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RESULTS OF TEST DRILLING BY CITY OF GALVESTON AND CONCLUSIONS

April 1941

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Since 1931 when available funds have permitted, the Texas Board of Water Engineers, in cooperation with the U. S. Geological Survey, has carried out a systematic program of ground-water studies in the Houston-Galveston areas, Texas. The work in Galveston County, until the latter part of 1938, had been more or less of a reconnaissance nature, carried on in connection with the more detailed Houston program. In 1938 the City of Galveston appropriated $2,500, matched with an equal amount by the U. S. Geological Survey and the Texas Board of Water Engineers, for a ground-water investigation of Galveston County and surrounding areas. This program was started in December 1938 with continuous field work until August 1939. Records of about 900 wells in Galveston County and 100 wells in Brazoria County were obtained during the investigation. Transmissibility and permeability figures were obtained from tests conducted at the City well field at Alta Loma. Time-pumpage tests were run on all the present city wells to determine the possibility of leakage. From information obtained during the field operations maps showing the piezometric surface and the chloride content of the water were constructed.

From a study of the data there appeared to be a considerable amount of conflicting information especially regarding the more shallow sands and clays in the Alta Loma well field. Also, the fact that the chloride content of the water from most of the Galveston City wells at Alta Loma was increasing at an alarming rate, a test well program was recommended to obtain accurate information as to the character and thickness of the sands and clays, and the quality of the water in selected horizons in this area. To this end, the City of Galveston appropriated a total amount of $9,000 in September 1940.

As originally planned, the main objectives of the program were as follows: (1) In the Alta Loma well field, to determine the depth, quality of water, head and the possibility of developing an auxiliary supply in the sands above the basal Beaumont sand, the present source.

(2) Northwest of Alta Loma, to determine the same information as that in the well field and in addition the depth, thickness and quality of water in the main water-bearing sand, the occurrence, thickness and quality of water in the sands underlying the main sands and the thickness of the intermediate clays.

(3) Southeast of Alta Loma, to determine the depth, thickness, quality of water and the possibility of developing additional supplies of water in the sands that lie above the main water horizon in areas adjacent to the present city water main. Three test wells drilled to approximately 600 feet and located along the pipe line southeast of Alta Loma were deemed sufficient to secure this information.

After the completion of the third test well (At Hitchcock, four miles southeast of Alta Loma) to a depth of 641 feet, inasmuch as no shallow sands of any value to the city had been encountered, it was decided in a conference with Mr. W. N. White, Senior Hydraulic Engineer, U. S. Geological Survey, Mr. R. W. Owens, Superintendent of the Galveston Water Department, Messrs. N. A. Rose and W. F. Guyton of the Geological Survey and the writer, that the program should be altered somewhat in order to secure the maximum information possible with the available funds. Due to the fact that all three test holes failed to show the presence of sands above the main horizon that would be suitable for municipal development, it was decided the most pertinent information to be obtained was that concerning the depth, thickness, and quality of water contained in the main water-bearing sands, and information as to the position of sands in the next underlying formations, the character of the water therein,

and the artesian head. The thickness and stratigraphic position of the clays separating the main sands from those below was deemed to be of special importance. To secure this information it was decided to drill number three to approximately 1200 feet and to deepen number one to a depth sufficient to determine the position and thickness of the immediately underlying sands and clays.

Test Well Number One

Location:- This well is in the present City well field at Alta Loma, about 350 feet south of well 2 and 150 feet north of well 7.

Sediments above the main water-bearing sands:- The material comprising the upper 600 feet at this location is a series of fine sands, clays, and sandy clays (see diagram). With the exception of the sand that occurs from 100 to 125 feet below the surface all of the sands appear to be quite thin and of low permeability.

Drill-stem test:- Samples of sand and water were obtained by a drill-stem test of the section between 280 and 360 feet below the surface. From a macroscopic examination, this sand appears to be finer but otherwise similar to the main sands. The water is of fair quality, containing about 258 parts per million chloride (see table 2 for complete analysis).

Main water-bearing sands:- The electric log of this test well shows that the main sand horizon has a thickness of about 175 feet including some clay. The first 30 feet of this horizon from 700 to 730 feet probably contains a considerable amount of clay and the section from 840 to 855 may be nearly all clay. The remainder or about 140 feet is believed to be practically all sand. The electric log shows a rapidly decreasing resistivity in the sands from a depth of about 800 to 840 feet. This may be caused by either a change in the character of the sand or a change in the character of the water in the sand or

by a combination of both. The present city well number 2, about 350 feet to the north, is screened in this zone from 740 to 835 feet and has yielded water of about 200 parts per million chloride since completion in 1914. Also, well number 7, about 150 feet to the south, yielded water of about 320 parts per million chloride in 1932, but at the present time the water from it contains about 480 parts per million chloride. This would seem to indicate that the water in the lower part of the main water-bearing sand was originally of moderately low chloride content. A screen was set in this test well from 860 to 870 feet and the well was pumped. The water, it was found, contains 705 parts of chloride per million.

