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FINAL REPORT

ENVIRONMENTAL AND ECOLOGICAL EFFECTS OF DRAWDOWN AND ENHANCED FLUCTUATION FOR LAKE APOPKA, FLORIDA

SEPTEMBER, 1990

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ENVIRONMENTAL AND ECOLOGICAL EFFECTS OF DRAWDOWN AND ENHANCED FLUCTUATION FOR LAKE APOPKA, FLORIDA

PREPARED FOR
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PALATKA, FLORIDA

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONT.)

LIST OF FIGURES

LIST OF TABLES

SECTION 1.0 EXECUTIVE SUMMARY

The potential ecological and environmental effects of a drawdown or enhanced lake level fluctuation program for Lake Apopka were assessed by Dames & Moore for the St. Johns River Water Management District as a part of the Lake Apopka SWIM Plan initiative. An extensive literature review and personal interviews were used to formulate a synopsis of the ecological effects of water level drawdown as a management and restoration technique. The application of drawdown or enhanced water level fluctuation to the restoration of Lake Apopka was addressed by evaluating the drawdown and enhanced fluctuation literature and existing studies on Lake Apopka.

The literature review indicates that lake drawdown or enhanced water level fluctuation generally results in increased sportfish production, increased macrophyte-associated macroinvertebrate populations, and littoral zone habitat enhancement. Short-term control of nuisance vegetation frequently occurs in cold climates. Drawdown or enhanced fluctuation generally does not result in long term improvements in water quality, or the control of nuisance macrophytes in warm climates. Significant sediment consolidation typically occurs only following long (>7 month) periods of sediment exposure, and usually only down to within 2 feet of the holddown lake elevation.

The information gained from the literature review was applied to four drawdown/enhanced fluctuation scenarios developed for Lake Apopka. These are:

1. Scenario 1: Enhanced fluctuation by gravity flow and pumping from 66 ft. NGVD (normal pool) to 63 ft. NGVD. At 63 ft. NGVD, only 8.6 percent (2640 acres) of the total lake area will be exposed, although the lake volume will have been reduced by almost 60 percent. A minimal drainage canal system within the lake will be necessary.

2. Scenario 2: Drawdown by gravity flow and pumping to 62 ft. NGVD. At this lake level elevation, 6980 acres (22.7 percent of the total lake area), will be exposed and lake volume will have been reduced by almost 77 percent. A slightly more extensive in-lake drainage system will be needed.

3. Scenario 3: Drawdown by gravity flow and pumping to 61 ft. NGVD. At 61 ft. NGVD, 56.3 percent (17,357 acres) of Lake Apopka sediments will be exposed, while almost 90 percent of the original lake volume will have been discharged from the lake. Due to the relative isolation of some pockets of remaining water, an extensive in-lake system of drainage pipes or canals will be required to remove enough water to reach a water level of 61 ft. NGVD in the lake basin.

4. Scenario 4: Drawdown by gravity flow and pumping to 60 ft. NGVD. At 60 ft. NGVD, 85 percent (26,174 acres) of the total lake area will be exposed, with 95 percent of the original lake volume having been discharged. An elaborate system of miles of drainage canals or pipes will be required.

The following in-lake effects of a Lake Apopka drawdown are likely to occur:

- Extensive germination of littoral zone vegetation and increased littoral zone habitat. Under Scenario 1, increased germination may be minimal due to the small percentage of total lake sediments exposed. More extensive germination would be anticipated under other scenarios. Longevity of littoral zone habitat enhancement will likely depend upon the degree of sediment consolidation during exposure;
- Increased sportfish populations as a result of increased littoral zone habitat, if sufficient stocks remain in Lake Apopka;

- Extensive cattail germination and growth, likely requiring some degree of management (herbicide or mechanical harvesting), especially for Scenarios 2, 3 and 4;
- Increased macrophyte-associated macroinvertebrate densities following refill but a decrease or elimination of some existing benthic species due to desiccation during dewatering;
- Little or no improvement in water quality (TP, TN, and chlorophyll a concentrations) under all drawdown scenarios, based on results from other Florida lake drawdowns;
- Development of a "cap" of consolidated sediments and germinated vegetation if the dewatering period is between three and seven months in duration, which can become dislodged from underlying unconsolidated sediments upon refill and cause "floating islands";
- Sediment exposure for longer than seven months will likely result in significant sediment consolidation down to within two feet of the holddown lake elevation.

The duration of any effects of drawdown or enhanced water level fluctuation observed in Lake Apopka will likely be relatively short-lived (a maximum of two to six years).

Potential effects of a drawdown or enhanced fluctuation on downstream water bodies include a possible shift in littoral zone plant community structure from nonaquatic species to aquatic species if maximum pool elevations in downstream lakes are maintained during Lake Apopka drawdown and holddown periods; excessive velocities in downstream channels during drawdown, with associated dislodging of sessile organisms; and the probability of significantly increased nutrient and sediment loading to downstream lakes during discharge and storage of Lake Apopka drawdown water.

SECTION 2.0 INTRODUCTION

Lake Apopka, located within Orange and Lake Counties in central Florida, has a surface area of approximately 31,000 acres at 66 ft. NGVD (National Geodetic Vertical Datum) and a drainage basin of almost 48,000 acres. Although this lake has been known historically for its sportfishing and wildlife, overall environmental quality has declined dramatically since the 1940's. Construction of the Apopka-Beauclair Canal in 1880 altered the hydrology of the lake (Conrow et al. 1989). External nutrient loadings, including sewage from several surrounding communities and wastewater from citrus processing plants, contributed to the decline in water quality during the 1920's. Drainage waters from muck farms bordering the northern shoreline began to affect the lake in the 1940's. In 1947, a hurricane destroyed much of Lake Apopka's aquatic macrophyte community, and one month later the lake's first algae bloom was recorded. Since then, environmental quality of the lake has exhibited a steady decline (Conrow et al. 1989).

In 1987, the Surface Water Improvement and Management (SWIM) Act was enacted by the Florida Legislature to address the degradation of surface waters throughout the State. Lake Apopka was specifically designated as a water body in need of restoration under the SWIM Program. The SWIM Plan for Lake Apopka (Conrow et al. 1989) identifies seven priority issues which the St. Johns River Water Management District (SJRWMD) considers critical for the restoration of Lake Apopka. These are:

- Agricultural discharge;
- Lack of fish and wildlife habitat;
- Poor water quality and flocculent sediments;
- Degradation of downstream lakes;
- Low recreational and aesthetic values;

- Non-point pollution sources; and
- Future basin development.

In October, 1989, Dames & Moore was selected by SJRWMD to examine the potential environmental and ecological effects of implementing one potential lake restoration technique, drawdown or enhanced water level fluctuation, for Lake Apopka. The project objectives (as described in the Lake Apopka SWIM Plan) are to evaluate the feasibility of (1) temporary lowering the water level in the lake, or (2) returning lake level fluctuations to a more natural regime (Conrow et al. 1989). Three of the seven SWIM priority issues are addressed in this project: lack of fish and wildlife habitat, poor water quality and flocculent sediments, and low recreational and aesthetic values.

Lake drawdown or enhanced water level fluctuation is not a new concept in the effort to restore Lake Apopka. In 1971, an experimental gravity drawdown was performed on Lake Apopka, but was terminated due to public concern when some fish, turtles, and alligators died, and when Aeromonas (a bacterial species implicated in serious human illness) was discovered in the lake (US EPA 1979). No evidence was found associating the drawdown with the animal kills, and Aeromonas has been found in virtually all Florida lakes that have been tested (US EPA 1979). Since little limnological or fisheries data were collected in Lake Apopka during this drawdown, it was not considered further in this report.

In 1979, the Environmental Protection Agency (EPA) issued a Final Environmental Impact Statement (FEIS) for the Lake Apopka Restoration Project, in which numerous restoration alternatives were considered and analyzed. Alternatives considered in the FEIS were enhanced fluctuation of lake levels, chemical sedimentation, dredging, nutrient diversion, flushing, aeration, and drawdown (US EPA 1979). Of these, only dredging and drawdown were judged to potentially yield the restoration objectives. Dredging was found to be prohibitively expensive for a 31,000 acre lake; therefore, drawdown was the recommended alternative (US EPA 1979).

The proposed drawdown was not implemented, however, primarily due to the projected cost of the program ($20,000,000) and concern over potential environmental and economic impacts. In 1986, the Lake Apopka Restoration Council (LARC) suggested that several additional reevaluations of the FEIS be conducted concerning the lake drawdown management option. These included an examination of the hydrologic feasibility of whole-lake drawdown and its potential impacts on Lake Apopka and downstream lakes; a reevaluation of a sectioned drawdown (as opposed to a whole-lake drawdown); and a reevaluation of enhanced water level fluctuation as a means of sediment consolidation and enhancing emergent macrophyte growth (Lake Apopka Restoration Council 1986).

The objective of this study is to provide an assessment of the potential ecological and environmental effects of a drawdown or enhanced lake level fluctuation program for Lake Apopka. To address this objective, Dames & Moore conducted an extensive literature review and personal interviews with federal, state, and local government agencies and private researchers to obtain information concerning the use of drawdown or enhanced fluctuation as lake management or restoration techniques. Results of the interviews and literature reviews were entered into a matrix to provide an orderly method of summarizing findings. Based on the literature review, a synopsis of the ecological effects of lake drawdown or enhanced water level fluctuation as management and restoration techniques was formulated. The application of drawdown or enhanced water level fluctuation to the restoration of Lake Apopka was addressed using the evaluation of the literature and studies relevant to Lake Apopka.

SECTION 3.0 METHODS

Several methods of collecting information addressing lake drawdown and enhanced water level fluctuation as management and restoration techniques were used for this project. Personal interviews, telephone interviews, and mailings were conducted to obtain recent and unpublished information from lake managers and aquatic scientists. Additional published information was found through an extensive literature review. Information from the interviews and the literature review was entered into a spreadsheet matrix to provide a summary. Finally, a meeting with SJRWMD engineers provided hydrologic and hydraulic information on Lake Apopka and the rest of the Oklawaha Chain of Lakes. This information was useful in developing drawdown scenarios for Lake Apopka and in examining possible downstream effects of a Lake Apopka drawdown.

3.1 INTERVIEW DATABASE

3.1.1 Mailings

The North American Lake Management Society (NALMS) maintains an "expert database" listing of all members of NALMS who have expertise in various lake management fields. A total of 83 professionals were identified from the NALMS database as having expertise in lake drawdown. A letter was sent to these individuals requesting information concerning their experience with drawdown or enhanced water level fluctuation as a management or restoration technique, and specifically requesting copies of publications or reports, personal observations, and additional contacts. Results from these mailing are included in the Interview Database (Appendix A), which contains the following descriptive headings:

- NAME AND ADDRESS
- WHEN AND HOW CONTACTED
- STUDY LOCATION
- DRAWDOWN TIMING/DURATION
- LAKE SIZE
- OBJECTIVES OF DRAWDOWN
- SUMMARY
- POSITIVE EFFECTS
- NEGATIVE EFFECTS
- KEYWORDS
- AVAILABLE PRINTED INFORMATION
- OTHER COMMENTS
- OTHER SUGGESTED CONTACTS

3.1.2 Personal Interviews

Several offices of the Florida Game and Freshwater Fish Commission (FGFWFC) were visited during the course of the data collection effort. FGFWFC has extensive experience with drawdown in Florida lakes and a large amount of information was available from them. Bill Johnson and John Benton (based in Eustis), Vince Williams (Kissimmee), and Danon Moxley and Tom Rosegger (Lakeland) were especially generous with their time and with access to the many FGFWFC reports addressing the effects of drawdown in Florida lakes. Other state and federal agency offices visited were the Florida Department of Natural Resources and the United States Geological Survey located in Tallahassee, Florida. Results of these visits and interviews are included in the Interview Database (Appendix A).

3.2 LITERATURE REVIEW DATABASE

3.2.1 Literature Searches

Several computerized database searches were conducted to obtain published information on drawdown or water level enhancement as a lake management and restoration technique. One of the most productive database searches was provided by the Environmental Protection Agency's Clean Lakes Clearinghouse. The Clean Lakes Clearinghouse is an information resource on lake restoration, protection, and management, and was initiated by the EPA's Clean Lakes Program to provide technical information to EPA/federal personnel, state and local lake managers, and researchers.

Additional computerized database searches which were utilized were:

1. Custom Search Bibliography, conducted by the Florida Educational Information Service, including Biosis, Pollution Abstracts, and Water Resources databases.

2. Center for Aquatic Plant Management, University of Florida Institute of Food and Agricultural Services, Gainesville, Florida.

3. Florida State University on-line search request.

Information was also collected by contacting the following agencies for their publication lists and reports:

- United States Geological Survey
- U.S. Army Corps of Engineers Waterways Experiment Station, Technical Information Center

- North American Lake Management Society Lending Library
- St. Johns River Water Management District Library
- Florida Game and Fresh Water Fish Commission Library
- Louisiana Wildlife and Fisheries Commission
- Louisiana State University Laboratory for Wetland Soils and Sediments
- Florida Department of Natural Resources Library
- South Florida Water Management District Library

The Literature Review Database (Appendix B) serves as an annotated bibliography derived from the literature review. It is formatted in WordPerfect to facilitate searching and alphabetization by author, thereby allowing it to be updated. The following descriptive headings are included for each citation:

- CITATION
- STUDY LOCATION: lake name (if known), state or country. N/A means that information is not available or not applicable
- DRAWDOWN TIMING/DURATION: month or season of initiation of drawdown/number of months from initiation of drawdown to complete refill
- LAKE SIZE: surface area of lake at normal pool elevation (in acres)
- OBJECTIVES OF DRAWDOWN: a priori goals of the drawdown
- SUMMARY: abstract or summary derived from the source article
- POSITIVE EFFECTS: positive effects with respect to the goals of the drawdown
- NEGATIVE EFFECTS: negative effects with respect to the goals of the drawdown
- KEYWORDS: major subjects addressed by the article
- COPY OBTAINED: whether a paper or microfiche copy of the article was provided to SJRWMD

3.2.2 Matrix Formulation

Only 42 lakes were identified from the interviews and literature search in which drawdown or enhanced water level fluctuation effects were documented in detail. Information describing the drawdown or enhanced fluctuation on these lakes was entered into three spreadsheet matrices (in Lotus 123). The purpose of these matrices is to summarize important aspects about these drawdowns. The matrices can be sorted by different variables (e.g., location, drawdown objective, or various observed effects). Copies of the matrices on a 5.25 inch floppy disk are provided in Appendix C.

3.3 APPLICATION TO LAKE APOPKA

Background information concerning Lake Apopka was also collected and entered into the Literature Review Database. This information, along with information obtained from SJRWMD engineers working with water budget and hydrologic data for the Oklawaha Chain of Lakes, was used to examine the potential ecological effects of a drawdown or enhanced water level fluctuation on Lake Apopka and the downstream Chain of Lakes.

