.13. The pack should extend well above the screen to compensate for settlement of the pack during development. Use of a caliper log may reveal the presence of washouts in the borehole, necessitating additional filter pack. It is good practice to have extra filter pack on the site, especially if the stability of the borehole is in doubt.

If the well designer and contractor carefully follow the foregoing steps, sand-pumping wells can be avoided. The pack will provide mechanical retention of the formation material and prevent sediment from moving through the filter pack into the well. Occasionally it may be necessary to install more than one size of filter pack in a borehole. For example, thick boulder beds may overlie sand deposits and the yield requirements may dictate that both layers be screened. If the use of more than one filter pack is contemplated, the screen manufacturer should be consulted for specific design recommendations.

### Thickness of Filter Pack

The design theory of filter pack gradation is based on the mechanical retention of formation particles; therefore, a pack thickness of only two or three grain diameters is actually needed to retain and control a formation. Laboratory tests made by Johnson Division show that a properly sized pack with a thickness of less than 0.5 in (12.7 mm) successfully retains the formation particles regardless of the velocity of water passing through the filter pack. It is impossible, however, to place a filter pack that is only 0.5 in thick and expect the material to completely surround the well screen. To insure that a continuous layer of filter material will surround the entire screen, the design should specify that the annulus around the screen be at least 3 in (76 mm).

Filter-pack thickness does little to reduce the possibility of sand pumping, because the controlling factor is the ratio of the grain size for the pack material in relation to the formation material. Also, a filter pack that is too thick can make final development of the well more difficult, as explained in Chapter 15. Under most conditions, filter packs should not be more than 8 in (203 mm) thick because the energy created by the development procedure must be able to penetrate the pack to repair the damage done by drilling, break down any residual drilling fluid on the borehole wall, and remove fine particles near the borehole.

It has been suggested that the presence of a filter pack will augment the well yield because water from an overlying aquifer can percolate downward through the filter pack and into the well screen. In practice, however, calculations show this contribution to be insignificant in relation to total yield. For example, assume the conditions shown in Figure 13.11, where 90 percent of a confined aquifer has been screened. The overlying sediments are water bearing and are connected hydraulically to the screened

**Table 13.13. Volume of Filter Pack Required***

| ID of Pipe or Borehole | | Outside Diameter of Well Screen | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| in | mm | 4 in ft³/ft | 102 mm m³/m | 6 in ft³/ft | 152 mm m³/m | 8 in ft³/ft | 203 mm m³/m | 10 in ft³/ft | 254 mm m³/m | 12 in ft³/ft | 305 mm m³/m | 16 in ft³/ft | 406 mm m³/m | 18 in ft³/ft | 457 mm m³/m | 20 in ft³/ft | 508 mm ms³/m |
| 8 | 203 | 0.27 | 0.03 | 0.15 | 0.01 | — | — | — | — | — | — | — | — | — | — | — | — |
| 10 | 254 | 0.47 | 0.04 | 0.36 | 0.03 | 0.20 | 0.02 | — | — | — | — | — | — | — | — | — | — |
| 12 | 305 | 0.70 | 0.07 | 0.60 | 0.06 | 0.45 | 0.04 | 0.24 | 0.02 | — | — | — | — | — | — | — | — |
| 16 | 406 | 1.30 | 0.12 | 1.20 | 0.11 | 1.05 | 0.10 | 0.86 | 0.08 | 0.62 | 0.06 | — | — | — | — | — | — |
| 20 | 508 | 2.10 | 0.20 | 2.00 | 0.19 | 1.90 | 0.18 | 1.65 | 0.15 | 1.40 | 0.13 | 0.80 | 0.07 | 0.42 | 0.04 | — | — |
| 24 | 610 | 3.05 | 0.28 | 2.95 | 0.27 | 2.80 | 0.26 | 2.60 | 0.24 | 2.35 | 0.22 | 1.75 | 0.16 | 1.40 | 0.13 | 1.00 | 0.09 |
| 30 | 762 | 4.85 | 0.45 | 4.70 | 0.44 | 4.60 | 0.43 | 4.40 | 0.41 | 4.15 | 0.39 | 3.50 | 0.33 | 3.15 | 0.29 | 2.75 | 0.26 |

*Slightly more filter pack is required for telescope-size screens, slightly less for pipe-size screens.






portion of the well by the 6-in (152-mm) filter pack. The theoretical volume of water that can move downward from the upper aquifer to the well screen can be calculated by the Darcy equation:

$$Q = KIA$$

where
$Q$ = vertical flow through the pack material, in gpd
$K$ = hydraulic conductivity of filter pack, in gpd/ft²
$I$ = hydraulic gradient causing vertical flow in the filter pack
$A$ = cross-sectional area of the filter pack, in ft²

In this example, the available head is 30 ft — the difference between the pumping level in the well and the static water level in the upper aquifer. The average distance through which the upper water must move is about 28 ft, the distance from the midpoint of the upper aquifer to the top portion of the screen. In this case, $I = 30/28 = 1.1$ and $A = 2.25$ ft². The hydraulic conductivity, $K$, of the filter pack must be estimated. A reasonable upper limit for pack materials is 17,000 gpd/ft².

The amount of water transmitted vertically in this example is, therefore:

$$Q = 17{,}000 \cdot 1.1 \cdot 2.25 = 42{,}075 \text{ gpd} = 29.2 \text{ gpm}$$

The contribution of 29.2 gpm is a relatively small proportion of the total amount of water that can be pumped from the hypothetical well. If the lower aquifer has a hydraulic conductivity of 1,000 gpd/ft², its transmissivity is about 50,000 gpd/ft. An efficient well in this aquifer should develop a specific capacity of about 25 gpm/ft of drawdown. A drawdown of 30 ft would mean that the yield of the lower formation alone is about 750 gpm. The theoretical yield from vertical flow in the filter pack is 29.2 gpm, or about 4 percent of the total for the well.

The actual contribution to the yield through the filter pack will depend on how the pack is placed, how much drilling fluid remains in the borehole, and the physical and chemical changes that take place in the pack over time. When the filter pack material is placed in the well, uneven settlement of the material can create zones of finer particles interspersed with coarser material. This layering effect can reduce significantly the vertical hydraulic conductivity of the pack. The remnants of clay additives left over from the drilling fluid also can decrease the porosity and hydraulic conductivity of the pack. Development methods are effective primarily around the screen, and only

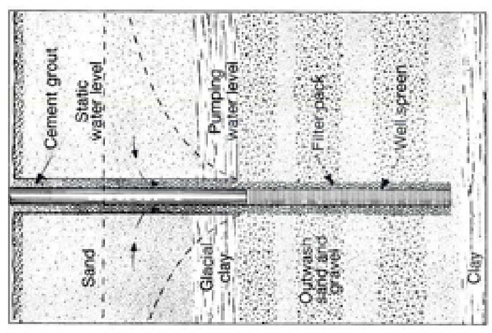



**Figure 13.11. In the conditions shown here, the filter pack above the glacial clay will not contribute greatly to the yield of the well.**

small amounts of fine material can be removed from the filter pack above the screen. Even more important than these two factors are the physical and chemical changes that occur in the upper part of the pack over time. Aeration of the filter pack occurs in the upper aquifer when pumping begins, and minerals in solution can precipitate and plug the filter pack, causing a significant reduction in the yield. Thus, an initial 4-percent contribution to the total yield can become much less after some months or years of pumping. In other situations, the percentage of contribution may vary but is always only a small part of the total yield.

**Cost Factors**

The cost of filter packing a well depends on the drilling method, the length of development time, the installation procedure, and the availability of filter pack material. The larger hole size required for a filter-packed well generally costs more per foot when drilled with any rig other than a reverse rotary machine. With cable tool drilling equipment, doubling of the well diameter may more than double the drilling cost. In direct rotary drilling, large-diameter holes also cost more, as a rule, because more viscous drilling fluids and higher drilling fluid circulation rates are needed to raise the cuttings to the ground surface. On the other hand, with reverse circulation drilling equipment, an increase in hole diameter is of little concern. Drilling a 36-in (914-mm) hole generally costs only slightly more than a 24-in (610 mm) hole because the only basic items of extra cost are a larger bit, a larger mud pit, and more filter material.

