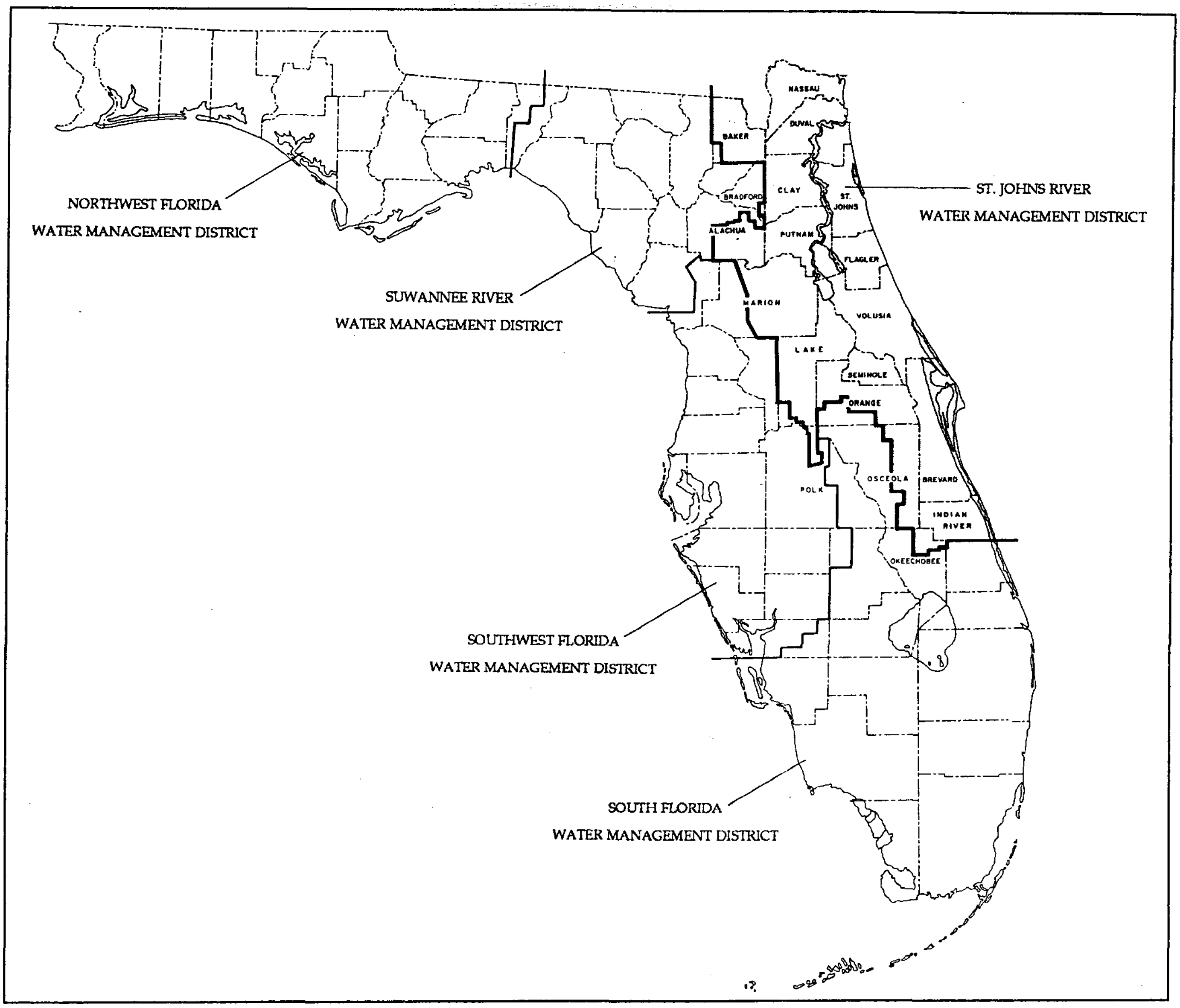
Technical Publication SJ92-3

SURFACE WATER MODELING STUDY OF THE UPPER ETONIA CREEK CHAIN OF LAKES, CLAY COUNTY, FLORIDA

by
C. Price Robison, P.E.

St. Johns River Water Management District
Palatka, Florida

1992



The **ST. JOHNS RIVER WATER MANAGEMENT DISTRICT** (SJRWMD) was created by the Florida Legislature in 1972 to be one of five water management districts in Florida. It includes all or parts of 19 counties in northeast Florida. The mission of SJRWMD is to manage water resources to ensure their continued availability while maximizing environmental and economic benefits. It accomplishes its mission through regulation; applied research; assistance to federal, state, and local governments; operation and maintenance of water control works; and land acquisition and management.

Technical reports are published to disseminate information collected by SJRWMD in pursuit of its mission. Copies of this report can be obtained from:

Library
St. Johns River Water Management District
P.O. Box 1429
Palatka, FL 32178-1429
Phone: (904) 329-4132

EXECUTIVE SUMMARY

In response to concerns over persistently low water levels in Brooklyn Lake, the St. Johns River Water Management District performed a study modeling the Upper Etonia Creek chain of lakes including Blue Pond, Sand Hill Lake, Magnolia Lake, and Brooklyn Lake in Clay County, Florida. The purpose of the study was to determine the hydrologic dynamics of the Upper Etonia Creek system and to evaluate possible measures toward mitigating the low lake levels. Brooklyn Lake has historically fluctuated between extremes nearly 28 ft apart.

In agreement with previous studies, results of this study indicate that Brooklyn Lake is a recharge source for the Floridan aquifer. As such the level of Brooklyn Lake depends to a great extent on the level of the potentiometric surface of the Floridan aquifer. In addition, results of this study indicate that reduced water levels are closely related to lack of rainfall in the area.

Specifically, the study addressed possible local measures—such as re-diverting water, cleaning out ditches, or lowering culverts—that might mitigate low water levels. The study concluded that local measures alone are not enough to increase levels on Brooklyn Lake much beyond 1 ft.

The surface water hydrology of the Upper Etonia Creek chain of lakes was successfully simulated with the Streamflow Synthesis and Reservoir Regulation model. Results, in the form of statistical comparisons of observed and simulated elevations, indicated that no major hydrologic changes have occurred in the Upper Etonia Creek chain of lakes over the period of study (1958–1991).

The simulation of the Upper Etonia Creek chain of lakes indicated that the declining water levels on Brooklyn Lake since 1975—and especially the extremely low levels since 1989—can be explained by below average amounts of rainfall and increased losses to the Floridan aquifer because of lower potentiometric surface levels.

Six problems that some area residents believe may be affecting the level of Brooklyn Lake are considered in this study.

- Loss of 260 acres of drainage area north of Blue Pond cut off by a berm put in by the DuPont mining operation on Camp Blanding
- Loss of surficial and intermediate aquifer flow toward Brooklyn Lake as a result of excavation for the DuPont berm
- Blockage of flow through creeks connecting Blue Pond, Sand Hill Lake, Magnolia Lake, and Brooklyn Lake
- Increased elevation of lake outlets upstream of Brooklyn Lake
- Culverts that are too small
- Culverts that are too high

Modeling results indicate that regaining 260 acres of drainage area north of Blue Pond would increase the level of Brooklyn Lake by a maximum of 0.9 ft. The excavation for the DuPont berm would not interrupt surficial or intermediate aquifer ground water flow toward Blue Pond and Brooklyn Lake.

Modeling results indicate that the outlet elevation of Magnolia Lake upstream from Brooklyn Lake has not changed significantly since 1958; this is supported by field surveys. In addition, lowering the elevations of the outlets of Magnolia Lake, Sand Hill Lake, and Blue Pond would not result in major changes in Brooklyn Lake levels. Any effect on Brooklyn Lake from lowered outlets would be minor and short-lived, while entailing periodic maintenance expenses.

Finally, modeling results and field surveys also indicate that the size and invert elevations of culverts between the lakes in the Upper Etonia chain of lakes do not significantly affect the hydrologic regime of flows into Brooklyn Lake.

CONTENTS

FIGURES

TABLES

INTRODUCTION

Brooklyn Lake, north of Keystone Heights, in Clay County, Florida, has had persistently low water levels in recent years. In response to citizen concerns, the St. Johns River Water Management District (SJRWMD) performed a study modeling part of the Upper Etonia Creek chain of lakes, from Blue Pond downstream to Brooklyn Lake (Figures 1 and 2). The purpose of the study was to determine the hydrologic dynamics present in this part of the Upper Etonia system and to evaluate possible measures that could be used to mitigate the low water levels.

The basic problem this study addresses is the declining water surface levels in Brooklyn Lake. Past studies (Clark et al. 1963; Yobbi and Chappell 1979; and Motz and Heaney 1991 and 1992) indicate that drought is the primary reason for declining lake levels. Brooklyn Lake has historically fluctuated between extremes nearly 28 feet apart. In general terms, Brooklyn Lake is affected in two ways by drought conditions.

- Brooklyn Lake provides recharge to the Floridan aquifer (Clark et al. 1963; Yobbi and Chappell 1979; and Motz and Heaney 1992). Recharge losses from Brooklyn Lake increase as potentiometric surface levels in the aquifer decline. Such potentiometric surface level declines are common during drought conditions.

- Lower rainfall results in reduced inflow of water to the lake thereby reducing the lake's ability to recuperate water losses due to recharge, evaporation, and direct withdrawals from Brooklyn Lake.

On the other hand, some area residents perceive that declines in Brooklyn Lake water levels are chiefly due to a combination of six factors not related to drought conditions.

- Loss of drainage area north of Blue Pond (Figure 2). This loss of drainage area occurred when the DuPont mining

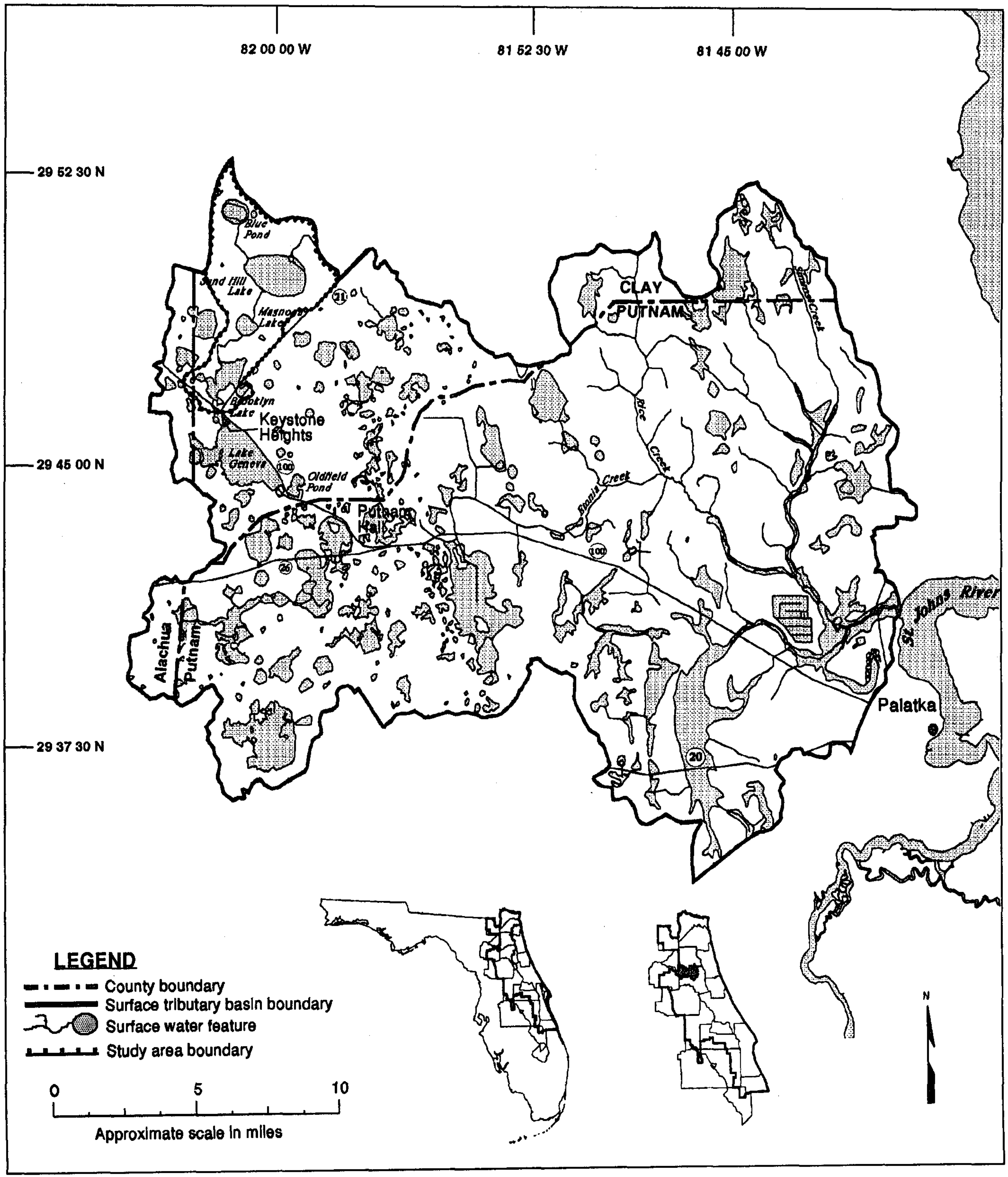


Figure 1. The Etonia Creek Drainage Basin. *This study concentrated on the Upper Etonia Creek chain of lakes, from Blue Pond downstream to Brooklyn Lake.*

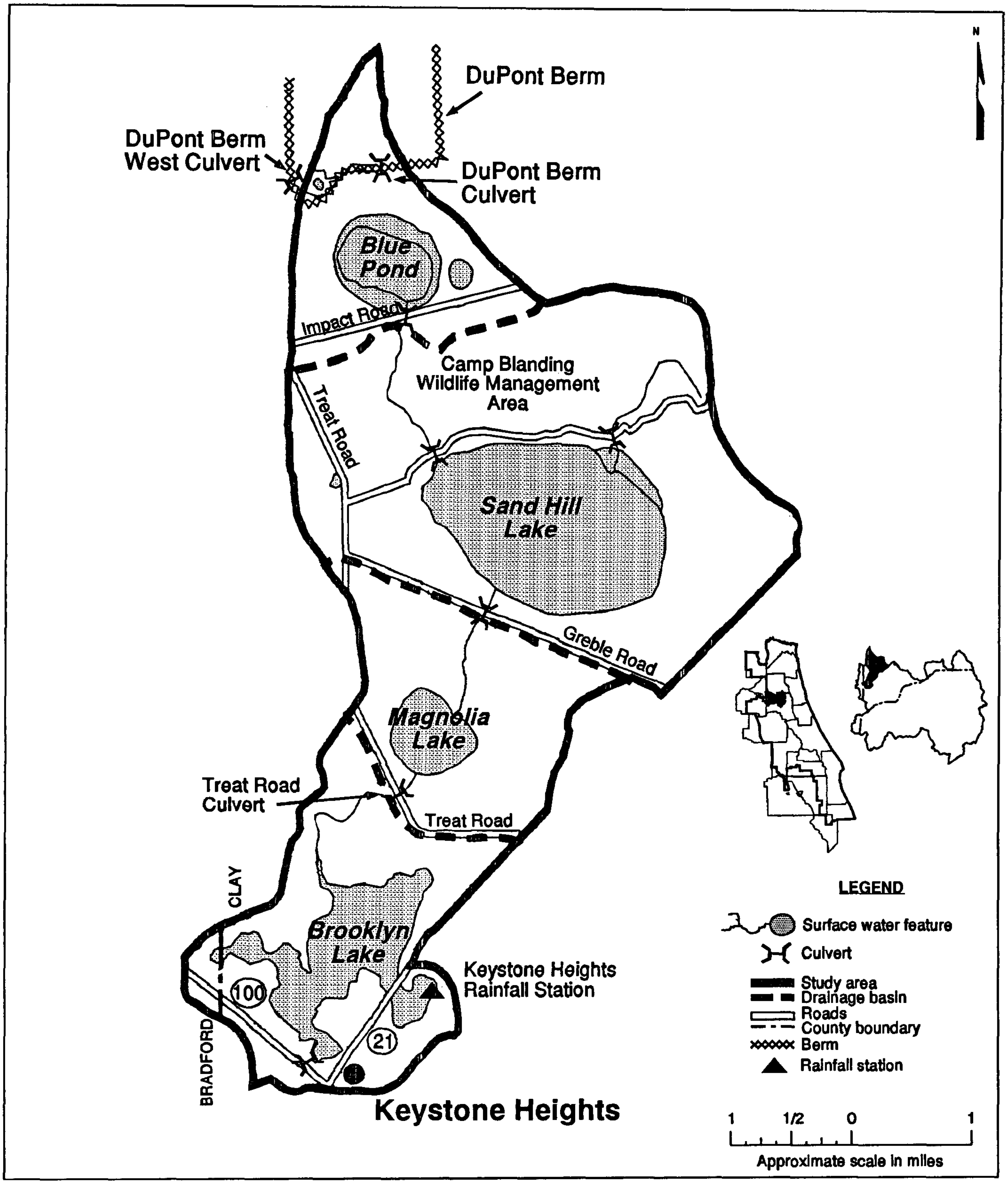


Figure 2. **The Upper Etonia Creek Chain of Lakes Drainage Basin.** *This study covered only to the outlet of Brooklyn Lake.*

operation on Camp Blanding, some time in the past, built a berm cutting off some 260 acres of drainage.

- Loss of surficial and intermediate aquifer ground water flow toward Brooklyn Lake as a result of the excavation for the DuPont berm.
- Blockage of flow through the creeks connecting Blue Pond, Sand Hill Lake, Magnolia Lake, and Brooklyn Lake.
- Blockage of outflow from lakes upstream of Brooklyn Lake caused by increased elevation of the lake outlets.
- Culverts that are too small for efficient movement of water through the basin toward Brooklyn Lake.
- Culverts that are installed too high, causing blockage of flow.

This study was designed to determine if these factors have indeed affected levels on Brooklyn Lake and if by changing them the situation could be improved.

HYDROLOGIC MODEL—SSARR

SJRWMD has been asked to consider a number of potential problems, local to the Upper Etonia Creek chain of lakes, that might affect Brooklyn Lake adversely. Some of the problems can be analyzed by using computer modeling techniques. The basic methodology is to simulate existing hydrologic conditions and compare that simulation to a simulation of a problem or a potential solution to a problem.

MODEL DESCRIPTION

The Streamflow Synthesis and Reservoir Regulation (SSARR) mathematical model, a rainfall/runoff/routing model developed by the Portland District of the U.S. Army Corps of Engineers (COE) (COE 1986, Ponce 1989) was used to simulate elevations of Blue Pond, Sand Hill Lake, Magnolia Lake, and Brooklyn Lake. The model also simulated the hydrologic conditions of drainage basins surrounding each lake.

SSARR comprises a watershed sub-model and a river system sub-model. The watershed sub-model simulates rainfall-runoff and accounts for interception, evapotranspiration, baseflow infiltration, and routing of runoff into the stream network. It also accounts for ground water flow through the local water table, but not for flow through the regional water table, the intermediate aquifer, or the Floridan aquifer.

The basic routing method used in the watershed model is a cascade of reservoirs technique (COE 1986). A watershed is represented as a series of lakes, which conceptually simulate the natural delay of runoff.

The river system sub-model routes streamflows from upstream to downstream points through lake storage. The river system sub-model also uses the cascade of reservoirs technique to simulate lakes and channels. The model accounts for evaporation from and rainfall to each of the lakes.

The SSARR User Manual (COE 1986) contains a complete description of the model. Ponce (1989) also provides a description of SSARR.

INPUT REQUIREMENTS

Input data needed for operation of SSARR include the following.

- Constant characteristics
- Initial conditions data
- Time series data
- Job control parameters

Constant Characteristics

The constant characteristics of a basin are physical features such as drainage area, watershed characteristics affecting runoff, lake storage and rating curves, drainage system configuration, and so on.

