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Borehole Completion and Seal Testing for Upper Confined Aquifer-Monitoring Wells in the 300-FF-5 Operable Unit

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1.0 INTRODUCTION

The remedial investigation of the 300-FF-5 operable unit was initiated in fiscal year 1991. A major part of the investigation involves the construction of eight new groundwater-monitoring wells in the upper confined aquifer beneath the operable unit. The upper confined aquifer has a head gradient significantly higher (approximately 30 ft) than the unconfined aquifer. Because of this, the U.S. Environmental Protection Agency and the State of Washington Department of Ecology requested, through review comments associated with the operable unit work plan (DOE 1990), the U.S. Department of Energy to prepare a description of borehole seal emplacement and testing for this specific operable unit. They further requested that the resulting documentation be approved by the regulatory agencies prior to constructing the first confined aquifer-monitoring well. This request was honored (DOE 1990, p. WP-159), and the description of seal emplacement and testing in new groundwater-monitoring wells completed in the upper confined aquifer in the 300-FF-5 operable unit is presented in this report. This work applies only to wells drilled for the 300-FF-5 operable unit.

2.0 BACKGROUND

The 300-FF-5 operable unit (Figure 1) is a groundwater operable unit beneath the 300 Area and nearby surrounding areas (WHC 1989; DOE 1990). As part of the investigation of this operable unit, new wells will be constructed at positions shown in Figure 2. Wells identified 1C through 8C in Figure 2 will be completed in the upper confined aquifer, and their construction, testing, and sealing are the subjects of this report.

The generalized stratigraphy of the 300-FF-5 operable unit is presented in Figure 3. This figure shows the four major stratigraphic units relevant to this report (in ascending order): the Saddle Mountains Basalt, Ringold Formation, Hanford formation, and recent eolian sand. As shown in Figure 3, the unconfined aquifer (water table) is located approximately at the Hanford formation-Ringold Formation contact and bounded at the bottom by the top of

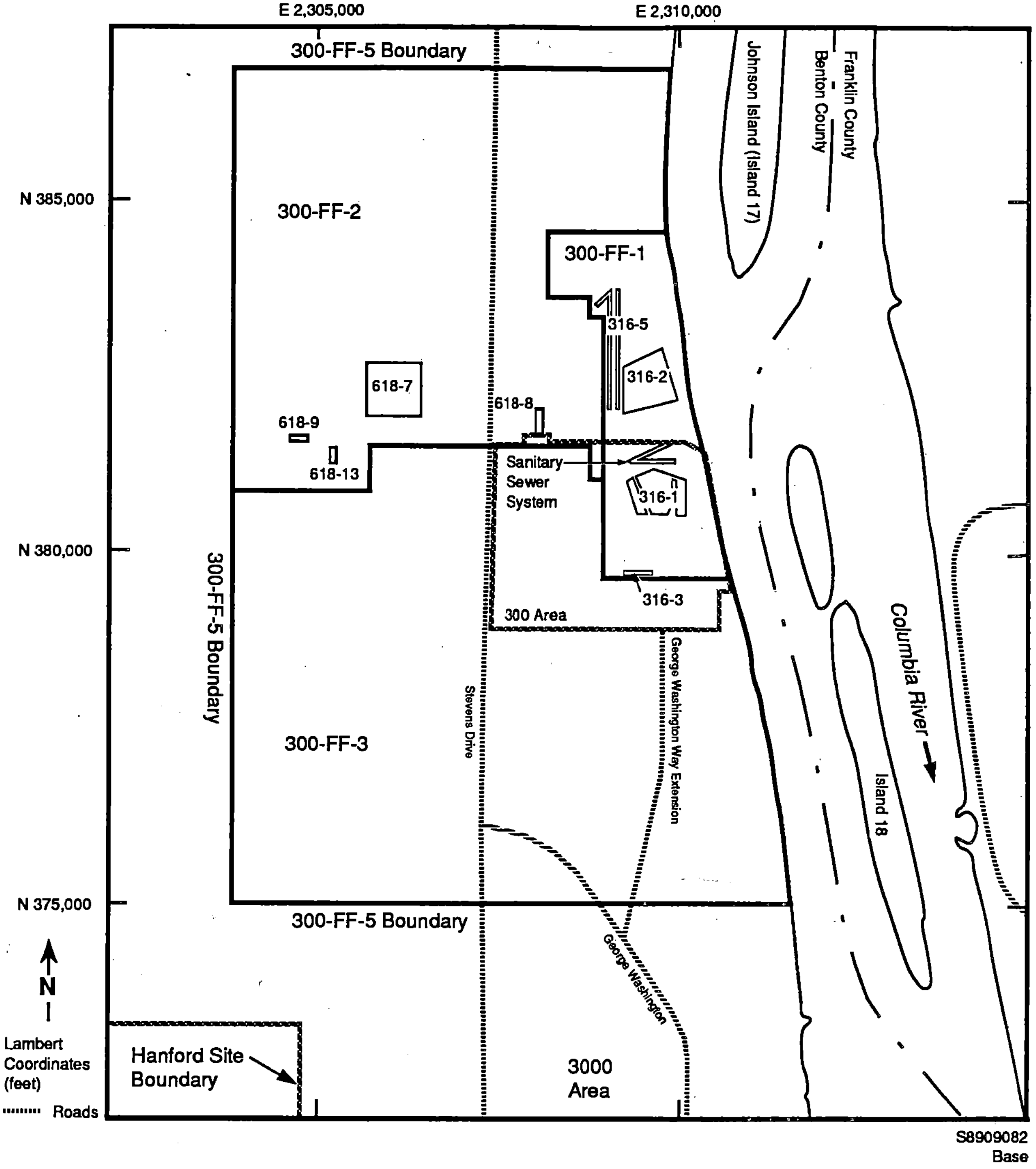
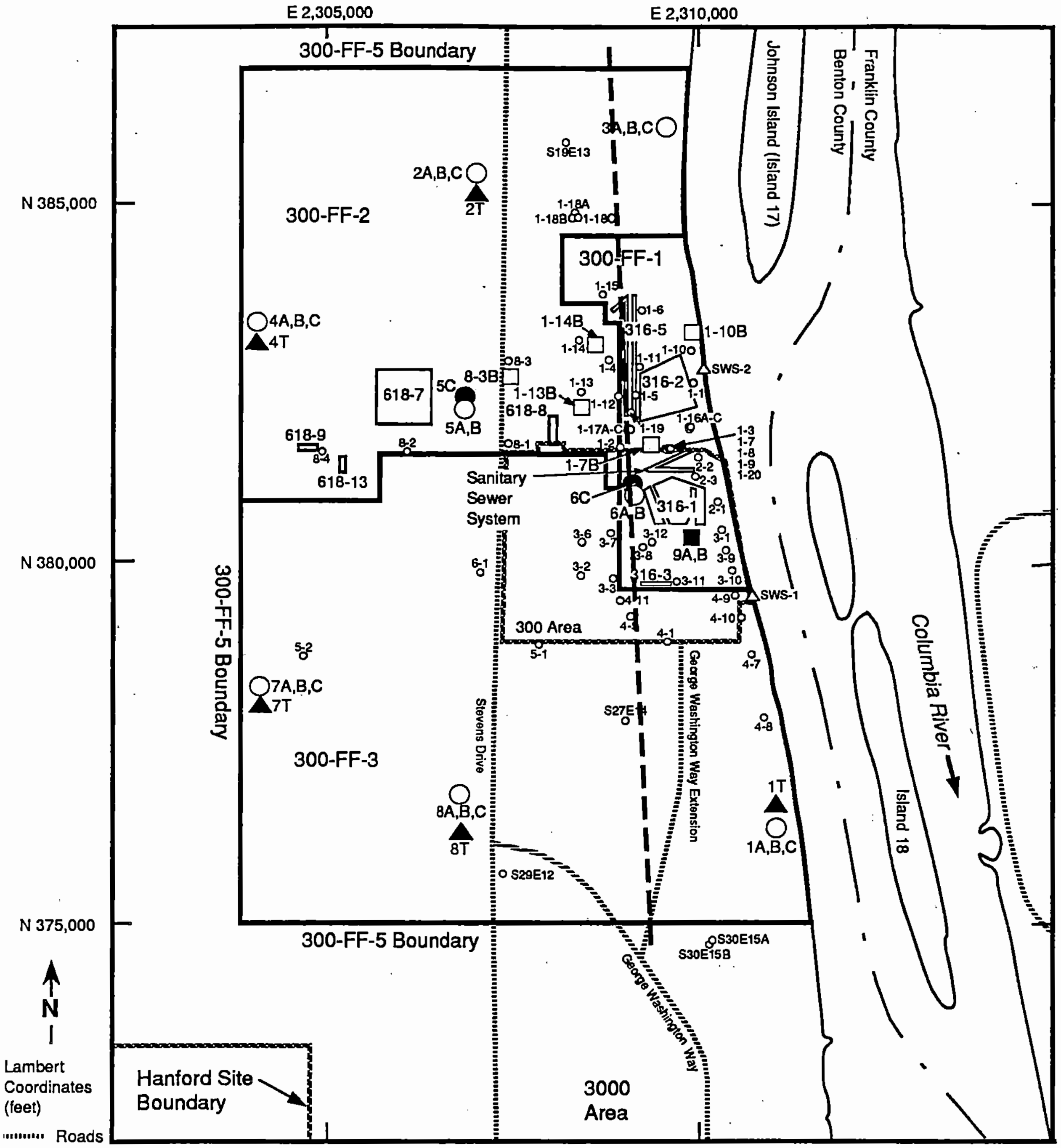


FIGURE 1. Location of the 300-FF-5 Operable Unit



o 1-12	Well Location and Number (Wells Prefixed by 399-, Except Those Beginning with S are Prefixed with 699-)
△ SWS-1	Surface-Water Monitoring Station
— — —	Cross Section Shown in Figure 4
○	Nested Wells
●	New Confined Aquifer Monitoring Well
□	Wells for Monitoring Dense Nonaqueous-Phase Liquids
■	Wells for Differentiating the Extent of Uranium Plumes
▲	Aquifer Test Pumping Wells

FIGURE 2. Proposed Locations and Primary Purposes for Monitoring Wells and Aquifer Test Pumping Wells

