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Hydrologic and Engineering Study for Extreme Drawdown of Lake Griffin: Part 1

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ABSTRACT

Extreme lake drawdown is a resource management technique which has received considerable attention and study during the past ten years. The purpose of an extreme drawdown is to artificially create a drought condition in a controlled lake system. The objective is to produce the benefits to a lake ecosystem which, under natural conditions occur as a result of periodic droughts and normal annual water level fluctuations. Controlled lake water levels characteristically have less frequent and less extreme low water levels than do natural lake systems.

Benefits which a controlled lake may receive due to extreme drawdown include water quality and improved habitat for some plant and animal species. The goal of the Lake Griffin drawdown is improvement of sport fish populations. This is expected to be achieved by drying and consolidation of exposed organic sediments in the lake such that they would support rooted aquatic plant species which are conducive to spawning sport fish. Rooted aquatic plants provide critical spawning and nursery habitats for sport and forage fish species.

This study used available streamflow and lake stage records to evaluate the prospects of a successful drawdown project. As is necessary for virtually all projects dependent on hydrologic conditions during a future period this was accomplished using a statistical and probabilistic approach. The results of this study can only provide estimates of what is likely and/or what is possible. Considerations which required investigation included water levels in Lake Griffin, the impact of an

extreme drawdown on downstream water quality, and on properties surrounding the lake. Because these are all related to the volume of runoff to the lake during the drawdown they can only be estimated based on probability.

The results of the study indicated that there is a wide range of responses which could occur with a reasonable probability if a drawdown were attempted. For instance if a drawdown were implemented in a year similar to 1960 it is not expected that the lake would fall much below normal levels at any time during the scheduled drawdown. If, however, the year turned out to be similar to 1978 the lake would probably drop about eight feet and not refill during the succeeding winter unless substantial withdrawals were made from upstream lakes. Most years, however, would result in a drop of about five feet for three consecutive months.

The impacts on downstream waters and on surrounding property owners are subject to uncertainties, also. Turbidity and nutrient impact to downstream waters are likely to occur but could be controlled to some degree by holding the discharge rate at Moss Bluff low enough to prevent unacceptable levels of entrainment and transport of suspended solids from Lake Griffin and the C-231 channel. Lake front and canal access homeowners could expect to lose normal boating access to the lake for part of the year. Citrus groves near the lake may experience a small, temporary drop of the water table level. If the late summer and fall were dry, however, the lake might not refill to normal levels and the water table would also remain at lower than normal levels.

INTRODUCTION

Background

It is well known that natural fluctuations of lake water levels or stages are an integral part of a lake ecosystem. The periodic inundation and exposure of lake bottom areas provide a unique and productive zone for many living organisms. Our utilization of land and water resources is related to our ability to regulate the flow of water. This regulation, be it for water supply, recreation, navigation or flood control, alters the natural stage fluctuations of lakes and impacts those organisms dependent on the lake littoral areas. Adoption of a lake regulation plan, therefore, becomes one of making trade-offs between competing uses in an effort to select a plan which optimizes the use of the resource.

Lake Griffin, located in Lake County in central Florida, is subject to this problem. The lake has been controlled by an outlet structure since 1925. Trends in fishery data in recent years indicate that the lakes habitat is becoming less favorable for sport fish. In an effort to restore the sport fish habitat the Florida Game and Fresh Water Fish Commission (FGFWFC) has proposed to conduct an extreme drawdown of the lake. The drawdown would simulate a natural drought event in the lake.

Objectives of Study

The purpose of this study is to provide an overall evaluation of the issues relating to the drawdown, with particular emphasis on the engineering feasibility of conducting an extreme drawdown for Lake Griffin and evaluation alternative drawdown plans. Extreme drawdowns have been accomplished on other lakes within Florida with varying degrees of success.

This management technique can temporarily reverse the eutrophication process and mitigate undesirable impacts caused by man's stabilization of lake water levels.

BACKGROUND INFORMATION

History of Oklawaha Chain of Lakes

Lake Griffin is located in Lake County in Central Florida. The approximately 17,000 acres of lake, marsh and river channel is the most downstream portion of what is known as the Oklawaha Chain of Lakes. The chain of lakes constitutes the headwaters of the Oklawaha River as seen on Figure 1. The chain of lakes has long been a prime fishing area as evident from the number of fish camps on the lakes. The river system possesses unusual scenic and ecologic characteristics.

The drainage area to Lake Griffin includes the Palatlakaha River Basin which discharges to Lake Harris which flows into Lake Eustis. Lakes Apopka, Beauclair and Dora also drain to Lake Eustis. Lake Eustis flows into Lake Griffin via Haines Creek. Lake Griffin has a drainage area of approximately 900 square miles.

A chronological listing of several significant developments within the Oklawaha River Basin above Moss Bluff Lock and Dam as given in Table 1, is useful in understanding the system and how it has changed through time.

The Oklawaha Chain of Lakes suffers a problem which is not unique. Mans development, encroachment and utilization of the resource has changed the hydrologic and ecologic systems of many lakes causing what has been called cultural and agricultural eutrophication. Some animal and plant species less well suited to the altered conditions and habitat suffer declining populations while others have prospered. Surface drainage characteristics, even drainage boundaries, have been changed. Many of the impacts are not desirable but have been allowed to occur either through

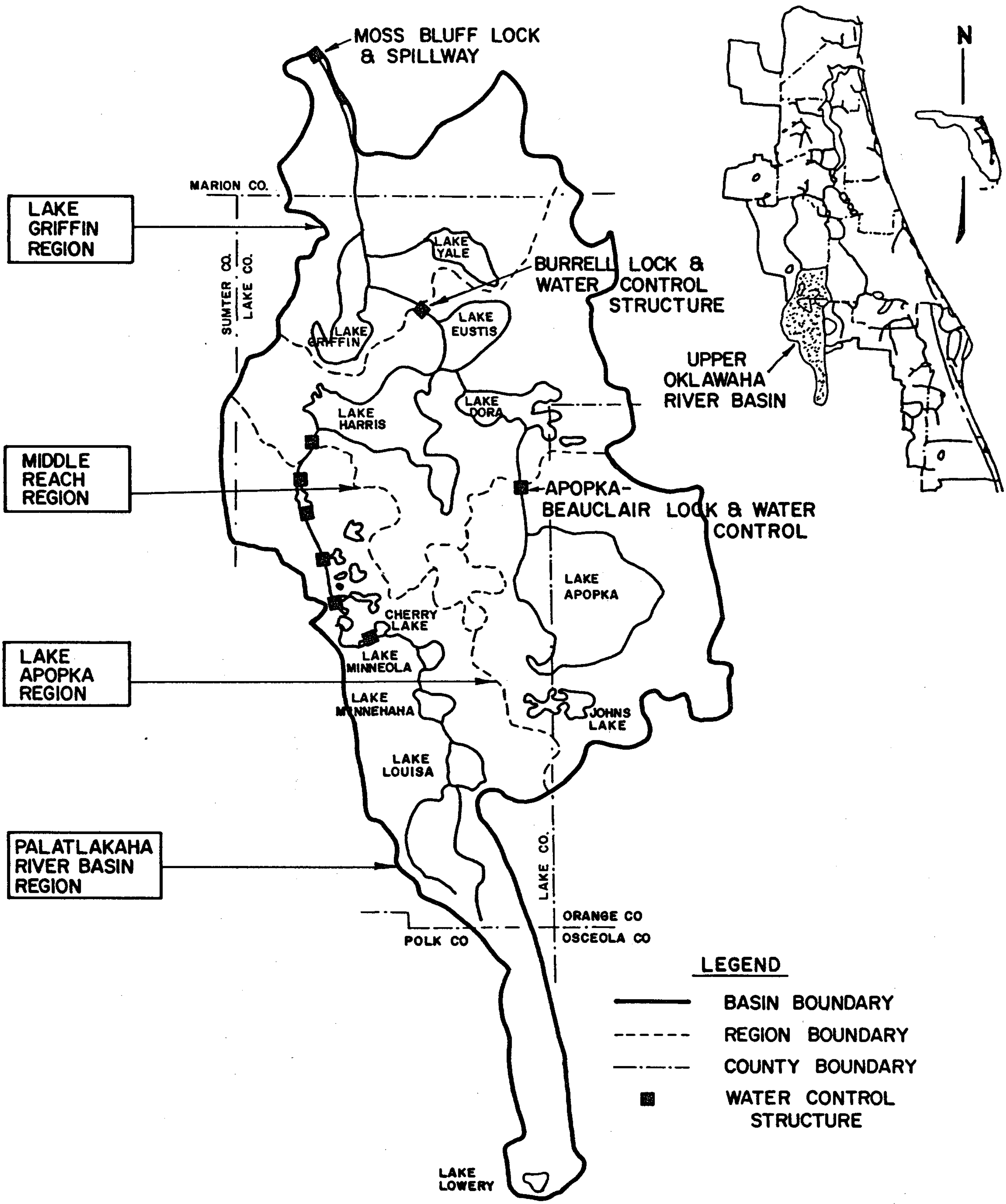


FIGURE 1. Project Area Map.

socio-economic decision making or through negligence.

Beginning in the 1960's, when acute eutrophication became apparent in Lake Apopka, there was interest in a restoration project for that lake. In 1976, the Florida Department of Environmental Regulation (DER) undertook a program to restore the lake. The program led to many extensive studies. Many of those studies are applicable to the Lake Griffin system and have been used in this study. The culmination of the Lake Apopka Restoration Project was a proposed plan to drawdown the lake over a 15 month period with the aid of pumps, pipelines and dredging at an estimated project cost of nearly 14 million dollars (1978 dollars). The project was never implemented.

Current Conditions

It is noticed in Table 1 that efforts to restore the natural character of the chain of lakes or at least prevent further degradation have been made within the past 15 years. This is seen in the actions which reduce wastewater inflows to the system. While much has been done, the resource today remains in a condition much less desirable than natural from a water quality and ecologic veiwpoint. Lake Apopka is hyper- eutrophic with nearly continuous algal blooms. Other lakes, while generally of better water quality, are not good. Sport fish populations continue to decline. Lake Apopka, a prime fishing lake in the early 1950's, now has virtually no bass population.

Water quality varies from lake to lake within the basin. Lake Apopka is usually considered to be by far the worst. Lake Harris has probably the best water quality. Lakes Eustis and Griffin, while not having good water quality, are generally better than Dora or Beauclair.

TABLE 1.

WATER MANAGEMENT IN THE OKLAWAHA CHAIN OF LAKES

Date	
1890	Congress authorized U. S. Army Corps of Engineers (Corps) to maintain a 4 foot deep channel from mouth of Oklawaha to Leesburg.
1925	First Moss Bluff Lock and Dam completed.
1941	Zellwood Drainage District Created.
1953	Florida Legislature established the Oklawaha Basin Recreation and Water Conservation and Control Authority in Lake County (LCWA) and the Lake Apopka Recreation and Water Conservation and Control Authority (AWA).
1957	LCWA completed construction of Burrell Lock and Dam on Haines Creek and Cherry Lake Dam on the Palatlakaha River.
1957	AWA completed construction of Apopka-Beauclair Lock and Dam and Apopka-Beauclair Canal.
1959	LCWA and AWA establish lake level ranges for Oklawaha Lakes.
1963	LCWA and AWA transferred operation of system (excluding Palatlakaha) to SWFWMD.
1969	Corps completed construction of Moss Bluff Lock and Dam.
	Winter Garden Citrus Co-operative constructed activated sludge waste water treatment plant.
1972	SWFWMD asked EPA for grant to draw down Lake Apopka.
1976	SJRWMD took over control of Oklawaha Basin from SWFWMD.
1976	LCWA completed construction of M-6 Dam on Palatlakaha River.
1979	SJRWMD completed construction of new Burrell Spillway.
1979	New Winter Garden Municipal Wastewater Treatment Plant constructed with secondary treatment of discharge to lake Apopka.
1979	Agricultural waste abatement program requiring detention of agricultural land pump discharges nearly completed.
1980	LCWA completed construction of M-4 and M-5 dams on Palatlakaha River.
1981	New Leesburg Municipal Wastewater Treatment Plant ceases discharge to Lake Griffin.

DRAWDOWN AS A MANAGEMENT ALTERNATIVE

Objectives of Drawdown

Man's control of lake water levels usually impacts lake ecosystems by reducing the fluctuation range. To understand why extreme drawdowns might provide a useful management alternative requires understanding the impacts which occur from controlled lake levels.

In a natural lake marginal areas undergo periodic inundation and dry conditions. Plant and animal species existing in the marginal or littoral zone are adapted to that hydrologic regime. When fluctuation ranges change, the new ranges may prove unsuitable to the existing populations and attractive to others. For example, some plant species which offer prime fish breeding area, i.e., spatterdock (Nuphar luteum) favor periodic high water and periodic exposure in order for germination of seeds and sediment consolidation.

Beyond the biological impacts, however, is another impact related to sediment characteristics. The natural low water periods provide time for recently deposited sediments to dry out and consolidate or to oxidize if organic in nature. The consolidated sediment provides a firm substance for rooted aquatic plants to grow. Without consolidation and exposure the sediments remain loose and easily resuspended by wave action. This not only prevents a firm substrate for plants, it reduces light penetration and may to bury fish eggs laid on or near the bottom.

The goal of an extreme drawdown is to simulate what nature provides periodically. It has been observed that fish populations often appear to be stimulated by water level fluctuations even when no apparent vegetative change occurs. The reasons are not understood at this time.

Previous Studies and Drawdowns

Although extreme drawdown is a relatively new management practice, a few lakes in Florida have been drawndown and several studies and reports are available. FGFWFC has generated several publications dealing with the drawdown as a management technique. Many of these publications are contained in the bibliography of this report.

Several lakes in Florida have been subjected to extreme drawdown projects with varying levels of success. These include but are not limited to the following:

Date(s)	Lake
1971, 1979	Lake Tohopekaliga
1977	Lake Kissimmee
1971	Lake Apopka experimental drawdown
1973	Accidental Lake Griffin drawdown
1977	Lake Carlton
1980	Conservation Area II A

In January 1973, a levee failure occurred along the eastern levee of the C-231 canal approximately one-half mile south of the Moss Bluff Structure. The water flowed through the breach, then northward and reentered the canal just downstream of the structure where a culvert through a small earth embankment was washed out. The water level dropped in Lake Griffin from 59.4 ft. to 58.4 ft. in 5 days, to 57.4 ft. in 10 days, to 56.1 ft. in 20 days and reached a minimum of 55.4 ft. after 26 days when the breach was presumably plugged. Aerial photographs were taken on March 18 of that year which were useful in this study.

Documentation of the levee failure and impacts are potential sources of information for this study. Stage records can be compared with predicted rate of lowering for the lake although the different discharge conditions must be considered. Also it must be considered that although discharge estimates were made, it would have been very difficult to get an accurate estimate especially in the first few days after the failure. Comparisons of this data does show relatively good agreement.

Probably the most informative data resulting from the levee failure was the fish population data collected by FGFWFC in succeeding years. This data indicated a substantial increase in fishing effort and fisherman success during the years following the failure.

DESCRIPTION OF LAKE GRIFFIN AND SURROUNDING AREA

Description of Hydrologic System

Lake Griffin is the most downstream lake in the Oklawaha Chain of Lakes which forms the headwaters of the Oklawaha River. The most upstream areas in the watershed include the Lake Apopka drainage basin and the Palatlakaha River drainage basin with its own headwaters formed by Lake Lowrey and the Green Swamp area. From Lake Griffin water flows northward through what was historically a marsh area and then into the C-231 canal. The canal was constructed by the Army Corps of Engineers in 1969. The canal extends approximately 7 miles downstream to the Moss Bluff Lock and Dam.

There are six major flow control structures in the Palatlakaha basin. There is a large amount of storage in the system with its lakes and marsh areas. The structures are controlled by the Lake County Water Authority at this time. The average discharge of the Palatlakaha River downstream of Cherry Lake is 44 cfs based on records from 1958 to 1978. It has been assumed in this study that because of the historic water management in the Palatlakaha, no water will be released from storage in this basin for refill of Lake Griffin.

Two other major control structures, both operated by the St. Johns River Water Management District, are located upstream of Lake Griffin. These are the Apopka-Beauclair Lock and Dam and the Burrell Lock and Dam. These two structures control a total of approximately 60,000 acres of lakes. It has been assumed for this study that the existing regulation schedules for these structures could be altered to improve the likelihood of a successful drawdown of Lake Griffin. The changes would, however, remain within the range of the current lake regulation levels. This would require consideration of impacts of lowered or raised lake stages, however.

The Burrell structure is located on Haines Creek which connects Lake Eustis with Lake Griffin. The structure is located approximately mid way on the 3 mile long creek. Discharge at Burrell is affected by back water from Lake Griffin. The normal water elevation difference at Burrell is approximately four feet.

The Apopka-Beauclair structure is located on the Apopka-Beauclair canal to the north of Lake Apopka. The structure has only limited short term control over Lake Apopka water levels during short duration storm events because its discharge capacity is 560 cfs. The water elevation drop at Apopka Beauclair Lock and Dam is normally about 4 feet.

