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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SOME HYDROLOGIC EFFECTS OF CANAL 111
NEAR HOMESTEAD, FLORIDA

By

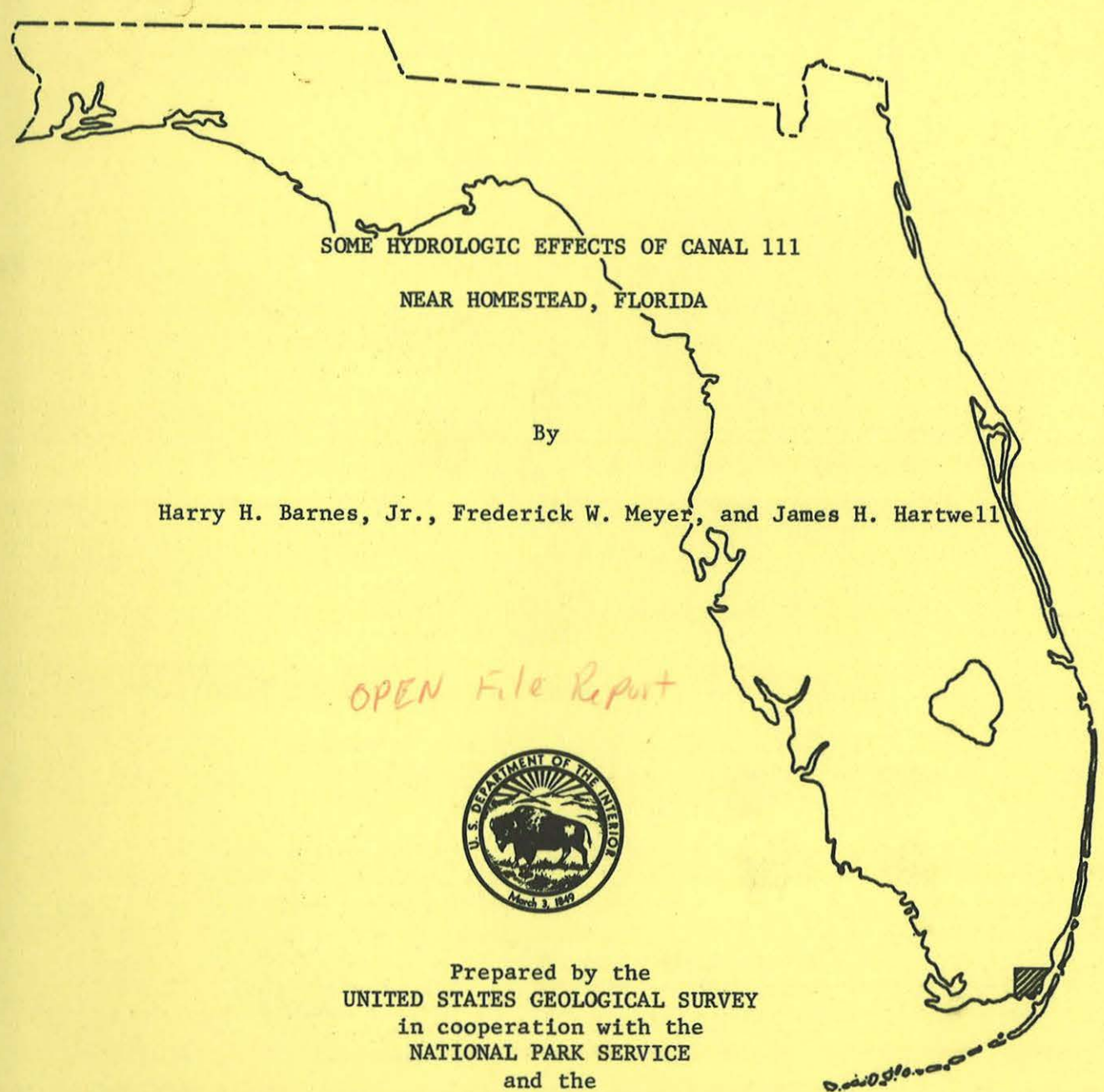
Harry H. Barnes, Jr., Frederick W. Meyer, and James H. Hartwell

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Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with the
NATIONAL PARK SERVICE
and the
CORPS OF ENGINEERS

Tallahassee, Florida
1968



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INTRODUCTION

Canal 111, in the area south of Homestead, Florida, is a part of the Central and Southern Florida Flood Control District's "South Dade County Area Plan of Improvement." The canal is planned to provide flood control, drainage, and navigation benefits for a large area bounded by the Everglades National Park on the west and south, by U.S. Highway 1 on the east, and by state road 27 on the north (see fig. 4).

This statement was requested by representatives of the Corps of Engineers and the National Park Service following a conference with U.S. Geological Survey hydrologists on April 5, 1967, in Arlington, Virginia. It was prepared in June 1967 when construction of the canal was in progress and expresses the Geological Survey's appraisal of the fresh-water seepage into Canal 111 between the salinity control structure S-18C and U.S. Highway 1 for the following conditions:

1. With the earthen plug at U.S. Highway 1 removed and Canal 111 a sea-level canal up to S-18C.
2. With a salinity-control structure at U.S. Highway 1 and the fresh-water level maintained above mean sea level.

The findings were used in the more immediate interagency discussions at the technical level. They will be updated on the basis of additional field data and included in a later report which will supplement the initial report by Klein (1965).

SUMMARY

The feasibility of a salinity-control structure on Canal 111 in the immediate vicinity of U.S. Highway 1 was under consideration. One aspect of the overall evaluation was fresh-water seepage into the canal. An analysis of ground-water records in the basin and of the streamflow record for structure S-18C revealed the following information:

1. For the condition where the earthen plug is removed and Canal 111 below S-18C is considered a sea-level, saline-water canal, the average annual seepage of fresh water into Canal 111 between S-18C and U.S. Highway 1 from the limestone aquifer is estimated to be 39,000 acre-feet. This volume of fresh water will be discharged to the ocean each year. The direct loss of this fresh-water volume will reduce the overall capability of the aquifer to resist salt-water encroachment. A salt-water condition in Canal 111 below S-18C and in the proposed aerofjet spur canal will accelerate inland encroachment of salt water especially during drought periods.

