DEWATERING
Revised Oct 98

1. Uncontrolled or improperly controlled groundwater can, by hydrostatic pressure and seepage, cause piping, heave, or reduction in the stability of excavation slopes or foundation soils so as to make them unsuitable for supporting the structure. For these reasons, subsurface construction is not permitted without appropriate control of the groundwater and hydrostatic pressure. Proper control of groundwater can facilitate construction of subsurface structures founded in, or underlain by, pervious soil strata below the water table. This is accomplished by intercepting seepage that would otherwise emerge from the slopes or bottom of an excavation. The result is an increase in the stability of excavated slopes and prevention of the loss of material from the slopes or bottom of the excavation and from the foundation of the flood control structure. The hydrostatic pressure at the bottom of the excavation should be determined as described in the topic UNDERSEEPAGE.

2. Considerations. The location of the excavation, its size, depth, and configuration, such as open cut, shaft, or tunnel, as well as the type of soil to be excavated are important considerations in the selection and design of a dewatering system. For most granular soils, the groundwater table during construction must be maintained at least 2 to 3 feet below the slopes and bottom of an excavation in order to ensure dry working conditions. It may need to be maintained at lower depths for silts (5 to 10 feet below subgrade) to prevent water from pumping to the surface through capillary action to prevent wet and spongy conditions in the excavation.

3. Groundwater control methods. Methods for controlling groundwater may be divided into three categories:

3.1. Interception and removal of groundwater from the site by pumping from wells, wellpoints, or drains. This type of control must include consideration of a filter to prevent migration of fines and possible development of piping in the soil being drained.

3.2. Reduction of hydrostatic pressure beneath the bottom of an excavation.

3.3 Isolation of the excavation from the inflow of groundwater by a sheet-pile cutoff, grout curtain, slurry cutoff wall, or by ground freezing.

4. Guidance. Design and construction of the dewatering system should conform to TM 5-818-5/AFM 88-S, Chap 6/NAVFAC P -418.

5. Dewatering or Relief Wells Design. The following clarifies only requirements specific for relief and dewatering wells in the critical areas of flood control projects constructed by the Corps of Engineers, Kansas City District. Dewatering or relief well general design and installation should conform to EM 1110-2-1914, “Design, Construction, and Maintenance of Relief Wells”.

5.1 General. Relief or dewatering wells consist of a drilled hole to facilitate the installation; a screen or slotted pipe section to allow entrance of ground water; a bottom plate; a filter pack to prevent entrance and ultimate loss of foundation material; a riser to conduct the water to the ground surface; a check valve to allow escape of water and prevent backflooding and entrance of foreign material; an annular seal to prevent recharge of the formation by surface water; and a cover and some type of barricade protection to prevent vandalism and damage to the top of the well by maintenance crews, livestock, etc. Figure 1 shows a typical relief well installation. The hole is drilled large enough to provide a minimum thickness of 4 to 6 in for a filer pack, depending on the gradation of the filter material as subsequently described. The hole is also typically overdrilled in depth to provide for settlement of cuttings and initial placements of filter material that may be segregated. The amount of overdrilling required is variable depending upon the size of tremie pipe used for filter placement, the total depth of the well, the types of aquifer materials encountered, and most importantly on the tendency of the selected filter material to segregate. The backfill indicated as sand in Figure 1 normally consists of concrete sand or otherwise excess filter material. Its only function is to fill the annular space around the riser pipe to prevent collapse of the boring. The backfill indicated as concrete in Figure 1 may also consist of cement grout or cement-bentonite grout Its purpose is to form a seal to prevent inflow of surface water from rains and from flooding.

5.1.1. The well diameter must be large enough to conduct the maximum anticipated flow to the ground surface and facilitate testing and servicing of the well after installation. Head loss in the well should also be taken into consideration in selecting a well diameter.

5.1.2. Generally, a pilot hole should be made at each relief well location, with samples taken at 5 foot intervals as a minimum. Gradation tests should be performed on representative samples using a wet-wash through the #200 sieve after getting an initial dry sample weight. The gradation testing should be submitted to the COE for review as part of the well design. A gradation test form can be obtained from the COE if needed. The design should be based on the finest gradation of the foundation materials within a selected screen interval, excluding zones of unusually fine materials where blank screen sections should be provided. If pilot holes indicate the foundation consists of strata with different grain size bands, different filter gradations may be designed for each band.