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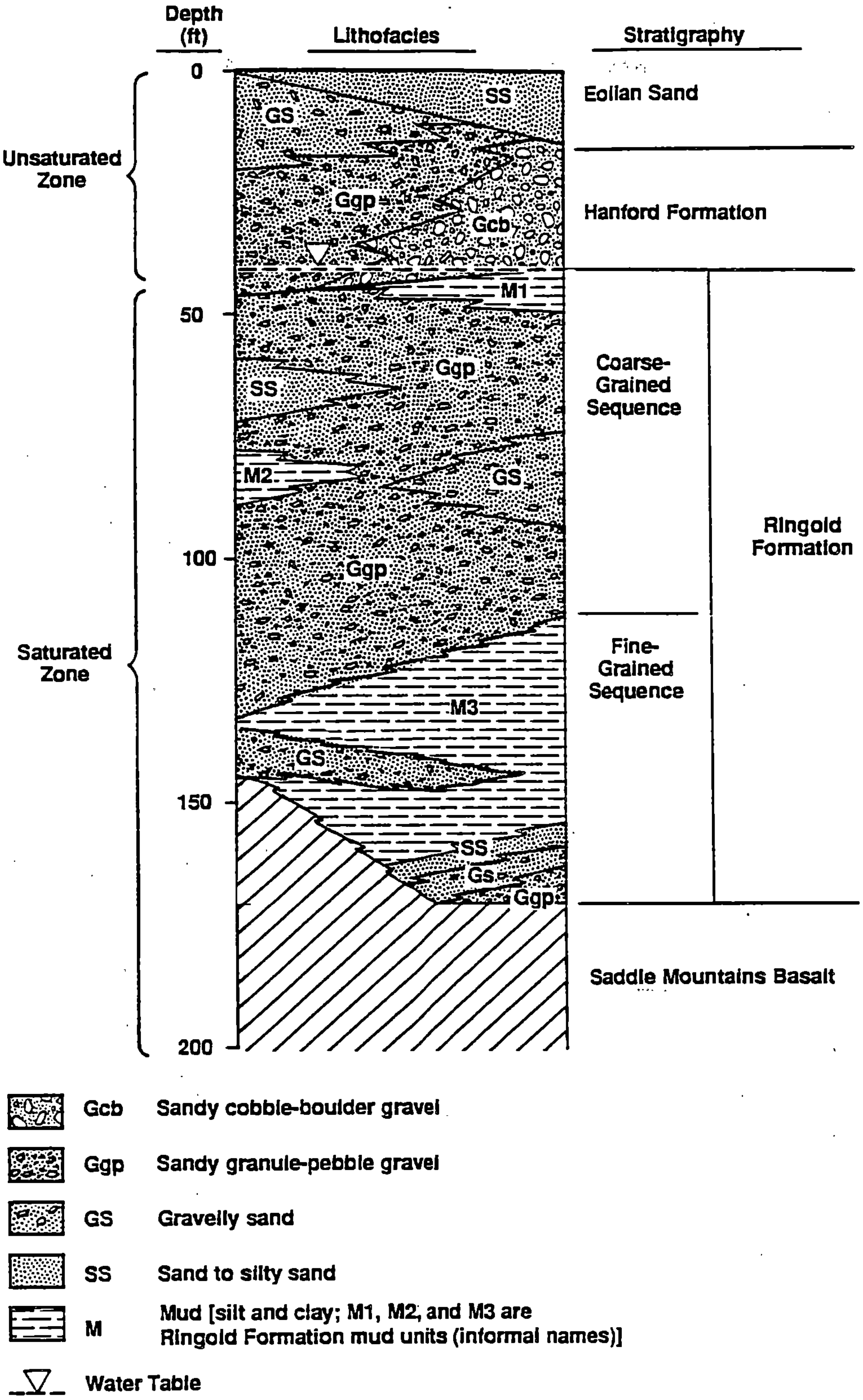

FIGURE 3. Generalized Geologic Strata of the 300-FF-5 Operable Unit

the M3 fine-grained sequence in the Ringold Formation. The upper confined aquifer is located in the coarse-grained facies of the Ringold Formation, located between the M3 layer and the Saddle Mountains Basalt. Water potentials differ by as much as 30 ft across the M3 layer, resulting in a large upward gradient in the area between the upper confined aquifer and the unconfined aquifer. Water potentials in the unconfined aquifer differ little with vertical position in the aquifer.

The local confining characteristics of the M3 layer have been observed in all wells that penetrate the M3 layer in the 300 Area, with the exception of well 399-1-18C. The geologic cross section presented in Figure 4 shows that the M3 layer disappears on the northern boundary of the operable unit in the vicinity of well 399-1-18C. The lack of a confining layer to the north provides a logical explanation for the lack of a head gradient across the M3 layer at that position. Because the M3 layer is a predominant, groundwater-flow-controlling feature in the area, it is important to ensure that the integrity of this layer is maintained during the execution of this project. This report will describe how the integrity of the M3 layer will be maintained and tested during the construction of monitoring wells associated with this project.

The M3 layer is a variable sequence of silt and clay with intercalated lenticular beds of sand and gravel. The sand and gravel interbeds tend to be silt rich. Throughout most of the western and southern parts of the 300 Area, the M3 layer generally consists of two fine layers separated by a layer of sandy gravel. Estimated depths to these layers and their thicknesses are presented in Table 1. The upper clay and silt layer generally is thinner than the lower clay and silt layer. To the north, the M3 layer thins to a single silt and clay zone that pinches out north of borehole 399-1-18C. At and north of boreholes 399-1-16C and 399-1-17C, the M3 layer usually directly overlies basalt. South of these boreholes the M3 layer is separated from the underlying basalt by a thin (<10-ft) zone of sandy gravel. During drilling, the M3 layer should be found between depths of 115 to 130 ft in the 300-FF-5 operable

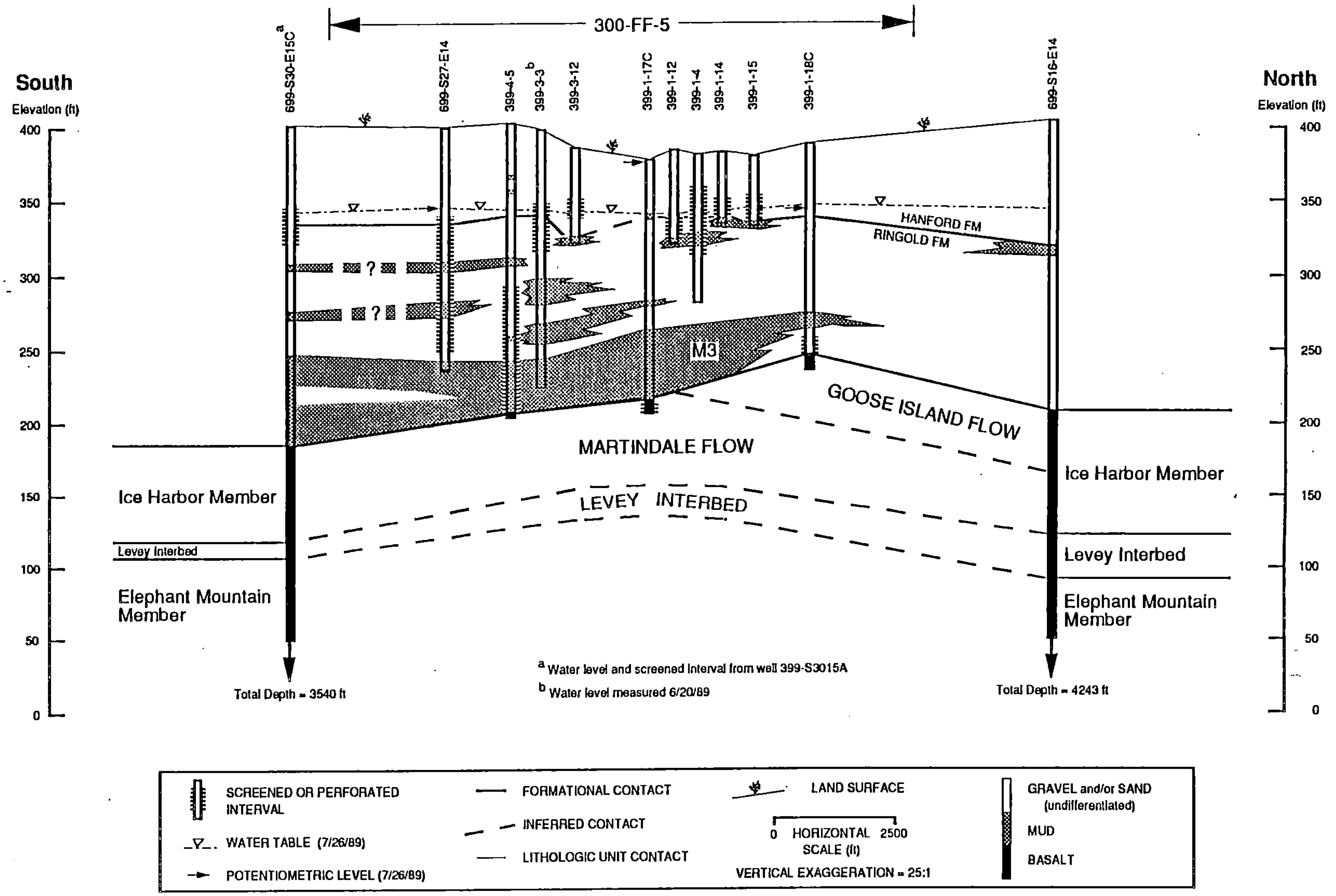

FIGURE 4. Geologic Cross Section of the 300-FF-5 Operable Unit (cross-section line shown in Figure 2)

TABLE 1. Estimated Lengths, Depths, and Thicknesses Important for Constructing Confined Aquifer Wells

Well Construction		Well Number							
		1C	2C	3C	4C	5C	6C	7C	8C
M3 Layering		M	S	S	S	M	S	M	M
Estimated Depth (ft) to M3 Layer(s)	1st Layer	120	120	120	130	130	115	120	120
	2nd Layer	160	None	None	None	145	None	170	170
	3rd Layer	None	None	None	None	None	None	None	None
Expected Head Differential (ft) Across M3 Layer	1st Layer	<1	0	0	30	<1	30	2	2
	2nd Layer	30	NA	NA	NA	30	NA	25	25
	3rd Layer	NA	NA	NA	NA	NA	NA	NA	NA
Estimated Thickness (ft) of M3 Layer	1st Layer	12	10	10	40	10	52	20	20
	2nd Layer	35	NA	NA	NA	25	NA	20	20
	3rd Layer	NA	NA	NA	NA	NA	NA	NA	NA
Estimated Depth (ft) to Basalt		190	145	150	170	170	170	190	190
Estimated Depth (ft) to Water	Unconfined	47	40	35	45	48	35	40	37
	Confined	17	NA	NA	15	18	5	15	12
Length of Temporary and Permanent Casing (in.)	16	45	35	30	40	43	30	35	32
	12	125	125	125	135	135	120	125	125
	10	165	None	None	None	150	None	175	175
	8	190	145	150	170	170	170	190	190
	4	192	142	147	172	172	172	192	192
Estimated Depth (ft) of Screened Interval		190-200	140-150	145-155	170-180	170-180	170-180	190-200	190-200

M = Multilayer; S = Single; NA = Not applicable.

unit. Although never observed in the 300-FF-5 operable unit, a third layer may exist if the first silt layer or the second silt layer of the M3 is bifurcated by a layer or lens of sand or gravel, thus creating a third layer (see Table 1). If the first layer is bifurcated, the hydraulic isolation may require driving the 12-in. casing into the lower half of the first layer. If the bifurcation occurs in the second layer (i.e., between 145 to 175 ft), the hydraulic isolation will probably not be compromised because stratigraphic closure (i.e., confinement) of the confined aquifer will be maintained (see Figure 3). Any fine-grained zones encountered above these depths will probably be restricted to laterally discontinuous intervals (sometimes referred to as M1 and M2).

The degree of confinement provided by the M3 layer is unknown. Where the M3 layer consists of two silt and clay zones, the lower zone is inferred to provide most of the hydraulic isolation because of its greater thickness. In addition, large changes in hydraulic head are not observed until the entire M3 sequence has been penetrated.

