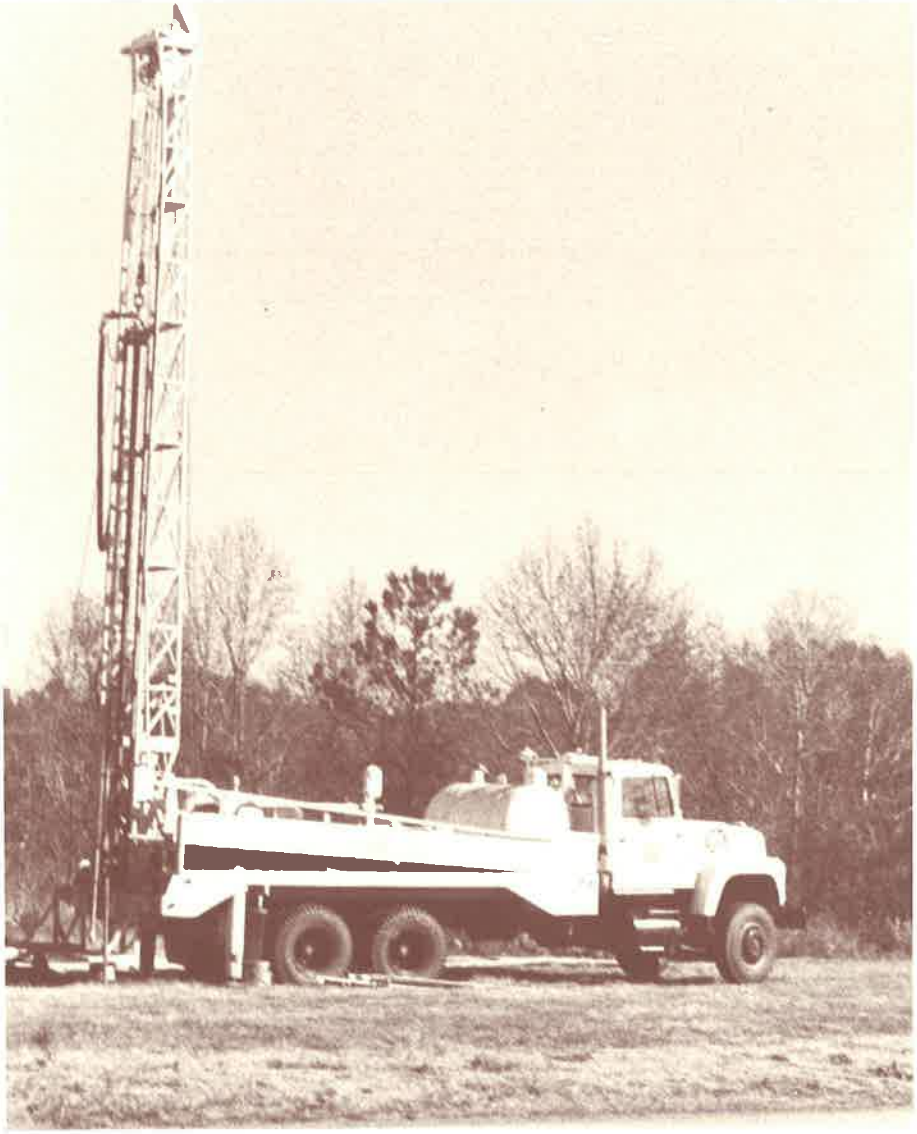
MONITORING WELL CONSTRUCTION FOR HAZARDOUS-WASTE SITES IN GEORGIA

by

William H. McLemore



Department of Natural Resources
Environmental Protection Division
Georgia Geologic Survey

Circular 5

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INTRODUCTION

In the past year, the Georgia Geologic Survey has been called upon on several occasions either to drill or comment upon the drilling and construction of monitoring wells. Typically, these wells were designed to evaluate the hydrology and geochemistry of the ground-water regime at existing or proposed hazardous waste facilities. With the above in mind, it is appropriate that we delimit our philosophy by which we construct monitoring wells or by which we would evaluate monitoring wells constructed by others. Obviously, because monitoring wells are designed to "look-at" the ground-water regime as well as gather water samples, local geologic conditions will play an important role in actual well construction, and rigid adherence to any set of criteria is neither practical nor prudent. Rather, our only objective in summarizing our philosophy in this Circular is to establish a set of "side-boards" that would be expected in a monitoring well construction program, which nevertheless, could be modified as local conditions dictate. The approaches set forth in the following sections are based on the experiences of the author in drilling and constructing many hundreds of monitoring wells in various parts of the country. The narrative is written in simple practical terms for geologists or engineers already familiar with the science of ground-water hydrology as well as well-drilling procedures. Lengthy technical descriptions are not provided; rather, the reader is referred to numerous USGS, EPA (especially a document such as EPA Manual SW-611) and other technical documents for such descriptions.

DRILLING SUPERVISION

Drilling and construction of monitoring wells should be under the close supervision of an experienced geologist or engineer. Changes in lithology, bedrock voids, pinchouts and so forth are rarely appreciated or observed by drillers. Obviously, as such variations affect hydrologic conditions, the geology of any site should be well understood.

For example, the author worked on a project to monitor a contamination plume at a manufacturing facility in the Coastal Plain of a mid-Atlantic state. At the manufacturing site, the shallow unconfined aquifer was separated from a deeper artesian aquifer by a dense clay. Also, the shallow aquifer was at a higher head than the deeper aquifer. Flow direction in the shallow aquifer was toward the northeast, whereas in the deeper aquifer, flow was toward the southwest. However, the detailed notes and observations of the field geologist indicated that the clay was thinning in a northeasterly direction; and apparently, the clay pinched-out immediately offsite and the two aquifers merged. As the site geologist had made careful observations and had taken good notes, it could be postulated that the plume was moving to the northeast, flowing over the lip of the pinchout into the deeper but lower head artesian aquifer, and thence moving to the southwest back underneath the manufacturing facility. Such an interpretation never could have been developed without having an experienced geologist continuously observing drilling operations and collecting cuttings.

Based on my experience, a single well-trained (i.e., at least one year of rig time) geologist or engineer can supervise two drilling rigs as long as they are not too far apart (i.e., a walk or drive of 5 minutes or less) and no other ancillary duties are required. If water sampling, pump testing, well development and so forth are scheduled, additional personnel would be necessary.