SECTION 4.0 A REVIEW OF ENVIRONMENTAL AND ECOLOGICAL EFFECTS OF DRAWDOWN AND ENHANCED FLUCTUATION AS LAKE MANAGEMENT AND RESTORATION TECHNIQUES

4.0.1 Interview Database

Twenty-two (26.5%) of the 83 professionals identified from the NALMS "expert database" responded to the letter requesting information concerning their experiences with the use of drawdown or enhanced water level fluctuation. Five of these initial contacts by letter (J. Arruda, Pittsburg State University; J. Filbin, Technical Resources, Inc; D. Moxley, Florida Game and Freshwater Fish Commission; J. Swartz, New York Department of Environmental Conservation; and G. Tichacheck, Illinois Department of Conservation) were followed with more in-depth telephone conversations. Within the State of Florida, personal interviews were conducted with Florida Game and Fresh Water Fish Commission (FGFWFC) scientists located in the Eustis, Lakeland, and Kissimmee offices, United States Geological Survey (USGS) personnel located in Tallahassee and Tampa, and Florida Department of Natural Resources (DNR) personnel in Tallahassee. Conversations or letter responses from a total of twenty-one lake managers and scientists are presented in detail in Appendix A.

Many references were obtained as a result of letter, telephone, and personal contacts. The FGFWFC provided peer-reviewed publications by members of their staff and 42 "gray literature" publications or reports addressing the effects of drawdown in Florida lakes. Fifteen additional references were obtained from non-FGFWFC sources as a result of the information letter request.

Several points were made by respondents to the letter request and during the personal interviews. Summer drawdown is used for fishery management in Kansas (W. Layher, personal communication, December 1989) and Illinois (G.

Tichacheck, personal communication, November 1989). A drawdown was used to attempt to reduce internal phosphorous loading in Minnesota (J. Barten, personal communication, November 1989). In general, lakes in northern or northeastern states use winter drawdown primarily for macrophyte control. Major effects of winter drawdown are freezing and ice scour-induced damage to macrophyte roots, rhizomes, or seeds, in addition to the effects of desiccation usually associated with lake level decline. These effects were observed in Eau Galle Reservoir, Wisconsin, (J. Filbin, personal communication, November 1989), Wolverine Lake, Michigan, (A. Groves, personal communication, November 1989), Deer Lake, New Jersey, (E. Kubersky, personal communication, November 1989) and three lakes in New York (J. Swartz, personal communication, December 1989).

In Florida, FGFWFC has completed over 15 major lake drawdowns since the early 1970's, primarily for fisheries management and habitat restoration. The FGFWFC feels that drawdown is one of the most, if not the most, effective fisheries management techniques available to them. They have found that early spring drawdowns lasting 2 to 3 months often result in germination of many species of aquatic and emergent plants. Positive effects they have observed include temporarily improved sport fisheries (due to growth and reinundation of aquatic vegetation and concentration of forage fish), short-term success with nuisance vegetation control (such as hydrilla), and reestablishment of littoral and shallow water vegetation. They have observed limited sediment consolidation in some cases (W. E. Johnson, personal communication, November 1989; D. Moxley, personal communication, January 1990; V. Williams, personal communication, December 1989).

Negative effects observed by FGFWFC (W. E. Johnson, pers. comm., November 1989) during and after drawdowns include the occurrence of settling and cracks in lakeside structures originally constructed on fill or muck; negative effects on trees (especially maple) and other shoreline vegetation during extended drawdown; fish kills in downstream canals due to anoxic conditions; and massive growth of cattails which can cause navigational or access problems (as littoral zone vegetation or free-floating islands) following reinundation. In-lake water quality (e.g., nutrient concentrations, algal biomass) generally declines during drawdown due to water reduction and remains unimproved following refill in Florida lakes.

Mr. Danon Moxley (Lakeland FGFWFC, personal communication January 1990) recommends a three step process for lake management in many Florida lakes: (1) conduct a drastic drawdown to oxidize sediments, followed by dredging (if necessary and practical) to remove excess organic muck, and sculpt the lake edge to create a littoral zone; (2) conduct annual water level fluctuations, never allowing water levels to remain constant for long time periods; and, (3) draw down the lake water level approximately once every six years to expose the littoral zone. This procedure aims to establish and promote the growth of desirable plant species in the littoral zone.

4.0.2 Literature Review and Matrix Summary

A total of 185 references are included in the Literature Review Database (Appendix B). Of these, 105 references describe a total of 61 actual lake drawdowns or water fluctuations; the remaining 80 references are general lake management or restoration review papers or background information papers and reports specific to Lake Apopka. The ecological effects of 42 of the 61 drawdown projects were explained in enough detail to include in the matrix summaries (described below).

Almost half of the references addressing the effects of lake drawdown or enhanced fluctuation were available only as non-reviewed or "gray" literature.

Ninety (48.6%) of the 185 references included in the Literature Review Database are reports from federal, state, or local governments. Although most of these reports are available to the public, many have very limited distribution. The FGFWFC provided the largest number of citations (42) to the Literature Review. A total of 26 government agencies contributed reports to the Literature Review.

Peer-reviewed citations included in the Literature Review were found in a wide variety of journals and books; forty-three journals are cited in the Review. The journals most frequently cited were:

Water Resources Bulletin (11 citations)
Lake and Reservoir Management (11 citations)
Southeastern Association of Game and Fish Commissioners Conference Proceedings (10 citations)
Aquatic Botany (7 citations)
Transactions of the American Fisheries Society (5 citations)
Hydrobiologia (4 citations)
Journal of Aquatic Plant Management (4 citations)

The remaining 36 journals with three or fewer citations are primarily aquatic science and environmental management journals.

The drawdown summary matrices (Tables 4.1 - 4.3) provide an effective method of summarizing the wide spectrum of observed effects of drawdown or enhanced water level fluctuation. Definitions of column headings for the matrices are shown in Table 4.4. Citation numbers in the first matrix (Table 4.1) correspond to page numbers in the Literature Review Database (Appendix B).

Table 4.1. Drawdown summary describing the lakes, timing and duration of drawdown, area exposed and depth of drawdown, and objectives of the drawdown.

LAKE NAME	CITATION NUMBERS IN APPENDIX B (page numbers)	LOCATION	SIZE	DRAWDOWN TIMING				DRAWDOWN DURATION MONTHS				AREA EXPOSED %	DRAWDOWN DEPTH (ft)	OBJECTIVES OF THE DRAWDOWN							
				FALL	WINTER	SPRING	SUMMER	<1	1-3	4-8	>8			HABIT IMPRV	FISH MGNT	MACRO PHYTE CONTR	SEDIMENT COMP	WATER QUAL IMPRV	LAKE MAINT	UNPLN DRAW DOWN	OTHER
Bear Lake	31,180	FL	M		S		S					50	8		Y	Y					
Fox Lake	31,121,124,186	FL	M						X							Y	Y				
Lake Carlton	3,31,52,53,54,55,105,182	FL	L	Y	Y	S	Y				X	80	12	Y	Y	Y					
Lake Davis	33,183	FL	M										12	Y	Y						
Lake Eola	33,66	FL	M									40									
Lake Griffin	31,60,104,188,I-1	FL	L			S			X			30	6		Y	Y	Y				
Lake Hunter	33,63,187	FL	M		S	Y				X		95		Y		Y					
Lake Juniper	31,189	FL	L									90	9		Y	Y			Y		
Lake Karick	32,129	FL	M				S					90	14		Y	Y					
Lake Kissimmee	32,50,56,181	FL	L									45	8	Y	Y						
Lake Miccosukee	155	FL	L	S	Y	Y				X		90	5			Y					
Lake Oklawaha	87,88,89,126	FL	L	S	Y					X		38	5			Y					
Lake Stone	32,185	FL	L		S		S					70	14		Y	Y					
Lake Talquin	177	FL	L									65		Y	Y	Y			Y		
Lake Tohopekaliga	33,48,49,61,90-92,I-3,162-171,178	FL	L	Y	Y	S	Y				X	50	7	Y	Y						
Lee County Lake	28	AL	L	S	Y					X			9			Y					
Lake Nimrod	26,95	AR	L										9		Y		Y				Y
Candlewood Lake	149	CN	L		S				X				7			Y					
Puyvalador Reservoir	44	France	L		S	Y				X		90									Y
Lake Laurel	7	GA	M	S	Y					X							Y	Y			
Ponds	135,136	GA	M	S	Y					X		90			Y						
Ridge Lake	11	IL	M	S	Y					X		70			Y						
Lake Kinneret	146	Israel	L	Y	Y	Y	Y				X									Y.	
Reservoirs	81,109	KS	L		S		S		X			20		Y	Y			Y			
Lake Anacoco	118,119	LA	L				S		X						Y	Y					
Lake Bussey	29,30,119	LA	L	S	Y				X				8		Y	Y					
Lake Chicot	18,74	LA	L	S					X							Y					
Lake Lafourche	119	LA	L				S		X						Y	Y					
Sebasticook Lake	25	ME	L	S						X		46	7					Y			
Backus Lake	107	MI	L				S		X				4	Y							
Michigan lakes	I-15	MI	M	Y	Y	S	Y				X		4			Y					
Wolverine Lake	138,I-17	MI	L		S								2.5			Y					
Loon Lake	I-25	MN	L	Y	Y	S	Y				X	72		Y				Y			
Little Dixie Lake	85,86	MO	L				S	X				42	8		Y						
Bluff Lake	5	MS	L	S					X				6								Y
Three lakes	I-28	NY	L		S	Y				X			7			Y					
Kahle Lake	156	PA	L		S				X				6			Y					
Lake Francis Case	13	Unknown	L	S					X				40								Y
Long Lake	98,99,172,173	WA	L	Y			S			X		90	6			Y		Y			
Eau Galle Reservoir	76,I-3	WI	L	S	Y					X		50	3						Y		
Jyme Lake	152,161	WI	S										8				Y				
Murphy Flowage	9,10,21	WI	L		S	Y			X			70				Y					

Table 4.2. Summary of drawdown effects during (D) and after (P) the drawdown.

LAKE NAME	DRAWDOWN EFFECTS																																	
	SPORT FISH		FORAGE FISH		OTHER FISH		WATER QUALITY		ALGAE		DESIRED PLANTS		NUISANCE PLANTS		SEDIMENT COMPACT		BENTHOS		WILDLIFE		DOWNSTRM WQ		ECONOMY		SHORLINE STRUCT		SHORLINE PLANTS		DOWNSTRM VEGETAT		WATER SUPPLY		LAKE ACCESS	
	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	D	P	P	D	P	D
Bear Lake		+																																
Fox Lake											+	+	+	+/-	+	+																		
Lake Carlton		+		-	0	0	+	+			+	-	+	+	+	+	-	-																
Lake Davis																																		
Lake Eola							+	+																										
Lake Griffin	-	+		+			+	+	0	+	+	+/-		+	+/0	-																		
Lake Hunter		+					+	+			+	+	+	+	+	+																		
Lake Juniper														-		+																		
Lake Karick		+		+																														
Lake Kissimmee		+					+	+				+			+	+		+																
Lake Miccosukee											+	+	-	-		+																		
Lake Oklawaha											-/+	-/+	+	+																				
Lake Stone		+											-	-																				
Lake Talquin		+		+				+			+	-																						
Lake Tohopekaliga		+		+		+	+	+/-	+	+		+	+	+	+	+		+					-	+				+	-					
Lee County Lake																		+																
Lake Nimrod		+						+																										
Candlewood Lake							0	0	0	0	-	-/+																						
Puyvalador Reservoir							+	+																										
Lake Laurel							+	-	+	-							-	-																
Ponds		+/0		+																														
Ridge Lake	0	+	-	-													-	-																
Lake Kinneret							+	+	-	-																								
Reservoirs		+		+				-			+	+								+								+		+		-		
Lake Anacoco		+		-			0	0					-	-																				
Lake Bussey		+/-		-/x									-	-			+	+					-	+										
Lake Chicot	-	+	-	+			0	0			-	-																						
Lake Lafourche		+/-		-									-	-																				
Sebasticook Lake		0					-	-	-	-							-	-																
Backus Lake							+	+			-	-						-	0	0							+	+						
Michigan lakes											-	-/+				+																-	-	+
Wolverine Lake											-	-/+	+	+																				
Loon Lake							+	+/-						+	+	+																		
Little Dixie Lake	-	+	-	+																														
Bluff Lake	+	+		+					+	+							0	0																
Three lakes								+			-	-							-										-	-				
Kahle Lake											+	+	+	+																				
Lake Francis Case																	+	+																
Long Lake							+	-	0			-/+			0	0																		
Eau Galle Reservoir		+									-	-		+																				
Jyme Lake															+/0	+/0											-	-						
Murphy Flowage		+		-			+		+	+				-					-	-								-					-	

Table 4.3. Summary of drawdowns showing comments.

LAKE NAME	STATE	COMMENTS
Bear Lake	FL	Initial costs $61.75/acre.
Fox Lake	FL	Mechanical pumping used for dewatering to control hydrilla; excessive growth of cattail resulted; $2,400/acre
Lake Carlton	FL	Typha uprooted and floating after refill; desirable species flooded out at refill
Lake Davis	FL	Drawdown and dredging, sediment removal.
Lake Eola	FL	
Lake Griffin	FL	Drying time limited due to heavy rains; $383/acre
Lake Hunter	FL	Lake drained, dredged, littoral zone resculptered. Chemical treatment of cattails; total cost $4,780
Lake Juniper	FL	Initial cost $62/acre
Lake Karick	FL	Purpose to control submerged bladderwort and establish sportfishery; success 1-2 years; $62/acre
Lake Kissimmee	FL	
Lake Miccosukee	FL	Sediment consolidation; macrophyte control.
Lake Oklawaha	FL	Short-term control of coontail, hydrilla; increase in water hyacinth and aligatorweed after 6 months.
Lake Stone	FL	Initial costs $62/acre.
Lake Talquin	FL	Mechanical pumping required; decrease in water quality
Lake Tohopekaliga	FL	Initial cost $69/acre; sediment consolidation lasts two years; drawdown recommended every 6-7 years; formation of water hyacinth mats; no water quality improvement
Lee County Lake	AL	
Lake Nimrod	AR	
Candlewood Lake	CN	Weed control in shallow water, not in deep.
Puyvalador Reservoir	France	
Lake Laurel	GA	Phytoplankton reduction for one year; low DO; phosphorus levels low for one year
Ponds	GA	
Ridge Lake	IL	Water level reduction too severe for fish forage.
Lake Kinneret	Israel	Natural drought; phosphorus release from sediments.
Reservoirs	KS	Improved water clarity, increased littoral zone vegetation.
Lake Anacoco	LA	Slow rate of refill hindered fish spawning.
Lake Bussey	LA	
Lake Chicot	LA	Fish kill due to low DO during drawdown.
Lake Lafourche	LA	
Sebasticook Lake	ME	Enhanced seasonal flushing; drawdown to flush out high nutrient water
Backus Lake	MI	Waterfowl management
Michigan lakes	MI	Short-term macrophyte control, nearshore wells dewatered; floating logs navigational hazard
Wolverine Lake	MI	Short-term macrophyte control
Loon Lake	MN	Increased water clarity and fishery; increase in TP first year; decrease in years 2 and 3
Little Dixie Lake	MO	Ten day drawdown
Bluff Lake	MS	Reservoir subject to annual fall drawdown.
Three lakes	NY	Macrophyte control for one season; drawdown in wetlands around lake
Kahle Lake	PA	Drawdown actually enhanced growth of bushy pondweed; ineffective macrophyte control
Lake Francis Case	Unknown	
Long Lake	WA	Short-term benefits; one year after drawdown macrophytes returned
Eau Galle Reservoir	WI	Plant diversity increased; frost and drying effects on nuisance vegetation
Murphy Flowage	WI	Winter drawdown caused shallow well to dry up; significant reduction in macrophytes
Jyme Lake	WU	Bog around lake dewatered; limited sediment consolidation

Table 4.4. Definitions used in the drawdown summaries.