3.0 SEALS EMPLACEMENT AND TESTING

3.1 GENERAL DESIGN CONSIDERATIONS

The design of the near-river-monitoring system requires the installation of monitoring wells that vary from 60 to 210 ft deep. These wells will be drilled in groups of two or three, called cluster wells. Each well will be drilled separately and will be completed in a different stratum in the groundwater. Proper design requires consideration of the geology and hydrology of the units in which the wells will be completed. The deepest screened interval will be immediately below the M3 layer in the fractured basalt or coarse-grained material of the Ringold Formation. Isolation of the unconfined and confined aquifers must be maintained during the drilling and emplacement of temporary casing and during completion of the well below the M3 confining layer. Required procedures and guidelines for drilling, emplacement of seals, well construction, and testing of seal integrity are presented in the following sections. If, during drilling, the M3 layer is not encountered before reaching basalt, the well should be completed as a deep monitoring well without the complication of a confining layer.

3.2 BOREHOLE DRILLING AND SEALS

This section presents a description of borehole-drilling and -sealing specifications and seal testing for a confined aquifer-monitoring well completed beneath the M3 layer. Minimum standards for construction and maintenance of wells are presented in WAC 173-160. Specific procedures that control all drilling activities specified herein are documented in Section 6.0 of WHC (1990). Detailed construction specifications are presented in Swanson (1990). A flow diagram of activities described in this section is presented in Figure 5.

3.2.1 Vadose Zone and Unconfined Aquifer

The first portion of the borehole will be drilled to within 5 or 10 ft of the water table (at approximately 40 ft below ground surface). This upper approximately 40 ft should be drilled using the cable-tool method and 16-in.-diameter casing with a tapered drive shoe. The casing is advanced by driving it while the borehole is underreamed during drilling. Hard tool is suitable for drilling through boulders and cobbles that likely will be encountered in this portion of the vadose zone; however, all drilling should utilize core-barrel techniques wherever possible, rather than hard tool. The configuration of the borehole at this stage is presented in Figure 6.

The next portion of the borehole will be drilled to the top of the M3 layer, approximately 80 ft deeper, using cable-tool and core-barrel techniques where possible and 12-in.-diameter casing with a tapered drive shoe. On reaching the top of the M3 layer, core samples of the upper 5 ft will be collected and examined for coarse-grained stringers. If none are found, the 12-in. casing should be driven into the M3 layer until the drive shoe has been driven approximately 5 ft into the silt and clay of the M3 layer (Figure 7). The actual penetration will depend on the resistance met while driving the casing. If coarse-grained stringers are encountered in the M3 layer, they will not provide adequate seals and, therefore, the 12-in. casing will not be

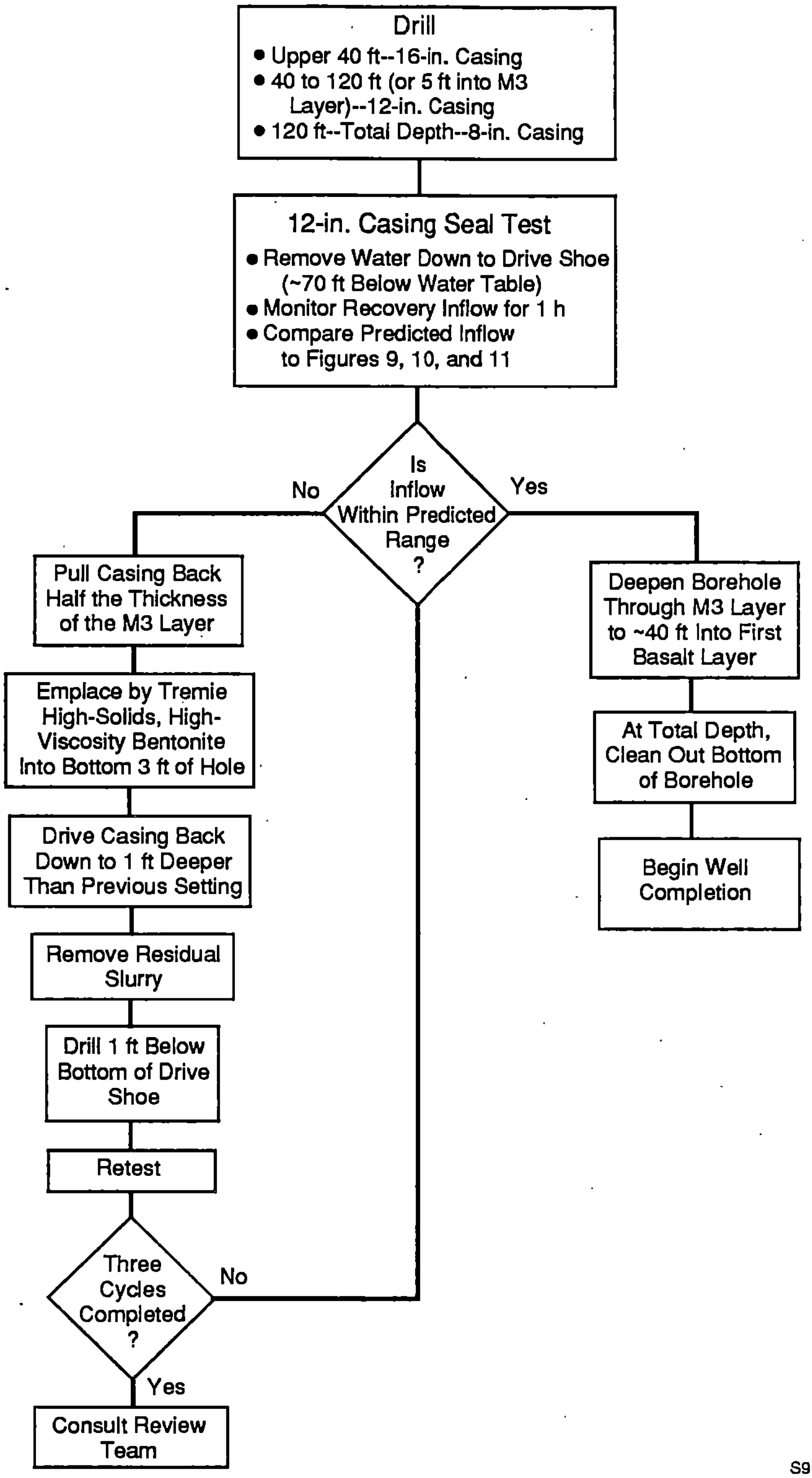

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FIGURE 5. Flow Diagram of Borehole Drilling and Testing Activities

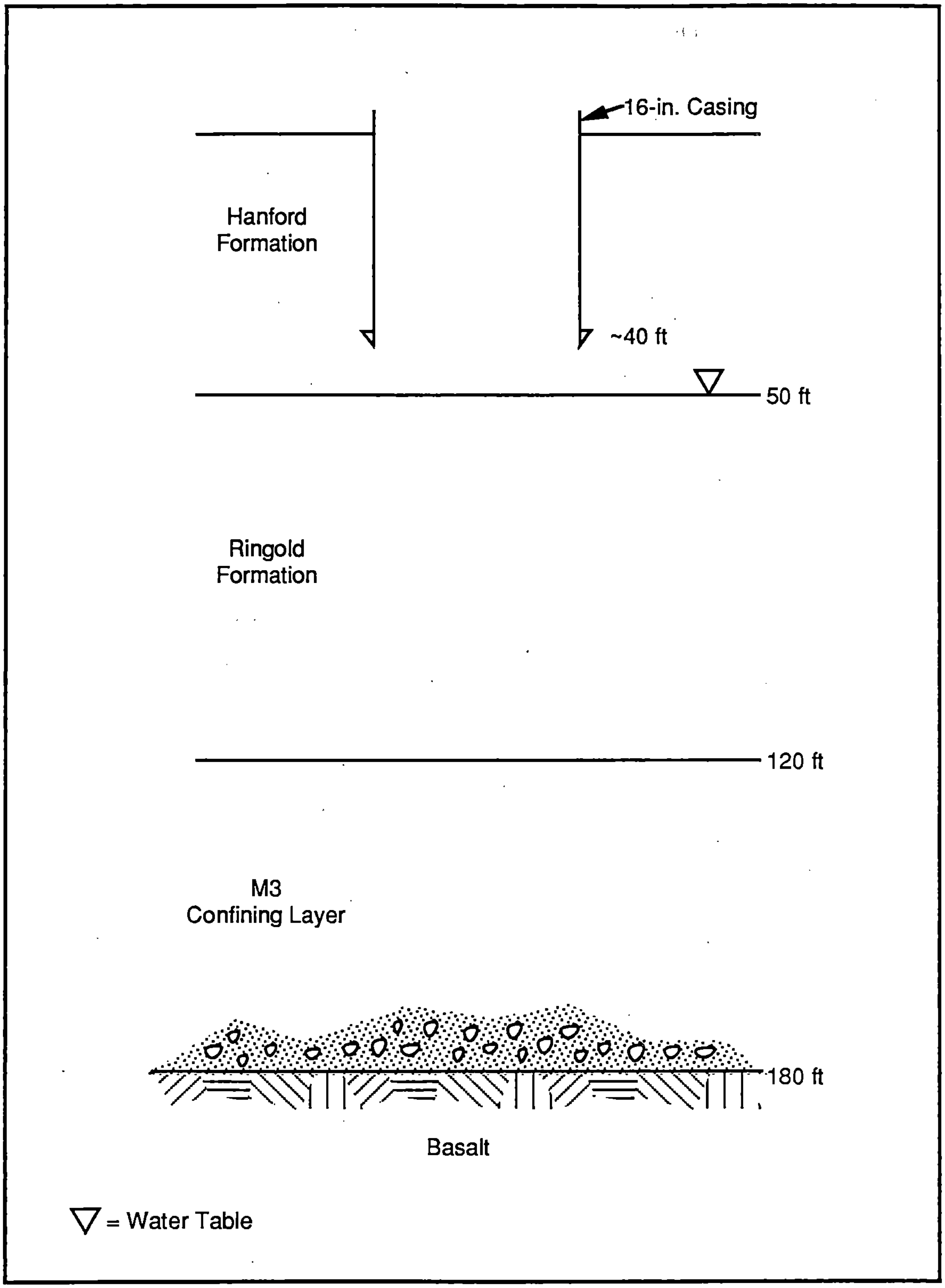

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FIGURE 6. Borehole Configuration, 16-in. Casing