During wet periods overland flow from the area immediately north of Canal 111 between S-18C and U.S. Highway 1 will discharge into the canal through eleven (11) gated culverts. After reaching the canal, this water will be discharged to the sea via the canal and, at times, by southward flow through the gaps in the spoil banks on the south side of the canal. The rate of overland flow into the canal from the north side and its subsequent disposal depend on factors such as tide level, wind speed and direction, the discharge rate through S-18C, and operating procedures for the culverts. The rate of flow southward through the spoil gaps will also depend on these factors. An evaluation of the overland flow from this area was impractical considering the meager data available.

2. For the condition where Canal 111 is maintained as a fresh-water canal by means of a salinity-control structure at U.S. Highway 1, the rate of fresh-water seepage into the reach of Canal 111 between S-18C and U.S. Highway 1 will depend on the elevation of water levels in the canal and the adjacent water table. The rate of fresh-water seepage into the canal will decrease as the canal level is increased. For example, the average annual fresh-water seepage into this seven-mile reach with the canal level maintained at 0.5, 1.0, and 1.6 feet msl (mean sea level) is estimated to be 39,000, 22,000, and 3,000 acre-feet, respectively.

These reductions in the volume of seepage as the canal level is increased imply an increase in fresh-water storage above the structure. Water in excess of the storage capacity of the area, that is not lost to the atmosphere by evapotranspiration, will help maintain higher water levels to the east and southeast.

During wet periods, when the ground-water levels in the area north of S-18C are high, seepage will accrue to Canals 111 and 111 E. The seepage flow discharged through S-18C will recharge the aquifer along C-111 downstream to U.S. Highway 1. If the structure at U.S. Highway 1 is designed to maintain water in the canal at levels of about 1.0 foot or higher, then some of the seepage flow through S-18C will flow southward through the spoil gaps.

DESCRIPTION OF THE AREA

The areas immediately north and south of Canal 111 between S-18C and U.S. Highway 1 are relatively flat with land-surface elevations adjacent to the canal ranging from 1 to 2 feet above mean sea level. The general area is underlain by 2 to 3 feet of marl and peat which supports a sparse growth of sawgrass. South of the canal widely dispersed sloughs support the growth of shrubs and stunted trees. The marl and peat layer immediately overlies about 60 feet of the highly permeable limestone called the Biscayne aquifer (Klein, 1965). Prior to construction of Canal 111 the natural surface drainage was generally southward over a gentle land slope of about two-tenths of a foot per mile. South of state road 27, both Canal 111 and the spur canal C-111 E have been incised into the highly permeable limestone aquifer to a depth of 12 to 15 feet below mean sea level.

HYDRAULIC CONSIDERATIONS OF THE AQUIFER

Because Canal 111 cuts into the limestone aquifer along its entire reach, fresh-water seepage into the canal will take place during periods when the water table in the adjacent aquifer exceeds the water level in the canal. A water-table map of the area by Klein (1965) for December 1962, indicates that the general slope of the piezometric surface is in a southeasterly direction toward the bays.

Water levels in the area fluctuate seasonally in response to local rainfall. The water table declines during the dry season, which begins late in the fall and generally lasts until the following May. Recharge to the aquifer usually takes place from May through October during the wet season. The seasonal fluctuation of the water table is shown by the hydrograph of monthly water levels in well G-613 (fig. 1), located about 5 miles north of S-18C. Water levels at this location have ranged from about 6 feet above to about 1.5 feet below mean sea level for the period 1950-65. The average water level at the well is 2.2 feet above mean sea level.

A water-level duration curve for well G-613 is shown in figure 2. The duration curve indicates the percent of time for which a particular water level was equaled or exceeded during the period of record. Because the distribution is uniform, the 50-percentile line indicates the average water level in the well. The water level at well NP-57, located at the site of S-18C, ranged from 4 feet above to more than 1 foot below mean sea level during the period 1961-65. The average level for the period of record is 1.4 feet above msl. The record for well NP-57 was adjusted to the 16-year period (1950-65) on the basis of a correlation of concurrent levels in well G-613 and is shown in figure 3.

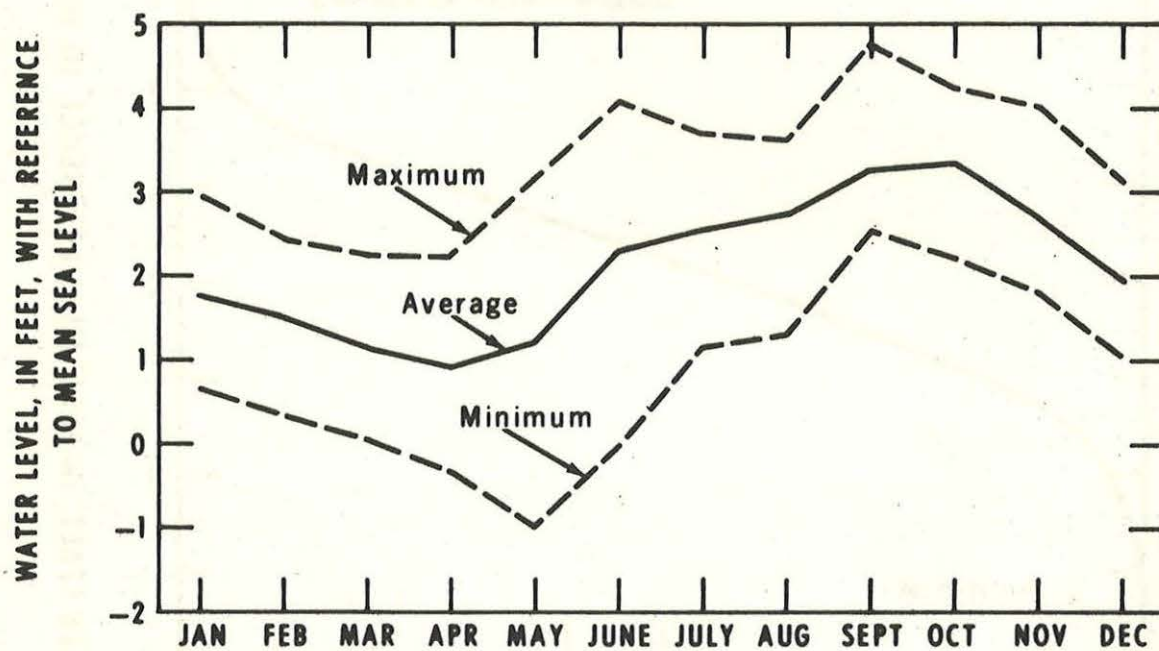


Figure 1.--Graph of maximum, average, and minimum monthly water levels in well G-613, 1950-65.