The Moss Bluff structure controls the water level in Lake Griffin but it is actually nearly 10 miles downstream of the lake outlet. The original structure was built in about 1925. The existing structure was built in 1970. The structure consists of a single chamber lock and two 20 x 12.4 feet slide gates. The structure rating curve is seen in Figure 2. The uncontrolled drainage area at Moss Bluff, that is, the drainage area between Burrell and Moss Bluff is 230 square miles. This includes 62 square miles which is the Lake Yale subbasin. Discharge from this subbasin

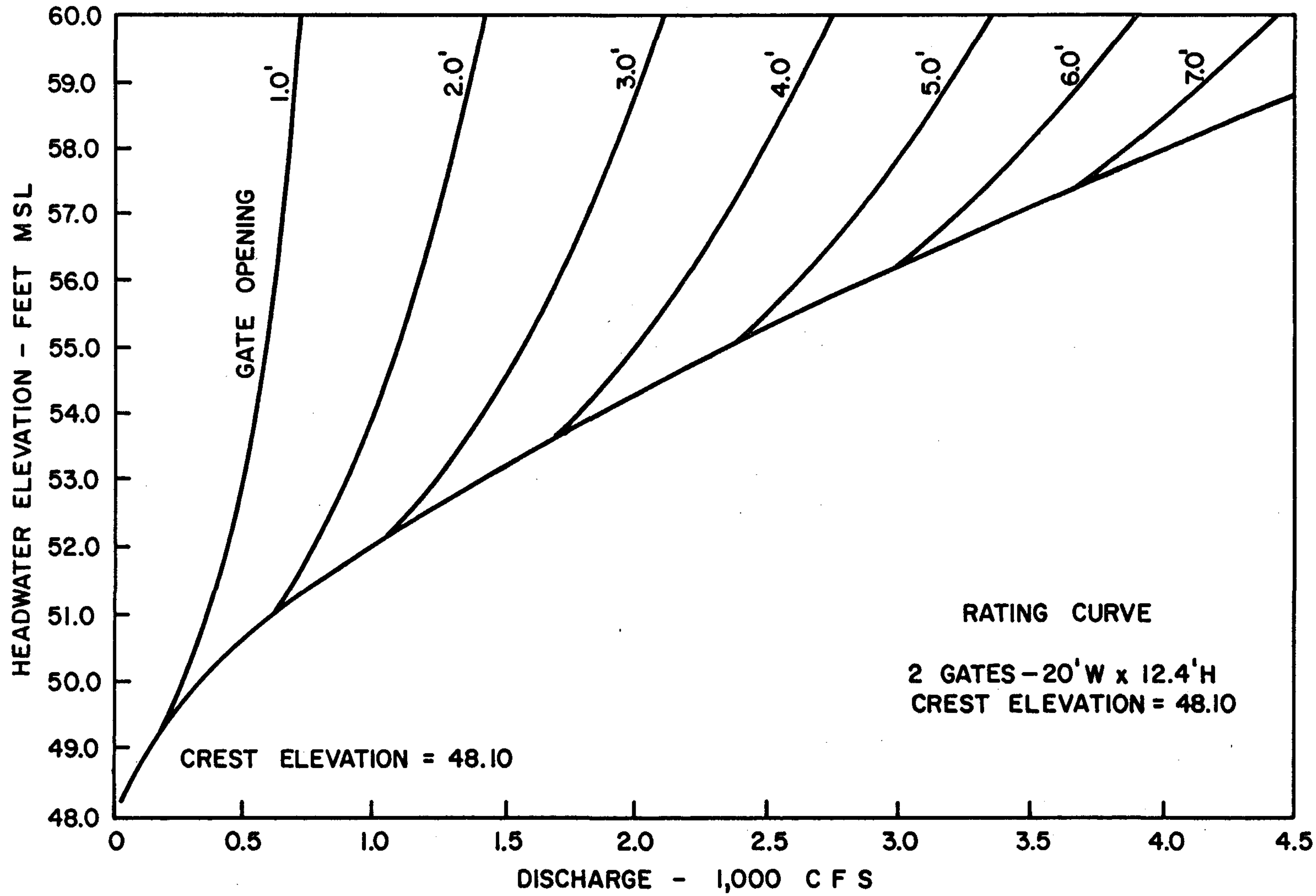


FIGURE 2. Moss Bluff Spillway Rating Curve.

is through a culvert and improved channel. The invert of the culvert is about elevation 59.0 ft. The Lake Griffin drawdown will not lower Yale below the culvert invert.

Description of Lake Sediments

The sediment in Lake Griffin is similar to the bottom sediments in other lakes of the Oklawaha Chain including Lake Apopka. It is high in organic content with silts, clays and fine to medium sands making up the remainder. The organic content is the result of the advanced eutrophic conditions in the lake. The lake has become eutrophic due to nutrient inflows from muck farms, industry and sewage and aided by water level stabilization.

Sediment sampling was done in Lake Griffin as part of this study but only for grain size analysis. Characterization of the existing sediment and physical changes which are expected to occur with exposure have not been done for this study Extensive work on this has been done for Lake Apopka. Because the sediments are believed to be very similar, data from those studies are assumed applicable to Lake Griffin sediments.

The success of a drawdown depends on the consolidation of the exposed sediments while exposed and also on the reaction of the sediment following refill. These topics are discussed in detail in the Lake Apopka Restoration Project report. A brief summary will be presented here.

Tests conducted on Lake Apopka muck included (1) in situ static cone penetration tests for measurement of muck depth and strength, (2) consolidation tests on undistributed samples for estimating effective stress-void ratio relationships and permeability, (3) drying test to determine drying rates, rainfall effects on drying rates, resubmergence reactions, and volumetric changes, (4) water content tests, (5) specific gravity test and (6) organic content tests.

The conclusions of the preceeding studies are:

- exposure to sun and atmosphere can dramatically consolidate the muck
- the consolidation process causes primarily physical changes rather than one chemical or biological change
- consolidation appears to be irreversible upon resubmergence
- rainfall during drying temporarily interrupts drying until water stored in cracks in muck evaporates
- average physical characteristics of muck are:

permeability (inches/sec)	void ratio (percent)	percent solids	percent water loss[1] after given number of days drying				percent volume loss
			5	10	23[2]	41[3]	
2×10^{-4}	25	7	33	44	81	91	90

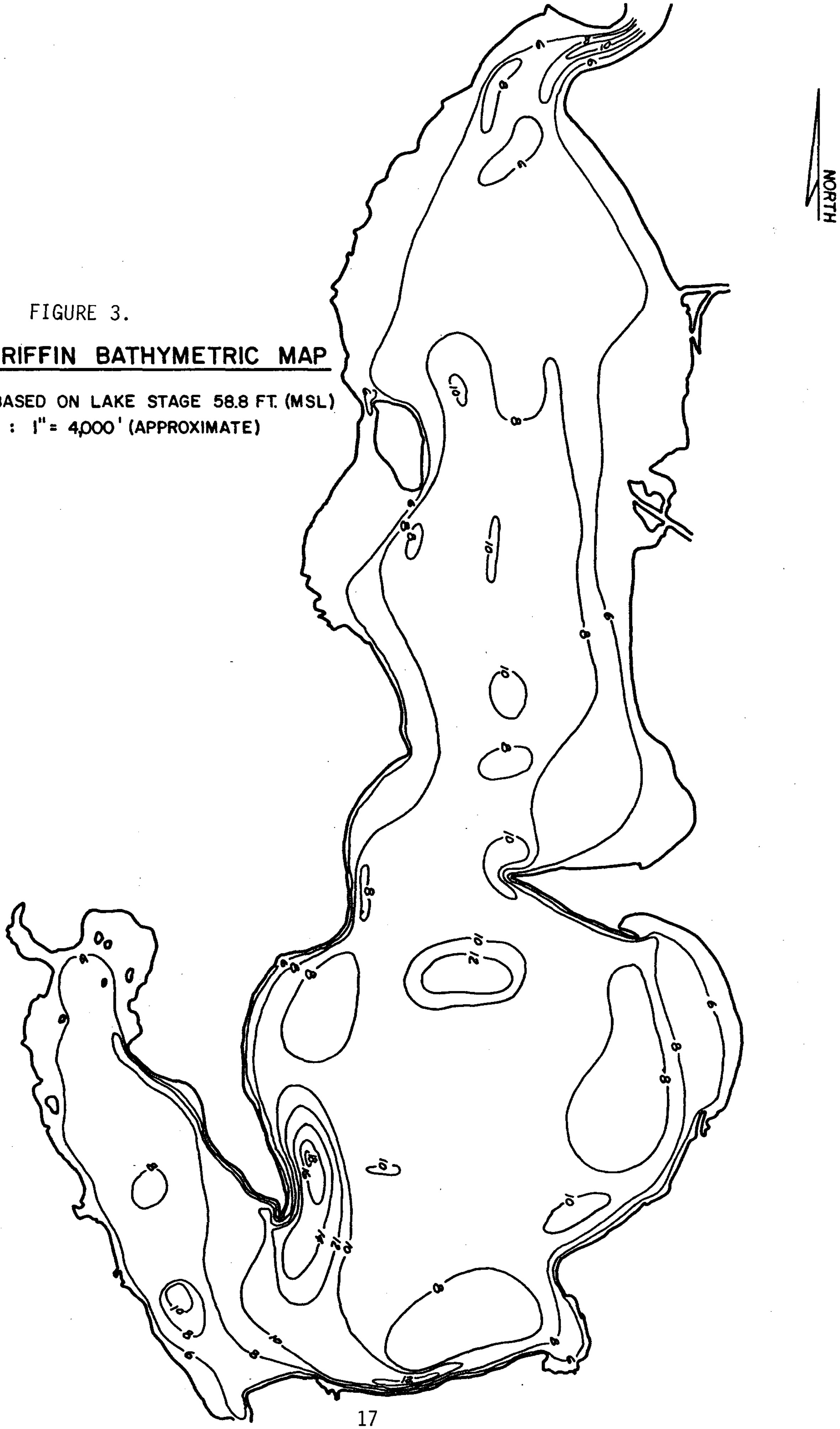
(1) defined as water loss/initial water content
(2) 1 cm of rain during first 20 days
(3) 8 cm of rain during final 18 days

A bathymetric map of Lake Griffin is seen in Figure 3. The south end of the lake is deepest and has a more steeply sloping bottom. The north end of the lake is at elevation 52 to 54 feet and is relatively flat. This is the area which has the highest potential for benefits by lake drawdown since a small decrease in water level will expose a large additional area.

FIGURE 3.

LAKE GRIFFIN BATHYMETRIC MAP

DEPTHS BASED ON LAKE STAGE 58.8 FT. (MSL)
SCALE : 1" = 4,000' (APPROXIMATE)



Description of Socio-Economic System

Lake Griffin lies in Lake County. The City of Leesburg with a 1980 population of 13,190 is located on the south shore. Fruitland Park with a population of 2,260 lies to the west of the Lake Griffin State Park. The total 1980 population of Lake County was nearly 105,000. A large number of residential areas lie around the southwest, south and southeast shores and on Picciola and Treasure Islands. North of these areas are primarily citrus on the west and muck farms on the east as seen in Figure 4.

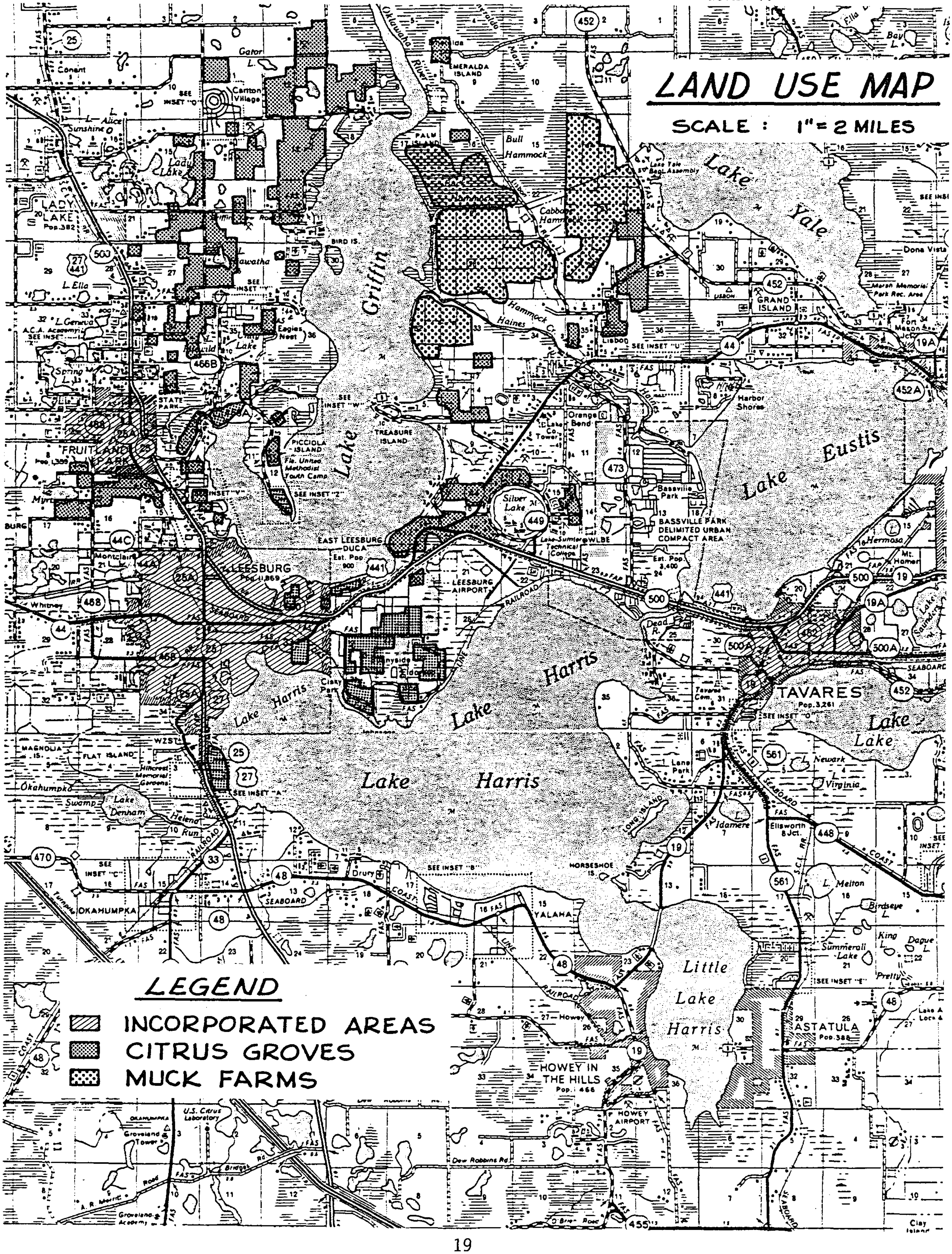
Several fish camps are located on Lake Griffin with boat slips accomodations ranging from around 30 to more than 100. According to FGFWFC the prime season for the fish camps is the winter months through March.

Some citrus owners along the western shore may use Lake Griffin for irrigation water. Most large groves are irrigated from wells, however. Other water uses include lawn sprinkling.

Muck farms are found along the eastern shore from just north of Treasure Island northward to the south side of Emeralda Island. These farms typically discharge seepage and rainfall runoff into Lake Griffin. The lake is available for irrigation use, but this is not practiced currently. Lake Griffin water is used by the muck farms periodically to flood fields for nemotode control. This is usually done once each two or three years in each field.

It is reasonable to assume that some retail business is generated for the Leesburg area due to proximity to Lake Griffin. Vacationers, primarily

FIGURE 4.



LAND USE MAP
SCALE : 1" = 2 MILES
LEGEND
INCORPORATED AREAS
CITRUS GROVES
MUCK FARMS

fishermen, who travel to the area and local residents purchase fishing equipment, boats, groceries, etc. which will be used for recreation on Lake Griffin. An estimate of these expenditures has not been made for this study but it is recognized that the economics of the area is dependent to some degree on the lake.

ENGINEERING CONSIDERATIONS FOR DRAWDOWN

Discharge Volumes and Rates

Early in the study it was recognized that the discharge capacity at Moss Bluff was a potential problem in formulating a drawdown plan with a high probability of achieving the desired goal. This is because of the large volume of water stored in Lake Griffin. There are two approaches to increasing the discharge capacity of the C-231 canal and Moss Bluff system. One is construction of a high capacity pump facility. A pump system was planned for the Lake Apopka Restoration project. The Lake Griffin system is quite different, however, both hydraulically and hydrologically. Where as Lake Apopka has an average discharge of approximately 85 cfs the average discharge at Moss Bluff is 325 cfs. A very large capacity pump station would be required even with the most optimistic plan for holding water upstream of Burrell during the drawdown. The pump station would be expensive to put in place and operate. A sump and headwall would also be costly and would have technical problems related to flood events.

The second approach would be to dredge a larger and deeper channel through the restricting channel reaches. The most restrictive reaches are the upstream portion of the C-231 canal and the north end of the lake where the bottom elevations are highest. The upstream end of the C-231 canal has a trapezoidal channel section with a bottom width of 22 feet. To deepen or enlarge this channel would require steepening the side slopes of the levee on the east or widening the channel, neither of which is considered to be an acceptable alternative. Dredging a channel through high points in the lake to improve drainage is a technically feasible alternative, however.