Drilling supervision by an experienced geologist or engineer also permits monitoring wells to be constructed to rather precise tolerances. By using a weighted steel measuring tape, sand/gravel packs, seals and so forth can be placed with an accuracy of ± ½ foot. Similarly, a competent geologist or engineer should know the depth within ± 1 foot of the boring at any time. And by collecting cuttings or noting variations in drilling progress/speed, the geologist or engineer should be able to make accurate predictions regarding changes in lithology, in those portions of the boring where samples are not being collected.

SELECTION OF THE DRILLING RIG

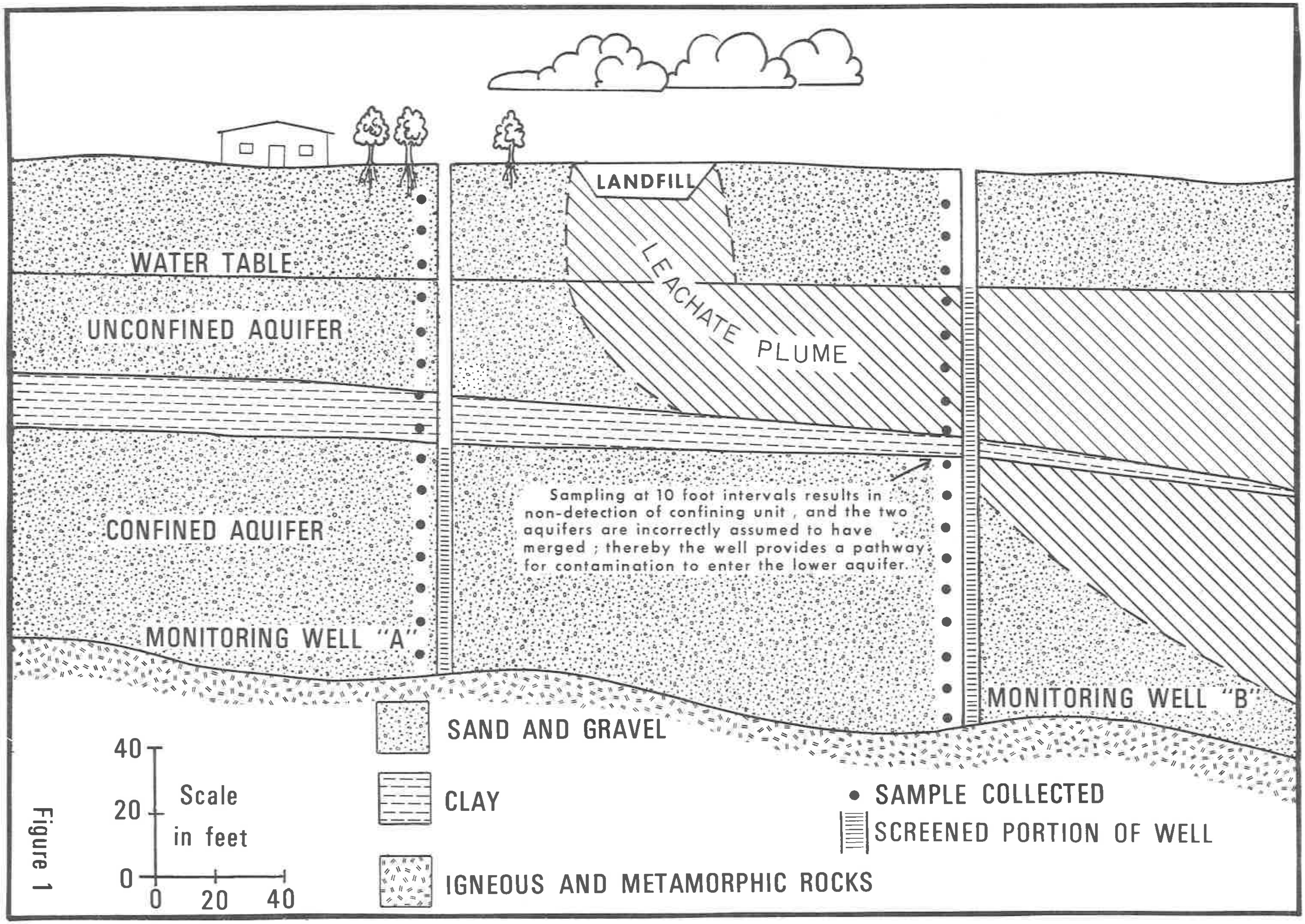
Selection of the drilling rig is extremely important. Because placement of screens and seals is extremely crucial in properly evaluating specific geologic horizons, the drill rig **must** have the capability to collect samples. Also, because porosity and permeability measurements, grain size, or strength tests may be necessary, the drill rig also should have the ability to collect undisturbed samples.

Cleanliness is another important criterion for the drill rig. Typically, drill rigs used for the construction of monitoring wells are contracted; and often they are covered with grease and grime from many different projects. As such grease and grime may contain a wide variety of solvents, metals or other chemicals, one cannot discount the possibility that trace amounts of contaminants may be introduced to the well. The author is aware of a situation where a drill rig was used for soil borings at a petrochemical complex in New Jersey and subsequently was employed for the construction of monitoring wells at a New York manufacturing plant. When unusual hydrocarbon compounds were detected in some of the monitoring wells at the manufacturing plant, management became quite concerned, as these hydrocarbon compounds were neither used nor stored at the plant. Finally, after much frustration, it was recognized that the hydrocarbon compounds had been "carried" by the drill rig from the petrochemical complex to the manufacturing plant. Such a situation easily can be mitigated by using a clean drill rig. The simplest way to obtain a high level of cleanliness is to steam clean the drilling rig. Steam jennys can be found almost everywhere; and steam cleaning of the drill rig more or less eliminates the possibility of "carrying" contaminants onto the site.

Thirdly, any drill rig used in the drilling and construction of monitoring wells should be free of oil and fuel leaks. Any oil or fuel leaking into the mud pad or adjacent to the bore hole will almost certainly enter the well. If this were to occur, total organic carbon (TOC) levels or detection of fuels and greases in ground-water samples might be spurious. Introduction of oils and fuels into the ground-water regime can be prevented by the site geologist or engineer performing a daily inspection of the drill rig and insisting that the driller tighten all parts, replace gaskets, and so forth.