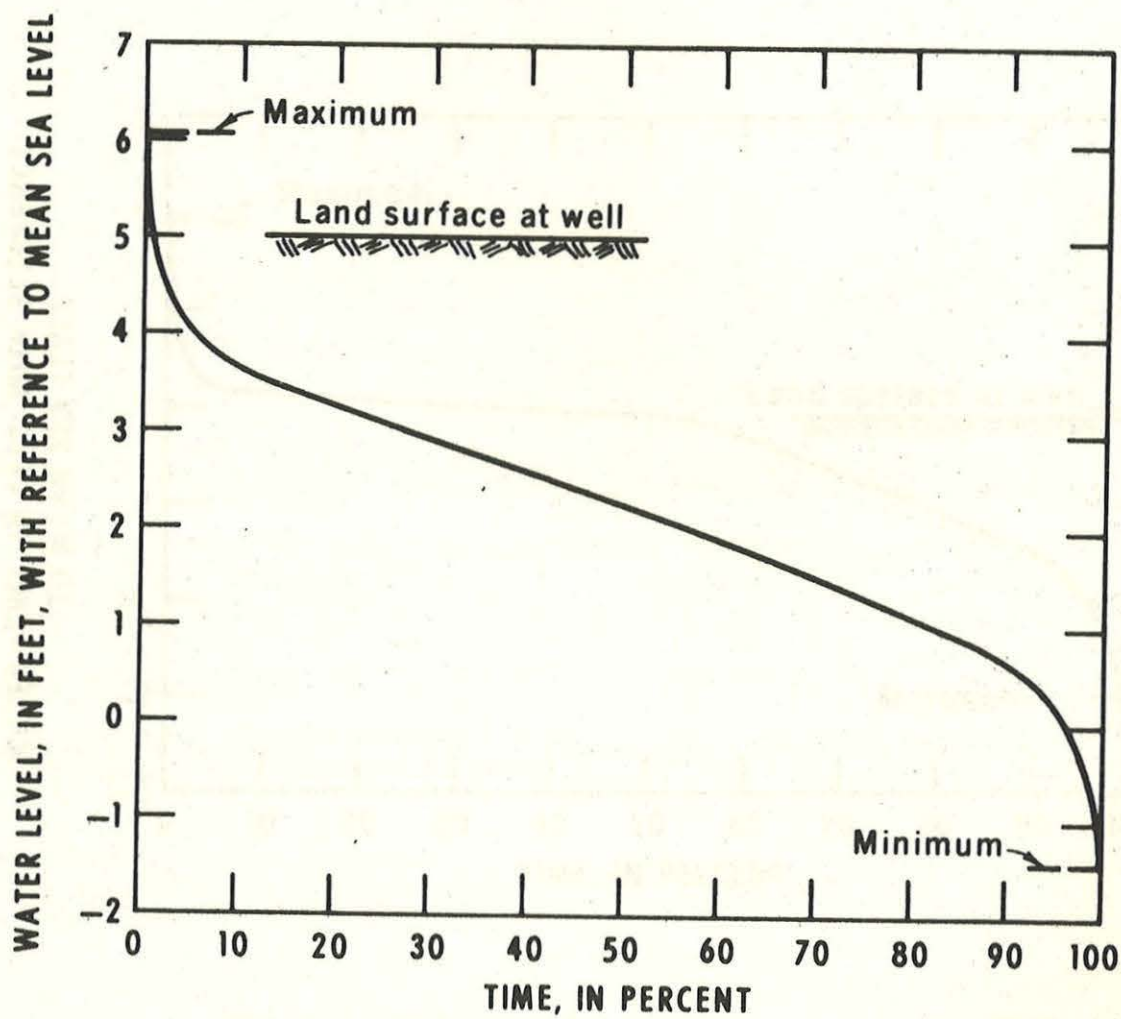


Figure 2.--Water-level duration curve for well G-613 for period 1950-65.

