Underground Water District. Except for alignment surveys, no bore hole surveys were made of the holes drilled below the surface casing for constructing the other monitor wells. Only one packer test was made in the test holes drilled for the other monitor wells, and this was at the site of Monitor Well C-2. The packer test was made in that hole to be sure there was sufficient production in the lower part of the hole that had been drilled to insure satisfactory completion of the monitor well at that depth. Productivity information from this packer test is included in Table 4.

MONITOR WELL CONSTRUCTION

Sequence of Drilling and Construction

The sequence of drilling and constructing the monitor wells is shown numerically by stages on Figure 3. It involves the following sequential steps.

Stage 1.

1. A 7-7/8-inch hole is drilled into the Georgetown Formation using the mud-rotary method of drilling.

Stage 2.

1. The 7-7/8-inch hole is reamed to a diameter of 14 inches (12 inches at Monitor Well D-2) using the mud-rotary method of drilling.

2. A 9-5/8-inch O.D. casing is installed to near the total depth of the 14-inch hole (7-5/8-inch O.D. casing installed in 12-inch hole at Monitor Well D-2).

3. The 9-5/8-inch casing is cemented back to the surface by placing sulfate-resistant cement in the annulus between the casing and the wall of the hole.

Stage 3.

1. A 7-7/8-inch hole (6-1/2-inch hole at Monitor Well D-2) is drilled in the Edwards aquifer below the surface casing using the air-assist reverse circulation method of drilling. This hole penetrates the entire section of the Edwards Group in the primary test holes and only to the depth selected for well completion at the other well sites.

Stage 4.

1. A cement plug is placed in the hole below the depth selected for well completion in the primary test hole (gravel is used between cement plugs if zones of high porosity are encountered, or if the length of the hole to be plugged is large).

2. Materials are installed for well construction as follows:

   a. A length of 2-inch pipe is placed at the bottom of the production string to serve as a sump for materials drawn into the well during development.

   b. Manufactured stainless steel screen, approximately 50 feet in length, is placed above the 2-inch sump. Stainless steel was used to insure the long-life required for 50 years or more of monitoring.

   c. Blank 2-inch pipe is installed from the top of the screen upward to within 200 feet of the surface.

   d. Blank 4-inch pipe is installed from a depth of 200 feet to a level a few feet above land surface. This 4-inch pipe allows a pump to be installed in the monitor well to produce water for collection of water samples if and when water levels decline to levels that provide unacceptable rates of natural flow.

   e. The 4-inch pipe is capped at the top and equipped with a valve to control the flow of water from the well.

3. Gravel is placed around the screen and the 2-inch pipe to a level several feet above the top of the screen to provide support for cementing the annulus back to the surface.

4. A layer of sand is placed above the top of the gravel to minimize invasion of cement into the gravel envelope.

5. Cement is placed in stages to fill and seal the annulus between the production string and the wall of the hole and surface casing back to the surface. In very porous zones gravel was placed in the annulus to provide fill up between underlying and overlying cemented zones. Cement in the annulus was placed in stages in order to prevent high pressure due to the height of the column of cement which would cause excessive loss of cement into the sand

layer on top of the gravel envelope or into cracks and porous zones in the Edwards Group.

Information on hole depths, and material sizes and settings is given in Table 1. The deepest monitor wells at Sites A and D were constructed in the primary test holes. At Site C a large cavity was encountered at the top of the Edwards aquifer in the primary test hole, and the hole for the other monitor well planned for this site was drilled to find out if cementing through the cavity could be avoided. The cavity was not encountered at the site of Monitor Well C-2 so the deeper well was constructed there. The primary test hole was then plugged back, and Monitor Well C-1 was constructed in it to produce water from the cavity in the upper part of the Edwards aquifer. No screen was installed in Monitor Well C-1, but a 4-inch and 2-inch production string with cementing baskets attached at the lower end of the 2-inch pipe was set in the 7-7/8-inch hole to just above the large cavity and the annulus above the cementing brackets was cemented back to the surface.

A similar cavity was encountered in the primary test hole at Site D, but the deeper well was constructed in it because of general aquifer conditions in the area and financial constraints. Problems were encountered in filling the annulus in the upper part of the hole where the large cavity was encountered, and considerable time and material were expended in completing the monitor well through this section.

The dimensions of Monitor Well D-2 also were modified because of financial constraints. No 2-inch or 4-inch pipe was set in this well, and the 7-5/8-inch O.D. surface casing serves as a production string for the water produced from the 6-inch hole that was drilled into the Edwards aquifer. Smaller hole and casing diameters were feasible in this case because no logging operations, bore hole surveys, or packer tests were planned for the Edwards Group.