The time required to drawdown the lake can be reduced by ways other than increasing discharge capacity. The alternative is to reduce inflows to the lake during the drawdown by manipulating upstream control structures. Normal regulation schedules for Burrell and Apopka-Beauclair call for lowering the upstream lakes during March through May. The flow released is therefore the runoff during that period plus the water removed from storage. By lowering the upstream lakes earlier, or later, the inflow to Lake Griffin during the drawdown could be reduced. Several different strategies for altering the regulation schedules for Burrell and Apopka-Beauclair were evaluated. These are described in detail in this report. It is interesting to note that a drawdown to elevation 53.0 ft. would require release from storage in Lake Griffin a volume approximately equal to one third of the total inflow to Lake Griffin during an average year.

Target Drawdown Elevation

To be successful, the drawdown must expose a significant area of lake bottom. For adequate drying and consolidation the sediment surface must be approximately one-half foot or more above the lake level. The shallow water area at the north end of Lake Griffin is characterized by flocculent organic sediments which should benefit greatly from a drawdown. It is seen in Figure 3 that much of this area is near elevation 53.0 to 53.5.

The muck characteristics of Lake Griffin make a precise estimate of lake bottom elevation difficult. The concentration of suspended solids in the water increases with depth due to continuous turbulence of the lake from wave action. Field measurements of depth-concentration relationships were made for the Lake Apopka Restoration study. The Lake Griffin sediments are believed to be very similar. The concentration will vary from one location to another in the lake and over time since it depends on water depth and wind among other factors. Also, the muck has a very high water content near the water soil interface. The density of the muck material increases with depth. The interface is a gradual one rather than a distinct water-soil interface. The importance of this is that the elevation of the soil surface is difficult to measure and after drainage by gravity may be several inches below what shows up as the interface elevation on depth soundings or fathometer chart.

Areas that are exposed during the drawdown but which did not sufficiently consolidate would still germinate and support vegetation such as cattails. Upon resubmergence, however, the buoyance of the vegetation could cause it to break loose and become a floating nuisance. Consideration must be given, therefore, to avoid exposure of a large area which would not throughly dry and consolidate. Because an exposed but unconsolidated area will exist at the perimeter of the pool regardless of the drawdown level, it is believed desirable to have flexibility to raise the water level one to two feet as rapidly as possible at the end of the hold down period. This would prevent light from reaching the new shoots, thus killing them and reducing the extent of uprooting that which might occur after refill.

Impacts of Drawdown

The impacts of a drawdown will depend on the stage to which the lake is lowered, the holddown duration and the weather, especially rainfall, during the project. Because the outcome of any plan will be dependent on the hydrologic cycle during the drawdown the impacts must be evaluated in a probabilistic manner.

Fish Habitats

The primary goal of the proposed drawdown is improvement of the sportfish populations in the lake. The improvement is expected as a result of exposed sediments drying and consolidating which will allow rooted vegetation to establish itself along the shore and in shallow areas. The vegetation would provide a habitat needed by the sport fish for spawning and feeding.

The improvements to be expected are not easy to quantify. The expected duration of benefits, i.e. enhanced fish habitat, is about six to seven years. Drawdowns in other lakes including the 1973 accidental drawdown of Lake Griffin, have produced altered conditions lasting for about seven years according to FGFWFC reports.

During the drawdown itself, the existing fish population would obviously have a reduced area. The impacts of this which were documented for the Lake Tohopekaliga drawdown (Wegener and Williams 1974), could be expected to include an increase in birth rate for forage fish as the food supply is condensed.

Downstream Impacts

A. Water Levels - A large release rate from the Moss Bluff Structure would create a high water level in downstream reaches of the river between Moss Bluff and Rodman Reservoir. This situation would be similar to a natural flood condition which would require high discharges from Moss Bluff. The difference would be that large amounts of runoff would probably not be occurring from downstream drainage areas. Assuming this to be the case, the peak discharge would be reduced in the downstream direction due to the storage in the intervening river reaches. This is in contrast to normal flood situations in which the peak rate of discharge would typically increase in the downstream direction due to additional runoff from additional drainage area. Thus no adverse impacts from flooding are expected downstream of Moss Bluff.

B. Erosion - Another potential problem resulting from high discharge from Moss Bluff is channel and bank erosion. A quantitative evaluation of this problem has not been performed due to physical complexities and time limitations.

Considerations of water levels and erosion requires that careful monitoring of the conditions downstream of Moss Bluff be performed during any high discharge periods. It will be necessary to slowly increase the discharge at Moss Bluff at the onset of drawdown to avoid rapid changes in stream stages and velocities.

C. Sediment Transport - Any increase in sediment load passing Moss Bluff above the natural load will be deposited somewhere between Moss Bluff and Rodman Dam. The location of deposition will depend on the particle characteristics and the streamflow velocities. Very small particles could travel into Rodman Reservoir before reaching sufficiently quiescent conditions to permit settling.

It is considered undesirable to increase sediment loads for several reasons. One is the problem associated with where the transported material will be deposited. As this is basically controlled by natural or existing channel geometry it is not controllable without expensive excavation work. If the material were deposited in undesirable locations it might require removal by dredge or drag line.

Another problem is ecologic impacts of the suspended material. The suspended material would decrease light penetration possibly impacting plant life. In addition, material could be harmful to fish by clogging, and thus reducing the respiratory efficiency, of the gills. Another impact relates to the organic nature of the sediment in Lake Griffin. Being highly organic and nutrient rich material, resuspension would lead to increased biochemical oxygen demand for oxidation of the organics and a consequent reduction in dissolved oxygen content. Also increased nutrient release would occur, potentially causing algal blooms in receiving waters. The probabilities and magnitudes of these impacts were not evaluated during this study, but the risk of problems is believed to be small.

Adjacent Properties

The impacts of a drawdown on property adjacent to the lake or connecting channels can be divided into two basic groups-residential and agricultural.

Residential

There are approximately 300 single family residences adjacent to Lake Griffin or having canal access to the lake. Nearly all of these are located at the south end of the lake. There are also several mobile home parks. The benefits which these owners derive from the location include aesthetic quality and easy boat access to the lake. A large portion of the lake front homes have private docks and/or boat houses. Some owners have pumps used for lawn sprinklers.

It is likely that any significant drawdown will make boat access via most of the canals impossible. Because of the relatively narrow fluctuation range of the lake, dredged channels were constructed at depths just sufficient for boating at the low regulation stage. For a three foot draft and clearance with the lake at 58.0 the channel bed elevation would need to be 55.0. It is reasonable to assume that all man made channels will be entirely exposed by a drawdown below 55.0. Although the owners will lose access via these channels, the drawdown period would be a good time to easily improve these channels (subject to normal agency permit requirements).

A second significant impact of the drawdown on property owners would be the temporary loss of the aesthetic advantages of a lake front location. A drawdown would expose some amount of near shore sediment which is highly organic. This could produce some objectionable odor, particularly immediately after exposure. It is noted, however, that the lake bottom drops much more rapidly along the southern portions of the lake than other areas. The exposed area would therefore be least along the southern shore of the lake where the population is concentrated.

Many of the owners have constructed retaining walls of concrete, sheet piling or wood. A drawdown will significantly increase the load on the walls. Because the age, conditions and construction of the walls vary widely and the under water portions of the walls could not be viewed it is impossible to determine the damages that would result, if any. The soils behind the walls are likely sandy. Because of the sandy material with good drainage and the relatively slow decline in lake level, it would not be expected to have a totally saturated soil behind the walls. When the lake is at a low stage, heavy rainfall could cause saturated conditions behind these walls, resulting in much higher stresses on the walls. A similar problem at the SR 42 bridge at Starkes Ferry is discussed elsewhere in this report. The period of low water would be a good opportunity for owners of retaining walls or docks to do repair work on these structures.

Agriculture

The land along the northern areas of the lake is predominantly agricultural. On the west side of the lake the land rises rapidly. This areas is mainly citrus. The areas to the east of the lake are much lower. A large part of the area is muck farm.

The impact of the drawdown on the low areas on the east is not expected to be significant. The muckland is several feet below the normal lake level. A drawdown would decrease the seepage from the lake to the muckland. This would decrease the pumpage required of the muck farms. The distance of significant impact is expected to be small, however, due to the low permeability of the muck soils. The potential for planned flooding of the muck farms by gravity might also be lost, although water might be available from the Yale outlet channel.

The land to the west is predominantly sandy material, which is more responsive to drainage than the muck soils. Lowering the level in Lake Griffin would increase the head, or water level difference, between the upland areas and the areas immediately adjacent to the lake. As the water table level drops in trying to reach a new "equilibrium", some water would be released from storage. The rate of lowering would depend on the rate of the lowering of the lake level, the permeability of the soil, the storage or porosity of the soil, the amount of percolation from rainfall, and dimensions of the water table aquifer.

Because of the variability of each of these factors it is difficult to calculate a representative estimate of the water table drawdown for the area and virtually impossible to do so for a particular location.

Work done for the Lake Apopka drawdown project is believed to be applicable to Lake Griffin. The planned drawdown for Lake Apopka was 6.75 feet for three months with the entire period of sub-regulation water levels being 15 months. The drop in water table level considered to be measurably impacted (greater than 0.1 foot decline) was estimated to be 1.5 miles on the east and west sides of Lake Apopka which is believed to be the most similar to the west side of Lake Griffin. It was concluded after consideration of the degree of dependence of citrus on water table and related factors that only trees within 1000 feet of the lake would actually be impacted. The impacts could include reduction in crop size. Similarly, lawns and lawn plants could be impacted and require additional sprinkling.

The depth and duration of drawdown on Lake Griffin are very similar to that studied for Lake Apopka. Consideration is therefore centered on citrus within approximately 1000 feet of Lake Griffin. An estimate of the major citrus groves acres versus distance from Lake Griffin was estimated from U. S. Geological Survey maps and 1973 aerial photographs and is given below.

Distance from Lake Griffin (miles)	Total area of citrus (acres)
0.2	100
0.5	1300
1.0	2700
2.0	4200

Freeze Protection

Lake Griffin, like all large bodies of water, can have an influence on atmospheric temperatures near the lake. This is because of the high heat storage capacity of water compared to organic soils and sands. When atmospheric temperatures drop below the water temperature, heat is given up by the water to the atmosphere. Wind is important also in temperature modification because it pushes the warmed air from the lake surface over the surrounding area. Obviously, the amount of temperature modification will decrease with distance from the lake.

Although the temperature modification effects of lakes is intuitively easy to understand, quantitative evaluation is difficult because of many uncertainties and complexities. An extensive study of freeze protection for citrus provided by Lake Apopka was completed for the Lake Apopka Restoration study. Results of that study can be applied qualitatively to the Lake Griffin area.

The Lake Apopka Freeze Protection study concluded that an insignificant reduction in freeze protection would occur if at least 1 meter of water depth was maintained over a large portion of the normal lake area. Assumptions made in the study were that temperature modification occurred on the south and southeast side of the lake or the downwind side.

For this study it has been assumed that a water surface elevation in Lake Griffin of 56 ft. is acceptable as a minimum lake stage to provide freeze protection not significantly different than normal conditions. It is desirable then to refill the lake to this target elevation before November which is typically the beginning of the dry season. The date of the first freeze event, if one occurs, in a given year can only be evaluated by probabilities. Data was plotted for two weather stations near

Lake Griffin (Lisbon and Ocala) which would not be significantly affected by lakes. Data from 1961 through 1981 was used. There is approximately a 5 percent chance of at least one 28·F or below temperature event occurring before December 1 from the Lisbon data. There is approximately a 50 percent and chance of such an occurrence before January 1.

It is assumed that freeze events are independent of long term surface runoff (and therefore lake stage). The risk of freeze damage beyond that expected under normal conditions can be estimated as the product of the probability of a freeze event before a given date and the probability of the lake stage being below a "safe" elevation on that date. It is believed that 56.0 feet will provide freeze protection not significantly different from normal conditions. At that elevation, approximately three feet of water covers nearly all the normal lake area. In particular, very little area is exposed on the south end of Lake Griffin (near the area suseptible to temperature modification) due to the fairly steep lake bed slope in that area. The probability of Lake Griffin not refilling to 56.0 feet would be about 15 percent. The probability of additional freeze damage beyond normal conditions, or damage due to drawdown, is then approximately 8 percent. These probabilities are for a freeze event defined as a 28 degree minimum temperature. Damage to the most susceptible citrus begins to occur at about 28 degrees for a period of four hours which results in leaf and twig damage. Temperatures of 22 to 26 degrees for four hours or more results in leaf loss. It would be likely that additional releases from upstream lakes could be made to minimize risks.

Drawdown Impact on Burrell Lock and Dam

During the proposed drawdown, Burrell Lock and Dam will be exposed to forces greater than it was designed to support. The difference between the upstream and downstream water levels, or 'head' at Burrell is normally 4 - 5 feet. During the drawdown, the head could be as much as 12 feet. This increase in head will result in increased pressures on the lock structure, the water control structure and the earthen embankment. The following steps will be needed to insure the safety of Burrell Lock and Dam.

1) The lock gates will be kept closed after the down stream water level drops below 55.5 feet NGVD. Leakage through the gates will cause the water level in the lock chamber to stay about halfway between the upstream and downstream levels. Pressure on the structure will thereby be halved.
2) The dam will be visually inspected at least twice daily for signs of increased seepage or other problems. Should the seepage through the earth embankment increase to unacceptable levels, the water control structure gates would be opened, thereby decreasing the head by as much as 4 feet due to the rise in tailwater elevation and decrease in headwater elevation..

A contingency plan would need to be established for implementation in event of a serious problem. Such a plan might involve construction of a temporary embankment downstream of the dam to raise the tailwater level. Such a structure could be quickly constructed by dumping approximately 1000 cubic yards of material across the channel.

Consolidation of Sediment Materials

The goal of a drawdown is to consolidate the sediment exposed by drawdown. The consolidation characteristics of the sediment material therefore need to be evaluated. Benefits of the project are dependent upon the extent of consolidation and time which the sediment will remain consolidated after refill.

Monitoring Program

Because of the inadequacies in engineering data, the stochastic, or random, processes related to hydrologic conditions, and the opportunity to gather useful data for future studies, a field monitoring program should be established and implemented during the drawdown project and succeeding the project for evaluation of predicted results versus actual. The monitoring which is of concern for this study, however, is primarily related to hydraulics during the drawdown. As discussed above potential impacts of the drawdown include sediment transport problems which may create turbidity problems and failure of banks and retaining walls due to increased unbalanced hydrostatic forces. The monitoring program would require measurement of turbidity using a standard method to insure that acceptable standards were being met. For example if higher turbidity water was passing Moss Bluff than desirable the discharge would be reduced to decrease the velocities and possibly increase the lake stage.

Frequent shoreline inspection should be made to detect bank and retaining wall movement.

SEDIMENT TRANSPORT

To evaluate the impacts of sediment transport during a drawdown a computer model was developed to simulate the changing hydrologic and sediment transport conditions. Considerable judgement was required in evaluating these impacts. The majority of sediment within Lake Griffin, and all the Oklawaha Chain of lakes, is very similar. It is high in organic content with estimates of 70 to 95 percent by weight. The remainder of the material is medium to fine sands, silts, and clays.

The size and weight of a particle are two important characteristics which determine if and how that particle will be moved by given force exerted on it by flowing water. Normally, samples of sediment are obtained and a grain size analysis is performed to determine the particle sizes and proportions of each size in each sample.

Sediment sampling was done in Lake Griffin, Haines Creek, Yale outlet channel and in the channel as far north as the SR 44 bridge. A grab bucket sampler was used. A grain size analysis was attempted on this material but without success. The samples contained significant quantities of fibrous, organic material which caused problems.

The sampling and analysis did yield some information however. The material appeared to be fairly uniform at all locations within the lake. Some locations including the SR 44 bridge below Burrell Lock and Dam and the SR 42 bridge appeared to have larger proportions of sands than other locations. The Yale outlet channel sediment contained very little sand. It was also noted that dried volume was approximately 10 percent of gravity drained volume.

Lack of representative particle size distribution make a reliable sediment transport evaluation difficult. Because it was believed that sediment transport would be a very important consideration for this project a quantitative analysis was considered necessary even if based on best estimates of particle size distribution. This created a need for an analysis which would consider the sensitivity of predictions to assumed data.

The dynamic nature of the drawdown process creates a very complex situation for sediment transport analysis which is, even in "normal" situations, a complex problem. The dynamic situation and the need for sensitivity analysis indicated need for a computer model. It was believed, however, that the model needed not be overly complex since the basic input data was not known with a good degree of accuracy. These considerations were the basis for development of a bed load transport model.

Bed load is the sediment material which moves along the channel bed by sliding, rolling, or bouncing. The other component of sediment transport, washload or suspended load, is kept in suspension against the forces of gravity by turbulence. Because smaller particles are also low weight, they are more easily suspended and therefore are more likely to move as suspended load. It is the bed load which shapes and reshapes the channel geometry, however. Bed load modeling will indicate how channel geometry and flow velocities will change with time at a particular point in a channel.