5.1.3. Wells screens and riser.

5.1.3.1. Materials. Commercially available well screens and riser pipes are fabricated from a variety of materials such as black iron, galvanized iron, stainless steel, brass, bronze, fiberglass, polyvinyl chloride (PVC), and other materials. Stainless steel is a durable, very stable material in most environments and is the preferred material for wells. Low-carbon or other-type steel may be more economical; however it has no corrosion resistance. Brass and bronze are extremely expensive and are not completely stable in some acid environments. Fiberglass is a stable material; however its durability is relatively poor. PVC appears to be completely stable in most environments, and it is easy to handle and install; however it is a relatively weak material and easily damaged. Ferrous and nonferrous metals should never be placed in direct contact with each other, such as the case of a brass screen and a steel riser; the direct contact of these dissimilar metals may induce electrolysis and a resultant deterioration of the material. Generally, the choice of well screen material will depend on three factors: (a) water quality, (b) potential presence of iron bacteria, and (c) strength requirements. A water quality analysis will determine the chemical nature of the ground water. The strength of the well screen is usually not a major factor when commercial well screens designed for deeper well installations are employed. The screen sections should be able to withstand maximum compression and tensile forces during installation operations as well as horizontal forces which may develop during installation and possibly later because of lateral earth movements.

5.1.3.2. Screen Slot. The size of the individual openings in a well screen is dictated by the grain size of the filter. The openings should be as wide as possible, yet sufficiently small to minimize entrance of filter materials. In general, the slot width (or hole diameter) of the screen should be equal to or less than the 50 percent size of the filter. Use of the 10 to 20 percent finer by weight size criterion for screen slot size is preferred for use with uniformly-graded filters. Criteria for selection of screen opening size are presented subsequently. The anticipated maximum flow of the well dictates both the minimum total open-slot area of the screen (the spacing and length of slots) and the minimum diameter of the well. The open area of a well screen should be sufficiently large to maintain a low entrance velocity of less than 0.1 ft per second (fps) at the design flow. Wire-wrapped screen designs have the most open area and are the best for permanent relief wells. Sawcut slotted pipe and louvered screens have a much lower open area but may be suitable for temporary dewatering wells.

5.1.4. Filter. The filter should consist of natural material made up of hard durable rounded siliceous particles. It should contain no detrimental quantities of organic matter or soft, friable, thin, or elongated particles. Crushed carbonate aggregates should be avoided because they tend to break down with a loss in permeability. Furthermore, they will tend to dissolve if the wells require future acid treatment as part of the routine well rehabilitation. Each filter gradation must meet the permeability criterion that the 15 percent size of the filter should be more than three to five times the 15 percent size of foundation sands. Either well graded or uniform filter materials may be used. A uniform filter material has a coefficient of uniformity, C_u, of less than 2.5 where C_u is defined as:

$$C_u = D_{60}/D_{10}$$

where: D_{60} = grain size at which 60 percent by weight is finer
D_{10} = grain size at which 10 percent by weight is finer

5.1.4.1. The C_u of well-graded filter materials should be greater than 2.5 and less than 6 to minimize segregation. The grain sizes should be reasonably well distributed over the specified range with no sizes missing. Well-graded filters should have an annular thickness of 6 to 8 in. Uniformly graded filters are preferred because they permit a lesser annular thickness of filter (4 to

6 in.), are not subject to segregation, reduce the needed amount of overdrilling, and reduce development time.

5.1.4.2. To prevent infiltration of the aquifer materials into the filter and the filter materials into the well, without excessive head losses, filters should meet the following criteria:

a. Screen-filter criteria

Slot or screen openings $\leq$ minimum filter D_{50}

b. Filter-aquifer criteria, as follows:

$$\frac{\text{Max } filter\ D_{50}}{\text{Min } aquifer\ D_{85}} \leq 5; \quad \frac{\text{Max } filter\ D_{50}}{\text{Min } aquifer\ D_{50}} \leq 25 \quad \frac{\text{Max } filter\ D_{15}}{\text{Min } aquifer\ D_{15}} \geq 2 - 5$$

5.2 Dewatering or relief well Installation.

5.2.1. Borehole drilling. An open boring of sufficient size and depth is necessary to facilitate the installation of a well. The hole should be vertical so that the screen and riser may be installed straight and plumb. As previously discussed, the hole is drilled large enough to provide a minimum thickness of 4 to 6 in. depending on the gradation of the filter material. The methods of providing an open boring in the ground are numerous; however not all are acceptable for the installation of permanent relief wells, and those considered acceptable are discussed in the following sections.