For certain uniform sediments, the cost for natural development of a well may exceed the extra costs for the large borehole and filter pack required for filter-packed wells. In most cases, the drilling contractor will charge approximately 50 percent of the drilling rate for development because the rig is still involved in the development process although there are no bit or casing costs. It is sometimes more economical, therefore, to construct a filter-packed well because the saving in development time may offset the extra initial cost. This is especially true in terrace and alluvial deposits like those found in Oklahoma, Kansas, and Nebraska.

In some areas of the world, filter pack materials are not readily available and must be transported hundreds of miles to the drilling site. Elsewhere, high-grade filter packs are available locally and cost relatively little. Many drilling contractors will stock one or more sizes of filter pack at their place of business because they drill continually in the same aquifers and

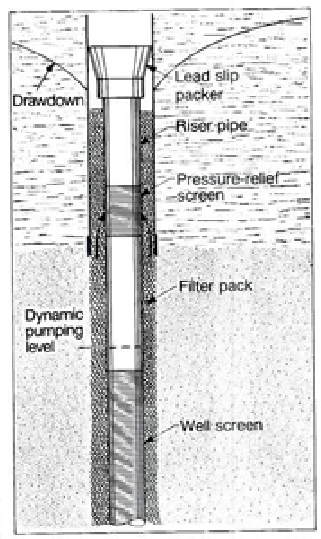



**Figure 13.12. A pressure-relief screen should be installed just up inside the bottom of the casing to relieve large differential pressures.**



can anticipate their needs. In this situation, the cost of the filter material is a small part of the total well cost.

Two design errors are common in filter-packed wells. First, some contractors use the same pack in all their wells regardless of the particular formation, a practice that can lead to low yields or sand-pumping wells. Second, a contractor may use the correct filter pack for a formation, but will use a screen from stock with slot sizes that are too small. Again, low yields are likely because of reduced hydraulic efficiency and a tendency for greater incrustation.

Cost comparisons between wells that are filter packed and those that are naturally developed can be made only for specific wells, depending on a number of factors. No general statement can be made that one method is more costly or will produce more efficient wells than the other. Both methods produce wells that have high specific capacities, are sand free, and will last many years without extensive maintenance.

## PRESSURE-RELIEF SCREENS

In some well installations, the drawdown outside the well may be significantly above the pumping level inside the casing. In these circumstances, high pressure differentials may cause a powerful upward flow of water in the filter pack. Occasionally, the difference between the pressure in the casing and the pressure in the borehole is great enough to lift off heavy lead slip packers, or to lift filter pack material up to the pump intake if no packer is used. Tight or highly stratified formations are most likely to lead to high differential pressures. To relieve pressure in the filter pack, a short pressure-relief screen should be installed in the riser pipe so that it is just up inside the bottom of the casing (Figure 13.12). During pumping, pressure differentials are relieved through the screen rather than up through the pack. It is good design practice to install a pressure-relief screen between the top of the production screen and the top of the riser pipe to eliminate the build-up of differential pressures during pumping.

## FORMATION STABILIZER

The primary purpose of a formation stabilizer is to keep the borehole open and prevent caving of overlying clays or other fine material into the screened portion of the well. In unstable formations, a stabilizer should be considered if the borehole is more than 2 in (51 mm) larger than the casing or screen. For example, in South Dakota, screened siltstone formations are often packed with stabilizer materials to prevent the pumping of silty water. Stabilizers are also used to prevent premature caving of formation material prior to development. This can be a major problem in oversized boreholes or where confining pressures are present, because caving of highly stratified materials can cause significant reduction in the porosity and permeability of aquifer materials for some distance away from the borehole. A second function of the stabilizer material is to maintain or augment the hydraulic conductivity of the natural formation.

The type of stabilizer used depends on the physical characteristics of the formation materials. For completely unconsolidated formations such as alluvial sands and silts, or glacial sands and gravels, the stabilizer should be chosen with care. Because the well is to be naturally developed, the 40-percent-retained size dictates the screen slot size. The stabilizer is then chosen so that its graded sizes are similar to or slightly larger than the natural formation. In practice, the median grain size (50-percent-with a chlorine solution to kill any bacteria remaining from previous drilling operations. Water used in the drilling process and filter pack materials should also be treated with a chlorine solution before introduction into the well. During construction, the well should be disinfected continuously by maintaining a free-chlorine residual of 10 mg/ℓ in the drilling fluid to retard the growth of bacteria introduced into the well while drilling. (No practical way exists to treat a well drilled with dry air.) Because the effectiveness of the chlorine solution is largely dependent on the amount of hypochlorous acid (HOCl) present. In high-pH waters, the sterilizing effect of the solution is less (EPA, 1975c). Thus, stronger chlorine solutions are recommended under these conditions. On the other hand, the addition of chlorine to low-pH waters may lead to excessive corrosion, thereby damaging the drilling equipment used in the hole. The chlorine required to produce a 50 mg/ℓ solution is given in Table 18.5. Chlorine pellets are often added to filter pack material when organic drilling fluid additives are used, because the chlorine helps to break down the viscosity of the drilling fluid residues during well completion. Chlorine technology is discussed later in this chapter.

## DISINFECTING WELLS AND PIPING

After the well has been completed, the water well contractor must disinfect the well, pump, and all piping to kill any bacteria that may be present. Materials and tools used in drilling and developing a water well are generally contaminated with earth materials and certain types of bacteria found living in soils. Throughout the well construction operation, some of these contaminants or bacteria may be introduced into the aquifer.

The bacteria and viruses picked up on drilling tools, pipes, and other materials are

**Table 18.5. Chlorine Compound Required to Produce a 50-mg/ℓ Solution in 100 ft (30.5 m) of Water-Filled Casing***

| Casing Diameter | | Volume 100 ft (30.5 m) | | 65% HTH, Perchloron, etc. (dry weight)† | | 25% Chloride of Lime (dry weight)† | | 5.25% Purex, Chlorox, etc. (sodium hypochlorite) (liquid measure) | |
|---|---|---|---|---|---|---|---|---|---|
| in | mm | gal | m³ | oz | g | oz | g | oz | ℓ |
| 2 | 51 | 16.3 | 0.06 | 0.2 | 5.7 | 0.5 | 14.2 | 2 | 0.06 |
| 4 | 102 | 65.3 | 0.25 | 0.7 | 19.8 | 2 | 56.7 | 9 | 0.3 |
| 6 | 152 | 147 | 0.56 | 2 | 56.7 | 4 | 113 | 20 | 0.6 |
| 8 | 203 | 261 | 0.99 | 3 | 85.1 | 7 | 198 | 34 | 1.0 |
| 10 | 254 | 408 | 1.5 | 4 | 113 | 11 | 312 | 56 | 1.7 |
| 12 | 305 | 588 | 2.2 | 6 | 170 | 16 | 454 | 80 | 2.4 |
| 16 | 406 | 1,045 | 4.0 | 11 | 312 | 28 | 794 | 128 | 3.8 |
| 20 | 508 | 1,632 | 6.2 | 17 | 482 | 43 | 1,219 | 214 | 6.4 |
| 24 | 610 | 2,350 | 8.9 | 24 | 680 | 63 | 1,786 | 298 | 8.7 |

Note: Liquid sodium hypochlorite in a 12-percent solution is often sold for use in water and wastewater treatment plants, and as a commercial bleach or for use in swimming pools. Utilizing a solution of this nature would call for a liquid (chemical) measure equal to one-half the volumes presented in column 5.

*EPA recommends a minimum concentration of 100 mg/ℓ available chlorine. To obtain this concentration, double the amounts indicated.

†Where a dry chemical is used, it should be mixed with water to form a chlorine solution before putting it into the well.

*(EPA, 1975c)*



commonly those living in the soil at the well site and are usually nonpathogenic. However, the bacteria used as an indicator of possible disease-producing bacteria may be among them. This indicator bacteria is known as coliform bacteria, and is taken as evidence that the water may contain disease-producing organisms that normally live in the intestinal tracts of man and warm-blooded animals. Identification of actual disease-producing micro-organisms is difficult, and the efficiency of any disinfection process is generally not measured by tests for the absence of pathogenic bacteria, but by tests for the number of coliform bacteria (EPA, 1978). The four major types of pathogenic organisms that can affect the safety of drinking water are bacteria, viruses, protozoa, and occasionally worm infections. Typhoid, cholera, and dysentery are caused by bacteria and protozoa. Diseases caused by viruses include infectious hepatitis and polio. Water from a well is considered bacterially safe to drink only when tests show that it contains no more than 1 coliform bacteria per 100 mℓ.