The sediment transport model simulates sediment movement over a series of time steps. For each time step a water surface profile is calculated based on an input discharge hydrograph, a downstream stage hydrograph, and channel geometry at a number of cross sections known either from initial input data or from results of the previous time step. The result is a water surface profile and channel configuration at an instant in time. From the water surface profile the parameters necessary for estimating bed load transport capacity are known at each cross section location. Beginning then at the most upstream cross section where it is assumed that no sediment movement can occur, sediment transport rates (weight/time) are estimated based on DuBoys Formula. The transport rates can be converted to volume by multiplying by the time step used and by a factor to convert weight to volume. The net sediment volume change in a reach of channel is determined by the volume influx from the next upstream reach minus the discharge volume to the next downstream reach. In this manner, the sediment volume changes are tracked in the downstream direction. The process is repeated for successive time steps.

Sediment transport concerns involve the major inflow and outflow channels for Lake Griffin, which, are respectively, Haines Creek downstream of Burrell Lock and Dam and C-231 Canal.

Haines Creek

Sediment transport in Haines Creek is dependent on Burrell discharges. In the existing condition the periodic high discharges from Burrell keep the Haines Creek channel flushed of sediments. The sediment load passing Burrell is very small due to the presence of Lake Eustis upstream of Burrell. However, a delta has formed at the outlet of Haines Creek. As the flow area increases moving from the channel into the lake, the carrying capacity decreases which has resulted in the formation of the delta.

During a drawdown a storm in the upstream areas would create a need to release water from Burrell. Discharge records were used to evaluate the peak discharge rates at Burrell for the period from May through July on a frequency basis. The results are given in Table 2.

Table 2.

Probability of Exceed. (percent)	Frequency (years)	Maximum Burrell Discharge (cfs)
4	25	*1200
10	10	1000
20	5	800
50	2	500

* approximate structure capacity.

A worst case situation would be if a high discharge were suddenly required from Burrell after the Lake Griffin stage had fallen to a low stage. In this situation a large sediment load would be delivered into the much reduced volume of water in the lake. The sediment load would come from the delta material. As the flow reached the lake the load would drop out in the slower moving waters. Because of the relatively low discharge capacity of the C-231 canal at low lake stages much of a high Burrell discharge would go into storage in Lake Griffin. This would cause currents to diverge at the Haines Creek outlet in all directions. If the C-231 canal capacity were as large as the Burrell release the current would be expected to turn northward and flow directly toward the lake outlet thus minimizing mixing with the deeper waters of Lake Griffin. It is believed, however, that should such a high discharge from Burrell be required, the mixing zone would remain confined to the north end of Lake Griffin.

State Route 42 Bridge

If the Lake Griffin water level drops and high discharges are maintained at the Moss Bluff structure, water velocities in the stream must increase. Increased velocity results in increased sediment transport potential. Velocities are further increased by obstructions in the water way such as the SR 42 bridge piers. A localized scouring of bed material around the base of piers is common during high flows. The maximum scour depth at SR 42 is estimated to be about 6 feet. The predicted elevation of the bottom of the scour hole is then approximately 45 feet. The design details of the bridge support piles are unknown. However, during the 1973 levee failure flow significantly greater than the Moss Bluff structure's capacity were estimated and no documentation of damage to the bridge was found.

Another matter of concern at the bridge is the abutment walls. The abuttments are subject to undermining by erosion similar to that described above for the piers. The abuttments would also be subject to increased loads if the water level is lowered. The condition of the relatively old structure is not good. A frequent inspection of the structure during the drawdown would be necessary. As noted above the levee failure in 1973, which would be expected to have produced a more severe condition at the bridge, resulted in no documented damage to the structure. The bridge has aged an additional 10 years, however, and water levels during the drawdown would probably be lower than those resulting from the levee failure.

The Department of Transportation has plans to construct a new bridge at the site. The current schedule calls for letting bids in May 1985 and construction beginning in September 1985. The project would require about two years to complete. Impacts of a drawdown during the construction would depend on construction methods used. If pile driving is done from a barge, the low water could be a detriment. The drawdown schedule proposed by FGFWFC would not conflict with this bridge construction schedule, however.

Settling of Suspended Sediments

As discussed previously, the altered flow is expected to cause significant changes in sediment transport. Because of the physical characteristics of the lake sediments much of the transported material is expected to move as suspended load. In reaches where velocity is reduced, the particles will begin to settle out as gravitational forces become dominant.

The settling zone is expected to extend a relatively short distance from the outlet of Haines Creek into the lakes. This is because of the wide channel with low velocity and shallow depths. Wind generated waves will be a limiting factor in settling of suspended solids in these shallow waters.

The north end of the lake transitions into the C-231 canal which flows approximately 7 miles to Moss Bluff. Channel constrictions and high points in this reach are expected to be locations of erosion. The eroded material will settle as the velocity decreases toward Moss Bluff. As seen in Figure 5 the channel widens from 22 feet bottom width to 30 feet, 40 feet, 50 feet and finally to 60 feet in the downstream direction. To estimate the natural settling capability of this channel reach, the channel can be compared to a long sedimentation tank. The maximum sediment influx rate can be used to estimate settling efficiency in this channel reach. If Moss Bluff is opened to maximum discharge capacity the maximum sediment load passing the structure is expected to be on the order of 1000 parts per million (ppm). If the discharge, while Lake Griffin is below approximately 58 feet, is limited to 1000 cfs and 750 cfs, the maximum sediment load is expected to be on the order of 400 ppm and 50 ppm, respectively.

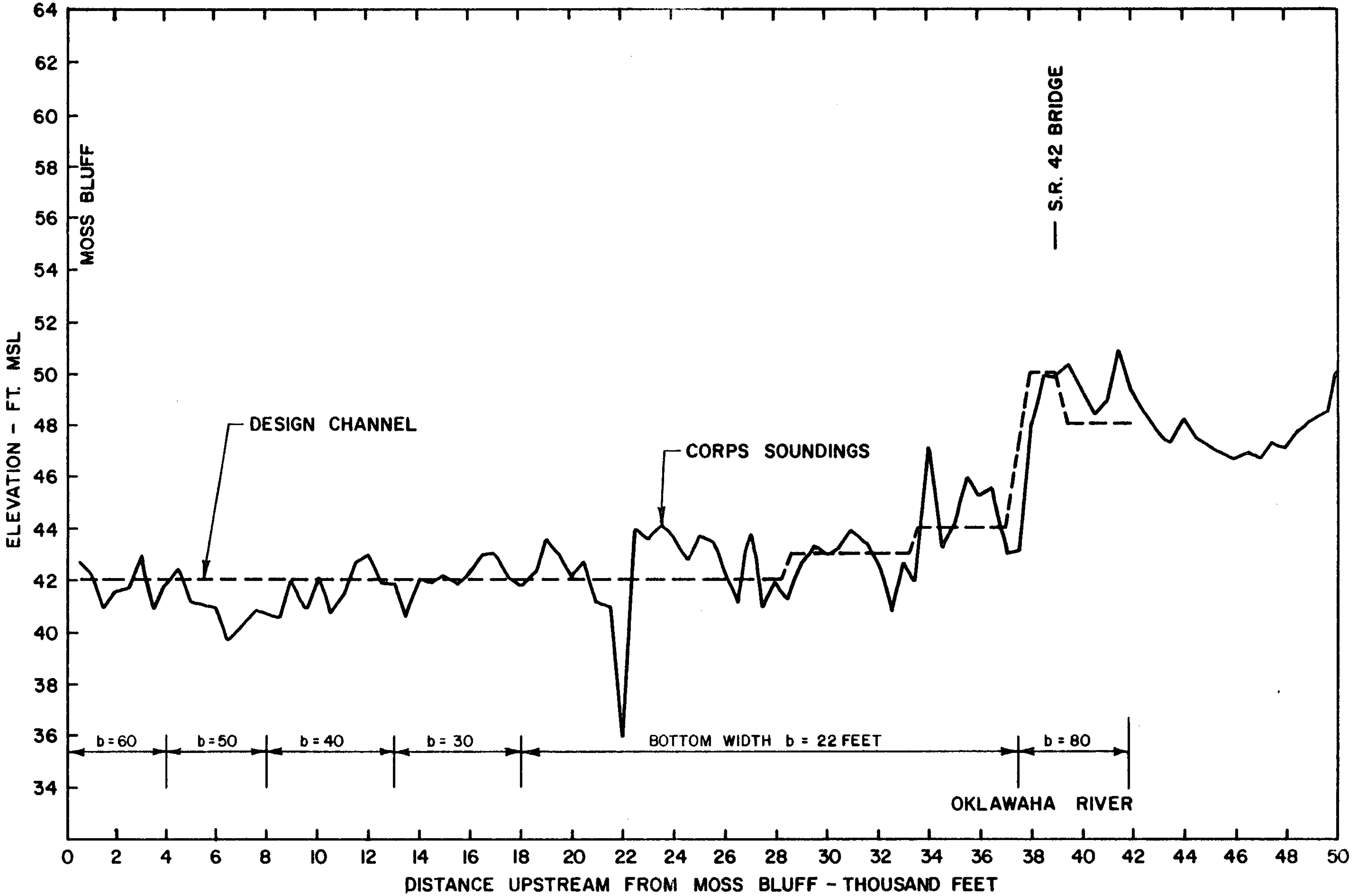


FIGURE 5a. Channel Profile.

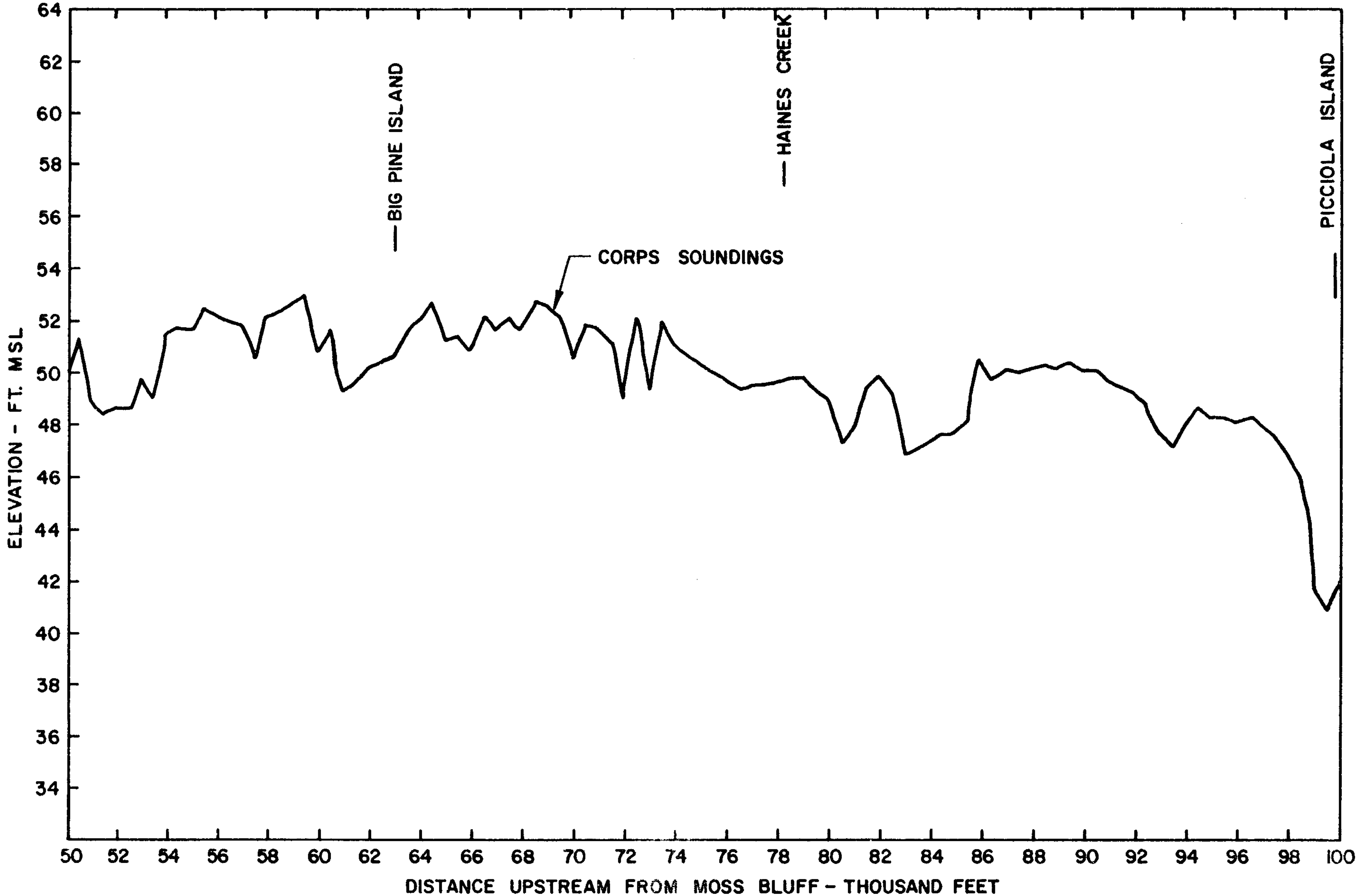


FIGURE 5b. Channel Profile.

ANALYSIS OF HYDROLOGIC/HYDRAULIC DATA

Runoff to the lakes upstream of Moss Bluff Lock and Dam is the factor which would determine the outcome of a drawdown project. Since rainfall and runoff volumes are unpredictable and may occur in an infinite number of patterns over a time period, the outcome of a drawdown is unknown. Only by assuming that the hydrologic characteristics will continue in the future to be similar to past years can an evaluation of a drawdown be accomplished. But the hydrologic pattern over the past 30 years has resulted in a wide range of conditions. The analysis can only be made based on probability. The year for which a project is scheduled may be a very wet year or it may be a dry one. By using records of rainfall, lake stage and stream flows the probability of a given outcome can be estimated.

For a drainage basin which has man made control structures such as the Oklawaha Chain of Lakes the historic flows at a given location will reflect the manner in which those structures were operated. If the operation of those structures were changed the pattern and even total volume of runoff at a downstream location would be changed. For this reason historic streamflow records are not sufficient to accurately evaluate a drawdown project. A method of "routing" the runoff through lake(s) upstream of the various control structures is necessary. After routing the several years of historic runoff to the lakes through the control points under an assumed operating plan the data for water levels and discharges will be different than the historic data. The new data can then be evaluated to estimate probabilities of selected important parameters.

Over 35 years of stream flow and lake stage data are available. Most of the hydrologic data used in this study has been obtained from these records. The data were used to estimate the net monthly mean inflow to Lake Griffin for the period of record. To accomplish this a continuity equation was used as follows:

$$IB + IY + IU + P + W - QMB - E + G = DS/DT \qquad (1)$$

Where:

IB = Burrell Discharge

IY = Lake Yale Discharge

IU = Uncontrolled surface runoff from the Lake Griffin drainage area

P = Precipitation falling directly on Lake Griffin

W = Total wastewater inflow to Lake Griffin

QMB = Moss Bluff Discharge

E = Evaporation from Lake Griffin and C-231 Channel

G = Ground Water seepage into Lake Griffin

DS = Change in storage volume over the time period

DT = Duration of Time Period

Gage records provide values of QMB and DS. The sum of the remaining terms (IB + IY + IU + P + W - E + G) represents the net inflow to Lake Griffin and can be estimated for a time period DT. Because data for QMB is readily available for a duration of one month, average monthly values of QMB have been used.

The net inflow to Lake Griffin (I) is obtained from:

$$I = QMB + DS/DT \qquad (2)$$

A similar method and equation was used to estimate net mean monthly inflows to upstream lakes. The monthly flows are given in the Appendix.

Gage Data

The Moss Bluff discharge record is available from the USGS. gage number 02238500 for the periods October 1943 to October 1955 and September 1967 to present. Lake Griffin stage records are available from USGS. gage number 02238300 for October 1944 to present. Discharge records are available for another gage on the Oklawaha River at Sharpes Ferry for February 1930 to July 1968. Overlapping data for the Sharpes Ferry and Moss Bluff flow gages were used to estimate the Moss Bluff discharge record for the period of missing data. A linear regression equation was determined for each month. The correlation coefficients ranged from 0.929 to 0.993 indicating a high dependence for the two gaging sites.

The problem of homogeneity is of concern in this hydrologic system. Apopka-Beauclair and Burrell control structures were built in 1957. These structures and the regulation schedules can be expected to have an impact on the inflows to Lake Griffin. For this reason only data since 1958 were used in the statistical analysis. Data after 1978 were not used due to uncertainty in the discharge measurements for the new Burrell structure. A total of 21 years of data were used.

Elevation-Area-Storage Relationships

Topographic and bathymetric data used in the study included previously existing data and some data obtained from field work performed during this study. A detailed bathymetric map with 2 foot contour intervals is available for Lake Griffin for as far north as Big Pine Island (Figure 3). Additionally, depth measurements are available from the Corps of Engineers Examination Survey Project in 1977, FGFWFC measurements made in 1977 and 1978, and SJRWMD soundings completed in November 1982. In areas of duplication no significant discrepancies were noted. Aerial photographs taken in 1973 with the lake stage at about 55 ft. are also useful for estimating areas at that elevation. Questions remain concerning the marsh areas at the north end of Lake Griffin. Insufficient topographic data is available to make accurate estimates of the elevation - area - storage relationships for these areas. An extensive survey effort would have been required to obtain an adequate number of ground elevations. Using all information available has led to development of the elevation - area relationship seen in Figure 6. This relation varies from some that were found from past work. It is believed that this data is the most accurate available.