SAMPLING

Sampling is especially important in any program of monitoring well construction. The reason for this is quite simple; namely, without a good understanding of lithologic variations, the screens and seals, which are so important in monitoring well construction, cannot be properly placed. Such samples also are useful in evaluating permeability, porosity, or subtle changes in facies. Moreover, an improperly constructed monitoring well can be a vehicle for interaquifer contamination. For example, as illustrated in Figure 1, an inappropriate sampling program can lead to an incorrect interpretation of stratigraphy, with resultant improper well construction. The author has found that, at those sites where comprehensive and rigid sampling programs were performed, well construction problems were minimal. Conversely, where sampling was de-



Sampling at 10 foot intervals results in non-detection of confining unit, and the two aquifers are incorrectly assumed to have merged; thereby the well provides a pathway for contamination to enter the lower aquifer.

Figure 1

emphasized, wells commonly were improperly drilled or located, and in some cases had to be drilled-out and plugged. The costs saved by curtailing or minimizing sampling are only imaginary. Drilling-out wells is prohibitively expensive as well as being emotionally quite frustrating. Rather, it is much more simple to initiate a comprehensive sampling program from the beginning.

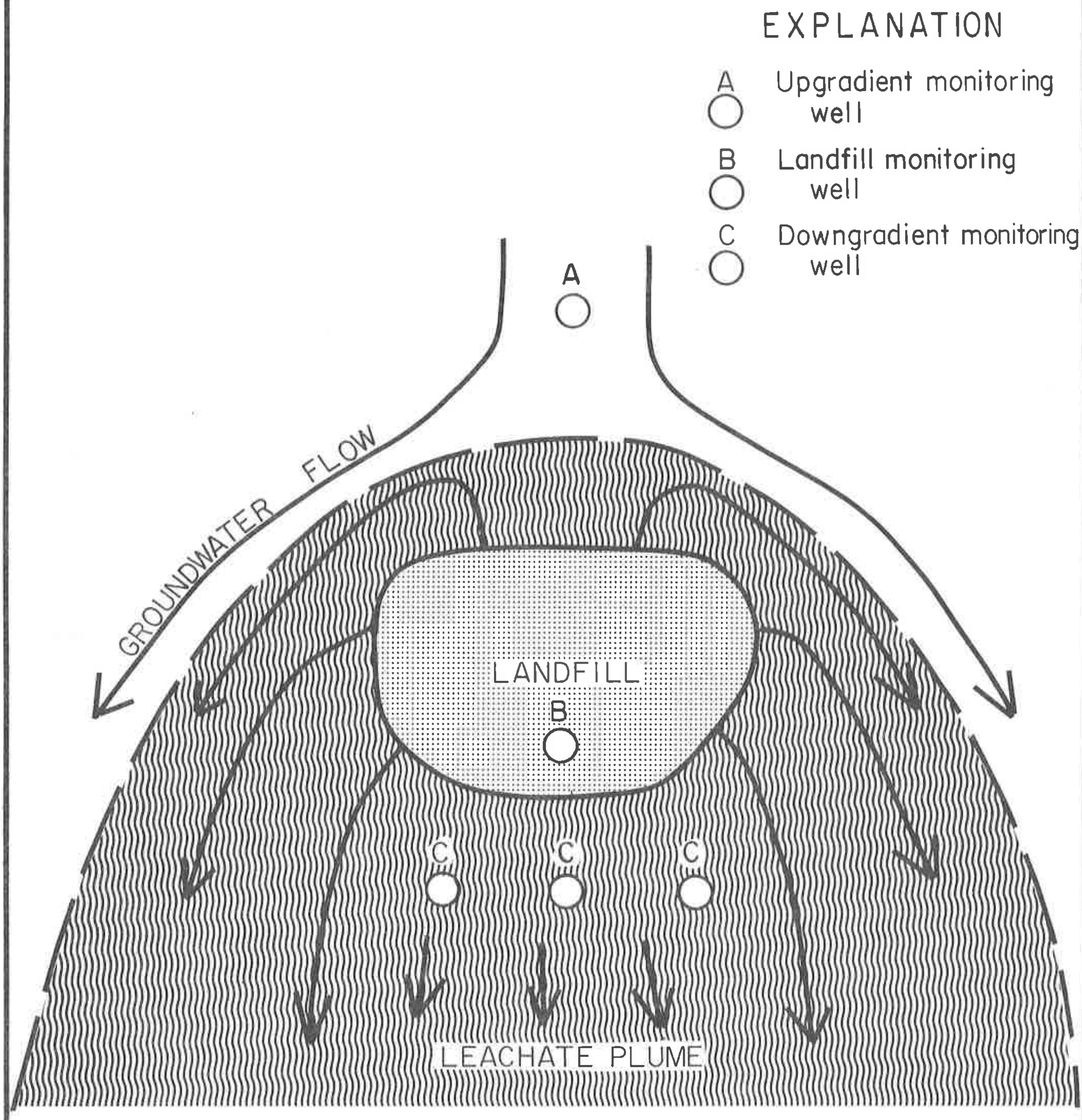
SELECTION OF MONITORING WELL SITES

One of the greatest mistakes any program of monitoring wells can incur is to "cut-corners" and drill an inadequate number of monitoring wells to properly assess or monitor the flow regime at the site. As an absolute minimum and where the site hydrology is simple and relatively well understood, five wells per aquifer system are necessary. Figure 2 illustrates a typical but yet quite simple arrangement of monitoring wells.