Sediments below the main water-bearing sands:-Immediately underlying the main sand zone there is approximately 165 feet of clay, sandy clays, and sands. The first 65 feet of this zone contains very little sand. The next well developed sand occurs from about 1040 to 1055 feet below the surface. No drill-stem sample of this was obtained but from the appearance of the electric log the water in those sands is becoming progressively saltier with depth.

Test Well Number Two

Location:- This well is located 1.3 miles northeast of Arcadia, Texas along the Dickinson road. The well was drilled to a total depth of 1221 feet.

Sediments above the main water-bearing sands:- As in test well number one, the material above the top of the main sand is made up of thin sand members interbedded with clays and sandy clays (see diagram). With the exception of a shallow sand from 85 to 115 feet below the surface, none of the sand members of this zone appear to be sufficiently thick or continuous to justify the opinion that they would yield much water. None of them were deemed sufficiently important to warrant a drill-stem test.

Test Well No. 2 (Continued)

Main water-bearing sands:- The main water-bearing sand in this test well is about 120 feet thick and occurs from about 680 to about 800 feet below the surface. Apparently the net thickness of sand in the basal zone in this well is about 20 feet less than in the same horizon in test well number 1 in the Alta Loma well field. From the appearance of the electric log it is believed that both the character of the sand and the water in the sand varies but little throughout the full thickness. As in the case of test well number 1, a clay lense occurs near the base of the sand between 778 and 782 feet.

Drill-stem test:- Samples of sand and water were obtained below the clay lenses from the section between 782 and 800 feet. A sample of water from this sand contained 288 parts per million of chloride (see table 2 for complete analysis).

Permeability:- Although there has not been sufficient time for more complete and accurate tests, the comparative permeabilities of the samples of sand obtained at several horizons are given in table 1, as well as the permeability of the sand obtained by a drill-stem test of the section between 782 and 800 feet below the surface. It is probable that the figures in table 1 do not represent the true permeability of the sands in place, but they may serve as a basis for rough comparison.

Sediments below the main water-bearing sand:- Immediately underlying the main sand zone is about 50 feet of clay, the lower third of which is somewhat sandy. This clay in turn is underlain by about 40 feet of sand (850 to 890 feet) which differs materially in character from the main water-bearing sand. It does not have the greenish tint which the main sand has, is somewhat finer,

Test Well No. 2 (Continued)

and does not contain mica commonly found in the main sand. A water sample obtained from pumping this well with a screen set at 850 to 870 feet contained 1030 parts per million chloride. From 890 feet to the bottom of the test well at 1221 feet is a series of thin sands, sandy clays, and clays, none of which is very thick, with the exception of one sand between 1175 and 1202 feet. A sample of water from this sand contained 1860 parts per million chloride (see table 2 for complete analyses). This well was cased and screened from 850 to 860 feet.

Test Well Number Three

Location:-Test well number 3, with a total depth of 1181 feet, is located about 0.2 mile west of Hitchcock along the north side of the Santa Fe Railway right-of-way.

Sediments above the main water-bearing sands:- The top portion of this test well down to about 650 feet is similar to the same section in both the other test wells (see diagram). With the exception of a fairly thick sand from 60 to 120 feet below the surface, all the sands occur in thin beds separated by clays and sandy clays. No drill-stem tests were taken in this section.

Main water-bearing sands:-The electric log of this test well shows that the main sandy zone is about 345 feet thick with the top at 680 feet and the bottom at 1025 feet below the surface. The top 30 feet from 680 to 710 feet is a well developed sand; the next 70 feet, from 710 to 780 feet, is largely clay and sandy clay; the remaining 245 feet from 780 to 1025 feet is nearly all sand. The electric log shows a more or less persistent decline in the resistivity from 930 to 1025 feet. This, as in well 1, could be caused either

Test Well No. 5 (Continued)

by a change in the character of the sand itself or of the water in the sand or by a combination of the two. In the lowermost part of the zone the salinity of the water undoubtedly caused a part of the lowering in resistivity, the water from 1001 to 1023 feet containing 1380 parts per million of chloride (see next paragraph).