Coliform bacteria can also be introduced into the water system while installing a pump in the well, connecting the pump to the distribution system, and installing the various elements of the piping system itself. Bacterial contamination can occur any time that the well or piping system is opened for repair or maintenance, because opening any part of the system offers an opportunity for foreign matter to enter it. Therefore, disinfection following construction or repair is necessary.

### Disinfection Procedures

Use of a chlorine solution is the simplest and most effective way to disinfect or sterilize wells, pumps, storage tanks, or piping systems*. Chlorine is a powerful oxidizing disinfectant that kills bacteria on contact, although it cannot, at normal dosages, eliminate most viruses (White, 1972). On the other hand, short-wave ultraviolet light is effective in destroying viruses. The effectiveness of the chlorine procedure will depend on (Walker, 1978):

1. Chlorine concentration
2. Free-chlorine residuals
3. pH of the water
4. Retention time
5. Turbidity

The chlorine concentration must be high enough so that a free-chlorine residual remains several hours after treatment; that is, the chlorine demand has been satisfied and some extra chlorine is present after the initial contact period. High-pH waters require higher chlorine dosages than do low-pH waters to obtain the same level of disinfection, because the hypochlorous ions, which have the principal germicidal effect, are increasingly neutralized as the pH rises. Enough retention time must be allowed so that the chlorine can kill the bacteria. High turbidity tends to reduce the effectiveness of the chlorine treatment, but this condition is generally not a problem with groundwater.

Highly chlorinated water may be prepared by dissolving calcium hypochlorite, so-

*Chlorine is irritating to skin, eyes, and respiratory tract; wear self-contained breathing apparatus and eye protection when handling chlorine. Dry chlorine does not react with metals, but when moisture is present chlorine becomes strongly corrosive. It is a strong oxidizing agent that will react violently with hydrocarbons (grease and oil) and other organic compounds (turpentine, ethyl alcohol, glycerol, carbon tetrachloride, and charcoal). Do not mix chlorine and acid; large amounts of chlorine gas will be released.

dium hypochlorite, or gaseous chlorine in water. The calcium hypochlorite most commonly used in water well drilling is a white, granular material containing about 65 percent available chlorine by weight. In recent years, this material has also been marketed in tablet form under several trade names, including Pit-Tabs and HTH Tablets*. To distinguish this chemical from chlorinated lime or bleaching powder, it is commonly referred to as high-test calcium hypochlorite.

When dissolved in water, 1 lb (0.5 kg) of calcium hypochlorite with 65 percent available chlorine produces a solution that has the oxidizing power of 0.65 lb (0.3 kg) of chlorine gas dissolved in the same quantity of water. Putting it another way, 1.54 lb (0.7 kg) of calcium hypochlorite is equivalent to 1 lb (0.5 kg) of chlorine gas in a water solution.

The strength of chlorine solutions is usually expressed in milligrams of chlorine per liter of water. A solution of 10 mg/ℓ means a proportion of 10 lb (4.5 kg) of chlorine to one million lb (0.5 million kg) of water. Solution strengths of 50 to 200 mg/ℓ chlorine are used commonly for sterilizing wells and well construction materials. Table 18.6 gives the quantities of chlorine required to make 1,000 gal (3.8 $m^3$) of sterilizing solution of various concentrations for use in disinfecting wells and pumps.

**Table 18.6. Quantities of Chlorine Compounds Required to Produce Chlorine Concentrations of 50, 100, 500, and 1,000 mg/ℓ in 1,000 gal (3.8 $m^3$) of Water**

| Strength (mg/ℓ) | Sodium Hypochlorite | | | | | | | | Calcium Hypochlorite | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 3% | | 5% | | 10% | | 12½% | | 65% | |
| | gal | ℓ | gal | ℓ | gal | ℓ | gal | ℓ | lb | kg |
| 50 | 1.7 | 6.4 | 1.0 | 3.8 | 0.5 | 1.9 | 0.4 | 1.5 | 0.6 | 0.3 |
| 100 | 3.3 | 12.5 | 2.0 | 7.6 | 1.0 | 3.8 | 0.8 | 3.0 | 1.3 | 0.6 |
| 500 | 16.7 | 63.2 | 10.0 | 37.9 | 5.0 | 18.9 | 4.0 | 15.1 | 6.4 | 2.9 |
| 1,000 | 33.3 | 126.0 | 20.0 | 75.7 | 10.0 | 37.9 | 8.0 | 30.3 | 12.8 | 5.8 |

If more accurate numbers are required or different volumes or sterilant concentrations are used, the following equations apply:

Calcium Hypochlorite:

$$\text{Wt (lb)} = \text{water volume (gal)} \cdot 8.33 \cdot \frac{\text{required concentration (mg/ℓ)}}{\text{sterilant concentration (\%)}}$$

Sodium Hypochlorite:

$$\text{Volume (gal)} = \frac{\text{water volume (gal)} \cdot 8.33 \cdot \frac{\text{required concentration (mg/ℓ)}}{\text{sterilant concentration (\%)}}}{8.33}$$

Notes:
1. When using the above equations, both required and sterilant concentration should be in decimal form. For example: mg/ℓ of 1,000 = 0.001; percent available chlorine of 5.25% = 0.0525.
2. Mg/ℓ conversion from trade percentages may be determined by using the following equation:

   mg/ℓ = trade percent · 10,000

   Using the above, a 5.25% solution is equivalent to 52,500 mg/ℓ chlorine.

*Pit-Tabs are made by Columbia-Southern Chemical Corporation and HTH is made by Olin Mathieson.



Dry calcium hypochlorite is a fairly stable material when stored properly, although it does lose some of its available chlorine over time. When packaged properly and stored in a cool place, it will retain 90 percent of its chlorine content for 12 months after manufacture. If the chemical becomes moist, it is quite corrosive and loses chlorine more rapidly.

Sodium hypochlorite is available only in solution form, because this chemical compound is very unstable. Practically all laundry bleach solutions sold in retail stores are sodium hypochlorite dissolved in water. They are prepared by bubbling chlorine gas through a solution of caustic soda. The solution loses chlorine at a rate such that a 10-percent solution will be reduced to about half strength after 6 months, even though stored under the best conditions. Solutions more than 60 days old should not be counted upon to contain the full amount of available chlorine originally in solution.

Sodium hypochlorite solutions are made in several strengths by many different producers in various localities. The maximum is about 12½-percent available chlorine. Much more common are household laundry bleaches such as Chlorox* and Hilex* that contain 5 to 5.25 percent available chlorine.

Disinfecting solutions can also be prepared by bubbling chlorine gas through water. The chlorine dissolves in the water and forms a mixture of hypochlorous and hydrochloric acid. The pH of the water is reduced and this enhances the disinfecting action of the solution. Use of this procedure is generally confined to water treatment plants because chlorine gas is extremely dangerous to handle.

A solution containing 50 to 200 mg/ℓ available chlorine should be used for disinfecting wells and piping systems. To provide this concentration of chlorine in the well, a stronger solution should be introduced so that, after mixing with the water in the well, 50 to 200 mg/ℓ chlorine will result. All pump parts must be thoroughly cleaned before being placed in the well. Many domestic wells, however, are completed weeks or sometimes months before the pumps are installed and the well is put into service. In the intervening period, a 5- to 10-mg/ℓ free-chlorine residual should be maintained in the well.

Before final disinfection of a well, storage tank, or piping system, the structure should be cleaned thoroughly. Foreign substances such as sediment, soil, grease, joint dope, and scum may harbor and protect bacteria and should be removed.

Chlorine or any other disinfecting agent can destroy only the bacteria it contacts. To simply pour chlorine into a well is not enough to disinfect it completely. The water in the well must be agitated to mix the solution thoroughly. In addition, surfaces of all components above the water level must be flushed or washed down with the sterilizing solution.