5.2.1.1. Standard Rotary Method. One method of drilling for well installation which has gained popularity in the well drilling industry is standard rotary drilling using a biodegradable, organic drilling fluid additive. No bentonitic clays are used in the drilling fluid. A rotary-type drill rig of sufficient hoisting and torque capacity is required. The cutter or drill bit can be of either drag or roller design. The drill pipe should be as large as practicable to increase the volume of fluid at the drill bit and, consequently, the velocity of the fluid returning up the open hole. The breakdown of the drilling fluid leaves a small amount of slimy ash which, unavoidably, is mixed into the filter material; however a large percentage of this ash is removed during development of the well.

5.2.1.2. Reverse-Rotary Method. This method is generally considered to provide the most acceptable drill hole and should be used whenever possible for the installation of relief or dewatering wells. In the reverse-rotary method, the hole for the well is made by rotary drilling, using a similar cutting process as employed in standard rotary drilling except the drilling fluid is pulled up through the drill pipe by vacuum and the drilling fluid reenters the top of the open boring by gravity. Soil from the drilling is removed from the hole by the flow of drilling fluid circulating from the ground surface down the hole and back up the hollow drill stem from the bit.

Since the cross-sectional area of the boring is many times larger than that of the drill pipe, the slow downward velocity of the fluid acting against the open boring does not erode the walls. The drilling fluid consists of water and, unavoidably, a small amount of the finer fraction of the natural material being drilled. A high velocity is attained with the fluid returning up through the drill pipe, thus eliminating the need for a high viscosity. The drill water is circulated by a centrifugal or jet-eductor pump that pumps the flow from the drill stem into a sump pit. Portable sumps are recommended to minimize problems with excavating in the critical zones. As the hole is advanced, the soil particles settle out in the sump, and the drilling fluid flows back into the drill hole. The sides of the drill hole are stabilized by seepage forces acting against a thin film of fine-grained soil that forms on the wall of the hole. No bentonitic drilling mud should be used because of gelling in the filter and aquifer adjacent to the well. If the hole is drilled in clean sands, some silt soil may need to be added to the drilling water to attain the desired degree of muddiness (approximately 3,000 ppm). A biodegradable organic drilling fluid additive may also be added to the drilling water to reduce water loss. Any rotary-type drill rig large enough to handle the load and having sufficient torque capability can be adapted to circulate water through an eductor to create a vacuum on the drill pipe. Drill pipe and hoses should be of a constant inside diameter throughout the system to assure that material entering the system can be circulated completely through it. In alluvial deposits, a drag-type bit similar to the cutter head for a dredge is sufficient. Roller-type bits are commercially available for use in consolidated deposits. It is necessary to maintain an excess hydrostatic pressure on the drill hole to stabilize the walls. In most materials, a minimum excess head of 7 ft. is required and greater is desirable. When the static water level is very near the ground surface or artesian conditions prevail, it may be necessary to elevate the drilling rig on temporary berms. Some success has been experienced by lowering the water level with well points, but if the pressure is derived from a deeper, artesian source, it is necessary to lower the pressure in the aquifer with deep wells. Since the formation in which a well is installed consists predominately of granular material, the loss of water into the formation presents a problem during drilling. An almost unlimited supply of water can be necessary to maintain a completely filled, open boring. A large sump is required to supply adequate water. During the drilling, all cuttings from the boring are deposited in the sump and must be provided for. A sump three times the anticipated volume of the completed boring is adequate, if it can be kept filled with water from another source. An instantaneous loss of water resulting in loss of excess head can cause failure of the boring walls. Often, if the rotation of the drill bit is stopped, the water loss is greatly reduced. The boring must be kept full of water until the well screen, riser, and filter are installed.

5.2.2. Disinfection. Before drilling begins, all tools, rods, bits, and pumps should be thoroughly washed with a chlorine solution to kill any bacteria remaining from previous well installations. Water used in the drilling process and filter materials should also be treated with a chlorine solution (Driscoll 1986). The strength of the chlorine solution should not be less than 100 ppm.