The constant characteristics discussed in detail here are the soil moisture-runoff relationships, drainage basin configuration, the relationship of lake storage to lake elevation, outlet rating curves, and Floridan aquifer loss curves.

Soil Moisture-Runoff Relationships. The Soil Moisture Index (SMI), measured in inches, is an indicator of relative soil wetness and, consequently, of watershed runoff potential. Rainfall input is divided by SSARR into runoff and soil moisture increases. The percentage of rainfall available for runoff (Runoff Percentage, ROP) is based on an empirically derived relationship between soil moisture and intensity of rainfall (I) (Figure 3). This relationship determines the runoff percentage; rainfall that is not converted by the model into runoff is added to the SMI.

Soil moisture (the SMI) in SSARR is depleted only by evapotranspiration (ET). Evapotranspiration losses, measured in inches, include transpiration of moisture by vegetation, interception losses, and direct evaporation of water from the ground to the atmosphere. The total of these losses is referred to as *potential* evapotranspiration (Ponce 1989). The potential evapotranspiration can be approximated by using a set percentage of the pan evaporation (Yobbi and Chappell 1979)—determined during model calibration. The average monthly evaporation at the Gainesville weather station was converted to daily potential evapotranspiration.

The actual amount of evapotranspiration, referred to as *effective* evapotranspiration, changes with changing soil moisture conditions. The amount of water that evaporates from the ground decreases as the soil dries out. Thus the potential evapotranspiration is multiplied by a reduction factor, based on the SMI, to obtain the effective evapotranspiration (Figure 3). SSARR determines the effective evapotranspiration and reduces soil moisture (the SMI) by the effective evapotranspiration before calculating runoff.

Drainage Basins. Drainage basins for individual lakes were determined based on elevation contours from USGS Quadrangle maps of the area. The drainage areas are 1.7 square miles (mi^2) for the Blue Pond subbasin, 6.6 mi^2 for the Sand Hill Lake subbasin, 2.6 mi^2 for the Magnolia Lake subbasin, and 2.8 mi^2 for the Brooklyn Lake subbasin (Figure 2).

Storage-Elevation Curves. The relationship of storage capacity to lake elevation for each lake was based on bathymetric data (Clark et al. 1964) (Figure 4).

Outlet Rating Curves. Outlet rating curves for each lake, relating elevation to discharge, were developed assuming a mild-sloped channel leaving a lake (Chow 1959, Henderson 1966) (Figure 5).

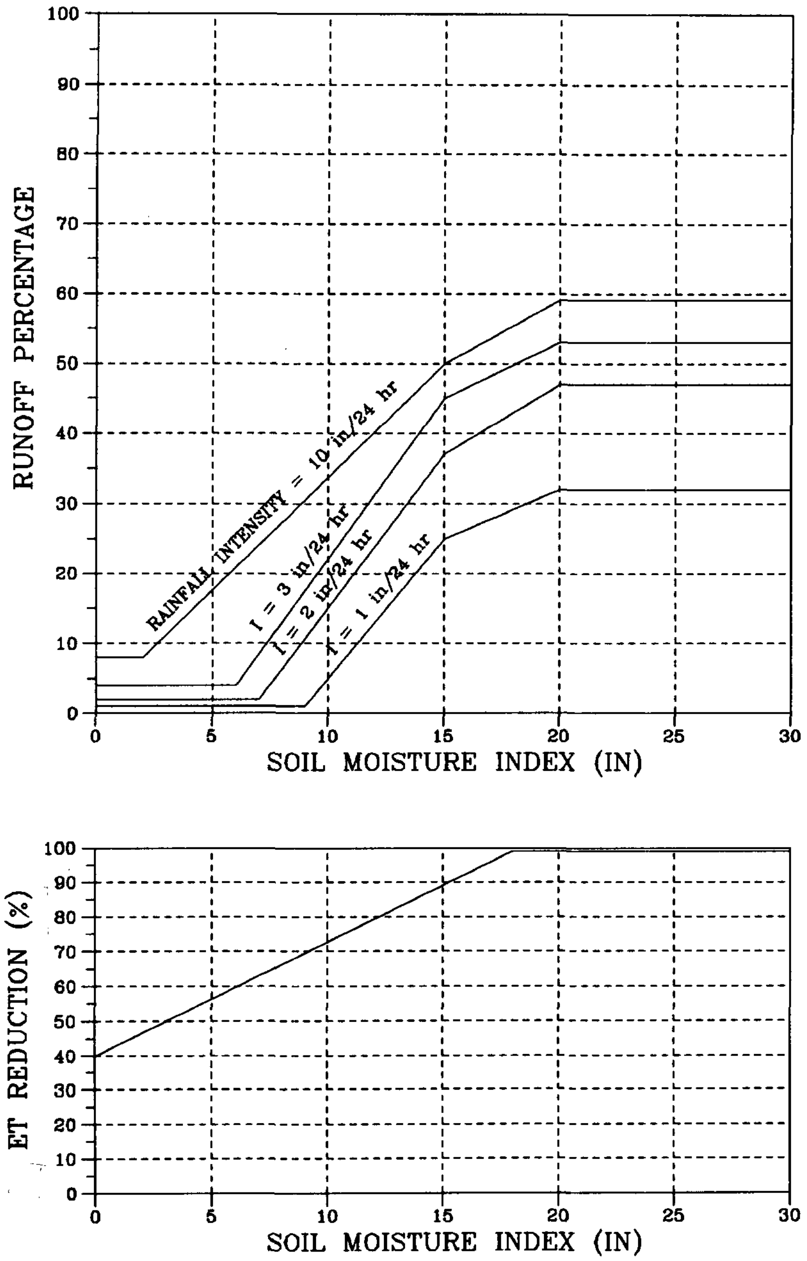


Figure 3. **SSARR Soil Moisture Relationships for the Upper Etonia Creek Chain of Lakes Drainage Basin.** *[Top] Runoff percentage versus soil moisture index curves. [Bottom] Evapotranspiration reduction factor versus soil moisture index curve. These curves were developed in calibration.*

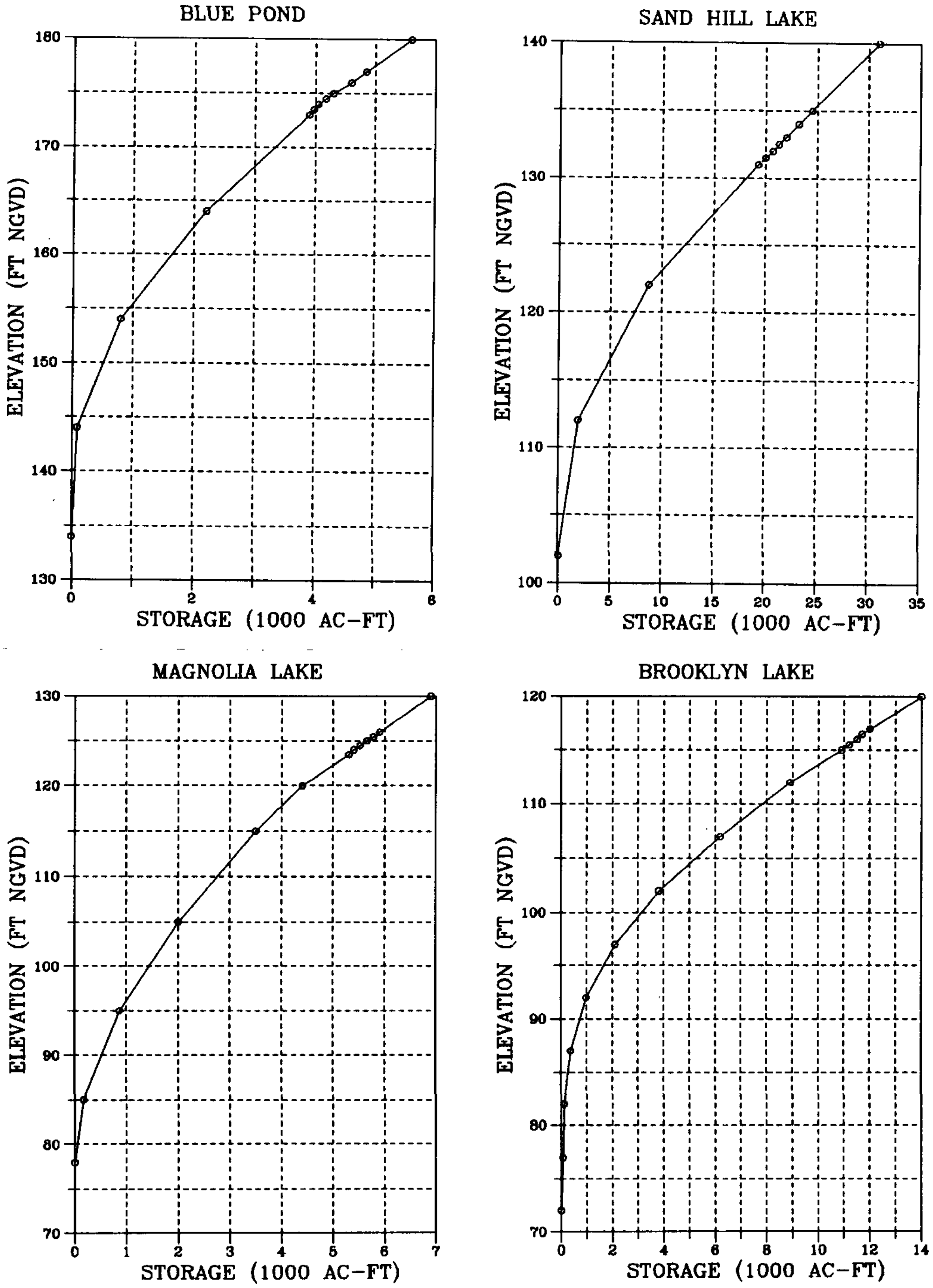


Figure 4. **Storage-Elevation Curves for the Upper Etonia Creek Lakes.** *Relationships of storage to lake elevation were determined from historical bathymetric maps.*

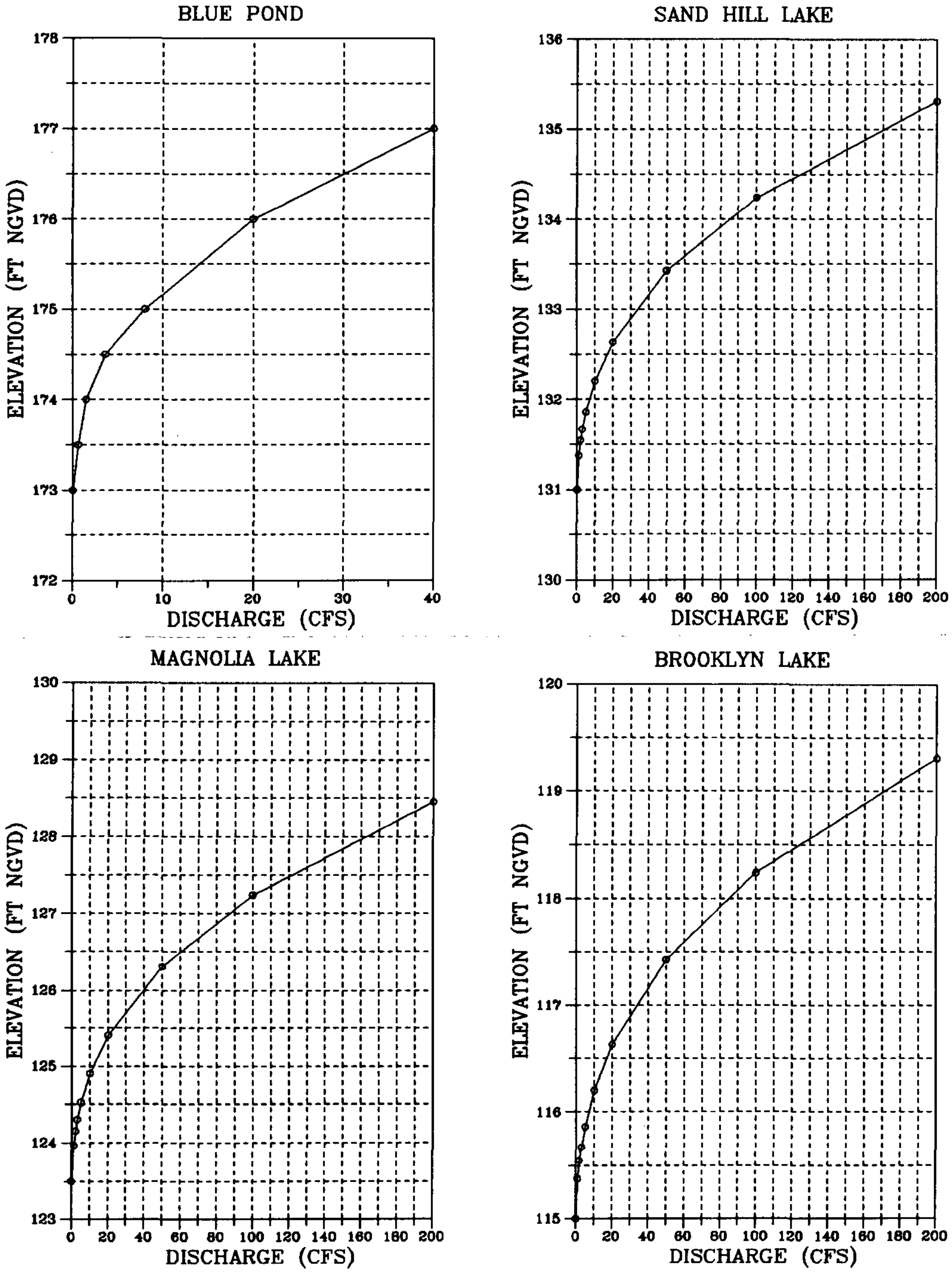


Figure 5. **Outlet Rating Curves for the Upper Etonia Creek Lakes.** *These curves relating lake elevation to discharge were developed in a uniform-flow analysis. Discharge is measured in cubic feet per second (cfs).*

In this situation, flow becomes uniform immediately after it enters the channel. The parameters used in a uniform-flow analysis (Henderson 1966, Chow 1959) to develop the rating curves are listed in Table 1.

Table 1. Outlet rating curve parameters in the Upper Etonia Creek chain of lakes drainage basin

Lake	Channel Configuration[1]	Channel Slope	n-Value[1,3]
Blue Pond	3-ft-wide, 1-ft-deep, rectangular, low-flow channel; trapezoidal main channel with 1V:4H side slopes	0.001[2]	0.05
Sand Hill	4-ft-base trapezoidal main channel with 1V:4H side slopes	0.002[2]	0.05
Magnolia	4-ft-base trapezoidal main channel with 1V:4H side slopes	0.001[2]	0.05
Brooklyn	4-ft-base trapezoidal main channel with 1V:4H side slopes	0.002[4]	0.05

[1] By field inspection
[2] From surveyed profiles (Appendix)
[3] (Henderson 1966, Chow 1959)
[4] From USGS quadrangle map

Floridan Aquifer Loss Functions. Losses from Brooklyn Lake to the Floridan aquifer are calculated based on a three variable relationship between the elevation of Brooklyn Lake, the potentiometric surface level of the Floridan aquifer, and the flow from the lake to the aquifer (Figure 6). The initial general form of the curves for this relationship was loosely based on the assumption of a submerged orifice (Brater and King 1976). Basically, the higher the elevation of Brooklyn Lake, the higher the flow to the Floridan aquifer. Likewise, the lower the potentiometric surface level of the Floridan aquifer, the higher the flow from the lake to the aquifer. This family of loss curves was developed in model calibration.

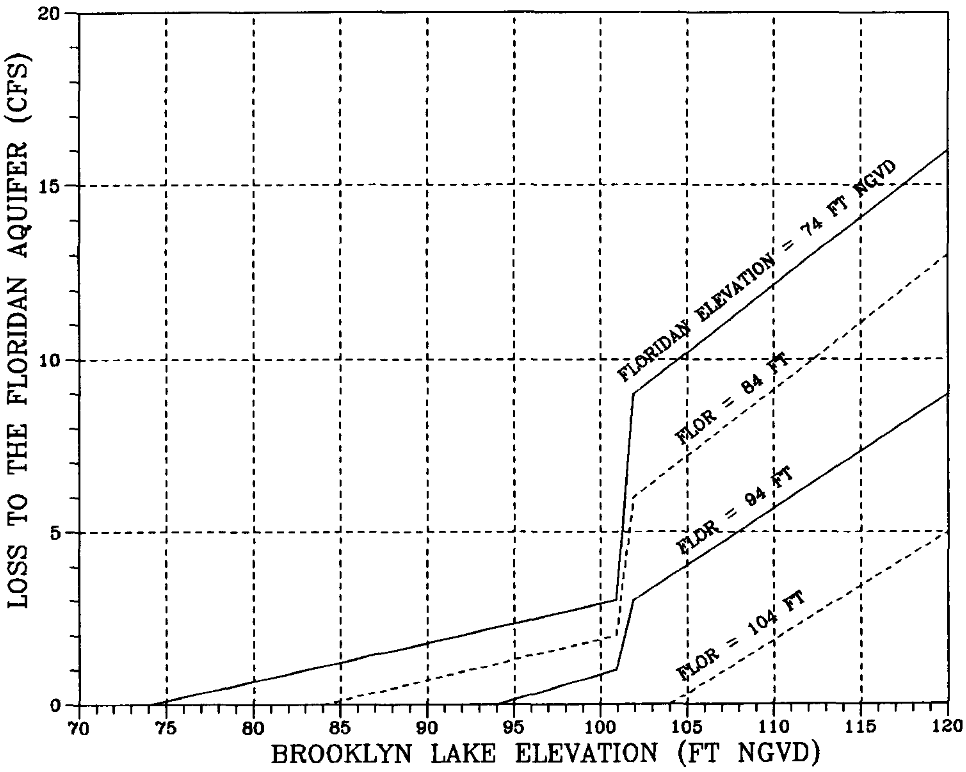


Figure 6. **Floridan Aquifer Loss Curves for Brooklyn Lake.** *These curves relating lake elevation, the potentiometric surface of the Floridan aquifer (FLOR), and loss from the lake to the aquifer were developed during model calibration.*

Blue Pond, Sand Hill Lake, and Magnolia Lake historically have fluctuated much less than Brooklyn Lake, indicating that losses to the Floridan aquifer are much less important. Therefore, much simpler relationships in the form of a constant loss—zero for both Blue Pond and Sand Hill Lake and 1 cubic foot per second (cfs) for Magnolia Lake—were assumed for these other lakes.

Other Relationships. Other constant characteristics used by SSARR include functions that divide runoff into surface and ground water (base) flows, a function to determine depression losses, and factors that determine the shape of hydrographs.

Initial Conditions Data

Initial conditions specify the basin parameters on the starting day of simulation. They include the current value of the SMI; the initial discharge from each subbasin; and initial storage, elevation, and outflow for each lake. The model automatically saves initial conditions calculated for any given time to be used in subsequent simulations.

Time Series Data

SSARR can use a number of time series as input. Rainfall, evaporation, potentiometric surface levels of the Floridan aquifer, and lake elevation data were used for the Upper Etonia model.

Rainfall. Because few on-site rainfall data are available for the period of study, the simulations were based on the nearest rainfall recording station (Table 2).

Table 2. Rain gage stations in and near the Upper Etonia Creek chain of lakes drainage basin

Station	Location	Period of Record	Type
Gainesville	Gainesville Weather Station, Alachua County	1954–present	Daily
Starke	Starke Weather Station, Bradford County	1958–1984	Daily
Keystone Heights	On Brooklyn Lake	September 1989–present	Daily

When available, rainfall data from a SJRWMD station on Brooklyn Lake were used (1989–1991). Otherwise records for the National Weather Service (NWS) stations in Starke (1958–1984) and Gainesville (1985–1989) were used. Starke is closer to the basin than Gainesville, so Starke data were used when available.

Evaporation. Lake evaporation was assumed to be a fixed percentage of daily pan evaporation at Gainesville. Initially, 70 percent was used (Linsley et al. 1975). Because this percentage produced satisfactory results, it was not changed.