Special steps are required to assure chlorination of the entire well bore. One practical scheme is to place dry calcium hypochlorite in a container made from a short length of perforated tubing, capped on both ends and fitted with an eye on one end for suspension on a cable. By lowering and raising the container throughout the full column of water in the well, the chemical will be distributed adequately. The same device may be lowered into a flowing well and moved up and down near the bottom of the well. The natural upward flow will then carry the chlorinated water to the surface. In other cases, a chlorine solution is mixed in a tank at the surface and then circulated in the well by the mud pump. Sometimes chlorine is placed intermittently at high concentrations in the well bore. Agitation by a surge plunger, air pump, or other means mixes the solution at the appropriate strength with the water in the well.

Duration of contact with the chlorine solution is another important factor in effective disinfection. After being agitated in the well, the chemical should be left for at least 4 hours and preferably longer to assure complete disinfection.

After the original well installation and any subsequent repairs, the pumping system, storage tanks, and piping also require disinfection. To do this, the disinfecting solution can be pumped from the well and into the tank and piping system. Steps should be taken to make certain that the chlorinated water is drawn into all tanks and pipes. Faucets, valves, and hydrants should be kept open until the odor of chlorine is detected. These should then be closed and the solution left in the storage and distribution system for 2 hours or more. Care should be taken to wet the entire inner surface of a pneumatic tank with the solution. Finally, it is imperative that all traces of the chlorine residue be thoroughly purged from the well system before placing it into service.

**Disinfection Byproducts**

The recent improvement in the ability of laboratories to measure small quantities of organic compounds in water has shown that certain byproducts such as trihalomethanes originate from the chlorine treatment process. Some of these byproducts may be hazardous to human health (Rook, 1974; Symons, 1976); however, the extent of this danger is still under study. Fortunately, most water from wells does not require continuous chlorine treatment and, except for the disinfection process described above, no chlorine needs to be added to the water. Exceptions do occur, however. Some treatment is usually advisable for shallow wells or wells located close to known sources of bacterial or chemical contamination. Another exception is when groundwater is obtained from limestone, fractured and jointed igneous and metamorphic rocks, and vesicular basalt; this water is not as safe as water filtered naturally through sand, sandstone, gravel, and clay.

**Bacteriological Analysis**

The effectiveness of disinfection should be checked after completing the work by testing water samples for the presence of coliform bacteria. The well must be pumped and the piping system flushed out thoroughly to remove all traces of chlorine before collecting water samples for testing. Samples should be collected in containers supplied by the laboratory and in accordance with laboratory instructions*.

At least ½ cup (118 m*l*) of water is required to check for the presence of coliform bacteria. In many states, sterile sample bottles are provided by health departments for taking samples. This sample bottle should never be rinsed prior to use. Some sample bottles may contain crystals of a chemical that adsorbs chlorine. The sampling procedure is outlined in Table 18.7. State agencies that provide water-sampling services are listed in Appendix 18.A.

Although rarely performed for domestic wells unless contamination is suspected, chemical analysis can be done to assure that the water does not have high concentrations of any toxic substances. This analysis will indicate whether the water must be treated before use. Even though the water may seem to be potable because no

*Samples can be taken from the well by pump, air-lift, bailer, or specific type of sampler method (thief, ball) if the plumbing has not been installed.

# APPENDIX E

## INSTRUCTIONS – WATER WELL SUMMARY SHEET
## To be Included in the Final well Completion Report

1. **PROJECT TITLE AND LOCATION** – Identify the type of ANP site or name of the ANA/ANP site and its location by District and Province.
2. **DATE OF REPORT –** The month and year that well was completed.
   2a. **CONTRACTOR NAME** – Provide the name of the prime contractor responsible for drilling the well.
3. **CONTRACT NO. –** Provide the AED contract number.
   3a. **ELEVATION** *(Top of Hole)* – This is the ground elevation at the well site.
4. **COORDINATES –** The coordinates can be in any one of the standard formats (e.g. lat/long, MGRS or UTM).
   4a. **TOTAL HOLE DEPTH –** The total hole depth should be in meters with an m (e.g. 120m).
5. **HOLE DIAMETER** – The diameter of the hole should be in millimeters with an mm.
   5a. **STATIC WATER LEVEL** (*Depth*) **–** This is the depth of water in the well after it has come to equilibrium without pumping. It should be reported in meters with an m.
6. **DRILLING METHOD** (*Rotary, Percussion, Other*) – The drilling method for the majority of the hole.
7. **CASING DIAMETER & LENGTH(S) –** The casing diameter should be in millimeters with an mm and the length in meters with an m. The setting of the casing should be provided (e.g. 150mm, 0-90m).
8. **SCREEN DIAMETER & DEPTHS –** The diameter of the screen in mm and the depths of the screen(s) in meters. If more space is required provide the data in REMARKS.
   8a. **SLOT SIZE –** Report in millimeters with an mm (e.g. 1mm). **CASING AND SCREEN MUST BE STEEL.**
9. **WELL DEVELOPMENT** *(Method*) – The method to develop the well (e.g. mechanical surging).
   10a. **SANITARY SEAL** (*Depth*) **–** The top and bottom depths in meters. Thickness must be at least 3 meters of bentonite..
10. **DEPTH OF FILTER PACK** – The depths from the ground surface to the top and bottom of the filter pack in meters (e.g. 46-57m). Must extend at least one meter above the top of screen.
    11b. **PUMP DEPTH –** Provide the depth from the ground surface to the intake of the pump in meters with an m.
11. **PUMPING TEST** (*Yes, No*)
    12a. **HOURS OF PUMPING** (*Pumping Test*) – Provide the longest continuous time of the pumping test(s).

12. **PUMPING WATER LEVEL** (*at Max. Drawdown*)—Provide the maximum depth to the water level in the well for the expected long-term pumping. This level is determined during the pumping test.
    13a. **FLOW RATE** (*Pumping Test*) **–** Provide the flow rate (Q) associated with the "PUMPING WATER LEVEL" of 13.
13. **AQUIFER MATERIALS** (*Unconsolidated, Porous Bedrock, Fractured Bedrock*)
14. **WATER QUALITY TESTED** (*Yes, No*)**—**This question is limited to an established water quality laboratory.
    14a. **TOTAL DISSOLVED SOLIDS –** This value is provided by a water-quality laboratory.
15. **COLIFORMS** (*Yes, No*), -- Are fecal or total coliforms present?
    15a **PUMP –** If information is available, provide the manufacturer and model so that the same pump could be replaced in the future.
16. **NAME OF PREPARER –** Provide name of preparer and supply additional information in the REMARKS section.
17. **REMARKS:** Provide any additional relevant information such as contact information, title and association of preparer, distinguishing features of the well and/or the site etc. Provide additional information such as screen lengths that will not fit in the space above.

# WATER WELL SUMMARY SHEET

1. **PROJECT TITLE AND LOCATION** ……………………………………………………………………………………………………………

2. **DATE OF COMPLETION**…………………2a. **CONTRACTOR NAME** ………………………………………………………………………..

3. **CONTRACT NO.**…………………………………………………………………………….3a. **ELEVATION** *(Top of Hole)*..........…………….

4. **COORDINATES** ………………………………………………………………………..................4a. **TOTAL HOLE DEPTH** (*m*) …………….

5. **HOLE DIAMETER** ……………………………………....5a. **STATIC WATER LEVEL** (*Non-Pumping Depth*) ……………….….………..

6. **DRILLING METHOD** (*Rotary, Percussion, Other*)…………………………………………………………………….....…………….

7. **CASING DIAMETER & LENGTH(S)** ……………………………………………………………………………………………………

8. **SCREEN DIAMETER & DEPTH(S)**……………………………………………………………8a. **SLOT SIZE**……………………………

9. **WELL DEVELOPMENT** (*Method*)…………………………………………9a. **SANITARY SEAL** (*Depth*)……………………...……….

10. **FILTER PACK** (*Yes, No*) …………..10a. **DEPTHS OF FILTER PACK** ……..…………10b. **PUMP DEPTH**……………..…………..

11. **PUMPING TEST** (*Yes, No*) …………………………………11a. **HOURS OF PUMPING** (*Pumping Test*)………………………........

12. **PUMPING WATER LEVEL** (*at Max. Drawdown*)…………………………12a. **FLOW RATE** (*Pumping Test*) ……………..………..

13. **AQUIFER MATERIALS** (*Unconsolidated, Porous Bedrock, Fractured Bedrock*)……………………………………………..…………

14. **WATER QUALITY TESTED** (*Yes, No*)………………….. 14a. **TOTAL DISSOLVED SOLIDS** ……………..……………………….……..