Selection of Hole and Pipe Diameters

Diameters of 9-5/8 inches O.D. for the surface casing and 7-7/8 inches for the hole through the Edwards Group were the minimum feasible sizes which allowed for drilling, testing, and construction operations. The diameter of the hole through the Edwards had to be large enough to accept the logging and bore hole surveying instruments and for installation and operation of expandable packers for testing. The surface casing in turn had to be large enough in diameter to permit drilling the 7-7/8-inch hole

into the Edwards aquifer and also to allow room for insertion of a tremie pipe in the annulus between the 4-1/2-inch O.D. pipe of the production string and the surface casing for placement of cement, sand, and gravel in constructing the monitor wells. A 4-inch diameter pipe is the smallest practicable size for installation of a submersible pump that will produce water at an acceptable rate for collection of water samples during long-term monitoring. Two-inch pipe and screen are considered to be the smallest size which will keep head losses due to pipe friction reasonably low at the yields that are desirable for water-sampling operations. In addition, the small diameter is needed in order to allow a tremie pipe to be inserted between the production string and the 7-7/8-inch hole for placement of gravel, sand, and cement.

Placement of Cement, Sand, and Gravel

Sulfate-resistant cement was used for plugging the bottom of the hole and for filling the annulus between the production string and the hole and surface casing in order to provide an effective seal and protection that would last during the expected 50 years or more of monitoring water levels and water quality.

The surface casing was cemented by using the standard Halliburton pumped plug method which involves forcing a predetermined volume of cement down the casing and into the annulus between the casing and the hole from the bottom upwards. In those instances where cement pumped into the annulus was insufficient to fill the annulus all the way back to the surface, the depth of the hardened cement in the annulus was sounded, a cementing line was installed to just above the top of the hardened cement, and cement was then placed in the annulus through the cementing line until the level of the cement was at the surface.

Gravel, sand, and cement used for filling the holes drilled deeper than the planned depth of well completion and for filling the annulus between the production string and the wall of the hole and surface casing were placed through a tremie line. Cement in the annulus above the gravel and sand that formed the envelope around the screen was placed in stages to minimize the loss of cement into the Edwards aquifer and the upper part of the gravel envelope. Cement placed in each stage was allowed to harden sufficiently for it to support the weight of the next stage of cement to be placed above it before cementing operations continued. As noted earlier, gravel was placed opposite the very porous zones in the Edwards aquifer to prevent the loss of cement. Any vertical communication between the porous zones through the bore hole was

prevented by the cement that was placed above and below each section of gravel.

Well Completion Checks

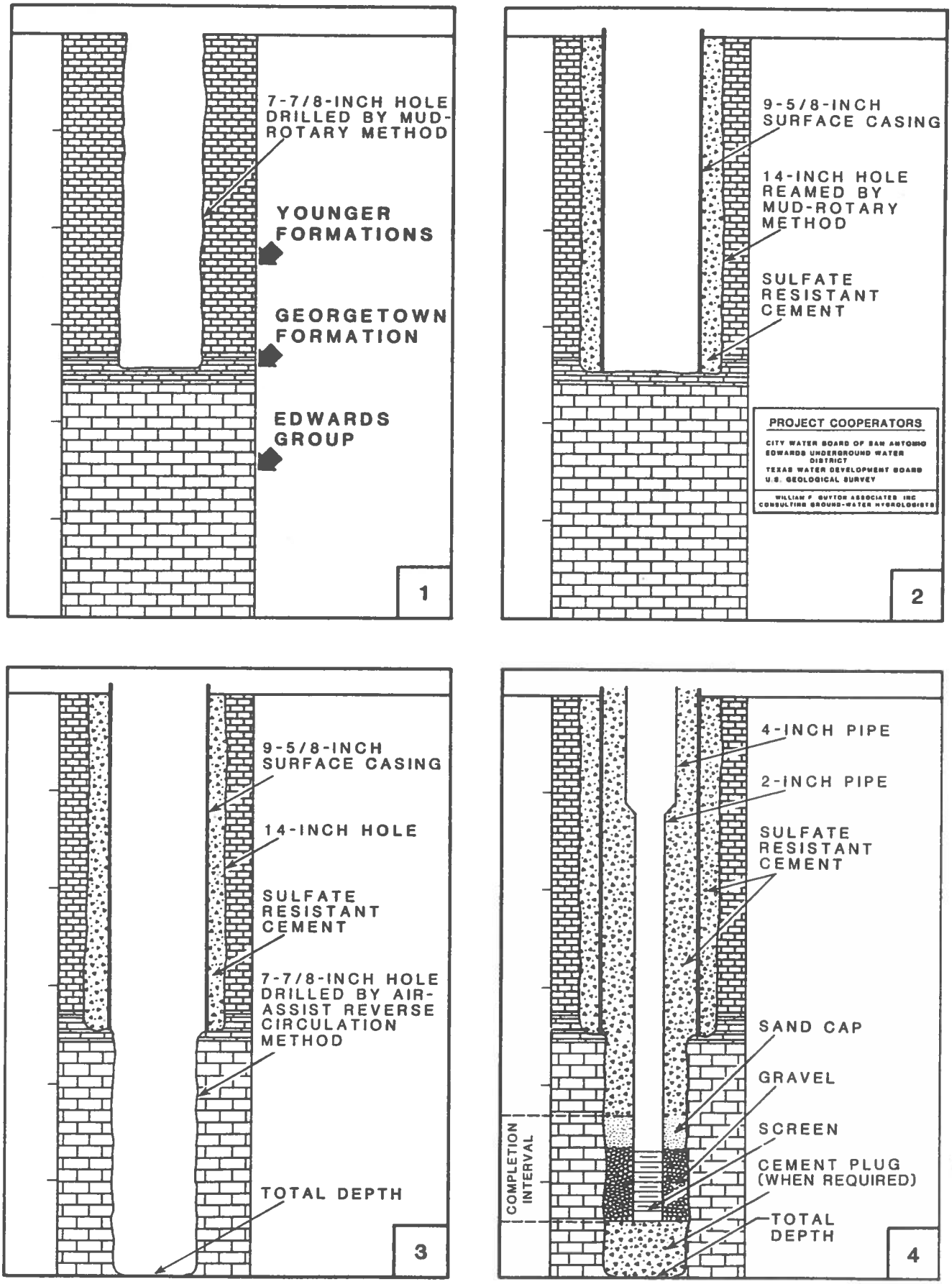
Production from each monitor well was checked immediately following the placement of the first stage of cement above the sand layer on top of the gravel envelope. This was done to be sure that the cement had not moved into the producing section through the gravel or through cracks or openings in the Edwards aquifer.