In the winter and spring of 1980, the Georgia Geologic Survey conducted a monitoring well program at a ten-acre hazardous waste facility in Wilkinson County, Georgia. The following description, which is from the report describing the results of this program, provides insight into how monitoring wells can be located:

> .... The first three Tuscaloosa aquifer wells (#1, #3, and #5) were selected to bracket the waste disposal trenches and establish the general direction of ground-water flow. Well #1 was drilled upslope from the burial trenches in order to penetrate a maximum (complete) thickness of the Twiggs Clay. Wells #3 and #5 were positioned downslope from the burial trenches at locations which, from field observations, appeared compatible for intercepting any potential migrating leachate.
>
> As these three wells generally form an equilateral triangle, true direction of ground-water flow within the Tuscaloosa can be established by performing a simple "3-point problem". (Note: from geometry, we know that 3 points determine a plane; hence the potentiometric surface, which is more or less a plane, also can be estimated.) Once the general direction of ground-water flow was established, wells #7 and #8 were drilled at locations that would be favorable for intercepting any leachate migrating from the trenches.
> In summary:
>
> (1) Wells #1, #3 and #5 were used to establish the general direction of ground-water flow in the Tuscaloosa as well as serve as monitoring wells.
>
> (2) Wells #7 and #8 were located at positions (identified from the direction of ground-water flow) favorable for intercepting any potential migrating leachate.
>
> .... Shallow wells #2, #4, and #6 were designed to evaluate the sandy zone at the base of the "upper" Twiggs Clay. For convenience, the shallow wells were placed adjacent to existing Tuscaloosa wells.
>
> Well depths for the first three Tuscaloosa wells were such that the wells penetrated a minimum of 20 feet of water bearing Tuscaloosa. After development, it was noticed that the water level in well #3 had dropped and was significantly lower than the levels in wells #1 and #5. This suggested perched water conditions; therefore, wells #7 and #8 were drilled through a minimum of 50 feet of water bearing Tuscaloosa. Also, in these latter two wells, steel casing was installed into a lignitic clay, thereby permitting us to assess the hydrogeological regime in the main water bearing zone of the Tuscaloosa beneath the lignitic clay....

In summary, indiscriminant drilling of monitoring wells on a site is counterproductive. Wells clearly need to be placed in locations favorable for intercepting any actual or potential plumes. Where the general flow patterns are not well understood, it is recommended that the initial wells be drilled to establish the hydrogeological regime. The latter wells, in turn, should be drilled to monitor specific facilities or potential contaminant sources. Considering the size of the facility in question, the number of potential onsite and offsite contaminant sources, as well as the geologic complexity of the site area, the number of wells could range from five to perhaps several hundred.



Typical arrangement or placement of monitoring wells (modified from EPA document SW-611).

Figure **2**

MONITORING WELL CONSTRUCTION

General

Monitoring wells may be of a variety of sizes, but 4-inch diameter wells are considered optimum as they are most versatile. A well of such diameter provides an opening adequate for the installation of a 3-inch submersible pump suitable for either well evacuation or water sampling. Also, such a diameter is amenable for gamma logging. Smaller diameter wells (i.e., 3-inch or 2-inch) are useful only where the water level is within about 30 feet of the surface as they typically are evacuated or sampled by means of a centrifugal pump.

The principal advantage of small diameter wells (namely 2-inch or smaller) is that they can be installed through the auger-flights of a hollow stem auger drilling rig. More complicated rotary drilling methods are required for 3 and 4 inch wells.* On the other hand, augers have great difficulty penetrating gravel zones or saprock, which is the partially decomposed but still resistant bedrock characteristic of much of the Piedmont of Georgia. Tables I and II provide general guidelines used by the Georgia Geologic Survey regarding selection of drilling rig as well as selection of monitoring well diameter. The guidelines presented in Tables I and II are intended to be practical rather than actual. That is, a good driller with an inappropriate drilling rig probably can accomplish more than an incompetent driller with an ideal rig. Therefore, the guidelines should be considered merely as a tool for optimum drill rig and well diameter selection.

The following descriptions and illustrations are for 4-inch diameter wells; naturally, wells of other dimensions would be somewhat different. Nevertheless, the descriptions provide the reader with insight into the necessary precision expected of hazardous waste monitoring wells.

Monitoring Wells in the Piedmont or Blue Ridge:

Typical Piedmont or Blue Ridge monitoring wells are illustrated in Figure 3. In general, ground water in these two physiographic provinces is unconfined, artesian conditions are rare, and the soil (either saprolite or colluvium) and rock aquifers are hydraulically interconnected. Three types of monitoring wells are anticipated in the Piedmont and Blue Ridge: (1) saprolite or colluvium wells, (2) combined soil and rock wells, and (3) rock wells. Each of these is described below:

(1) *Saprolite or Colluvium Wells* - The recommended well construction involves:

- Drilling an 8-inch diameter boring into hard rock;
- Confirming that the boring has bottomed in hard rock (rather than saprock) by NX-coring 5 feet into hard rock with at least 50 percent recovery.* (Note: a good driller often can accurately identify hard rock merely by "feeling" the change in drilling progress; if the driller is capable of making such identification, this coring step may be omitted).

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* The author is aware that 6-inch hollow stem augers are now available. Obviously such a large auger would be extremely versatile and could be used to construct 4-inch wells. Nevertheless, since 6-inch hollow stem augers are so rare in Georgia, I will not address them further.

* The author recognizes that rock coring at the base of a relatively large diameter boring is quite difficult and often involves the use of casing, which potentially may become stuck in the hole. It is not the intent of the author to add a burdensome or unnecessary drilling task, but rather to emphasize the importance of accurately defining the soil-rock interface. If coring can be avoided without compromising the identification of this interface, then by all means do so.