COLUMN HEADING	DEFINITION
SIZE	Surface area of lake: S = Small (0 to 10 acres) M = Medium (11 to 100 acres) L = Large (> 100 acres)
DRAWDOWN TIMING	Season(s) during which drawdown occurred: S = season when drawdown was started Y = seasons during which drawdown occurred
DRAWDOWN DURATION	Number of months from start of water removal until return of water level to normal pool: < 1 less than 1 month 1-3 one to three months 4-8 four to eight months > 8 greater than eight months
AREA EXPOSED	Percentage of lake bottom exposed during the drawdown
DRAWDOWN DEPTH	Depth (ft) below normal pool elevation to which water level declined during the drawdown
OBJECTIVES OF THE DRAWDOWN	Stated purpose of the drawdown:
HABIT IMPRV	Fish or wildlife habitat restoration or improvement
FISH MGNT	Fishery management; usually gamefish or sportfish
MACROPHYTE CONTR	Control of nuisance or undesirable macrophytes
SEDIMENT COMP	Sediment compaction
WATER QUAL IMPRV	Water quality improvement
LAKE MAINT	Maintenance of lake shoreline structures or dams
UNPLN DRAWDOWN	Unplanned (natural) drawdown
OTHER	Other objectives such as flood control, water supply needs, or electric power generation
DRAWDOWN EFFECTS	Reported effects of the drawdown: + indicates an increase in numbers, densities, or concentrations - indicates a decrease in numbers, densities, or concentrations 0 indicates no change blank indicates that these impacts were not addressed D means during the dewatering period P means after (post) refill
SPORT FISH	Effects on sportfish populations
FORAGE FISH	Effects on forage fish populations
OTHER FISH	Effects on other fish species populations
WATER QUALITY	Effects on water quality (+ indicates increased concentrations)
ALGAE	Effects on algal biomass or density
DESIRED PLANTS	Effects on desired macrophyte species (ie. native species,fish or wildlife food plants)
NUISANCE PLANTS	Effects on nuisance macrophtye species
SEDIMENT COMPACT	Effects on sediment compaction
BENTHOS	Effects on benthic organisms
WILDLIFE	Effects on wildlife or waterfowl
DOWNSTRM WQ	Effects on downstream water quality (+ indicates increased concentrations)
ECONOMY	Effects on economy of the surrounding area
SHORLINE STRUCT	Effects on shoreline structures, such as seawalls or dams
SHORLINE PLANTS	Effects on shoreline plants or trees
DOWNSTRM VEGETAT	Effects on downstream vegetation
WATER SUPPLY	Effects on water supply
LAKE ACCESS	Effects on lake access for recreation or other uses

A total of 42 lakes were included in the summary matrix (Table 4.1). Of these, 15 (36%) are located in Florida, 8 (19%) are located in other southeastern states, 14 (33%) are located in northern or northeastern states, and the remaining lakes are located elsewhere in the Unites States or in Europe. The two objectives most often cited for drawdowns (Table 4.1) were macrophyte control (60% of the lakes) and fishery management (43% of the lakes). Habitat restoration was a stated objective for 24 percent of the drawdowns, sediment consolidation for 12 percent, and water quality improvement for 14 percent (Figure 4.1).

Drawdown was initiated during all four seasons of the year (Table 4.1); however, more lake drawdowns were initiated in the fall (33% of those records stating initiation times) and winter (28%) than spring and summer (14% and 21% of the time, respectively). Only one lake reported a drawdown time of less than one month (Table 4.1); most drawdowns were 1 to 3 months in duration (45% of those reporting duration) or 4 to 8 months long (36%). Five lakes (15%) had long (>8 month) drawdown duration times (Figure 4.2).

The observed effects of drawdown were complex for some components (such as water quality), while other effects were relatively uniform for all types of lakes. Each ecological effect is addressed separately below.

4.1 EFFECTS ON FISH PRODUCTION AND LITTORAL ZONE HABITAT

Of the 22 drawdowns which included gamefish monitoring, 21 (95%) recorded improvements in sportfish or gamefish populations (as total numbers, densities, and/or growth) for some length of time after drawdown and refill. Only one lake (Sebasticook Lake in Maine; Courtemanch 1986) reported no observed effect on gamefish populations, and no lakes reported a negative effect after refill. However, gamefish populations were generally negatively impacted in the

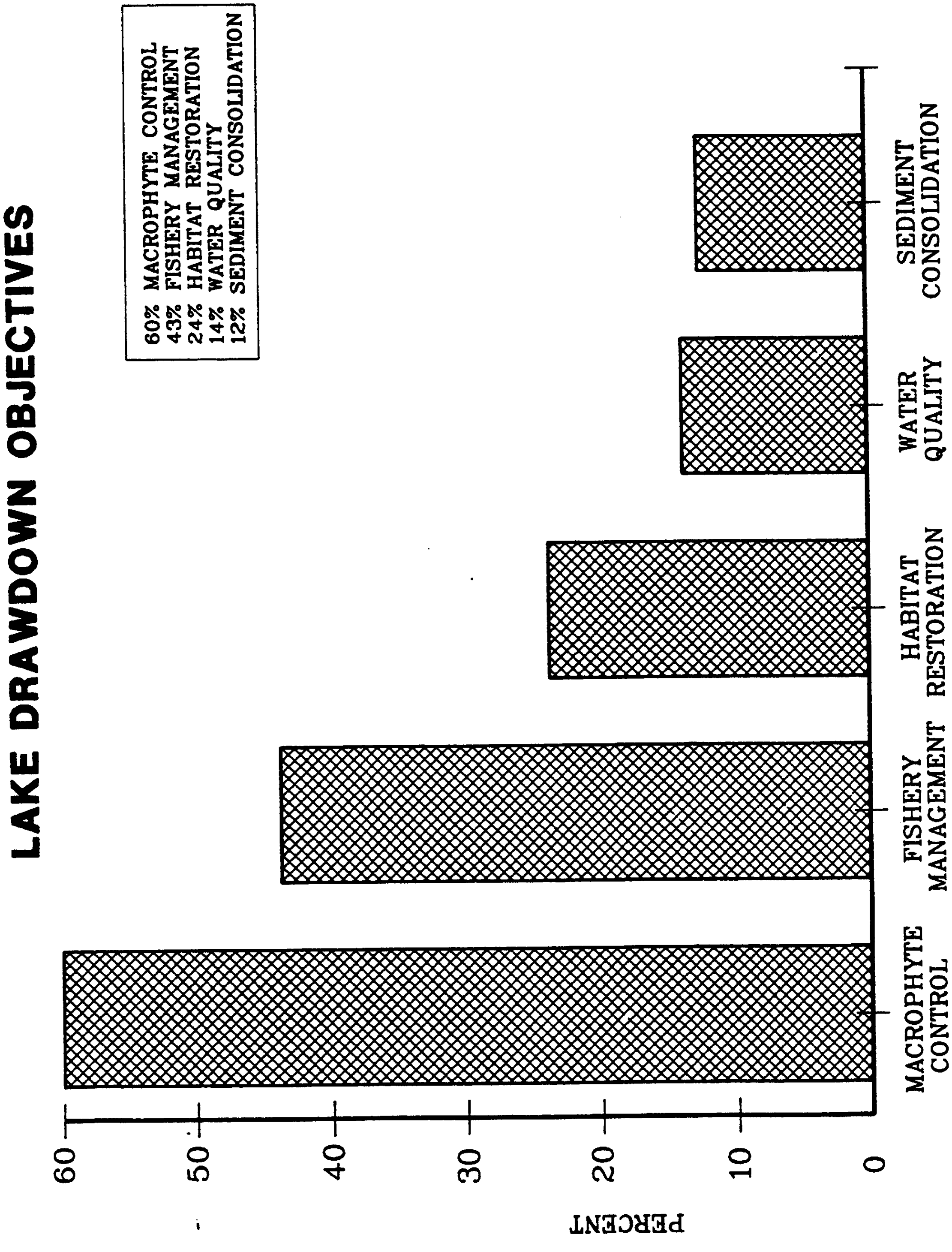


Figure 4.1 Objectives of Drawdown

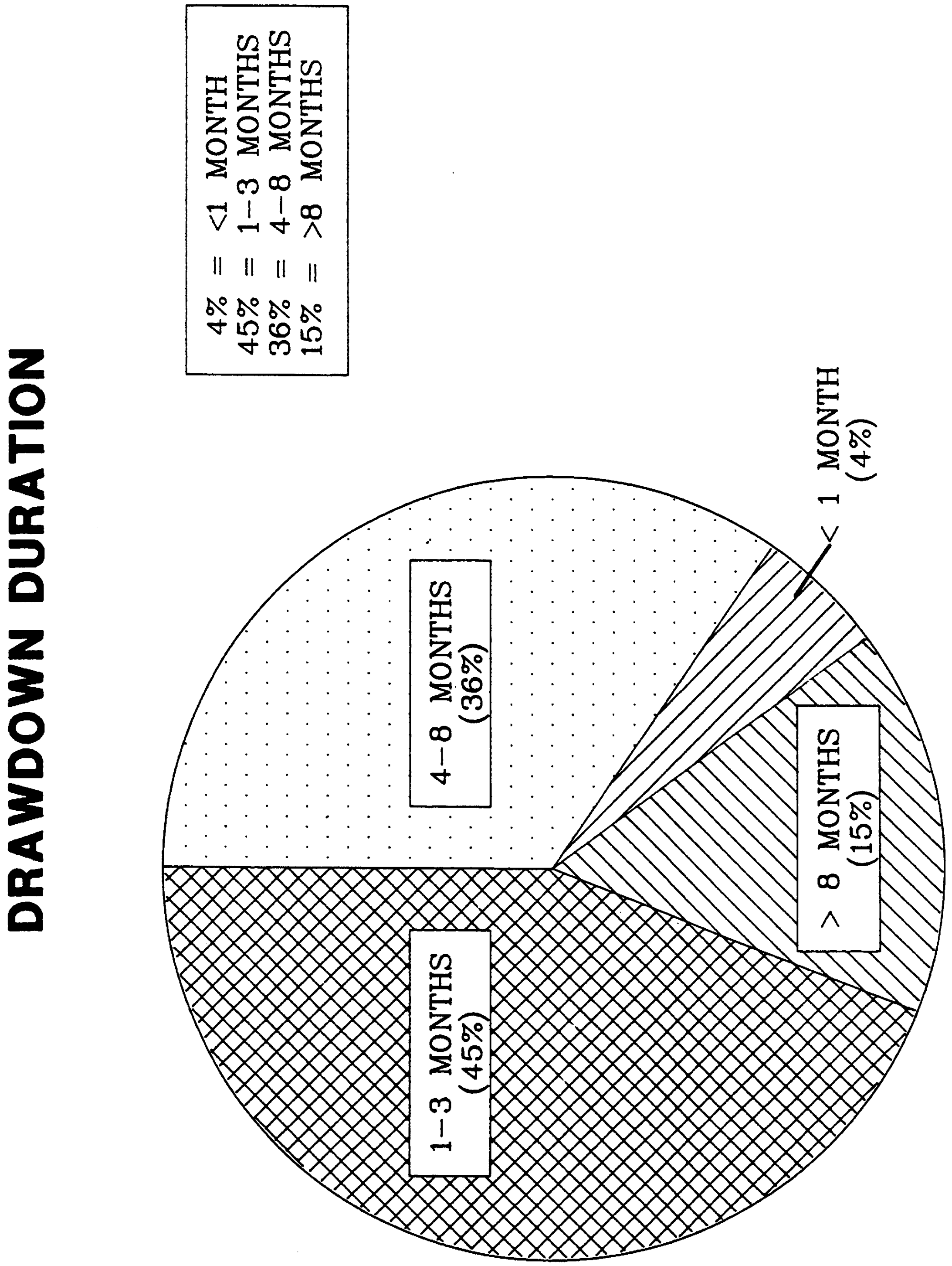


Figure 4.2 Duration of Drawdown

few observations made during drawdown dewatering (Johnson et al. 1988; FGFWFC 1986; Geagan 1961; Heman et al. 1969), primarily from death due to low dissolved oxygen in the reduced water volume, stranding, or from reduced spawning success.

Several explanations have been suggested for the observed increase in gamefish populations after drawdown and refill, the most common being the "new lake effect." This term originated from observations of high productivity and fish densities in newly created reservoirs, caused by an increase in spawning sites, food, and habitat for many species of fish and invertebrates in the recently inundated shoreline vegetation (Aggus 1971; Culver et al. 1980; FGFWFC 1979(a); Groen and Schroeder 1978; Holcomb et al. 1975). Other factors include the concentration of forage fish during drawdown (creating a concentrated food source for piscivorous gamefish; Arner et al. 1971; Williams 1985), an increase in densities and productivity of invertebrate food organisms (Davies 1981; Davis and Hughes 1970; Hunt and Jones 1972; Wegener and Williams 1974(a)), and an increase in suitable spawning sites after refill (Jenkins 1969).