For calculating the combined evaporation and transpiration (evapotranspiration) losses from the remaining basin (page 7), 90 percent of daily pan evaporation at Gainesville was used as the potential daily evapotranspiration. This value is similar to ratios determined in other studies (Ponce 1989, Linsley et al. 1975). SSARR reduces the potential evapotranspiration, based on soil moisture (the SMI), to obtain the effective evapotranspiration (Figure 3).

Lake Elevations and Floridan Aquifer Potentiometric Surface Levels. USGS lake elevation data for Blue Pond, Sand Hill Lake, Magnolia Lake, and Brooklyn Lake were used to calibrate and verify the model (Table 3). The USGS also published well data from 1960 to the present for a Floridan aquifer well located in Keystone Heights (well number 948-202-8). An older well in Keystone Heights (USGS number 947-201-4) was used for data from August 1959 through October 1960 (Clarke et al. 1963).

Job Control Parameters

Job control parameters used by SSARR include the total simulation period, time intervals for the data (daily, hourly, etc.), and input/output instructions.

Table 3. USGS gaging stations in the Upper Etonia Creek chain of lakes drainage basin

Station	USGS Number	Period of Record	Frequency of Measurement	Type
Blue Pond	02244550	1958–1967	sporadic	Lake elevation
Sand Hill Lake	02244600	1958–present	approximately monthly	Lake elevation
Magnolia Lake	02244650	1958–present	approximately weekly	Lake elevation
Brooklyn Lake	02244750	1958–present	approximately weekly	Lake elevation
Floridan aquifer	948-202-8	1960–present	approximately weekly	Potentiometric surface level
Floridan aquifer	947-201-4	1959–1960	approximately weekly	Potentiometric surface level

ASSUMPTIONS

No model can include all factors affecting the hydrologic cycle. Therefore, any study has to include simplifying assumptions. (In analyzing the final product of the model, a judgement is made as to the sufficiency of the assumptions.) In particular, including ground water movement between lakes is beyond the scope of this study. The following assumptions were made for simulating the Upper Etonia Creek chain of lakes.

- There is no long-term net loss (or gain) from any lake to the surficial or the intermediate aquifers. This implies that the same amount of ground water flows into each lake as flows out.

- Based on the small range of elevations on Blue Pond, losses to the Floridan aquifer from Blue Pond are negligible. Eighty percent of observed elevations on Blue Pond (between 1959 and 1967) were between about 174.0 ft NGVD and 173.1 ft NGVD (page 27).

- Based on the small range of elevations on Sand Hill Lake, the difference between losses to the Floridan aquifer from Sand Hill Lake and spring flow into Sand Hill Lake are small. Eighty percent of observed elevations on Sand Hill Lake (from 1958 to present) were between about 132.0 ft NGVD and 131.1 ft NGVD (page 27).

- The culvert discharging from the DuPont bermed area (Figure 2) was crushed some time in the past. The condition with the 260 acres cut off will be assumed as existing.

MODEL CALIBRATION

Fit of Calculated Values

Transformation of rainfall into runoff in the Upper Etonia Creek chain of lakes drainage basin is controlled by various basin characteristics. SSARR simulates hydrologic processes which, with input of observed data such as rainfall and evaporation, replicate to some degree other observed data such as lake elevation. Calibration is the manipulation of various model parameters to optimize the *fit* of calculated data to observed data.

Several factors affect closeness of fit.

- Availability of rainfall data

- Density of the rain gage network

- Availability of lake elevation data

- Frequency of lake elevation measurement

Availability of Rainfall Data. The best available rainfall data were from the NWS stations in Gainesville and Starke (Table 2). The exception was during the years 1989 through 1991 when there were data available from a SJRWMD station in Keystone Heights. Both Gainesville and Starke are outside the Upper Etonia Creek chain of lakes drainage basin. So although the long-term statistics of the rainfall records will tend to be similar, on a day-to-day basis they might differ substantially.

Density of the Rain Gage Network. Rainfall is spatially and temporally variable. Therefore, the more dense a network, the more accurately will be represented the true amount and location of rainfall over a basin. For this model only one rainfall station (the closest available) was used.

Availability of USGS Lake Elevation Data. The lake elevation data for Sand Hill, Magnolia, and Brooklyn lakes cover the period of study between 1958 and 1991, although somewhat sporadically at times (Table 3). Some statistical analyses of observed values might be affected by sporadic observations. The elevation of Blue Pond was recorded only between 1958 and 1967. There were so few measurements taken that no meaningful statistical comparison can be made for Blue Pond.

Frequency of Lake Elevation Measurements. Some events, especially high water events, are missed when measurement is not daily (Table 3). This fact might affect the statistical comparisons between observed and calculated values. (Throughout this report the term *calculated* will refer to values obtained by model simulation.)

All these factors combine to make calibration and verification difficult. However, the study covered a long enough period to make possible a meaningful comparison of observed and calculated values and thus a meaningful assessment of model performance.

Calibration of SSARR for the Upper Etonia Creek Chain of Lakes

SSARR was calibrated for the Upper Etonia Creek chain of lakes using observed lake elevation measurements for Blue Pond, Sand Hill Lake, Magnolia Lake, and Brooklyn Lake. Calibration of SSARR involved a series of trial and error runs to obtain the best fit with observed values, adjusting some model parameters while maintaining others fixed. The following model parameters were adjusted.

- The ratio of potential evapotranspiration in the basin to pan evaporation. The ratio was changed from 0.75 (Yobbi and Chappell 1979) to 0.90.
- The SMI versus ROP curves and the SMI versus evapotranspiration reduction curves. The final curves appear in Figure 3.
- The Brooklyn Lake–Floridan aquifer loss function. The final curves appear in Figure 6.
- The Magnolia Lake–Floridan aquifer loss function. The loss was determined to be a constant 1 cfs.

The following model parameter also could have been adjusted but was not.

- The ratio of lake evaporation to pan evaporation. The ratio was 0.70 (Linsley et al. 1975).

The following model parameters were constant.

- Drainage areas
- Storage-elevation curves
- Outlet rating curves

Two different years were used to calibrate the Upper Etonia Creek SSARR model: 1965 and 1989. The year 1965 was used for the following reasons.

- In 1965, all the Upper Etonia lakes were high and discharging. This was especially important for Brooklyn Lake because it discharges downstream so seldom. This year also provided the opportunity to develop the Floridan aquifer loss curves (Figure 6) for higher elevations in Brooklyn Lake and the Floridan aquifer.
- Because no data were available for Blue Pond in 1989, 1965 data were used to calibrate the model. (The elevation of Blue Pond was recorded only up to 1967 [Table 3].)

The year of 1989 was used for the following reasons.

- Even though rainfall data for the period between January and August 1989 was available only at Gainesville (Table 2), this year was used because it is recent and, therefore, represents the "existing condition."
- Sand Hill Lake, Magnolia Lake, and Brooklyn Lake were all low during much of this year. This year provided the opportunity to develop the Floridan aquifer loss curves (Figure 6) for lower elevations in Brooklyn Lake and the Floridan aquifer.

Calibration: 1965

Rainfall recorded at the Starke station (Table 2) was used as the input for simulation of 1965 lake elevations. In general, there is good agreement between calculated and observed lake elevations (Figure 7). The calculated values (except for Brooklyn Lake where there are few observed elevations) are consistently high between July and September, indicating that there was probably less rainfall over the basin than was recorded at Starke.

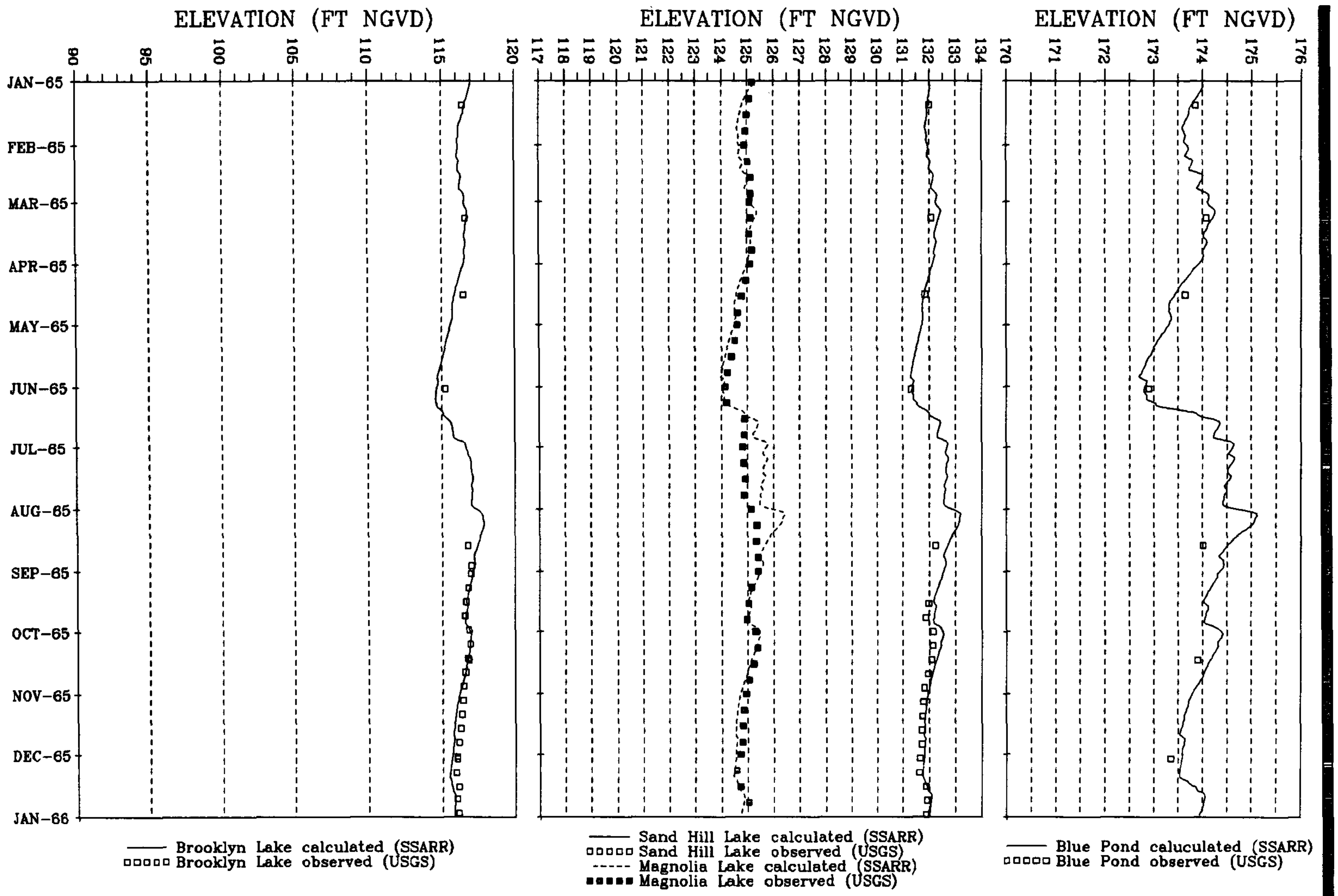


Figure 7. **SSARR Calibration for 1965.** *Rainfall data from the Starke station (Table 2) was used for 1965. The elevation scales are different for each graph*

Calibration: 1989

Rainfall recorded at Gainesville was used for January through August, and rainfall recorded at Brooklyn Lake was used for the remainder of the year (Table 2). Until about July, there is good agreement between calculated and observed values (Figure 8). Thereafter, calculated values for both Sand Hill and Magnolia lakes are high, indicating that there was probably more rainfall recorded at Gainesville than over the upper portion of the Upper Etonia Creek chain of lakes drainage basin. The important thing to note about Brooklyn Lake is the correct simulation of a 7-ft drop in elevation during the year.

MODEL VERIFICATION

Verification indicates how well the model is performing as well as how appropriate any assumptions might have been. The Upper Etonia SSARR model was verified with data from 1990 and 1991.

Verification: 1990

The agreement between calculated and observed lake elevations for Sand Hill Lake are good through about October (Figure 9). This deviation did not affect the simulation of Magnolia and Brooklyn lakes because Sand Hill Lake was below its discharge elevation of 131 ft NGVD.

The agreement between observed and calculated lake elevation values from 1990 is excellent for Magnolia and Brooklyn lakes (Figure 9). The model correctly simulated a 3.5 ft drop for Magnolia Lake and a 6 ft drop for Brooklyn Lake during the year.

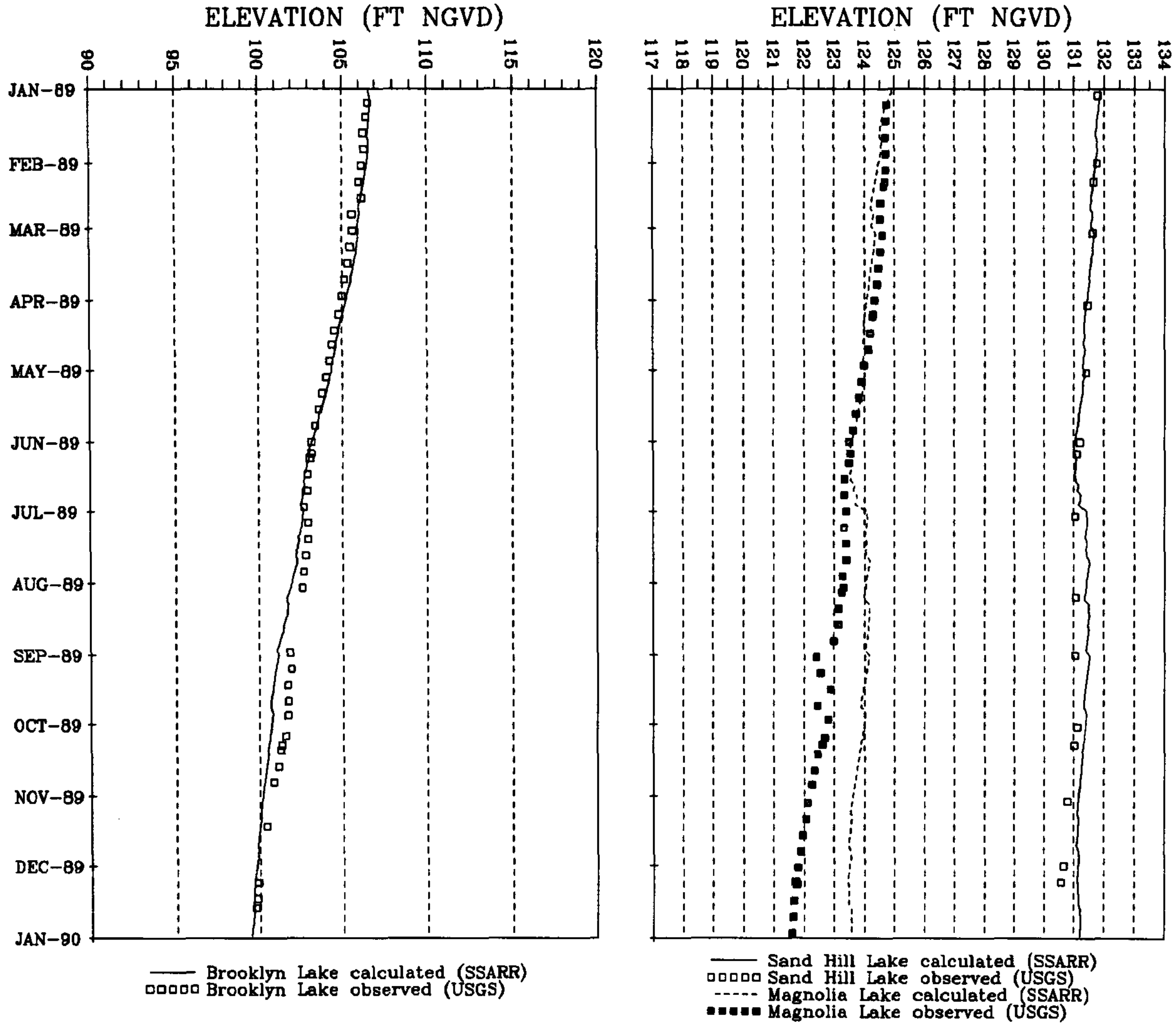


Figure 8. **SSARR Calibration for 1989.** *There are no observed lake elevations for Blue Pond. The elevation scales are different for each graph.*

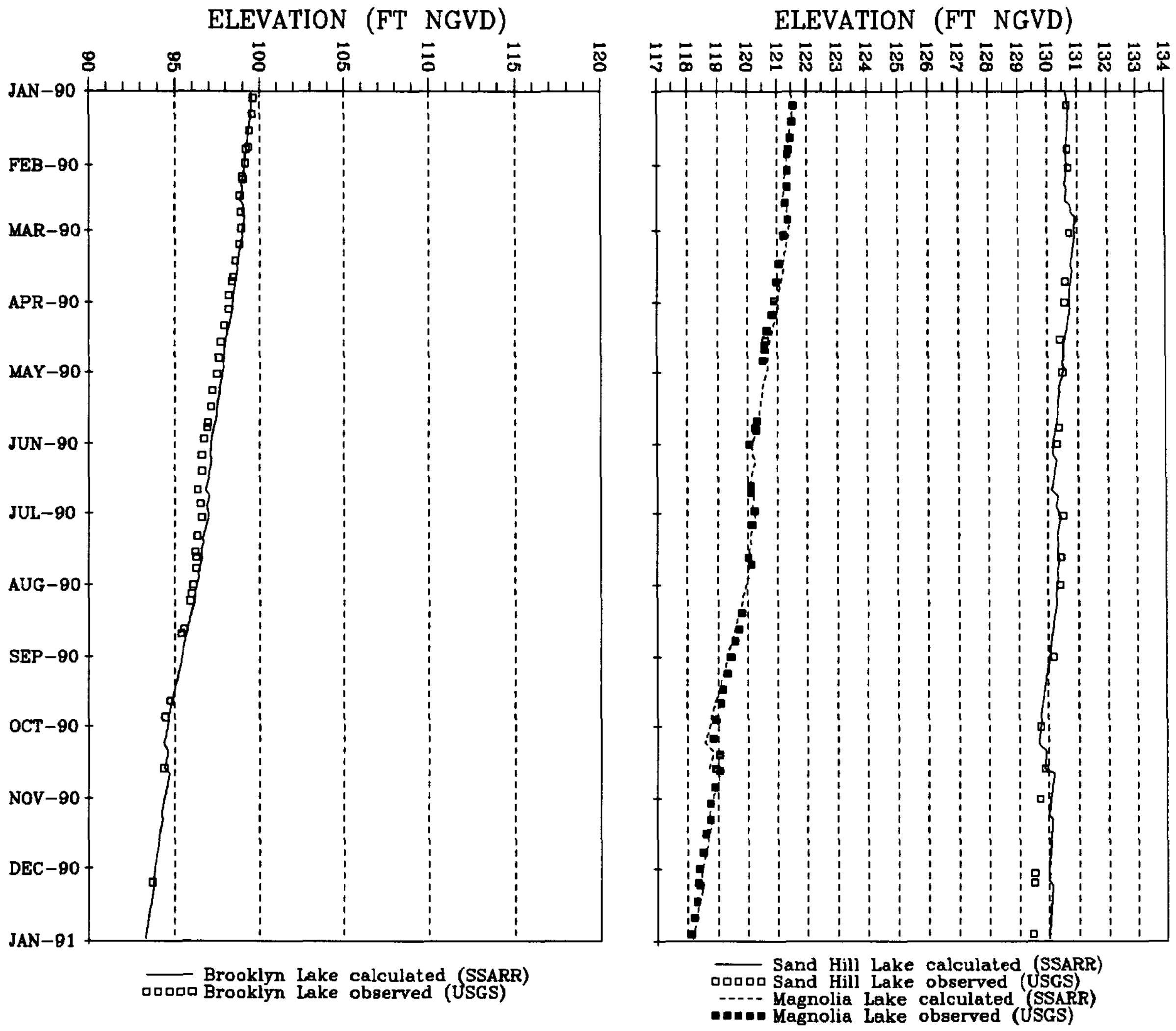


Figure 9. **SSARR Verification for 1990.** *There are no observed lake elevations for Blue Pond. The elevation scales are different for each graph.*

Verification: 1991

The agreement between calculated and observed elevations for Sand Hill Lake is excellent through about September (Figure 10); the calculated values are about half a foot too high after September. The agreement between calculated and observed elevations for Magnolia Lake is good, although the calculated values are about 1 ft too low during August through September. Overall, the maximum increase in elevation of over 6 ft is successfully simulated.