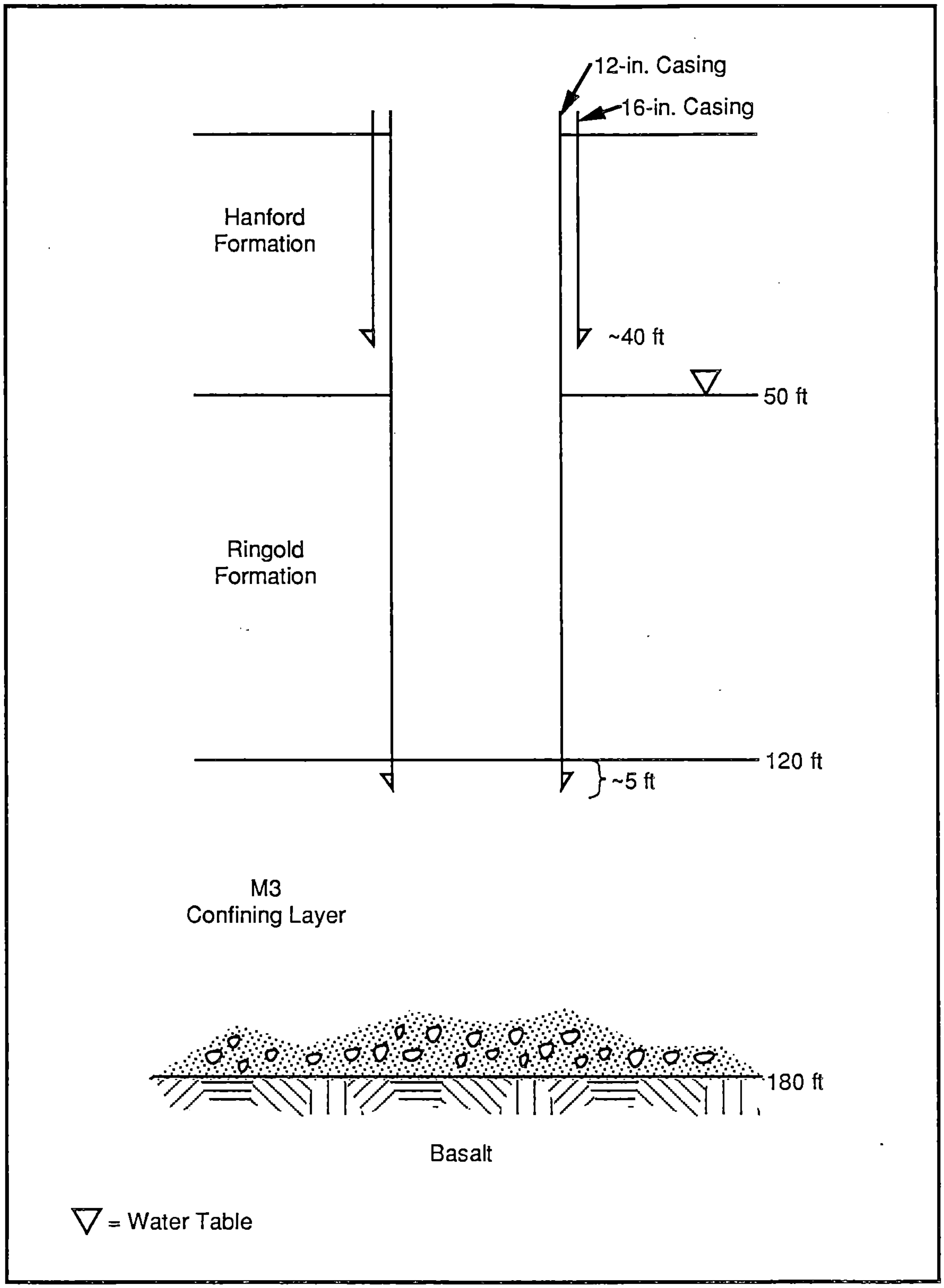

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FIGURE 7. Borehole Configuration, 12-in. Casing

terminated in such a stringer. If coarse-grained layers are encountered, the borehole will be advanced to the bottom of the coarse-grained layer using core-barrel techniques. The sequence of activities that began at the top of the M3 layer will be repeated, with the exception that coring will be only 3 ft ahead of the 12-in. casing. At the completion of the activities, the 12-in. casing will terminate in a fine-grained sequence. After driving the 12-in. casing to its final depth, the borehole will be completed to 1 ft below the casing. The configuration of the borehole at this stage is presented in Figure 8.

3.2.2 Temporary 12-Inch Casing Seal Test

At this point, a slug withdrawal test will be performed to determine if an adequate seal, as determined by a leakage rate less than a threshold value determined in predictions, between the 12-in. casing and the top of the M3 layer has been achieved.

The slug withdrawal test can be conducted by lowering the water level within the 12-in. casing to near the drive shoe depth (i.e., approximately 70 ft below the existing water table) and then monitoring the recovery inflow rate of water levels within the well casing. The initial removal and resultant lowering of the water level in the sealed well (i.e., to start the slug withdrawal test) can be accomplished by pumping the water from the casing, using either a submersible pump or air-lift methods. Alternatively, water could be removed from the well by bailing until the desired water level is reached. The selected method should provide for rapid (3-min time frame) removal of the water to more closely approximate an instantaneous slug withdrawal, on which acceptable inflow rates have been calculated. The method of removing the water should enable its collection and proper handling as indicated by the concentration of contaminants present. The water-level recovery inside the 12-in. casing can be measured using standard hydrologic water-level sensors, such as pressure transducer, electric water-level sensor, or steel tape.

Predicted recovery inflow water levels within the 12-in. casing following slug withdrawal initiation are shown in Figures 9, 10, and 11 for the following range of hydrogeologic properties: hydraulic conductivity, $K = 10^{-4}$ to

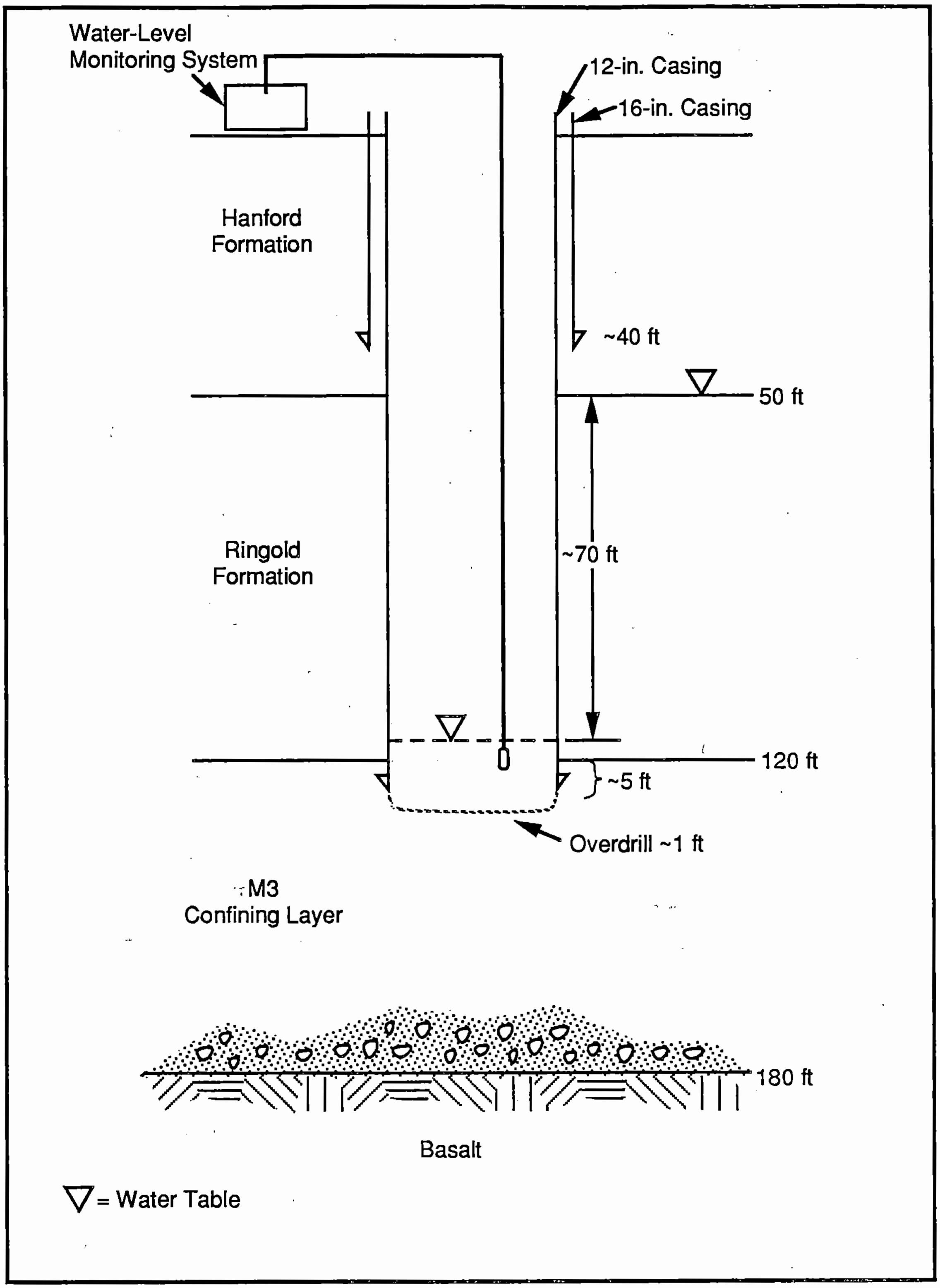

FIGURE 8. Borehole Configuration, 12-in. Casing Seal Test

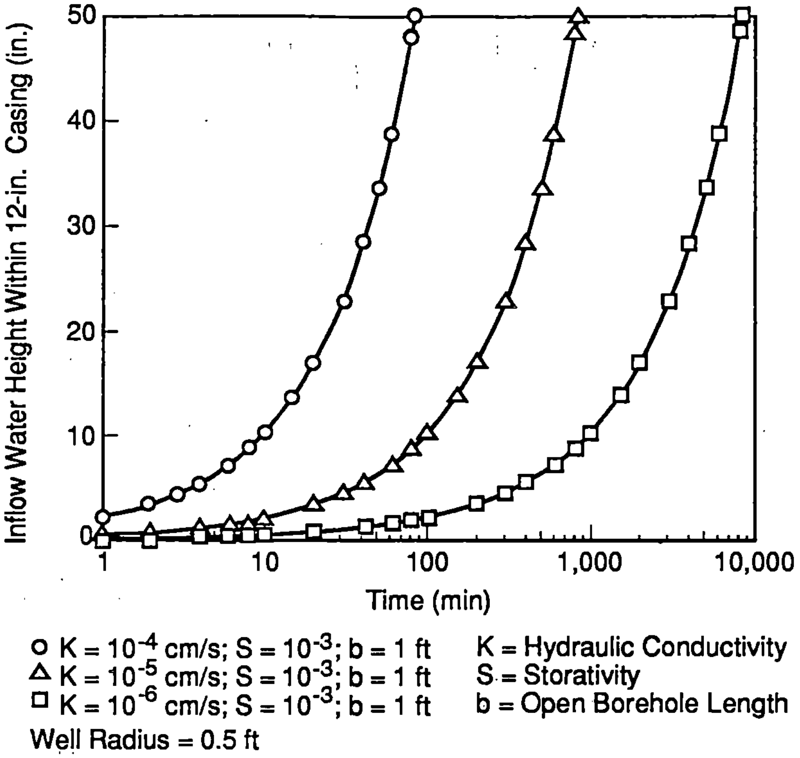

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FIGURE 9. 12-Inch Casing Seal Test, Variable Hydraulic Conductivity

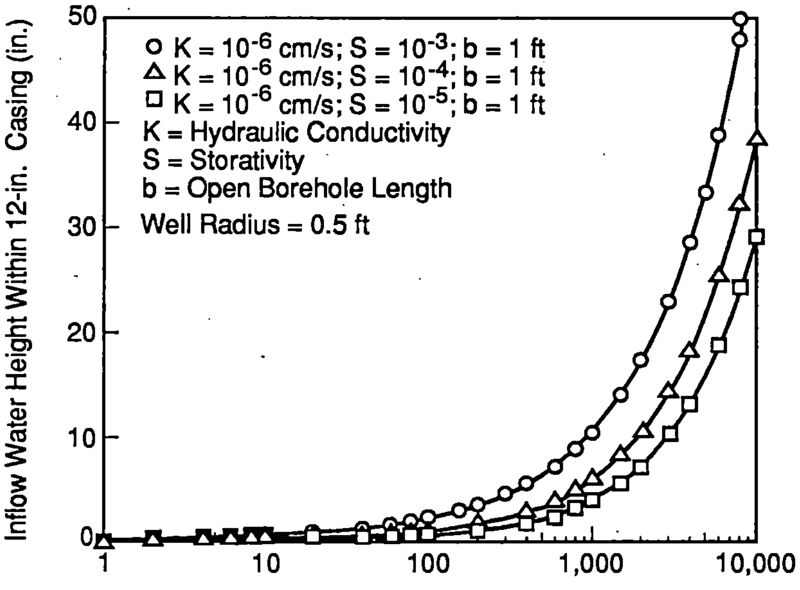

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FIGURE 10. 12-Inch Casing Seal Test, Variable Storativity