Lake drawdown has not always been viewed as having positive effects on sportfisheries. Ellis (1937) notes that "of all factors affecting fisheries in reservoirs, drawdown is the easiest to recognize. Nesting areas are exposed in the spawning season, beds of submerged vegetation are left dry and fish are forced into waters that are unsuitable." Additional references to negative effects of drawdown or enhanced water level fluctuation on littoral zone habitat and fish production in lakes and reservoirs include the following:

- Winter drawdown in northern states may cause fish kills (Beard 1973)
- Fish are stranded under drying vegetation during drawdown (Bennett 1954; Frey 1967; Heman et al. 1969)

- Forage fish can become concentrated and more susceptible to predators during drawdown (Bennett 1954; 1962; Dunst et al. 1974)
- Increased risk of oxygen depletion (Cooke et al. 1986; Geagan 1961)
- Reduced spawning during drawdown (FGFWFC 1986; Heisey et al. 1980; Heman et al. 1969; Jenkins 1969)

Fish species vary in their response to drawdown or enhanced fluctuation. In a statistical evaluation of the standing crop of fish in 140 large reservoirs in the southeastern United States, Jenkins (1970) found that water level fluctuation had a positive influence on the biomass of spotted gar, flathead catfish, black bass, and white crappie, but that it exerted a negative influence on the standing crops of gizzard shad, northern pike, pickerel, carpsucker, and sunfish. Williams (1985) also found that a drawdown in Lake Carlton, Florida, produced mixed responses in fish populations. The Lake Tohopekaliga, Florida, drawdown adversely affected chain pickerel populations, while other sportfish species were positively affected (Wegener and Williams 1974(b)).

In Florida, 67 percent (10 of 15) of the drawdowns reviewed here stated fishery management as an objective and 90 percent of these reported increased gamefish and forage fish populations following drawdown and refill (Tables 4.1 and 4.2). The FGFWFC has conducted most of the lake drawdown projects in Florida specifically for littoral zone habitat improvement and fish production. To document ecological effects of this lake restoration technique, extensive studies were conducted by FGFWFC on Lake Tohopekaliga before, during and after a 15-month drawdown in 1970. Wegener and Williams 1974(a) reported that the Lake Tohopekaliga drawdown rejuvenated littoral substrate, stimulated development of desirable aquatic plants and increased macroinvertebrate production. As a result of these changes, biomass of sportfish nearly doubled, although forage fish accounted for a higher percentage of the population following reflooding. Similar fish production increases have been reported by

FGFWFC after drawdown and refill for Lake Talquin (Williams 1985), Lake Kissimmee (FGFWFC 1982 (a)), Lake Griffin (Johnson et al. 1988), Juniper Lake (Williams 1985), Lake Hunter (FGFWFC 1989), and Lake Davis (Williams 1985). Fishery populations may remain high for 2 to 6 years before returning to pre-drawdown levels (D. Moxley, personal communication, January 1990).

However, not all drawdowns conducted by FGFWFC have resulted in complete fisheries management successes. A drawdown of Lake Carlton resulted in a short-term (less than 2 years) net gain in rooted aquatic vegetation and an increase in black crappie populations following refill, but no substantial improvements in largemouth bass, bluegill, or redear sunfish populations (Williams 1985).

4.2 EFFECTS ON MACROINVERTEBRATES

Effects of drawdown or enhanced fluctuation on macroinvertebrate populations are similar to those observed for fisheries: populations generally exhibit temporary increased densities in littoral areas after refill [a result of the "new lake effect" (Davies 1981; Davis and Hughes 1970; Holcomb et al. 1975; Johnson et al. 1981; Wegener and Williams 1974(a), Wegener et al. 1974). However, decreases in some species or communities have also been observed (Dooris and Copeland 1962; FGFWFC 1979(a), in Lake Carlton; Frey 1967).

Several studies have shown almost complete elimination of benthic invertebrates from the exposed sediment areas during drawdown (Barman and Baarda 1978; Bennett 1954; White and White 1977). Alteration of macroinvertebrate species composition as a result of drawdown or water level fluctuation has also been observed. Catastrophic loss of the littoral zone mussel population occurred after the first year of drawdown in Sebasticook Lake, Maine (Courtemanch 1986). Annual water level fluctuations in a Great

Britain reservoir resulted in the almost complete elimination of sponges, flatworms, leeches, gastropods, amphipods, and insects, but an increase in littoral zone macroinvertebrate density because of a greatly increased number of oligochaetes (Hynes 1961).

One reference was found which addressed zooplankton response to drawdown. Zooplankton densities were higher in the 2 years after reflooding in Lyon County Lake, Kansas (Prophet 1970), but declined the following two years.

4.3 EFFECTS ON WATER QUALITY

The effects of drawdown or enhanced fluctuation on water quality are not as clear as those regarding fishery management. Of the 20 drawdowns where water quality was monitored, 13 (65%) report that water quality decreased during drawdown, and 13 (65%) also report that water quality decreased after refill. One lake (Sabasticook Lake in Maine) observed an increase in water quality during drawdown, and 5 (25%) of those lakes reporting data observed increased water quality after refill. Three lakes reported no change in water quality during or after drawdown (Figure 4.3).

The primary nutrient forms of nitrogen and phosphorous can show different responses during dewatering and after refill. A six-month drawdown in Lake Laurel, Georgia resulted in significantly lower concentrations of total phosphorus, total soluble phosphorus, and orthophosphorus concentrations after refill, but no change in nitrate or nitrite concentrations (Barman and Baarda 1978). In Lake Hunter, Florida, total phosphorus concentrations were significantly higher in the year following drawdown than the year before, but

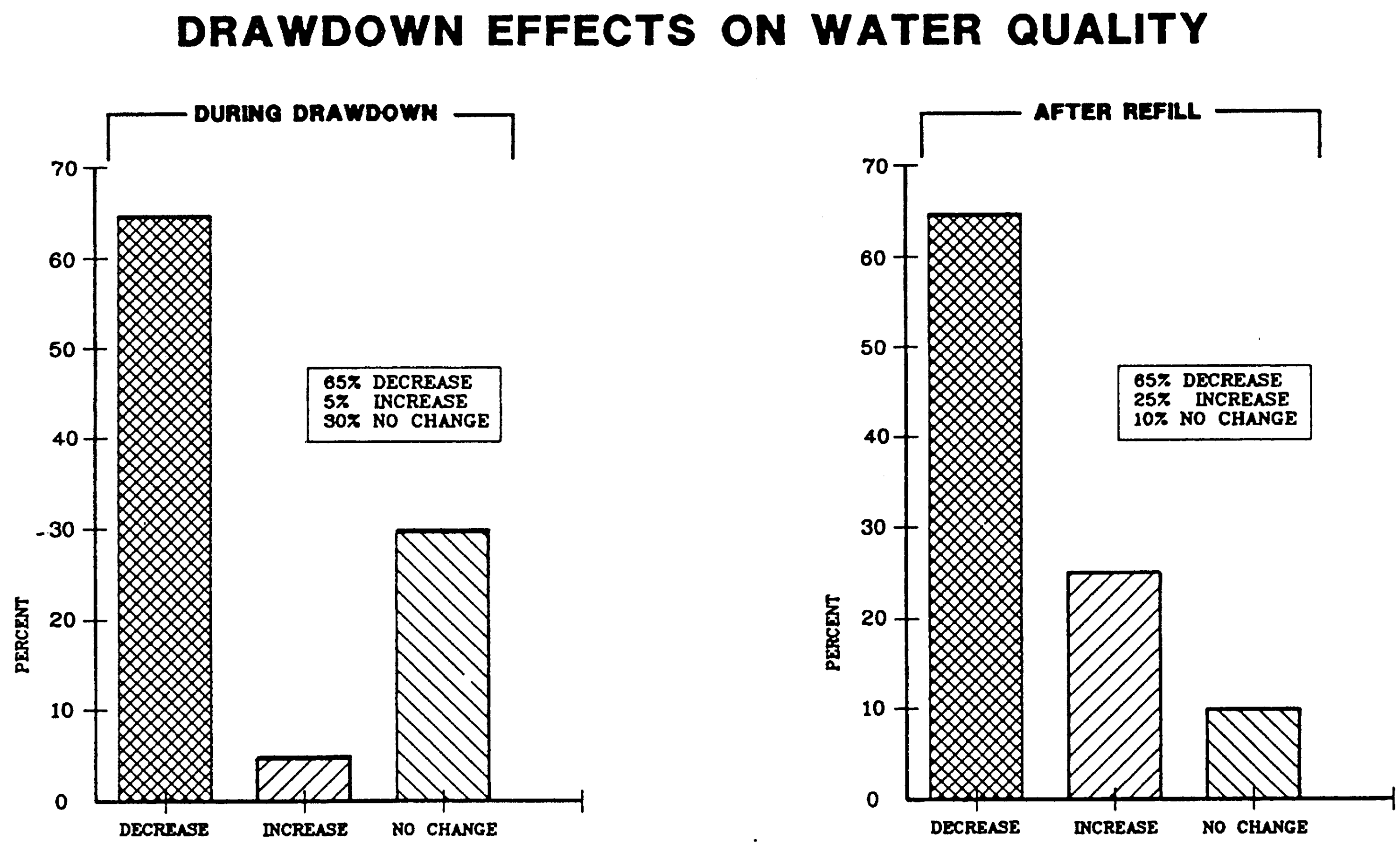


Figure 4.3 Summary of Water Quality Results. In this figure, a decrease in water quality should be interpreted as an increase in the concentrations of nitrogen and/or phosphorus nutrient species. These increases in nutrient concentrations are coded with "+" in Tables 4.1 - 4.3.

total nitrogen and Trophic State Index (TSI) remained unchanged (FGFWFC 1989). In Lake Griffin, total nitrogen and total phosphorus concentrations were significantly higher during dewatering than pre-drawdown, and did not show improved water quality after refill (FGFWFC 1986).

Experimental studies on sediments of the Puyvalador Reservoir (France) show that the quantity of orthophosphorus solubilized after annual drawdown and reinundation varies according to (1) the refill rate (in this experiment, lower refill rates resulted in increased resuspension and increased ortho-P concentration in the water column of the sediment), (2) the degree of sediment desiccation (air dried sediments resulted in higher concentrations of ortho-P in the water column than did sediments which remained inundated), and (3) the origin of the refill water (low phosphorus concentrations in the refill water resulted in increased ortho-P release from the sediments into the water column; Fabre 1988). Similar experiments on sediment from Lake Howard, Florida, showed increases in nutrient concentrations (TP and TKN) in various sources of refill water after reinundation of dried sediments (Water and Air Research, Inc. 1980).

Water quality changes in a lake during and after drawdown appear to be the result of several factors. Increased water column nutrient concentrations have been attributed to release of nutrients from sediments during dewatering and refill, and subsequent aeration, oxygenation, and increased microbial activity. At reflooding, considerable nutrient release into the water column may occur (Cooke 1980; Fabre 1988; Kadlec 1960; Serruya and Pollingher 1977). Another source of nutrients to the water column is aquatic vegetation which has been desiccated by the lowered water levels (Welch et al. 1988). Terrestrial plants which germinate and grow on the exposed sediment surface during drawdown often die upon reinundation, and thereby release additional nutrients into the water column (reviewed in Jacoby et al. 1982; 1983).

Temporary improvements in water quality (i.e., lowered phosphorous but not nitrate concentrations) after drawdown were associated with lower algal biomass and therefore greater water clarity in Lake Laurel, Georgia (Barman and Baarda 1978).

Water quality improvements, however, are generally short-lived. Reservoirs in Kansas experienced greater water clarity in the season following drawdown due to the compaction of silt deposits (Groen and Schroeder 1978). The reestablishment of vegetation on exposed mud flats also resulted in reduced wave action-induced turbidity. Annual drawdowns are practiced for continuing effectiveness in these Kansas reservoirs. Other studies have indicated that macrophytes which become established during drawdown can help uptake excess nutrients in the water column or sediments [thereby making these nutrients unavailable for algal growth (Groen and Schroeder 1978; reviewed in Jacoby et al. 1982; 1983)], and can help stabilize sediments, thereby preventing resuspension of flocculent material.

In Long Lake, Washington, the reduction in macrophyte biomass during a summer drawdown (due to desiccation and decomposition) resulted in greatly reduced nutrient loading to the water column during the following winter (when decomposing macrophytes normally supply large amounts of nutrients to the water column). Consequently, total phosphorus concentrations in the water column during the following summer were 50 percent lower (Jacoby et al. 1982; 1983). However, the beneficial effects of this drawdown were expected to be short term, as macrophyte recolonization was rapid (Jacoby et al. 1983).

In Georgia, Lake Laurel was drained and the sediments allowed to dry for 6 months (Barman and Baarda 1978). Water column total phosphorus, total soluble phosphorus, and orthophosphorus concentrations were significantly lower during the summer immediately after drawdown, as was phytoplankton biomass. As with the other observations, however, water quality benefits appeared to be temporary, lasting only 1 year after drawdown (Barman and Baarda 1978).

The Maine Department of Environmental Protection uses drawdown for a unique purpose, "enhanced seasonal flushing," which reduces internal P loading in Sebasticook Lake by flushing out nutrient-laden water before nutrients can become incorporated in the lake sediments (Courtemanch 1986). Each year in September, the lake is lowered 46 percent by volume over a very short time period, flushing out nutrient and algae-laden water. Internal P loading declined 46 to 85 percent over pre-drawdown estimates. No mention was made of downstream effects of this rapid release of poor quality water.

A pilot scale experimental investigation was conducted by Fox et al. (1977) to examine the effects of sediment dewatering and reinundation on Lake Apopka sediments and overlying water quality. Muck (sediment) from Lake Apopka was placed in aquaria and allowed to dry for various lengths of time. Refill water was collected from Gould Neck Springs (Apopka Springs), a primary source of groundwater for Lake Apopka. The effect of drying period on inorganic nutrient levels in the refill water was different for each of the nutrient forms. Drying enhanced nitrate release from the sediments. However, initial nitrate release was inversely related to the extent of drying, with the short drying period treatment yielding nitrate spikes greater than 2 mg N/l. Longer drying period treatments showed lower initial spikes but increasing nitrate levels with time following refill. Orthophosphate levels for all drying periods showed increasing concentrations with time following refill. Extensive drying led to elevated phosphate release compared to the control, whereas less drying showed orthophosphate levels in the water to be somewhat lower to slightly more than the control. Fox et al. (1977) concluded that there is an optimal level of drying in terms of effects on water quality. Too little drying stimulates nitrate release and will not consolidate the sediments and stabilize the interface. However, extensive drying tends to release more phosphate, at least in short term tests, than does undried sediments.

During actual drawdowns in Florida lakes, nutrient concentrations increased during drawdown. Lakes Tohopekaliga (Holcomb et al. 1975), Carlton (Williams 1985), Kissimmee (FGFWFC 1982(a)), Griffin (Williams 1985), and Hunter (FGFWC 1989) also exhibited lowered water quality after refill than that observed prior to drawdown, including increased total phosphorus, total nitrogen and algae concentrations, and decreased water clarity. For example, extensive monitoring was conducted on Lake Tohopekaliga, before, during, and after drawdown (Holcomb et al. 1975; Williams 1985). Most water quality constituents measured, including TP and TN, increased in concentration during drawdown, and remained higher after drawdown than they had been prior to dewatering. Algae blooms occurred with increasingly greater frequency after drawdown.