The agreement between calculated and observed values for Brooklyn Lake is excellent until about August 15; the calculated values end the year almost 1.5 ft too high (Figure 10). Although water did flow from Magnolia Lake in late 1991, none reached Brooklyn Lake. This water probably was recharged to the ground water system between Magnolia and Brooklyn lakes. The model cannot simulate this effect.

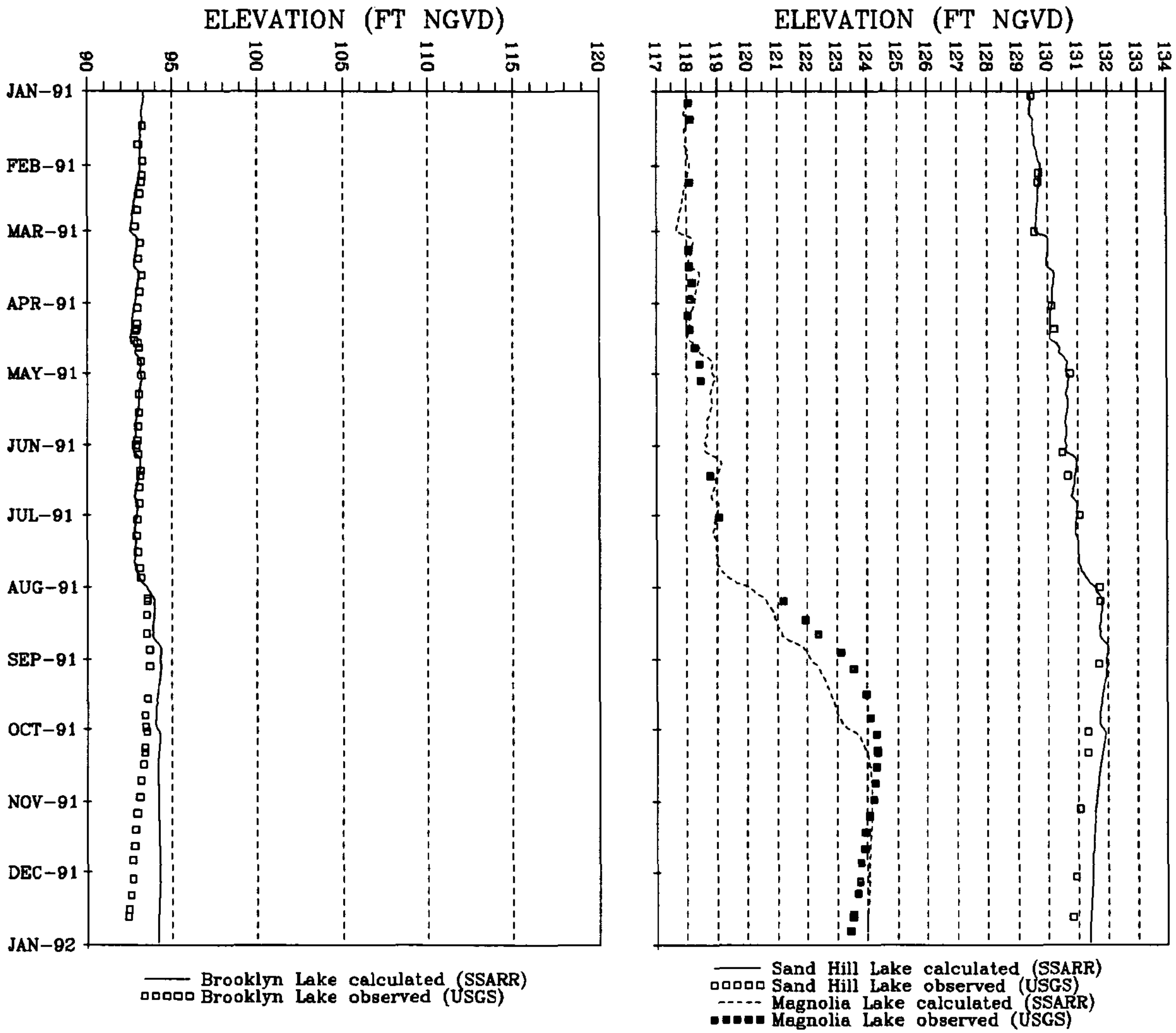


Figure 10. **SSARR Verification for 1991.** *There are no observed lake elevations for Blue Pond. The elevation scales are different for each graph.*

RESULTS OF LONG-TERM SIMULATIONS

STATISTICAL ANALYSIS

Differences between available rainfall data and actual rainfall data should balance out over the long-term. Therefore, statistical analyses can be used to compare SSARR performance with long-term observed gage readings. Comparison of these analyses can indicate whether or not major changes have occurred in the basin over the period of record. Any major hydrologic change, such as a major loss of drainage area, would be reflected in significant differences between observed and calculated statistics.

Elevation-Duration Curves

SSARR was run simulating the Upper Etonia Creek chain of lakes between 1958 and 1991. Lake elevations were analyzed to compare the observed elevation-duration curve with the calculated curve (Figure 11). An elevation-duration curve shows the percentage of time the lake elevation will exceed the indicated value (Linsley et al. 1975).

Elevation-Duration Curves: Brooklyn Lake. A comparison of elevation-duration curves for observed and calculated elevations for Brooklyn Lake shows good agreement between the two (Figure 11). This agreement indicates that the modeling assumptions (page 15) were reasonable, and that no major changes have occurred within the Upper Etonia Creek chain of lakes during the period of record.

Elevation-Duration Curves: Magnolia Lake. A comparison of elevation-duration curves for observed and calculated elevations for Magnolia Lake shows good agreement between the two (Figure 11), except for the two extremes of the curves. Since the observed elevations sometimes were read only sporadically, some short-term peaks in elevation would tend to be missed. This

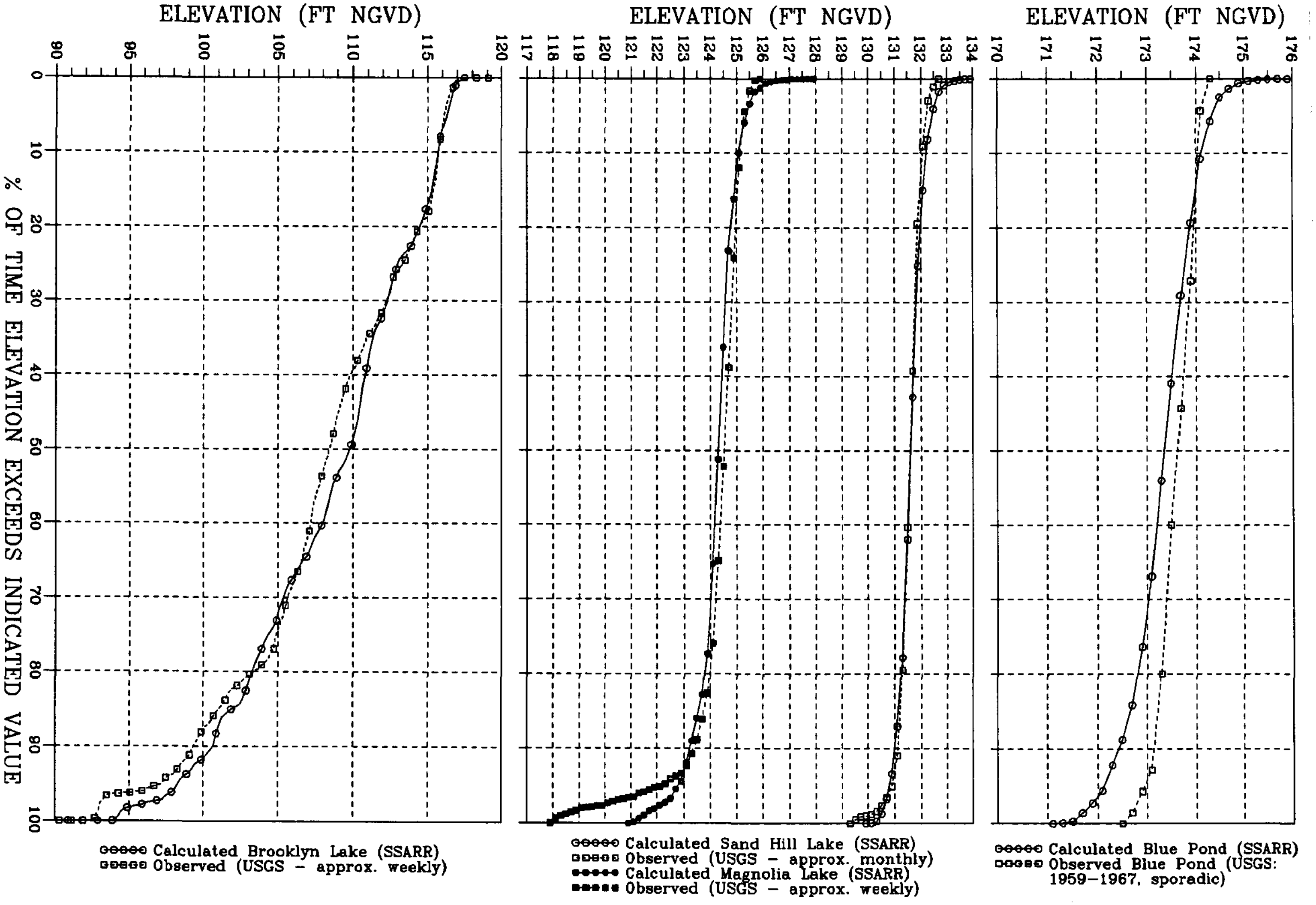


Figure 11. **Elevation–Duration Curves: 1958–1991.** *This figure shows comparisons of curves for observed and calculated data.*

would explain the divergence of the curves above a duration of 5 percent.

The portion of the observed curve between durations of 95 and 100 percent correspond to 1990 and parts of 1989 and 1991. If only two or three Gainesville rainfall events were removed from the simulation (Figure 8) for 1989, the agreement between 95 and 100 percent durations would be much closer.

The agreement between the two curves indicates that the modeling assumptions (page 15) were reasonable, and that no major changes have occurred around or upstream of Magnolia Lake during the period of record.

Elevation-Duration Curves: Sand Hill Lake. A comparison of elevation-duration curves for observed and calculated elevations for Sand Hill Lake shows very good agreement between the two (Figure 11). As with the Magnolia Lake curves there is some divergence at the extremes (and they can be explained in the same manner), though to a lesser extent. The agreement between the two curves indicates that the modeling assumptions (page 15) were reasonable, and that no major changes have occurred around or upstream of Sand Hill Lake during the period of record.

Elevation-Duration Curves: Blue Pond. Only 70 elevation readings were taken on Blue Pond, between 1958 and 1967. Because these readings were taken so sporadically, and at a time of relatively high lake levels, elevation-duration curves for Blue Pond are of limited value. However, they do indicate (Figure 11) that the calculated elevations are reasonable when compared to the observed elevations.

Elevation-Frequency Curves: Brooklyn Lake

Elevation-frequency analysis seeks to define the elevation with a certain probability of being equaled or exceeded in any year (Linsley et al. 1975). So if a model is performing correctly the elevation-frequency curves for observed and calculated values (in a long-term simulation) should be relatively close.

The elevation-frequency curves for observed and calculated mean annual elevation are shown in Figure 12. The Weibull plotting position formula (Linsley et al. 1975) is used. Except for the very lowest elevation, there is good agreement between the two curves. The agreement between the two curves indicates that the modeling assumptions (page 15) were reasonable, and that no major changes have occurred in the Upper Etonia Creek chain of lakes over the period of record.

BROOKLYN LAKE WATER BUDGET

Analysis of the output of the long-term simulation by SSARR can yield a water budget. A water budget indicates the relative importance of different hydrologic components of the Brooklyn Lake part of the Upper Etonia Creek system. In general the most important components are inflows from Magnolia Lake (Column 2, Table 4) and losses to the Floridan aquifer (Column 6, Table 4). The yearly error (Column 10, Table 4) originates from the fact that the data analysis module, part of SSARR, truncates instead of rounding. The error is not in the simulation itself and so does not affect overall results.

EFFECT ON BROOKLYN LAKE OF A CONSTANT POTENTIOMETRIC SURFACE LEVEL IN THE FLORIDAN AQUIFER

To get a sense of the importance of the potentiometric surface level in the Floridan aquifer with respect to maintaining water levels in Brooklyn Lake, SSARR was run with a constant potentiometric surface level (92.0 ft NGVD), just higher than the maximum historical level. The results indicate that the lake stage elevations would be somewhat higher but would still fluctuate in a pattern similar to that which exists under the existing-conditions simulation (Figure 13). These fluctuations in lake

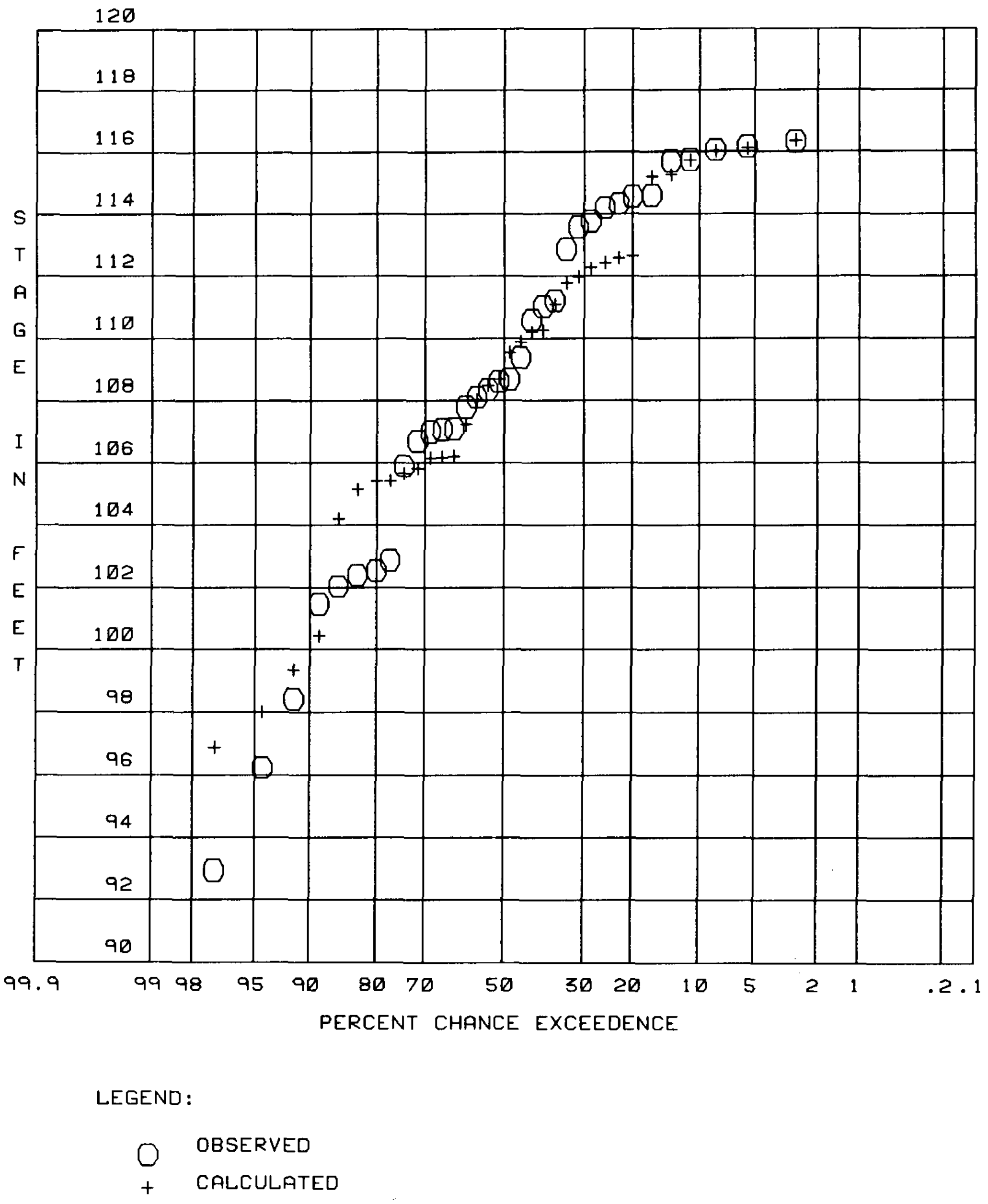


Figure 12. **Elevation-Frequency Curves for Lake Brooklyn: 1958–1991.** *This figure shows a comparison of curves for observed and calculated data.*

Table 4. **Brooklyn Lake Water Budget (1958–1991).** *In acre-feet. The most important components are inflows from Magnolia Lake and losses to the Floridan aquifer.*

Year	Inflows			Outflows			Initial Storage	Final Storage	Error
	Inflow from Magnolia Lake	Inflow from Basin	Direct Rainfall	Direct Evaporation	Loss to Floridan	Outflow Downstream			
1958	2,069	407	1,460	1,079	1,265	0	2,250	3,607	235
1959	12,700	2,158	3,007	1,537	5,875	2,225	3,606	11,163	671
1960	6,014	1,438	2,704	1,936	6,532	938	11,152	11,171	731
1961	6,113	1,404	2,729	2,045	6,103	1,492	11,158	10,955	809
1962	2,097	559	2,154	1,682	5,897	0	10,942	7,658	515
1963	657	109	1,365	1,505	4,487	0	7,647	3,395	391
1964	9,027	2,184	2,705	1,382	3,531	93	3,402	11,734	578
1965	10,893	2,003	3,235	2,225	6,629	6,956	11,748	11,390	679
1966	6,922	1,482	2,733	2,045	6,476	2,239	11,386	10,975	788
1967	2,317	813	2,285	1,984	5,907	0	10,960	7,999	485
1968	4,990	980	2,015	1,587	5,738	0	7,998	8,249	409
1969	6,083	1,295	2,561	1,442	5,986	0	8,236	10,070	677
1970	10,441	1,985	2,777	1,863	6,712	5,131	10,080	10,924	653
1971	1,972	534	2,007	1,638	6,256	0	10,930	7,035	514
1972	6,375	1,345	2,505	1,628	5,419	0	7,026	9,446	758
1973	3,781	776	2,053	1,743	5,756	0	9,440	8,047	504
1974	4,233	891	2,279	1,498	5,260	0	8,031	8,046	630
1975	5,131	1,117	2,227	1,500	5,925	0	8,041	8,491	600
1976	2,079	587	1,565	1,462	6,093	0	8,533	4,662	547
1977	367	202	1,192	1,141	2,416	0	4,664	2,557	311
1978	8,551	1,807	2,168	1,337	5,004	0	2,556	8,342	399
1979	8,118	1,702	2,880	1,603	7,178	79	8,328	11,562	606
1980	5,709	1,252	2,136	1,807	7,845	1,186	11,560	9,135	684
1981	1,228	395	1,839	1,561	6,192	0	9,113	4,334	488
1982	6,246	1,164	1,898	1,141	5,336	0	4,342	6,521	652
1983	5,951	1,577	2,557	1,505	5,952	0	6,513	8,446	695
1984	5,185	1,063	1,863	1,745	6,601	0	8,511	7,689	587
1985	2,434	538	1,753	1,309	5,399	0	7,674	5,203	488
1986	3,241	791	1,775	1,295	5,018	0	5,197	4,293	398
1987	5,171	1,045	1,753	1,503	5,502	0	4,294	4,802	456
1988	7,454	1,418	2,212	1,325	5,623	0	4,789	8,384	541
1989	1,067	464	1,367	1,466	5,826	0	8,376	3,376	606
1990	26	56	952	958	1,440	0	3,368	1,614	390
1991	2,606	962	1,091	742	1,573	0	1,609	3,399	554
Total	167,248	36,503	71,802	52,219	182,752	20,339			
Percent	61	13	26	20	72	8			