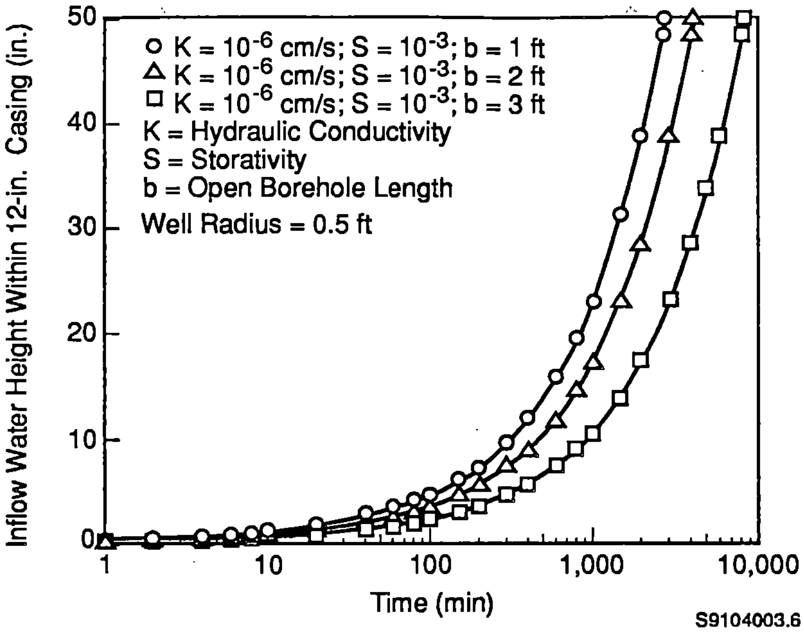

FIGURE 11. 12-Inch Casing Seal Test, Variable Open Borehole Length

10^{-6} cm/s (Schalla et al. 1988); storativity, $S = 10^{-3}$ to 10^{-5} (assumed); open borehole length, b = 1 to 3 ft (specified); and initial stress level = 70 ft (specified). These predictions were calculated using the finite radius, slug test response method described by Copper et al. (1967). Water inflow rates that fall below and to the right of the curves indicate that a seal is acceptable. As indicated in Figures 9, 10, and 11, the predicted recovery inflow water levels are low, less than 12 in., for periods up to 10 min following slug initiation. This corresponds to inflow rates that range from a high of approximately 3000 mL/min during the first minute of the test to a low of approximately 2 mL/min for 100 min following slug initiation. Figure 12 shows predicted leakage rates after 1 min for a range in hydraulic conductivity, based on the slug test response method described by Cooper et al. (1967).

If, after 1 h of slug withdrawal recovery, the inflow water levels are considerably higher than predicted (e.g., >5 ft) for intact formation material, the well casing seal should be considered suspect. If this occurs, the casing should be pulled back approximately half the thickness of the M3 layer penetrated. Next, a seal material that consists of a high solids (i.e., 30%

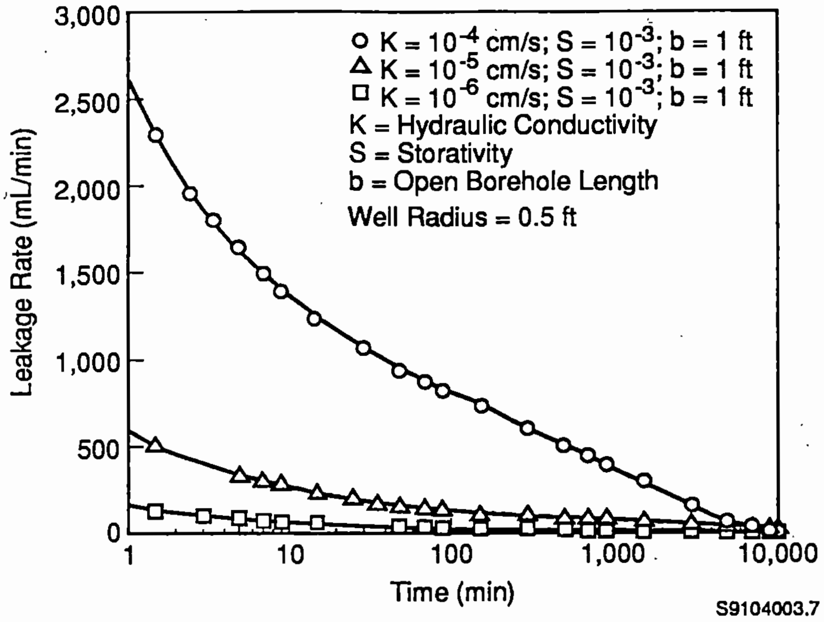

FIGURE 12. 12-Inch Casing Seal Slug Test

or greater), high viscosity (greater than 120 s using the Marsh Funnel method), bentonite slurry (e.g., Pure Gold Grout™ by American Colloid Company, Arlington Heights, Illinois) should be emplaced in the bottom of the borehole by use of a tremie. The bentonite slurry should fill approximately the lower 3 ft of the borehole. Before the bentonite slurry can set up and completely hydrate, the 12-in. casing should be driven to the original total depth of the borehole, which will be approximately 1 ft deeper than its setting during the previous unsuccessful test. Next, the residual slurry is removed, and the borehole is drilled to approximately 1 ft below the bottom of the drive shoe. Another slug withdrawal test will be conducted in the same manner as during the first test. This cycle is repeated until an adequate seal is established. After three unsuccessful cycles to establish a seal, a team will be convened to review the situation. A decision regarding the next action will be made by the team. One option available will be to install 10-in. casing and establishing a seal around that casing. If 10-in. casing is installed, the predicted inflow recovery rates shown in Figures 13, 14, and 15 should be used to judge the success of the seal emplacement.

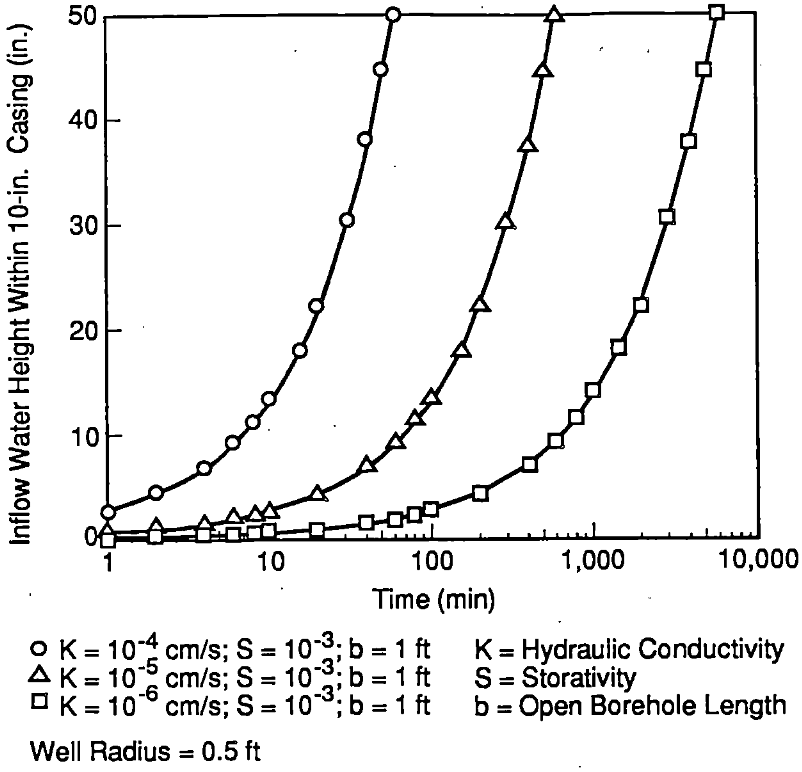

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FIGURE 13. 10-Inch Casing Seal Test, Variable Hydraulic Conductivity

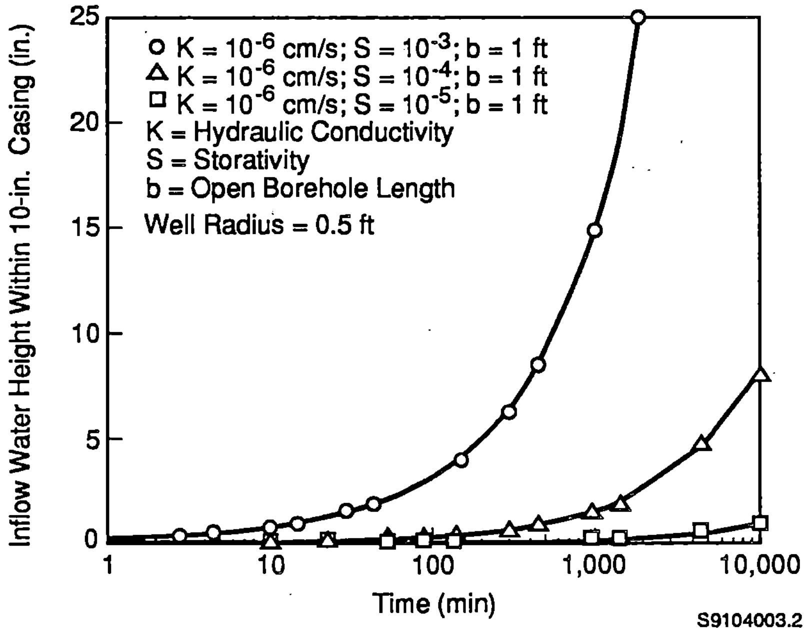

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FIGURE 14. 10-Inch Casing Seal Test, Variable Storativity

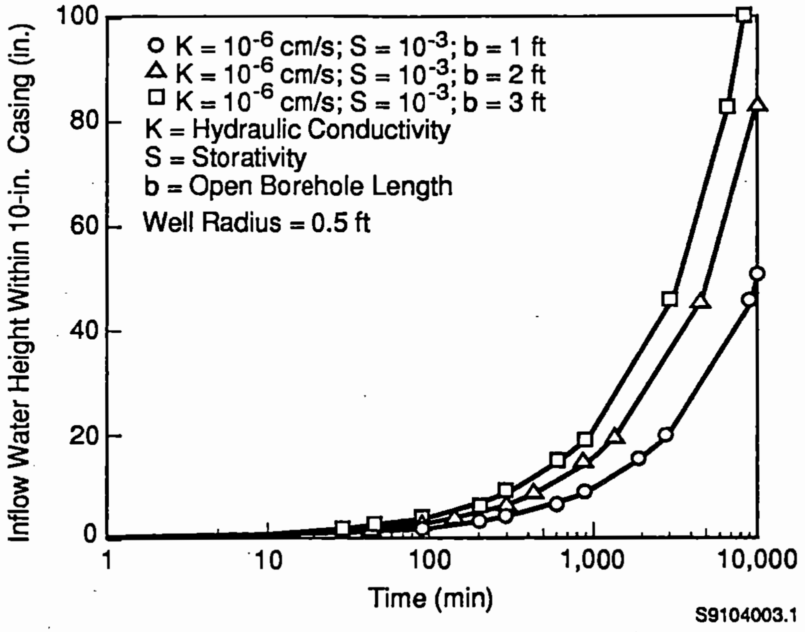

FIGURE 15. 10-Inch Casing Seal Test, Variable Open Borehole Length

3.2.3 M3 Layer and Confined Aquifer Drilling

After the successful completion of the slug withdrawal test, the borehole is deepened through the M3 layer to a total depth of approximately 10 ft into the first basalt layer, using cable-tool drilling with 8-in.-diameter steel casing with drive shoe driven to the top of the basalt (Figure 16). Core samples will be collected by use of a 4-in. split-barrel sampler while drilling through the M3 layer. If a distinct, thick (10 ft or more) sandy gravel layer is present, drilling will cease and water levels will be allowed to equilibrate. If the water level in the well rises rapidly or exceeds the water level of the unconfined aquifer by several feet, it may be necessary to use 10-in. casing inside the 12 in. to provide hydraulic isolation. Again, the 10-in. casing would be driven 5 ft into the lower silt layer of the M3 and drilling would continue with 8-in. casing to the top of the basalt. Drilling should continue into the basalt without advancing the casing. After the total drilled depth has been reached (i.e., approximately 10 ft into basalt), the bottom of the borehole will be cleaned out.