Statistical Analysis of Runoff Data

Some statistical analysis of the runoff data was done. The analysis included estimation of the monthly mean discharges, the standard deviation and the skew coefficient for the uncontrolled runoff to each control structure. Monthly correlation coefficients (correlation of flow during a month to flow during the previous month) were calculated. This data is given in the Appendix.

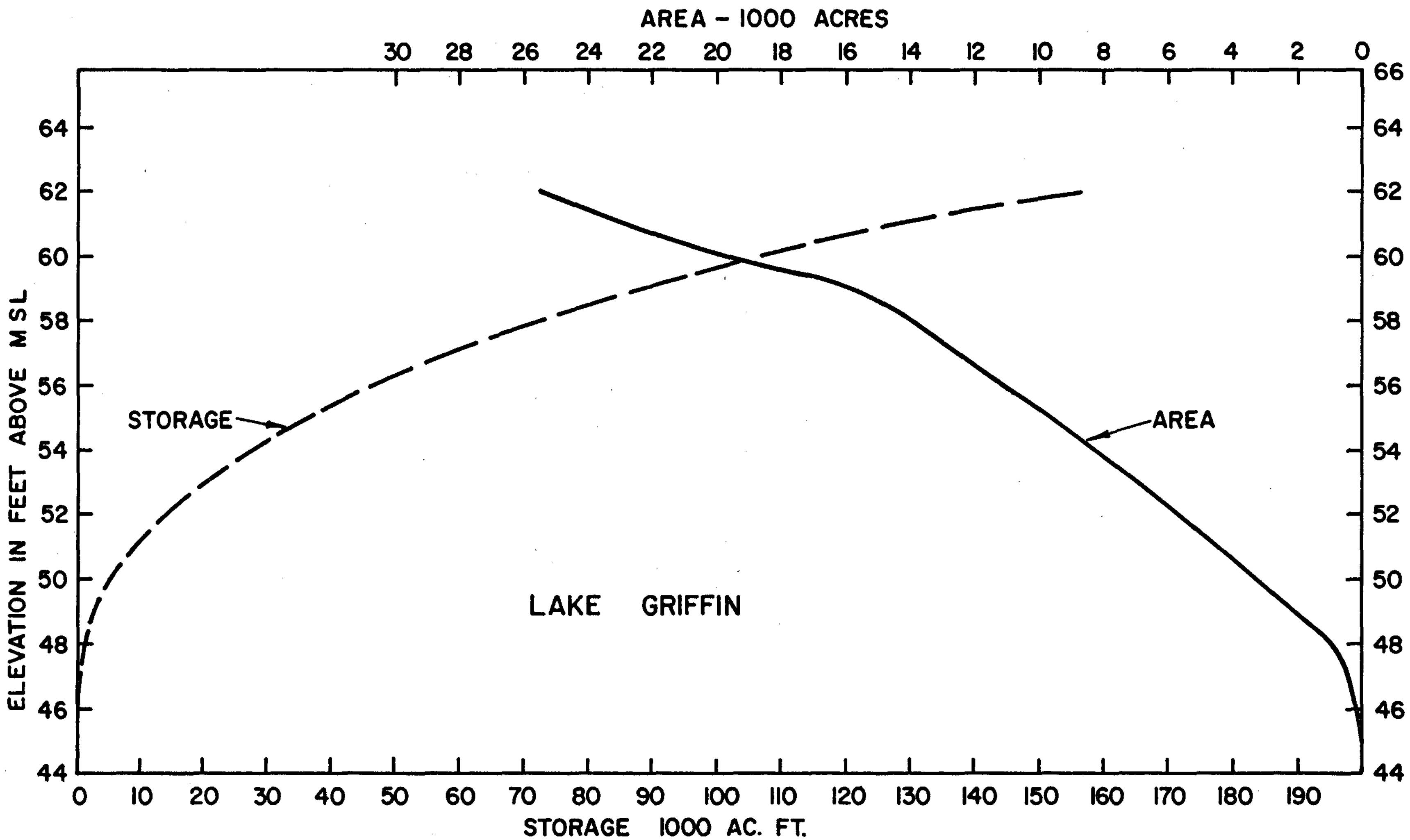


FIGURE 6. Lake Griffin Elevation - Area Storage Curves.

Annual data was estimated for the total drainage area upstream of Moss Bluff. This data is seen in Table 3.

TABLE 3.

TOTAL NET RUNOFF UPSTREAM OF MOSS BLUFF

Year	*Mean Annual (cfs)	Year	Mean Annual (cfs)
59	348	69	327
60	985	70	610
61	1227	71	405
62	224	72	204
63	68	73	140
64	211	74	210
65	367	75	164
66	316	76	170
67	401	77	180
68	100	78	42
		79	132

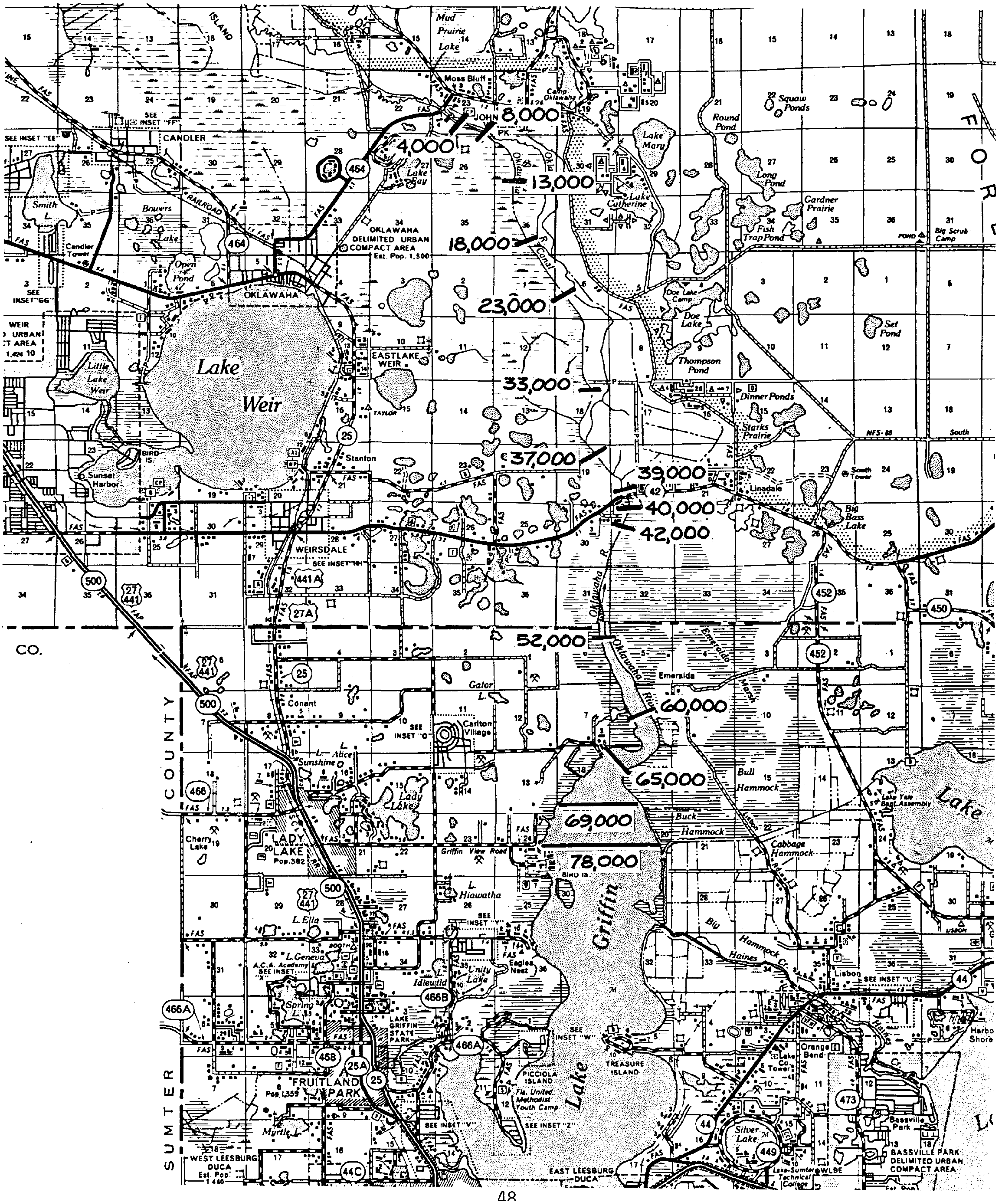
Annual mean = 325.
*Based on Calendar year

Hydraulic Data

To evaluate the capability of the Moss Bluff structure and the C-231 channel to drawdown Lake Griffin and hold it down during a storm, an existing rating curve or water surface elevation versus discharge relationship, for the structure was used and water surface profiles were calculated using the Corps of Engineers HEC-2 computer program. Cross section data for the model were obtained from as built plans where applicable. Cross sections south of SR 42 were obtained from recent soundings. Locations of the cross sections are seen in Figure 7 and plots

CROSS SECTION LOCATION MAP

FIGURE 7.



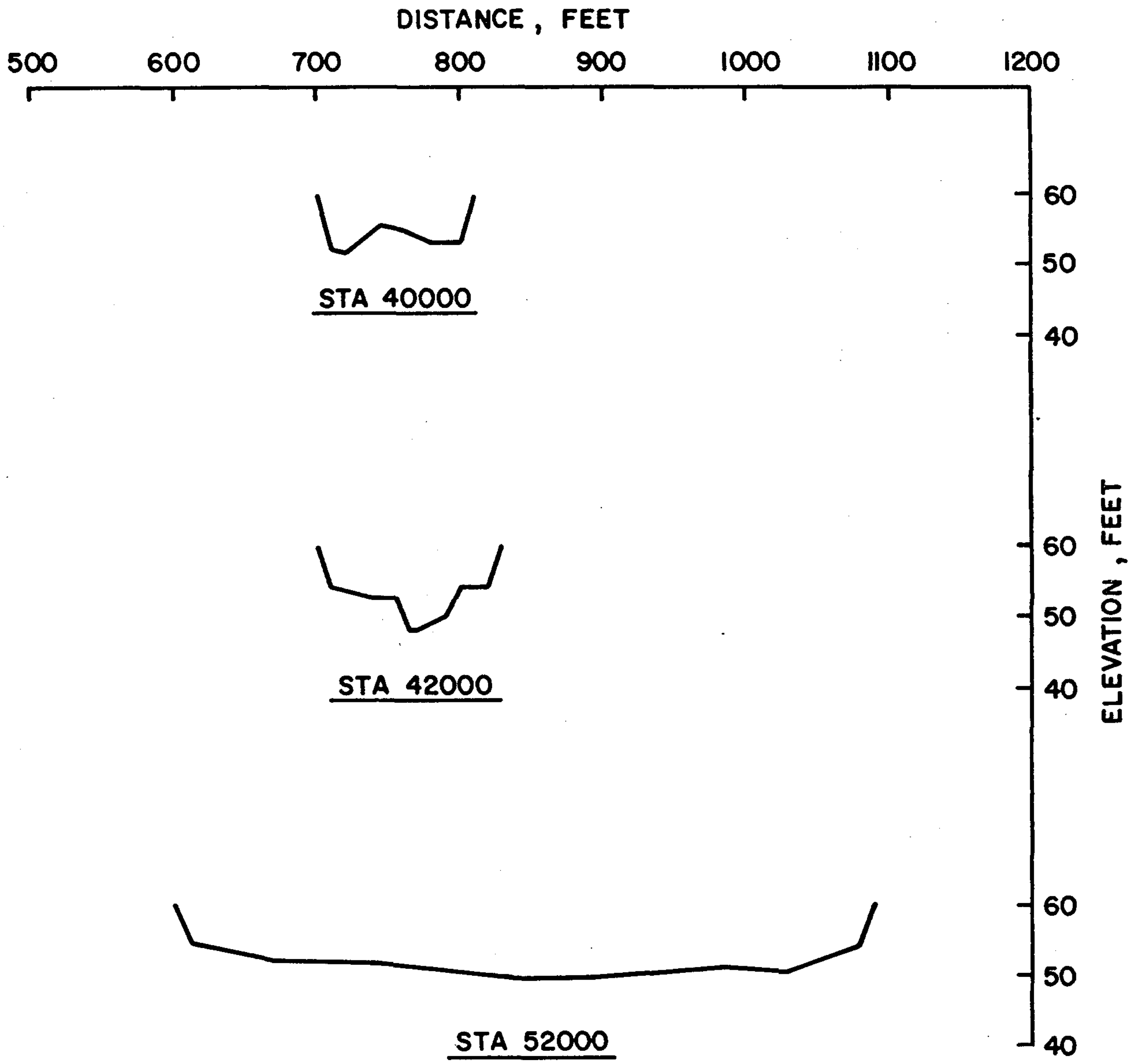


FIGURE 8a. Channel Cross Sections.

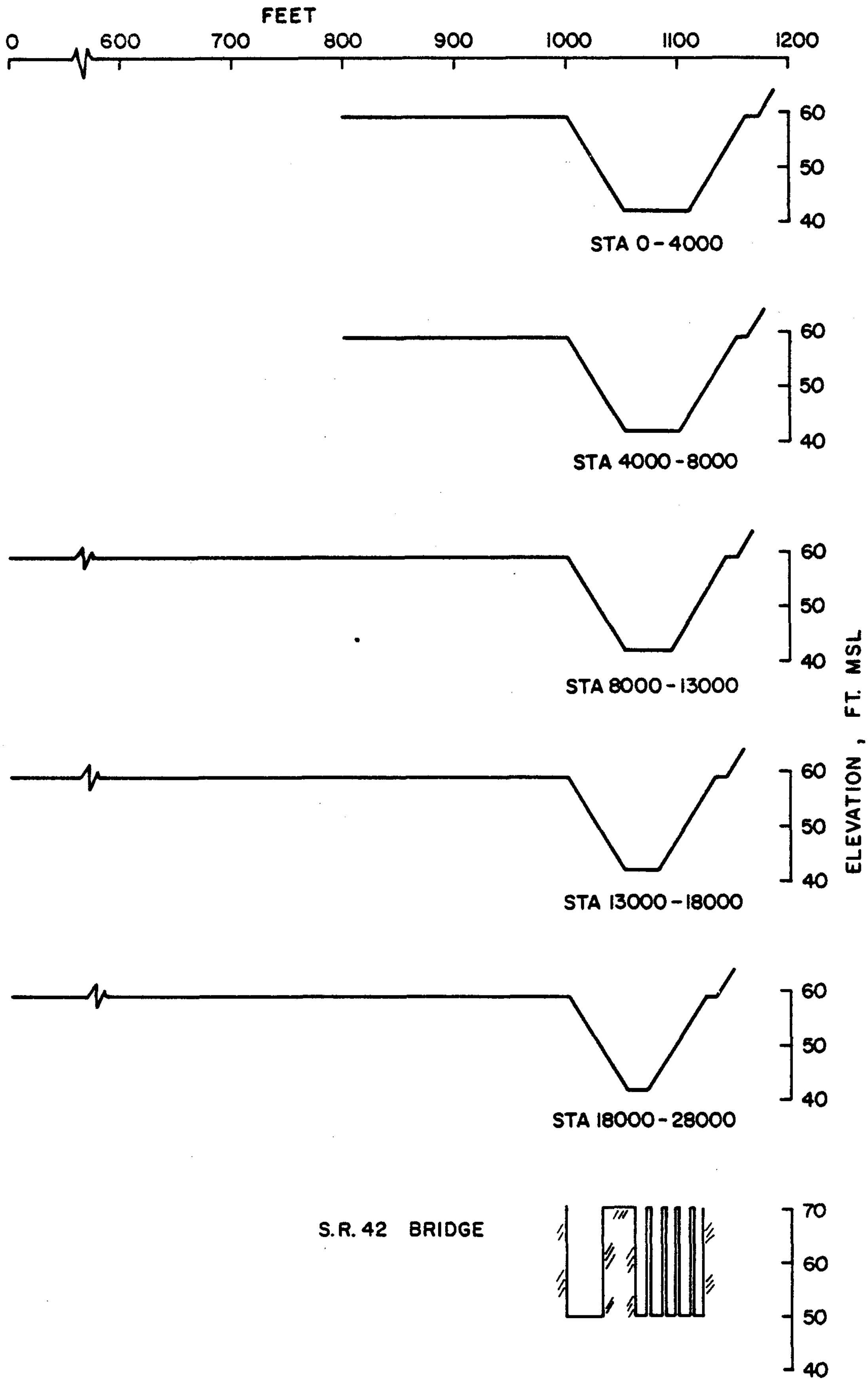


FIGURE 8b. Channel Cross Sections.