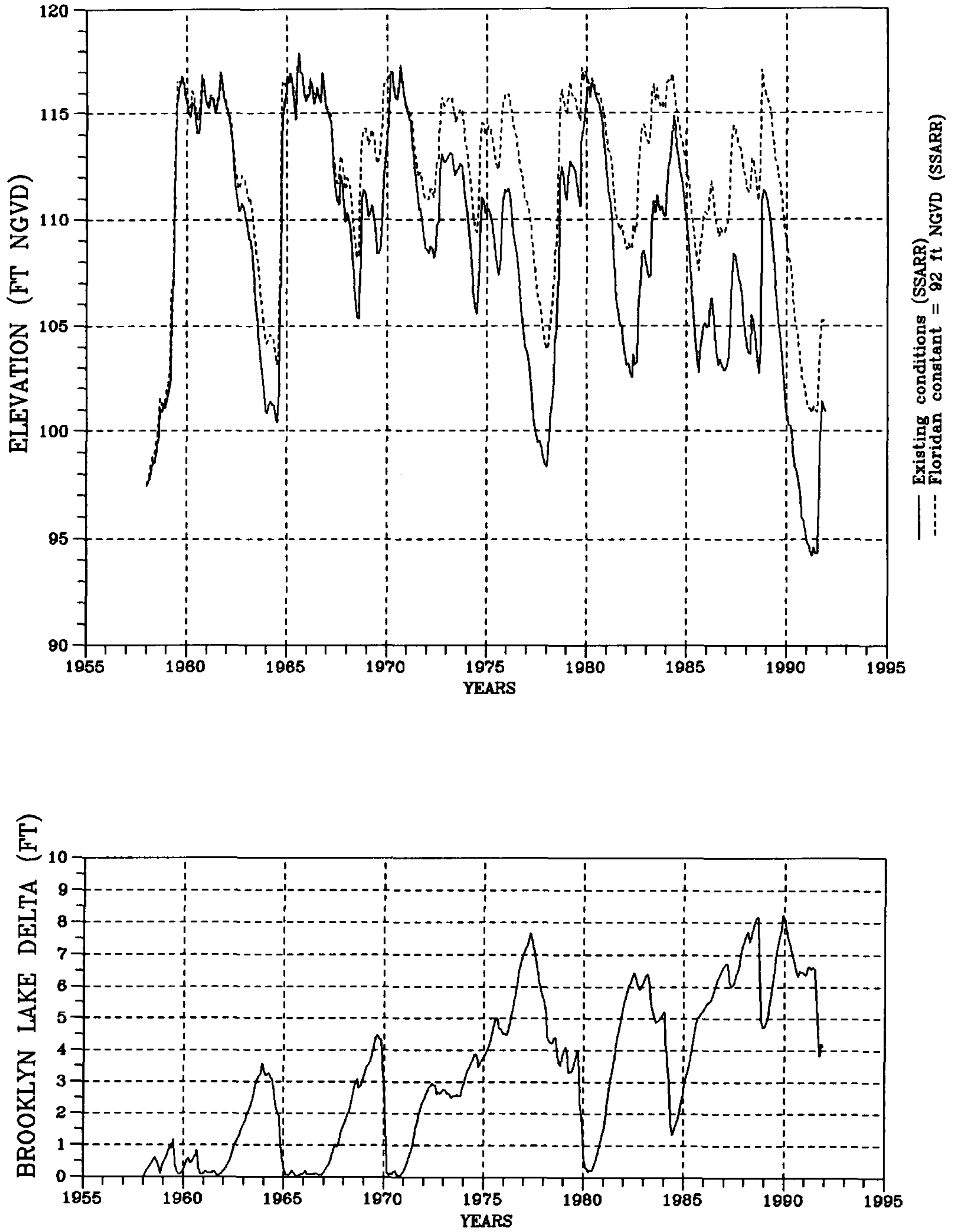


Figure 13. **Effect on Brooklyn Lake of a Constant High Level for the Floridan Aquifer.** *<u>Delta</u> is the difference between the adjusted simulation and the existing-conditions simulation.*

elevations can be attributed to variations in rainfall in the Upper Etonia Creek chain of lakes.

A comparison of the existing-conditions simulation (potentiometric surface levels of the Floridan aquifer fluctuate) and the constant potentiometric surface level simulation indicates that differences in Brooklyn Lake levels reach a maximum of 8.2 ft in 1991 (Figure 13). The average difference of the lake levels over the entire period of simulation is 3.2 ft. These figures are reasonably similar to those obtained by Motz and Heaney (1992)—a maximum difference of 6.7 ft and an average difference of 2.1 ft.

EFFECTS ON BROOKLYN LAKE OF LOCAL CHANGES TO THE SYSTEM

The existing-conditions simulation for Brooklyn Lake and the Upper Etonia Creek chain of lakes is the result of calibration and verification of SSARR (pages 16 through 24). The following simulations were performed using the hydrologic model and the results were compared to the existing-conditions simulation to determine their effect on elevations in Brooklyn Lake.

- Loss of 260 acres of drainage area north of Blue Pond, cut off by the DuPont berm (Figure 2)
- Blockage of flow through the creeks connecting Blue Pond, Sand Hill Lake, Magnolia Lake, and Brooklyn Lake caused by siltation and vegetation
- Blockage of outflow from lakes upstream of Brooklyn Lake caused by increased elevations of the lake outlets

Three problems were not simulated (because they are beyond the scope and/or detail of the model), but will be discussed.

- Loss of surficial and intermediate aquifer flow due to the excavation for the DuPont berm (Figure 2)
- Alteration of basin hydrology by culverts that are too small
- Blockage of flow caused by culverts that are too high

LOSS OF DRAINAGE AREA

The culvert that would normally discharge water from the DuPont bermed area toward Blue Pond (Figure 2) was recently discovered crushed (it has since been replaced). In calibrating and verifying the Upper Etonia SSARR model, it was assumed that this culvert did not discharge during the period of study.

Restoring this drainage area was simulated by increasing the drainage area contributing to Blue Pond from 1.7 to 2.1 mi^2. It was assumed that this culvert discharged all the water that historically flowed south to Blue Pond and that the western culvert discharged water that historically flowed west and east towards the existing berm (Figure 14).

Simulating regaining 260 acres of drainage area shows little effect on Brooklyn Lake (Figure 15). The maximum effect of increasing the drainage area would be to increase water levels by nearly 0.9 ft. This effect does not accumulate indefinitely because of higher losses to the Floridan aquifer (Figure 6) (due to an increased difference between lake elevations and the level of the potentiometric surface of the Floridan aquifer) and higher Brooklyn Lake outflows.

BLOCKAGE OF FLOW THROUGH THE CREEKS BETWEEN THE LAKES

The effect on Brooklyn Lake of cleaning out the creeks connecting the lakes in the chain was simulated by increasing the efficiency of flow out of each upstream lake by 50 percent. The intent here is not to judge what "historical" conditions might have been, but simply to show how effective cleaning out the creeks would be in increasing levels in Brooklyn Lake.

From 1975 on, Brooklyn Lake rarely discharged toward Lake Geneva in the existing-conditions simulation. To minimize the effect of any discharge, the model was run for the period from 1975 to 1991. Each creek connecting two lakes was considered to be cleaned out at the beginning of 1975. The effect on the level of Brooklyn Lake of this increased outlet efficiency in the upstream lakes is very small, and sometimes negative as well as positive (Figure 16). The maximum positive effect would be about 0.6 ft; the maximum negative effect would be about 0.2 ft. Furthermore, there is no evidence from the surveys (Appendix) that channel-bottom irregularities have significantly altered the hydraulic characteristics of the system during the study period. The

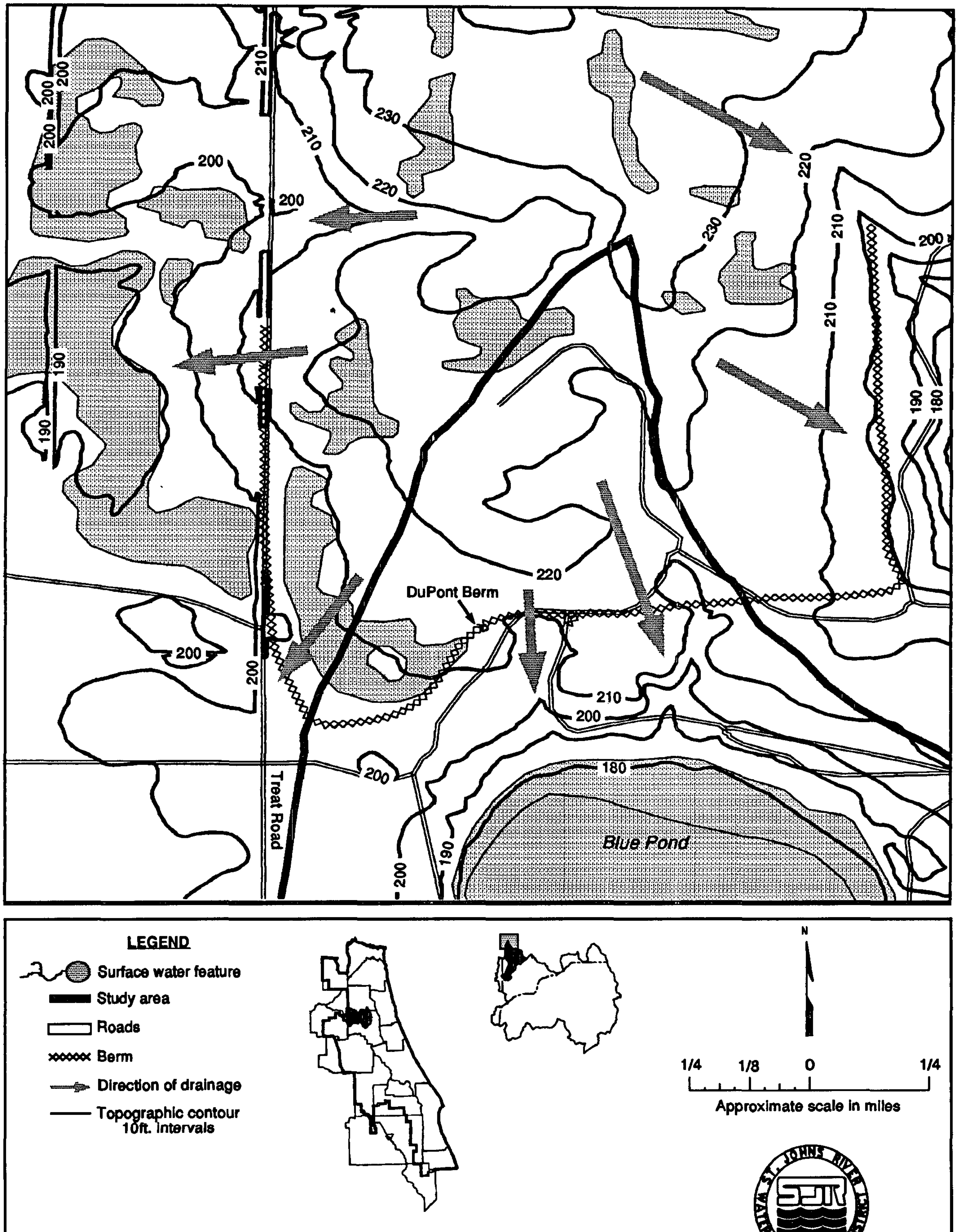


Figure 14. Historic Drainage Patterns North of Blue Pond, in the DuPont Mining Area. *Contours developed in 1949 appear.*

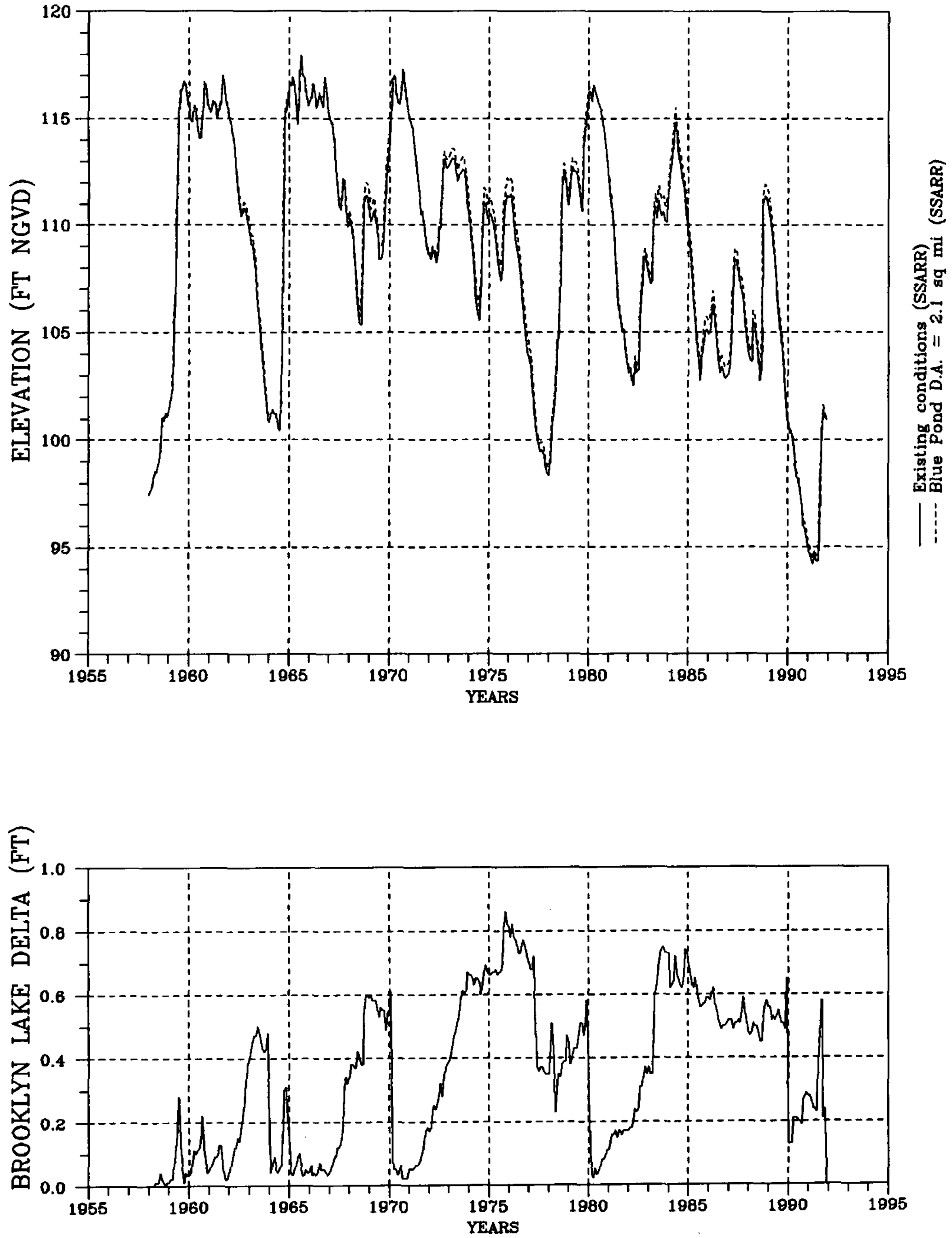


Figure 15. **Effect on Brooklyn Lake From a Loss of 260 Acres of Blue Pond Drainage Area.** ***Delta** is the difference between the adjusted simulation and the existing-conditions simulation. The difference is at most 0.9 ft.*

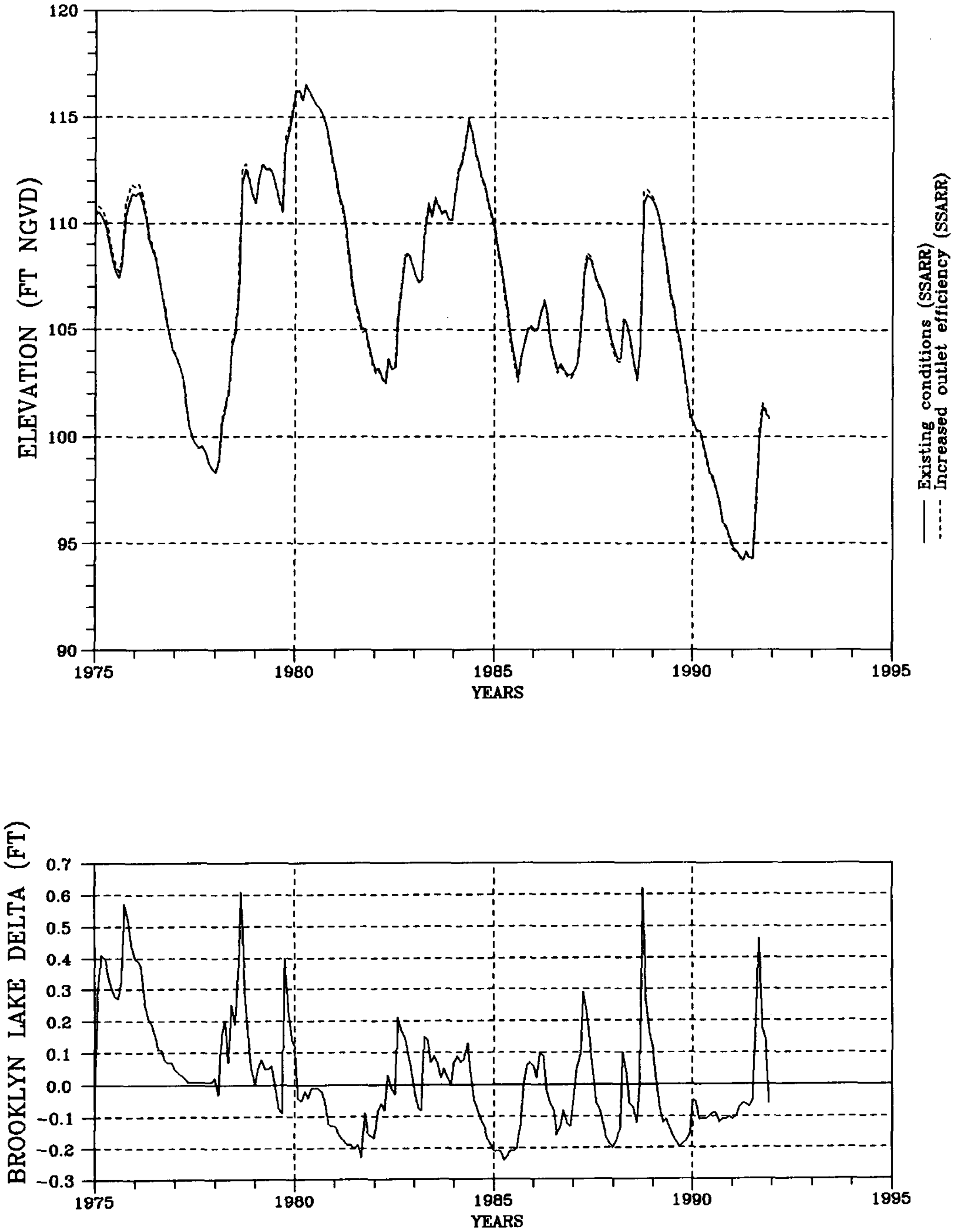


Figure 16. **Effect on Brooklyn Lake of Cleaning Out Connector Creeks.** *Delta is the difference between the adjusted simulation and existing-conditions levels. The effect of cleaning out connector creeks is sometimes to lower lake levels and sometimes to raise them.*

irregularities in channel bottom are apparently just the natural irregularities present in any natural stream.