5.2.3. Installation of Well Screen and Riser Pipes. Once the boring is completed and the tools withdrawn, the boring should be sounded to assure an open hole to the proper depth. The well screen and riser pipe can be fabricated at the factory in varying lengths. The contractor will determine these lengths based on the capacity of his equipment. The bottom joint of the well screen should be fitted with a cap or plug to seal the bottom of the screen. The lengths of screen are connected together as they are lowered into the hole. Each length must be measured to determine its total made-up length, and the bottom of the screen should be set at the designed depth, or as field conditions require. The method of connecting the lengths of screen and riser vary: metal screen and riser have threaded or welded joints; field-welded joints should be made by a qualified welder. Each joint should be made up securely to prevent separation of the well during installation and servicing activities. Each joint should be kept as straight as possible to facilitate ease of servicing and testing. The riser and screen sections of the well should be centered in the drill hole by means of appropriate centering devices to facilitate a continuous filter around the well screen. If materials appreciably finer than anticipated in design are encountered, design personnel should be notified. In such cases, it may be necessary to replace portions of the screen by a solid pipe or blank screen to prevent piping of foundation materials into the well. Immediately after installation of the well screen and riser, the total inside depth should be sounded. The exact inside depth of the well must be known to prevent damage during development and servicing of the well.

5.2.4. Filter Placement. Caution in proper design, control of manufacture, and handling of filter materials at the job site can be completely negated by improper placement of the filter material in the well. Acceptable construction of wells demands that the filter be placed without segregation because widely graded filters when placed in increments tend to segregate as they pass through water, with coarse particles falling faster than fine particles. A tremie should be used to maintain a continuous flow of material and thus minimize segregation during placement. The tremie pipe should be at least 2 in. in diameter, be perforated with slots 1/16 to 3/32 in. wide and about 6 in. long, and have flush thread joints. The slots allow the filter material to become saturated, thereby breaking the surface tension and preventing "bulking" of the filter in the tremie. One or two slots per linear foot of tremie is generally sufficient. To avoid contamination by iron bacteria, the filter should be washed through the tremie pipe using a 100-ppm chlorine solution. The tremie pipe is lowered to the bottom of the open drill hole, outside the well screen and riser pipe. The presence of centering devices will interfere with the proper use of the tremie by preventing uniform filling to some extent. The use of dual diametrically opposed tremie pipes helps ensure more uniform placement. After the tremie pipe or pipes have been lowered to the bottom of the hole, they should be filled with filter material and then slowly raised to keep them full of filter material at all times. Extending the filter material at least 2 ft above the top of the screen will compensate for settlement during well development. The level of drilling fluid or water in a reverse-rotary drilled hole must be maintained at least 7 ft above the natural ground-water level until all the filter material is placed. If a casing is used, it should be pulled as the filter material is placed, and the bottom of the casing kept 2 to 10 ft below the top of the filter material.

5.3. Development. Development procedures include both chemical and mechanical processes. Development of a well should be accomplished as soon after the hole has been drilled as practicable. Delay in doing this procedure may prevent a well being developed to the efficiency assumed in design.

5.3.1. Chemical Development. Chemical development is applied usually in the case where special drilling fluids are utilized and chemicals are injected into the well to aid in the breakdown of the residual drilling fluid in the filter. The chemicals should be of a type and concentration recommended by the manufacturer of the drilling fluid. They should be placed starting at the bottom of the well and dispersed throughout the entire screen length by slowly raising and lowering the injection pipe. After the chemicals have been dispersed, the well should be pumped and the effluent checked to ensure that the drilling fluid has completely broken down.

5.3.2. Mechanical Development. The purpose of mechanical development is to remove any film of silt and clay from the walls of the drilled hole and to remove fine material from the filter to permit an easy flow of water into the well. The effect of proper development is an increase in the effective size of the well, a reduction of entrance losses into the well, and an increase in the efficiency of the well. Many factors, including but not limited to development methods, well design, and filter installation, affect the time it takes to fully develop a well. Basically there are three methods used in development as discussed below.