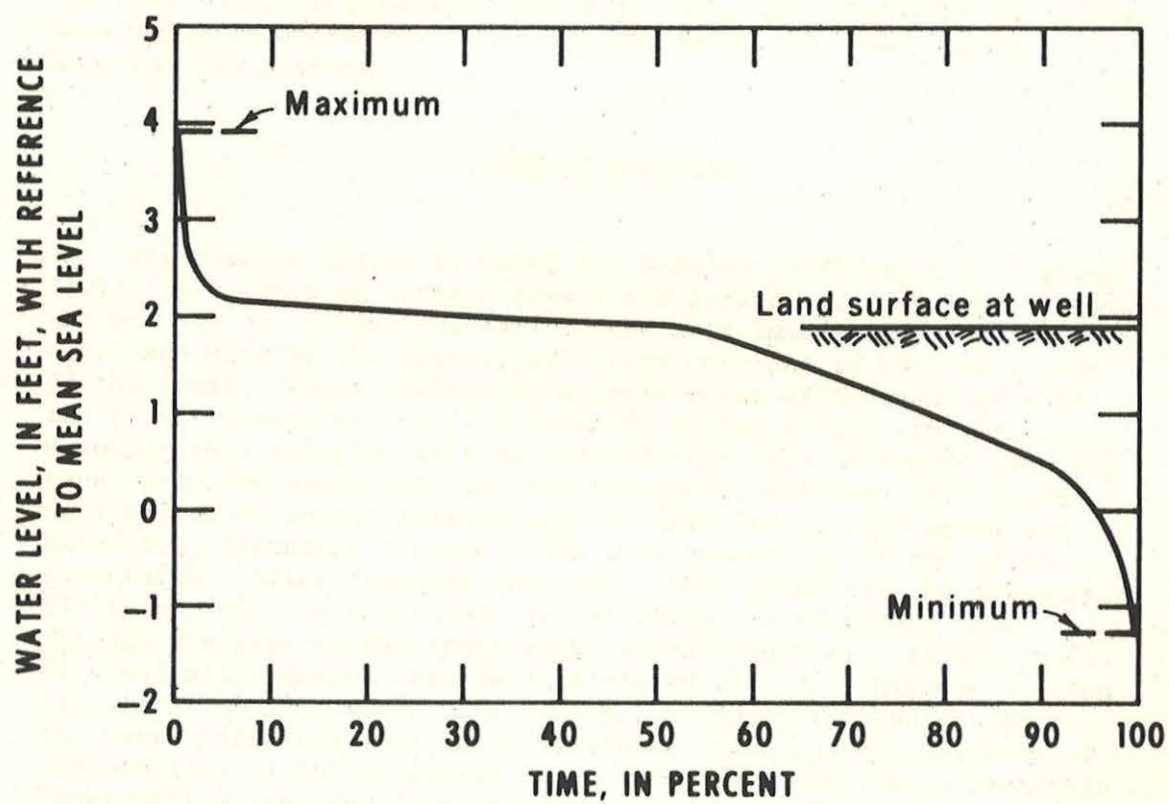


Figure 3.--Water-level duration curve for well NP-57 adjusted to period 1950-65.

The average water level at NP-57, for the longer period, is estimated to be about 1.5 feet above msl.

If the plug at U.S. Highway 1 is removed, the fresh water presently in the canal between S-18C and U.S. Highway 1 will be replaced by salt water and the runoff of fresh water will be accelerated. The water level in the canal will adjust to that of the bay and will respond to the tidal fluctuations. The canal will then allow a finger of salt water to intrude inland from the present 1,000 ppm (parts per million) isochlor portrayed by Klein (1965). This canal, if opened at the plug, will provide an avenue for salt-water encroachment laterally along its length to the inland area where ground-water levels decline below sea level during seasonal dry periods.

SEEPAGE ANALYSIS

Fresh-water inflow to Canal 111 between S-18C and U.S. Highway 1 will occur both by surface runoff and ground-water seepage. During the wet season, excess rainfall in the area immediately north of the canal and west of the highway will flow overland to the north side of the canal. Water collecting at this point will discharge into the canal through eleven (11) culverts equipped with stop logs. Assuming that the plug will be removed, the rate of runoff into the canal from the north side and its subsequent disposal will depend on a number of considerations such as tide level, wind speed and direction, discharge through S-18C, and operations of the culvert structures. After reaching the canal, this water will be discharged (1) to sea via the canal and, (2) at times, by southward flow through the gaps in the spoil banks on the south side of the canal. If a salinity-control structure is placed near U.S. Highway 1, then its operation also would be a factor. A meaningful evaluation of the many combinations of these variables which control the rate of surface flow is not practical considering the meager data available. Consequently, the analysis is concerned principally with ground-water seepage.

The rate of ground-water seepage into the canal between S-18C and U.S. Highway 1 depends primarily on the hydraulic gradients and the coefficient of transmissivity of the aquifer. The transmissivity can be determined from water-level gradients in the aquifer and streamflow measurements in the canal. Therefore, a hypothetical water-table map (fig. 4) of the area was constructed to represent the average hydrologic conditions for the period December 1-29, 1966. The map was constructed using the relation between water levels in wells G-613 and NP-57 (fig. 5), and the trend of contours shown in figure 3 (the map for December, 1962) by Klein (1965). The relation between time and variation of water levels in the aquifer was described in the previous section.

