DRE-67

TECHNICAL MEMORANDUM

SUBJECT: C-51 Leakage

September, 1976

T E C H N I C A L
M E M O R A N D U M

9-1-2H

September 7, 1976

TO: Peter B. Rhoads, Deputy Director, Resource Planning Department

FROM: D. Allman and G. Winter, Groundwater Division

SUBJECT: C-51 Leakage

Statement of Problem Addressed

The basic problem addressed in this memo is the impact on the groundwater flow system and the modification that can be expected in the water budget for the C-51 canal between S-5A-E and above S-155A as a result of raising the stage in the canal to between approximately 8.5 ft. and 14.0 ft. MSL. This increase in canal stage could change the basin water budget by increasing evapotranspirative consumptive use (ET) and changing basin inflow-outflow relationships. USGS water table contour maps from May, 1974 to May, 1976 were examined to ascertain the basin inflow-outflow change that could be expected. Figure 1 is the water table contour map for May 3-5, 1976. Proposed structure S-155A is to be located just east of the junction of canal E-1 and C-51. Since E-1 and E-2 have good interconnections and since E-2 is located below S-155A, raising the canal stage above S-155A will have a negligible affect on the hydrology of the E-1 and E-2 canal drainage areas during normal runoff conditions. The stages of the tributary canals above S-155A except E-1 as determined from USGS water table contour maps are summarized in Table 1. In general, the stages in the canals south of C-51 are about 11.2 feet MSL whereas those north of C-51 are about 14 ft. MSL. The combined average stage for the tributary canals north and south of C-51 is approximately 12.6 ft. MSL.

Groundwater seepage into C-51 from the reaches of the tributary canals near C-51 will become negligible when C-51 stages are increased. However, the existing seepage from the tributary canals is believed to be relatively small and is effectively rendered negligible under existing conditions on some canals because of backpumping facilities. Stages in the tributary canals can be expected to be controlled to maintain favorable land use conditions. This control via pumping facilities of canal and groundwater stages in the tributary canal drainage basins will probably result in a negligible impact in the net water budget for the C-51 basin above S-155A. Water that is discharged into C-51 as groundwater under existing conditions will simply be discharged into the canal as surface water under increased operating stages for C-51. Since the proposed C-51 canal stage will be lower than the existing stages on the tributary canals to the north of C-51, a negligible change in stages on these tributary canals will result when the stage in C-51 is increased. The canals and groundwater stages to the south of C-51 can be expected to be controlled near existing levels even though the proposed C-51 stage will be higher than existing stages because all the tributary canals are equipped with facilities to pump water into C-51. Thus, negligible changes in the combined surface water ground water discharge from the basins can be expected assuming the ET consumptive use does not change significantly.

Evapotranspirative consumptive use from the basin is not expected to change significantly as a result of raising the stage in C-51. Since existing tributary canal stages will not change significantly, ET consumptive use over

almost all of the drainage basin will not increase significantly. The ET consumptive use could only be expected to increase in the immediate vicinity of the C-51 canal where the existing water table is depressed because of the direct inflow of groundwater to the C-51 canal. According to the USGS water table contour maps, the water table may be depressed within a 2,000 ft. wide tract on both sides of the canal, although this is probably an educated guess on the part of the USGS. If ET consumptive use were suppressed by 5 inches/year over this entire tract, which is not very likely because of the rigid control of water in the agricultural areas adjacent to the canal, the average annual ET consumptive use would increase by 2.99 cfs or 0.346 inches over the 117 square miles drainage basin. For a 45.13 inch annual rainfall, the change in ET consumptive use would amount to 0.77% of the rainfall. For practical purposes this increase in ET consumptive use from the basin as a whole is negligible.

In conclusion, since the tributary canal stages will undoubtedly be closely controlled at levels necessary to accommodate the basin development with the levels being set independent of the C-51 canal stage regimen, a negligible effect would result in the hydrologic system throughout the C-51 drainage basin outside of a 4,000 ft. wide tract centered on the C-51 canal. A negligible increase in basin ET consumptive use can be expected with increased C-51 canal stages because of the relatively small area whose water table is depressed as a result of direct groundwater drainage into C-51. The calculations that follow are provided to give some hint of the magnitude of the direct groundwater seepage that could be expectedto occur into the C-51 canal.

Aquifer Transmissivity

Aquifer transmissivity was estimated by indirect means since pump test data are not available along the reach of C-51 between S-155A and S-5A-E. Figure 2 is the geologic section along C-51 from S-5A-E to S-155A. From station 0 to 31,000, the geologic section is rather complex with relatively thin limestone and sand units contained throughout the section. From station 31,000 to 53,875, the geologic section consists primarily of clean sand overlying silty sand. These two reaches of canal will be treated separately because of their obviously different hydraulic characteristics. In the western 31,000 ft. of the study reach, the overall geologic section penetrated by the borings consists of 55.6% sand that is silty or clayey, 36.6% limestone that contains solution cavities that are either open or partially filled, and 7.8% sand that is clean and fine to medium grained.

The principle problem is to estimate the permeability of the 3 groups of geologic materials. Several estimates using different data sources will be used if possible. For the sand that contains silt or clay, the permeability would equal 7.6 gpd/ft.^{2} if it were equivalent to a loam soil (Israelsen, O. W. and Hansen, V. E., "Irrigation Principles and Practices," John Wiley & Sons, 1967, p.411). The soil would have a permeability of 21.21 gpd/ft.^{2} if it had a permeability used to separate 2 soil types; the first type consisting of clean sands, and a clean sand and gravel mixture; and the second type consisting of very fine sands, organic and inorganic silts, mixtures of sand, silt, and clay, etc. (Terzazhi, K. and Peck, R. R., "Soil Mechanics in Engineering Practice,"

John Wiley & Sons, 1964, p.48, Todd, D. K., "Ground Water Hydrology," John Wiley & Sons, 1959, p.53). The sequential ordering of the above list of soils suggests the permeability would probably be nearer 2.12 gpd/ft.^{2} rather than 21.21 gpd/ft.^{2}. The classification of "clayey sands, fine sands (poor aquifers)" has an estimated permeability range from 10 to 0.01 gpd/ft.^{2} (Davis, S. N., DeWiest, R. J. M., "Hydrogeology," John Wiley & Sons Inc., 1966, p.164). From the above estimates, it shall hereafter be assumed that the permeability for the silty and clayey sand is 10 gpd/ft.^{2}

The estimated permeability value for the limestone is the critical value because the permeability of the limestone can be so large that it can almost completely dominate. The Corps of Engineers performed specific capacity tests on the limestone underlying the proposed S-319 pumping station as indicated in Figures 3 and 4.

The specific capacity value of 0.04 gpm/ft. obtained from borehole CB-S319-5 was omitted from the following analysis because the very low value is not believed to be representative of a limestone specific capacity. The specific capacities per foot of borehole were obtained from the Corps' data and plotted on log probability paper (Figure 5). Since the data plots as a reasonably straight line, the population of specific capacities per foot of borehole is assumed to be log normally distributed. The mean is 0.6716 gpm/ft.^{2}. The 5% and 95% confidence limits differ by about a factor of 10 from the mean. Thus, calculations using the mean can be in considerable error.

Before the specific capacity data can be used to calculate the permeability, corrections for partial penetration are necessary. It was assumed that each specific capacity test spanned a 3 ft. vertical section of open borehole in an aquifer 15 ft. thick. Equation 5.17 from Walton (Groundwater Resource Evaluation, McGraw-Hill 1970, p.319) was used. The equivalent specific capacity per foot of borehole is calculated to be 0.3444 gpm/ft.^{2}

The permeability can be calculated using equation 5.16 from Walton. It was assumed that the storage coefficient was 0.001; the radius of the well was 0.125 ft.; and the specific capacity was determined 10 minutes after injection started. The calculated permeability is 432 gpd/ft.^{2} for the limestone.

The permeability for the clean fine to medium sand was obtained from estimates using the grain size distribution. Assuming the median grain size to be 0.25 mm which separates the fine and medium grain size classification, the permeability is estimated to be 240 gpd/ft.^{2} based on data for the Washita River alluvium (Naney, J. W., et. al., "Evaluating Ground-Water Paths Using Hydraulic Conductivities," Ground Water, V. 14, No. 4, p.205, 1976). Data for the Arkansas River alluvium suggests a permeability of 150 gpd/ft.^{2} (Bedinger, M. S., USGS Prof. Paper 424-C, 1961, p.31). Based on the above references, it was assumed that the permeability of the clean fine to medium sand is 200 gpd/ft.^{2}

The effective permeability of the geologic section for the western 31,000 ft. of C-51 can be ascertained by summing the products of the percentages of the various materials present by their respective permeabilities. The effective permeability thus equals 179.3 gpd/ft.^{2} (55.6% X 10 gpd/ft.^{2}) + (36.6% X 432 gpd/ft.^{2}) + (7.8% X 200 gpd/ft.^{2}). The aquifer is estimated to be approximately

100 feet in depth. Thus, the aquifer transmissivity is hereafter assumed to be 17,930 gpd/ft.

The reach of canal from station 31,000 to 53,875 can be treated in a manner similar to that for the western 31,000 ft. As indicated in Figure 6, the geologic materials occur in much thicker and apparently more continuous units than in the reach from 0 to 31,000 ft. Based on the borings at S-155A, 40.5% of the geologic section consists of clean, fine to medium grain sand while 59.5% of the section consists of silty or clayey sand. The permeabilities for clean fine to medium sand and for the sand that is silty or clayey are assumed to be 200 and 10 gpd/ft.^{2} respectively. Thus, the effective permeability is 86.95 gpd/ft.^{2} ((40.5% X 200 gpd/ft.^{2}) + (59.5% X 10 gpd/ft.^{2})). For a 100 ft. thick aquifer, the transmissivity would be 8,695 gpd/ft. The vertical permeability is generally 2 to 10 times less than the horizontal permeability. Thus, the estimated effective transmissivity is probably too large and will thus result in an estimated discharge to C-51 that is greater than that actually occurring.

<u>Canal Partial Penetration</u>

The C-51 canal is assumed to behave as a fully penetrating drain. According to Huisman (Groundwater Recovery, Winchester Press 1972, p.56), the additional drawdown Δs_0 due to the partial penetration of a random shaped gallery to maintain the same discharge as a fully penetrating drain is:

$$\Delta s_o = \frac{q_o}{\pi k} \ln \frac{H}{\Omega}$$

Where

Δs_o = additional drawdown in the ditch due to partial penetration (m).

q_o = discharge per unit length of gallery (m^3/m/sec.).

k = coefficient of permeability (m/sec.).

H = thickness of aquifer (m).

Ω = wetted gallery circumference (m).

From the channel cross sections, the estimated wetted perimeter (Ω) is approximately 100 ft., which is also the thickness of the aquifer (H). Since the ln of 1 is zero, the correction for partial penetration of the canal is small and will be considered to be negligible.

Canal Inflow

The problem of selecting a model to calculate the inflow to the canal is difficult because of the lack of data regarding water table fluctuations in the immediate vicinity of the canal. For the canal reach between stations 0 and 31,000 ft., the discharge to a drain whose stage has been suddenly lowered was calculated at various times following the hypothetical, abrupt lowering of the canal stage that was assumed to equal the head difference between the tributary canals and the C-51 canal. The head for the tributary canals is estimated to be 12.6 feet MSL while the C-51 canal stage is approximately 8.25 ft. MSL according to stage records at S-5A-E and West Palm Beach. Thus, the differential head between the tributary canals and C-51 is approximately 4.35 ft. Table 2 lists the discharge into C-51 between

station 0 and 31,000 at the end of periods ranging from 30 to 180 days. Drawdowns in the water table at distances of 1,000 ft. and 2,000 ft. from the canal are also listed in Table 2. It would not appear unreasonable to assume a discharge of 5.77 cfs into the canal. This would result after a period of 45 days. Recharge to the water table occurs quite frequently during the wet season (June-September) which could result in relatively high discharge rates into the canal. During the dry season, recharge does not occur as frequently and thus the water table would decline unless irrigation occurred. The drawdown of the water table would be approximately 1.61 ft. and 0.223 ft. at distances of 1,000 ft. and 2,000 ft. respectively from the canal. These drawdown data do not appear unreasonable based on vehicle hydrology (observations from a speeding car or motorcycle).

The inflow to the reach of C-51 between stations 31,000 and 53,875 can be calculated in a manner similar to that for the reach from 0 to 31,000. Table 3 lists the discharge into the C-51 canal in the 22,875 ft. reach at the end of periods varying from 30 to 180 days following the hypothetical lowering of the canal stage by 4.35 ft. Water table drawdowns at distances of 1,000 ft. and 2,000 ft. from the canal are also listed in Table 3. After a period of 45 days, the discharge to the canal is 2.96 cfs with a water table drawdown of 0.520 ft. and <0.05 feet at distances of 1,000 ft. and 2,000 ft. respectively from the canal. The discharge into the canal is not overly sensitive to the length of the period that has elapsed following the initial hypothetical lowering of the water table. The calculated discharge into the C-51 canal is relatively small for this 22,875 ft. reach of canal.

An alternate method to calculate seepage into the canal in the reach from station 31,000 to 53,875 would be to assume one dimensional flow in an unconfined aquifer above a semi-pervious layer (Huisman p.52). Figure 6 can be interpreted as a fully penetrating canal in an unconfined aquifer consisting of clean sand separated by sand which is silty and clayey from an underlying sand and limestone leaky artesian aquifer. Royal Palm Beach has several production wells within a few hundred feet of C-51 at a depth of 65 ft. which presumably obtain water from a limestone unit of high permeability. It has also been reported that a high permeability unit is present in the vicinity of C-51 at a depth of approximately 50 ft. Assuming the vertical permeability of the silty and clayey sand semi-pervious unit to be 2 gpd/ft.^{2}, the discharge into the C-51 canal would be approximately 4.35 cfs for the reach from 31,000 to 53,875 excluding the effects of the tributary canals. The numeric difference in the canal inflow using this method compared with the method used to obtain the inflow after 45 days as tabulated in Table 3 (2.96 cfs) is only 1.39 cfs. This difference is negligible.