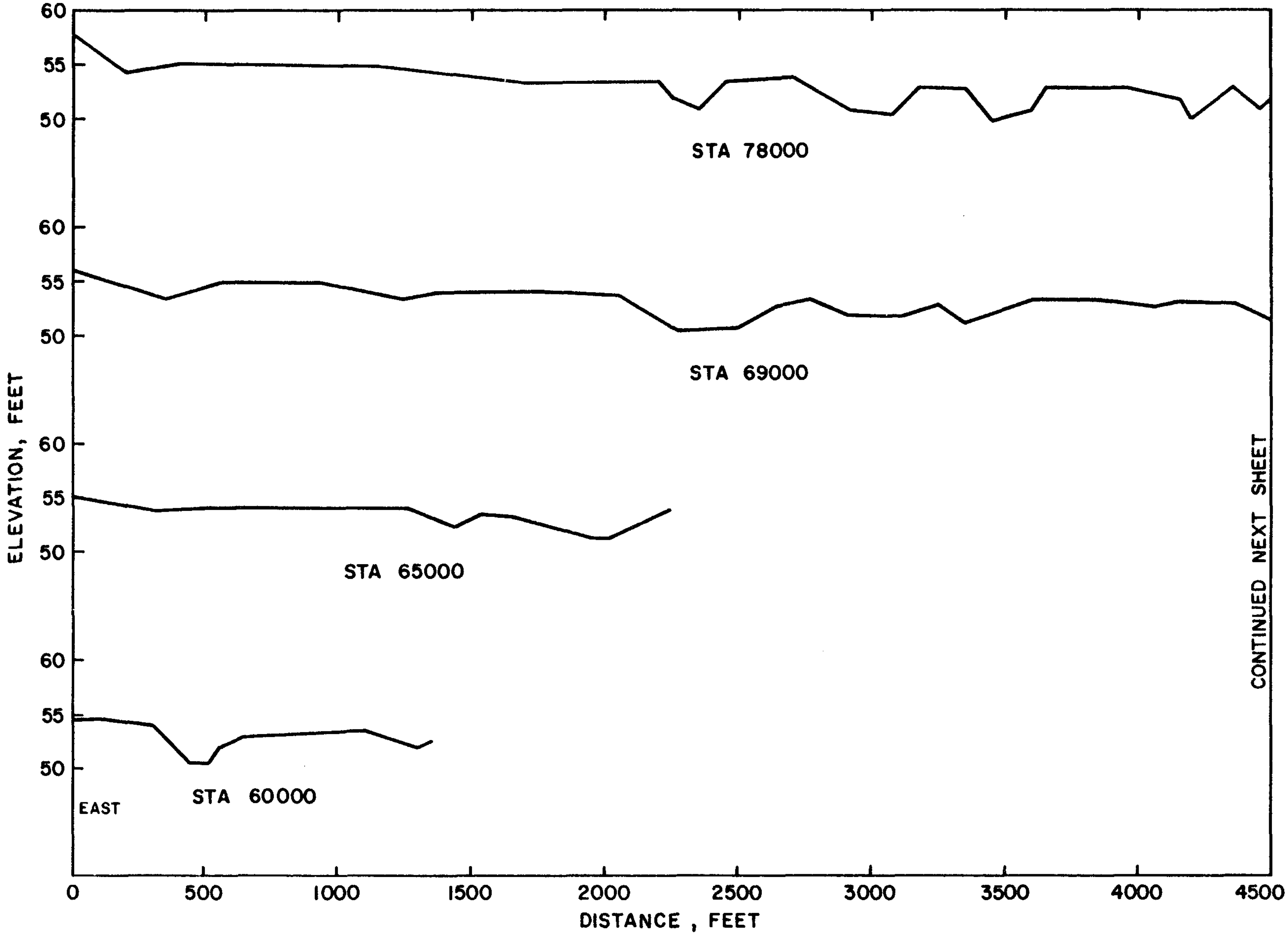


FIGURE 8c. Channel Cross Sections.

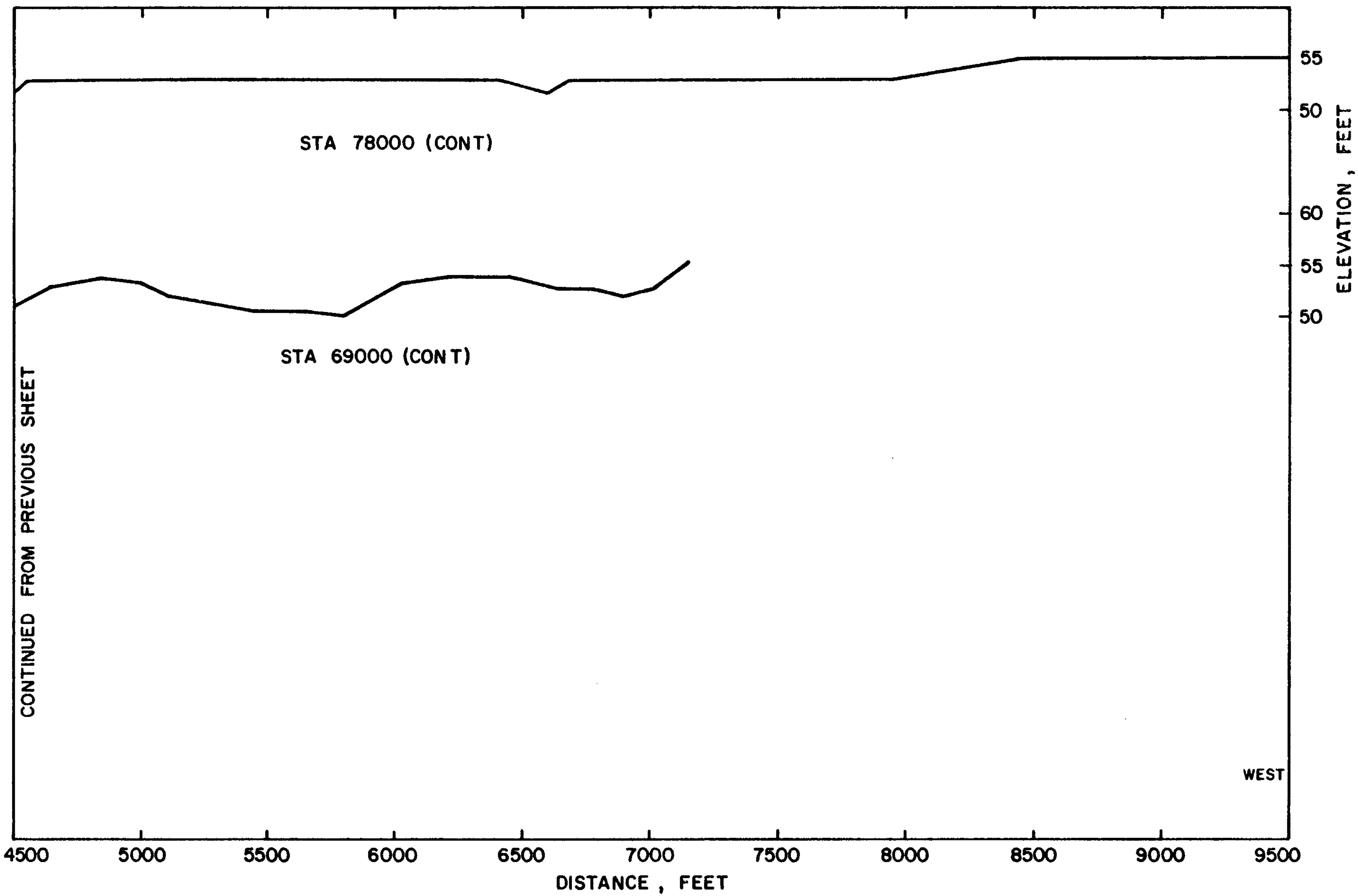


FIGURE 8d. Channel Cross Sections.

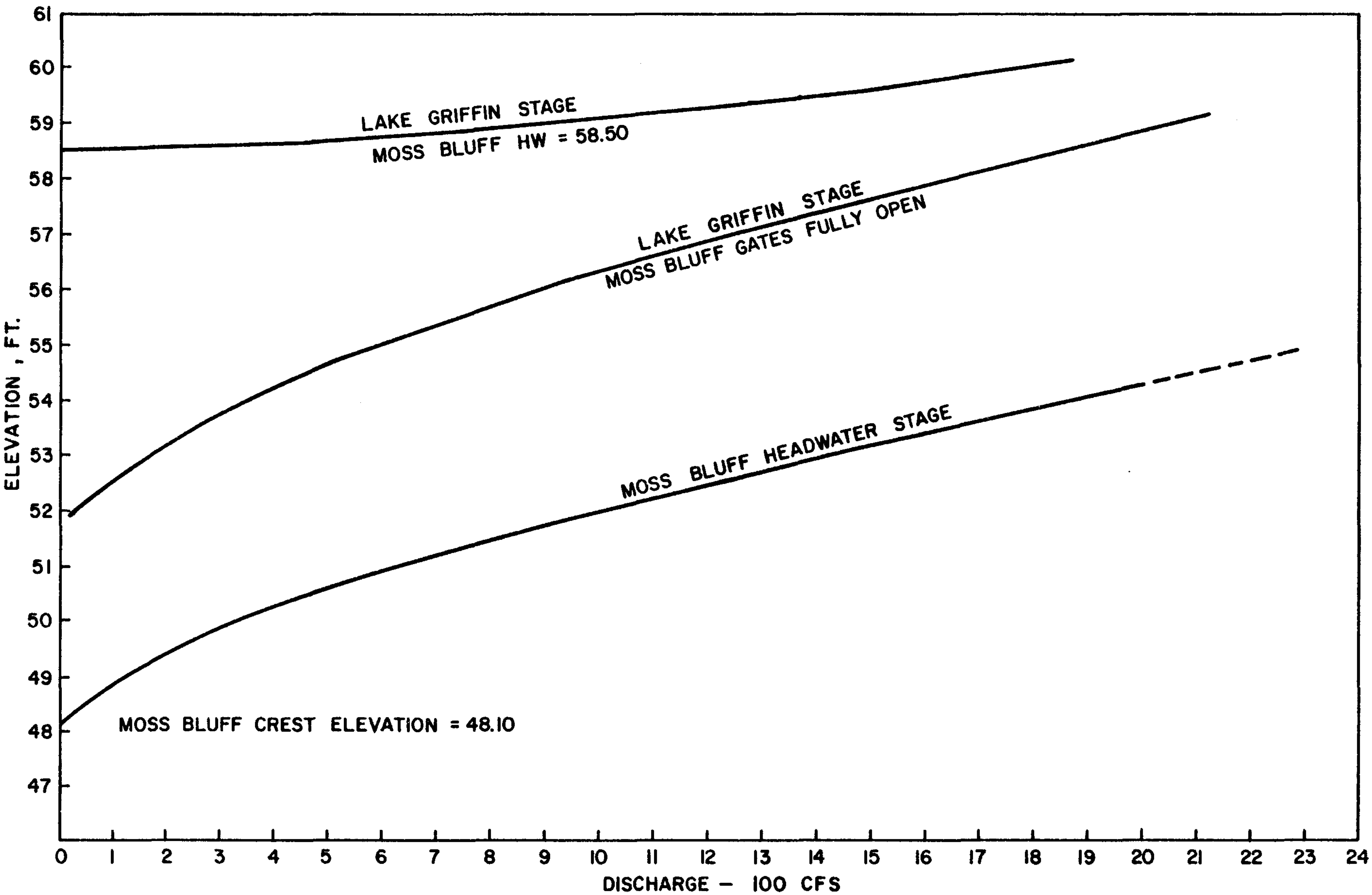


FIGURE 9. Lake Griffin Rating Curves.

are seen on Figure 8. The model was calibrated by reproducing recorded profiles. The head water elevation from the Moss Bluff rating curve with the gates fully open was used as the starting water surface elevation for a wide range of discharges. The result of this is the rating curve seen on Figure 9.

ROUTING

Methodology

To evaluate the outcome had a drawdown been conducted in each year of record under an assumed plan, a computer model was used. The model routed net monthly mean flows through the three control points, Apopka-Beauclair, Burrell and Moss Bluff structures. Input to the model included net monthly mean flows for the period of record, stage-storage-discharge data, and a regulation schedule for each control point. At each time step the routing was carried out from upstream to downstream. The only objective at each successive control point was to discharge at a rate which would meet the regulation schedule given the uncontrolled runoff for that time step and the inflow from upstream releases. This was accomplished within the constraints of hydraulic capacity of each structure. The routing proceeded in the downstream direction without regard for conditions downstream; that is, no adjustment in discharge was made due to lake stage downstream being either above or below regulation.

An option in the program allowed decision making for going ahead with the project or for canceling the project for that year. The decision making parameter used was mean runoff to the three routing points over a specified time period prior to scheduled beginning of the drawdown. The project could be cancelled any year the mean runoff was outside the specified range.

Net monthly mean flows estimated as described above were used. The underlying assumption for this are that 1) the drawdown will not make significant impacts on the net uncontrolled inflows to the system under normal conditions and 2) the hydrologic characteristics of the basin in the future will be similar to the period from 1958 through 1979. Alterations which could theoretically have an impact are changes in evaporation due to changes in lake surface area, and changes in seepage due to changes in water level.

Changes in evaporation were accounted for in the model by estimating the reduction in evaporation losses. Long term mean monthly lake evaporation rates were applied to the change in lake surface area from normal and the resultant decrease in loss was added to the inflow to Lake Griffin in each month of simulation.

The assumption of no change in seepage could lead to either a positive or negative error, depending on whether seepage is into or out of the lake. The drawdown is not expected to impact the Floridan Aquifer unless a significant hydraulic connection, such as an artesian spring, exists within the lake. In that case the lowered potential, or head, created by lowering the water surface would cause an increase in discharge to the lake, or decrease in recharge to the aquifer depending on the relative location of water and potentiometric elevations. Although the existence of one small spring near the southeastern bank of Lake Griffin is known, it is believed that no significant changes in ground water flows is likely.

It is known that the drawdown will cause a lowering of the water table surrounding the lake over what would have existed under normal conditions. The lower water level in the lake would increase the difference in elevation of the phreatic surface between the lake and upland areas, thereby increasing the seepage to the lake and loss of storage for the upland water table aquifer. The seepage from the lake to the muck farms would be decreased due to a decrease in head difference. From the point of view of lake drawdown capabilities, all seepage changes are believed to be insignificant.

Results of Routing

Because of the many parameters involved in the routing, the significant parameters were varied individually and compared against a "base case" to determine the impacts of changing that parameter. These results are discussed below.

The impacts on probabilities of a "successful" project of various parameters were evaluated by trial. A wide range of plans was evaluated initially and ones showing greatest potential were evaluated in more detail. Trade offs in low stage versus refill by a selected date are necessary because of the competing objectives of sediment consolidation, freeze protection, etc. To aid in identifying each plan or routing simulation, an alphabetic identifier was given to each simulation.

For plan A the drawdown schedule was essentially the same as that initially proposed by FGFWFC as seen in Figure 10. The regulation schedule and the proposed drawdown schedule represent elevations at which it is desired to maintain the lake level at any time during the year. Whether or not the lake stage is at regulation depends on inflow and discharge capabilities for the system.