15. **COLIFORMS** (*Yes, No*)………………..15a. **PUMP** (*Manufacturer & Model*) ………………………………………………………..

16. **NAME OF PREPARER** ……………………………………………………………………………………………………………………

17. **REMARKS:** ……………………………………………………………………………………………………………………………..

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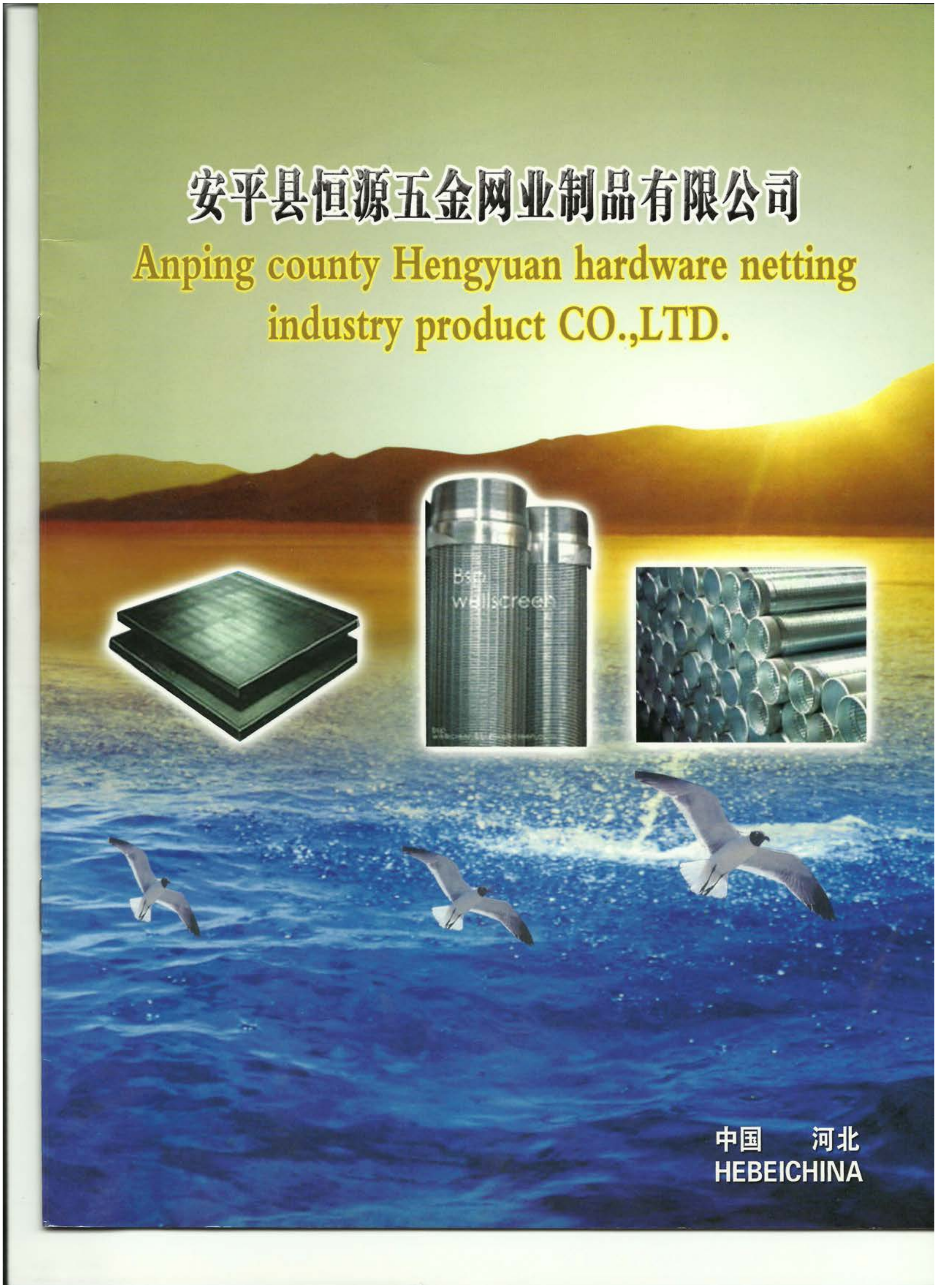
Note: *Measurements are metric.*

**Afghanistan Engineering District – North, US Army Corps of Engineers** **JUL 2012**

**Appendix F.**

# Well Screen and Bentonite Suppliers

USACE includes the following supplier catalogs for information purposes only.  USACE does not endorse, nor does it require use of the following suppliers.


安平县恒源五金网业制品有限公司
Anping county Hengyuan hardware netting industry product CO.,LTD.
中国 河北
HEBEICHINA

## 公司简介

安平县恒源五金网业制品有限公司位于著名的"丝网之乡"河北省安平县，公司设备先进，技术力量雄厚，是具有高新技术的丝网生产及深加工的专业公司。多年来，我们坚持信誉至上，质量第一的经营原则，让客户满意是我们最高的标准。本公司生产经营V型丝不锈钢滤水管、低碳钢绕丝滤水管、约翰逊筛管，各种矿筛网：筛篮、筛板、弧型筛、筛片，不锈钢网、护栏网、电焊网、钢板网、轧花网、菱形网、六角网、带式自动滤网等丝网产品及深加工制品,产品广泛用于打井、污水处理、石油、化工、建筑、交通等行业和领域。产品畅销全国各地，并远销非洲、中东及东南亚地区.

[Brief introduction]

Anping county Hengyuan hardware netting industry product CO,.LTD. is located in Anping county reputation of "Chinese hometown of wire mesh ". The company is equiped with advanced equipment and tremendous technical capability. It's a company which owns advanced technology and produces wire mesh and further processed products. For years, we have been sticking to the business principel of prestige thehighest quality–the first it's our highest standard to make the customers satisfied.Our company produce and sell as following :"V" shaped wire welded stainless steel screens, low carbon steel screens, Johnson Specialty screens,various kinds of orescreen meshes , stainless steel network,chain link fence ,welded wire mesh, expanded plate mesh series, bringing type automatic filter screen, crimped wire mesh, hexaogonal wire mesh,etc. The products are used in the trades,such as ore choosing, petroleum , chemical industry , electron , transportation , plastics , food , architecture , traffic,etc. Our products can be seen everywhere in China,as well as African countries, Middle East and the regions of Southeast Asia.

# Anping county Hengyuan hardware netting industry product CO.,LTD.

## 公司产品 Company products

### 过滤管 Strainers Pipe/ Water Well Screen

材料：302、304、304L、316、316L等不锈钢丝.

特点：不锈钢熔接式过滤管是由支撑条和筛条两部分构成。支撑条可以是圆丝也可以是三角形丝或梯形丝，筛条是三角形丝（v型丝），缝隙尺寸精确，过滤精度高；具有结构坚固，耐高温，耐腐蚀，机械性能好，使用寿命长，安全可靠等特点．可用于多种介质的过滤。

用途：滤水管是一种有孔眼的滤水器材。可与深井泵、潜水泵配套使用、也可以用于水处理设备，环境保护、海水转化为工业用水及生活用水的淡化处理、自来水的处理、水软化处理、石油化工业：石油产品的终端过滤及化工酸、碱液体的过滤、酒精等有机溶液的回收过滤．

Materials: 304 302 304L 316 316L stainless steel wire .

characteristics: The welded stainless steel water well screen is made up of rods and warp. The rod can be round wire ,triangular wire or trapezoid wire.The warp is triangular wire(V-shaped wire). Water well screens have a structure and high open area,as well as accurate slot dimension. In the same time , water well screen have heat-resisting, anti-corrosive, good machine capability, long life span,safety and reliability and so on characteristics. It can be used in many kinds of medium filtering.

Uses:The strainer is a kind of filtered water tubing with the perforation .it can use with the deep well pump, dive the water pump, also may use in the water-treating equipment, the environmental protection, the sea water transforms into the industrial water and life use water desalination treatment, running water treatment, water softening treatment, the petroleum industry: The petroleum product terminal filters and the chemical acid, the alkali liquid filters, the ethyl alcohol and so on the organic solution recycling filters.