Another elementary method can also be used to estimate the seepage inflow to C-51 between stations 31,000 and 53,875. From Table 3, the drawdown of the water table is only 0.53 ft. at a distance of 1,000 ft. after 45 days. If it is assumed that the drawdown in the sand unit overlying the impervious layer averages 2.175 feet from the canal bank to a distance of 500 ft. on each side of the canal, and the drawdown under the 80 ft. wide canal is 4.35 ft., Darcy's law can be used to compute the vertical seepage from the leaky artesian aquifer. The vertical permeability of the confining unit is assumed to be 2 gpd/ft.[2] The seepage inflow Q, is calculated using the following equation:

$$Q = \frac{22875 \times ((40 \times 4.35) + (500 \times 4.35/2)) \times 2 \times 2}{7.48 \times 1440 \times 60 \times 40} = 4.47 \text{ cfs}$$

This seepage rate is also comparatively low and is only 1.5 cfs greater than the value of 2.96 cfs in Table 3 forty-five days after a hypothetical lowering of the canal stage.

Since the canal inflows which are calculated assuming: a) an unconfined aquifer overlying a leaky artesian aquifer; and b) vertical upward flow in the immediate vicinity of the canal, are not significantly different from the value (2.96 cfs) obtained assuming a fully penetrating drain in a 100 ft. thick aquifer, the latter value will be assumed to be the canal inflow.

The calculated discharge of groundwater into the reach of canal above S-155A based on a simple seepage model is summarized in Table 4. Under existing conditions, the average annual groundwater inflow is estimated to be 8.73 cfs neglecting the additional seepage that will result because of the tributary canals. The additional seepage that will result because of the tributary canals is uncertain. If the 15 or more tributary canals contribute as much groundwater seepage to C-51 as the groundwater flow system that would develop without the tributary canals, the groundwater inflow would equal 17.46 cfs or 2.03 inches over a 117 square mile basin. The effective groundwater seepage into the C-51 canal would be reduced by any backpumping into tributary canals. Thus, the groundwater inflow under existing conditions is estimated to be

approximately 17.5 cfs. Significant errors are associated with the above value for seepage. Errors of an order of magnitude are possible. Thus, the estimated values should be used in a discrete manner.

DAVID W. ALLMAN, Ph.D
Groundwater Division
Resource Planning Department

GERRY WINTER
Groundwater Division
Resource Planning Department

js

TABLE 1

STAGES ON TRIBUTARY CANALS TO C-51 WEST OF PRUPOSED S-155A

DATE	NORTH SIDE (FEET MSL)	SOUTH SIDE (FEET MSL)
May 7, 8, 1974	14	10
October 9-10, 1974	16	14
May 6-7, 1975	12	10
October 8, 4, 1975	16	10
May 3-5, 1976	12	12
Average	14	11.2
Combined Average	12.6	

TABLE 2

INFLOWS TO C-51 BETWEEN STATIONS 0 AND 31,000

TIME AFTER LOWERING C-51 CANAL STAGE (DAYS)	DISCHARGE (cfs)	DRAWDOWN AT VARIOUS DISTANCES FROM C-51 1,000 FEET (FEET)	2,000 FEET (FEET)
30	7.06	1.04	.095
45	5.77	1.61	.223
60	4.99	1.78	0.422
90	4.08	2.18	0.761
180	2.88	2.38	1.480

TABLE 3

INFLOWS TO C-51 BETWEEN STATIONS 31,000 and 53,875

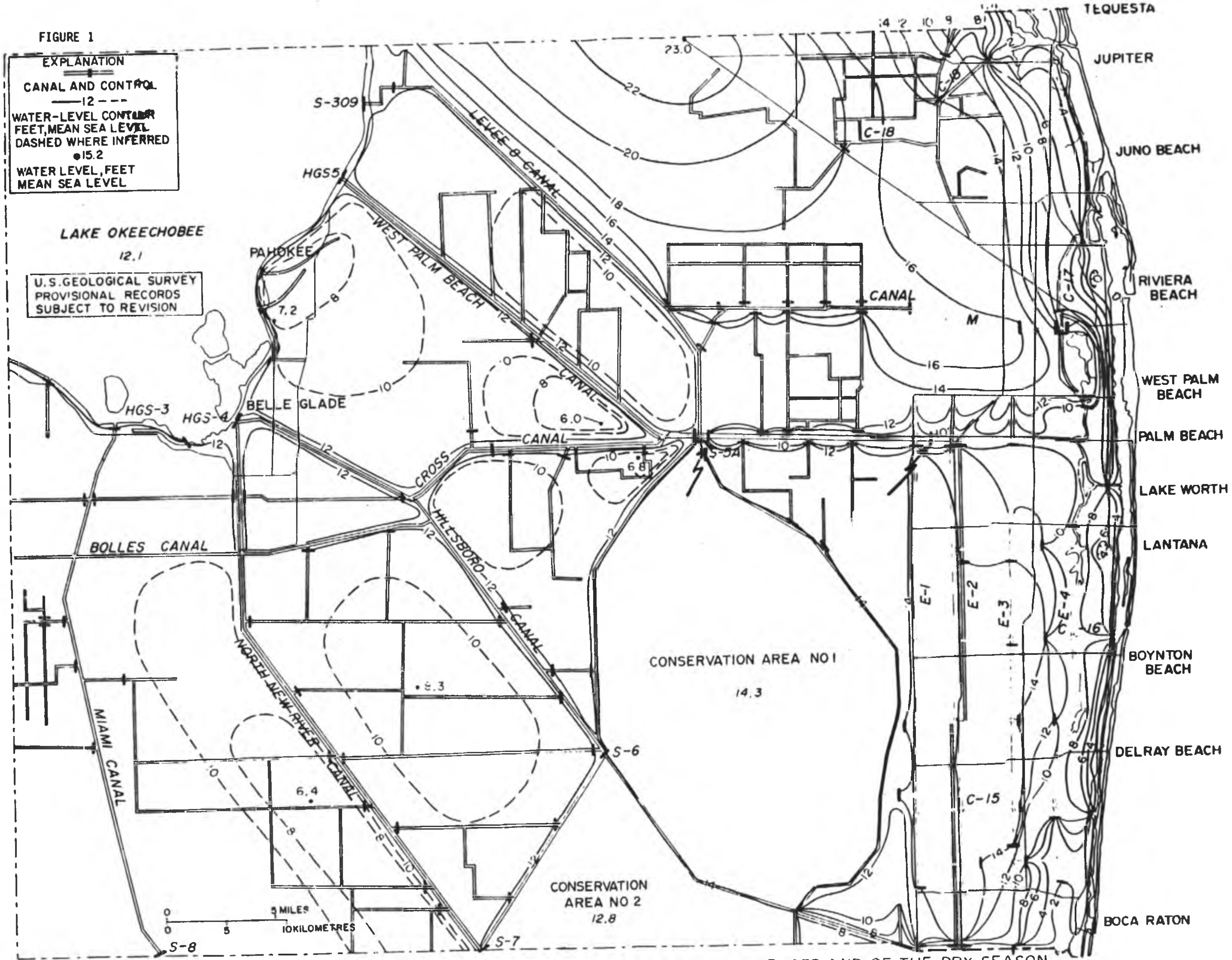
TIME AFTER LOWERING C-51 CANAL STAGE (DAYS)	DISCHARGE (cfs)	DRAWDOWN AT VARIOUS DISTANCES FROM C-51	
		1,000 FEET (FEET)	2,000 FEET (FEET)
30	3.63	0.400	<0.05
45	2.96	0.520	<0.05
60	2.57	1.02	0.0735
90	2.10	1.45	0.221
180	1.48	2.13	0.731

TABLE 4

INFLOWS INTO C-51 BETWEEN S-5A-E AND S-155A

TIME AFTER LOWERING C-51 CANAL STAGE (DAYS)	DISCHARGE (cfs)
30	10.69
45	8.73
60	7.56
90	6.18
180	4.36

FIGURE 1



WATER-TABLE CONTOUR MAP OF PALM BEACH COUNTY, MAY 3-5, 1976, END OF THE DRY SEASON

FIGURE 2

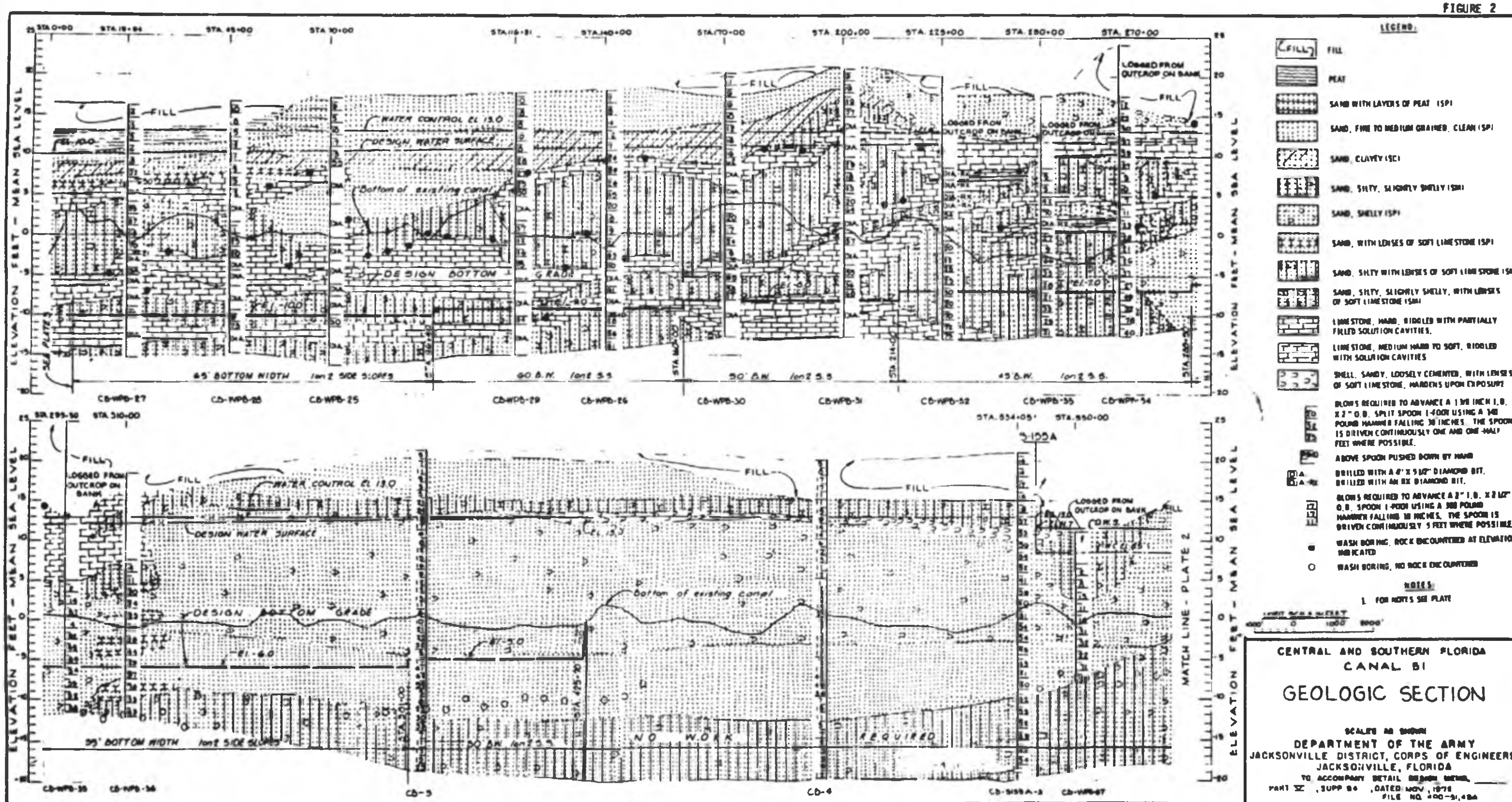
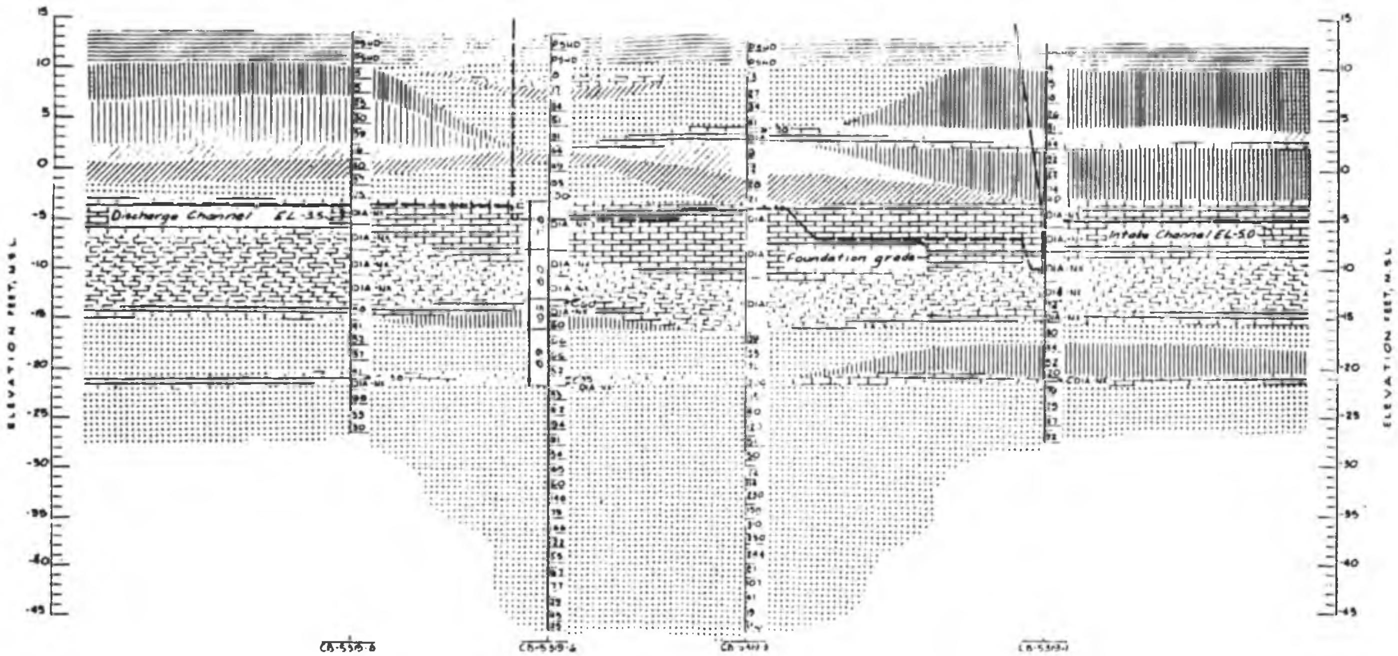
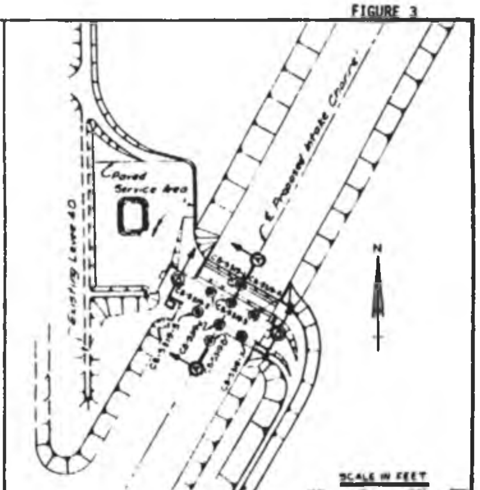