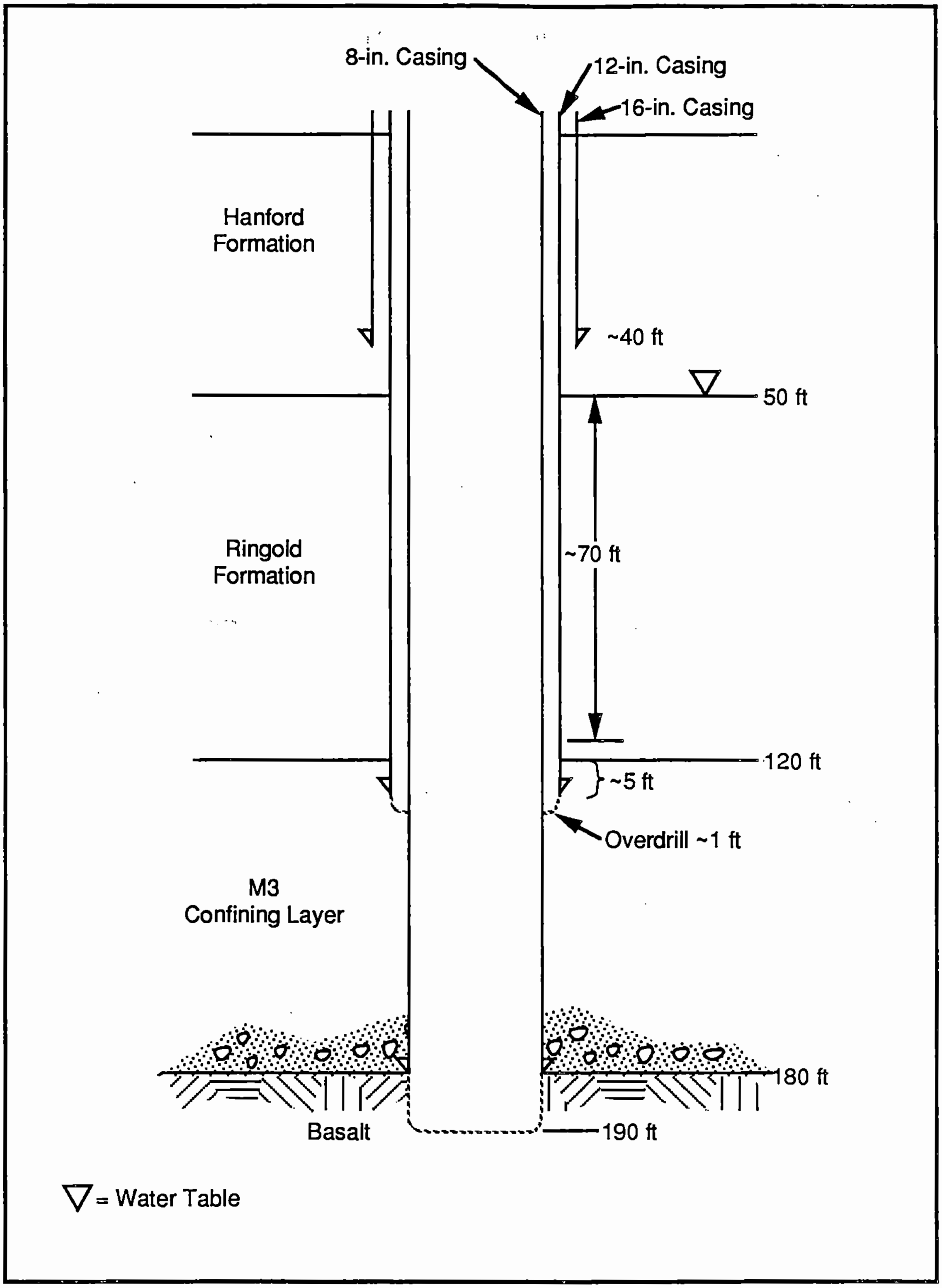

FIGURE 16. Borehole Configuration, Total Depth

At this phase of the installation, the nature of the water-bearing zone between the M3 layer and the basalt should be evaluated. If the zone differs little in water level from the unconfined aquifer, is isolated, and is not capable of producing much water, consideration should be given to eliminating this location as a monitoring horizon. A simple, qualitative slug withdrawal test could be conducted to determine the conditions. If significant drawdown with slow recovery is observed after rapidly bailing the well, the zone might not be appropriate for a monitoring horizon. If the zone is deemed acceptable, well completion can begin.

3.3 WELL COMPLETION AND TESTING

The final monitoring well is completed inside the 8-in.-diameter casing. Both the materials used and their emplacement are important to the success of the monitoring well. This section describes the materials used in the well, installation procedures, and testing of the seal in the M3 layer.

3.3.1 Materials

Information presented in this section conforms with specifications found in the generic well specifications of Swanson (1990). Additional detail is provided here to document the rationale or more closely define the material requirements specific for this work.

The wells will be constructed of 4-in.-inside-diameter, flush-threaded, stainless steel well screen and pipe. The monitoring well pipe (casing) will be schedule 5S, meeting American Society for Testing and Materials (ASTM) specification A 312 or A 778. The end fittings will be schedule 40, two threads per inch, single entry, flush screw threads, conforming to ASTM F 480-90ϵi with a Viton O ring on male end fittings. The pipe should be furnished in various lengths to eliminate the need for cutting. Well screens may be 0.010 or 0.020 in. slot size or dual screen (channel pack), but the final determination will be made in the field by the site geologist. All well screens will be of continuous slot type. All factory welding of fittings to screen or casing and welding to the locking caps will be performed with an approved inert gas, stainless steel wire feed welding process. The stainless steel wire feed must be of the same material as the casing or screen being welded. Stainless steel well screen and pipe may be composed of these four types: 304, 304L, 316, and 316L.

To minimize (virtually eliminate) damage to the well screen and pipe, the following is recommended:

- All male threads should be wrapped with expandable polyethylene mesh.
- All pipe and screen must be wrapped in 7-mil polyethylene packaging.
- Each wooden box containing pipe and screen should be clearly marked as to material type.
- Stainless steel caps and centralizers should be the same type as the well screen to which they are attached to prevent or minimize galvanic corrosion.

Any stainless steel casing, well screen, or accessories (caps, centralizers, spacers, etc.) must conform to the above specifications, be documented with certificates of conformance, be submitted to, and be approved by Kaiser Engineers Hanford prior to use.

The deep well in each cluster will be constructed with a 10-ft or shorter well screen to ensure that adequate quantities of water are available for purging and obtaining representative samples of the confined aquifer. A plate should be welded to the bottom of each well screen at the factory. Silt traps should not be used.

It is a common practice in water-supply wells to install a sediment sump or trap (also called a tailpipe), or a piece of blank casing installed below the well screen, to collect sediment either brought into the well during development or carried into the well by continued pumping over time. Some contractors have carried this practice over to the installation of monitoring wells. Other monitoring well designers have suggested that a sump installed below the screen would allow for the collection of samples of dense, nonaqueous-phase liquids (DNAPLS).

In a properly installed filter-packed monitoring well, very little sediment should be developed into the well. Yu (1989) points out that sediment brought into the well during development or well purging should be removed prior to groundwater sampling to avoid the phenomenon of chemicals sorbing onto and then desorbing from the sediments that may have collected in the sump. Furthermore, Yu (1989) contends that the two suggested uses of the sump are mutually exclusive (i.e., if the sump traps sediment, it cannot trap DNAPLS, and that if it does trap DNAPLS, it would be difficult to purge without leaving residue at the bottom of the well that would contaminate future samples taken from the well). With these apparent problems, the use of a sediment sump is not appropriate for monitoring well applications in the 300-FF-5 operable unit.

Because the settling rate of sand in water is controlled by particle size and shape, it is desirable to obtain a filter pack that consists of sand grains that are uniform in shape and size. The filter pack surrounding the well screen should consist of kiln-dried, subrounded to rounded, and spherical grains of sand composed of at least 95% quartz. The grains will have a Power's roundness of 3 to 6, or a Krumbein sphericity of 0.6 to 1.0. The maximum projection sphericity (Folk 1968) will be 0.6 to 1.0 (Schalla and Walters 1990). The sand particles should be very uniform in size; specifically, the uniformity coefficient should be less than 2.5 (ASTM D 5092-90). The effective size will be proportional to the sieve size. For example, the 10- to 20-mesh size (United States) will have an effective size of 1.0 to 1.2 mm (0.033 to 0.045 in.), and the 8- to 12-mesh size (United States) will have an effective size of 1.7 to 2.0 mm (0.067 to 0.079 in.). The paper sacks containing the sand should have polyethylene liners to prevent contamination and water damage. Two currently approved supply sources for the quartz sand pack are the Fountain Sand and Gravel Company, Pueblo, Colorado, and Colorado Silica Sand, Inc., Colorado Springs, Colorado.

When the bentonite slurry is placed above the secondary filter pack, a 2-ft-thick layer of bentonite chips (0.25 to 0.75 in.) is necessary to prevent invasion of slurry into the secondary and primary filter packs. A secondary filter is a layer of material that is placed in the annular space between the filter pack and the bentonite seal. Unlike the filter pack, which is very uniform in size, the secondary filter above the sand pack should not be uniform. The greater variation in size will allow the coarser grained sand fraction of the secondary filter to settle first on equivalently coarse sand pack followed by progressively finer grained sand. Therefore, the finest sand particles will be adjacent to the overlying bentonite slurry, which is placed next. This secondary filter prevents migration of the bentonite into the coarser primary filter pack. Selection of slot sizes, filter packs, and secondary filters should be in accordance with ASTM D 5092-90, and details of emplacement are discussed in Nielsen and Schalla (1990).

Bentonite seals will be composed of commercially available granular bentonite. Granular bentonite will be composed of coarse bentonite chips, 8- to 20-sieve size (United States). The sacks of bentonite chips will be shipped on pallets and sealed with plastic sheeting.