4.4 EFFECTS ON MACROPHYTES

The effects of drawdown or enhanced water level fluctuation on macrophytes are two-fold. Drawdown can adversely affect aquatic species by desiccation, and/or can result in germination of littoral zone species on newly exposed sediments.

Control of nuisance macrophyte species was the single most cited objective for drawdown; 23 of the 42 lakes included in the drawdown summary (Table 4.1) stated this objective. In Florida, 11 of the 15 (73%) lake drawdown projects cited nuisance macrophyte control as one of the project objectives. The effectiveness of drawdown or enhanced water level fluctuation to control undesirable vegetation or nuisance species is variable. Drawdown is effective, but is species specific, and some nuisance plants are revived or stimulated (Cooke 1980). Increased biomass or coverage of nuisance species (such as hydrilla, milfoil, water hyacinth) occurred in 11 of 17 (65%) drawdowns included in this review, while decreased coverage was observed in the remaining 6 (35%) drawdowns.

Cooke (1980) reviewed published case histories of the use of lake level drawdown as a nuisance macrophyte control technique. He listed the response of 63 nuisance plants to summer, winter, or whole year drawdown. Cooke found that only three species, Brasenia schreberi (water shield), Hydrochloa caroliniensis and Potamogeton robbinsii (pondweed) seem to be consistently controlled. Nuphar sp. (spatterdock), Eichhornia (water hyacinth) and Myriophyllum (milfoil) are also usually controlled. Alligatorweed (Alternanthera), duckweed (Lemna), cutgrass (Leersia) and naiad (Najas) always increase after a drawdown (Cooke 1980). Cattails (Typha) were found to respond with an increase in biomass to a winter drawdown in Wisconsin (Nichols 1975), but showed no change in biomass after an annual drawdown in Michigan (Kadlec 1960). Cooke concluded that water level drawdown is an effective technique for at least short-term control (1-2 years) of susceptible nuisance macrophyte species. Drawdown for nuisance macrophyte control is recommended for situations where prolonged dewatering of lake sediments is possible under rigorous conditions of cold or heat, and where susceptible species (water hyacinth, water lily) are the major nuisances. Cooke also points out that lakes with gradual basin slopes are ideal since small drops in lake level will expose large areas.

Successful control of nuisance vegetation is most common using winter drawdown in northern or northeastern states. During winter drawdown, the littoral zone and shallow sections of a lake are exposed to freezing, desiccation, and scouring by ice. Vegetation control generally lasts from 6 months to a year after winter drawdown, after which some species become reestablished from tubers or seeds. There is a distinct difference in susceptibility to desiccation and freezing among plant species, and differential rates of recovery from damage alters species composition in the littoral zones after refill. In some cases, drawdown conducted to control a nuisance species results in the control of the target species, but the proliferation of other nuisance species more tolerant of drawdown conditions (Godshalk and Barko 1987; Cooke 1980; Progressive Architects Engineers Planners 1988). For example, Eau Galle Reservoir in Wisconsin underwent an over winter drawdown to control coontail (Ceratophyllum), resulting in a 50 percent reduction of this species in the littoral zone for two years. However, pondweed (Potamegeton) proliferated and became as much of a nuisance as the coontail (J. Filbin, personal communication, November 1989).

Similar varied responses to drawdown have been observed in Florida. The Lake Oklawaha surface water elevation was lowered 1.5m from September to February (1972-1973), resulting in temporary control of coontail, hydrilla, southern naiad, and elodea; however, there was a substantial increase in water hyacinth, alligatorweed, smartweed, and water purslane. Within 9 months of drawdown, hydrilla had increased tremendously in coverage, as did pickerelweed and water hyacinth (Hestand and Carter 1975). An 8 month drawdown of Lake Miccosukee, Florida, resulted in the reduction of some plant species: water shield, cabomba, millfoil, water willow and bladderwort. Several other species increased in abundance or were unaffected; azolla, duckweed, bog mat, frog's bit, water lily, spatterdock, and terrestrial annuals (Tarver 1980).

An experimental 3-stage dewatering plan to control hydrilla was implemented in Fox Lake, Florida, in 1979. An 11 week dewatering desiccated portions of hydrilla and stimulated germination of hydrilla turions and tubers. Within 3 weeks of reflooding, cattail seedlings, hydrilla and eel grass were observed throughout the basin. The second and third dewatering resulted in a significant decrease in hydrilla biomass, but dense stands of cattails became established over most of the basin (McKinney and Coleman 1980).

In Florida lakes and reservoirs, drawdown generally results in greatly increased plant germination on exposed sediments. In lake simulation studies using sediment from Lake Apopka, Fox et al. (1977) reported that seventeen plant species colonized drying sediments; however, only two aquatic macrophytes species (cattail and water hyacinth) were observed to germinate. The only plant which survived refill was cattail. Following refill, however, Chara sp. (stonewort), a macroscopic green alga, was observed in several experimental tanks (Fox et al. 1977).

Emergent and aquatic species can provide improved habitat for fish and wildlife (see Section 4.1, Littoral Zone Habitat); however, terrestrial species which germinate and grow during the dewatering period die upon inundation and can contribute additional nutrients and Biochemical Oxygen Demand (BOD) to the lake (Hestand and Carter 1975; Johnson et al. 1981). Several lake drawdowns in Florida have resulted in large growths of undesirable vegetation. The drawdown on Lake Tohopekaliga (FGFWFC 1975; Wegener and Williams 1974(a)) resulted in rank water hyacinth growth and the formation of persistent mats. The Lake Hunter drawdown (FGFWFC 1989; Williams 1985) required chemical control of large floating mats of cattails which became unmanageable after refill. Lakes Fox and Carlton also experienced excessive growth of cattails during drawdown which persisted after refill (McKinney and Coleman 1980; Williams 1985). Drawdown on Lake Oklawaha provided short-term (6 month) control of coontail and hydrilla, but increased growth of water hyacinth and alligatorweed (Hestand and Carter 1974). The year-round growing season in Florida undoubtedly contributes to the difficulties in managing macrophytes for enhanced growth of desirable species while controlling the growth of nuisance species.

4.5 EFFECTS ON SEDIMENT CHARACTERISTICS

Only 5 drawdowns were found which were conducted for sediment consolidation, and only 2 of those (Fox Lake and Lake Griffin) are located in Florida. However, some degree of sediment consolidation was observed in 11 drawdowns. Of the 8 lake drawdowns in which the drawdown duration was documented, 3 had durations of 1 to 3 months, 2 had durations of 4 to 8 months, and 3 had durations of greater than 8 months.

Both Fox Lake and Lake Griffin in Florida had drawdown durations of less than three months. Significant sediment consolidation of the surface organic muck layer (top 5-10 cm) was observed in Fox Lake during dewatering, but cattail growth on the exposed consolidated sediment caused large segments of sediment and cattails to become dislodged from the underlying unconsolidated muck and float to the surface after refill (McKinney and Coleman 1980). Significant consolidation was not observed in Lake Griffin due to heavy rains and incomplete dewatering (Williams 1985). A five month dewatering in Lake Hunter resulted in the formation of a 15 cm thick crust over areas of deep unconsolidated muck deposit (FGFWFC 1989). Lake Miccosukee underwent a seven month dewatering after which significant reductions in the peat zone and in the muck layer were observed (Tarver 1980). A 12 month dewatering on Lake Carlton caused significant sediment consolidation, which was still compacted one year after refill (FGFWFC 1979(b)). A 15 month dewatering in Lake Tohopekaliga resulted in a reduction of the depth of organic sediments by 50 to 80 percent. Flocculent sediments disappeared completely in areas that were dewatered, apparently in part due to higher microbial activity within exposed sediments (Holcomb et al. 1975).

From these limited observations, it appears that approximately five to seven months of desiccation may be the minimum amount of time necessary for significant sediment consolidation to occur in Florida lakes. In addition, water levels must be significantly below the muck layer for complete dewatering (V. Williams, personal communication, December 1989). A shorter exposure time may result in a cap of dried organic material forming over unconsolidated wet sediments; this cap appears to be susceptible to becoming dislodged and floating to the water surface during and after refill.

Nutrient concentrations in exposed and reinundated lake sediments can be affected, and in turn, affect overlying water quality (see Section 4.3). In a waterfowl impoundment in Michigan, soil nitrates increased during drawdown due to aerobic nitrification (Kadlec 1960). The response of other nutrients was less obvious. During a drought on Lake Kinnert, Israel, sediment exposure increased the decay of organics, improved solubility of salts such as calcium phosphate, and increased the release of orthophosphate due to the more effective oxidation of sediments (Serruya and Pollingher 1977). Water and Air Research (1980) conducted a microcosm simulated drawdown experiment using Lake Howard, Florida sediments, and concluded that desiccation reduced sediment nutrient release. However, their conclusions are suspect because they used the same sediments for the undried and dried treatments. The partial removal of sediment nutrients prior to desiccation may have caused the lower water column nutrient concentrations observed over dried sediments, compared to those over these same sediments prior to desiccation. Regardless, total Kjeldahl nitrogen and total phosphorus concentrations doubled in the refill water after reinundation of the dried sediments, representing a deterioration in water quality.

4.6 OTHER EFFECTS

Other ecological effects of drawdown or enhanced water level fluctuation include the following:

- Curtailed use of the lake by wildlife and waterfowl during drawdown (Beard 1973; Johnson and Montabano 1989; Kansas Water Office 1989)
- Shallow wells around the perimeter of the lake can be affected by a lowered surficial water table (Beard 1973; D. Jude, personal communication, November 1989)
- Drawdown can be used as a precursor to other restoration or management techniques, in particular sediment removal or manipulation, in-lake repair of structures, weed harvesting, and rough fish removal (Cooke 1983; Peterson et al. 1974)
- High discharge rates during spring drawdowns may result in flushing fish larvae and fry from the lake (Kansas Water Office 1989)
- Marshes and wetlands adjacent to a drawdown lake can experience subsidence and consolidation (Smith et al. 1972; J. Swartz, personal communication, December 1989)
- Fish kills can occur in downstream canals during drawdown due to anoxic conditions, (W. E. Johnson, personal communication, November 1989)
- Potential water supply or frost protection are concerns for agriculture around lakes (W. E. Johnson, personal communication, November 1989)

5.0 APPLICATION OF DRAWDOWN AND ENHANCED FLUCTUATION TO THE RESTORATION OF LAKE APOPKA

Lake Apopka, the fourth largest lake in Florida at approximately 31,000 acres, has been a state concern for the past 30 years due to declining water quality. The size of the lake and its severe cultural eutrophication problem has generated significant interest, producing numerous reports, assessments, and evaluations on the lake's quality, ecology, hydrology, etc. Many of these studies have focused on the cause of the lake's accelerated decline. Since the early 1970's, more emphasis has been placed on restoring the lake and reducing nutrient loads into the lake.

Historically, Lake Apopka naturally drained to the northwest to Little Lake Harris during periods of high water. In 1887, the Apopka-Beauclair Canal was constructed, connecting Lake Apopka to Lake Beauclair, and thus Lake Apopka became part of the Oklawaha Chain of Lakes (Figure 5.1; Conrow et al. 1989). The lake was further regulated in the 1950's, when the Apopka-Beauclair Lock and Dam was constructed by the Oklawaha Basin Recreation and Water Conservation and Control Authority of Lake County. Lake level regulations were established and have been promulgated since that time. Currently, the St. John's River Water Management District maintains these regulations. The current lake level is regulated as shown in Figure 5.2.

This evaluation applies information from the literature review with specific conditions currently existing in Lake Apopka to predict the potential ecological effects of a drawdown or enhanced fluctuation in Lake Apopka and effects on the downstream Oklawaha Chain of Lakes. Several different drawdown and enhanced fluctuation scenarios are considered.