ELEVATION FEET - MEAN SEA LEVEL
STA 0+00
STA 45+00
STA 70+00
STA 200+00
STA 225+00
STA 250+00
STA 270+00
FILL
WATER CONTROL EL 13.0
DESIGN WATER SURFACE
Bottom of existing canal
DESIGN BOTTOM GRADE
LOGGED FROM OUTCROP ON BANK
45' BOTTOM WIDTH 1 on 2 SIDE SLOPES
60 B.W. 1 on 2 S.S.
50' B.W. 1 on 2 S.S.
45 B.W. 1 on 2 S.S.
CB-WPB-27
CB-WPB-25
CB-WPB-29
CB-WPB-26
CB-WPB-30
CB-WPB-31
CB-WPB-32
CB-WPB-33
CB-WPB-34
STA 310+00
STA 550+00
MATCH LINE - PLATE 2
35' BOTTOM WIDTH 1 on 2 SIDE SLOPES
NO WORK REQUIRED
CB-3
CB-4
LEGEND
FILL
PEAT
SAND WITH LAYERS OF PEAT (SP)
SAND, FINE TO MEDIUM GRAINED, CLEAN (SP)
SAND, CLAYEY (SC)
SAND, SILTY, SLIGHTLY SHELLY (SM)
SAND, SHELLY (SP)
SAND, WITH LENSES OF SOFT LIMESTONE (SP)
SAND, SILTY WITH LENSES OF SOFT LIMESTONE (SM)
SAND, SILTY, SLIGHTLY SHELLY, WITH LENSES OF SOFT LIMESTONE (SM)
LIMESTONE, HARD, RIDDLED WITH PARTIALLY FILLED SOLUTION CAVITIES.
LIMESTONE, MEDIUM HARD TO SOFT, RIDDLED WITH SOLUTION CAVITIES
SHELL, SANDY, LOOSELY CEMENTED, WITH LENSES OF SOFT LIMESTONE, HARDENS UPON EXPOSURE
BLOWS REQUIRED TO ADVANCE A 1 3/8 INCH I.D. X 2" O.D. SPLIT SPOON 1-FOOT USING A 140 POUND HAMMER FALLING 30 INCHES. THE SPOON IS DRIVEN CONTINUOUSLY ONE AND ONE-HALF FEET WHERE POSSIBLE.
ABOVE SPOON PUSHED DOWN BY HAND
DRILLED WITH A 4" X 5 1/2" DIAMOND BIT.
DRILLED WITH AN BX DIAMOND BIT.
BLOWS REQUIRED TO ADVANCE A 2" I.D. X 2 1/2" O.D. SPOON 1-FOOT USING A 300 POUND HAMMER FALLING 18 INCHES. THE SPOON IS DRIVEN CONTINUOUSLY 5 FEET WHERE POSSIBLE.
WASH BORING, ROCK ENCOUNTERED AT ELEVATION INDICATED
WASH BORING, NO ROCK ENCOUNTERED
NOTES
1. FOR NOTES SEE PLATE
CENTRAL AND SOUTHERN FLORIDA
CANAL 51
GEOLOGIC SECTION
SCALES AS SHOWN
DEPARTMENT OF THE ARMY
JACKSONVILLE DISTRICT, CORPS OF ENGINEERS
JACKSONVILLE, FLORIDA
TO ACCOMPANY DETAIL DESIGN MEMO.
PART V, SUPP 34, DATED NOV, 1971
FILE NO. 400-31,484

FIGURE 3



SECTION A-A



CORE BORING LOCATIONS

NOTES

1. (SP) AND (SC) ETC. REFERS TO THE CORPS OF ENGINEERS UNIFIED SOILS CLASSIFICATION SYSTEM. CLASSIFICATION OF MATERIALS IS BASED ON VISUAL EXAMINATION.
2. ROCK HARDNESS AND SOIL CLASSIFIED IN ACCORDANCE WITH EM 1110-1-1806.

HORIZ. SCALE IN FEET

LEGEND

- PEAT (PT)
- SAND, FINE GRAINED (SP)
- SAND, CLAYEY (SC)
- SAND, SILTY (SM)
- CLAY (CL)
- SILT (ML)
- LIMESTONE, HARD, INTERBEDDED SOFTER MATERIAL
- LIMESTONE, MEDIUM HARD, VOIDS PARTLY FILLED UNCONSOLIDATED MATERIAL
- CB-5319-6 — CORE HOLE LOCATION AND DESIGNATION, PROFILE VIEW.
- CB-5319-6 — CORE HOLE LOCATION AND DESIGNATION, PLAN VIEW
- NUMBER OF HAMMER BLOWS REQUIRED TO ADVANCE A SPLIT SPOON (1 3/8" I.D. x 2" O.D.) ONE HALF FOOT. THE SPOON IS 2.0 FEET LONG AND DRIVEN CONTINUOUSLY ONE AND ONE HALF FEET WHERE POSSIBLE. BLOWS FOR FIRST 0.5 FT. OMITTED FOR EASE OF PRESENTATION
- PSHD — PUSHED SPOON DOWN BY HAND
- DIA — DRILLED WITH 4" X 5 1/2" DIAMOND BIT
- DRILLED WITH NX DIAMOND BIT
- RECHARGE TEST. GALLONS PER MINUTE PER FOOT OF HEAD. TESTS MADE IN THE FOLLOWING MANNER: CASING IS INSTALLED IN THE HOLE TO THE UPPER LIMIT OF THE ZONE TO BE TESTED. THE HOLE IS THEN DRILLED TO THE LOWER LIMIT OF THE SECTION TO BE TESTED. WATER IS PUMPED INTO THE CASING AT A RATE SUFFICIENT TO MAINTAIN A CONSTANT HEAD ABOVE THE NORMAL WATER TABLE, IF POSSIBLE, AND THIS RATE OF FLOW IS DETERMINED. THE RATE OF FLOW DIVIDED BY THE HEAD MAINTAINED GIVES GALLONS PER MINUTE PER FOOT OF HEAD.

CENTRAL AND SOUTHERN FLORIDA

PUMPING STATION 319

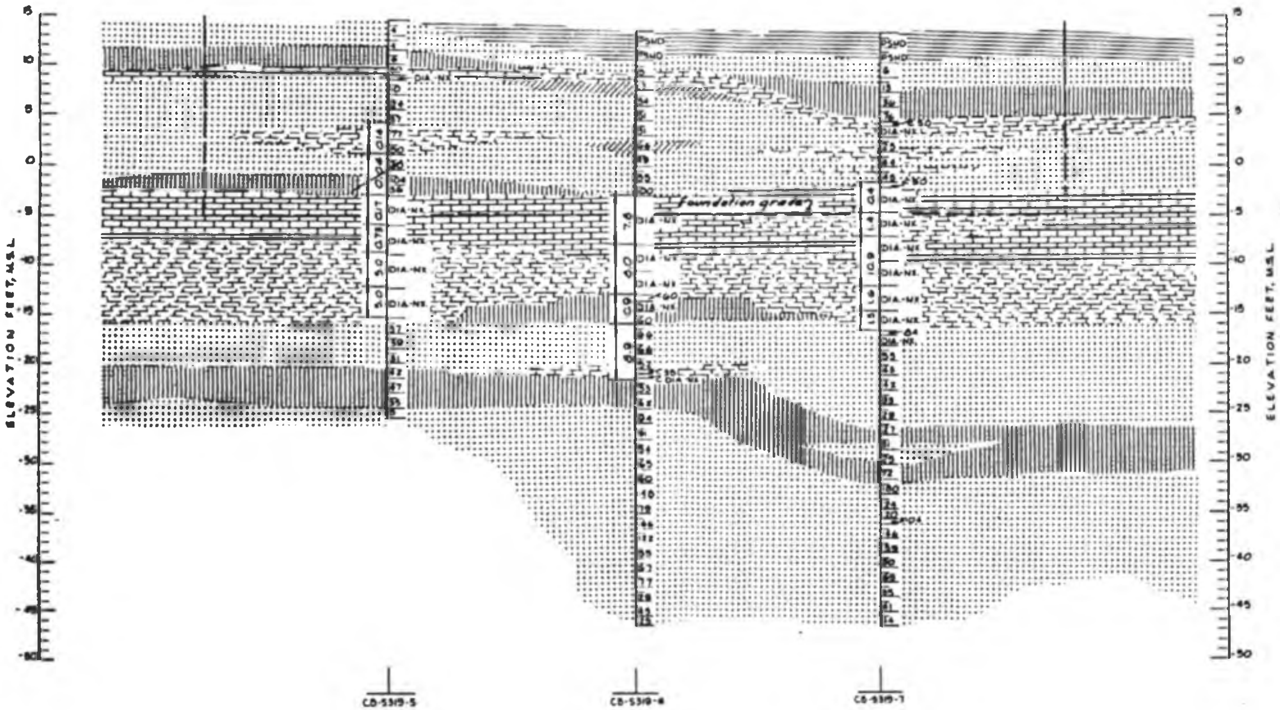
GEOLOGIC SECTION A-A

SCALES AS SHOWN

DEPARTMENT OF THE ARMY
JACKSONVILLE DISTRICT, CORPS OF ENGINEERS
JACKSONVILLE, FLORIDA

TO ACCOMPANY GENERAL & DETAIL DESIGN MEMO.
PART V, SUPP 31, DATED MAY 1972
FILE NO. 400-31,300

FIGURE 4



SECTION B-B

NOTE:

FOR NOTES, LEGEND, AND CORE BORING LOCATIONS, SEE PLATE A-12

HORIZONTAL SCALE IN FEET

0 10' 20'