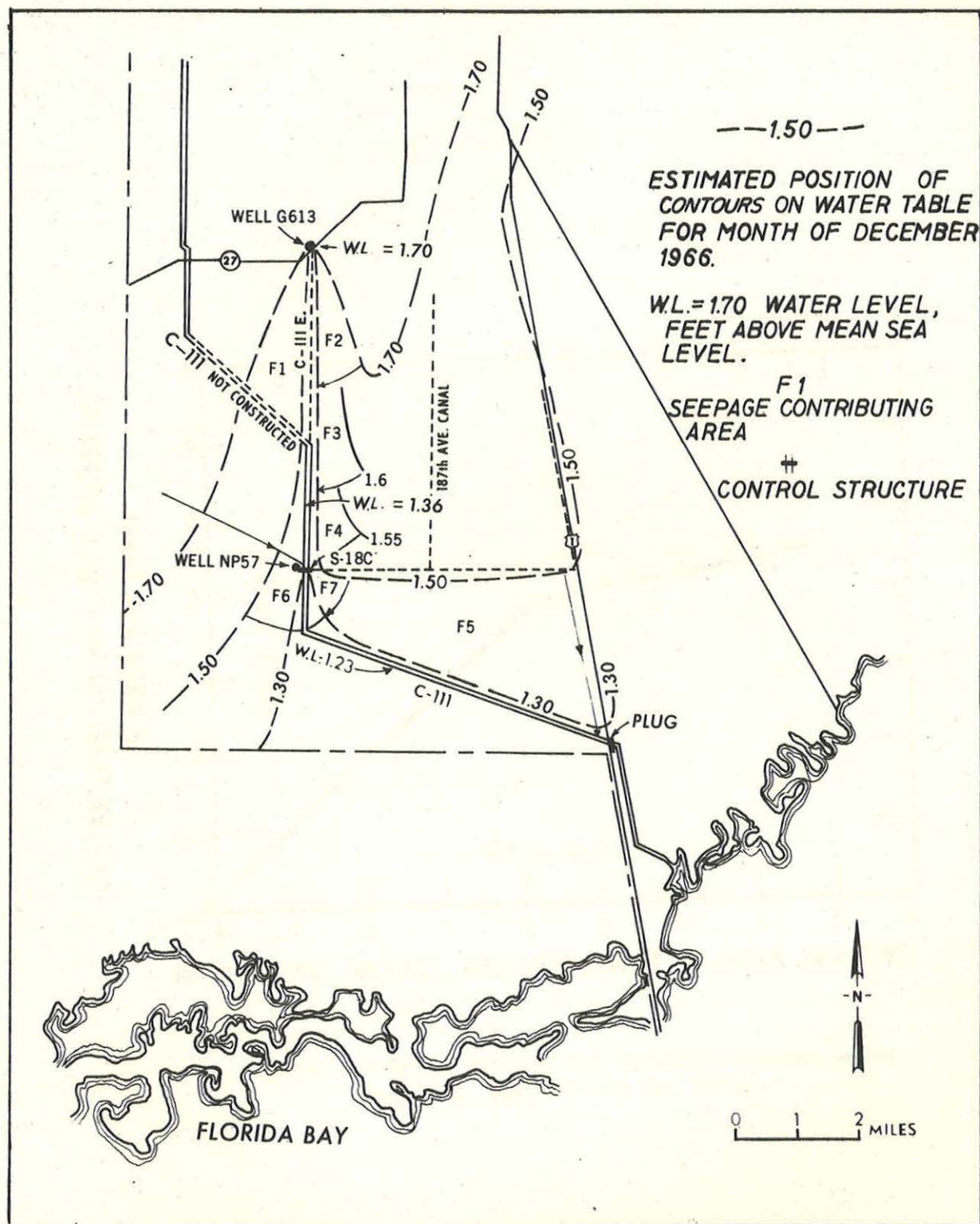


Figure 4.--Hypothetical water-table contour map of Canal 111 area, December 1-29, 1966, representative of the 65-percent duration of water levels in wells G-613 and NP-57 for the 1950-65 period.

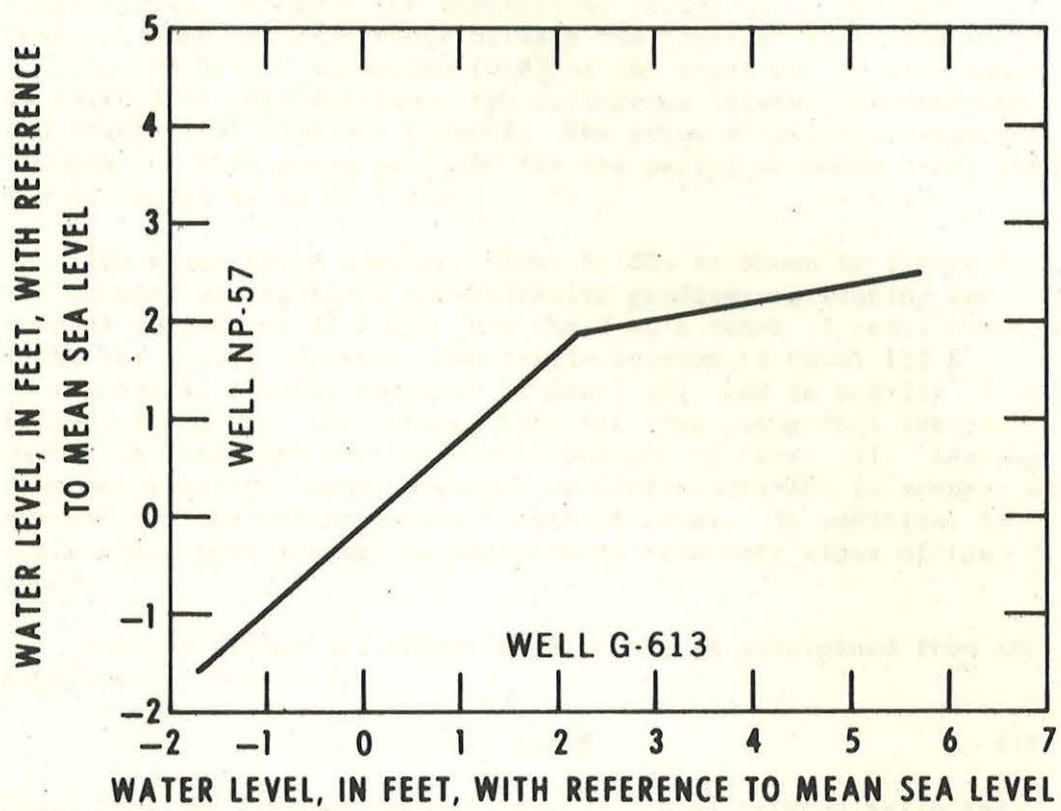


Figure 5.--Graph showing the relation between water levels in wells G-613 and NP-57.

The average water level in Canal 111 above and below S-18C for the period December 1-29, 1966, was estimated to be 1.36 and 1.23 feet above mean sea level, respectively. The mean daily discharges for the period were estimated by using mean-daily stages obtained from the Flood Control District's gages at S-18C and a theoretical discharge rating for the six (6) slot openings in the two (2) vertical lift gates at S-18C. The slots were assumed to be fully open during the period. The theoretical rating (fig. 6), is based on sharp-crested weir equations by Rouse (1956) and King (1954). The theoretical discharge was then compared to the discharge measured on September 1, 1966, by the U.S. Geological Survey, and to that measured by the Central and Southern Florida Flood Control District on October 5, 1966. In each case the measured discharge, 44 cfs (cubic feet per second) and 125 cfs, respectively, exceeded the theoretical rating by 42 percent. However, when the difference between the "design" elevation (1.0) and the "as built" elevation (0.8) of the crest on the slot gates is taken into consideration, the difference between the observed and theoretical flow was reduced. The adjusted average discharge through the slot gates at S-18C for the period December 1-29, 1966, was estimated to be 27.7 cfs.

The water-table contours above S-18C, as shown in figure 4, are assumed to represent the hydraulic gradients producing the average seepage of 27.7 cfs into the 5-mile reach of canal between S-18C and S-178. However, the 3-mile section of Canal 111 E is relatively shallow compared to Canal 111, and is heavily silted; therefore, the seepage rate per foot along this section should be less than for the 2-mile section of Canal 111. Lacking some quantitative basis, however, no differentiation in seepage was assumed for the entire 5-mile length of canal. In addition, it was assumed that seepage is contributed from both sides of the canal.