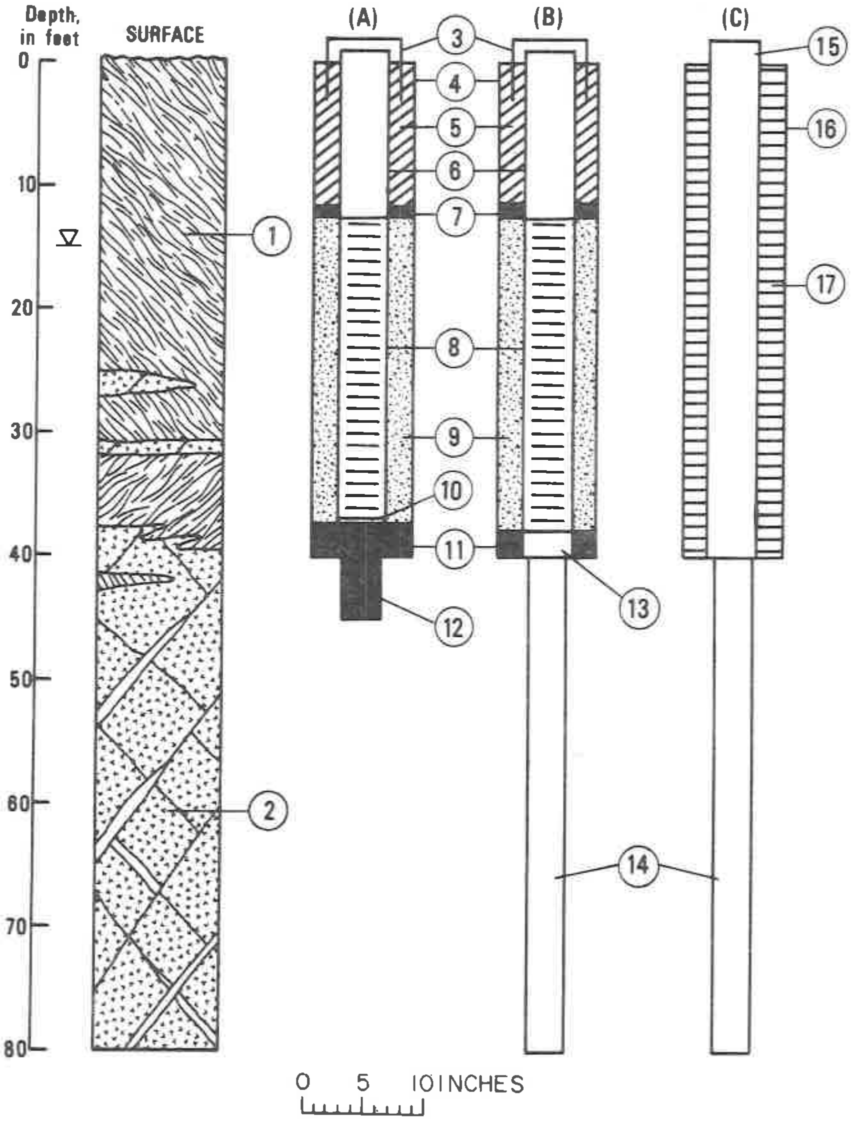
Table I. Guidelines For Drilling Rig Selection

Anticipated Drilling Conditions For Well Construction Program	**Optimum Drill Rig** **Auger**	 **Rotary**
(1) Shallow water table (less than 30 feet)	Yes	Yes
(2) Deep water table (greater than 30 feet)	No	Yes
(3) Gravel and resistant zones	No	Yes
(4) Loose sand or thick clays	Difficult	Yes
(5) Undisturbed samples required	Difficult	Yes
(6) Disturbed samples required	Yes	Yes
(7) Depth to bedrock less than 80 feet	Yes	Yes
(8) Depth to bedrock greater than 80 feet	Difficult	Yes
(9) Rock coring	Yes	Many rotary rigs are not capable of coring
(10) Seals and screens to be placed at specific intervals	Difficult	Yes

Table II. Guidelines For Selection Of Monitoring Well Diameter

Anticipated Drilling Conditions For Well Construction Program	**Monitoring Well Diameter**		
	2-inch	**3-inch**	**4-inch**
(1) Shallow water table (less than 30 feet)	Yes	Yes	Yes
(2) Deep water table (greater than 30 feet)	No	Possibly	Yes
(3) Well to be considered for decontamination or dewatering	No	Possibly	Yes
(4) Well to be sampled on frequent basis	Possibly	Possibly	Yes
(5) Water level recorder to be installed	No	Difficult	Yes
(6) Clayey soils that may be difficult to develop	No	Possibly	Yes
(7) Bedrock coring NX-sized or overburden to be cased-off.	No	No	Yes
(8) Gamma logging anticipated	No	Yes	Yes

TYPICAL PIEDMONT OR BLUE RIDGE MONITORING WELLS



EXPLANATION

(1) Saprolite/colluvium (soil), usually highly weathered near surface, progressively less weathered at depth.

(2) Crystalline bedrock, grading from partially weathered saprock to virtually unweathered rock; fracture porosity.

(3) Protective steel casing with locking cap.

(4) 8-inch boring.

(5) Bentonite-cement mixture tremie-grouted into annular space between PVC casing and edge of bore hole.

(6) Blank 4-inch PVC casing.

(7) Bentonite pellet seal placed into annular space between PVC casing and edge of bore hole.

(8) 4-inch PVC screen with appropriately sized slots; top of screen is placed above unconfined water table surface and takes both seasonal and multi-year fluctuations in water levels into account.

(9) Sand/gravel pack.

(10) PVC cap.

(11) Bentonite pellet seal; for saprolite/colluvium (soil) wells, the seal fills both the drilled and cored portion of the boring thereby isolating and separating the soil and rock aquifers; for combined soil and rock wells, the seal is placed in the annular space opposite a short piece of blank PVC at the base of the drilled portion of the boring, thereby preventing the overlying sand/gravel pack as well as rock debris from "falling into the cored portion of the boring".

(12) NX-sized core hole to confirm character of bedrock.

(13) Short piece of blank 4-inch PVC casing, opposite which a bentonite pellet seal is placed.

(14) NX-sized core hole.

(15) 4-inch steel casing with locking cap.

(16) 8-inch boring.

(17) Neet cement pressure grouted into annular space between 4-inch steel casing and edge of bore hole; if well is shallow, a bentonite-cement mixture may be tremie-grouted into the annular space.

(A) Saprolite/colluvium (soil) well.

(B) Combined soil/rock well.

(C) Rock well.

∇ Unconfined water level.

NOTE: Horizontal scale only applied to wells; no horizontal scale implied for lithologic section.

Unless otherwise stated, porosity is intergranular.

Figure 3

- Backfilling with expandable bentonite pellets to slightly above the soil-rock contact. By doing such, the boring can be hydraulically separated from the rock aquifer.

- Installing slotted PVC screen of appropriate size from the bottom of the boring to several feet above the water table. The base of the screen should be capped; and the top of the slotted portion of the screen should take into account both seasonal as well as multi-year fluctuations in water levels. Blank PVC casing is extended from the top of the screen to one or two feet above ground surface.

- Filling the annular space between the bore hole and the PVC screen with an appropriate sand/gravel pack.

- Placing a one or two foot thick bentonite pellet seal above the sand/gravel pack.

- Tremie-grouting a bentonite-cement mixture to the ground surface in the annular space between the bore hole and the PVC casing.

- Cementing in a 5-foot (3-feet below ground and 2-feet above ground) section of protective 6-inch steel pipe with a locking cap.