CENTRAL AND SOUTHERN FLORIDA

PUMPING STATION 319

GEOLOGIC SECTION B-B

SCALES AS SHOWN

DEPARTMENT OF THE ARMY
JACKSONVILLE DISTRICT, CORPS OF ENGINEERS
JACKSONVILLE, FLORIDA

TO ACCOMPANY GENERAL & DETAIL DESIGN MEMO., PART V, SUPP 51, DATED: MARCH, 1978
FILE NO. 400-51.506

46 8080

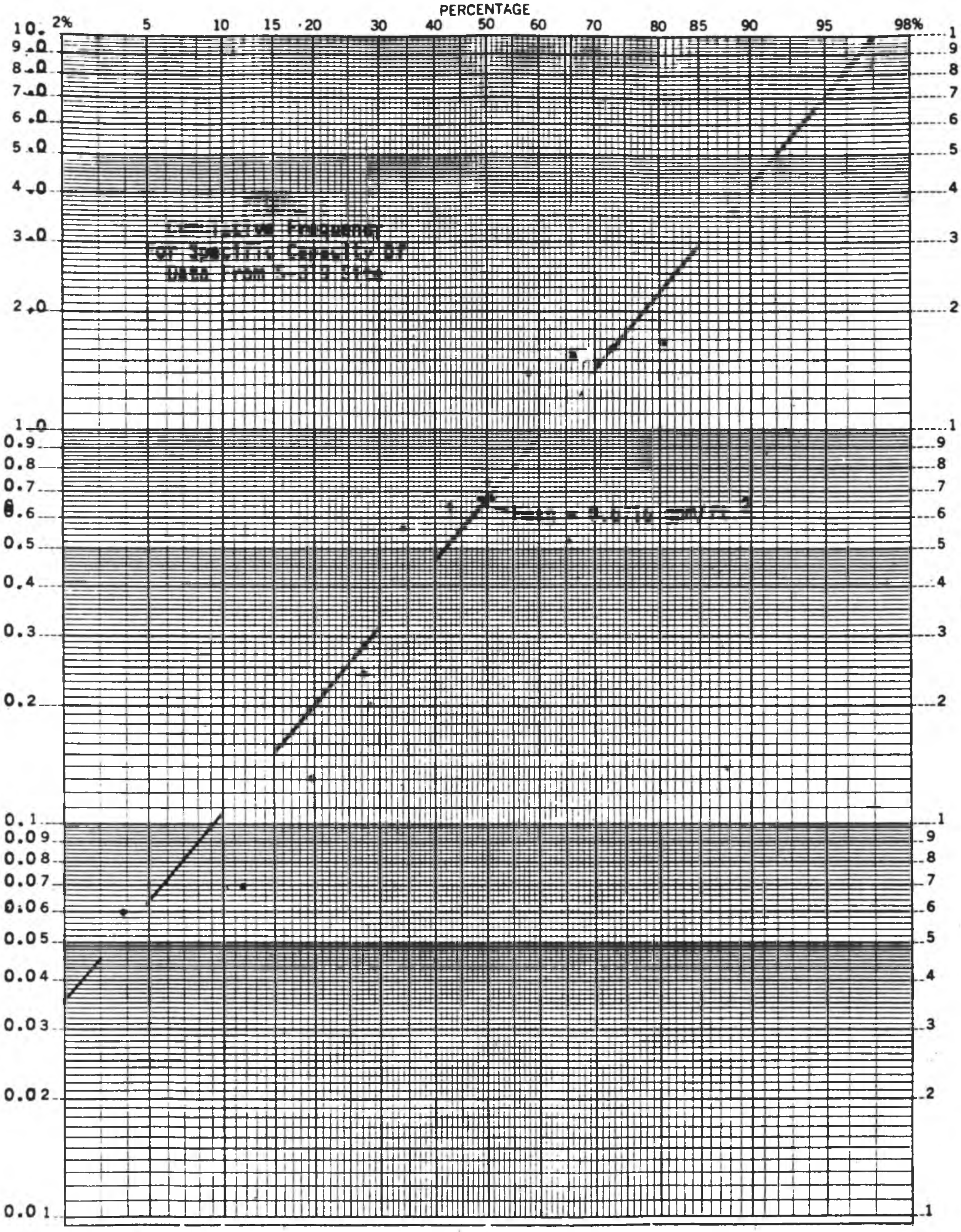
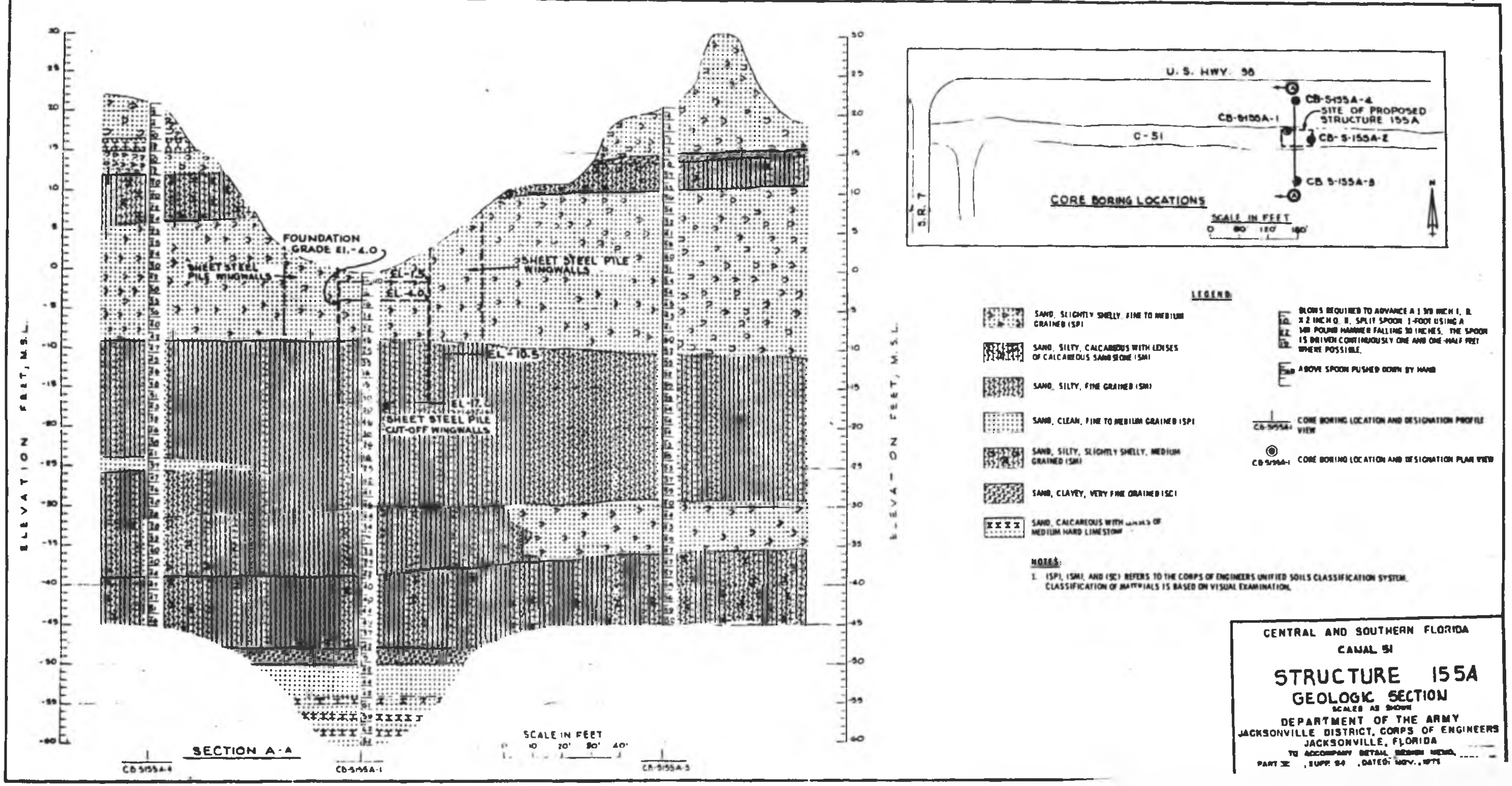

SPECIFIC CAPACITY PER FT. BOREHOLE - GPM/FT.2
PERCENTAGE
2%
5
10
15
20
30
40
50
60
70
80
85
90
95
98%
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.

FIGURE 6



SECTION A-A
ELEVATION FEET, M.S.L.
ELEVATION ON FEET, M.S.L.
FOUNDATION GRADE EL.-4.0
SHEET STEEL PILE WINGWALLS
SHEET STEEL PILE WINGWALLS
EL.-10.5
SHEET STEEL PILE CUT-OFF WINGWALLS
SCALE IN FEET
CB-5155A-4
CB-5155A-1
CB-5155A-3
U.S. HWY. 98
CB-5155A-4
SITE OF PROPOSED STRUCTURE 155A
CB-5155A-1
C-51
CB-5-155A-2
CB 5-155A-3
S.R. 7
CORE BORING LOCATIONS
SCALE IN FEET
LEGEND
SAND, SLIGHTLY SHELLY, FINE TO MEDIUM GRAINED (SP)
SAND, SILTY, CALCAREOUS WITH LENSES OF CALCAREOUS SANDSTONE (SM)
SAND, SILTY, FINE GRAINED (SM)
SAND, CLEAN, FINE TO MEDIUM GRAINED (SP)
SAND, SILTY, SLIGHTLY SHELLY, MEDIUM GRAINED (SM)
SAND, CLAYEY, VERY FINE GRAINED (SC)
SAND, CALCAREOUS WITH ... OF MEDIUM HARD LIMESTONE
BLOWS REQUIRED TO ADVANCE A 1 3/8 INCH I. D. X 2 INCH O. D. SPLIT SPOON 1-FOOT USING A 140 POUND HAMMER FALLING 30 INCHES. THE SPOON IS DRIVEN CONTINUOUSLY ONE AND ONE-HALF FEET WHERE POSSIBLE.
ABOVE SPOON PUSHED DOWN BY HAND
CORE BORING LOCATION AND DESIGNATION PROFILE VIEW
CORE BORING LOCATION AND DESIGNATION PLAN VIEW
NOTES:
1. (SP), (SM), AND (SC) REFERS TO THE CORPS OF ENGINEERS UNIFIED SOILS CLASSIFICATION SYSTEM. CLASSIFICATION OF MATERIALS IS BASED ON VISUAL EXAMINATION.
CENTRAL AND SOUTHERN FLORIDA
CANAL 51
STRUCTURE 155A
GEOLOGIC SECTION
SCALES AS SHOWN
DEPARTMENT OF THE ARMY
JACKSONVILLE DISTRICT, CORPS OF ENGINEERS
JACKSONVILLE, FLORIDA

TECHNICAL MEMORANDUM

9-1-2H September 7, 1976

TO: Peter B. Rhoads, Deputy Director, Resource Planning Department

FROM: D. Allman and G. Winter, Groundwater Division

SUBJECT: C-51 Leakage

Statement of Problem Addressed

The basic problem addressed in this memo is the impact on the groundwater flow system and the modification that can be expected in the water budget for the C-51 canal between S-5A-E and above S-155A as a result of raising the stage in the canal to between approximately 8.5 ft. and 14.0 ft. MSL. This increase in canal stage could change the basin water budget by increasing evapotranspirative consumptive use (ET) and changing basin inflow-outflow relationships. USGS water table contour maps from May, 1974 to May, 1976 were examined to ascertain the basin inflow-outflow change that could be expected. Figure 1 is the water table contour map for May 3-5, 1976. Proposed structure S-155A is to be located just east of the junction of canal E-1 and C-51. Since E-1 and E-2 have good interconnections and since E-2 is located below S-155A, raising the canal stage above S-155A will have a negligible affect on the hydrology of the E-1 and E-2 canal drainage areas during normal runoff conditions. The stages of the tributary canals above S-155A except E-1 as determined from USGS water table contour maps are summarized in Table 1. In general, the stages in the canals south of C-51 are about 11.2 feet MSL whereas those north of C-51 are about 14 ft. MSL. The combined average stage for the tributary canals north and south of C-51 is approximately 12.6 ft. MSL.

almost all of the drainage basin will not increase significantly. The ET consumptive use could only be expected to increase in the immediate vicinity of the C-51 canal where the existing water table is depressed because of the direct inflow of groundwater to the C-51 canal. According to the USGS water table contour maps, the water table may be depressed within a 2,000 ft. wide tract on both sides of the canal, although this is probably an educated guess on the part of the USGS. If ET consumptive use were suppressed by 5 inches/year over this entire tract, which is not very likely because of the rigid control of water in the agricultural areas adjacent to the canal, the average annual ET consumptive use would increase by 2.99 cfs or 0.346 inches over the 117 square miles drainage basin. For a 45.13 inch annual rainfall, the change in ET consumptive use would amount to 0.77% of the rainfall. For practical purposes this increase in ET consumptive use from the basin as a whole is negligible.

In conclusion, since the tributary canal stages will undoubtedly be closely controlled at levels necessary to accommodate the basin development with the levels being set independent of the C-51 canal stage regimen, a negligible effect would result in the hydrologic system throughout the C-51 drainage basin outside of a 4,000 ft. wide tract centered on the C-51 canal. A negligible increase in basin ET consumptive use can be expected with increased C-51 canal stages because of the relatively small area whose water table is depressed as a result of direct groundwater drainage into C-51. The calculations that follow are provided to give some hint of the magnitude of the direct groundwater seepage that could be expectedto occur into the C-51 canal.

John Wiley & Sons, 1964, p.48, Todd, D. K., "Ground Water Hydrology," John Wiley & Sons, 1959, p.53). The sequential ordering of the above list of soils suggests the permeability would probably be nearer 2.12 gpd/ft.^{2} rather than 21.21 gpd/ft.^{2}. The classification of "clayey sands, fine sands (poor aquifers)" has an estimated permeability range from 10 to 0.01 gpd/ft.^{2} (Davis, S. N., DeWiest, R. J. M., "Hydrogeology," John Wiley & Sons Inc., 1966, p.164). From the above estimates, it shall hereafter be assumed that the permeability for the silty and clayey sand is 10 gpd/ft.^{2}

The estimated permeability value for the limestone is the critical value because the permeability of the limestone can be so large that it can almost completely dominate. The Corps of Engineers performed specific capacity tests on the limestone underlying the proposed S-319 pumping station as indicated in Figures 3 and 4.

The specific capacity value of 0.04 gpm/ft. obtained from borehole CB-S319-5 was omitted from the following analysis because the very low value is not believed to be representative of a limestone specific capacity. The specific capacities per foot of borehole were obtained from the Corps' data and plotted on log probability paper (Figure 5). Since the data plots as a reasonably straight line, the population of specific capacities per foot of borehole is assumed to be log normally distributed. The mean is 0.6716 gpm/ft.^{2}. The 5% and 95% confidence limits differ by about a factor of 10 from the mean. Thus, calculations using the mean can be in considerable error.

100 feet in depth. Thus, the aquifer transmissivity is hereafter assumed to be 17,930 gpd/ft.

The reach of canal from station 31,000 to 53,875 can be treated in a manner similar to that for the western 31,000 ft. As indicated in Figure 6, the geologic materials occur in much thicker and apparently more continuous units than in the reach from 0 to 31,000 ft. Based on the borings at S-155A, 40.5% of the geologic section consists of clean, fine to medium grain sand while 59.5% of the section consists of silty or clayey sand. The permeabilities for clean fine to medium sand and for the sand that is silty or clayey are assumed to be 200 and 10 gpd/ft.^{2} respectively. Thus, the effective permeability is 86.95 gpd/ft.^{2} ((40.5% X 200 gpd/ft.^{2}) + (59.5% X 10 gpd/ft.^{2})). For a 100 ft. thick aquifer, the transmissivity would be 8,695 gpd/ft. The vertical permeability is generally 2 to 10 times less than the horizontal permeability. Thus, the estimated effective transmissivity is probably too large and will thus result in an estimated discharge to C-51 that is greater than that actually occurring.