BLOCKAGE OF OUTFLOW FROM LAKES UPSTREAM OF BROOKLYN LAKE

The effect on Brooklyn Lake of lowering minimum outflow elevations of Blue Pond, Sand Hill Lake, and Magnolia Lake was simulated by assuming that the outflow elevations on all three lakes were lowered by 2 ft. This simply took the form of shifting the outlet rating curves (Figure 5) downward by 2 ft. To minimize the effect of any discharge, the model was run for the period from 1975 to 1991. The intent here was not to judge what "historical" conditions might have been, but simply to show how effective lowering outlet elevations of upstream lakes would be in increasing levels in Brooklyn Lake.

The adjusted simulation showed an immediate increase of nearly 5 ft as the "slug" of water stored between the existing-conditions outlet elevations and the adjusted outlet elevations flowed through the system to Brooklyn Lake (Figure 17). This increase eventually disappeared because of increased losses to the Floridan aquifer, due to an increased difference between lake elevations and the level of the potentiometric surface of the Floridan aquifer (Figure 6). The increased lake level did not reappear because the system established a new equilibrium, and no "new" water was being created or entered the system. Essentially, the elevations of upstream lakes would fluctuate within the same range but the minimum and maximum points would be 2 ft lower.

LOSS OF GROUND WATER FLOW

One factor some area residents believe to be an important cause of low water levels in Brooklyn Lake is the loss of surficial and intermediate aquifer ground water flow caused by the excavation for the Dupont berm (Figure 2). SSARR accounts for local ground water flow, which is flow from the drainage area that seeps into

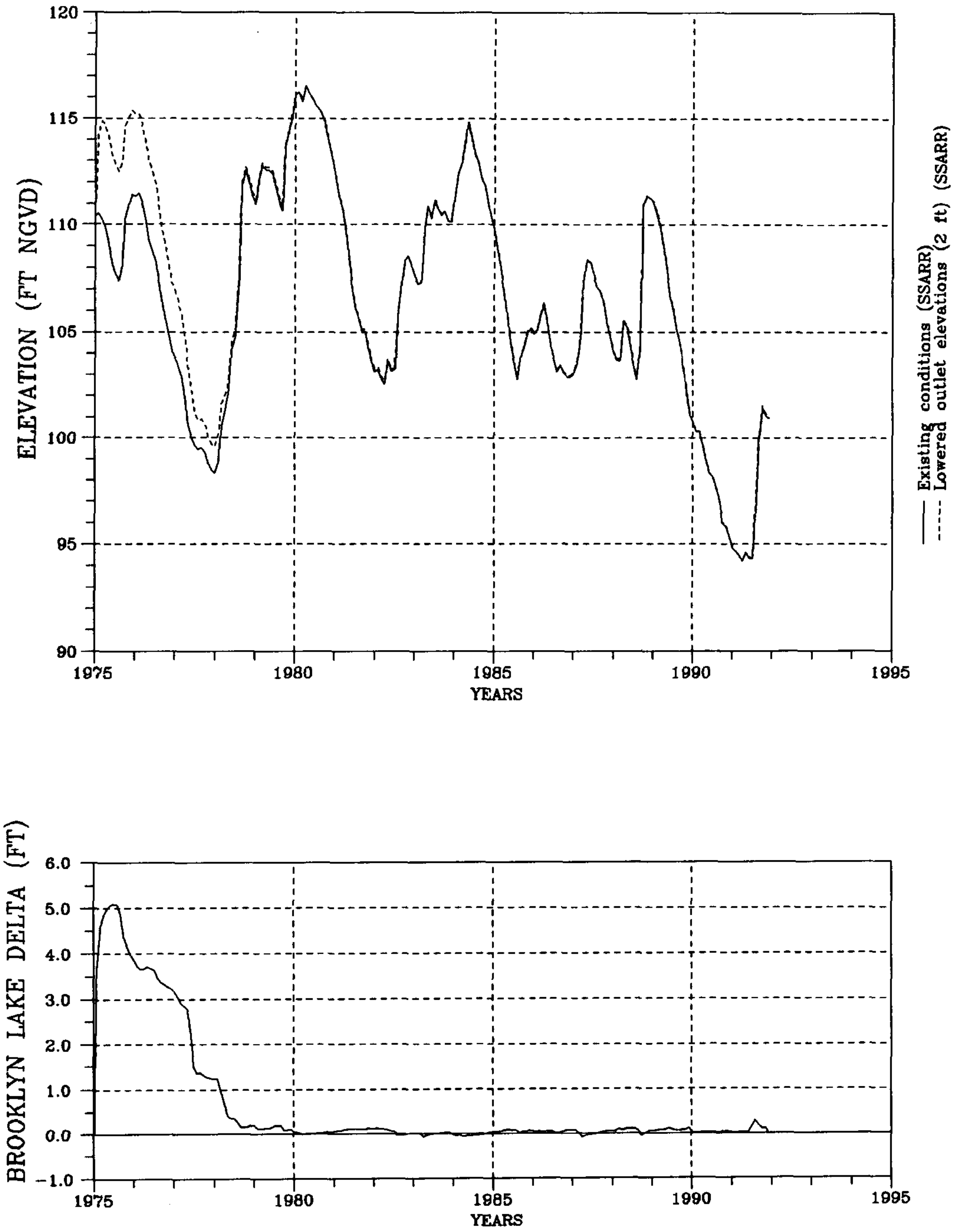


Figure 17. **Effect on Brooklyn Lake of Lowering Outlet Elevations on Blue Pond, Sand Hill Lake, and Magnolia Lake.** *Delta is the difference between the adjusted simulation and the existing-conditions simulation.*

the ground to discharge as ground water. SSARR does not simulate surficial or intermediate aquifer ground water flow, so modeling assumptions were necessary (page 15).

However, excavation of the material for the berm would not interrupt the flow of surficial ground water. If anything, the ponding of water behind the berm would tend to increase flows through the surficial aquifer. Because the berm did not penetrate the intermediate aquifer (personal communication, Doug Munch, Ground Water Programs, SJRWMD) flow through the intermediate aquifer would not be significantly affected.

CULVERTS THAT ARE TOO SMALL

One factor some area residents believe to be an important cause of low water levels in Brooklyn Lake is the small size of the new Treat Road culvert (built in 1986) (Figure 2). As shown in the simulation of increased outlet efficiency (page 35), the problem on Brooklyn Lake is one of volume of flow rather than timing of flow. Increasing the size of the Treat Road culvert will do nothing to solve the long-term problem of low water.

CULVERTS THAT ARE TOO HIGH

Another factor some area residents believe to be an important cause of low water levels in Brooklyn Lake is that the new Treat Road culvert was installed too high, blocking flow toward Brooklyn Lake. The old culverts had been buried, probably by sand coming from a pit adjacent to the creek. The new culvert was installed without clearing the channel and without removing the old culverts.

According to surveys of the channel between Magnolia and Brooklyn lakes (Appendix, sheet 8 of 12), the invert elevation of the new culvert is 123.1 ft NGVD. The outlet elevation has historically been at about 123.5 ft NGVD (Yobbi and Chappell 1975), so this culvert elevation is not a hydraulic control for water moving out of Magnolia Lake. Furthermore, comparison of observed and calculated elevation-duration curves does not show the shift in the curve that would indicate a substantial change in the outlet elevation of Magnolia Lake over the 34-year period simulated (1958–1991) (Figure 11).

Surveys of the Upper Etonia Creek chain of lakes show no significant blockage at any of the other culverts (Appendix). The model confirms this, as no significant differences were indicated between elevation-duration curves of observed and calculated lake elevations (Figure 11).

CONCLUSIONS

The surface water hydrology of the Upper Etonia Creek chain of lakes was successfully simulated with the SSARR model. Results, in the form of lake elevation-duration curves (Figure 11) for simulations of Sand Hill, Magnolia, and Brooklyn lakes, are close to those obtained using observed data. An elevation-frequency curve for calculated mean annual elevation on Brooklyn Lake compares favorably with the curve developed from observed data (Figure 12). The agreement between curves for observed and calculated values indicates that no major hydrologic changes have occurred in the Upper Etonia Creek chain of lakes over the period of study (1958–1991).

The simulation of the Upper Etonia Creek chain of lakes involved a number of assumptions to cover various hydrologic aspects beyond the scope of this study (page 15). The simulation results (Figures 11 and 12) indicate that the assumptions were justifiable.

The successful simulation of the Upper Etonia Creek chain of lakes indicates that most of the variation in the level of Brooklyn Lake can be explained by rainfall and losses to the Floridan aquifer. The declining water levels on Brooklyn Lake since 1975 (Motz and Heaney 1991 and 1992)—and especially the extremely low levels since 1989—can be explained by below average amounts of rainfall and increased losses to the Floridan aquifer because of lower potentiometric surface levels.

Regaining 260 acres of drainage area to the north of Blue Pond would increase the level of Brooklyn Lake by a maximum of 0.9 ft. Excavation for the DuPont berm would not interrupt surficial or intermediate aquifer ground water flow toward Blue Pond and Brooklyn Lake (page 39).

Modeling results (Figure 11) indicate that the outlet elevations of Magnolia and Sand Hill lakes have not changed significantly since 1958; this is supported by field surveys (Appendix). Modeling results and field surveys also indicate that the size and invert elevation of culverts between the lakes do not significantly impact the hydrologic regime of flows into Brooklyn Lake.

Finally, the study shows that altering the outlets of Magnolia Lake, Sand Hill Lake, and Blue Pond will not result in major changes in Brooklyn Lake levels. Any effect on Brooklyn Lake from lowered outlets would be minor and short lived, while entailing periodic maintenance expenses.

REFERENCES

Brater, E.F. and H.W. King. 1976. *Handbook of hydraulics*, 6th ed. New York, N.Y.: McGraw-Hill.

Chow, V.T. 1959. *Open-channel hydraulics*. New York, N.Y.: McGraw-Hill.

COE. 1986. *Streamflow synthesis and reservoir regulation, user manual*. Portland, Oreg.: U.S. Army Corps of Engineers, North Pacific Division.

Clark, W.E., R.H. Musgrove, C.G. Menke, and J.W. Cagle, Jr. 1963. *Hydrology of Brooklyn Lake near Keystone Heights, Florida.* Report of Investigations No. 33. Tallahassee, Fla.: U.S. Geological Survey.

________. 1964. *Water resources of Alachua, Bradford, Clay, and Union counties, Florida*. Report of Investigations No. 35. Tallahassee, Fla.: U.S. Geological Survey.

Henderson, F.M. 1966. *Open channel flow*. New York, N.Y.: MacMillan.

Linsley, R.K., M.A. Kohler, and J.L.H. Paulhus. 1975. *Hydrology for engineers*. 2d ed. New York, N.Y.: McGraw-Hill.

Motz, L.H. and J.P. Heaney. 1991. *Upper Etonia Creek hydrologic study: Phase I: Final report*. Special Publication SJ91-SP5. Palatka, Fla.: St. Johns River Water Management District.

________. 1992. *Upper Etonia Creek hydrologic study: Phase II: Final report*. Special Publication SJ92-SP18. Palatka, Fla.: St. Johns River Water Management District.

Ponce, V.M. 1989. *Engineering hydrology*. Englewood Cliffs, N.J.: Prentice Hall.

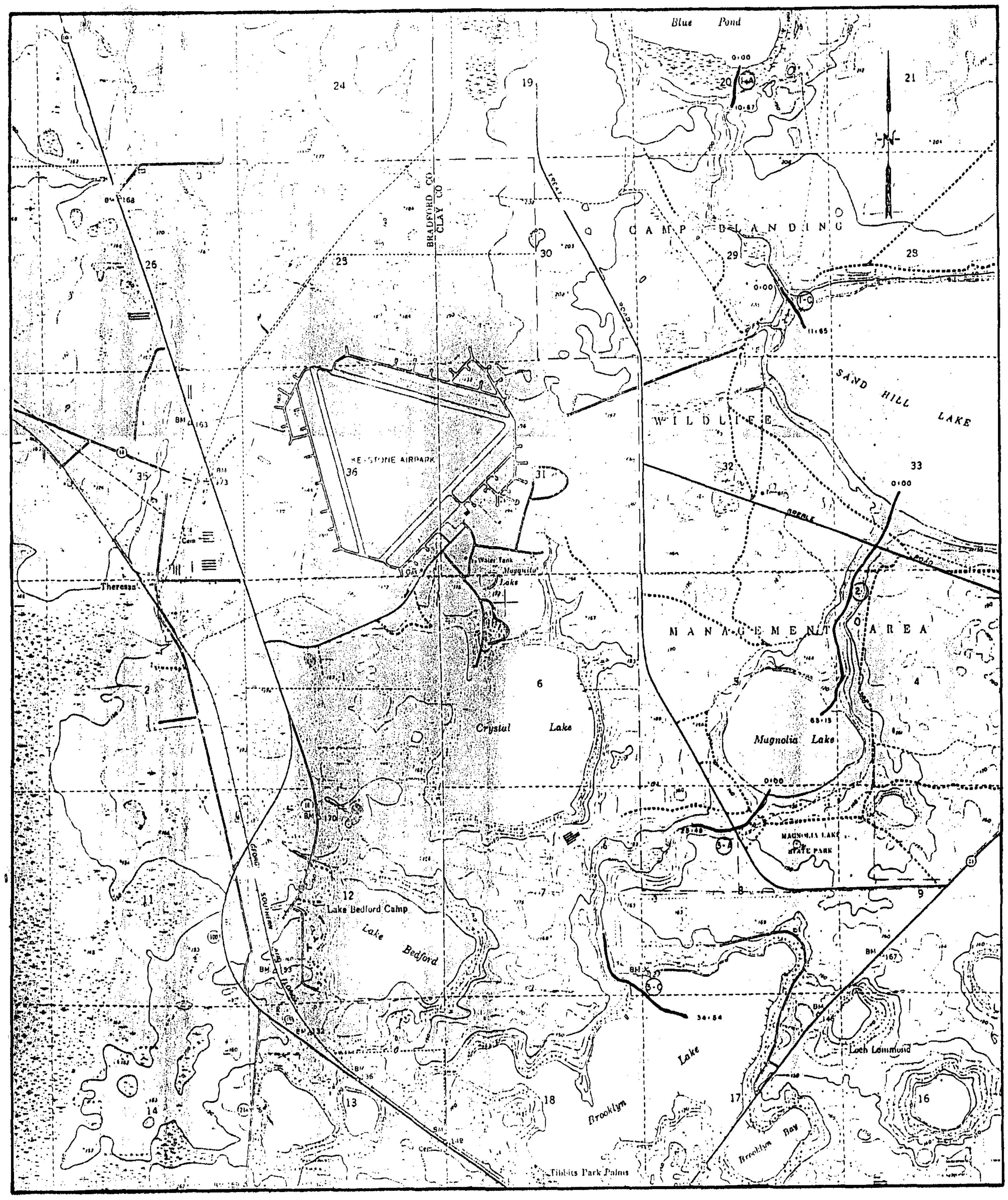
Yobbi, D.K. and G.C. Chappell. 1979. *Summary of the hydrology of the Upper Etonia Creek Basin*. Technical Publication SJ79-5. Palatka, Fla.: St. Johns River Water Management District.

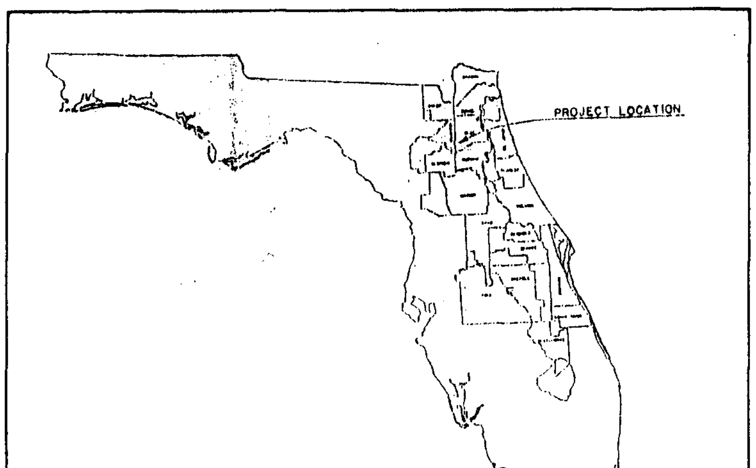
56

APPENDIX: SURVEY RESULTS

This appendix contains results of a field survey conducted by SJRWMD personnel (Sheets 1 through 12). This survey was conducted between 19 March and 29 March 1990.

CREEK BED PROFILES
UPPER ETONIA CREEK BASIN
CAMP BLANDING



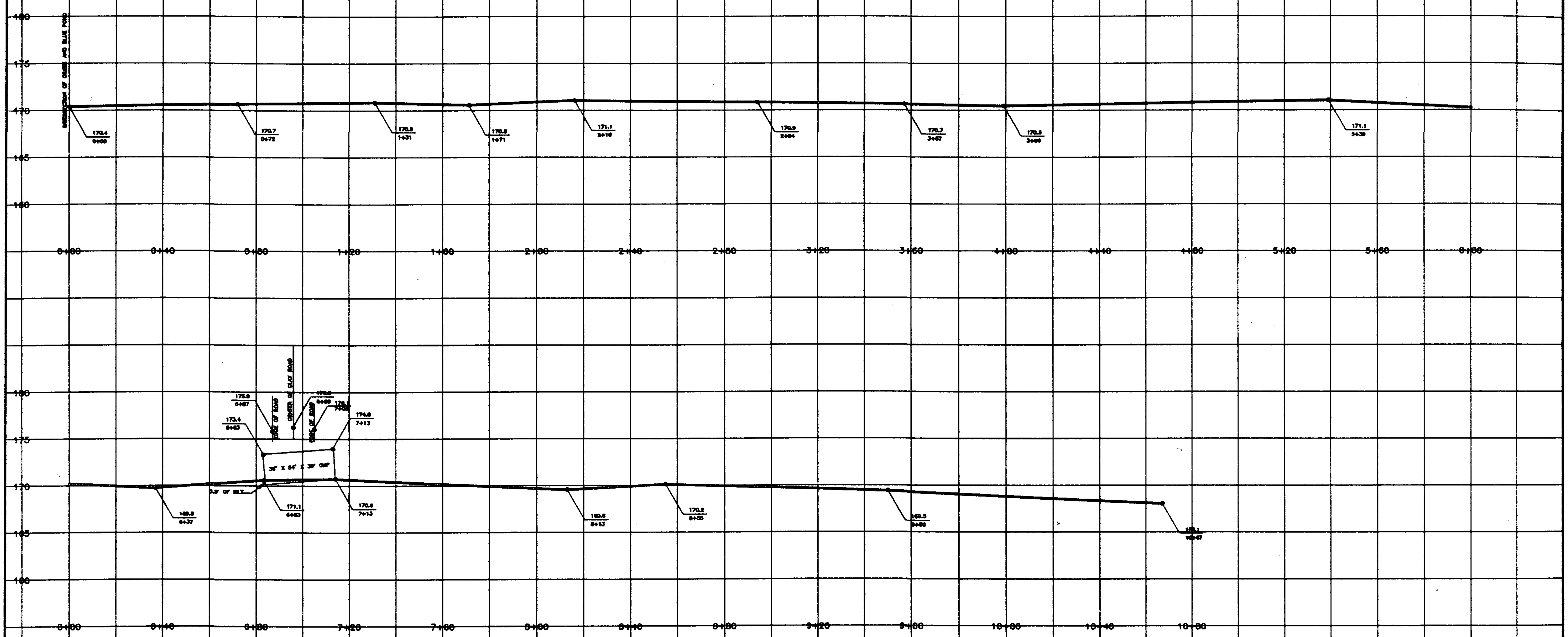


ST. JOHNS RIVER
WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

PROFILE OF CREEK BEDS
CAMP BLANDING AREA

PROJ NO 90-93 & 90-98
SCALE 1" = 2000'
DRAWN S.O.K. 9/90
TRACED
DESIGN CHECKED W.O. 5-161-90
SURVEY CHECKED
SIZE D
DRAWING NUMBER
SHEET NO 1 of 12