The coefficient of transmissivity, T, is determined from the equation

$$T = \frac{Q}{F} \quad (1)$$

where Q is the average seepage into the canal between S-178 and S-18C for the period December 1-29, 1966, and F, the flow factor, is equal to the product of L, the length of the contour line contributing flow to the canal, and I, the piezometric gradient.

$$F = LI \quad (2)$$

The 5-mile reach of canal, shown in figure 4, was subdivided into contributing areas, labeled F1 through F7, and the flow factor computed for each area. The solution of equation 1 for the areas contributing flow to S-18C (F1-F4) yields an apparent coefficient of transmissivity of 4.6 million gallons per day per foot. This is consistent with values of T found by Parker (1955) for the

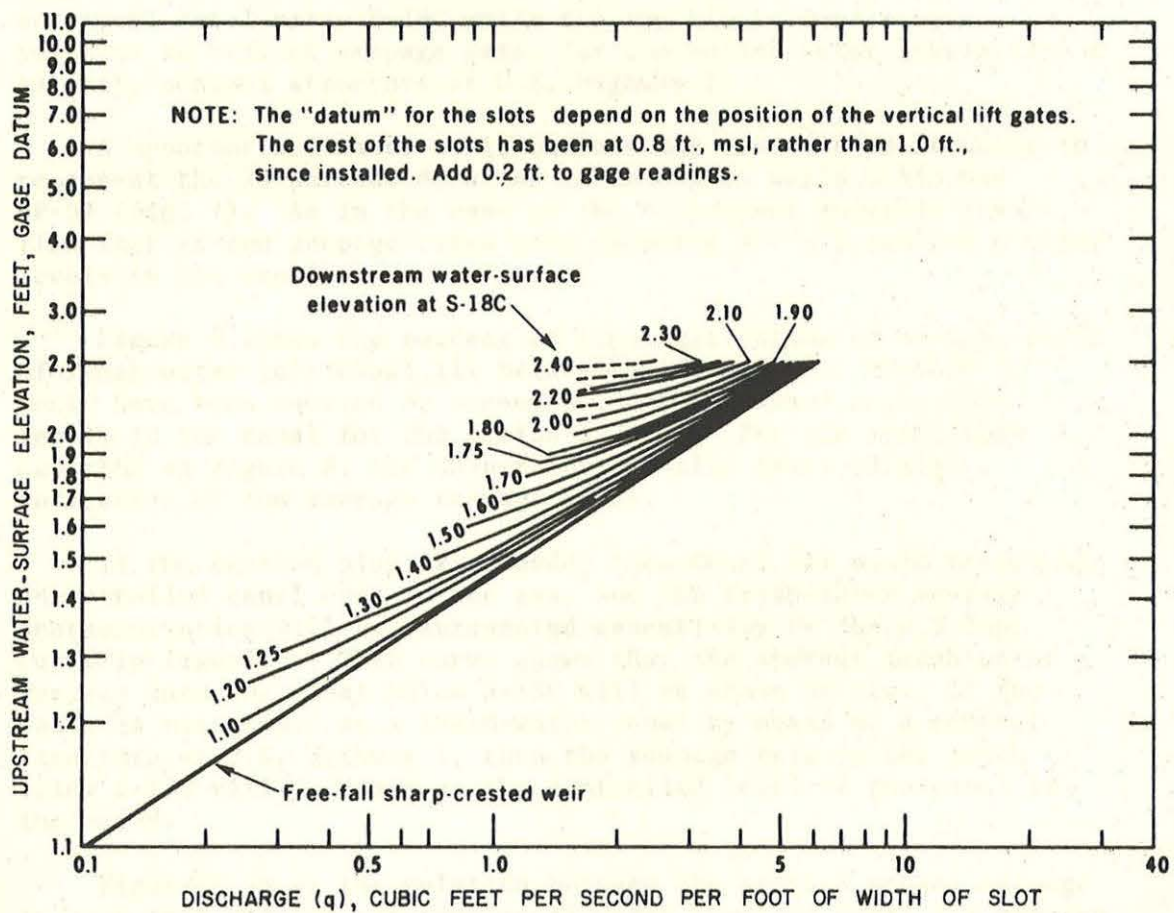


Figure 6.--Theoretical rating curves for S-18C slot gates.

Biscayne aquifer in the Miami area. Seepage into Canal 111 between S-18C and U.S. Highway 1 was determined by using the apparent transmissivity, by computing the flow factors, F5-F7, and by solving equation 1 for Q. The average seepage was computed to be 12.2 cfs for the period December 1-29, 1966.

The water-table map shown in figure 4 represents the 65-percent duration of levels in wells G-613 and NP-57 (figs. 2 and 3). Flow factors for the contributing areas (F5-F7) and seepage between S-18C and U.S. Highway 1 were computed assuming controlled water levels of 0.5, 1.0, and 1.6 feet above mean sea level in this reach of the canal. The lowest canal level, 0.5 foot, represents a sea level canal below S-18C while the two higher levels were selected to reflect seepage rates for controlled water levels with a salinity-control structure at U.S. Highway 1.

A hypothetical water-table contour map also was constructed to represent the 20-percent duration of levels in wells G-613 and NP-57 (fig. 7). As in the case of the 65-percent duration levels, flow factors and seepage rates were computed for the assumed control levels in the canal.

Figure 8 shows the percent of time that estimated seepage rates of fresh water into Canal 111 between S-18C and U.S. Highway 1 would have been equaled or exceeded for the assumed controlled levels in the canal for the period 1950-65. For the conditions depicted in figure 8, the 50-percent duration level is also indicative of the average seepage rates.

If the earthen plug is removed, then Canal 111 would become an uncontrolled canal open to the sea, and the fresh-water seepage characteristics will be represented essentially by the 0.5 foot curve in figure 8. This curve shows that the average fresh-water seepage into the canal below S-18C will be about 54 cfs. If the canal is maintained as a fresh-water canal by means of a control structure at U.S. Highway 1, then the seepage rate in the reach below S-18C will decrease as the controlled level of the canal is increased.

Figure 9 shows the relation between the average annual seepage in acre-feet and the average annual water level in Canal 111 between S-18C and U.S. Highway 1.