The bentonite slurry will be a bentonite clay powder with a specific gravity of 2.5, a dry bulk density of 55 lb/ft^3, and a pH of 9 to 10.5. The bentonite clay powder used below the water table will be Pure Gold Grout™, or an approved equal, and bentonite chips will be used above the water table. The sacks of bentonite powder will be shipped on pallets and sealed with plastic sheeting. Water from an approved source will be mixed with these bentonite powders or chips to form thick slurries. The seal will consist of a high-solids (i.e., 30% or greater), high-viscosity (greater than 120 s, using the Marsh Funnel method) bentonite slurry (e.g., Pure Gold Grout™) that will be emplaced in the borehole by means of a tremie. The slurry seal will be placed in one continuous operation.

Cement grout should consist of a mixture of Portland cement (ASTM C 150-89) and water, in the proportion of 5 to 6 gal of clean water per bag (94 lb or 1 ft^3) of cement. Because of volumetric shrinkage, an additive should be combined with the cement to cause it to expand on setting, thus providing a tighter seal (Aherns 1970; Sutton and Sabins 1990). The two primary choices are aluminum powder (1%) and gypsum (3% to 6%).

3.3.2 Installation Procedures

The stainless steel well screen and riser pipe are lowered to the predetermined depth and held in position by suspending the riser pipe or column.

Centralizers should be attached immediately above the well screen and also, where necessary, to ensure an adequate distribution of filter pack and sealants. When the couplings are threaded together, each O ring must be inspected prior to tightening to ensure that the seals will be adequate for subsequent testing prior to completion of the well. When tightening the couplings, the O rings should be lubricated with water or some acceptable silicon gel to prevent dislodging the O ring during tightening. Based on known contaminants in the 300-FF-5 operable unit, O rings should be composed of Viton, which is a fluorocarbon elastomer. However, if high concentrations of methyl ethyl ketone, methyl isobutyl ketone, or methylene chloride are encountered during drilling, ethylene propylene should be used as the O ring elastomer material in strata containing any of those chemicals.

3.3.3 <u>Well Casing Integrity Test</u>

Next, a test with packers is conducted to determine if the casing O ring integrity is adequate (Figure 17). This test is needed in this special case (seal emplacement across a confining layer) because joint leakage must be eliminated as a pathway so that seal leakage can be evaluated following emplacement of the M3 layer seal.

After the 4-in. casing has been installed to its design depth within the borehole (i.e., but prior to sand pack and bentonite/grout seal installation), the integrity of the casing joint connections should be tested for leakage. Alternate methods of casing integrity testing will be explored. The following is a description of a constant-head injection test that could be used. To conduct the integrity test, an inflatable packer, with a sealing length of 2 ft or greater, should be installed below the bottom casing tubing joint connection and inflated with pressure greater than 50 $lb/in.^2$ above the planned constant-head injection pressure (i.e., above the hydrostatic pressure exerted at the packer depth). The packer can be installed on pipe or wireline. The critical factor is that the system must be free of leakage. The inside of the casing should be filled with fresh water from an approved source, and then the decline of water level within a smaller diameter manometer (e.g., 0.25 to 0.75 in.) mounted on the 4-in. casing at ground surface should be monitored (see Figure 17). The decline in water level within the surface manometer can

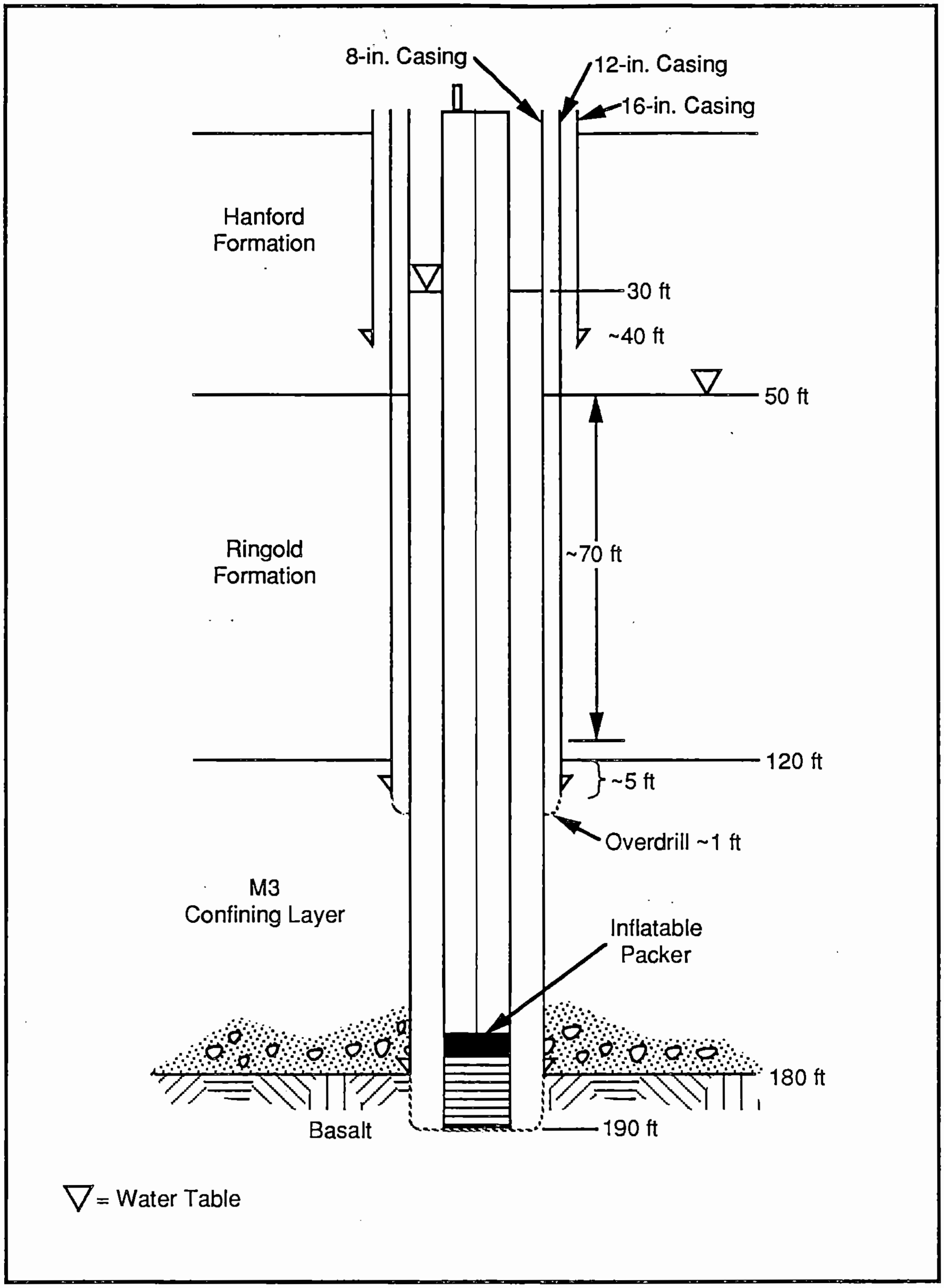

FIGURE 17. Borehole Configuration, Well Casing Integrity Test

be measured directly with standard hydrologic water-level-detection equipment. The surface manometer should be re-topped with fresh water after every water-level measurement, and the quantity used in refilling recorded.

To minimize the effects of multiphase conditions and thermal equilibration of the fluid column inside the 4-in. casing, the fresh water should be maintained at a temperature close to the expected, equilibrated, geothermal temperature (i.e., ≈55° to 60°F) and added by means of a tremie, which has its delivery end located near the base of the well. Leakage rates in excess of 5 mL/min should be considered significant. This was calculated using Darcy's law for a leakage feature with a hydraulic conductivity of 10^{-5} cm/s, width of 1 mm, casing thickness of 0.25 in., and an applied head of 50 ft. In these situations, an effort should be exerted to determine the general location of the joint leakage. To determine the location of joint leakage, the packer should be reset at a higher position in the 4-in. well and the test conducted again. This resetting sequence is continued until the leaking joint is identified. A duplication of leakage rate estimates for this test would indicate that the leaky joint connection occurs above the packer setting. A significant decrease in leakage (i.e., ≤1 mL/min), however, would indicate that the leaky joint connection is below the new packer setting.

If a leaky joint connection is identified, the casing should be removed from the borehole and the leaky connection joint replaced or repaired. After completion of each test, water in the well should be removed prior to releasing the packer to minimize water lost to the horizon that will be monitored. The preferred method for removal of the water is air lifting. The water level should be lowered slightly below the natural water level of the formation to ensure that formation water enters the well.

3.3.4 Well Construction

The top of the screen must be set 3 ft below the top of the permeable sediments overlying the basalt because the primary filter pack must extend at least 3 ft above the well screen (Figure 18). Also, if permeable sediment (i.e., sand and gravel) is not present, the top of the 10-ft or shorter well screen should be set 3 ft below the top of the basalt surface to minimize the potential of fines from entering the well screen from the M3 layer. The

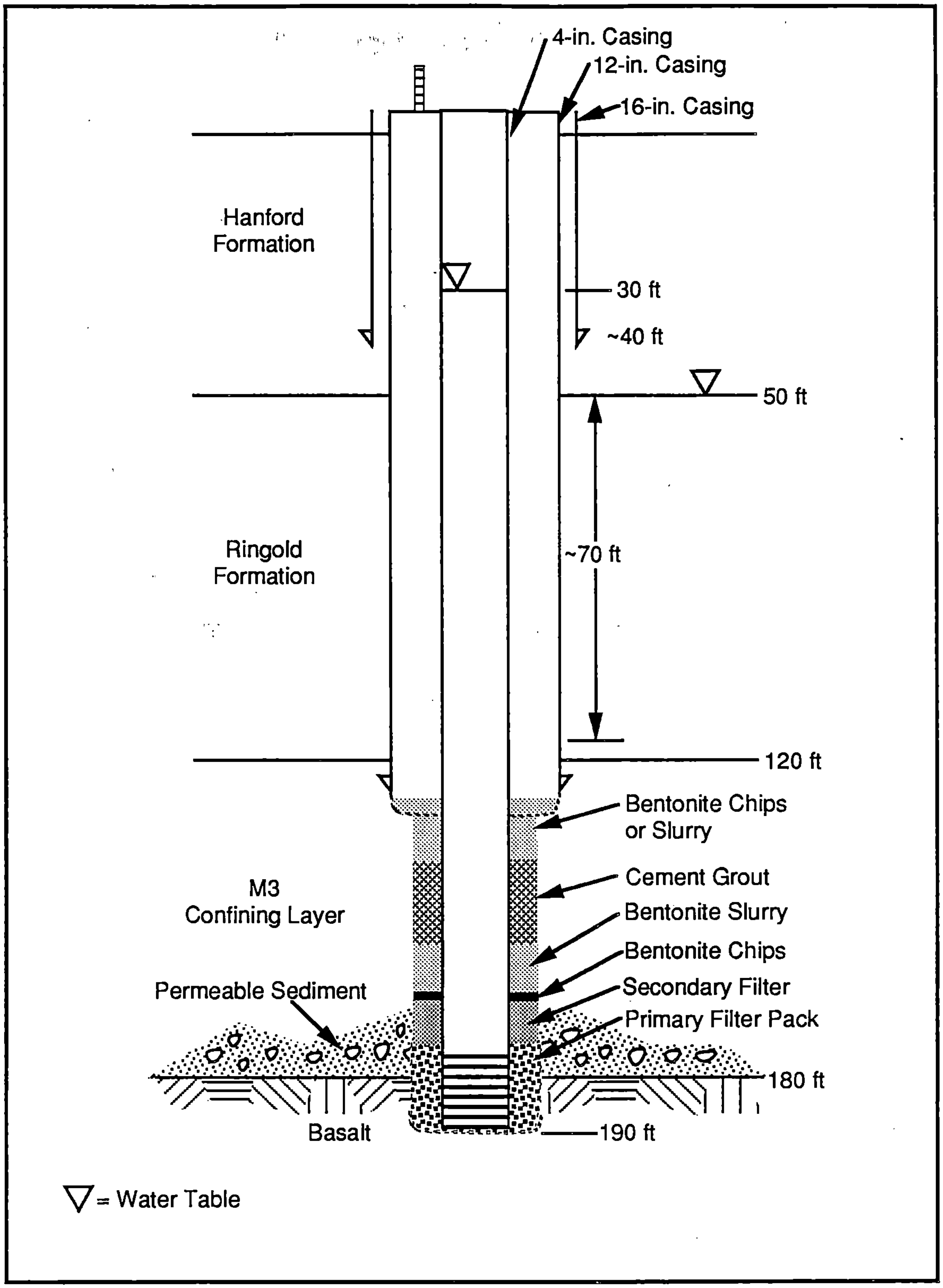

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FIGURE 18. Borehole Configuration, M3 Layer Seal Test