(2) *Combined Soil and Rock Wells* - In this case, well construction is similar to that for saprolite/colluvium wells except that the NX-sized coring is not stopped at 5 feet, but rather is continued until an adequate section of saturated rock is penetrated. (Based on the author's experience in Georgia, the saturated rock portion of the well should be at least 40 feet.) Also, recommended at the base of the soil portion of the well is a 2-3 foot section of blank PVC casing, with a 2-3 foot bentonite pellet seal in the opposite annular space. Such casing and seal often are necessary to prevent rock and/or the sand/gravel pack from sloughing-off into the cored portion of the well. Combined soil and rock wells are difficult to drill and construct, and often it is most prudent to drill two separate wells (a soil well and a rock well) side by side at a few feet apart.

(3) *Rock Wells* - For this type of well, the recommended well construction involves:

- Drilling an 8-inch diameter boring into the hard rock.

- Confirming that the boring has bottomed into hard rock by NX-coring 5 feet into rock with at least 50 percent recovery (refer to earlier descriptions regarding identification of soil/rock interface).

- Cementing-in, by pressure grout methods, 4-inch steel casing.

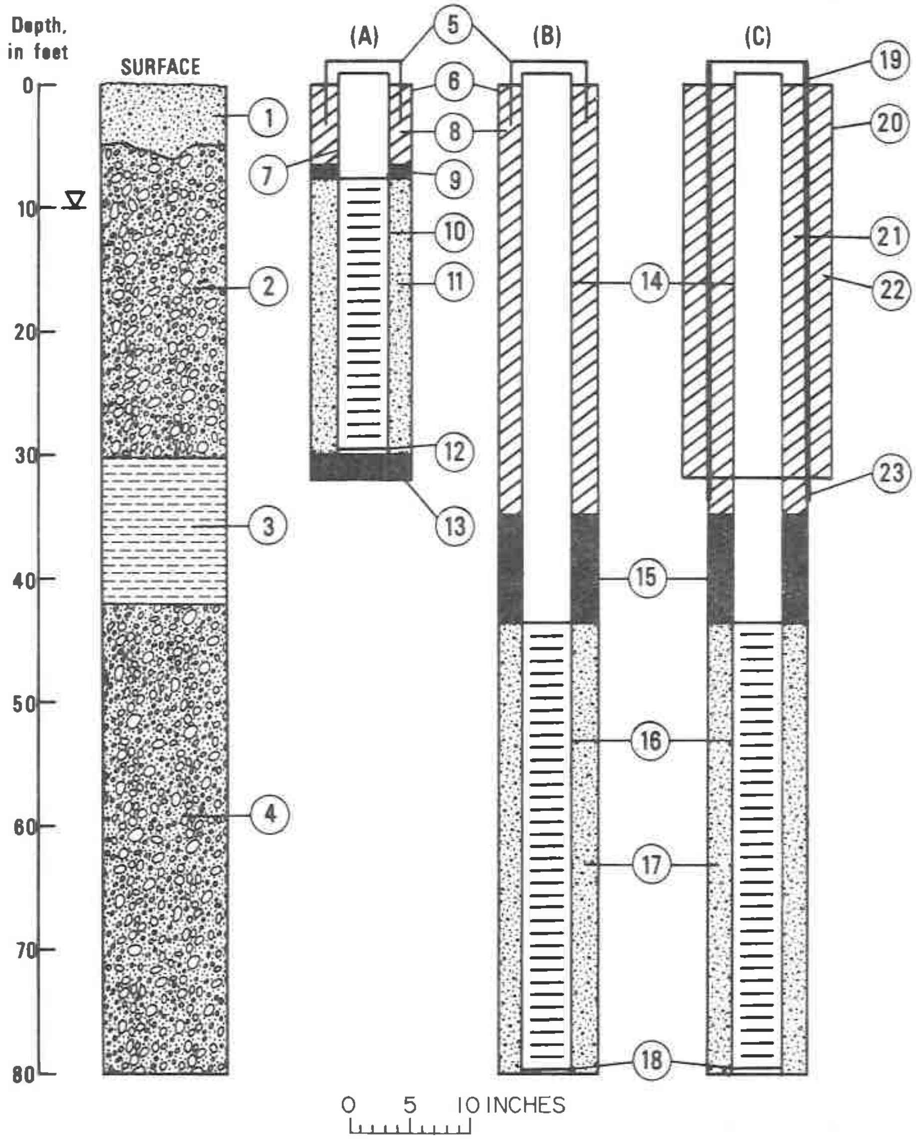
- NX-coring an appropriate depth into rock.

- Attaching a locking cap to the 4-inch steel casing.

Monitoring Wells in the Coastal Plain:

Typical Coastal Plain monitoring wells are illustrated in Figure 4. In the Georgia Coastal Plain, the shallow aquifer is typically unconfined and underlain by one or more artesian aquifers. Two types of monitoring wells are anticipated in the Coastal Plain: (1) shallow aquifer wells and (2) deeper (artesian) aquifer wells. The deeper wells are of two types; a simple construction and a more complex construc-

TYPICAL COASTAL PLAIN MONITORING WELLS



EXPLANATION

(1) Uppermost sandy soils.
(2) Shallow unconfined aquifer.
(3) Confining unit.
(4) Deeper artesian aquifer.
(5) Protective steel casing with locking cap.
(6) 8-inch boring.
(7) Blank 4-inch PVC casing.
(8) Bentonite-cement mixture tremie-grouted into annular space between PVC casing and edge of bore hole.
(9) Bentonite pellet seal placed into annular space between PVC casing and edge of bore hole.
(10) 4-inch PVC screen with appropriately sized slots; top of screen is placed above unconfined water table surface and takes both seasonal and multi-year fluctuations in water levels into account.
(11) Sand/gravel pack.
(12) PVC cap.
(13) Bentonite pellet seal backfill to slightly above the contact between base of shallow aquifer and top of confining unit.
(14) Blank 4-inch PVC casing.
(15) Thick bentonite pellet seal placed into annular space between PVC casing and edge of bore hole opposite confining unit.
(16) 4-inch PVC screen with appropriately sized slots; top of screen is slightly below contact between base of confining unit and top of deeper aquifer.
(17) Sand/gravel pack.
(18) PVC cap.
(19) 8-inch steel casing with locking cap.
(20) 12-inch boring.
(21) Bentonite-cement mixture tremie-grouted into annular space between PVC casing and 8-inch steel casing.
(22) Bentonite-cement mixture tremie-grouted into annular space between 8-inch steel casing and edge of bore hole.
(23) 8-inch steel casing either driven or spun-into confining unit.
(A) Shallow unconfined aquifer well.
(B) Deeper artesian aquifer well (simple construction).
(C) Deeper artesian aquifer well (complex construction).
∇ Unconfined water level.