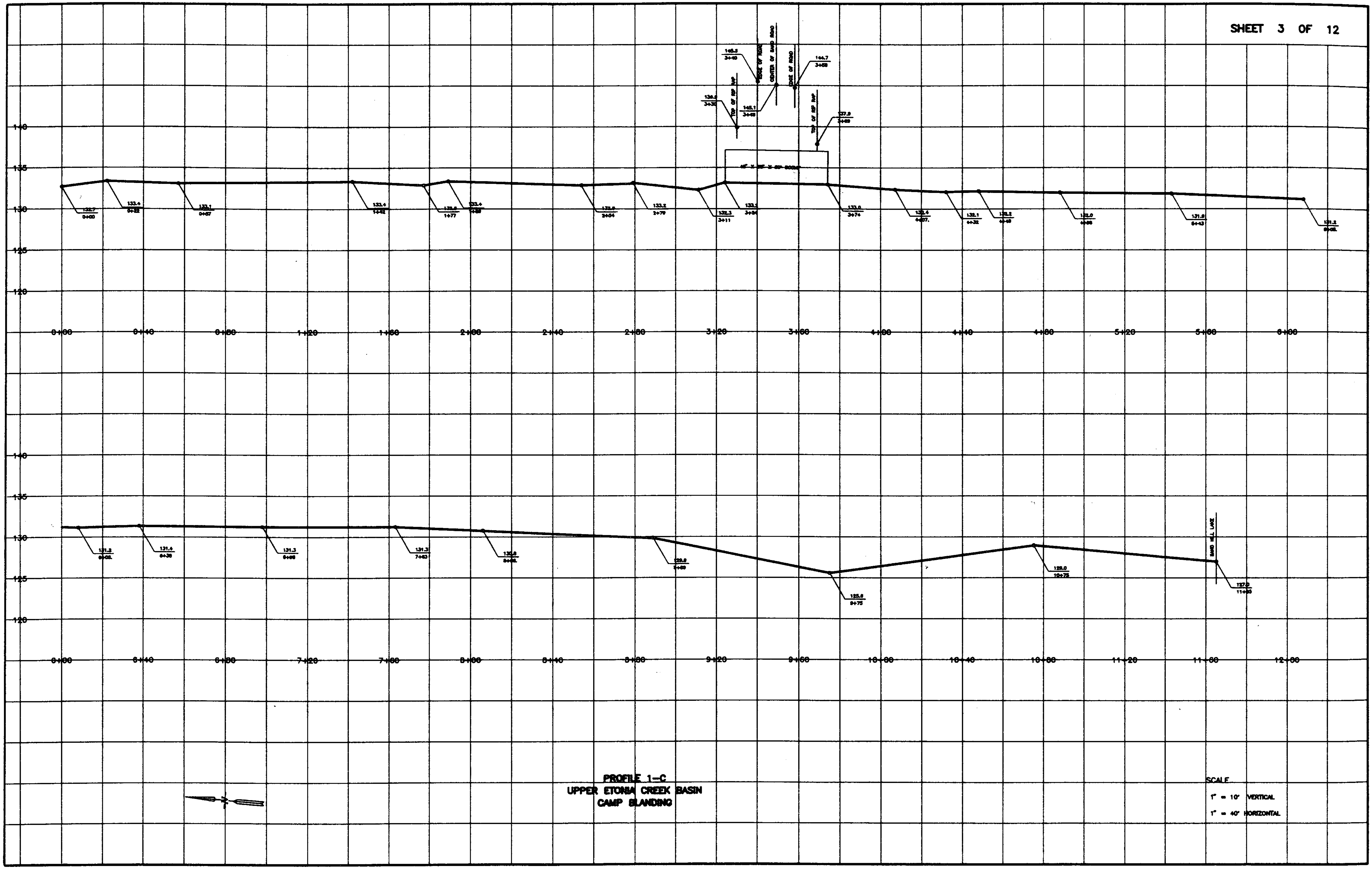
SHEET 2 OF 12



PROFILE 1-A
UPPER ETONIA CREEK BASIN
CAMP BLANDING

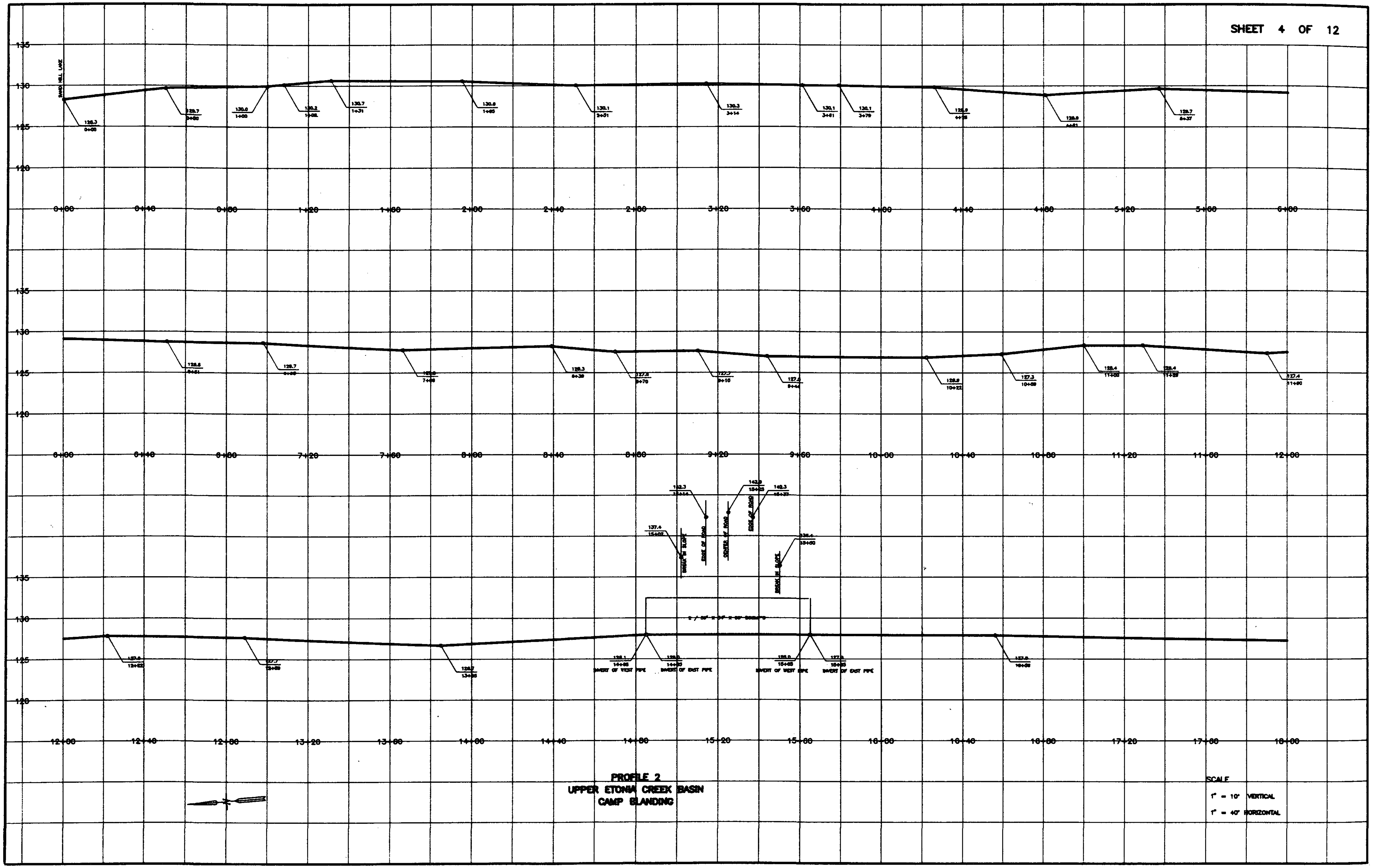
SCALE
1" = 10' VERTICAL
1" = 40' HORIZONTAL

SHEET 3 OF 12



PROFILE 1-C
UPPER ETONIA CREEK BASIN
CAMP BLANDING

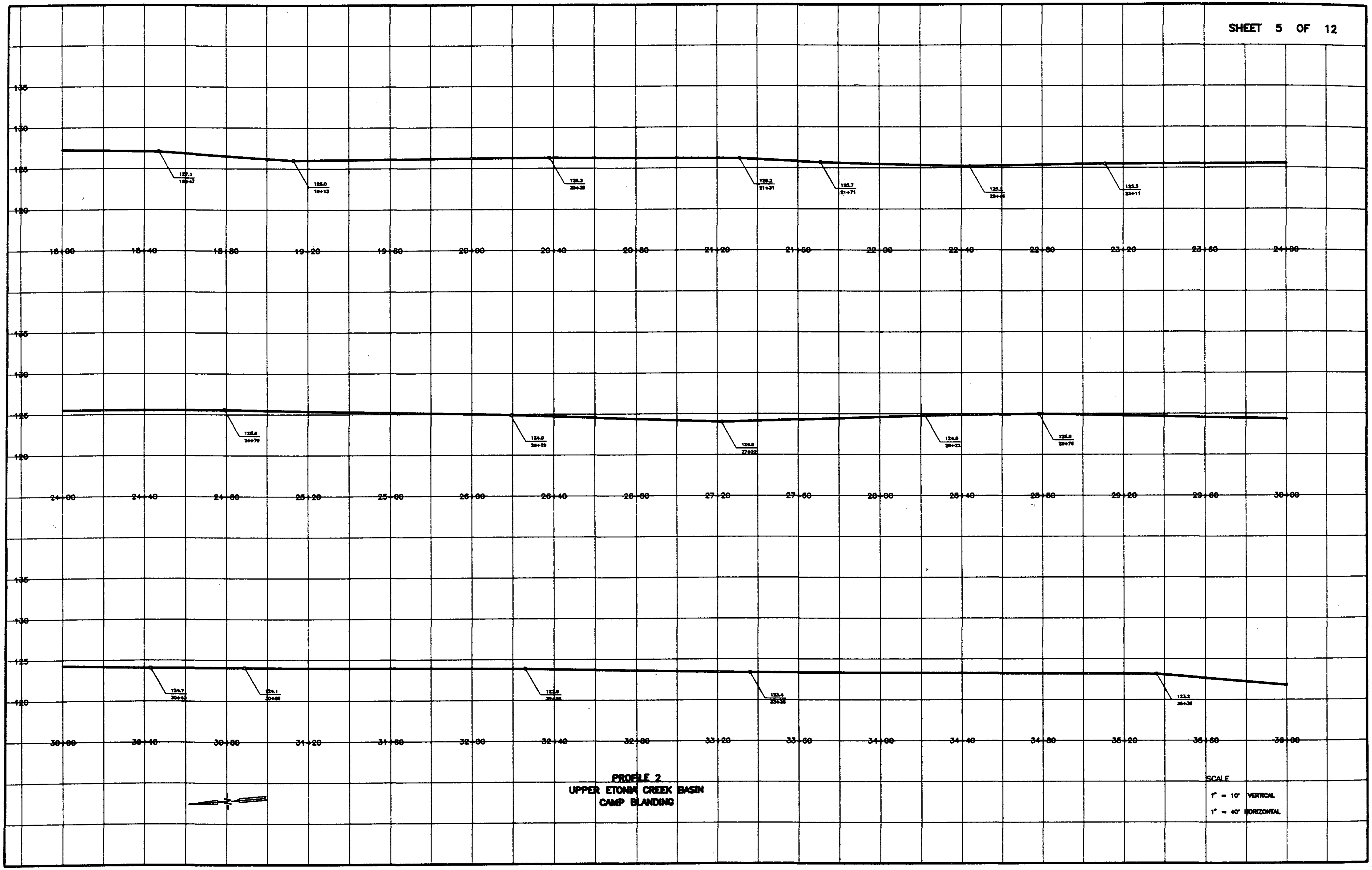
SCALE
1" = 10' VERTICAL
1" = 40' HORIZONTAL