The regulation schedules for plan A are seen in Figure 11a. The solid line in Figure 11 indicates current regulation schedules while dashed lines indicate schedules for each drawdown plan. Plan A would lower Lake Griffin from 59.25 on January 1 to elevation 58.0 on February 1 where it would remain during February. On March 1 the drawdown would actually begin with a target elevation of 51.5 feet on April 1. As will be seen later there is no reasonable chance of actually lowering the lake to elevation 51.5 feet in one month. Refill would then begin on July 1. Again the schedule

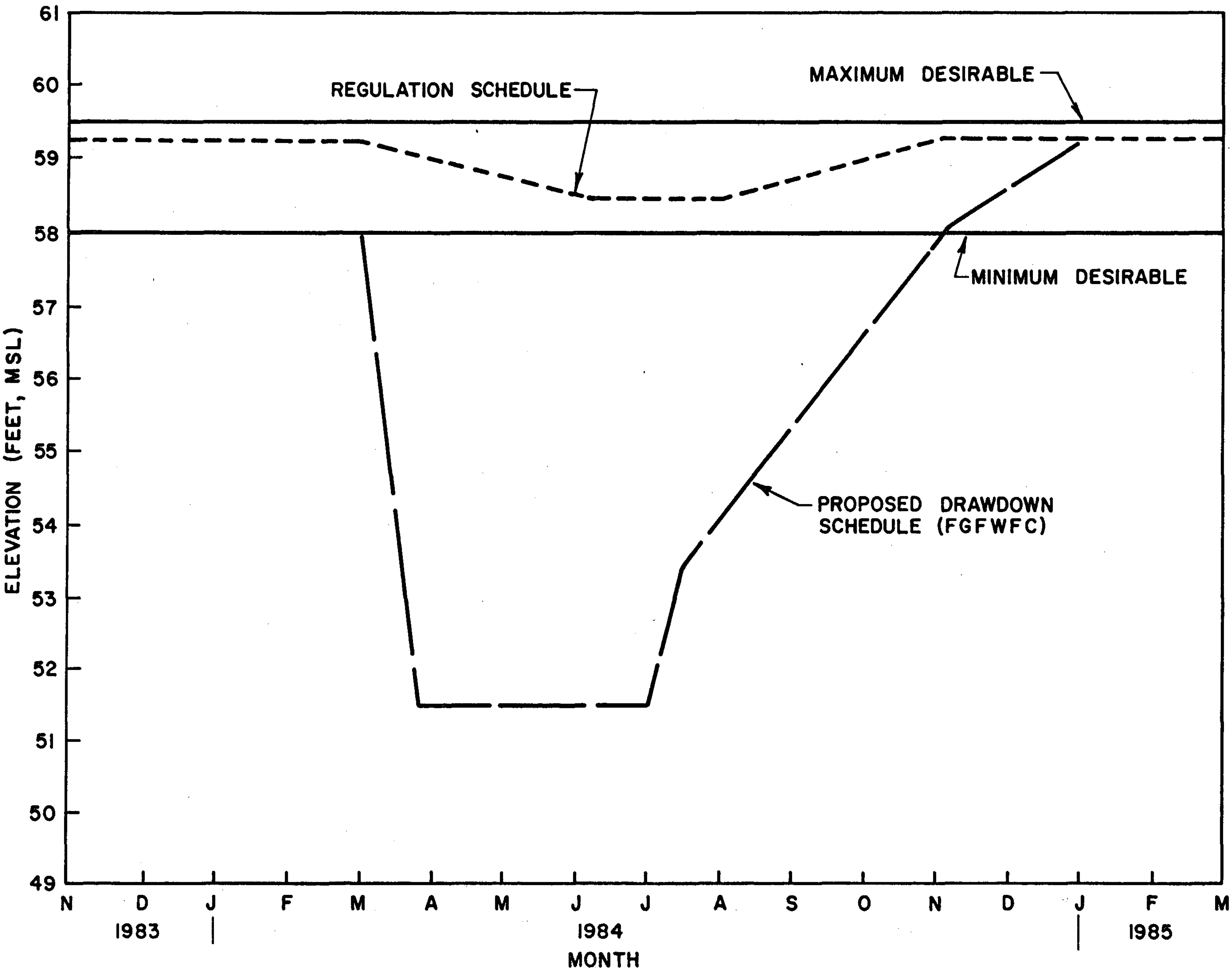
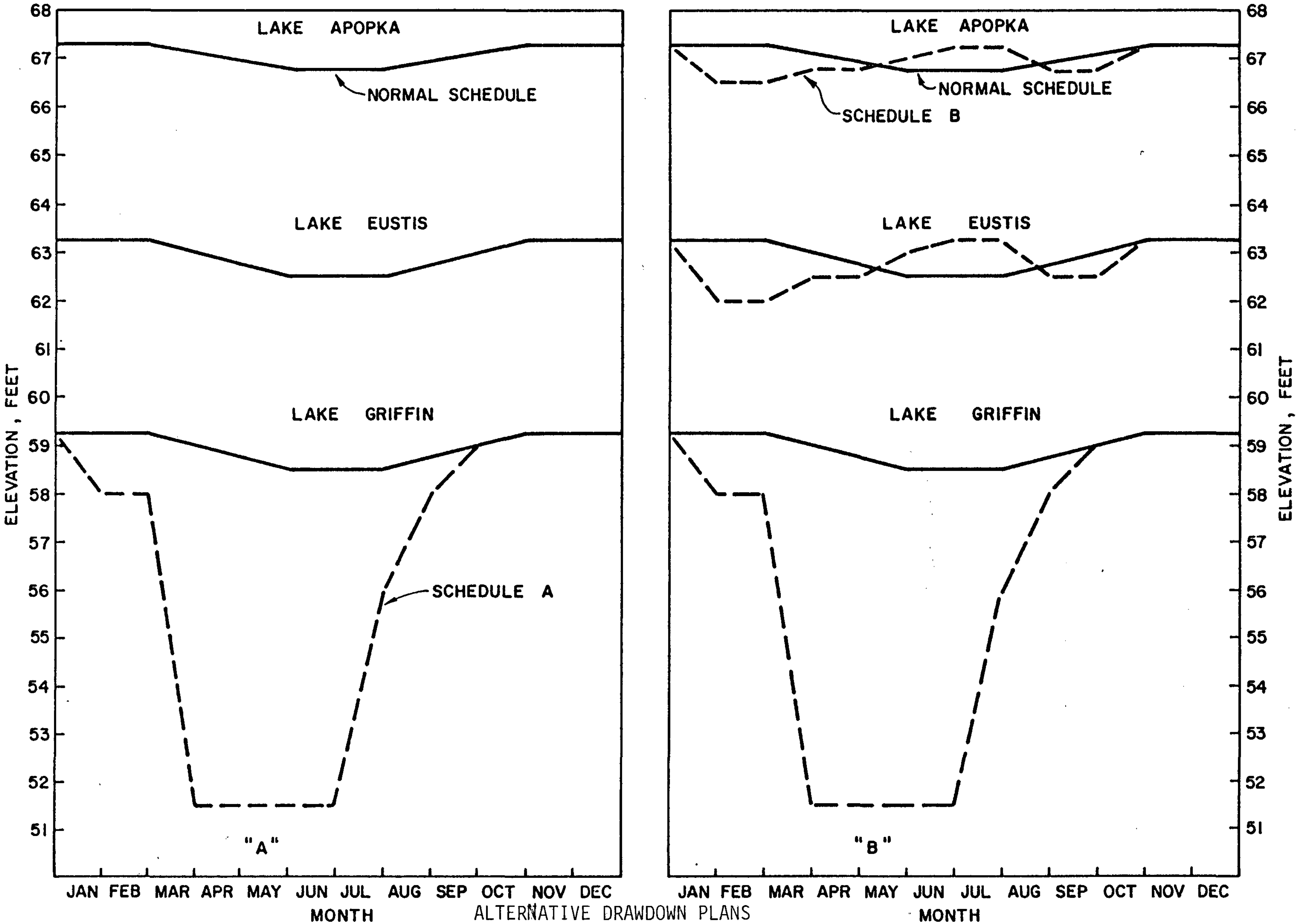


FIGURE 10. Drawdown Schedule Proposed by FG&FWFC.



ALTERNATIVE DRAWDOWN PLANS
FIGURE 11 a.

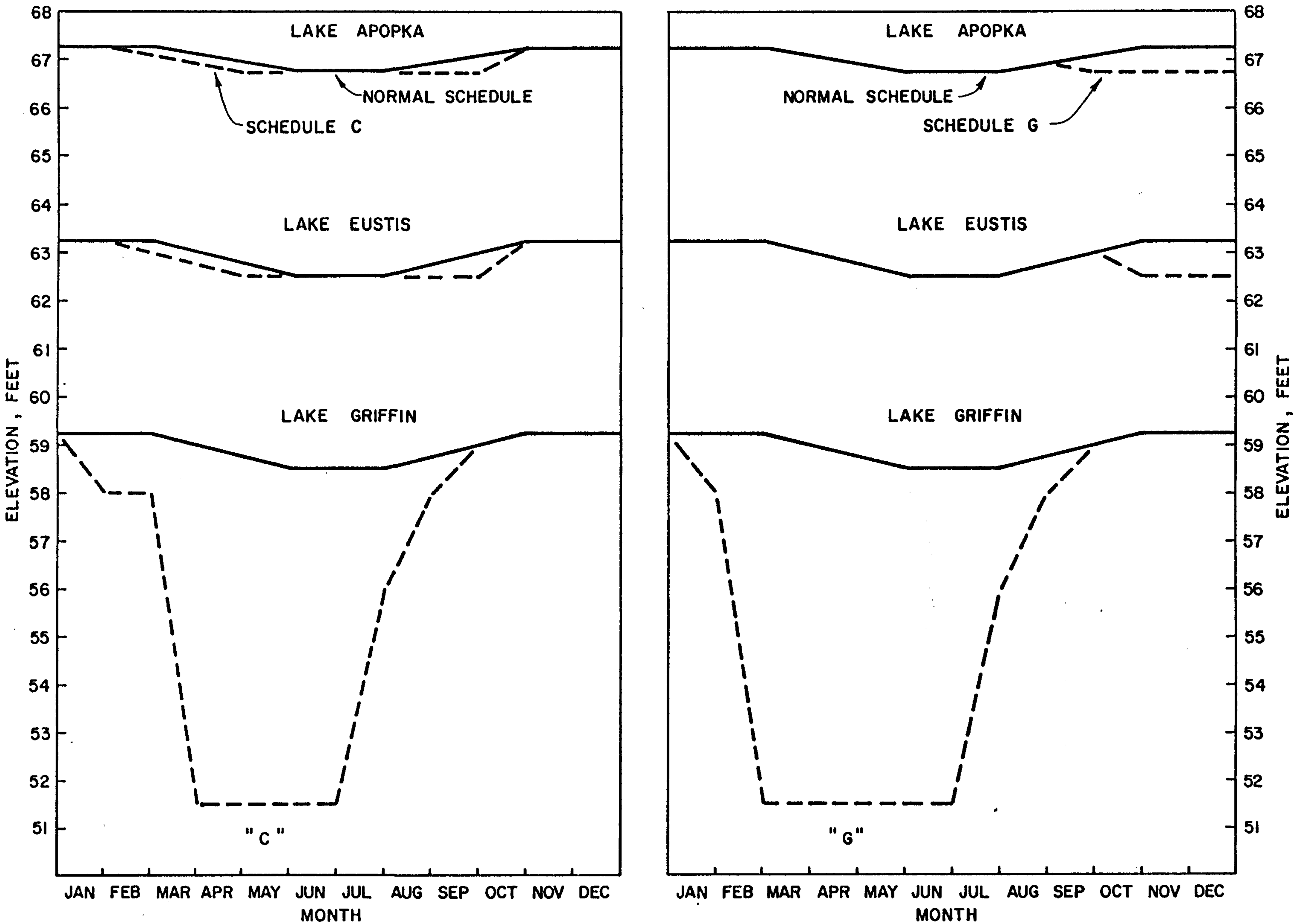


FIGURE 11b. Alternative Drawdown Plan.

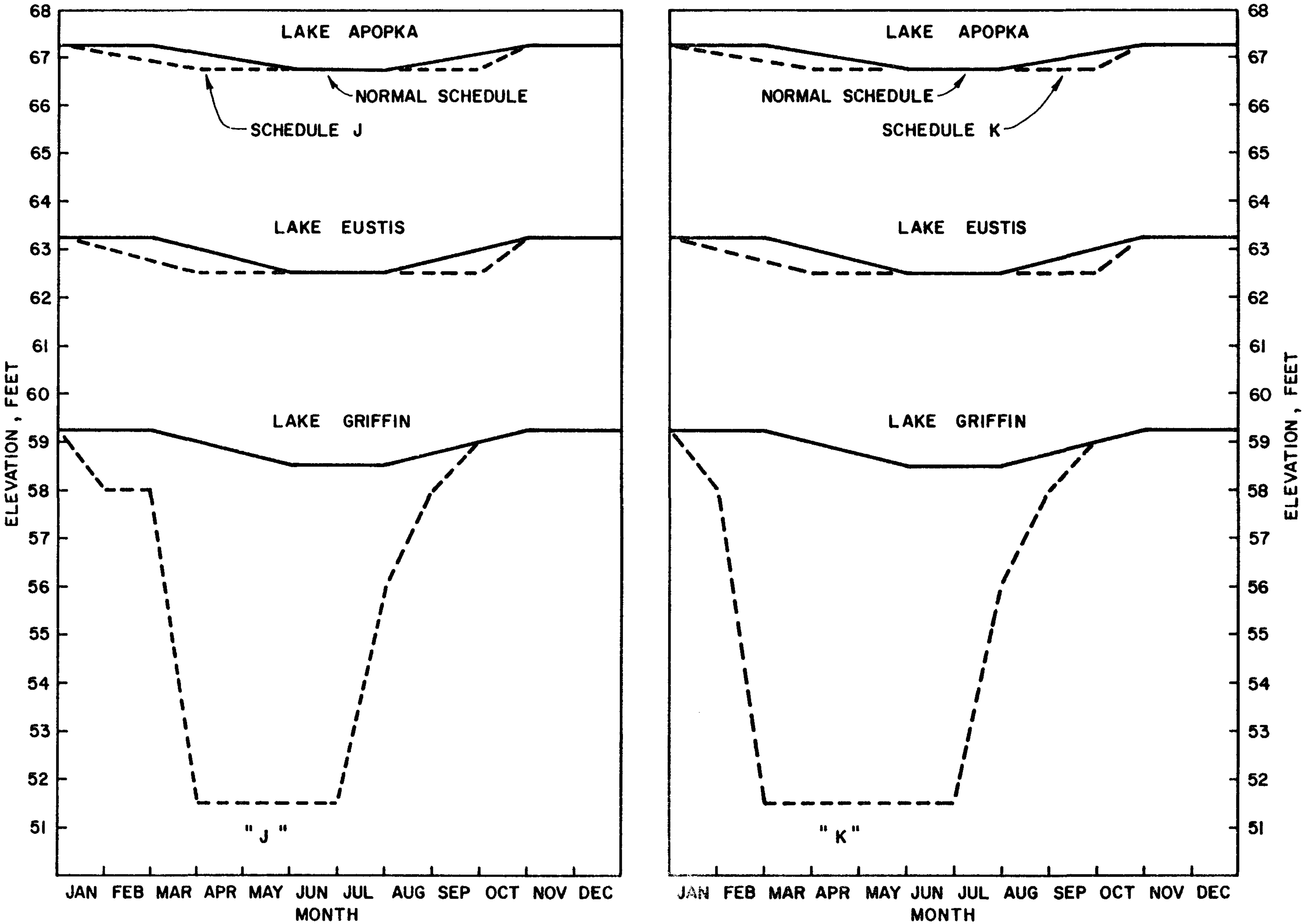


FIGURE 11c. Alternative Drawdown Plan.

indicates only the desired lake stage during refill. The actual stage will depend on the inflow during the summer and fall months.

Whereas schedule A plans no alteration of upstream lake regulation schedules, plan B calls for the most extreme change of any plan. In fact, plan B is considered unacceptable. This is due to the high lake stage set down under plan B for the high rainfall months. The increased potential for flood damage with plan B is not acceptable. The simulation was made to evaluate the most favorable plan considering Lake Griffin alone. The remaining regulation plans are self explanatory. Generally, the objective of altering upstream regulation schedules is to reduce upstream releases from storage during the Lake Griffin drawdown and hold down periods and to delay refill to allow additional inflow to Lake Griffin for refill.

The results of the simulation, or routing model, for six selected years under plan A are seen in Figure 12. This figure is included only for descriptive purposes. The six years of data plotted on this figure are representative of the range of drawdown results. The majority of the remaining years are similar to 1967 and 1976. It is apparent from Figure 12, however, that the drawdown rate is very likely to be much slower than the regulation schedule indicates.

The impact of postponing the drawdown to another year due to either high average runoff or low average runoff during a period immediately preceeding the planned drawdown was evaluated. By doing so it was hoped to determine a parameter which improve the probabilities of success. Various ranges of acceptable flows were tried. Setting a lower limit on pre drawdown average runoff did not significantly affect the probabilities of achieving a given target stage. Only a relatively large value of maximum discharge, provided improved probabilities of achieving a target lake

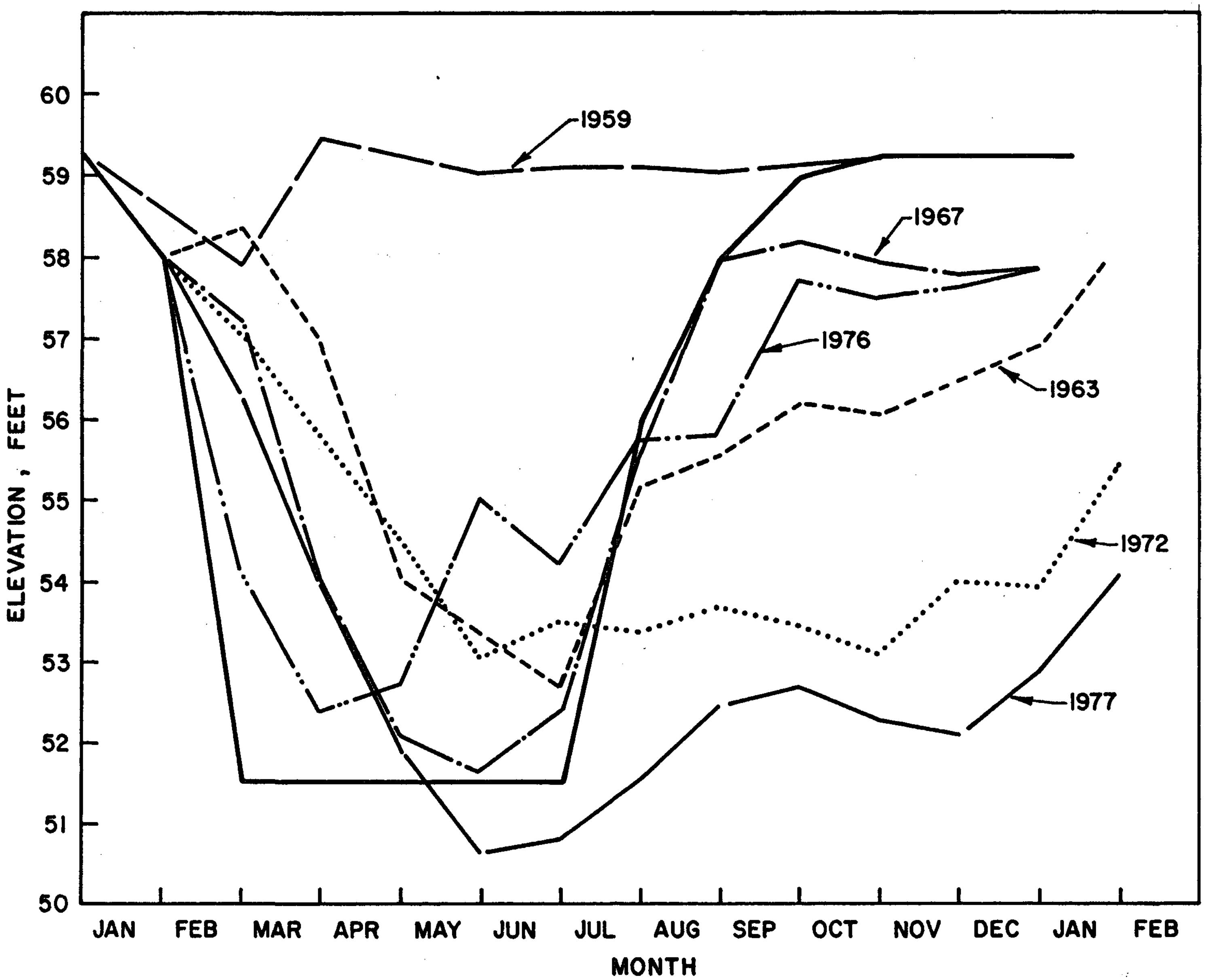


FIGURE 12. Simulated Drawdown Results for Selected Years of Record.

stage. The best results were achieved if drawdown was cancelled for years with net mean runoff during October through December greater than 500 cfs.