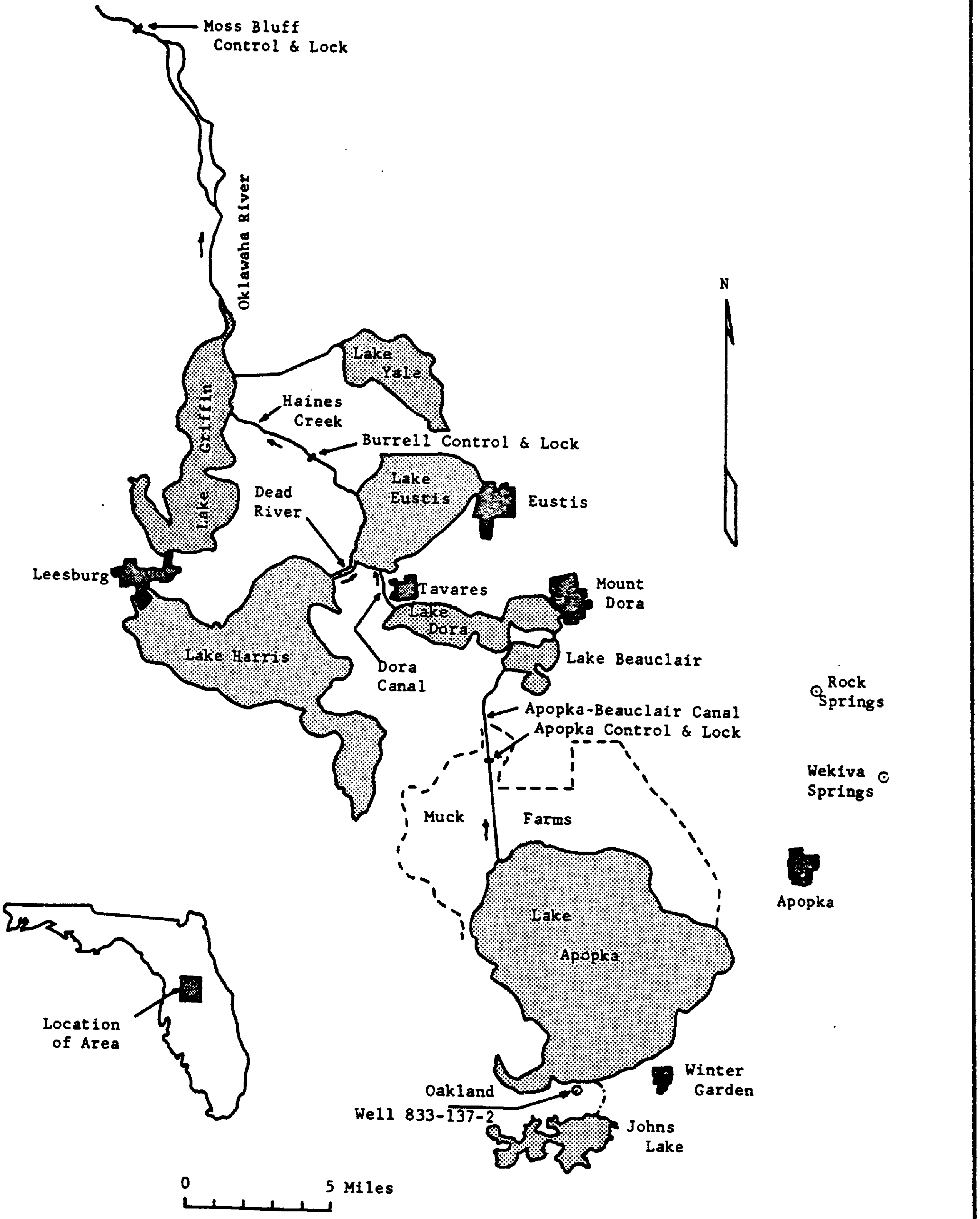


Figure 5.1 Oklawaha Chain of Lakes

Dames & Moore

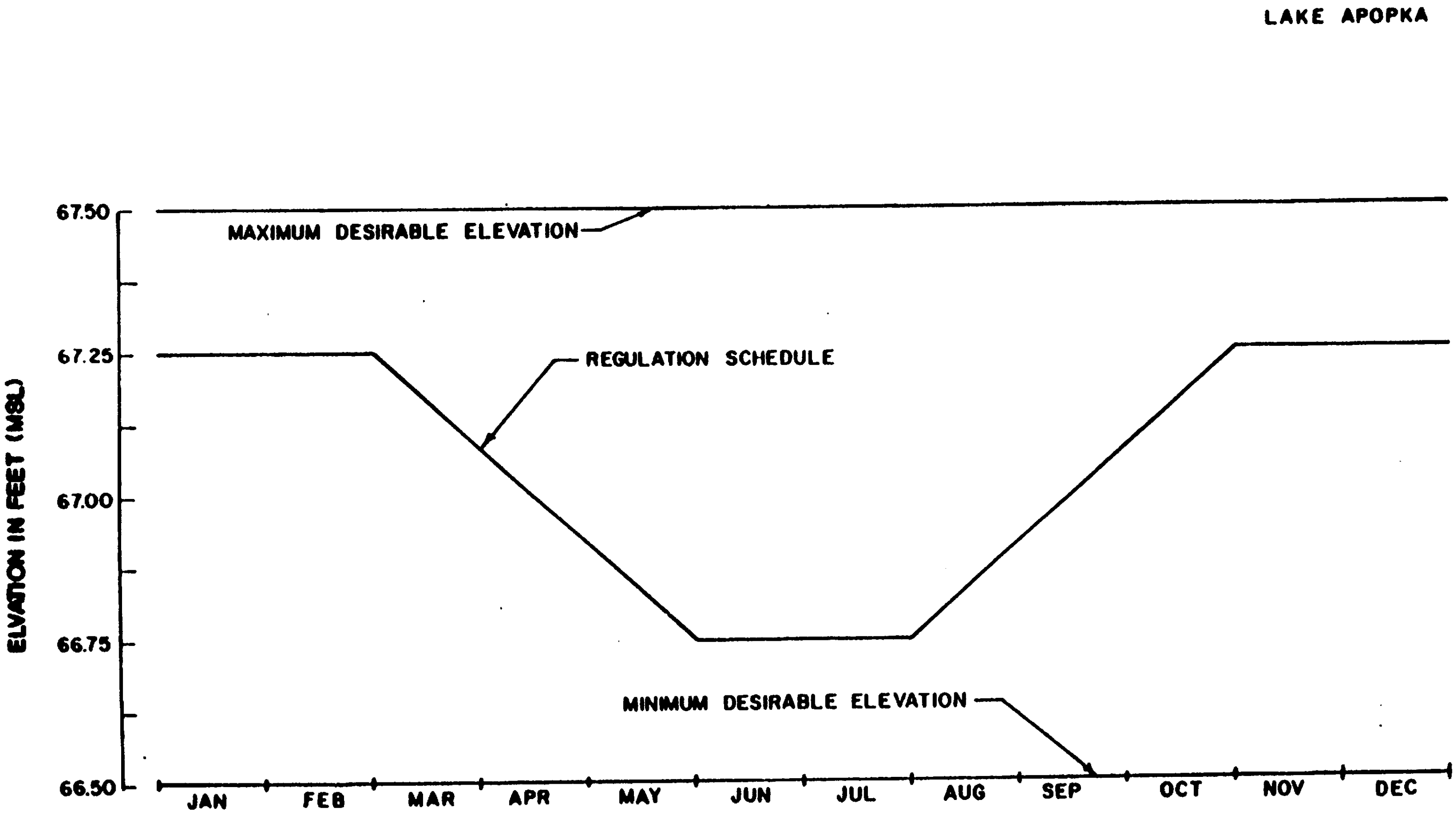


Figure 5.2 Regulation Schedule for Lake Apopka (SJRWMD)

5.1 PREVIOUS STUDIES

Although there have been numerous studies on Lake Apopka, there are no comprehensive water resource management studies on the lake. Most of the previous studies have focused on specific aspects of lake restoration, water quality, ecology, aquatic biology, hydrology, etc. without examining the entire Oklawaha chain. The major studies examining drawdown or enhanced fluctuation are reviewed below.

A bathymetric survey of Lake Apopka conducted in June 1989 (Environmental Consulting & Technology, Inc. (ECT) 1989) indicates that the lake is generally flat and shallow (Fig. 5.3). Hypsographic data (Table 5.1) show that lowering the water level from 66 ft. NGVD to 64 ft. NGVD would expose only about 4 percent of the surface area (Figure 5.4), and require discharging about 40% of the lake volume (Figure 5.5). At 60 ft. NGVD, 85 percent of the lake bottom would be exposed, but 95% of the lake volume would have to be discharged (ECT 1989).

Sheffield and Kuhrt (1969) reported on a drawdown scenario for Lake Apopka from 66.5 ft. to 58.0 ft. NGVD based on USGS analyses as part of a Lake Apopka Restoration Plan. At 58 ft. NGVD, they estimated that, due to the thickness of the sediments, drying would actually take place to elevation 61.0 NGVD. At 61 NGVD, 56 percent of the lake would be exposed and 89 percent of the volume of the lake would be discharged (Table 5.1).

Anderson (1971) investigated downstream hydrologic considerations for draining Lake Apopka. Using a water budget, various scenarios of lake drawdown were examined. Anderson concluded that (1) the channel capacities below Lake Eustis were adequate to accept the volume of water released during a Lake Apopka drawdown, (2) channel capacities were marginal in the Dora

Table 5.1 Hysographic Data for Lake Apopka (Computed from the English-Units Chart)

Depth Contour (ft.)	Lake Level (ft.)	Cumulative Area (sf. X 10**9)	Cumulative Area (acres)	Layer Volume (cf X 10**9)	Lake Volume (cf X 10**9)	Lake Volume (%)
0	66	1.342	30812	1.329	6.518	100.00 %
-1	65	1.316	30215	1.304	5.189	79.61 %
-2	64	1.291	29641	1.259	3.885	59.60 %
-3	63	1.227	28172	1.131	2.626	40.29 %
-4	62	1.038	23832	0.801	1.495	22.94 %
-5	61	0.586	13455	0.377	0.694	10.65 %
-6	60	0.202	4638	0.163	0.317	4.86 %
-7	59	0.126	2893	0.09	0.154	2.36 %
-8	58	0.059	1355	0.041	0.064	0.98 %
-9	57	0.025	574	0.014	0.023	0.35 %
-10	56	0.005	115	0.004	0.009	0.14 %
-11	55	0.003	69	0.002	0.005	0.08 %
-12	54	.001	23	0.001	0.003	0.05 %
-13	53	0.001	23	0.001	0.002	0.03 %
-14	52	< 0.001	--	< 0.001	< 0.001	0.02 %
-15	51	< 0.001	--	--	--	-- %

sf = square feet
cf = cubic feet

Source: ECT, 1989

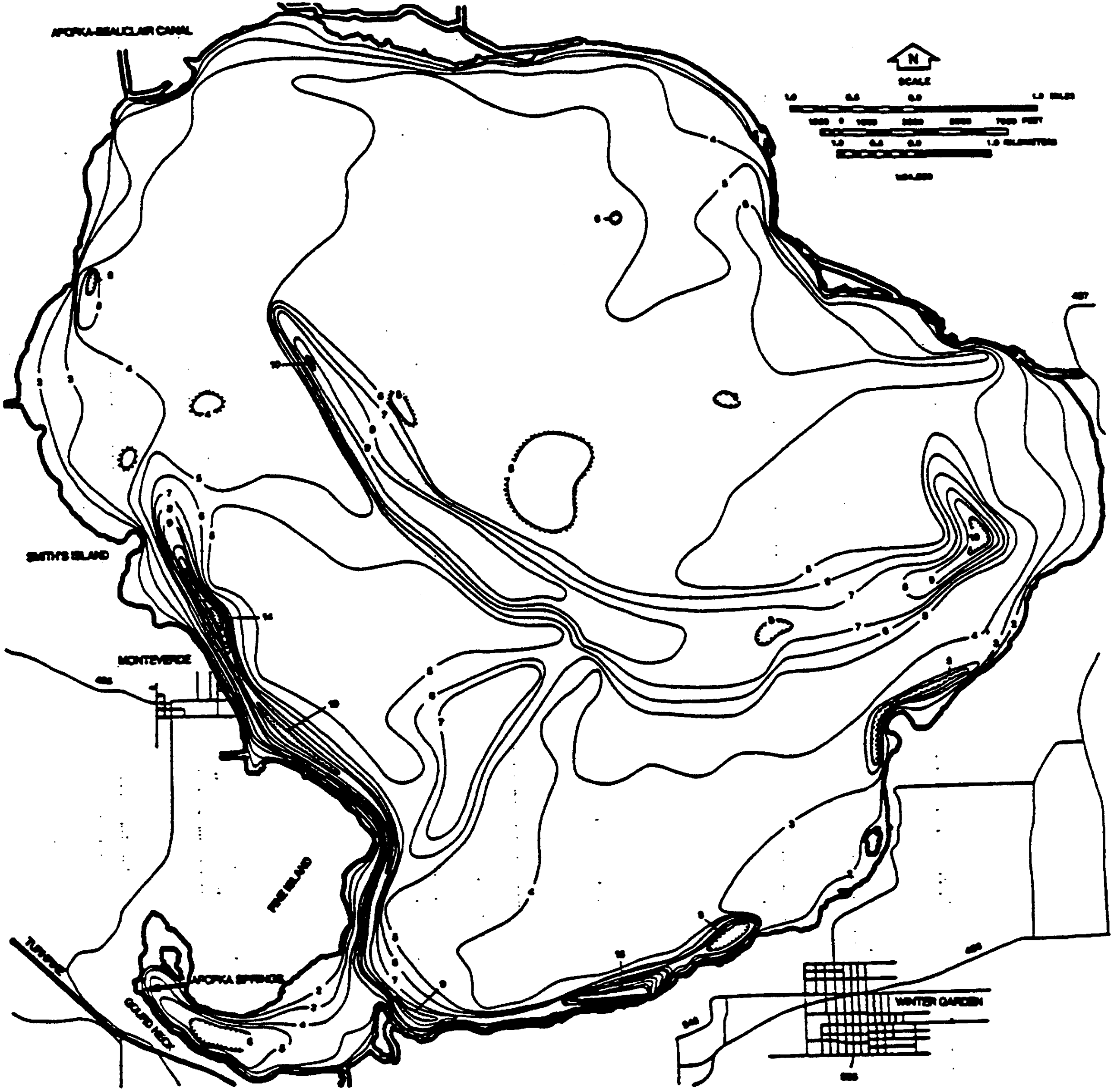


Figure 5.3 Lake Apopka Bathymetry Chart (ECT, 1989)

FIGURE 5.4

PERCENT LAKE BOTTOM EXPOSURE AT VARIOUS LAKE ELEVATIONS - MODIFIED FROM ECT (1989)