Canal Partial Penetration

The C-51 canal is assumed to behave as a fully penetrating drain. According to Huisman (Groundwater Recovery, Winchester Press 1972, p.56), the additional drawdown Δs_0 due to the partial penetration of a random shaped gallery to maintain the same discharge as a fully penetrating drain is:

station 0 and 31,000 at the end of periods ranging from 30 to 180 days. Drawdowns in the water table at distances of 1,000 ft. and 2,000 ft. from the canal are also listed in Table 2. It would not appear unreasonable to assume a discharge of 5.77 cfs into the canal. This would result after a period of 45 days. Recharge to the water table occurs quite frequently during the wet season (June-September) which could result in relatively high discharge rates into the canal. During the dry season, recharge does not occur as frequently and thus the water table would decline unless irrigation occurred. The drawdown of the water table would be approximately 1.61 ft. and 0.223 ft. at distances of 1,000 ft. and 2,000 ft. respectively from the canal. These drawdown data do not appear unreasonable based on vehicle hydrology (observations from a speeding car or motorcycle).

The inflow to the reach of C-51 between stations 31,000 and 53,875 can be calculated in a manner similar to that for the reach from 0 to 31,000. Table 3 lists the discharge into the C-51 canal in the 22,875 ft. reach at the end of periods varying from 30 to 180 days following the hypothetical lowering of the canal stage by 4.35 ft. Water table drawdowns at distances of 1,000 ft. and 2,000 ft. from the canal are also listed in Table 3. After a period of 45 days, the discharge to the canal is 2.96 cfs with a water table drawdown of 0.520 ft. and <0.05 feet at distances of 1,000 ft. and 2,000 ft. respectively from the canal. The discharge into the canal is not overly sensitive to the length of the period that has elapsed following the initial hypothetical lowering of the water table. The calculated discharge into the C-51 canal is relatively small for this 22,875 ft. reach of canal.

the leaky artesian aquifer. The vertical permeability of the confining unit is assumed to be 2 gpd/ft.^{2} The seepage inflow Q, is calculated using the following equation:

$$Q = \frac{22875 \times ((40 \times 4.35) + (500 \times 4.35/2)) \times 2 \times 2}{7.48 \times 1440 \times 60 \times 40} = 4.47 \text{ cfs}$$

This seepage rate is also comparatively low and is only 1.5 cfs greater than the value of 2.96 cfs in Table 3 forty-five days after a hypothetical lowering of the canal stage.

Since the canal inflows which are calculated assuming: a) an unconfined aquifer overlying a leaky artesian aquifer; and b) vertical upward flow in the immediate vicinity of the canal, are not significantly different from the value (2.96 cfs) obtained assuming a fully penetrating drain in a 100 ft. thick aquifer, the latter value will be assumed to be the canal inflow.

The calculated discharge of groundwater into the reach of canal above S-155A based on a simple seepage model is summarized in Table 4. Under existing conditions, the average annual groundwater inflow is estimated to be 8.73 cfs neglecting the additional seepage that will result because of the tributary canals. The additional seepage that will result because of the tributary canals is uncertain. If the 15 or more tributary canals contribute as much groundwater seepage to C-51 as the groundwater flow system that would develop without the tributary canals, the groundwater inflow would equal 17.46 cfs or 2.03 inches over a 117 square mile basin. The effective groundwater seepage into the C-51 canal would be reduced by any backpumping into tributary canals. Thus, the groundwater inflow under existing conditions is estimated to be

TABLE 1

STAGES ON TRIBUTARY CANALS TO C-51 WEST OF PROPOSED S-155A

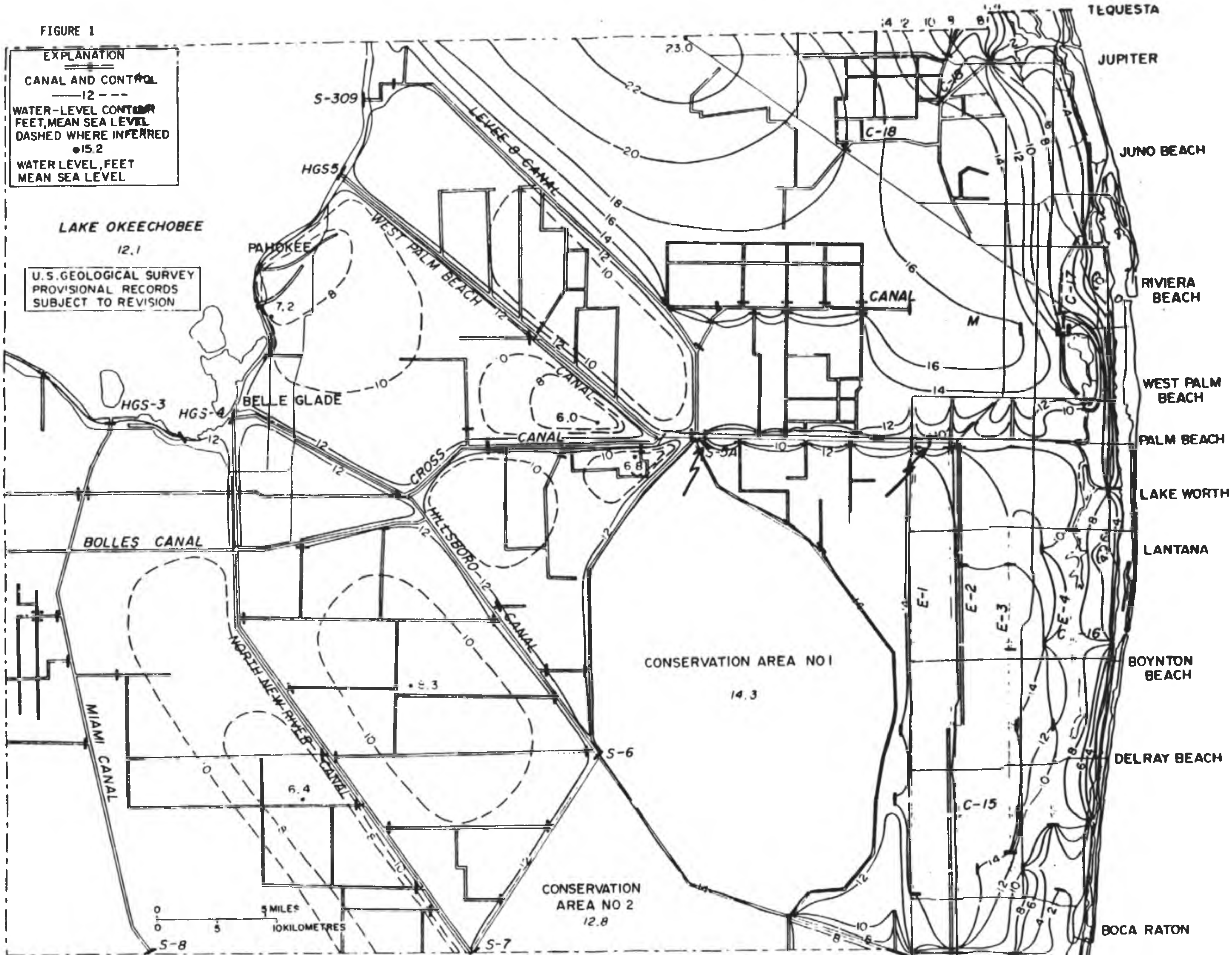
DATE	NORTH SIDE (FEET MSL)	SOUTH SIDE (FEET MSL)
May 7, 8, 1974	14	10
October 9-10, 1974	16	14
May 6-7, 1975	12	10
October 8, 4, 1975	16	10
May 3-5, 1976	12	12
Average	14	11.2
Combined Average	12.6	

TABLE 3

INFLOWS TO C-51 BETWEEN STATIONS 31,000 and 53,875

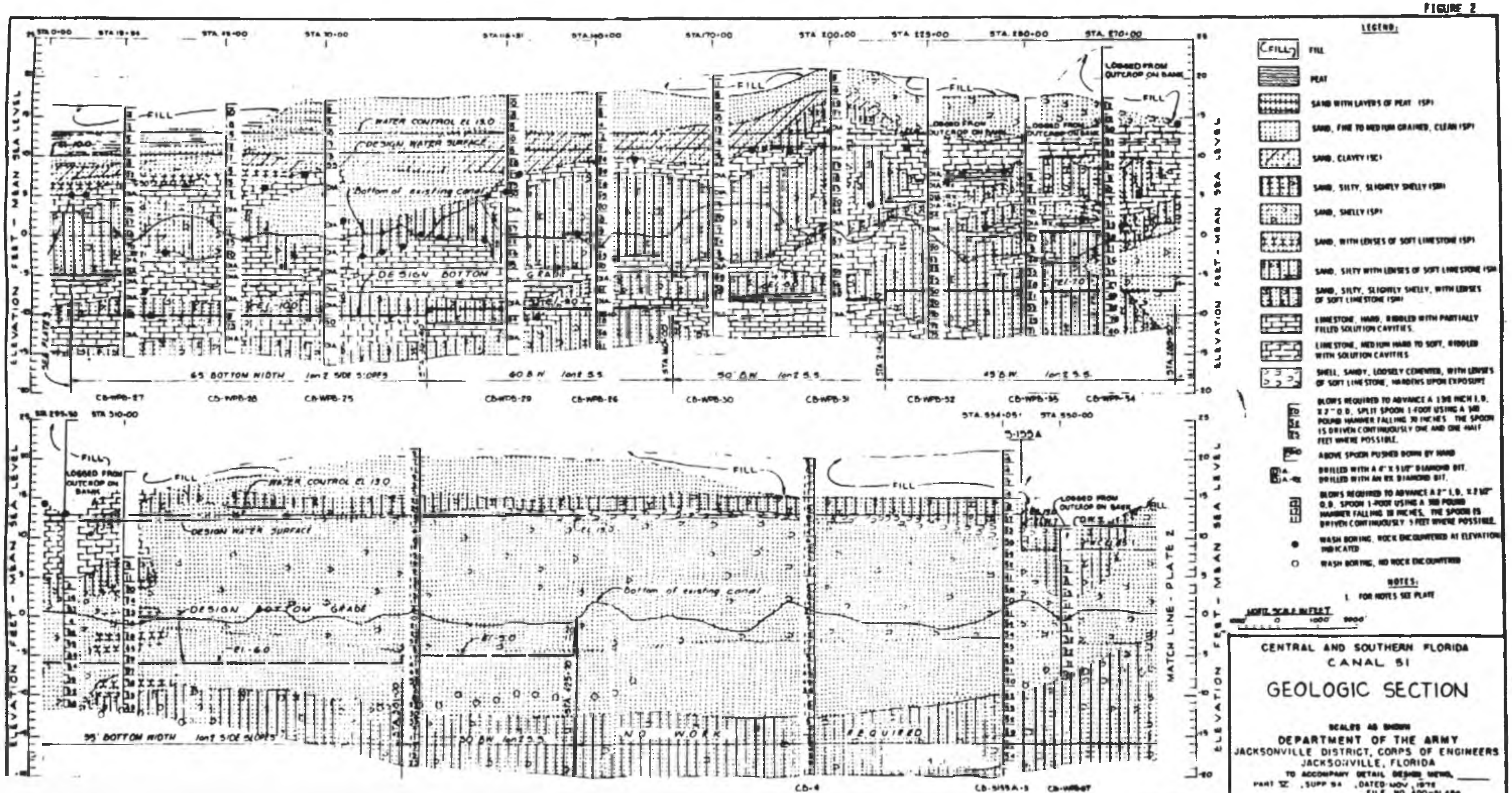
TIME AFTER LOWERING C-51 CANAL STAGE (DAYS)	DISCHARGE (cfs)	DRAWDOWN AT VARIOUS DISTANCES FROM C-51 1,000 FEET (FEET)	2,000 FEET (FEET)
30	3.63	0.400	<0.05
45	2.96	0.520	<0.05
60	2.57	1.02	0.0735
90	2.10	1.45	0.221
180	1.48	2.13	0.731

FIGURE 1



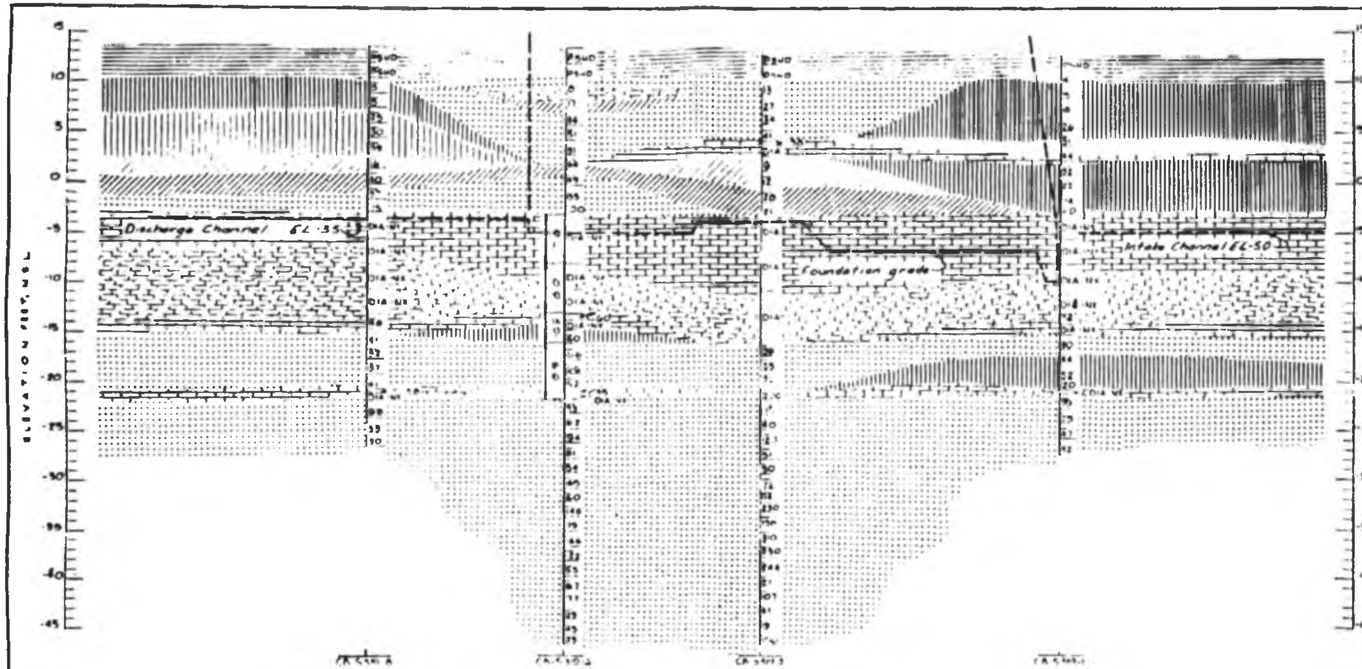
WATER TABLE CONTOUR MAP OF PALM BEACH COUNTY, MAY 3-5, 1976, END OF THE DRY SEASON