Because of the uncertainties in channel conveyance, lake storage and inflow estimates the discharge rating curve at Moss Bluff and the elevation area curve for the lake were varied by 20 percent to evaluate sensitivity to these parameters. To evaluate the most extreme case for errors of 20 percent to evaluate the discharges were reduced while the area was increased and vice versa. The results indicated that significant errors should not be expected due to errors in determining these basic input quantities.

Table 4 lists the estimated probabilities of parameters important to the success, or failure, of the drawdown project. For each plan which was evaluated the two and three consecutive month low water level in Lake Griffin was determined. The data was then ranked and assigned a plotting position using Weibull's formula, m/(n+1), where m is the rank and n is the number of years of data.

For each plan and parameter in Table 4, four probabilities are given as "Probability of exceedence". The meaning of this is, for example, if plan A were implemented in any year, one year out of ten or a 10 percent probability, the 3 month low stage would exceed elevation 54.7

Obviously, lower lake levels provide more consolidation benefits and a high probability of achieving an intended low water level is desirable. It is seen in Table 5 that plan B would be expected to yield the best consolidation results. However, plan B is not considered acceptable due to the high water levels schedule for Burrell and Apopka during the high rainfall months of June and July. The increased risk of flooding in those areas out weighs the benefits of Plan B over other plans.

TABLE 4

DATA FROM SIMULATED REGULATION PLANS

	PROB. OF EXCEED.	A	B	C	G	J	K	L
LAKE GRIFFIN:								
3-MO LOW STAGE	10%	54.7	53.2	54.6	54.1	55.0	54.5	54.3
	20%	54.3	53.0	54.2	53.8	54.5	54.2	54.0
	50%	53.6	52.7	53.5	53.3	53.6	53.5	52.8
	80%	52.9	52.2	52.5	52.8	52.7	52.5	52.0
2-MO LOW STAGE	10%	53.6	52.9	53.6	53.6	53.4	53.2	53.2
	20%	53.4	52.4	53.0	53.2	53.0	52.9	52.2
	50%	53.0	52.2	52.5	52.8	52.6	52.5	51.9
	80%	52.4	52.0	52.0	52.2	52.2	52.2	51.6
NOV.1 STAGE	90%	53.0	52.8	53.7	53.6	53.7	53.7	53.0
	80%	55.4	54.8	56.8	57.0	56.8	56.8	56.2
	50%	58.4	58.4	58.9	59.2	58.8	58.8	58.8
	20%	59.1	59.2	59.2	59.3	59.2	59.2	59.2
JAN.1 STAGE	90%	54.2	53.4	54.7	55.2	54.2	54.2	53.6
	80%	56.5	55.4	57.4	58.1	56.8	56.8	56.4
	50%	58.6	58.4	59.0	59.2	58.8	58.8	58.8
	20%	59.3	59.3	59.3	59.3	59.3	59.3	59.3
LAKE APOPKA:								
MAY 1 STAGE	90%	66.5	65.7	66.4	66.5	66.2	66.2	66.2
	80%	66.6	65.9	66.5	66.6	66.3	66.3	66.3
	50%	66.8	66.3	66.6	66.8	66.4	66.4	66.4
	20%	66.9	66.5	66.8	66.9	66.6	66.6	66.6
NOV.1 STAGE	90%	66.4	66.1	66.2	66.3	66.2	66.2	66.2
	80%	66.7	66.3	66.4	66.4	66.4	66.4	66.4
	50%	67.0	66.6	66.6	66.6	66.6	66.6	66.6
	20%	67.2	67.0	67.0	66.8	67.0	67.0	67.0

"J" AND "K" LIMIT DISCHARGE TO 750 CFS
"L" IS WITH DREDGED CHANNEL AND LIMIT DISCHARGE TO 1000 CFS

There are two important factors to be considered in addition to the Lake Griffin drawdown elevation. One of these is impact on upstream water level. It is seen in Table 4 that for plan A, with no alteration of current regulation schedules for Burrell and Apopka, there is a 10 percent probability that the Lake Apopka stage will be below 66.4 on November 1.

November 1 has been selected because it is the earliest expected date that a freeze event might occur in the region. Because of the temperature modification impacts the lakes are believed to have on the surrounding citrus groves, the lake stages on this date and later are important. Studies of this phenomena have predicted no significant change in temperature modification south of Lake Apopka unless Lake Apopka stage falls below the normal summer regulation schedule. This elevation is believed to be well above any which might increase freeze damage risks.

A second important consideration beyond drawdown stage in Lake Griffin is water quality of releases from Moss Bluff to the Oklawaha River and, in particular, turbidity. Under normal conditions even high discharges do not produce high turbidity because of the high lake levels at which these occur. The depth is sufficient to maintain fairly low velocities which have a low sediment carrying capacity. When the lake stage is lowered and high discharges are made, however, the velocity must increase with a resultant increase in transport capacity of suspended and bed material.

This problem is intensified because of the increased potential for resuspension of sediment in the lake. This is expected because of the increased orbital velocities generated by waves. Orbital velocities naturally decrease with depth of water. If the water depth is decreased, greater forces are therefore exerted on the bed which tend to resuspend the non cohesive material. The suspended material could then be carried downstream. The rate at which it is carried downstream would depend on the flow.

An additional result can be expected from the resuspension of sediment. Because the sediment is highly organic, when resuspended it could exert a biochemical oxygen demand which would reduce the dissolved oxygen concentration in the water.

Hydraulic analysis of the system indicated that discharges above about 750 cfs while the lake stage was low would lead to rapidly increasing sediment transport rates and related problems. For this reason, plans J and K were simulated with a maximum discharge at Moss Bluff of 750 cfs for lake stages below 58.0 feet.

Dredging a channel through high points in the C-231 canal and the north end of Lake Griffin would improve drawdown capabilities and reduce sediment transport problems. To evaluate this alternative a trapezoidal dredged channel from just downstream of the SR 44 bridge to Little Pine Island with a bottom width of 10 feet and invert at elevation 45.0 feet was assumed. Such a channel would require dredging approximately 250,000 cubic yards of material. The cost of dredging is highly dependent on spoil disposal. Plan L includes these assumptions. Examination of the probabilities for this plan indicates only small improvements. Consideration of the uncertainties of benefits in relation to the additional drawdown achieved suggests that dredging is not a desirable alternative.

SOCIO-ECONOMIC EVALUATION

To better understand the costs, benefits and impacts of a drawdown, a number of drawdown alternatives were evaluated without regard for funding feasibility. At one end of the spectrum is a project which would have no project costs as far as construction or maintenance. At the opposite end is a project with all the engineered works necessary to drawdown Lake Griffin to a very low stage with a high probability of success.

Each project would create benefits and costs to the public which have been estimated as described below.

Cost to Residential Water Front Property Owners

A drawdown would create what can be considered a temporary cost to owners of residential water front property. Water front property, whether it be lake front or canal access, typically has a higher value. This higher value is established on the market by benefits related to boating access or scenic value. Although it can be argued that under natural conditions periodic droughts would cancel those benefits it is assumed in this study that a cost will be incurred by those property owners.

The method used for assigning a cost considers the water front property to have a value no different than non-water front property during the drawdown period. The difference in value of water front versus non water front property was used to estimate a "cost" value to the property owner.

Statistics compiled by the Board of County Commissioners, Lake County, Division of Development and Public Works, was used to estimate this incremental value. Comparison of three bedroom non water front home prices with water front home prices over the years 1979 through 1981 indicates an average difference in value of about \$26,000. The difference is a sum of two components, however. Water front property can be expected to have both a higher lot value and a higher structure value. It was assumed that 50 percent of the \$26,000 difference, or \$13,000 is a result of lot, or "location", value. For the purpose of this cost estimate it was assumed that the cost could be estimated as the annual interest on the difference in value of water front and non-water front lots. Furthermore, because the drawdown is expected to have a duration of only eight months, a factor of 8/12 can be multiplied to yield a cost per lot. Through field investigations and areal photographs, the total number of residential lots impacted was estimated at 300. Assuming an average interest rate of 10 percent, the total cost to water front residential property owners is assigned a value of

$$300 \text{ lots} \times .10 \times \frac{8 \text{ months}}{12 \text{ months/year}} \times \$13{,}000 = \$260{,}000$$

It is important to recognize that this cost is a measure of the inconvenience experienced by the current residents and not a loss in property value. Actual property values could conceivably increase due to the drawdown as a result of the improved fishery in Lake Griffin.

Dredging Costs

Dredging a channel for improved drawdown capability and reduced sediment problems was evaluated in Plan L. This included removal of approximately 250,000 cubic yards of material. The cost of this amount of dredging is expected to be approximately \$750,000.

Irrigation Costs

Citrus within approximately 1,000 feet of the lake may require additional irrigation due to the expected lowering of the water table. The amount of additional irrigation required will depend on the rainfall during the drawdown as well as other factors. Recent data (Harrison et. al., 1982) indicates an operation and maintenance cost of about $3 per acre inch for under tree systems and about $11.50 per acre inch for traveling gun systems.

Cost to Fish Camps

Because the prime season for fish camp and tourist related business runs only through March and because the long term benefits from an improved fishery are expected to outweigh short term losses to these businesses, no cost was assigned to them.

Project Benefits

The drawdown is expected to benefit sportfish population in Lake Griffin. Placing a value on a recreational fishery is a nearly impossible task. However, direct benefits included increase demand for fish camp facilities or other fishing recreation facilities as well as individual recreational use. Benefits may also occur from retail sales of fishing equipment, rentals, lodging and meals. As each of these businesses benefit the effects are passed on throughout the economy of the region.

Previous studies have calculated benefits based on fish population increases and a unit value assigned to the fishery resource. Estimation of the unit value, usually in dollars per pound, has relied on data for value of fish killed by pollution. The source of this data was "Fish Values" a

Florida Department of Pollution Control publication (adopted from an amendment of Chapter 70-141 Section 403.141, Florida Statutes by 1970 legislature).

Calculating a benefit based on a fish value approach requires estimating the increase in fish attributable to the drawdown. Lack of understanding of the effects of a drawdown on vegetation and fish populations make this difficult. Estimates must rely on a limited number of previous experiences.

The increase in fish can be estimated from the data collected for Lake Tohopekaliga. The two lakes are different and impacts can not be expected to be totally similar. This is, however, the best available quantitative data. The fish crop increased in Lake Tohopekaliga from 191 ponds per acre to 455 pounds per acre in littoral areas and from 59 pounds per acre to 127 pounds per acre in the limnetic areas. Using published fish values pre drawdown fish crops translated to \$321/acre and \$1333/acre for limnetic and littoral zones, respectively. Assuming similar impacts on Lake Griffin as occurred on Lake Tohopekaliga where the fishery value was estimated to increase by 37 percent the benefit could be estimated at nearly \$4.7 million.

Estimation of economic benefits using this method is arbitrary. It does not consider such fundamental economic concepts as the "utility" or economic value of the fish on an incremental value basis.

Another method of estimating benefits is based on the value of a recreational experiences. The number of user days and a unit value, usually in dollars per day, can be used to calculate a value of the resource. The unit value is often estimated based on a willingness-to-pay concept, or what a user is willing to pay for the recreational experience including travel, equipment and other related expenses. Many publications have suggested dollar values for a man day on a fishing outing. The values range form approximately $10 to $80 per day varying with geographic region and different situations. A value of $45 per man day is approximately average.

Data collected by FGFWFC for Lake Griffin during the 1970's is available to estimate the impact of the 1973 accidental drawdown on fishing use as measured in man hours. The average use during '70-'72 was 183,148 man hours/year. The use after the drawdown for years '74-'79 averaged 228,848 man hours/year. Assuming the increase of 45,700 man hours/year was due to the improved fishery, it can be used to estimate a benefit. If a man day for a fishing outing is assumed to be 4 hours the benefit is approximately 45,700/4 x 45 = $514,125/year.

Using a discount rate of 9 percent and a period of 7 years the present worth value is approximately $2.6 million.

DRAWDOWN PROJECT IMPLEMENTATION

The previous discussion of expected impacts of a drawdown and the complexities involved, all indicate that many uncertainties exist. Evaluation of the costs, benefits and probabilities associated with each alternative plan all required certain simplifying assumptions. While these assumptions are believed to be adequate for evaluation of the feasibility of conducting a drawdown, the actual implementation would require many judgement decisions. For example, certain parameters were investigated which should reasonably be expected to improve the likelihood of a successful project. These were the runoff rates previous to onset of the drawdown. Data indicated that no lower limit on acceptable range for runoff previous to the scheduled drawdown improved the chances of success, while canceling drawdown for years with average runoff upstream of Moss Bluff greater than 500 cfs during October through December increased the chances. This resulted from only 20 years of data, however, out of which only 4 years contained this information. Obviously, this number of samples is not sufficient to yield highly accurate estimates of the actual situation. Judgement would therefore be necessary for the final go ahead decision for the project.

Another factor which will require decisions involves discharge rates during the drawdown. Analysis has indicated that after the lake level drops below approximately elevation 58 feet the discharge should be limited to about 750 cfs to avoid excessive sediment transport problems. Observations and standard sampling methods should be used however to adjust this number appropriately. If this discharge is not creating unacceptable conditions, there is no reason to not increase the discharge thereby increasing the potential for exposure and drying of the lake bottom.

Other situations which would require remedial action could develop. There is potential for masses of plant material to develop and float following refill. This could be a problem which would require removal of the debris. If Lake Griffin did not refill to an acceptable level before the threat of freeze arose, it might be desirable to lower upstream lakes to prevent severe impacts to the Lake Griffin area.

SUMMARY AND CONCLUSIONS

The hydrologic and hydraulic characteristics of the Lake Griffin system are such that a drawdown such as that proposed to 51.5 feet can not be accomplished with a high probability of success. The benefits are limited in wet years because the hydraulic capacity of the system is not sufficient to quickly lower the lake and hold it at a desirable elevation of about 52.0 feet or lower. In the event of a dry year with a probability of occurrence of 20%, the lake could not be expected to refill above elevation 56 feet approximately by November 1 without withdrawals from upstream lakes. Large construction expenditures for dredging and/or construction of a sedimentation basin would be necessary to maximize the drawdown. Because of the relatively slight increase in drawdown expected to result from these costly engineering projects, alternatives which include such projects would not be feasible. This is particularly true if the uncertainties in drawdown benefits, or more specifically, the uncertainties of drawdown impacts on the fishery resource, are considered.

For these reasons most alternatives evaluated included no capital outlay for the drawdown project. Alternatives which would result in significant increases in flood potential either upstream or downstream of Lake Griffin, such as plan B are not considered feasible. Alternatives which include discharge at Moss Bluff up to the hydraulic capacity of system are also not considered desirable because of the potentially harmful impacts of the sediment transport which could occur. Evaluation indicates, however, that desirable results can be achieved with drawdown plans which satisfy the assumed criteria and limitations.

Project costs are those which would be temporarily borne by recreational users of Lake Griffin, and those who own or rent homes or businesses adjacent to or very near the lake. Estimating these costs is difficult because so many intangibles are involved. It might even be argued that drawdown is a reasonable management practice for a resource that would suffer droughts under natural conditions. Assuming the homeowners on Lake Griffin incurred an expense during the drawdown related to the value of those locations above non-lake front property, the cost can be estimated at approximately $260,000.

Project benefits are related to improvements in the fishery resource. This benefit, assuming an increase in fish similar to that which occurred in Lake Tohopekaliga, can be estimated at $4.7 million. An alternative method of calculating a benefit based on recreational use of Lake Griffin results in a project benefit of $2.6 million, or $514,000 per year.

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