Quality of water; drill-stem tests:- Water from nearby wells that draw from only the extreme upper part of this sand zone, at about 680 feet, contains about 100 parts per million of chloride. A sample of water obtained by pumping an offset well (5-A) screened between 930 and 940 feet contained 175 parts per million chloride. A drill-stem sample of the water from the sand between 1001 and 1023 feet in the test well itself contained 1380 parts per million. Thus it is apparent that there is a rapid increase in the chloride content of the water at this location between the depths of 940 and 1000 feet. (See table 2 for complete analysis of water samples.)

Permeability:- Table 1 gives the comparative permeabilities of sand samples obtained at different horizons in the main water-bearing zone.

Sediments below the main water-bearing sands:-Underlying the main sands, from 1025 to 1130 feet, is a series of clays, sandy clays and thin sands. Next, from 1130 to 1155 feet is a sandy section. A drill-stem sample of the water from this sandy section contained 3820 parts per million of chloride. (See table 2 for complete analysis.) The last 26 feet, to the bottom at 1181 feet, is clay.

Test Well Number 3-A

Location:-This test well is located about 70 feet east of test well number 3.

Sediments above the main water-bearing sands:-Above the top of the main sand zone the occurrence of the sands and clays correlates very closely with the same section in number 3 test well.

Main water-bearing sands:- The upper 100 feet in this well is practically identical with the corresponding zone in number 3 test well; however, the section from 780 to 820 feet is a clay in this well whereas in test well number 3 it is a well-developed sand. There is practically no difference shown on the electric log between this and number 3 well between 820 and the bottom of the well at 940 feet.

Quality of Water:-A sample of water obtained from the section screened at a depth of 930 to 940 feet contained 175 parts per million of chloride.

Summary

The test drilling program has disclosed information that was not heretofore known and has made fairly clear the reasons for the invasion of saline water into the Alta Loma wells. The outstanding facts which have been brought out by the drilling are as follows:

The sands above the main water-bearing beds in the Alta Loma well field and adjacent areas are thin bedded and more or less lenticular, that is, they tend to pinch out laterally; these beds can not be expected to yield much water. This is a disappointment. It was hoped that they might provide a supplementary

water supply of considerable magnitude and thus prolong the life of the Alta Loma well field to some extent.

The main water-bearing sands tend to thicken toward the southeast (see diagram). They have a net total thickness of about 120 feet in test well 2 about 2½ miles northwest of the old Alta Loma pumping plant; about 140 feet in test well 1 and well 7 near the old plant; about 200 feet in well 8 and 250 feet or so at Hitchcock.

According to electrical logs of oil tests, the sands persist in areas at considerable distances to the north, northwest, west, and southwest of Alta Loma, in the League City oil field, and in localities near Alvin and in the territory adjacent to the Brazoria County line south of Arcadia.

The test drilling had exploded the theory that the main water-bearing sands in this area are underlain by thick persistent beds of clays. The clays are there but they are not very thick nor persistent and they are underlain by or interbedded with sands which contain salty water. The individual beds of clay immediately below the fresh water-bearing sands vary in thickness from place to place and in all probability pinch out altogether in places within or closely adjacent to the Alta Loma well field, thereby permitting the upward movement of salty water to the fresh water-bearing beds and its subsequent movement laterally toward the wells. That such interconnections do exist is proven by the fact that the artesian head in the salt water sands is the same as that in the fresh water sands. This was demonstrated in both test well 1 and test well 2. Moreover, salt water actually has invaded the lower part of the fresh water-bearing beds in test well 1 at Alta Loma and test well 3 at Hitchcock.

While the fresh water-bearing beds thicken toward the southeast the thickening seems to be in the upper part of the zone where the sands are interbedded with clays and the sands themselves do not seem to be as permeable as they are in the main water-bearing zone below. For example, five samples of sand obtained from well 2 at different depths from 680 to 800 feet had an average coefficient of permeability of about 280 whereas 8 samples from well 3 obtained between 678 and 900 feet had an average of only about 140. Moreover, 3 samples of sands from the lower part of the sandy zone in well 3, 920 to 960 feet, had an average permeability of about 320. The lowermost part of the sandy zone in test 3, however, from 1001 to 1023 feet, which contains salty water (1380 parts per million) has a permeability of only 89, according to a test of a drill-stem sample.

It is clear from the above that the thickness of the sands in this area is not the only factor that controls the yield of a well. The permeability of the sands, in other words their capacity to transmit water, isequally important.