# 安平县恒源五金网业制品有限公司

## V型丝不锈钢滤水管 "V"shaped wire welded stainless steel screens

### 产品性能

我们公司生产的V型丝全焊式梯形绕丝滤水管，是用V型绕丝和V型筋条（或圆型筋条）在每个交叉点处焊接而成。

"V" shaped ladder–like stainless/carbon steel screen is a perfect combination of V–shaped wire and V–shaped rod or round rod. The wire is welded onto the rod at each intersection point.

1、连续的缝隙大大增加了过水面积，因此与含水层接触更好。
2、V型剖面结构避免堵塞，确保流通顺畅。
3、连续的孔隙能长期有效使用。
4、梯形滤水管结构坚固，孔隙率高，缝隙尺寸精确。
5、梯形丝滤水管容易反冲洗，使用寿命长，安全可靠，综合成本低。

### Features of products

1. A continuous slot opening which significantly increases the available open area, thus providing greater access to the water bearing zone.
2. A "V" shaped profile wire which avoids clogging and ensures an uninterrupted flow.
3. A uniform and efficient well development due to the continuous slot opening.
4. Ladder–like wire welded screens have a strong structure and high open area, as well as accurate slot dimension.
5. Ladder–like wire welded screens have the features of easy backwashing, long life span, safety and reliability as well as low comprehensive cost.

### 产品特点

1、孔隙率较高的滤水管更适用于建造高效率的水、油、气井。
2、运行成本低　　孔隙率高的滤水管更有利于地下水的渗入，充沛的水量使得水位的降深减小，从而减少能量消耗。
3、减小泵的磨损　　在同等条件下，较高的孔隙率使得地下水在渗入滤水管时的速度较渗入其它过滤装置时的速度要慢的多，这样就避免沙子在较大的水压下进入滤水管，减小水泵磨损。
4、延长水井的寿命　　相对而言，地下水渗入孔隙滤高的滤水管更容易一些，水流速度低，延长水井的使用寿命。

### Features of products

1. Screens with high open area are more suitable for the construction of high–quality water wells, oil wells and gas wells.
2. Low cost operation Screens with high open area shall favor groundwater infiltration. Abundant water shall reduce the water level's down, thus to save energy consumption.
3. Reduce the abrasion of the pump Under the same condition, high open area can make the speed of groundwater's entering into the screen much more slower than any other filtration apparatus, which will avoid sand's entering into screen because of high pressure, thus reduce the abrasion of the pump.
4. Extend the life span of wells Comparatively, groundwater's entering into screen with higher open area is much easier than the entering into lower open area screen. The slow water flow shall extend the life span of wells.

# Anping county Hengyuan hardware netting industry product CO.,LTD.

## 基本规格 Basic specification for ladder–like screen

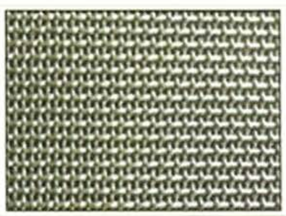
| 材质 Material | 型号 SIZE INCH | 外经 O.D (MM) | 缝隙 SLOT INCH | 长度 LENGH (M) | 可承受外力 COLLAPSE STRENGTH (PSI) | 拉申力 TENSIE WEIGT (TON) | 筛丝规格 宽*高 WRAP (MM) | 托条 RODS (MM) | 端头连接 End Connection |
|---|---|---|---|---|---|---|---|---|---|
| 304 304L 316 316L | 4 | 117 | 0.040 | 3–6 | 395 | 6 | 2.2*3.0 | 3.8MM/22 | 丝扣管头或直接管头 by welding or by threaded male/female couplin. |
| | 4 | 114.3 | 0.040 | 3–6 | 395 | 6 | 2.3*3.0 | 3.8MM/22 | |
| | 6 | 168.3 | 0.040 | 3–6 | 252 | 8 | 2.3*3.5 | 3.8MM/32 | |
| | 8 | 219.1 | 0.010 | 3–6 | 399 | 10.5 | 3.0*5.0 | 3.8MM/48 | |
| | 8 | 219.1 | 0.020 | 3–6 | 370 | 10.5 | 3.0*5.0 | 3.8MM/48 | |
| | 8 | 219.1 | 0.040 | 3–6 | 323 | 10.5 | 3.0*5.0 | 3.8MM/48 | |
| | 10 | 273.1 | 0.010 | 3–6 | 206 | 11 | 3.0*5.0 | 3.8MM/50 | |
| | 10 | 273.1 | 0.020 | 3–6 | 191 | 11 | 3.0*5.0 | 3.8MM/50 | |
| | 10 | 273.1 | 0.040 | 3–6 | 167 | 11 | 3.0*5.0 | 3.8MM/50 | |

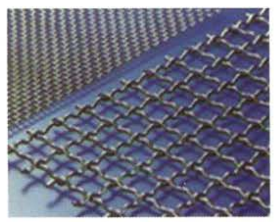
备注：数据仅供参考，我们能根据客户的需求生产。直径：80mm–900mm．缝隙：0.1mm–10mm
The data only to reference, we can design it as the client's request Diameter: 80mm–900mm.
Shot: 0.1mm–10mm

★连接方式：焊接和螺纹连接。
★标准长度：50mm–5850mm
★Styles of connection: by welding or by threaded male/female couplin.
★Standard length: 50mm–5850mm

## 轧花网 Crimped Mesh

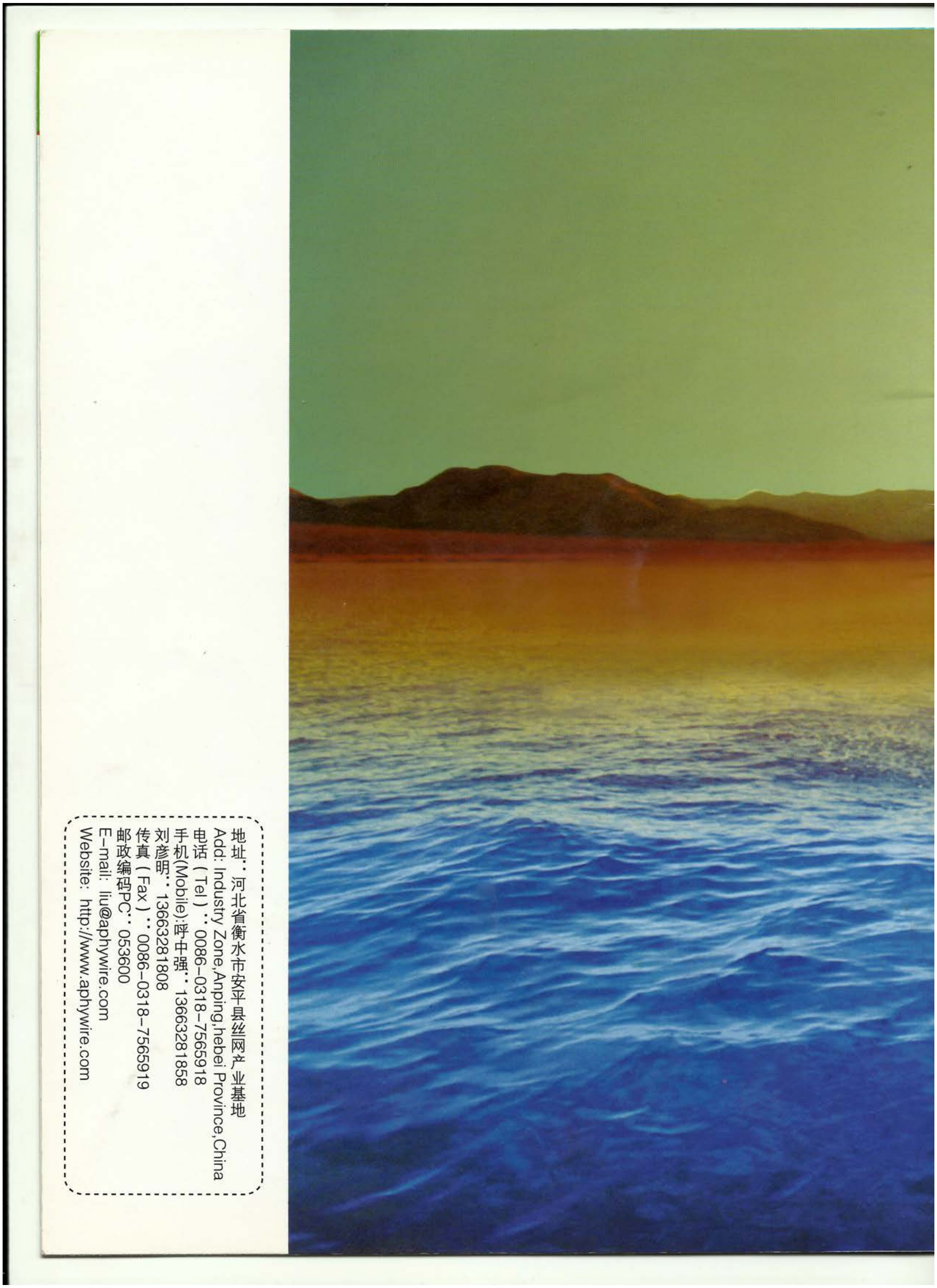
材料：302、304、304L、316、316L等不锈钢丝，也可以根据客户的要求订做。
编织及特点：平织、斜织、竹花编织、密纹编织而成，具有耐酸、耐碱、耐温、耐磨等性能。
用途：用于矿业、石油、化工、食品、医药、机械制造等行业。
Materials: 304 302 304L 316 316L stainless steel wire ,can be made according to the customers' requirement.
Weaving and characteristics : plain weave . twilled weave, dutch weave, stainless ssteel wire mesh is heat–resisting, acid–resisting, wear–resisting, corrosion–resisting.
Usage: used in petroleum, chemical industry, mine, environment protection, food industry, medicine, machine making, etc.