NOTE: Horizontal scale only applies to wells; no horizontal scale implied for lithologic section.

Unless otherwise stated, porosity is intergranular.

Figure 4

tion, for which steel casing is extended into the confining unit separating the shallow from the deeper aquifer. USE OF STEEL PROTECTIVE CASING IS RECOMMENDED WHENEVER THERE IS ANY POTENTIAL, NO MATTER HOW SMALL, FOR CONTAMINATED WATER TO MOVE FROM ONE AQUIFER TO ANOTHER. SPECIAL CARE SHOULD BE EXERCISED SO THAT MONITORING WELLS DO NOT ACT AS PATHWAYS FOR CONTAMINATION. Each of the aforementioned types of monitoring wells is described below:

(1) *Shallow Aquifer Wells* - The recommended well contruction involves:

- Drilling an 8-inch diameter boring to hard rock, to a lower confining unit (illustrated), or until an appropriate section of aquifer has been penetrated (at least 40 feet of saturated material).
- Confirming the lithologic character of the geologic materials at the base of the boring. This may be done by coring, split spoon sampling, Shelby tubes, etc.
- Backfilling with bentonite pellets to slightly above the contact between the shallow aquifer and the lower confining unit or the hard rock. This step may be omitted for those wells merely penetrating saturated material.
- Installing slotted PVC screen of appropriate size from the bottom of the boring to several feet above the water table. The base of the screen should be capped; and the top of the slotted portion of the screen should take into account both seasonal and multi-year fluctuations in water levels. Blank PVC casing is extended from the top of the screen to one or two feet above ground surface.
- Filling the annular space between the bore hole and the PVC screen with an appropriate sand/gravel pack.
- Placing a one or two foot thick bentonite pellet seal above the sand/gravel pack.
- Tremie-grouting a bentonite-cement mixture to the ground surface in the annular space between the bore hole and the PVC casing.
- Cementing in a 5-foot (3-feet below ground and 2-feet above ground) section of protective 6-inch steel pipe with a locking cap.

(2) *Deeper (Artesian) Aquifer Wells* - The recommended simple well involves:

- Drilling an 8-inch diameter boring until an adequate section of the deeper aquifer is penetrated (at least 40 feet).
- Confirming the lithologic character of the geologic materials at the base of the boring. This may be done by coring, split spoon sampling, Shelby tubes, etc.
- Installing slotted PVC screen of appropriate size from the base of the boring to slightly **below** the contact between the deeper aquifer and overlying confining unit. The base of the screen should be capped. Blank PVC casing is extended from the top of the screen to one or two feet above ground surface.
- Filling the annular space between the bore hole and the PVC screen with an appropriate sand/gravel pack.

- Placing a thick bentonite pellet seal above the sand/gravel pack. This seal is quite important in separating the shallow aquifer from the deeper aquifer, and should be of sufficient thickness to insure that the bore hole does not act as a pathway between the shallow and deeper aquifers.

- Tremie-grouting a bentonite-cement mixture to the ground surface between the bore hole and the PVC casing.

- Cementing in a 5-foot (3-feet below ground and 2-feet above ground) section of protective 6-inch steel pipe with a locking cap.

The recommended complex well construction is quite similar except that an oversized (about 12 inches) boring is drilled to the top of the confining unit. Once the presence of the confining unit is established by sampling, 8-inch steel casing is driven-in or spun-into the confining unit. Next, a bentonite-cement mixture is tremie-grouted into the annular space between the bore hole and the steel casing, thereby hydraulically separating the shallow aquifer from the bore hole. The remaining steps are identical to those described above for the simple well construction program except that the locking steel cap can be attached to the 8-inch casing.

Monitoring Wells in the Valley and Ridge:

Typical monitoring wells in the Valley and Ridge are illustrated in Figure 5. From a general hydrogeologic point of view, Valley and Ridge aquifers are quite similar to Coastal Plain aquifers except that the former commonly are steeply dipping and characterized by fracture porosity. From a practical point of view, Valley and Ridge dips are of little consequence in monitoring well construction. When considering the relative small size of the well (only a few inches in diameter), geologic contacts only affect a few inches of bore hole and are of minor concern. Fractures in confining units can easily be isolated from the bore hole by careful use of bentonite pellet seals. For example, the reader should note that bentonite pellet seals illustrated for Valley and Ridge monitoring wells (Figure 5) are substantially thicker than the seals illustrated for Coastal Plain wells (Figure 4). Thus, except for seal placement, Valley and Ridge monitoring wells are constructed in a similar fashion to Coastal Plain monitoring wells.

DEVELOPMENT

Development involves removal of drilling fluids and formational fines from around the bore hole so that the well will produce clear water.

Development adds an insurance factor to minimize the potential that trace amounts of contaminants will be "carried" from one bore hole to the next.* This is the result of fluids in closest proximity to the well (i.e., drilling fluids and ground water immediately outside the bore hole) being removed by the development process. Also, as development removes drilling fluids and formational fines, the water level within the well commonly changes as the well comes into more direct hydraulic intercommunication with the ground-water regime. Thus the water levels in the well more closely reflect the potentiometric surface. Moreover, some metals and organics will preferentially sorb onto fine particulates or be concentrated in the drilling process. Development, therefore, also insures that analytical bias will not occur and that the water samples collected for chemical analyses will be representative of ground water in the vicinity of the well. In summary, IT IS THE OPINION OF THE AUTHOR THAT CHEMICAL AND HYDROLOGIC MEASUREMENTS MADE FROM UNDEVELOPED WELLS ARE SUSPECT AND CANNOT BE RELIED UPON.