Conclusions

The invasion of saline waters into the Alta Loma well field sooner or later was inevitable. Before pumping was started the artesian pressures in the fresh water-bearing sands and the sands containing salty water, it is believed, were approximately equal. As pumping progressed in the Alta Loma field and later at Texas City, Dickinson, League City, in the oil fields, and at Baytown in Harris County, the artesian pressures declined until now they are about 80 feet lower than they were at the start. As the pressures declined the difference in head between the salt water and fresh water horizons increased until it was great enough to cause the salty water to

penetrate the barriers of the clay or sandy clay separating the two horizons and merge with the fresh water. The saline invasion has been materially expedited by over-pumping in the Alta Loma field itself. The wells should have been more widely spaced and the individual wells should have been more lightly pumped.

The evidence all tends to show that no more pumping should be done in the Alta Loma field or in closely adjacent areas. New wells should be located well to the outside of the present field. Some locality to the northwest near test well 2, it is believed, would be suitable. The indications for obtaining good wells seem reasonably good also toward the north and west of Alta Loma. The new wells in no case should be pumped at more than an average rate of one million gallons a day apiece. Before the location of the new wells is definitely determined, a small test hole should be put down and an electrical log run in it.

If a well is to be put down in territory closely adjacent to the Alta Loma field to meet the present emergency, some locality due north of test 1 or along the Alvin highway to the northwest would be as desirable as any. The well should be located not less than 6000 feet from City well no. 2 and preferably should be at a distance of 2 miles from it. The well should be pumped at a rate not to exceed one million gallons a day in order to delay a further rise of chloride in wells 2, 7, 3, 4, 5, and 6, which might become serious within a relatively short time.

Finally it is recommended that immediate consideration should be given to the necessity of obtaining an additional supply from surface water sources.

TABLE I

Relative Permeability of Samples Collected from Galveston Test Wells

Depth of Sample	Test Well Number 2				Test Well Number 3			
	Cuttings		Drill stem samples		Cuttings		Drill stem samples	
	a/	b/	a/	b/	a/	b/	a/	b/
680 - 700	367	376			365	201		
700 - 720	322	271						
720 - 740					161	176		
740 - 760	308	265						
760 - 780					127	97		
780 - 800	293	278	204	95				
800 - 820								
820 - 840					187	113		
840 - 860					171	111		
860 - 880					177	177		
880 - 900					176	94		
900 - 920					129	185		
920 - 940					345	415		
940 - 960					287	369		
1001 -1023							49 c/ 89 d/	9 c/ 21 d/

a/Determinations by Rose b/Determinations by Meador c/2-15 stems above bottom d/Last 2 drill stems of sand.

TABLE 2

Analyses of water from Galveston City Test Wells
(Results are in parts per million)

Well	Owner	Depth of well (ft.)	Date of collection	Total dissolved solids (calc.)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na + K) (calc.)	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Fluoride (F)	Total hardness as $CaCO_3$ (calc.)
1	Test Well #1 a/	282-360	Dec. 12, 1940	939	20	14	330	531	24	258	1.2	-	107
1	do. b/	850-875	Mar. 14, 1941	1,508	23	10	549	358	4	705	-	-	97
2	Test Well #2 c/	784-801	Jan. 4, 1941	758	22	8	264	304	5	238	.50	-	86
2	do. c/	868-895	Jan. 17, 1941	1,655	29	13	592	296	26	790	-	-	126
2	do. d/	853-873	Jan. 26, 1941	1,988	37	16	712	319	1	1,010	-	-	158
2	do. b/	853-873	do.	2,017	39	16	728	322	1	1,030	-	.9	163
2	do. c/	1,177 1,206	Jan. 22, 1941	2,770	45	21	999	294	26	1,480	-	-	199
2	do. e/	1,177 1,206	Jan. 26, 1941	3,467	-	-	1,340	488	36	1,860	-	-	182
3	Test Well #3 e/	1,001 1,023	Feb. 11, 1941	2,628	33	17	969	356	20	1,380	-	-	152
3	do. e/	1,130 1,150	do.	-	-	-	-	268	-	3,820	-	-	-
3	do. c/	1,130 1,150	do.	6,544	109	55	2,322	306	20	3,740	-	-	498
3-A	Test Well #3A f/	930	Feb. 28, 1941	600	13	3.8	212	298	2	175	-	-	48

a/ Drill stem sample
b/ Sample obtained after 10½ hours continuous pumping.
c/ Sample from last 8 drill stem joints.
d/ Sample obtained after 5½ hours continuous pumping.
e/ Sample from last drill stem.
f/ Sample obtained after 16½ hours continuous pumping.