5.3.2.1. Water Jetting. A water jet, consisting of a series of small nozzles at the end of a pipe, lowered into the well screen, is very effective in developing the continuous slot-type, wire-wrapped screens. Water is pumped down and out through the nozzles at a high velocity. Nozzles are directed toward the screen slots in small concentrated areas. The water jet equipment can be fabricated in local welding shops. The size and number of nozzles must be consistent with the size and length of the pipe through which the water is pumped to ensure a high-pressure and high-velocity jetting action. This method requires a high-pressure, relatively high-volume water pump. The lowest effective nozzle velocity for water jetting is about 100 fps. Better results are obtained with nozzle velocities between 150 and 300 fps. Normally, development with a water jet is started at the bottom of the screen. Jetting is accomplished at one depth with the jet rotated for a fixed period of time. The jet is raised approximately 0.5 ft; rotation and jetting is continued for another fixed period of time. Wells must be pumped or airlifted during jetting to remove the fines as they are dislodged by the jetting. This process is continued until the entire well screen has been jetted. The jetting tool should be continuously in motion since a small amount of sand is disturbed and may cause localized erosion of the screen. Jetting must be repeated a number of times to ensure optimum development of the well.

5.3.2.2. Surging. A surging block is a plunger consisting of one or more stiff rubber or leather discs attached to a heavy shaft. These discs should be about 1 in. smaller in diameter than the screen ID. Surging consists of moving water in and out of the screen using the up and down motion of the surge block through short sections of the well screen. The well should always be pumped or bailed to ensure a relatively free inflow of water prior to surging. Surging should begin with a slow and gentle motion above the well screen and continue with more vigor from the top of screen downward. The surging block should be pulled at approximately 2 fps for effective surging. For record keeping purposes, it is convenient to use 15 round trips as one cycle. The amount of material deposited in the bottom of the well should be determined after each cycle (about 15 trips per cycle). Surging should continue until the accumulation of material pulled through the well screen in any one cycle becomes less than about 0.2 ft deep. The well screen should be bailed clean if the accumulation of material in the bottom of the screen becomes more than 1 to 2 ft at any time during surging, then recleaned after surging is completed. Material bailed from a well should be inspected to see if any foundation sand is being removed. If the well is oversurged, the filter may be breached with resulting infiltration of foundation sand when the well is pumped.

5.3.2.3. Pumping. One of the least effective and slowest methods of developing a well is simply pumping from the well. Pumping should be accomplished at a sufficient rate to effect maximum drawdown in the well. The water passing from the formation through the filter into the well removes part of the finer fraction of the filter material. The pumping equipment required depends on the size, yield, and anticipated drawdown in the well. Surging produced by repeatedly starting and stopping a pump is only effective where the static water level is well below the ground surface. Pumping, continued over a long period of time, is a reasonably effective method of well development. Pumping of the well by airlift methods is normally accomplished by inserting a pipe in the well and forcing compressed air to the inside bottom of the pipe. If the depth of submergence of the pipe is at least 50 percent of its length, air bubbles reduce the weight of the water column and will cause a flow to the ground surface. If 50 percent submergence is not possible, the water column which must be physically blown out of the pipe as it accumulates will require a large supply of air. Airlifting in an open well without an eductor pipe is not recommended. Pumping can be accomplished using a mechanical pump, but granular material in the water can cause pump damage.

5.3.2.4. Sand Infiltration. During the development process, sand and silt will be brought into the well. When the depth of sand collected in the bottom of the screen reaches 1 ft, it should be removed by bailing. The accumulation of sand in the screen prevents development of that portion of the screen. A properly developed well will not produce an appreciable amount of sand, and entrance losses through the filter will be reduced to a minimum. In each of the methods discussed above, the actual amount of development must be recorded: the length, diameter, speed, and number of cycles of a surging block; the volume, pressure, and diameter of water jets; and the rate and method of pumping and length of time pumped. In addition, the amount of filter and foundation materials brought into the well and bailed out should be recorded. Sand infiltration is recorded in terms of parts per million (PPM) as measured with a centrifugal sand tester or other approved sediment concentration test. Upon completion of the development of the well, all material infiltrated into the well should be bailed out. The well should be pumped to achieve a drawdown in the order of 5 ft. in the well. If the well produces sand during pumping in excess of 5 PPM, the well should be resurged or developed further and re-pumped. Wells continuing to produce excessive amounts of sand after 4 to 8 hours of surging or pumping should be abandoned and properly plugged.

5.4. Testing of Wells. Performance of wells properly installed and developed is determined by pumping tests. The pumping test is used primarily to determine the specific capacity of the well and the amount of sand infiltration experienced during pumping. The information from this test is required to determine the acceptability of the well and will be used to evaluate its performance and loss of efficiency over time.