primary filter pack should be extended to 3 ft above the top of the screen, so that the top of the filter pack is the same as the bottom of the M3 layer. This filter material is poured into the annular space through a clean, flush-threaded tremie (1-in. minimum diameter) that has been lowered to below the water surface. The volume of the filter pack required to fill the annular space between the well screen and the borehole must be computed and carefully measured. While suspending the riser pipe, the temporary casing (8 in.) should be carefully withdrawn until the lowermost point on the casing is within approximately 2 ft from the top of the filter-packed portion of the hole. This casing withdrawal/sand emplacement should be accomplished in increments (lifts).

To prevent downward migration of a bentonite slurry into the sand pack, a carefully measured volume of secondary filter sand should be placed above the top of the primary filter pack. This filter material is poured into the annular space through a clean, flush-threaded tremie that has been lowered to within 3 ft of the water surface. The secondary filter should be 1 to 2 ft thick, and added quickly in one operation. This will allow for adequate segregation of the particle sizes (Schalla and Walters 1990). In addition, a 3- to 5-ft-thick layer of bentonite chips is to be emplaced by means of a tremie on top of the secondary filter.

The following is a description of the process in which bentonite slurry and cement grout should be placed. The general guidance provided may require modification, depending on actual field conditions. The bentonite slurry and chips will be the only form of bentonite used below the water table. The bentonite slurry will be pumped under pressure into the annular space between the permanent and temporary 8-in. casing using a tremie. The end of the tremie must be equipped with a side-discharge array to prevent displacement of the bentonite chips and secondary filter. The openings of the discharge pipe should be approximately 2 ft above the bentonite chips or point of emplacement. The pull back of the temporary casing will be conducted concurrently during emplacement of the bentonite slurry, always keeping the bottom of the tremie immersed in the slurry to prevent gaps in the seal. A minimum of 2 ft of materials (sand, pellets, grout, or slurry) will be maintained in the annulus during emplacement. It is recommended that no more than 5 ft of filter pack, 2 ft of bentonite chips, or 20 ft of bentonite slurry be installed before the casing is pulled back.

A small quantity of bentonite slurry (e.g., Pure Gold Grout™) will be emplaced immediately above the bentonite chips. The grout should extend 5 to 10 ft above the chip layer and, therefore, the grout will always be opposite the M3 layer (see Figure 18). Great care must be taken in emplacing the grout to avoid destroying the M3 Layer. Allow at least 12 h for the Pure Gold Grout™ slurry to set before emplacing the cement grout. Also, before preparing to mix the cement grout, test the set of the Pure Gold Grout™ by lowering a 10-lb steel weight to determine if the bentonite is sufficiently firm to proceed with grouting.

The cement grout will be emplaced by means of a tremie into the open annulus from immediately above the Pure Gold Grout™ seal to 10 to 12 ft below the top of the M3 layer. The preferred technique for placing the cement grout plug is the balanced method technique of Smith (1976). The top of the cement grout will be within 5 to 7 ft of the bottom of the 12-in. temporary casing. The 8-in. casing should be pulled 1 ft above the top of the cement grout seal. Allow 8 h for the cement grout to set. If the grout settles more than 5 ft or if the net thickness of the cement grout layer is less than 10 ft, add a small amount of cement grout to refill the annulus to within 5 to 7 ft of the bottom of the 12-in. casing.

Next, either bentonite chips or bentonite slurry are used to fill the annulus to the bottom of the 12-in. casing. Chips should be dropped into the annulus slowly through a 1.5- to 2.0-in. tremie, and measured frequently to ensure that the bentonite chips are not bridging. If a bentonite slurry is used, a small quantity of Pure Gold Grout™ will be installed immediately above the cement grout layer. The bentonite slurry should extend to the bottom of the 12-in. casing (see Figure 18). The 8-in. casing will have to be removed completely from the borehole. Allow at least 12 h for the Pure Gold Grout™ slurry to set before emplacing the equipment for testing the effectiveness of the annular seal opposite the M3 layer. Before testing the seal, water-level data must be collected in the annulus to determine the amount of moisture losses to the bentonite, which will continue to hydrate. Although it is expected that the water loss caused by continuing hydration of the bentonite will probably be insignificant, measurements should be taken with a high-resolution transducer/data logger before conducting the seal test to confirm that the change in water volume is not significant. Before measuring these changes, sufficient water should be removed from the well, so that the water level in the annulus is approximately equal to the water level in the unconfined aquifer; that is, there should be no significant energy difference to cause flow into or out of the annulus.

3.3.5 M3 Layer Seal Test

The bentonite-cement seal across the M3 layer is tested by monitoring water levels inside and outside the 4-in. casing. A falling water level in the 4-in. casing to near what is present in the unconfined aquifer would indicate a leak in the M3 layer seal. Water levels in the annulus between the 4- and 12-in. casings will be used to indicate seal integrity. If the water level in the annulus stabilizes at the confined aquifer level or some intermediate level between the confined and unconfined water levels, an M3 layer leak is indicated. A falling, intermediate water level can be attributed to a failure in the 12-in. casing seal that might mask a slower leak in the M3 seal. If this occurs, the water level should be lowered to the unconfined aquifer level and observed for changes. An increase in water level would indicate an M3 seal failure. If the water level stabilizes at the unconfined aquifer level, a 12-in. casing seal failure is indicated. If the water level stabilizes outside the range between the level of the two aquifers, good seals across the M3 layer and the 12-in. casing are indicated. If at this point the M3 layer seal is shown to be leaking, the review team will be convened to decide a corrective action. This action may range from emplacement of a more elaborate seal using pressure grouting to well abandonment.

3.3.6 Unconfined Aquifer and Vadose Zone

If the test indicates an adequate seal, then the remainder of the borehole annulus should be sealed with bentonite chips or slurry to within 21 ft below ground surface (Figure 19). The 10-in. temporary casing should be

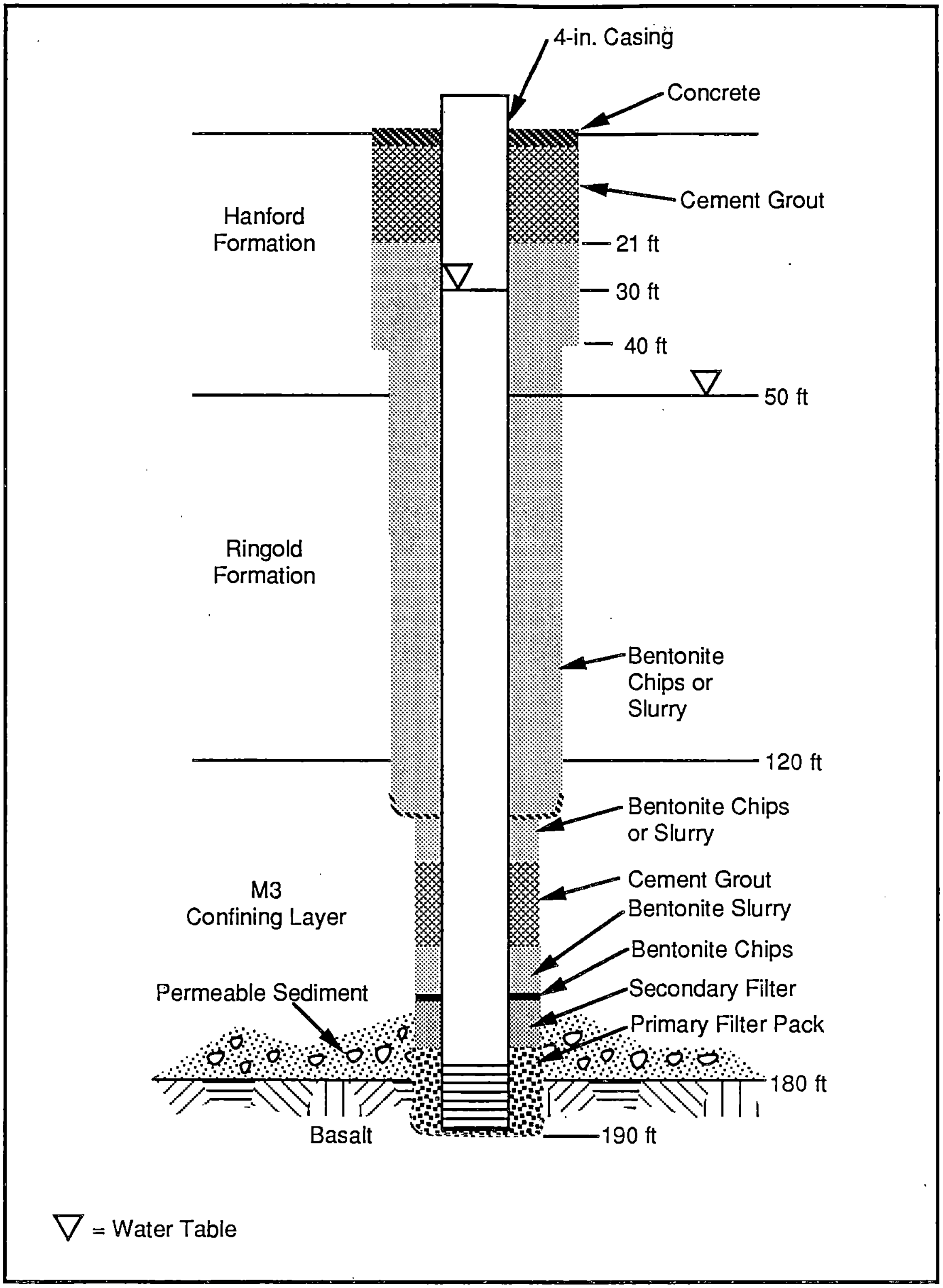

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FIGURE 19. Borehole Configuration, Final Completion

removed as grouting proceeds. Then, once the drive shoe of the 10-in. casing is up to the drive shoe of the 12-in. casing, the 10-in. casing should be removed completely. Above 21 ft below ground surface, the wells should be completed in accordance with the standard specifications for cement grout and concrete.

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