Surface Facilities

Concrete slabs, as required by the Texas Water Commission Rules and Regulations, were placed around the monitor wells at the surface after they had been constructed.

At Wells D-1 and D-2 the top of the surface casing is about 4 feet below ground level. A concrete slab was poured at this level and a 48-inch diameter reinforced concrete pipe was set from the land surface down to the top of this slab to provide a vault. The 4-inch pipe which extends upward through this vault is equipped with a 4-inch gate valve just above the bottom of the vault. The vault is filled with sand to just above the land surface where a second concrete slab was poured to provide the foundation around the well. Construction of this vault allows for continued monitoring of water levels and water quality in the event the Bexar County Coliseum Board requires use of the land surface for parking lots or other facilities. This can be accomplished by removing the concrete slab at the surface, the sand from inside the vault, and the piping above the 4-inch gate valve at the bottom of the vault, and then installing an access cover which will allow periodic entry for monitoring purposes. Special drainage facilities for water produced during sampling also were provided at the sites of Monitor Well D-1 and D-2 to avoid interference with use of the surrounding land by the Bexar County Coliseum Board.

Each monitor well is enclosed by a 6-foot chain-link fence equipped with a gate that provides access to the well. The fencing meets the requirements of the City of San Antonio Parks Department and the Bexar County Coliseum Board and provides protection for the well, any monitoring equipment that is installed, and the cathodic protection equipment which is an integral part of the monitoring well system. Photographs of the completed monitor well installations are shown on Figure 9.



SEQUENCE OF DRILLING AND CONSTRUCTION

Figure 3

TABLE 1. MONITOR WELL COMPLETION DATA

Monitor Well Number		Ground Elevation, Feet	Total Depth, Feet	Surface Casing		Completion Interval, Feet 1/		Material Settings, Feet			Date Completed	Rate of Flow, gpm	Static Head, Feet 2/
Project	State			Diameter, Inches	Depth, Feet	From	To	Material	From	To			
A-1	AY-68-37-521	620	1,489	9	965	1,193	1,303	4-inch Pipe	0	200	8-14-85	22	24.0
								2-inch Pipe	200	1,218			
								2-inch Screen	1,218	1,264			
								2-inch Pipe	1,264	1,275			
A-2	AY-68-37-522	620	1,075	9	964	1,001	1,075	4-inch Pipe	0	200	9-17-85	24	29.8
								2-inch Pipe	200	1,014			
								2-inch Screen	1,014	1,067			
								2-inch Pipe	1,067	1,075			
A-3	AY-68-37-523	620	1,175	9	964	1,087	1,175	4-inch Pipe	0	200	10-21-85	35 3/	40.3
								2-inch Pipe	200	1,115			
								2-inch Screen	1,115	1,165			
								2-inch Pipe	1,165	1,175			
C-1	AY-68-37-524	626	1,396	9	832	840	891	4-inch Pipe	0	200	1-31-86	42	46.7
								2-inch Pipe	200	840			
								Open Hole	840	891			
C-2	AY-68-37-525	624	1,150	9	832	1,068	1,150	4-inch Pipe	0	200	1-22-86	28	46.2
								2-inch Pipe	200	1,090			
								2-inch Screen	1,090	1,140			
								2-inch Pipe	1,140	1,150			
D-1	AY-68-37-526	642	1,384	9	854	1,150	1,223	4-inch Pipe	0	200	4- 1-86	7.5	17.3
								2-inch Pipe	200	1,156			
								2-inch Screen	1,156	1,209			
								2-inch Pipe	1,209	1,220			
D-2	AY-68-37-527	641	926	7	874	874	926	Open Hole	874	926	5- 6-86	351	13.2

Footnotes:

1/ - Producing interval considered to extend from top of open hole or bottom of cement cap above sand and gravel envelope to bottom of open hole as drilled or plugged back from a greater drilled depth (as illustrated by part 4 of Figure 3).

2/ - Static head is in feet of water above ground level.

3/ - Pumped by airlift method because of small natural flow rate (13.3 gallons per minute).