5.4.1. Equipment. The equipment required for a pumping test consists of a pump of adequate size to effect a substantial drawdown. If the water level in the well is near enough to the ground surface, and the specific capacity of the well is high enough to produce a substantial flow with a small drawdown, a centrifugal pump may be used for this purpose. If the water level in the well is lower than about 18 to 20 ft, a deep-well pump will be required to effect substantial drawdown. A flow meter is required to measure the flow rate. A flat-bottom sounding device and a steel tape are required to determine the amount of sand infiltration deposited in the bottom of the well. A sounding device suitable for determining the depth to the top of the water is needed to find the exact drawdown in the well.

5.4.2. Pumping. The well must be pumped to obtain a specified drawdown or flow rate. Drawdown measurements in the well should be made to the nearest 0.01 ft and recorded with the flow rate at 15-minute (min) intervals throughout the duration of the tests. Sufficient sand infiltration determinations are necessary to establish an infiltration rate for each hour of the pumping test. The rate of sand infiltration may be determined from sounding and measurements of sand in the effluent. For most properly developed wells, the amount of sand deposited in the well will be negligible and sand infiltration in the effluent can be recorded in terms of parts per million as measured with a centrifugal sand tester or other approved sediment concentration test (Driscoll 1986) The length of time that the pumping test must be continued is normally specified for the particular project. If the rate of sand infiltration during the last 15 min of the pumping test is more than 5 ppm, the well should be resurged by manipulation of the test pump for 15 min; then the test pumping should be resumed until the sand infiltration rate is reduced to less than 5 ppm. If after 6 hours (hrs) of pumping the sand infiltration rate is more than 5 PPM, the well should be abandoned.

5.5. Backfilling of Well. After completion of the well testing, the annular space above the top of the filter pack should be filled with filter pack if necessary to achieve design grade. The remainder of the hole should be filled with a cement or cement-bentonite mixture tremied into place. In both cases, a 12-in. layer of concrete sand or excess filter material should be placed on top of the filter before placement of grout or concrete. A tremie equipped with a side deflector will prevent jetting of a hole through the sand and into the filter.

5.6.. Sterilization. Upon completion of the pumping tests each well should be sterilized by adding a chlorine solution with a minimum strength of 500 ppm. Sufficient solution should be added to the well to provide a volume equal to three times the volume of the well based on the outer diameter of the filter. Before the solution is introduced into the well, all flow from the well should be stopped with inflatable packers or riser extensions. The solution should be injected into the well through a jetting tool by slowly raising and lowering the tool through the screened portion of the well. The well should be gently agitated at 10-min intervals every 2 hr for the first

8 hr and then at 8 hr intervals for at least 24 hr. As the chlorine will dilute with time, the concentration should be periodically checked; if it falls below 500 ppm, additional chlorine compound should be added. It should be noted that calcium hypochlorite may combine with naturally occurring calcium in the ground water to form a precipitate of calcium hydroxide which can plug the pores of the foundation soils. Therefore, chlorine in the form of calcium hypochlorite should not be used in waters containing high calcium content.

5.7. Abandoned Wells. Abandoned wells should be sealed to eliminate physical hazards, prevent contamination of ground water, conserve hydrostatic heads in aquifers, and prevent intermingling of desirable and undesirable waters. Primary sealing materials consist of cement or cement-bentonite grout placed from the bottom upward. In general, abandoned wells should be sealed following procedures established by local, state, or Federal regulatory agencies. Details of well abandonment should conform to Appendix A: EXCAVATIONS AND BACKFILL.

6. Recommended references.

6.1. Army TM 5-818-5, Navy NAVFAC P-418. Air Force AFM 88-5, Chap. 6, DEWATERING AND GROUNDWATER CONTROL, describes the following:

a. Subsurface investigation necessary for groundwater control and analysis.
b. Methods for dewatering, pressure relief, and seepage cutoff.
c. Dewatering of open excavations.
d. Design of groundwater control structures such as temporary and permanent pressure relief well systems, wellpoints, vertical sand drains, grout curtains, slurry walls.
e. Groundwater monitoring system instruments such as piezometers.
f. Operation and performance of groundwater control system.
g. Installation of dewatering, pressure relief, and ground water control systems.