FIGURE 2

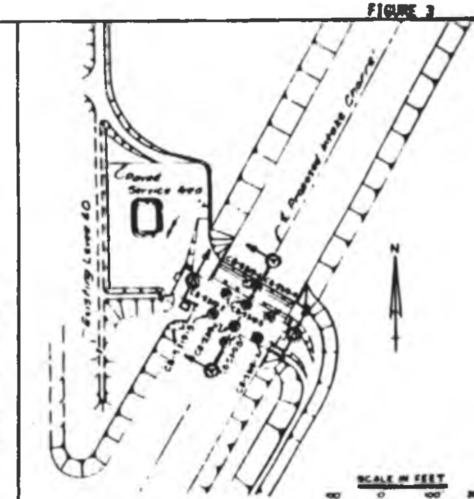


LEGEND:
FILL
PEAT
SAND WITH LAYERS OF PEAT (SP)
SAND, FINE TO MEDIUM GRAINED, CLEAN (SP)
SAND, CLAYEY (SC)
SAND, SILTY, SLIGHTLY SHELLY (SM)
SAND, SHELLY (SP)
SAND, WITH LENSES OF SOFT LIMESTONE (SP)
SAND, SILTY WITH LENSES OF SOFT LIMESTONE (SM)
SAND, SILTY, SLIGHTLY SHELLY, WITH LENSES OF SOFT LIMESTONE (SM)
LIMESTONE, HARD, RIDDLED WITH PARTIALLY FILLED SOLUTION CAVITIES.
LIMESTONE, MEDIUM HARD TO SOFT, RIDDLED WITH SOLUTION CAVITIES
SHELL, SANDY, LOOSELY CEMENTED, WITH LENSES OF SOFT LIMESTONE, HARDENS UPON EXPOSURE
ABOVE SPOON PUSHED DOWN BY HAND
WASH BORING, ROCK ENCOUNTERED AT ELEVATION INDICATED
WASH BORING, NO ROCK ENCOUNTERED
NOTES:
1. FOR NOTES SEE PLATE
ELEVATION FEET - MEAN SEA LEVEL
WATER CONTROL EL 13.0
DESIGN WATER SURFACE
Bottom of existing canal
DESIGN BOTTOM GRADE
LOGGED FROM OUTCROP ON BANK
65' BOTTOM WIDTH
95' BOTTOM WIDTH
NO WORK REQUIRED
MATCH LINE - PLATE 2
CENTRAL AND SOUTHERN FLORIDA
CANAL 51
GEOLOGIC SECTION
SCALES AS SHOWN
DEPARTMENT OF THE ARMY
JACKSONVILLE DISTRICT, CORPS OF ENGINEERS
JACKSONVILLE, FLORIDA

FIGURE 3



SECTION A-A



CORE BORING LOCATIONS

LEGEND

- PEAT (PT)
- SAND, FINE GRAINED (SP)
- SAND, CLAYEY (SC)
- SAND, SILTY (SM)
- CLAY (CL)
- SILT (ML)
- LIMESTONE, HARD, INTERBEDDED SOFTER MATERIAL
- LIMESTONE, MEDIUM HARD, VOIDS PARTLY FILLED UNCONSOLIDATED MATERIAL
- CORE HOLE LOCATION AND DESIGNATION, PROFILE VIEW
- CORE HOLE LOCATION AND DESIGNATION, PLAN VIEW
- NUMBER OF HAMMER BLOWS REQUIRED TO ADVANCE A SPLIT SPOON (1 3/8" I.D. x 2" O.D.) ONE HALF FOOT. THE SPOON IS 2.0 FEET LONG AND DRIVEN CONTINUOUSLY ONE AND ONE HALF FEET WHERE POSSIBLE. BLOWS FOR FIRST 0.5 FT. OMITTED FOR EASE OF PRESENTATION.
- PUSHED SPOON DOWN BY HAND
- DRILLED WITH 4" X 5 1/2" DIAMOND BIT
- DRILLED WITH NX DIAMOND BIT
- RECHARGE TEST: GALLONS PER MINUTE PER FOOT OF HEAD. TESTS MADE IN THE FOLLOWING MANNER: CASING IS INSTALLED IN THE HOLE TO THE UPPER LIMIT OF THE ZONE TO BE TESTED. THE HOLE IS THEN DRILLED TO THE LOWER LIMIT OF THE SECTION TO BE TESTED. WATER IS PUMPED INTO THE CASING AT A RATE SUFFICIENT TO MAINTAIN A CONSTANT HEAD ABOVE THE NORMAL WATER TABLE, IF POSSIBLE, AND THIS RATE OF FLOW IS DETERMINED. THE RATE OF FLOW DIVIDED BY THE HEAD MAINTAINED GIVES GALLONS PER MINUTE PER FOOT OF HEAD.

NOTES

1. (SP) AND (SC) ETC. REFERS TO THE CORPS OF ENGINEERS UNIFIED SOILS CLASSIFICATION SYSTEM. CLASSIFICATION OF MATERIALS IS BASED ON VISUAL EXAMINATION.
2. ROCK HARDNESS AND SOIL CLASSIFIED IN ACCORDANCE WITH EM 1110-1-1806

HORIZ. SCALE IN FEET

CENTRAL AND SOUTHERN FLORIDA

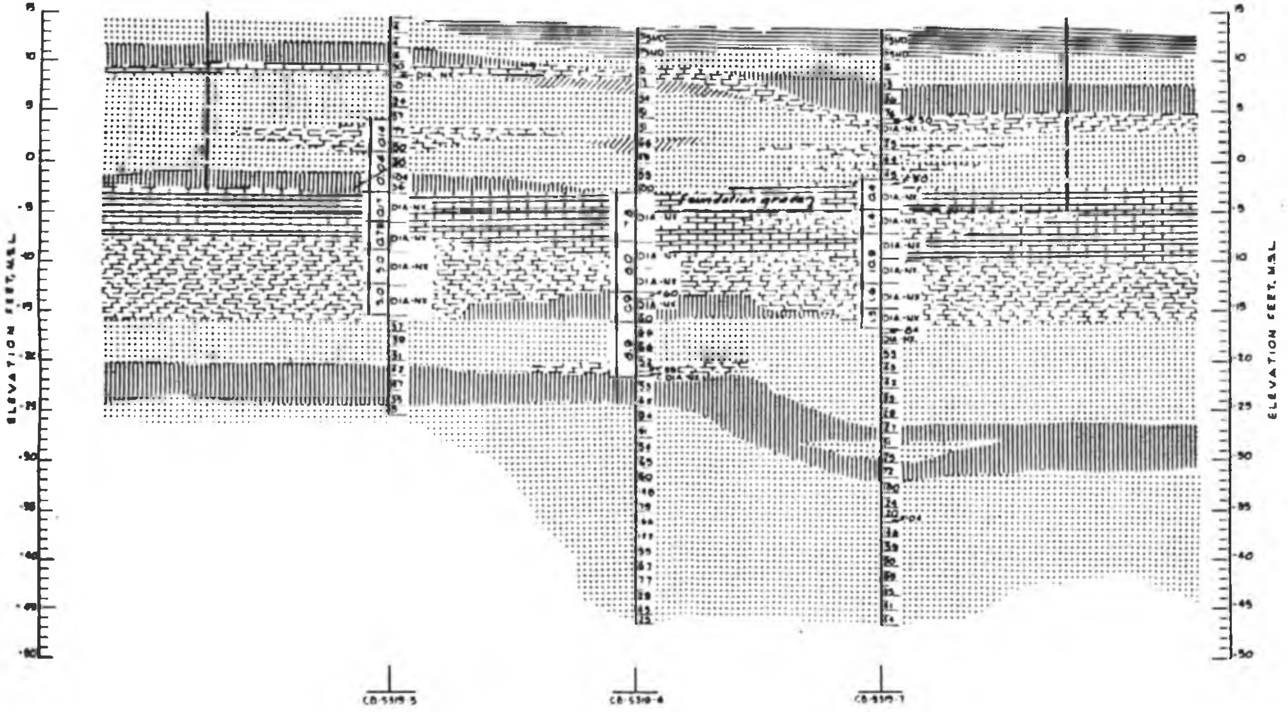
PUMPING STATION 319

GEOLOGIC SECTION A-A

SCALED AS SHOWN

DEPARTMENT OF THE ARMY
JACKSONVILLE DISTRICT, CORPS OF ENGINEERS
JACKSONVILLE, FLORIDA

FIGURE 4



SECTION B-B'

NOTE:
FOR NOTES, LEGEND, AND CORE BORING LOCATIONS, SEE PLATE B-12

HORIZONTAL SCALE IN FEET

CENTRAL AND SOUTHERN FLORIDA
PUMPING STATION 319
GEOLOGIC SECTION B-B

SCALES AS SHOWN
DEPARTMENT OF THE ARMY
JACKSONVILLE DISTRICT, CORPS OF ENGINEERS
JACKSONVILLE, FLORIDA
TO ACCOMPANY GENERAL & DETAIL DESIGN MEMO, PART IV, SUPP 51, DATED MARCH 1971
FILE NO. 400-81,140

K·E PROBABILITY X 3 LOG CYCLES
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 8080