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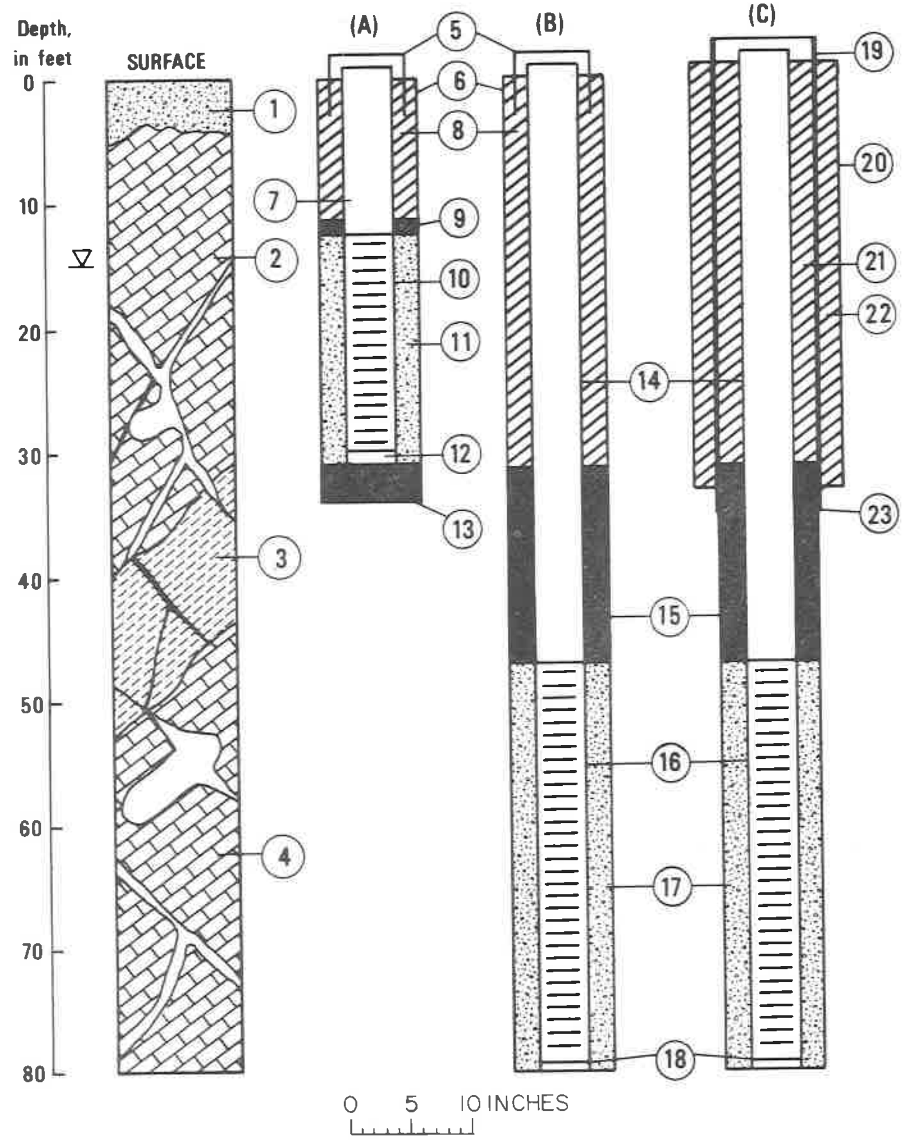
* The anomalous hydrocarbon compounds previously discussed in the Selection of the Drilling Rig section were removed from the monitoring wells at the manufacturing plant by extensive well development.

TYPICAL VALLEY AND RIDGE MONITORING WELLS



EXPLANATION

(1) Uppermost sandy soils.
(2) Dipping shallow unconfined aquifer; may have intergranular, fracture, and solution cavity porosity.
(3) Dipping confining unit with some fractures.
(4) Dipping artesian aquifer; may have intergranular, fracture, and solution cavity porosity.
(5) Protective steel casing with locking cap.
(6) 8-inch boring.
(7) Blank 4-inch PVC casing.
(8) Bentonite-cement mixture tremie-grouted into annular space between PVC casing and edge of bore hole.
(9) Bentonite pellet seal placed into annular space between PVC casing and edge of bore hole.
(10) 4-inch PVC screen with appropriately sized slots; top of screen is placed above unconfined water table and takes both seasonal and multi-year fluctuations in water levels into account.
(11) Sand/gravel pack.
(12) PVC cap.
(13) Bentonite pellet seal back fill to slightly above contact between base of shallow aquifer and top of confining unit.
(14) Blank 4-inch PVC casing.
(15) Bentonite pellet seal placed into annular space between PVC casing and edge of bore hole opposite confining unit; because of the often fractured character of Valley and Ridge confining units, especial care should be exercized in placing of this seal; if possible and appropriate, the entire confining unit should be sealed-off.
(16) 4-inch PVC screen with appropriately sized slots; top of screen is slightly below contact between base of confining unit and top of deeper aquifer.
(17) Sand/gravel pack.
(18) PVC cap.
(19) 8-inch steel casing with locking cap.
(20) 12-inch boring.
(21) Bentonite-cement mixture tremie-grouted into annular space between PVC casing and 8-inch steel casing.
(22) Bentonite-cement mixture tremie-grouted into annular space between 8-inch steel casing and edge of bore hole.
(23) 8-inch steel casing either driven or spun-into confining unit.
(A) Shallow unconfined aquifer well.
(B) Deeper artesian aquifer well (simple construction).
(C) Deeper artesian aquifer well (complex construction).
∇ Unconfined water level.

NOTE: Horizontal scale only applies to wells; no horizontal scale implied for lithologic section.

Figure 5

DOWNHOLE GEOPHYSICAL LOGGING

Borehole geophysical logging, such as spontaneous potential (SP), resistivity, or gamma, is recommended for all Coastal Plain wells and those wells in the Valley and Ridge where stratigraphic interpretations are important. On the other hand, borehole logging is not a particularly useful test in Piedmont and Blue Ridge wells where the saprolite-bedrock interface is gradational and/or ill-defined.

GENERAL SUMMARY

The text and illustrations that have been presented are not meant to be inclusive; rather, the author is attempting merely to stress that monitoring wells for hazardous waste facilities should never be drilled in a haphazard fashion. The reader should clearly understand that monitoring wells are, in effect, rather sophisticated scientific instruments, and as such, require a high degree of technical expertise to be properly constructed.

Perhaps no greater mistake can be made than to regard monitoring wells as simply "wells", which can be more or less drilled by anyone. Such an attitude can, at worst, result in interaquifer contamination or, at best, result in the gathering of meaningless information.

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