If the earthen plug is removed and an uncontrolled sea-level canal (0.5 foot) prevails, an estimated average annual volume of about 39,000 acre-feet of fresh water will discharge to tidewater -- the loss of which represents a reduction in the aquifer's potential to resist salt-water encroachment. The curves in figure 9 show that this discharge of fresh water can be reduced by maintaining fresh water in Canal 111 upstream from the highway at higher elevations above mean sea level. With the plug in the canal for the higher canal levels, much of the flow through S-18C and seepage entering

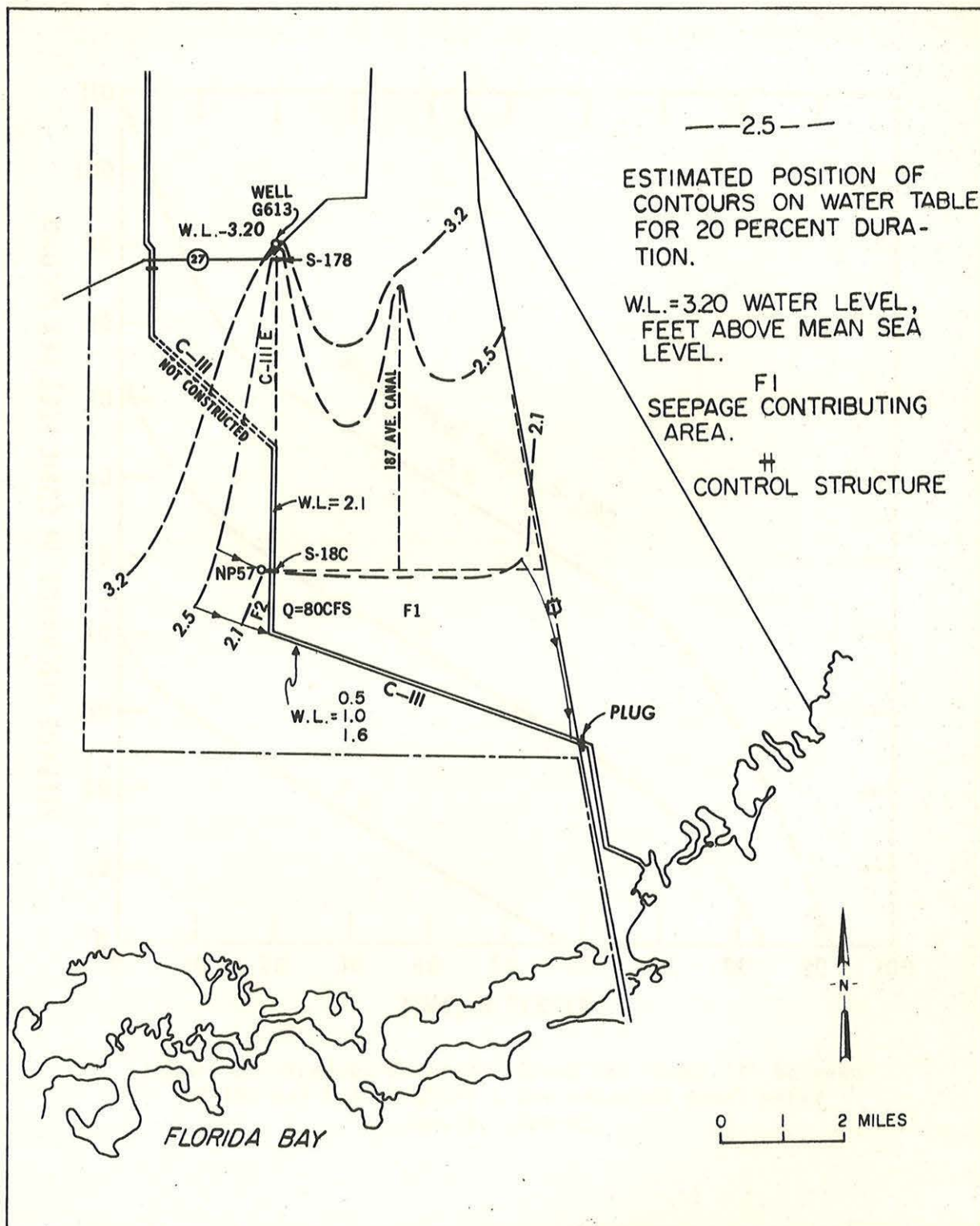


Figure 7.--Hypothetical water-table contour map of Canal 111 area for 20-percent duration of water levels in wells G-613 and NP-57 for the 1950-65 period.