## 护栏网 Chain link fence

用途：用于公路、铁路、飞机场、住宅小区、港口码头、花园、饲养、畜牧等的护栏防护
产品特点：防腐、防老化、抗晒、耐候等特点。防腐形式有电镀、热镀、喷塑、浸塑.
General Use: Chain link fence mainly serves in protection of road, railway, airport, residence, port, garden and farms.
Product characteristic: The anticorrosion, anti– exposes to the sun, Anti– aging characteristic and so on. The anticorrosion form has the galvanization, the heat degree, spurts models, soaks models.


地址：河北省衡水市安平县丝网产业基地
Add: Industry Zone,Anping,hebei Province,China
电话（Tel）：0086-0318-7565918
手机(Mobile):呼中强：13663281858
刘彦明：13663281808
传真（Fax）：0086-0318-7565919
邮政编码PC：053600
E-mail: liu@aphywire.com
Website: http://www.aphywire.com

## C) Quality Control

We have serious quality control system, and have gain the ISO9001:2000 Quality Certification

CIC

Certificate of Quality Management System

**Registration Number:** 4002Q10367R2S

This is to certify that

HEBEI HENGYUAN HARDWARE NETTING INDUSTRY PRODUCTS CO.,LTD.

East Developing Zone Anping County,Hebei Province. 053600

**has been assessed and registered against the following quality management standard:**

ISO9001: 2000

CERTIFICATION SCOPE:

Design and Production Manufacturing of Melting Filter Elements,Filter Cloth Packs,Disc Filters and other Industrial Filter Elements

**Date: July 04,2008**
**Valid Until: July 03,2011**

**Signed and issued by:**

CNAS
MANAGEMENT SYSTEM
CNAS C040-Q

IAF

CCIC CONFORMITY ASSESSMENT SERVICES CO.,LTD.

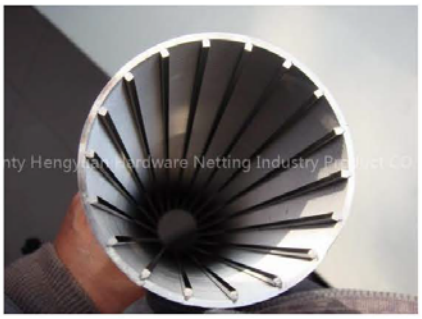
**Johnson Well Screen**

# A) Introduction

### 1. Materials: 304 302 304L 316 316L stainless steel wire

**Characteristics:** The welded stainless steel water well screen is made up of rods and warp. The rod can be round wire, triangular wire or trapezoid wire. The warp is triangular wire (V-shaped wire). Water well screens have a structure and high open area, as well as accurate slot dimension.

At the same time, water well screen have heat - resisting, anti-corrosive, good machine capability, long time span, safety and reliability and so on. It can be used in many kinds of medium filtering.




"V"shaped wire welded stainless steel screens

### 2. Features of products

1. A continuous slot opening which significantly increases the available open area, thus providing greater access to the water bearign zone.

2. A "v" shaped profile wire which avoids clogging and ensures a uninterrupted flow.

3. A uniform and efficient well development due to the continuous slot opening.

4. Ladder-like wire welded screens have a strong structure and high open area.

5.Ladder-like wire welded screens have the features of easy backwashing ,long life span, safety and reliability as well as low comprehensive cost.



### 3. Advantages of products

1. Screens with high open area are more suitable for the construction of high quality water wells oil wells and gas wells

2. Low cost operation Screens with high open area shall favor groundwater infiltration. Abundant water shall reduce the water level's down, thus to save energy consumption.

3. Reduce the abrasion of the pump under the same condition, high open area can make the speed of groundwater's entering into the screen much slower than any other filtration apparatus, which will avoid sand's entering into screen because of high pressure, thus reduce the abrasion of pump.

4. Extend the life span of wells comparatively; groundwater's entering into screen with higher open area is much easier than the entering into lower open area screen. The slow water flow shall extend the life span of wells.

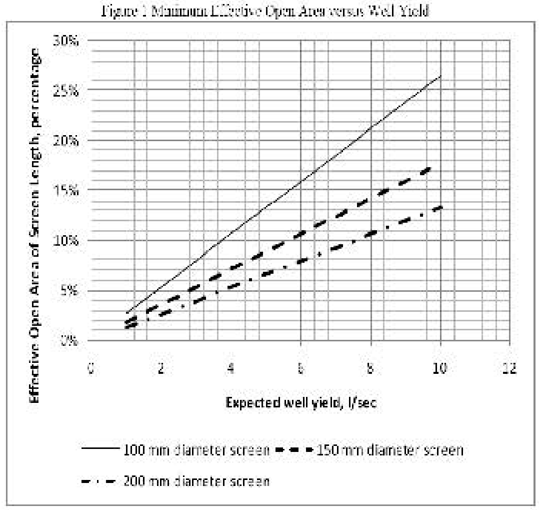
### Effective open area for permanent Stainless Steel screen

The permanent stainless steel screen is said to be 8 inch (200 mm) diameter with opening slot size = 1 mm. The percentage of open area for this standard screen is 25%.

| Nominal Well Screen Diameter | Screen Slot Size | | Steel Continuous Slot | | PVC Continuous Slot | | PVC Slotted Pipe | |
|---|---|---|---|---|---|---|---|---|
| mm | No | mm | cm2/m | % | cm2/m | % | cm2/m | % |
| 100 | 20 | 0.508 | 931 | 25 | - | - | - | - |
| 100 | 60 | 1.524 | 1,905 | 52 | 1,100 | 30 | 381 | 11 |
| 150 | 30 | 0.762 | 1,693 | 25 | 1,206 | 18 | 550 | 8 |
| 150 | 60 | 1.524 | 2,857 | 41 | 1,968 | 29 | 995 | 14 |
| 150 | 95 | 2.413 | 3,492 | 51 | - | - | - | - |
| 200 | 30 | 0.762 | 1,629 | 16 | - | - | - | - |
| 200 | 60 | 1.524 | 2,857 | 28 | - | - | - | - |
| 200 | 95 | 2.413 | 3,851 | 38 | - | - | - | - |
| 200 | 125 | 3.175 | 4,529 | 45 | - | - | - | - |

The below equations was performed accordance with the equations presented in **Ground Water and Wells** (Second Edition) by Principal Author Fletcher G. Driscoll (published by Johnson Filtration Systems Inc., St. Paul, Minnesota 55112), page 451.