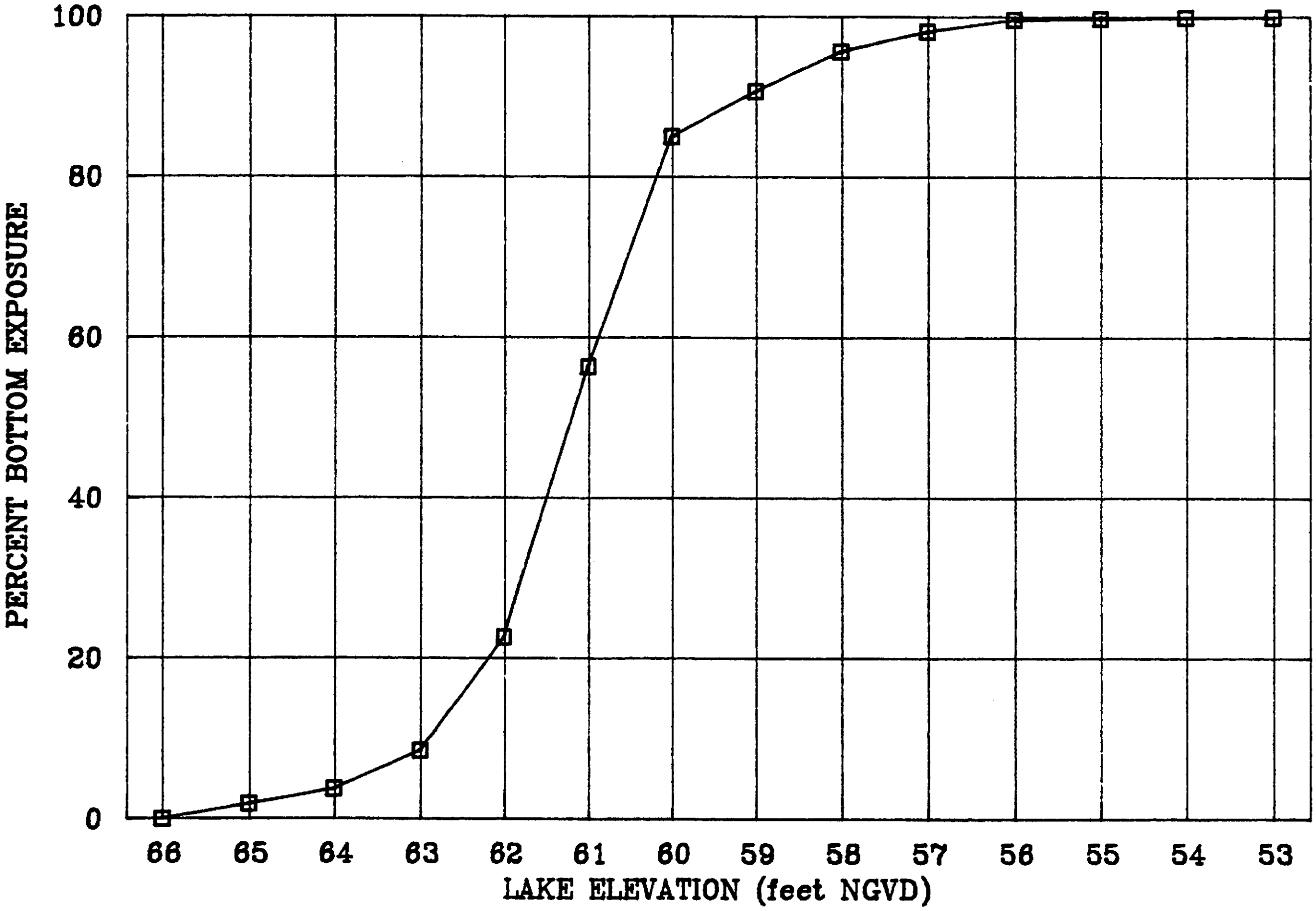
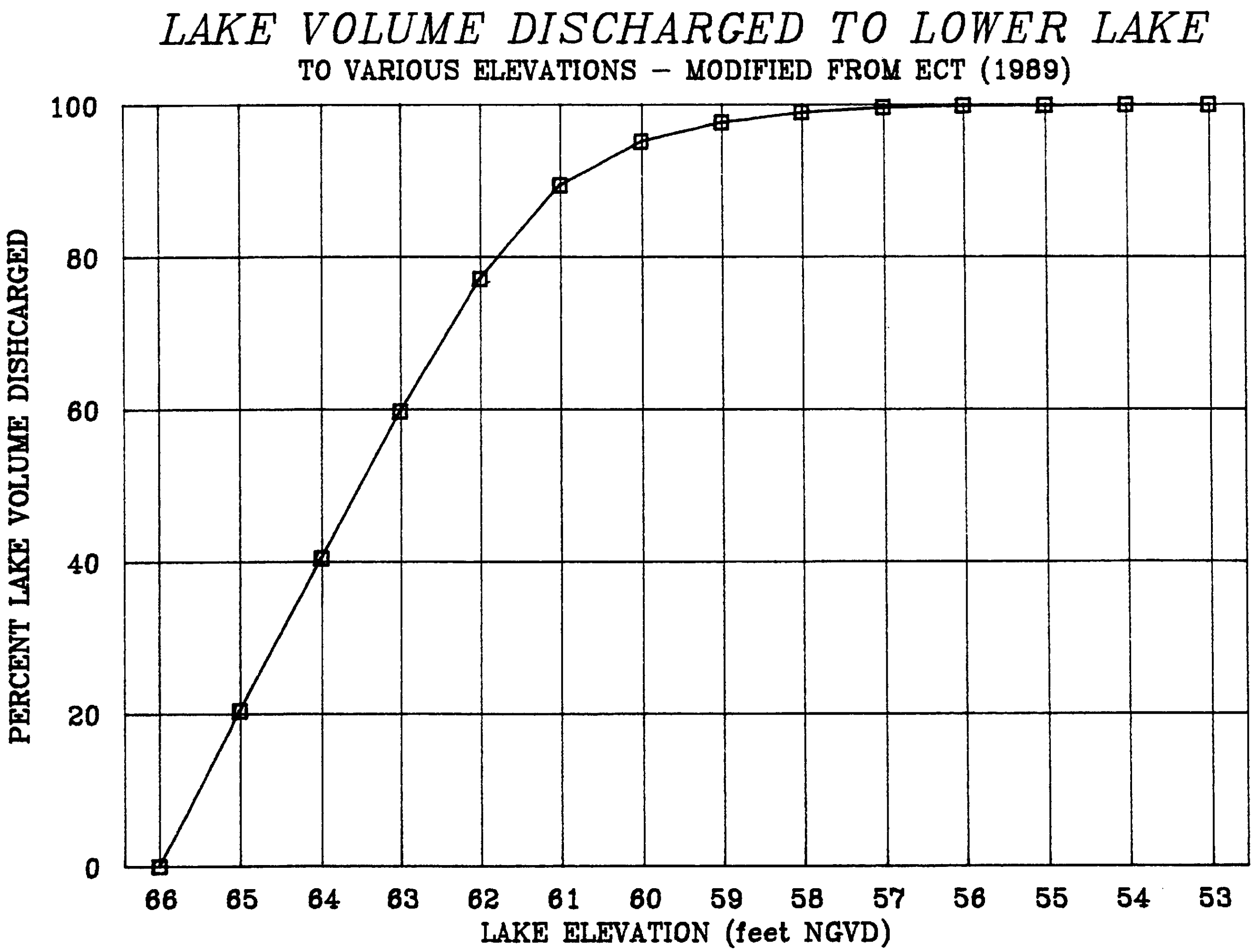


FIGURE 5.5


LAKE VOLUME DISCHARGED TO LOWER LAKE
TO VARIOUS ELEVATIONS - MODIFIED FROM ECT (1989)
PERCENT LAKE VOLUME DISHCARGED
100
80
60
40
20
0
66
65
64
63
62
61
60
59
58
57
56
55
54
53
LAKE ELEVATION (feet NGVD)

and Apopka-Beauclair canals, and (3) velocity must be kept at a minimum to avoid excessive scour. After further evaluation, Anderson concluded that the capacity of Dora Canal would have to be increased in order to pump or drain a maximum of 400,000 gpm (891 cfs) from Lake Apopka.

Anderson (1971) further determined that the lowest elevation which could be reached in Lake Apopka by gravity drainage was 62.0 ft NGVD, due to the elevation of the Apopka-Beauclair Lock and Dam. Anderson further concluded that this could only occur if the downstream lakes were more than a foot below their average levels. He concluded that it would take seven years to reach this elevation in Lake Apopka using gravity drainage. Anderson therefore concluded that gravity drawdown was not feasible due to the length of time required for drainage.

Anderson (1971) also investigated pumping the lake down to an elevation of 58 ft. NGVD, thereby allowing 50 percent of the muck bottom to compact. More recent information (ECT 1989, Table 5.1) indicates that 95.6 percent of the lake bottom would be exposed at 58 ft. NGVD, but compaction may only occur in those sediments above 61 ft. NGVD (Anderson 1971; Sheffield and Kuhrt 1969, a 56% areal exposure (Table 5.1). Anderson's scenario involved either placing pump intakes at an invert elevation below 58 ft. NGVD or dredging a canal in the lake to drain water to a pump located at the outfall. Various drawdown times were evaluated based on pumping rates. Assuming Dora Canal could convey a maximum of 300,000 gpm (669 cfs), the required drawdown time would be 105 days. It was concluded that a pump capacity of 200,000 gpm (445 cfs) would be adequate to maintain a lake level of 58 ft. NGVD. Two methods of refilling the lake were examined: (1) natural inflow, and (2) backpumping. The first method would require approximately 450 days and the second would require 86,000 gpm (192 cfs) pumping for 153 days (Anderson 1971).

Camp, Dresser and McKee, Inc. (1976) developed a study of water management alternatives for the Middle Oklawaha River Basin. This study did not involve the Upper Oklawaha Chain of Lakes in detail. Water management alternatives designed to decrease flooding in the middle basin involved a scenario to allow greater fluctuation in lake levels in the Upper Oklawaha Chain to provide flood storage in the chain. The study concluded that, by allowing Lakes Apopka, Dora, Harris, Eustis, Griffin and Yale to fluctuate up to a four-foot range in lake level, approximately 181,200 ft^2 of additional storage would be available.

Fox et al. (1977) discussed lake drawdown as a restoration method, using Lake Apopka as a model. It was determined that at least two months of drying time were required for consolidation of muck sediment. It was also mentioned that care should be taken during pumping to minimize the discharge of loose sediment downstream.

Ross, Saarinen, Bolton and Wilder (RSB&W) (1978) developed a preliminary engineering report on the restoration of Lake Apopka by drawdown. Their drawdown plan involved eight phases over two years and included a drawdown of Lake Beauclair to mitigate impacts associated with the drawdown of Lake Apopka. The first phase of this project involved construction of a cofferdam on Dead River to prevent backflow of poor quality water to Lake Harris during drawdown. A pump station bypass transmission main was planned around Dora Canal to meet a constraint that the maximum flows in the canal not exceed 200,000 gpm (446 cfs). Further phases involved dike protection along the Apopka-Beauclair Canal and dredging of silt in this canal. This would be followed by construction of a large pump station at the outfall of Lake Apopka along with an in-lake sedimentation basin to reduce downstream impacts.

The RSB&W plan called for a gravity drawdown from September through January to 64 ft. NGVD, followed by a three-month pumping schedule to further lower the lake to 58 ft. NGVD. Pumping rates in the Apopka-Beauclair Canal were expected to reach 780 cfs (350,087 gpm). Downstream water levels were not expected to exceed 64 ft. NGVD, which were within acceptable regulated levels. The pumping schedule would be followed by a two-month holddown period (June through July) to consolidate sediments. A maintenance pumping rate of 500 cfs (224,416 gpm) was expected to be sufficient to maintain the holddown. Refill was expected to take four months (August through November), using three refill pump stations located at Lakes Dora, Beauclair and Apopka. These pumps would pump downstream water back to Lake Apopka following the holddown period. Following the drawdown of Lake Apopka, the RSB&W plan called for a seven-month drawdown of Lake Beauclair, involving a pumped drawdown, two-month holddown, and refill phase (RSB&W 1978).

The U.S. Environmental Protection Agency (U.S. EPA 1979) issued an Environmental Impact Statement on the proposed restoration of Lake Apopka. This report discussed drawdown in great detail, relying heavily on the RSB&W report.

Brezonik et al. (1981) conducted a limnological study of the Oklawaha Chain Lakes, including Lakes Apopka, Beauclair, Dora, Eustis and Griffin which detailed the water quality in the chain from 1977 to 1980. Statistical differences were evident between some lakes for certain parameters. The upstream lakes, Apopka and Beauclair, were the most eutrophic and had the poorest water quality, and a gradual improvement downstream was observed. For example, Secchi disk transparency values were highest in the downstream lakes (Lakes Eustis and Griffin, with 51.8 and 51.5 cm, respectively), followed by Lake Dora (41 cm), Lake Beauclair (33 cm), and Lake Apopka (26 cm). The upstream lakes, Apopka and Beauclair, were found to have statistically higher soluble reactive phosphorus (four-year average of 0.050 and 0.066 mg/l) than did Lakes

Dora, Eustis and Griffin (0.032, 0.019, and 0.024 SRP mg/l, respectively). Total phosphorus value trends were similar, with upstream Lakes Beauclair and Apopka values (four-year average of 0.263 and 0.250 mg/l TP) consistently higher than those measured in Lakes Dora (0.143 mg/l), Eustis (0.097 mg/l), or Griffin (0.142 mg/l; Brezonik et al. 1981).

Analysis of total organic nitrogen levels divided the lakes into three groups; Lakes Apopka and Beauclair were significantly higher than the other lakes and Lake Dora was significantly higher than Lake Eustis. Analysis showed concentrations of inorganic nitrogen are low and showed no differences between lakes or years for either nitrate or ammonia were found, indicating that maximum algal uptake of these available forms is occurring in all lakes (Brezonik et al. 1981).

Chlorophyll a concentrations did not follow the general declining trend observed for most nutrient forms in the Oklawaha Chain of Lakes. Significant differences were found in mean annual chlorophyll a levels both over time and among lakes, and Duncan's Multiple Range Test grouped the lakes as Beauclair (annual average of 118.2 mg/m^3 > Dora (85.4 mg/m^3) > Apopka and Griffin (67.3 mg/m^3 and 64.7 mg/m^3) > Eustis (34.2 mg/m^3). Blue-green algae were always the dominant phytoplankton group, contributing at least 60 percent of total phytoplankton abundance in all lakes (Brezonik et al. 1981).

Carlson's Trophic State Index (TSI) for Secchi disk transparency (SD), chlorophyll a concentration (CHL) and total phosphorus (TP) and a similar index based on nitrogen [TSI (TN)] were combined to calculate an average TSI, TSI (AV), by using TSI (SD), TSI (CHL) and the lower of TSI (TP) and TSI (TN). Values above about 50-55 represent eutrophic conditions while values below about 45 represent oligotrophy. Values for TSI (AV) ranged from 65 (Lake Eustis) to 78 (Lake Apopka) and generally indicate eutrophic to hypereutrophic conditions. The three upstream lakes (Apopka, Beauclair and Dora) all demonstrate hypereutrophic conditions with values of TSI (AV) greater than 70. Of the two downstream lakes, Lake Griffin borders on hypereutrophy, and Lake Eustis is eutrophic, with values centering around 65. Generally, the trophic status of the five lakes can be summarized as:

Apopka and Beauclair > Dora > Griffin > Eustis (Brezonik et al. 1981).

The St. Johns River Water Management District is currently investigating the feasibility of establishing an enhanced lake level fluctuation on Lake Apopka, with the primary objective being to restore the natural water level fluctuation to Lake Apopka (Rao et al. in prep.). This would be accomplished by increasing discharges to the Apopka-Beauclair Canal. The study is investigating the establishment of a five-year regulation schedule to accomplish this objective.

5.2 DRAWDOWN AND ENHANCED FLUCTUATION SCENARIOS FOR LAKE APOPKA

Based on discussions with SJRWMD and examination of the hypsographic data presented in Table 5.1 and Figures 5.4 and 5.5, four enhanced fluctuation scenarios were selected for further assessment. In-lake and downstream ecological effects of these scenarios are addressed in Section 5.3. Details regarding pumpage rates and times and refill times and methods are currently being addressed by SJRWMD engineers and are not included in this report.

5.2.1 Enhanced Fluctuation by Gravity Flow and Pumping to 63 ft. NGVD

This scenario is the five year regulation schedule currently being developed by SJRWMD. Gravity discharge and pumping will be used to lower the lake to 63 ft. NGVD (Rao et al. in prep.). A discharge of 500 cfs will be made starting from March 1 until the lake reaches an elevation of 63 ft. NGVD. After the elevation of 63 ft. NGVD is reached, discharge will be made to maintain the lake at 63 ft. NGVD, limiting the maximum rate to 500 cfs. Refill will start on September 1. The probability that the lake would be maintained at 63 ft. NGVD for three months is 29 percent; two months is 41 percent and one month is 70 percent (Rao et al. in prep.).

At 63 ft. NGVD, only 2640 acres (8.6%) of the total lake area (at 66 ft. NGVD) will be exposed (Figures 5.6 and 5.4), although the lake volume will have been reduced by almost 60 percent (Table 5.1, Figure 5.5). The 64 ft. NGVD natural berm near the mouth of the Canal (Figure 5.3) will require either digging a channel through the berm or installing a drainage system to allow water flow to the Canal.