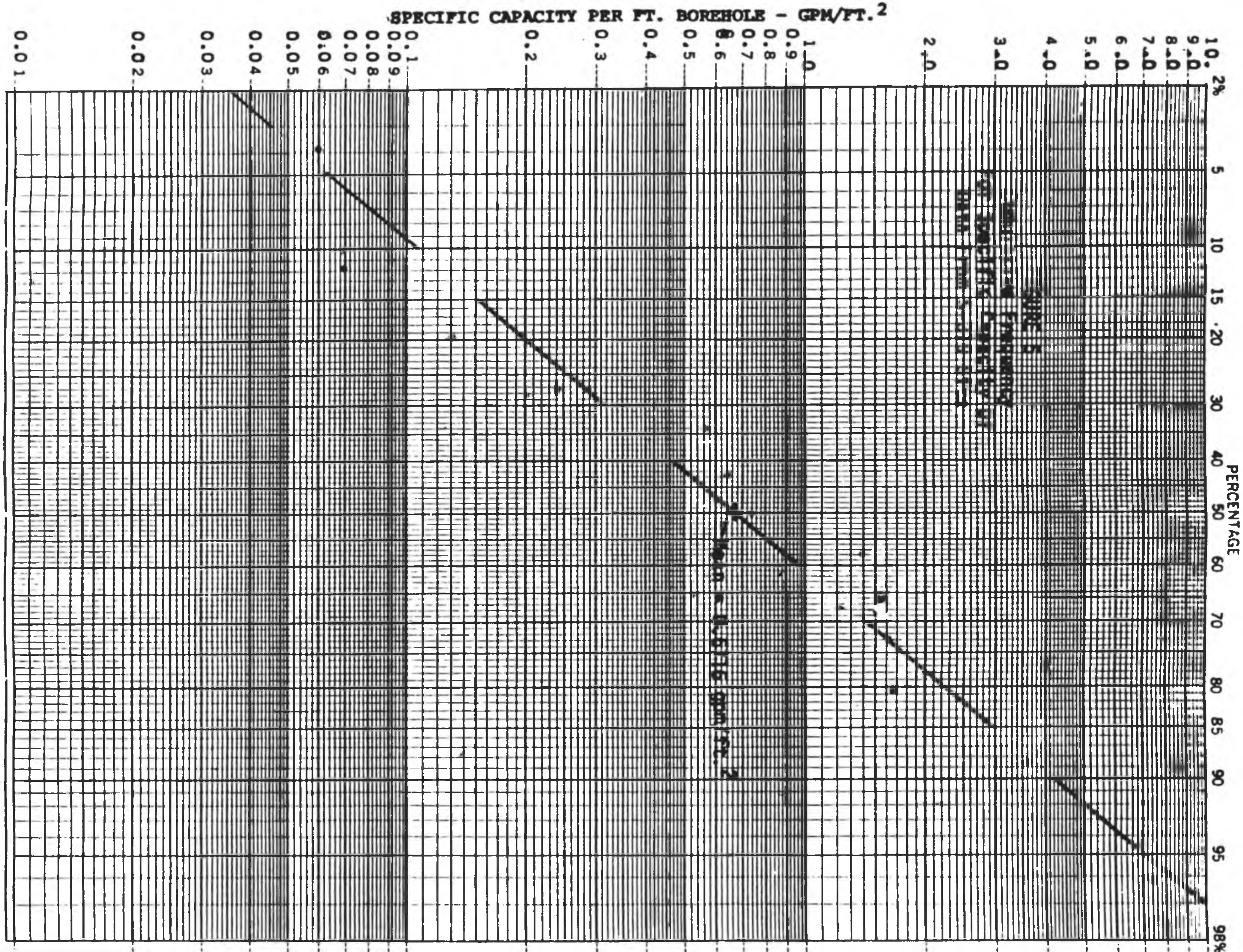
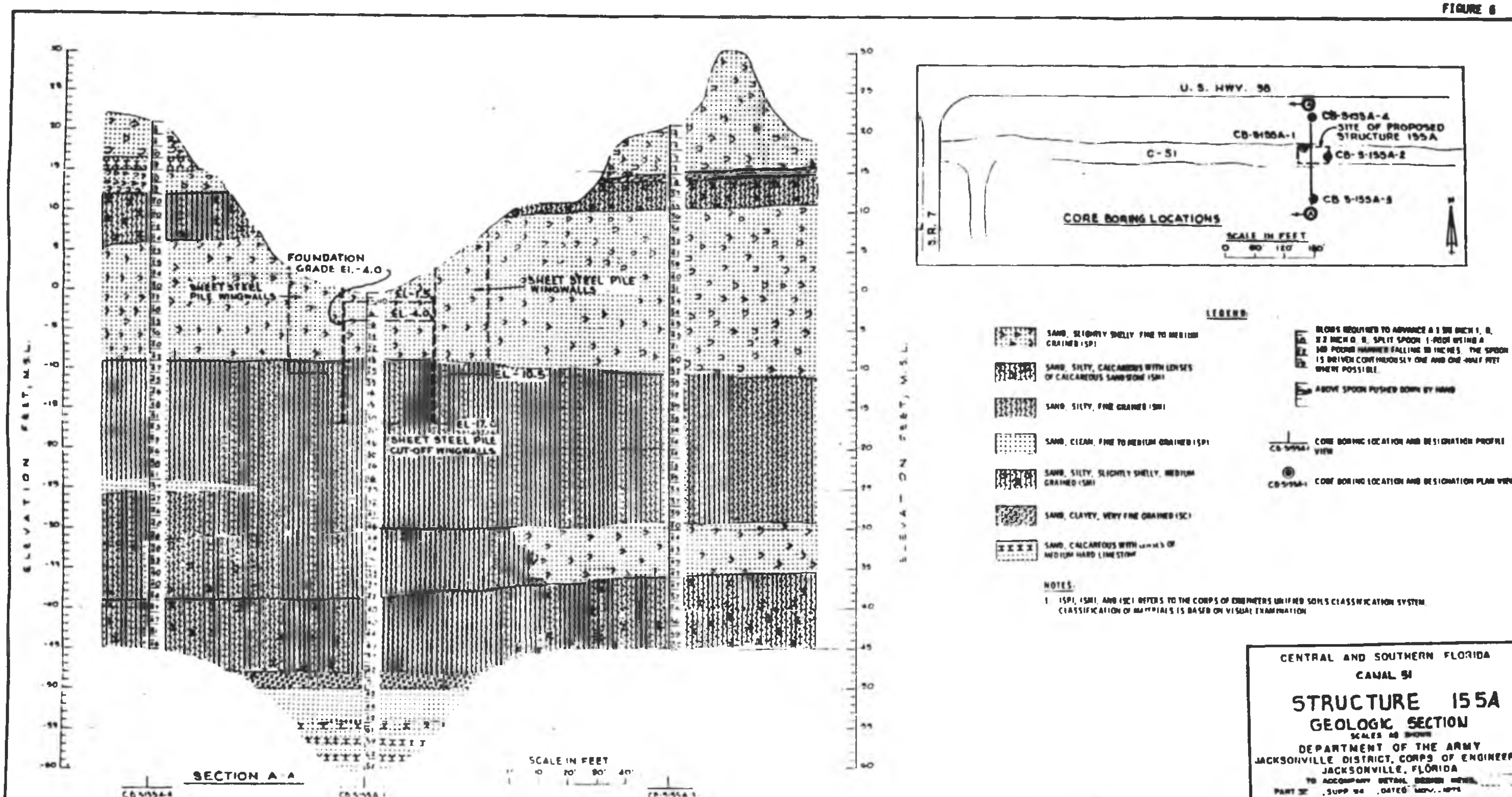


FIGURE 6



ELEVATION FEET, M.S.L.
FOUNDATION GRADE EL. -4.0
SHEET STEEL PILE WINGWALLS
SHEET STEEL PILE WINGWALLS
EL. -7.5
EL. -4.0
EL. -10.5
EL. -17.
SHEET STEEL PILE CUT-OFF WINGWALLS
SECTION A-A
SCALE IN FEET
ELEVATION FEET, M.S.L.
U. S. HWY. 98
CB-S155A-4
SITE OF PROPOSED STRUCTURE 155A
CB-S155A-1
C-51
CB-S-155A-2
CB S-155A-3
S.R. 7
CORE BORING LOCATIONS
SCALE IN FEET
LEGEND
NOTES:
CENTRAL AND SOUTHERN FLORIDA
CANAL 51
STRUCTURE 155A
GEOLOGIC SECTION
DEPARTMENT OF THE ARMY
JACKSONVILLE DISTRICT, CORPS OF ENGINEERS
JACKSONVILLE, FLORIDA

TECHNICAL MEMORANDUM

9-1-2H September 7, 1976

TO: Peter B. Rhoads, Deputy Director, Resource Planning Department

FROM: D. Allman and G. Winter, Groundwater Division

SUBJECT: C-51 Leakage

Statement of Problem Addressed

The basic problem addressed in this memo is the impact on the groundwater flow system and the modification that can be expected in the water budget for the C-51 canal between S-5A-E and above S-155A as a result of raising the stage in the canal to between approximately 8.5 ft. and 14.0 ft. MSL. This increase in canal stage could change the basin water budget by increasing evapotranspirative consumptive use (ET) and changing basin inflow-outflow relationships. USGS water table contour maps from May, 1974 to May, 1976 were examined to ascertain the basin inflow-outflow change that could be expected. Figure 1 is the water table contour map for May 3-5, 1976. Proposed structure S-155A is to be located just east of the junction of canal E-1 and C-51. Since E-1 and E-2 have good interconnections and since E-2 is located below S-155A, raising the canal stage above S-155A will have a negligible affect on the hydrology of the E-1 and E-2 canal drainage areas during normal runoff conditions. The stages of the tributary canals above S-155A except E-1 as determined from USGS water table contour maps are summarized in Table 1. In general, the stages in the canals south of C-51 are about 11.2 feet MSL whereas those north of C-51 are about 14 ft. MSL. The combined average stage for the tributary canals north and south of C-51 is approximately 12.6 ft. MSL.

Groundwater seepage into C-51 from the reaches of the tributary canals near C-51 will become negligible when C-51 stages are increased. However, the existing seepage from the tributary canals is believed to be relatively small and is effectively rendered negligible under existing conditions on some canals because of backpumping facilities. Stages in the tributary canals can be expected to be controlled to maintain favorable land use conditions. This control via pumping facilities of canal and groundwater stages in the tributary canal drainage basins will probably result in a negligible impact in the net water budget for the C-51 basin above S-155A. Water that is discharged into C-51 as groundwater under existing conditions will simply be discharged into the canal as surface water under increased operating stages for C-51. Since the proposed C-51 canal stage will be lower than the existing stages on the tributary canals to the north of C-51, a negligible change in stages on these tributary canals will result when the stage in C-51 is increased. The canals and groundwater stages to the south of C-51 can be expected to be controlled near existing levels even though the proposed C-51 stage will be higher than existing stages because all the tributary canals are equipped with facilities to pump water into C-51. Thus, negligible changes in the combined surface water ground water discharge from the basins can be expected assuming the ET consumptive use does not change significantly.

Evapotranspirative consumptive use from the basin is not expected to change significantly as a result of raising the stage in C-51. Since existing tributary canal stages will not change significantly, ET consumptive use over

almost all of the drainage basin will not increase significantly. The ET consumptive use could only be expected to increase in the immediate vicinity of the C-51 canal where the existing water table is depressed because of the direct inflow of groundwater to the C-51 canal. According to the USGS water table contour maps, the water table may be depressed within a 2,000 ft. wide tract on both sides of the canal, although this is probably an educated guess on the part of the USGS. If ET consumptive use were suppressed by 5 inches/year over this entire tract, which is not very likely because of the rigid control of water in the agricultural areas adjacent to the canal, the average annual ET consumptive use would increase by 2.99 cfs or 0.346 inches over the 117 square miles drainage basin. For a 45.13 inch annual rainfall, the change in ET consumptive use would amount to 0.77% of the rainfall. For practical purposes this increase in ET consumptive use from the basin as a whole is negligible.

In conclusion, since the tributary canal stages will undoubtedly be closely controlled at levels necessary to accommodate the basin development with the levels being set independent of the C-51 canal stage regimen, a negligible effect would result in the hydrologic system throughout the C-51 drainage basin outside of a 4,000 ft. wide tract centered on the C-51 canal. A negligible increase in basin ET consumptive use can be expected with increased C-51 canal stages because of the relatively small area whose water table is depressed as a result of direct groundwater drainage into C-51. The calculations that follow are provided to give some hint of the magnitude of the direct groundwater seepage that could be expectedto occur into the C-51 canal.

Aquifer Transmissivity

Aquifer transmissivity was estimated by indirect means since pump test data are not available along the reach of C-51 between S-155A and S-5A-E. Figure 2 is the geologic section along C-51 from S-5A-E to S-155A. From station 0 to 31,000, the geologic section is rather complex with relatively thin limestone and sand units contained throughout the section. From station 31,000 to 53,875, the geologic section consists primarily of clean sand overlying silty sand. These two reaches of canal will be treated separately because of their obviously different hydraulic characteristics. In the western 31,000 ft. of the study reach, the overall geologic section penetrated by the borings consists of 55.6% sand that is silty or clayey, 36.6% limestone that contains solution cavities that are either open or partially filled, and 7.8% sand that is clean and fine to medium grained.

The principle problem is to estimate the permeability of the 3 groups of geologic materials. Several estimates using different data sources will be used if possible. For the sand that contains silt or clay, the permeability would equal 7.6 gpd/ft.^{2} if it were equivalent to a loam soil (Israelsen, O. W. and Hansen, V. E., "Irrigation Principles and Practices," John Wiley & Sons, 1967, p.411). The soil would have a permeability of 21.21 gpd/ft.^{2} if it had a permeability used to separate 2 soil types; the first type consisting of clean sands, and a clean sand and gravel mixture; and the second type consisting of very fine sands, organic and inorganic silts, mixtures of sand, silt, and clay, etc. (Terzazhi, K. and Peck, R. R., "Soil Mechanics in Engineering Practice,"

John Wiley & Sons, 1964, p.48, Todd, D. K., "Ground Water Hydrology," John Wiley & Sons, 1959, p.53). The sequential ordering of the above list of soils suggests the permeability would probably be nearer 2.12 gpd/ft.^{2} rather than 21.21 gpd/ft.^{2}. The classification of "clayey sands, fine sands (poor aquifers)" has an estimated permeability range from 10 to 0.01 gpd/ft.^{2} (Davis, S. N., DeWiest, R. J. M., "Hydrogeology," John Wiley & Sons Inc., 1966, p.164). From the above estimates, it shall hereafter be assumed that the permeability for the silty and clayey sand is 10 gpd/ft.^{2}

The estimated permeability value for the limestone is the critical value because the permeability of the limestone can be so large that it can almost completely dominate. The Corps of Engineers performed specific capacity tests on the limestone underlying the proposed S-319 pumping station as indicated in Figures 3 and 4.

The specific capacity value of 0.04 gpm/ft. obtained from borehole CB-S319-5 was omitted from the following analysis because the very low value is not believed to be representative of a limestone specific capacity. The specific capacities per foot of borehole were obtained from the Corps' data and plotted on log probability paper (Figure 5). Since the data plots as a reasonably straight line, the population of specific capacities per foot of borehole is assumed to be log normally distributed. The mean is 0.6716 gpm/ft.^{2}. The 5% and 95% confidence limits differ by about a factor of 10 from the mean. Thus, calculations using the mean can be in considerable error.

Before the specific capacity data can be used to calculate the permeability, corrections for partial penetration are necessary. It was assumed that each specific capacity test spanned a 3 ft. vertical section of open borehole in an aquifer 15 ft. thick. Equation 5.17 from Walton (Groundwater Resource Evaluation, McGraw-Hill 1970, p.319) was used. The equivalent specific capacity per foot of borehole is calculated to be 0.3444 gpm/ft.^{2}

The permeability can be calculated using equation 5.16 from Walton. It was assumed that the storage coefficient was 0.001; the radius of the well was 0.125 ft.; and the specific capacity was determined 10 minutes after injection started. The calculated permeability is 432 gpd/ft.^{2} for the limestone.

The permeability for the clean fine to medium sand was obtained from estimates using the grain size distribution. Assuming the median grain size to be 0.25 mm which separates the fine and medium grain size classification, the permeability is estimated to be 240 gpd/ft.^{2} based on data for the Washita River alluvium (Naney, J. W., et. al., "Evaluating Ground-Water Paths Using Hydraulic Conductivities," Ground Water, V. 14, No. 4, p.205, 1976). Data for the Arkansas River alluvium suggests a permeability of 150 gpd/ft.^{2} (Bedinger, M. S., USGS Prof. Paper 424-C, 1961, p.31). Based on the above references, it was assumed that the permeability of the clean fine to medium sand is 200 gpd/ft.^{2}

The effective permeability of the geologic section for the western 31,000 ft. of C-51 can be ascertained by summing the products of the percentages of the various materials present by their respective permeabilities. The effective permeability thus equals 179.3 gpd/ft.^{2} (55.6% X 10 gpd/ft.^{2}) + (36.6% X 432 gpd/ft.^{2}) + (7.8% X 200 gpd/ft.^{2}). The aquifer is estimated to be approximately

100 feet in depth. Thus, the aquifer transmissivity is hereafter assumed to be 17,930 gpd/ft.