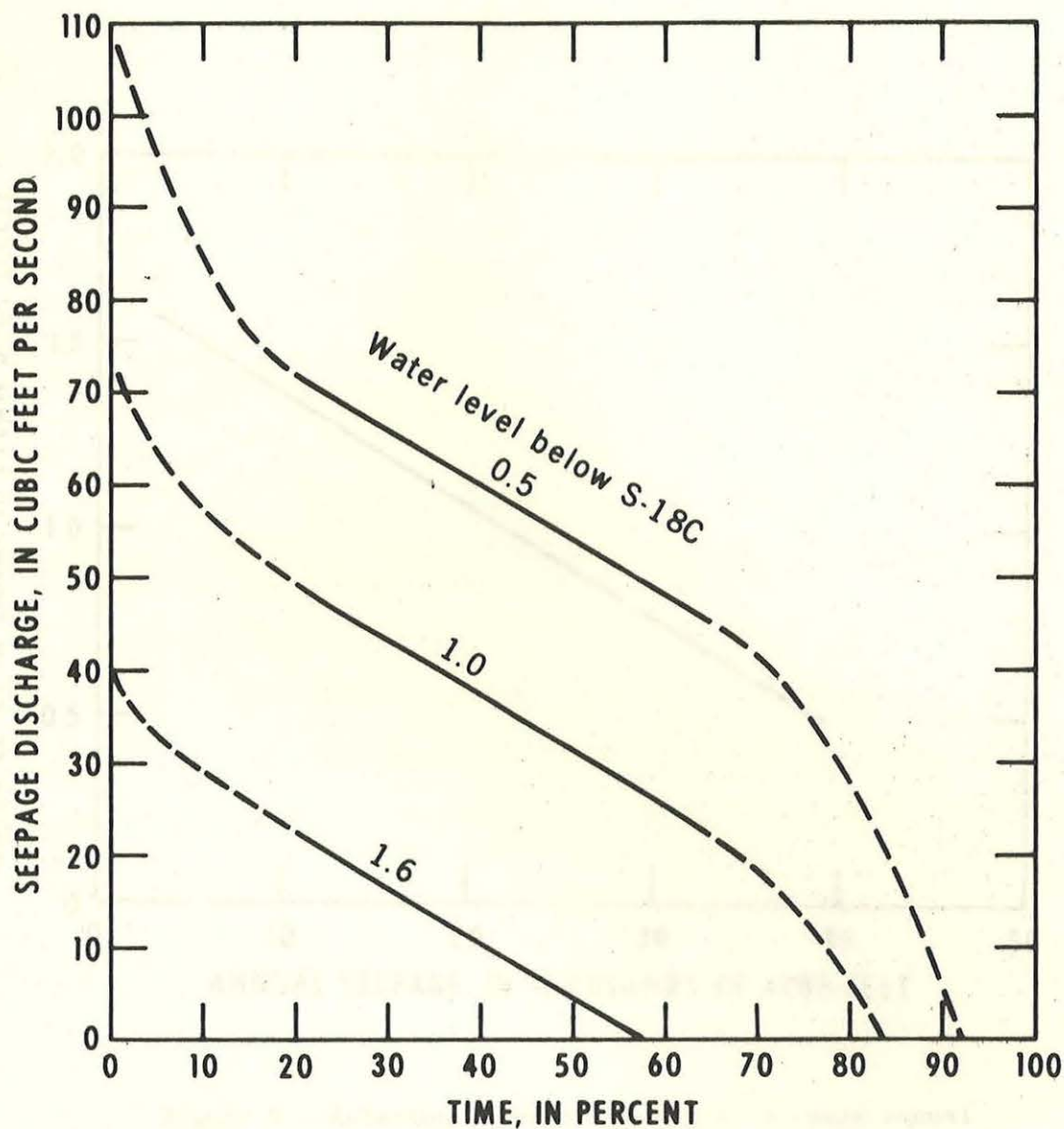


Figure 8.--Seepage-duration curves for Canal 111 between S-18C and U.S. Highway 1 for selected canal water levels, 1950-65.

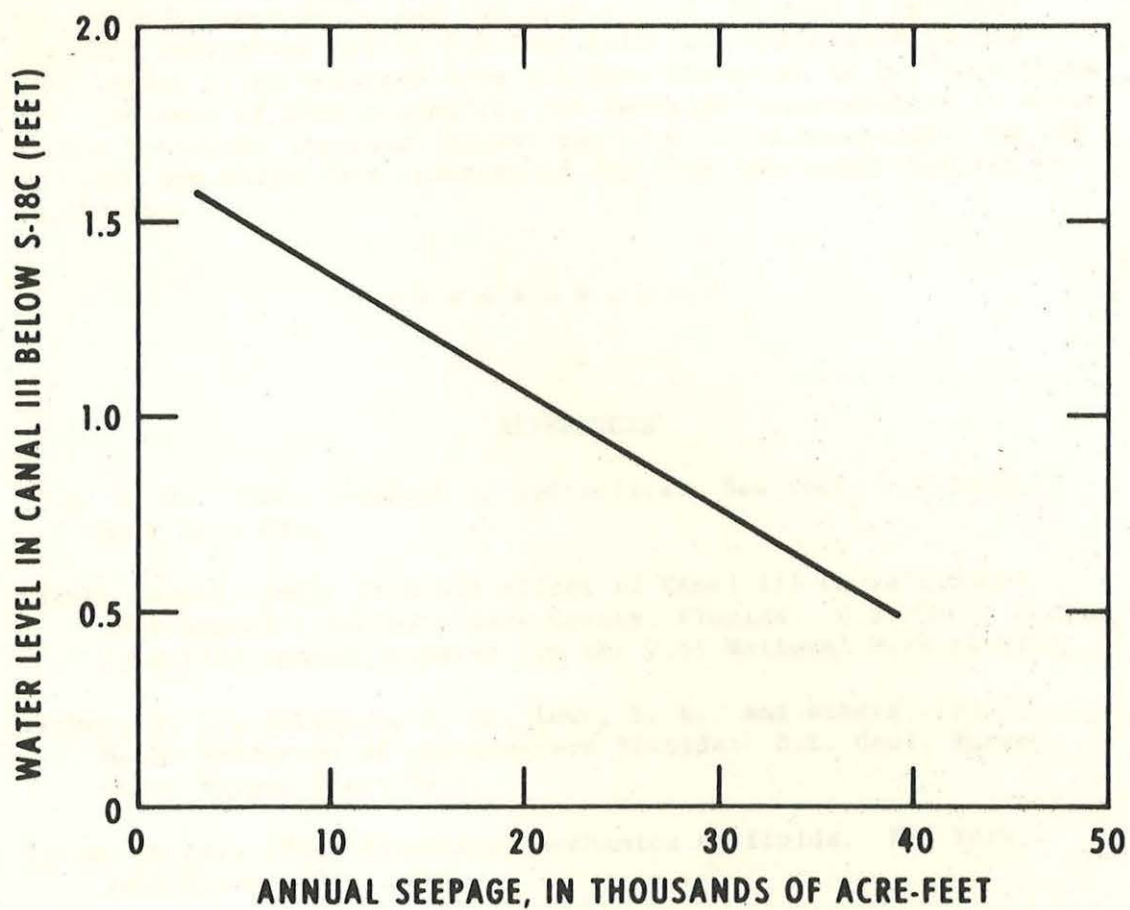


Figure 9.--Relation of water level and average annual seepage in Canal 111 between S-18C and U.S. Highway 1, 1950-65.

downstream probably would flow overland southward through the levee gaps. During wet periods, however, it may be desirable to discharge water to the sea for flood-control purposes. During dry periods, the canal will tend to recharge the aquifer in its lower reaches. For instance, when the water table at S-18C falls below 0.5 foot, msl, the piezometric gradient reverses, sloping landward from the coast, and the salt front moves inland.

During the period March 3 to May 8, 1967, the water level in the reach between S-18C and the plug at U.S. Highway 1 declined from 0.7 foot above msl to 0.5 foot below msl while that in the reach above S-18C declined from 1.0 foot above msl to 0.6 foot below msl. Because of this recession, the chloride concentration in water at the bottom of the canal downstream from S-18C increased from 116 to 4,200 ppm while that upstream of the plug increased from 156 to 13,700 ppm.

* * * * *

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