PROFILE 2
UPPER ETONIA CREEK BASIN
CAMP BLANDING

SCALE
1" = 10' VERTICAL
1" = 40' HORIZONTAL

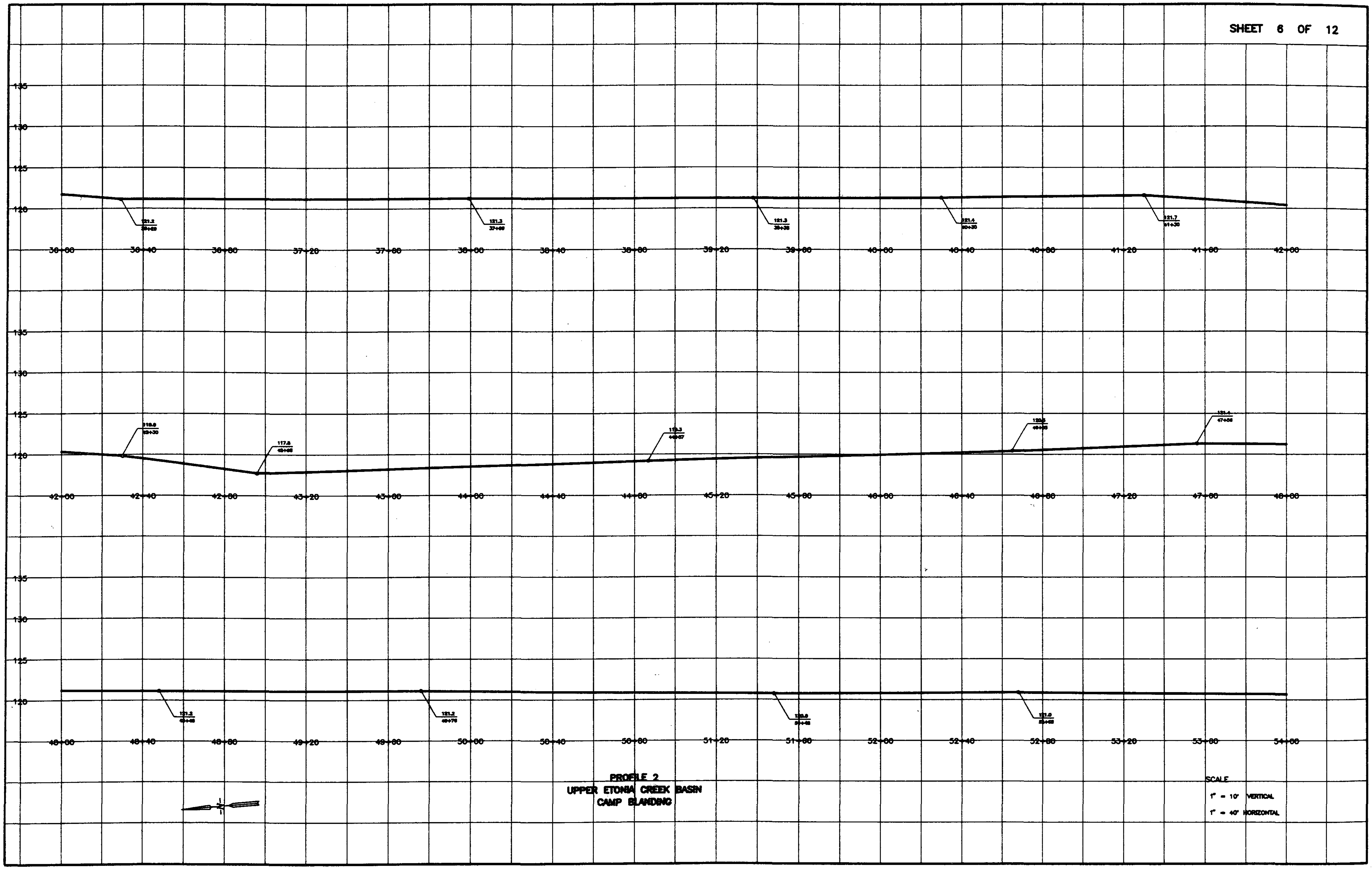
SHEET 5 OF 12



PROFILE 2
UPPER ETONIA CREEK BASIN
CAMP BLANDING

SCALE
1" = 10' VERTICAL
1" = 40' HORIZONTAL

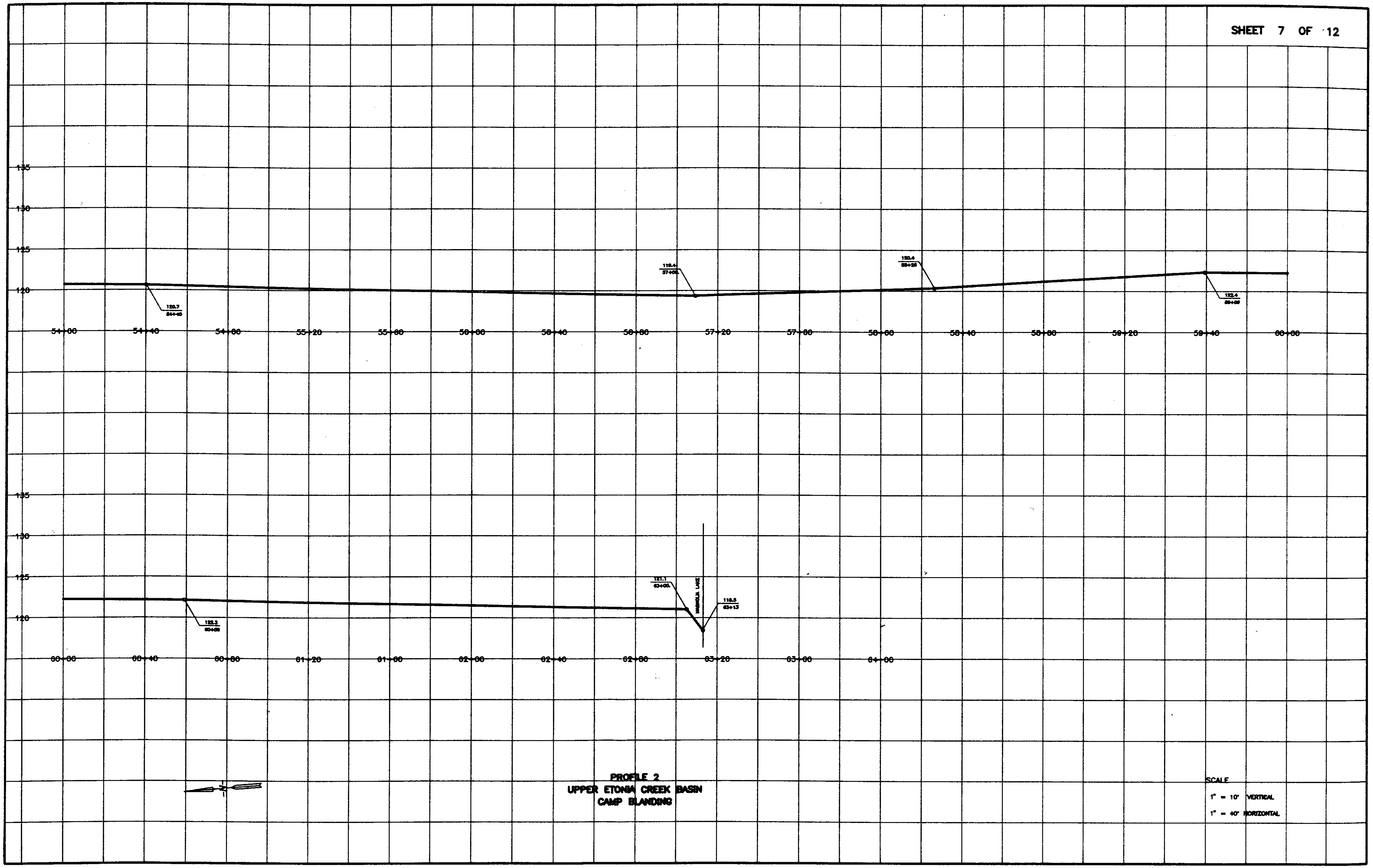
SHEET 6 OF 12



PROFILE 2
UPPER ETONIA CREEK BASIN
CAMP BLANDING

SCALE
1" = 10' VERTICAL
1" = 40' HORIZONTAL

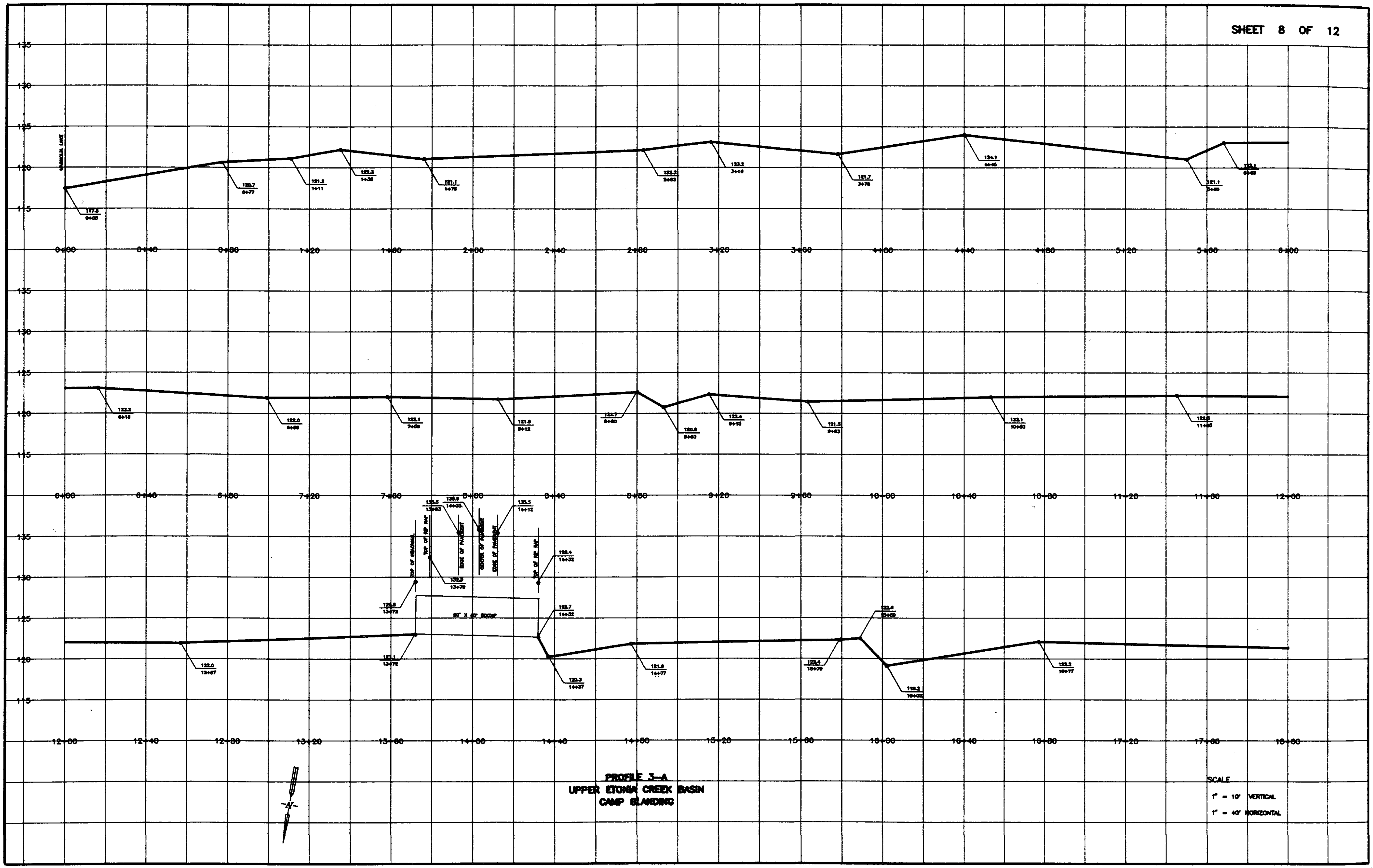
SHEET 7 OF 12



PROFILE 2
UPPER ETONIA CREEK BASIN
CAMP BLANDING

SCALE
1" = 10' VERTICAL
1" = 40' HORIZONTAL

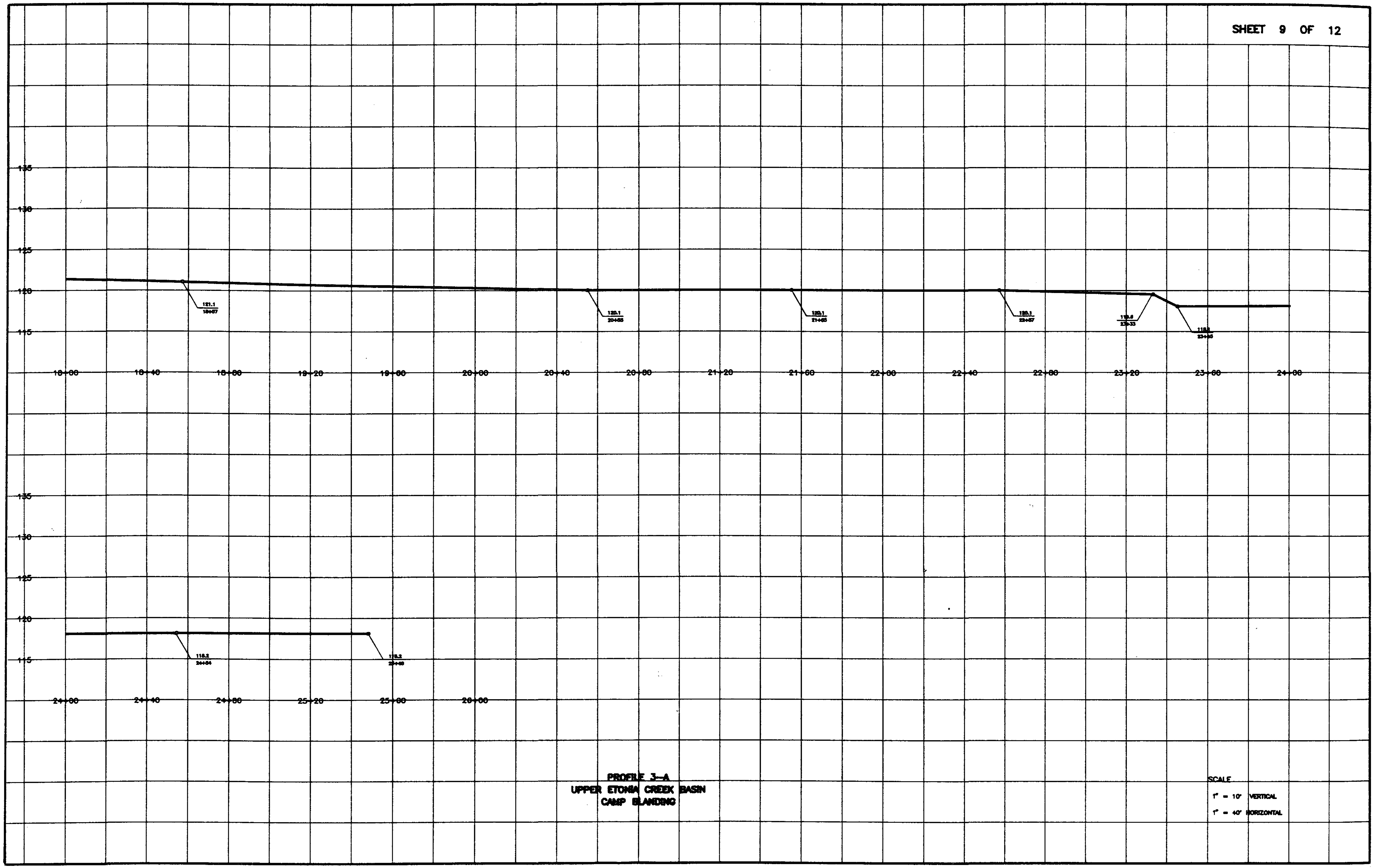
SHEET 8 OF 12



PROFILE 3–A
UPPER ETONIA CREEK BASIN
CAMP BLANDING

SCALE
1" = 10' VERTICAL
1" = 40' HORIZONTAL

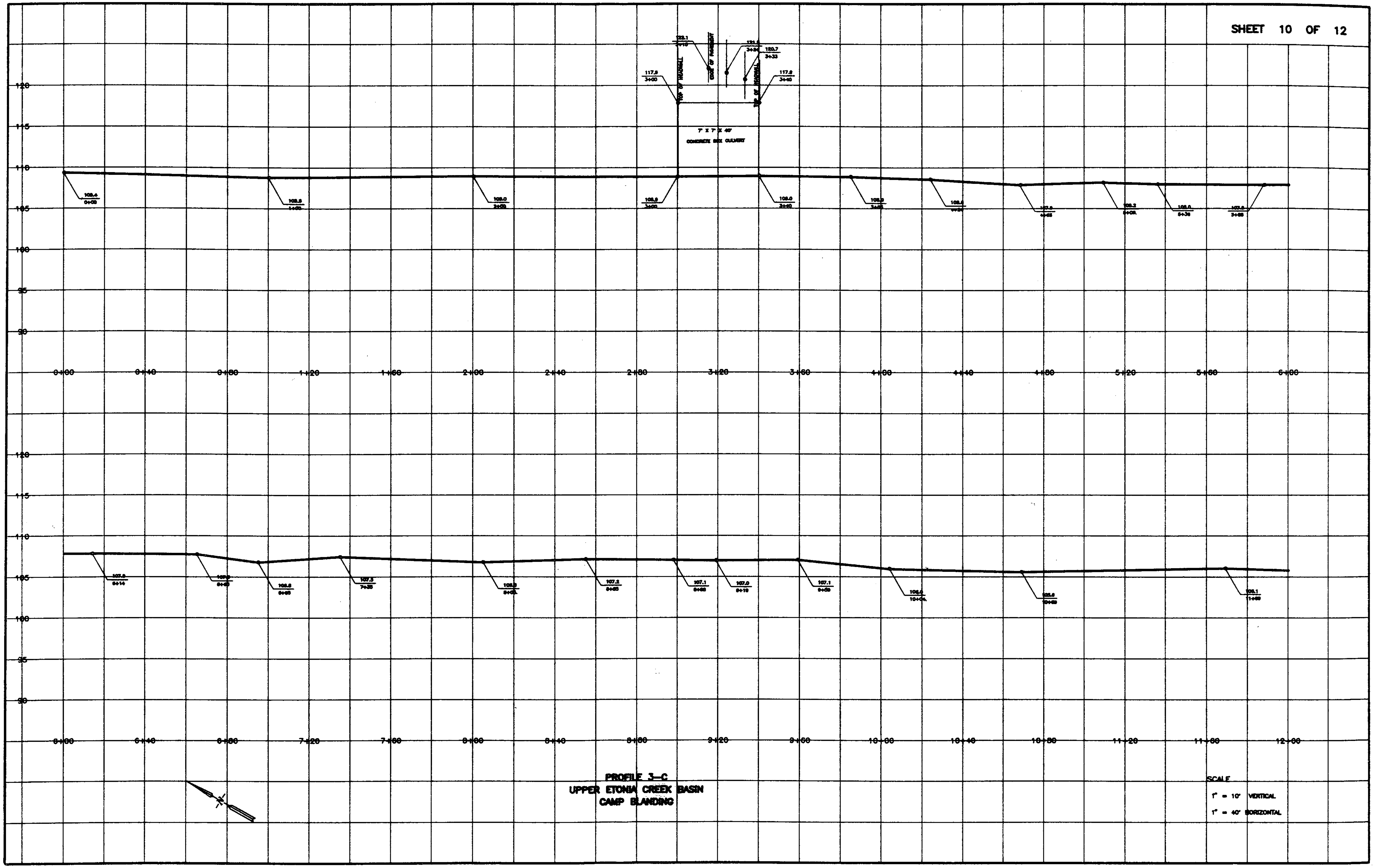
SHEET 9 OF 12



PROFILE 3-A
UPPER ETONIA CREEK BASIN
CAMP BLANDING

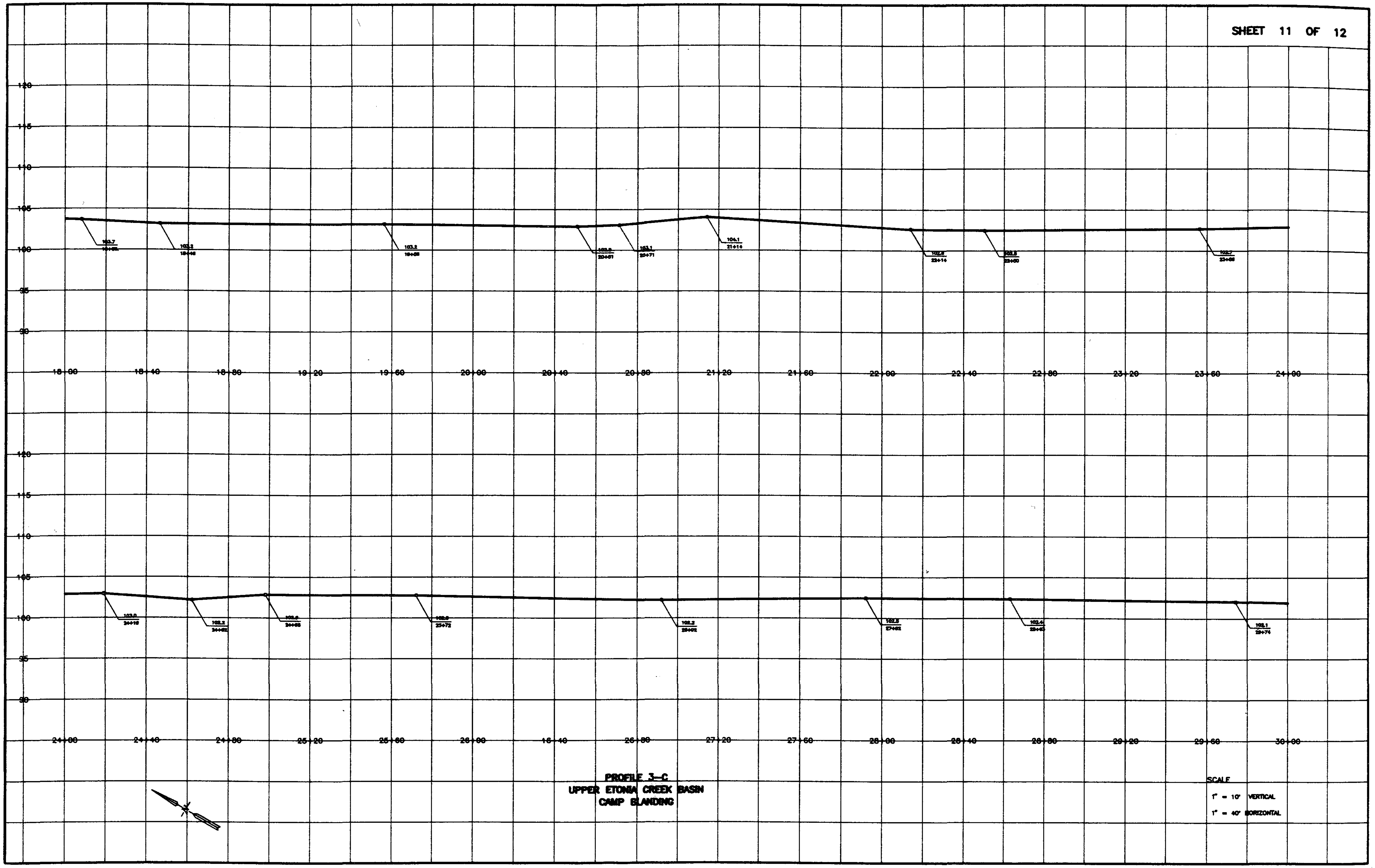
SCALE
1" = 10' VERTICAL
1" = 40' HORIZONTAL

SHEET 10 OF 12



PROFILE 3–C
UPPER ETONIA CREEK BASIN
CAMP BLANDING

SCALE
1" = 10' VERTICAL
1" = 40' HORIZONTAL

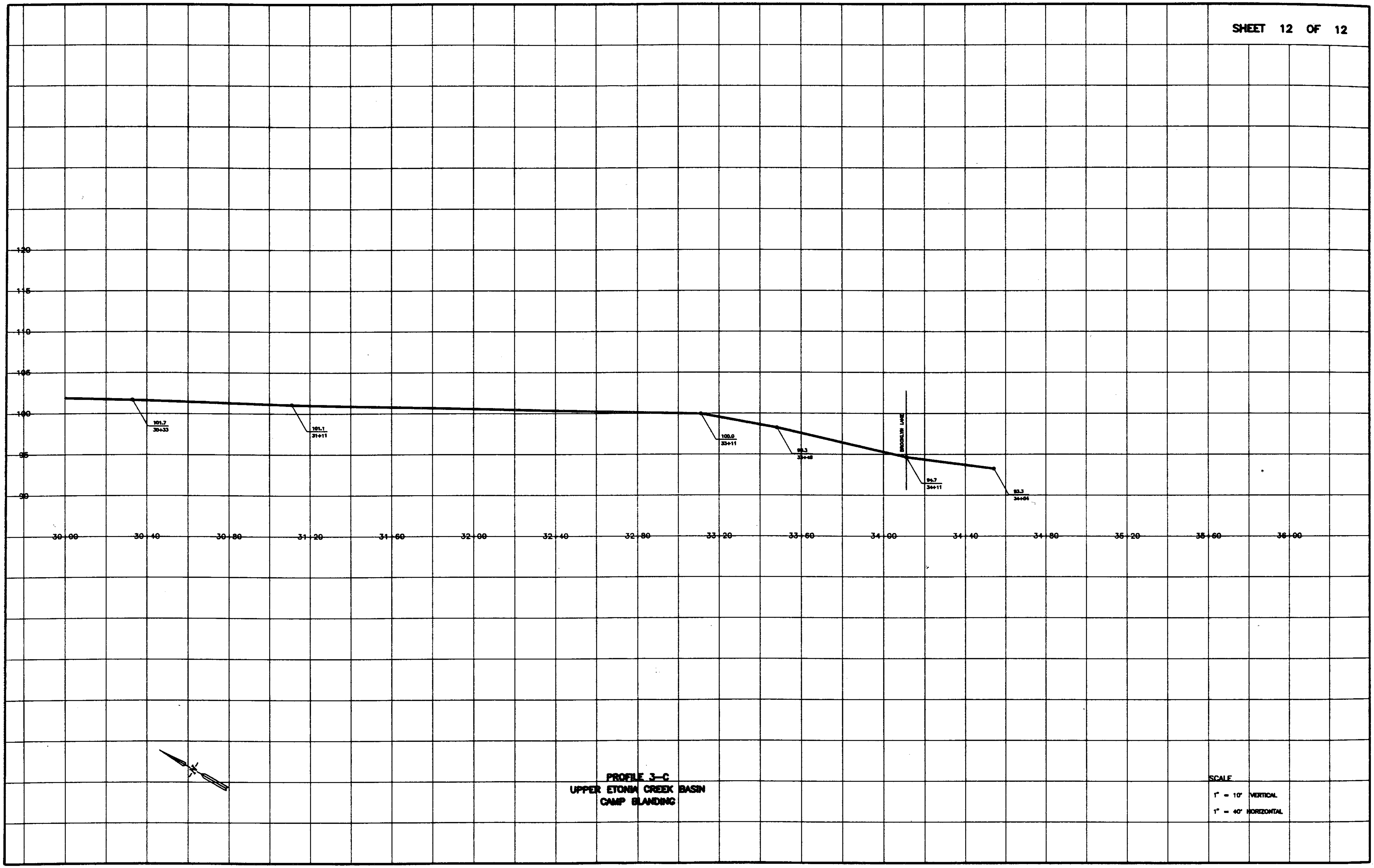


SHEET 11 OF 12

PROFILE 3-C
UPPER ETONIA CREEK BASIN
CAMP BLANDING

SCALE
1" = 10' VERTICAL
1" = 40' HORIZONTAL

SHEET 12 OF 12



PROFILE 3–C
UPPER ETONIA CREEK BASIN
CAMP BLANDING

SCALE
1" = 10' VERTICAL
1" = 40' HORIZONTAL