The reach of canal from station 31,000 to 53,875 can be treated in a manner similar to that for the western 31,000 ft. As indicated in Figure 6, the geologic materials occur in much thicker and apparently more continuous units than in the reach from 0 to 31,000 ft. Based on the borings at S-155A, 40.5% of the geologic section consists of clean, fine to medium grain sand while 59.5% of the section consists of silty or clayey sand. The permeabilities for clean fine to medium sand and for the sand that is silty or clayey are assumed to be 200 and 10 gpd/ft.^{2} respectively. Thus, the effective permeability is 86.95 gpd/ft.^{2} ((40.5% X 200 gpd/ft.^{2}) + (59.5% X 10 gpd/ft.^{2})). For a 100 ft. thick aquifer, the transmissivity would be 8,695 gpd/ft. The vertical permeability is generally 2 to 10 times less than the horizontal permeability. Thus, the estimated effective transmissivity is probably too large and will thus result in an estimated discharge to C-51 that is greater than that actually occurring.

Canal Partial Penetration

The C-51 canal is assumed to behave as a fully penetrating drain. According to Huisman (Groundwater Recovery, Winchester Press 1972, p.56), the additional drawdown Δs_0 due to the partial penetration of a random shaped gallery to maintain the same discharge as a fully penetrating drain is:

$$\Delta s_o = \frac{q_o}{\pi k} \ln \frac{H}{\Omega}$$

Where

Δs_o = additional drawdown in the ditch due to partial penetration (m).

q_o = discharge per unit length of gallery (m^3/m/sec.).

k = coefficient of permeability (m/sec.).

H = thickness of aquifer (m).

Ω = wetted gallery circumference (m).

From the channel cross sections, the estimated wetted perimeter (Ω) is approximately 100 ft., which is also the thickness of the aquifer (H). Since the ln of 1 is zero, the correction for partial penetration of the canal is small and will be considered to be negligible.

Canal Inflow

The problem of selecting a model to calculate the inflow to the canal is difficult because of the lack of data regarding water table fluctuations in the immediate vicinity of the canal. For the canal reach between stations 0 and 31,000 ft., the discharge to a drain whose stage has been suddenly lowered was calculated at various times following the hypothetical, abrupt lowering of the canal stage that was assumed to equal the head difference between the tributary canals and the C-51 canal. The head for the tributary canals is estimated to be 12.6 feet MSL while the C-51 canal stage is approximately 8.25 ft. MSL according to stage records at S-5A-E and West Palm Beach. Thus, the differential head between the tributary canals and C-51 is approximately 4.35 ft. Table 2 lists the discharge into C-51 between

station 0 and 31,000 at the end of periods ranging from 30 to 180 days. Drawdowns in the water table at distances of 1,000 ft. and 2,000 ft. from the canal are also listed in Table 2. It would not appear unreasonable to assume a discharge of 5.77 cfs into the canal. This would result after a period of 45 days. Recharge to the water table occurs quite frequently during the wet season (June-September) which could result in relatively high discharge rates into the canal. During the dry season, recharge does not occur as frequently and thus the water table would decline unless irrigation occurred. The drawdown of the water table would be approximately 1.61 ft. and 0.223 ft. at distances of 1,000 ft. and 2,000 ft. respectively from the canal. These drawdown data do not appear unreasonable based on vehicle hydrology (observations from a speeding car or motorcycle).

The inflow to the reach of C-51 between stations 31,000 and 53,875 can be calculated in a manner similar to that for the reach from 0 to 31,000. Table 3 lists the discharge into the C-51 canal in the 22,875 ft. reach at the end of periods varying from 30 to 180 days following the hypothetical lowering of the canal stage by 4.35 ft. Water table drawdowns at distances of 1,000 ft. and 2,000 ft. from the canal are also listed in Table 3. After a period of 45 days, the discharge to the canal is 2.96 cfs with a water table drawdown of 0.520 ft. and <0.05 feet at distances of 1,000 ft. and 2,000 ft. respectively from the canal. The discharge into the canal is not overly sensitive to the length of the period that has elapsed following the initial hypothetical lowering of the water table. The calculated discharge into the C-51 canal is relatively small for this 22,875 ft. reach of canal.

An alternate method to calculate seepage into the canal in the reach from station 31,000 to 53,875 would be to assume one dimensional flow in an unconfined aquifer above a semi-pervious layer (Huisman p.52). Figure 6 can be interpreted as a fully penetrating canal in an unconfined aquifer consisting of clean sand separated by sand which is silty and clayey from an underlying sand and limestone leaky artesian aquifer. Royal Palm Beach has several production wells within a few hundred feet of C-51 at a depth of 65 ft. which presumably obtain water from a limestone unit of high permeability. It has also been reported that a high permeability unit is present in the vicinity of C-51 at a depth of approximately 50 ft. Assuming the vertical permeability of the silty and clayey sand semi-pervious unit to be 2 gpd/ft.^{2}, the discharge into the C-51 canal would be approximately 4.35 cfs for the reach from 31,000 to 53,875 excluding the effects of the tributary canals. The numeric difference in the canal inflow using this method compared with the method used to obtain the inflow after 45 days as tabulated in Table 3 (2.96 cfs) is only 1.39 cfs. This difference is negligible.

Another elementary method can also be used to estimate the seepage inflow to C-51 between stations 31,000 and 53,875. From Table 3, the drawdown of the water table is only 0.53 ft. at a distance of 1,000 ft. after 45 days. If it is assumed that the drawdown in the sand unit overlying the impervious layer averages 2.175 feet from the canal bank to a distance of 500 ft. on each side of the canal, and the drawdown under the 80 ft. wide canal is 4.35 ft., Darcy's law can be used to compute the vertical seepage from the leaky artesian aquifer. The vertical permeability of the confining unit is assumed to be 2 gpd/ft.^{2} The seepage inflow Q, is calculated using the following equation:

$$Q = \frac{22875 \times ((40 \times 4.35) + (500 \times 4.35/2)) \times 2 \times 2}{7.48 \times 1440 \times 60 \times 40} = 4.47 \text{ cfs}$$

This seepage rate is also comparatively low and is only 1.5 cfs greater than the value of 2.96 cfs in Table 3 forty-five days after a hypothetical lowering of the canal stage.

Since the canal inflows which are calculated assuming: a) an unconfined aquifer overlying a leaky artesian aquifer; and b) vertical upward flow in the immediate vicinity of the canal, are not significantly different from the value (2.96 cfs) obtained assuming a fully penetrating drain in a 100 ft. thick aquifer, the latter value will be assumed to be the canal inflow.

The calculated discharge of groundwater into the reach of canal above S-155A based on a simple seepage model is summarized in Table 4. Under existing conditions, the average annual groundwater inflow is estimated to be 8.73 cfs neglecting the additional seepage that will result because of the tributary canals. The additional seepage that will result because of the tributary canals is uncertain. If the 15 or more tributary canals contribute as much groundwater seepage to C-51 as the groundwater flow system that would develop without the tributary canals, the groundwater inflow would equal 17.46 cfs or 2.03 inches over a 117 square mile basin. The effective groundwater seepage into the C-51 canal would be reduced by any backpumping into tributary canals. Thus, the groundwater inflow under existing conditions is estimated to be

approximately 17.5 cfs. Significant errors are associated with the above value for seepage. Errors of an order of magnitude are possible. Thus, the estimated values should be used in a discrete manner.

David W. Allman
DAVID W. ALLMAN, Ph.D
Groundwater Division
Resource Planning Department

Gerry Winter
GERRY WINTER
Groundwater Division
Resource Planning Department

js

TABLE 1

STAGES ON TRIBUTARY CANALS TO C-51 WEST OF PROPOSED S-155A

DATE	NORTH SIDE (FEET MSL)		SOUTH SIDE (FEET MSL)
May 7, 8, 1974	14		10
October 9-10, 1974	16		14
May 6-7, 1975	12		10
October 8, 4, 1975	16		10
May 3-5, 1976	12		12
Average	14		11.2
Combined Average		12.6	

TABLE 2

INFLOWS TO C-51 BETWEEN STATIONS 0 AND 31,000

TIME AFTER LOWERING C-51 CANAL STAGE (DAYS)	DISCHARGE (cfs)	DRAWDOWN AT VARIOUS DISTANCES FROM C-51 1,000 FEET (FEET)	2,000 FEET (FEET)
30	7.06	1.04	.095
45	5.77	1.61	.223
60	4.99	1.78	0.422
90	4.08	2.18	0.761
180	2.88	2.38	1.480

TABLE 3

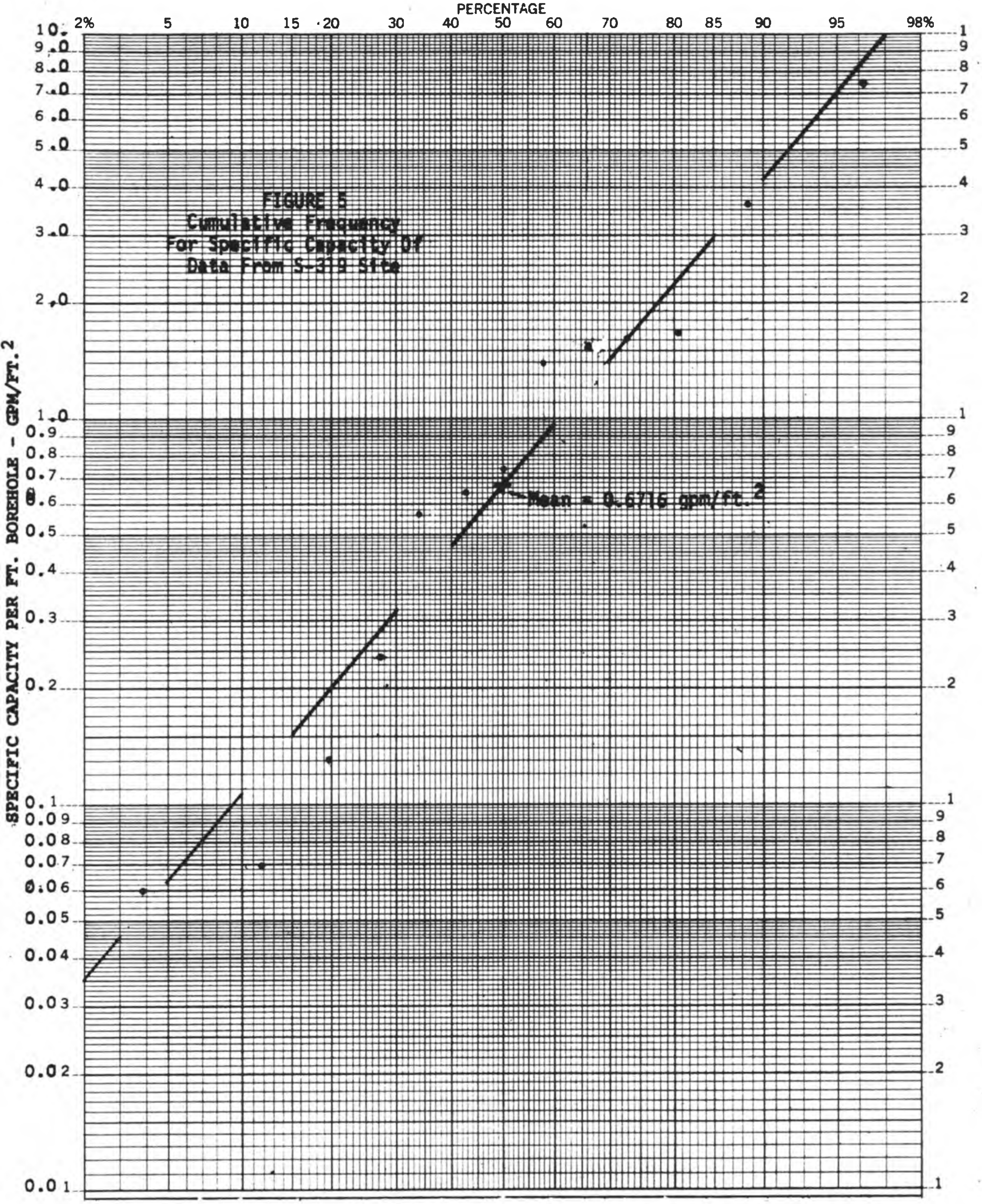
INFLOWS TO C-51 BETWEEN STATIONS 31,000 and 53,875

TIME AFTER LOWERING C-51 CANAL STAGE (DAYS)	DISCHARGE (cfs)	DRAWDOWN AT VARIOUS DISTANCES FROM C-51 1,000 FEET (FEET)	2,000 FEET (FEET)
30	3.63	0.400	<0.05
45	2.96	0.520	<0.05
60	2.57	1.02	0.0735
90	2.10	1.45	0.221
180	1.48	2.13	0.731

TABLE 4

INFLOWS INTO C-51 BETWEEN S-5A-E AND S-155A

TIME AFTER LOWERING C-51 CANAL STAGE (DAYS)	DISCHARGE (cfs)
30	10.69
45	8.73
60	7.56
90	6.18
180	4.36


PERCENTAGE
FIGURE 5
Cumulative Frequency
For Specific Capacity Of
Data From S-319 Site
Mean = 0.6716 gpm/ft.2
SPECIFIC CAPACITY PER FT. BOREHOLE - GPM/FT.2