Figure 1 Minimum Effective Open Area versus Well Yield




**Effective Open Area Calculation:**

According to screen design and well design:

Number of slot per each meter length of screen: 250

Thickness of slots: 1 mm

Total Area of slots per each meter of screen pipe:

$2 \times 3.14 \times 10 \times 25 = 1570$ cm2

Surface area of one meter stainless steel slotted

Screen = 6280 cm2

$$\%\ open\ area\ = \frac{\text{slot size}}{\text{slot size} + \text{wire width}} \times 100$$

$$\%\ open\ area\ = \frac{1}{1 + 2.9} \times 100\ =\ 25\%$$

Example of joining two branch of screen

## B) Basic Specification for Screens

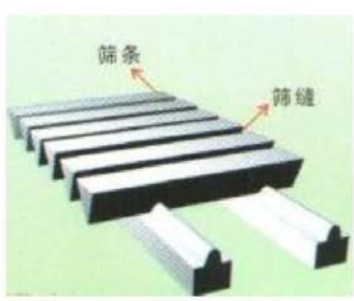
| SIZE (INCH) | O.D (MM) | SLOT (INCH) | LENGTH (M) | COLLAPSE STRENGTH (PSI) | TENSILE WEIGHT (TON) | WRAP（thick*deep）(MM) | RODS (MM) |
|---|---|---|---|---|---|---|---|
| 4 | 117 | 0.040 | 3-6 | 395 | 6 | 2.2*3.0 | 3.8MM/22 |
| 4 | 114.3 | 0.040 | 3-6 | 395 | 6 | 2.3*3.0 | 3.8MM/22 |
| 6 | 168.3 | 0.040 | 3-6 | 252 | 8 | 2.3*3.5 | 3.8MM/32 |
| 8 | 219.1 | 0.010 | 3-6 | 399 | 10.5 | 3.0*5.0 | 3.8MM/48 |
| 8 | 219.1 | 0.020 | 3-6 | 370 | 10.5 | 3.0*5.0 | 3.8MM/48 |
| 8 | 219.1 | 0.040 | 3-6 | 323 | 10.5 | 3.0*5.0 | 3.8MM/48 |
| 10 | 273.1 | 0.010 | 3-6 | 206 | 11 | 3.0*5.0 | 3.8MM/50 |
| 10 | 273.1 | 0.020 | 3-6 | 191 | 11 | 3.0*5.0 | 3.8MM/50 |
| 10 | 273.1 | 0.040 | 3-6 | 167 | 11 | 3.0*5.0 | 3.8MM/50 |

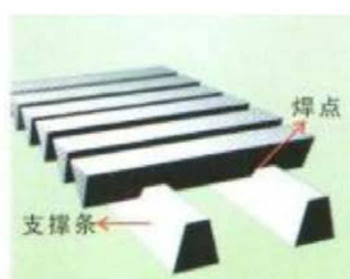
The data for reference only and can design with client's request.

Diamter: 80mm-900mm, slot of screen size: 0.1mm-10mm

Styles of connection: by welding or by threaded male /female coupling.

Standard length: 50mm-5850mm



## D) Detail Information for Johnson Stainless Steel pipes for Referenced Task Order Well

**Material type:** Stainless Steel 304

**Nominal size:** 8 Inches

**OD:** 219.1 mm

**Length:** 2.0 and 4.0 meter

**Slot Opening Size:** 1.0 mm

**KARAKAYA**
**Bentonit Sanayi ve Ticaret A.Ş.**
**Büro :** Necatibey Cad. Sezenler Sk No:1-12 Ankara Tel: (312) 2297626 Fax : (312) 2297872
**Fabrika :** Esenboğa yolu 24 Km Ankara Tel: (312) 3980145 Fax: (312) 3980146
**http** : //www.karakaya.com.tr **e.mail** : kkaya@ tr.net

# BENTONITE TEST CERTIFICATE

**DATE: 18/01/2010**

1. **DESCRIPTION OF SAMPLE** : NON TREATED BENTONITE
   **GTİP** :2508

**ORIGIN**
Reşadiye [X] Çankırı [ ] Any other [ ]

**SAMPLED FROM**
Pit [ ] Stock Area [ ] Production [X] Delivery [ ]

If Delivery , name :

2. EXPERIMENTS

**A-) FILTRATE VOLUME** ml [12,1]

**B-) VISCOSITY** (Direct Indicating Viscometer)

Weight of Bentonite added in 350 ml distilled water, during preparation of suspension

22,5gr (% 6,43) [ ] 25gr(%7,15) [X]

a-)Dial reading at 600 r / min. [36]

b-) Dial reading at 300 r / min. [22]

**C-) CALCULATION**

a-) Plastic Viscosity PV =600 r / min - 300 r / min. **( 36 ) – ( 22 ) =** [14]

b-) Yield point (YP ) = 300 r / min –Pv ( **22** ) – ( **14** ) = [8]

c-) YP / PV Yield Point / Plastic viscosity **( 8 ) / (14** ) = [0,57]

| EXPERIMENTIST | COMMANDS |
|---|---|
| Bünyamin ERTEK<br>Mining Engineer. | Meets the Non treated Bentonite Standards of ISO 13500 and **API 13 A Section 10.** |

| **Bentonite A.P.I** | |
|---|---|
| Analysis report of Bentonite A.P.I | |
| Consentration | 22.5 g/350 cc |
| 600 RPM | 30-32 |
| 300 RPM | 23-25 |
| PV | 7-9 |
| YP | 16-18 |
| YP/PV | 2-3 |
| Filter Loss | 15 ml Max. |
| Moisture | 10 % W Max. |
| Residue on 200 Mesh Wet Screen | 1 % W |
| | |
| **Bentonite O.C.M.A** | |
| Analysis report of Bentonite O.C.M.A | |
| Yeild Point | 20 m3 / T |
| Filter Loss | 15 ml Max. |
| Moisture | 10 % W Max. |
| Residue on 200 Mesh Wet Screen | 3 % W Max |
| Residue on 200 Mesh Wet Screen | 1 % W Max. |
| | |
| **Bentonite For Foundry Uses** | |
| Phisical Analysis report of Bentonite For Foundry Uses | |
| Montmoriloite | 70 % Min. |
| Gellation Factor | 20 % Min. |
| Swelling Factor | 30 ml / 2gr Min. |
| Green Compresive Strengh | 4.5-5.5 gr/cm2 |
| Sintering Point | 1100 c Min. |
| | |
| **Bentonite For Pelleting** | |
| Phisical Analysis report of Bentonite For Pelleting | |
| Plat Test (Wet Absorbation) | 500-700 % W |
| Moisture | 5 % W Max. |
| Residue on 45 Mic. | 5 % W Max. |
| Iron Content (FeO) | 2 % W Max. |

# KARAKAYA Bentonit Sanayi ve Ticaret A.Ş.

## CERTIFICATE OF ANALYSIS

**Producer** : Karakaya Bentonite Manufacture & Trade Co.
**Commodity** : Natural, non-treated Na - Bentonite

---

## DESCRIPTION

The natural bentonite, is pure, natural sodium based nontreated one, contains 90 % of Montmorillonite, has a high swelling capacity, conforms to API 13 A Section – 10 nontreated Bentonite ,TS EN ISO 13500 and TS 977 Type – 2 bentonite's specification. In water suspansion the natural bentonite is dispersed not flocculate. The product has the certificate of conformance to TS 977, given by Turkish Standards Institution.

Samples have been prepared according to the International Standards from the stocks at the premises of Karakaya Co.. Tests have been carried out at the quality control laboratory of Karakaya Co. and the following results were obtained.

| **Physical Properties** | | |
|---|---|---|
| | API 13 A **section 10** and TS EN ISO 13500 STANDARTS for **NON-TREATED BENTONITE** | **TEST RESULTS** |
| Moisture ( % ) | 12.5 max | 8 |
| SieveAnalysis ( 200 mesh ) | 4 max | 1,01 |
| Disperse Plastic Viscosity ( PV ) | 10 min | 12,7 |
| Viscosity point<br>( Yield Point/plastic viscosity ) | 1,5 max | 0,4 |
| Disperse Filtration volume | 12.5 max | 11,8 |
| | | |
| | | |

**Chemical Analyis**

| | |
|---|---|
| $SiO_2$ | = 61.28 % |
| $Al_2O_3$ | = 17.79 % |
| $Fe_2O_3$ | = 3,01 % |
| CaO | = 4,54 % |
| $Na_2O$ | = 2.70 % |
| MgO | = 2.10 % |
| K2O | = 1.24 % |

Bunyamin ERTEK
Mining Engineer