6.2. EM 1110-2-1914, “Design, Construction, and Maintenance of Relief Wells", includes the following requirements:

a. Necessary seepage analysis which provides the conditions for the design of relief well systems and the determination of the allowable hydrostatic heads to prevent piping and to obtain the allowable factor of safety with respect to uplift and heave.
b. Methods of analysis of single well or multiple well systems.
c. Recommendations for well design, including well screen and filter pack.
d. Recommendations for well system design.
e. Installation, maintenance, operation, and evaluation of relief wells.
f. Well rehabilitation methods.

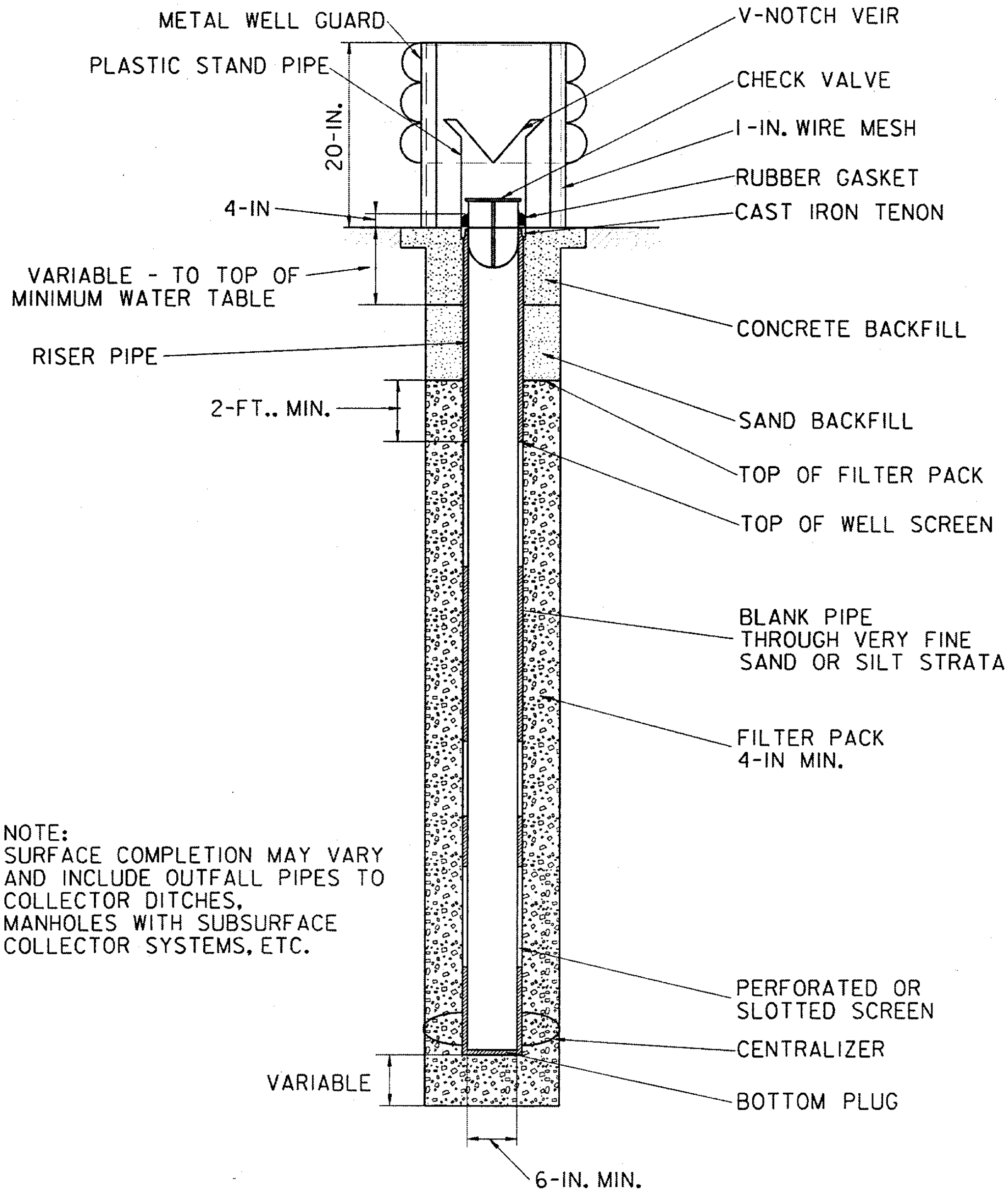

FIGURE 1

TYPICAL RELIEF WELL CONFIGURATION

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