Assuming a 120 day drainage period, 3.2×10^7 cubic feet per day, or 375 cfs is required to remove water currently stored in Lake Apopka. Determination of additional water imports (including rainfall, groundwater, Apopka Springs, and surface water runoff) and exports (evaporation) will require a detailed water budget and are not considered here.

5.2.2 Drawdown by Gravity Flow and Pumping to 62 ft. NGVD

As for the first scenario, gravity discharge and pumping will be used to lower the lake to 62 ft. NGVD. This scenario assumes a holddown time period of 3 months (J. Shuman, personal communication). At 62 ft. NGVD, 6980 acres (22.7%) of the total lake area will be exposed (Figure 5.7); however, lake volume will have been reduced by almost 77 percent (Figure 5.5).

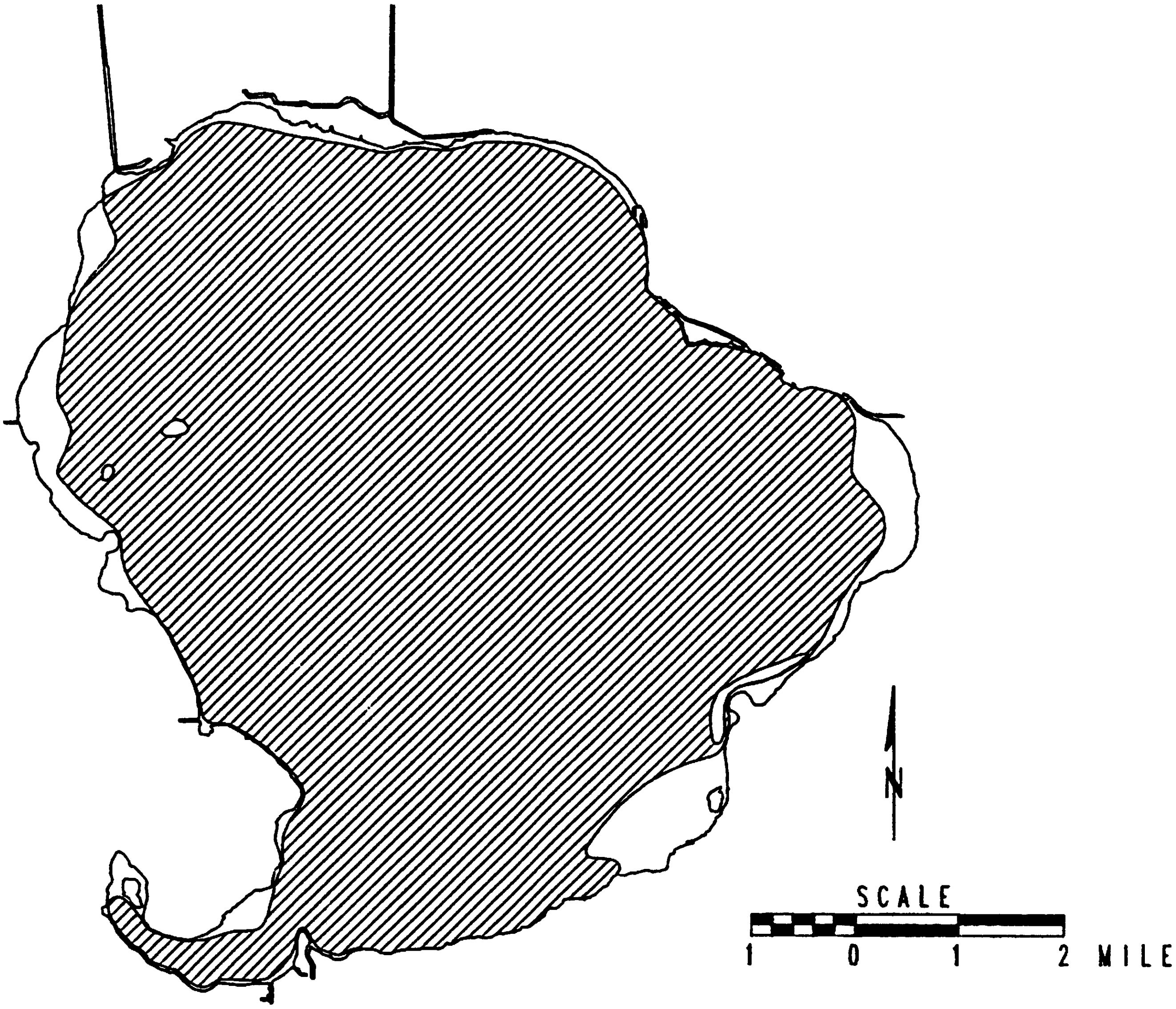


Figure 5.6 Sediment Exposure (unshaded area) in Lake Apopka at Elevation 63 ft. NGVD (Rao et al., in prep.)

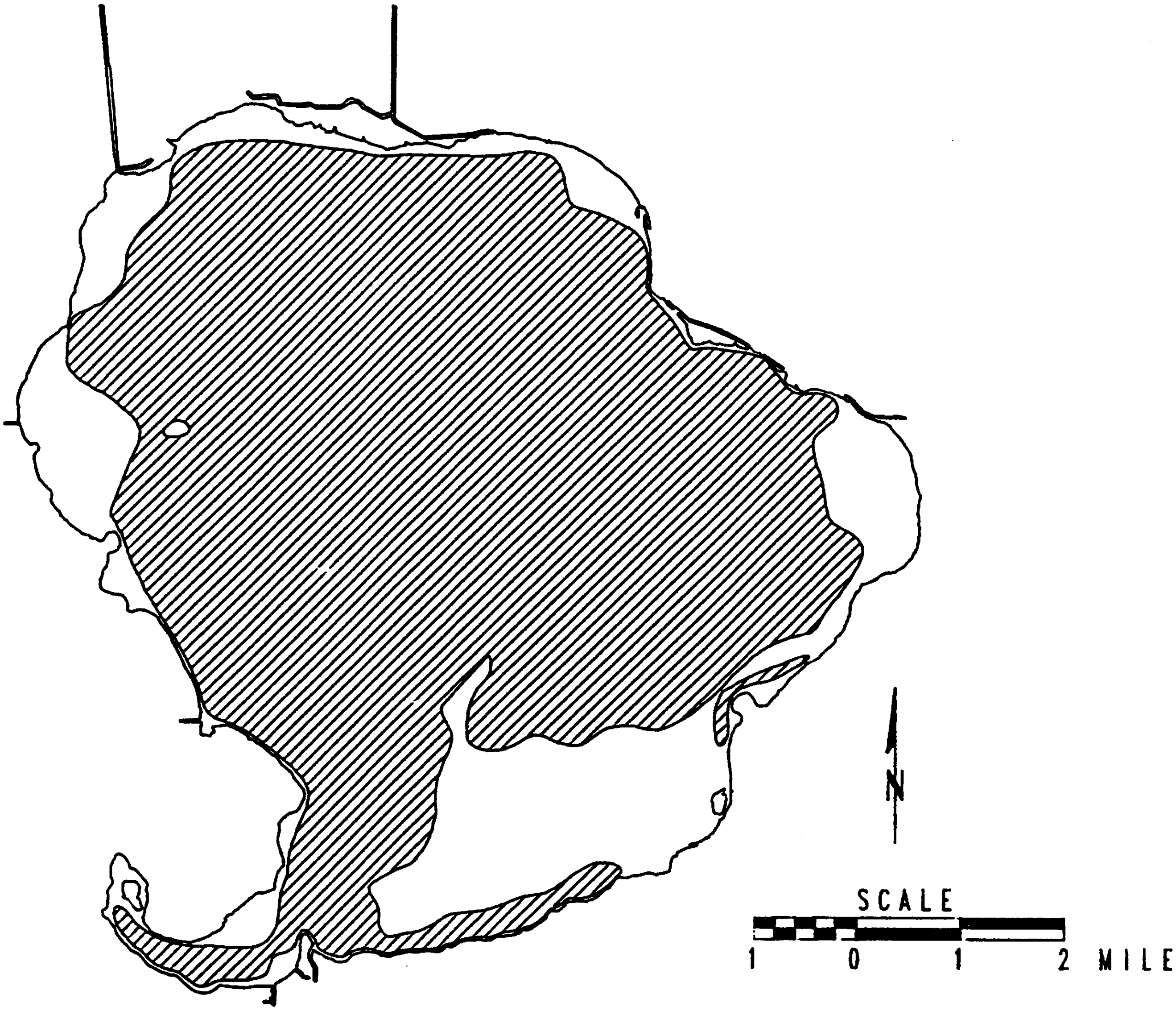


Figure 5.7 Sediment Exposure (unshaded area) in Lake Apopka at Elevation 62 ft. NGVD (Rao et. al., in prep.)

The access channel or drainage system from the Apopka-Beauclair Canal to water remaining in Lake Apopka will need to be slightly more extensive for the 62 ft. NGVD fluctuation than that required to reach 63 ft. NGVD (Figure 5.7). More than 5 x 10^9 cf of water (excluding additional inputs) will be removed. In addition, there is a possibility that some dredging of the Apopka-Beauclair Canal may be necessary. Assuming a 120 day drawdown time, a 485 cfs discharge rate would be required to reach 62 ft. NGVD.

5.2.3 Drawdown by Gravity Flow and Pumping to 61 ft. NGVD

At 61 ft. NGVD, 17,357 acres (56.3%) of Lake Apopka sediments will be exposed, while 89.3 percent of the original lake volume (at 66 ft. NGVD) will have been discharged from the lake (Figures 5.4 and 5.5). Due to the relative isolation of some pockets of remaining water, an extensive system of drainage pipes or channels will be required to remove enough water to reach to 61 ft. NGVD (Figure 5.8). Drainage pipes will have to extend to the lock and dam, unless the Apopka-Beauclair Canal is dredged to 61 ft. NGVD. A total of 5.82 x 10^9 cf (Table 5.1) will be discharged downstream through the Apopka-Beauclair Canal (excluding continual inputs), requiring a discharge rate of 562 cfs for 120 days.

5.2.4 Drawdown by Gravity Flow and Pumping to 60 ft. NGVD

Sediment exposure at 60 ft. NGVD is extensive; 26,174 acres (85 percent of the total lake area) would be exposed, with 95 percent of the original lake volume having been discharged (Figures 5.4 and 5.5). An elaborate system of miles of drainage channels or pipes including extension to the lock and dam would be required to remove the remaining isolated pockets of water (Figure 5.9). A total of 6.2×10^9 cf of water in the lake would be discharged, requiring a discharge rate of 598 cfs for 120 days.

Refill for all four scenarios could be accomplished by natural inflow, pumping from outside sources, or a combination of the two. The RSB&W (1978) plan detailed an extensive back pumping scheme involving three lift stations and a refill period of four months. As mentioned previously, Anderson (1971) examined refilling either naturally or by back pumping. He estimated that the time needed to refill the lake by natural inflow from 58 ft. to 64 ft. NGVD would be about 450 days (an impractical long period for their study), and therefore recommended that refill be backpumped at 192 cfs from the downstream system for a period of five months.

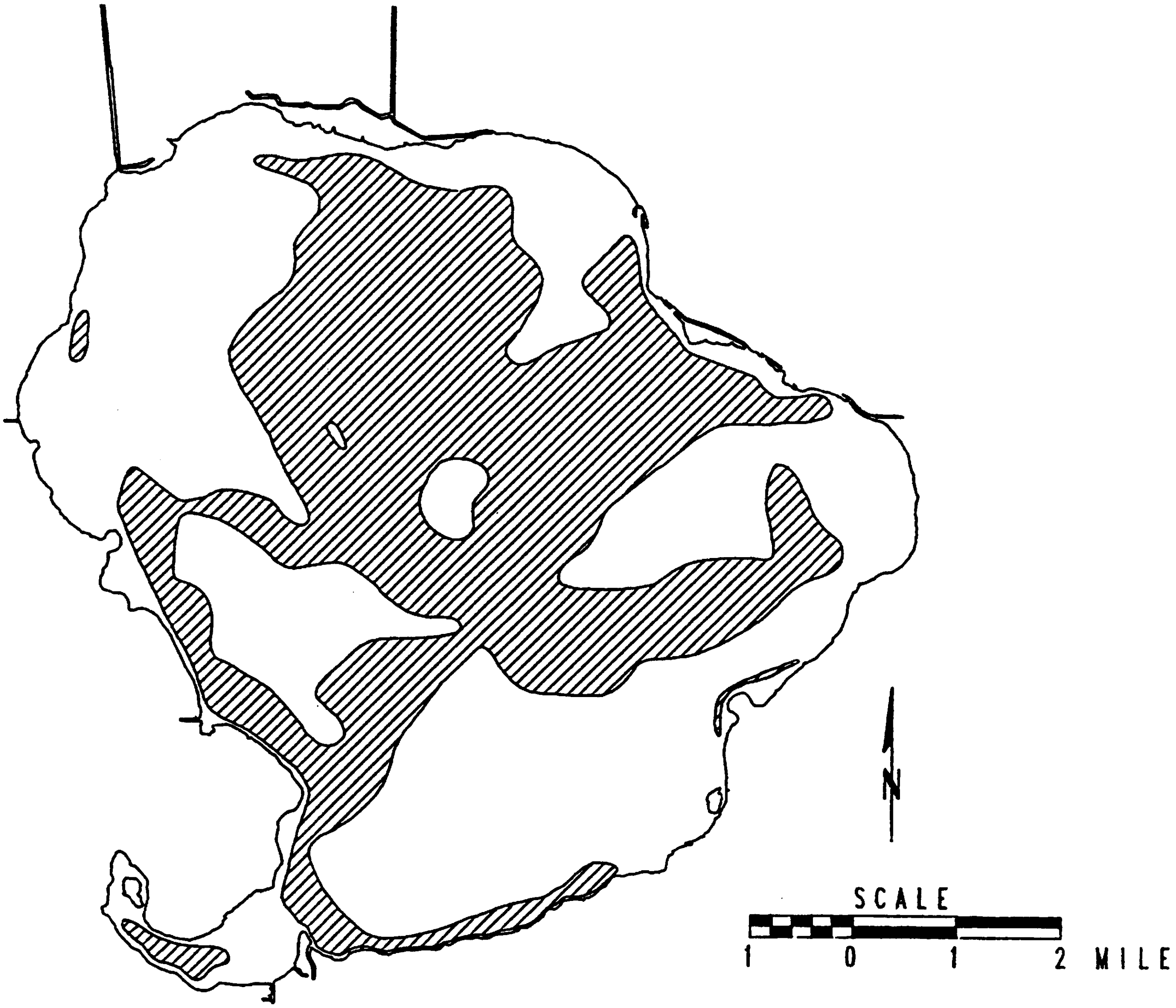


Figure 5.8 Sediment Exposure (unshaded area) in Lake Apopka at Elevation 61 ft. NGVD (Rao et al., in prep.)

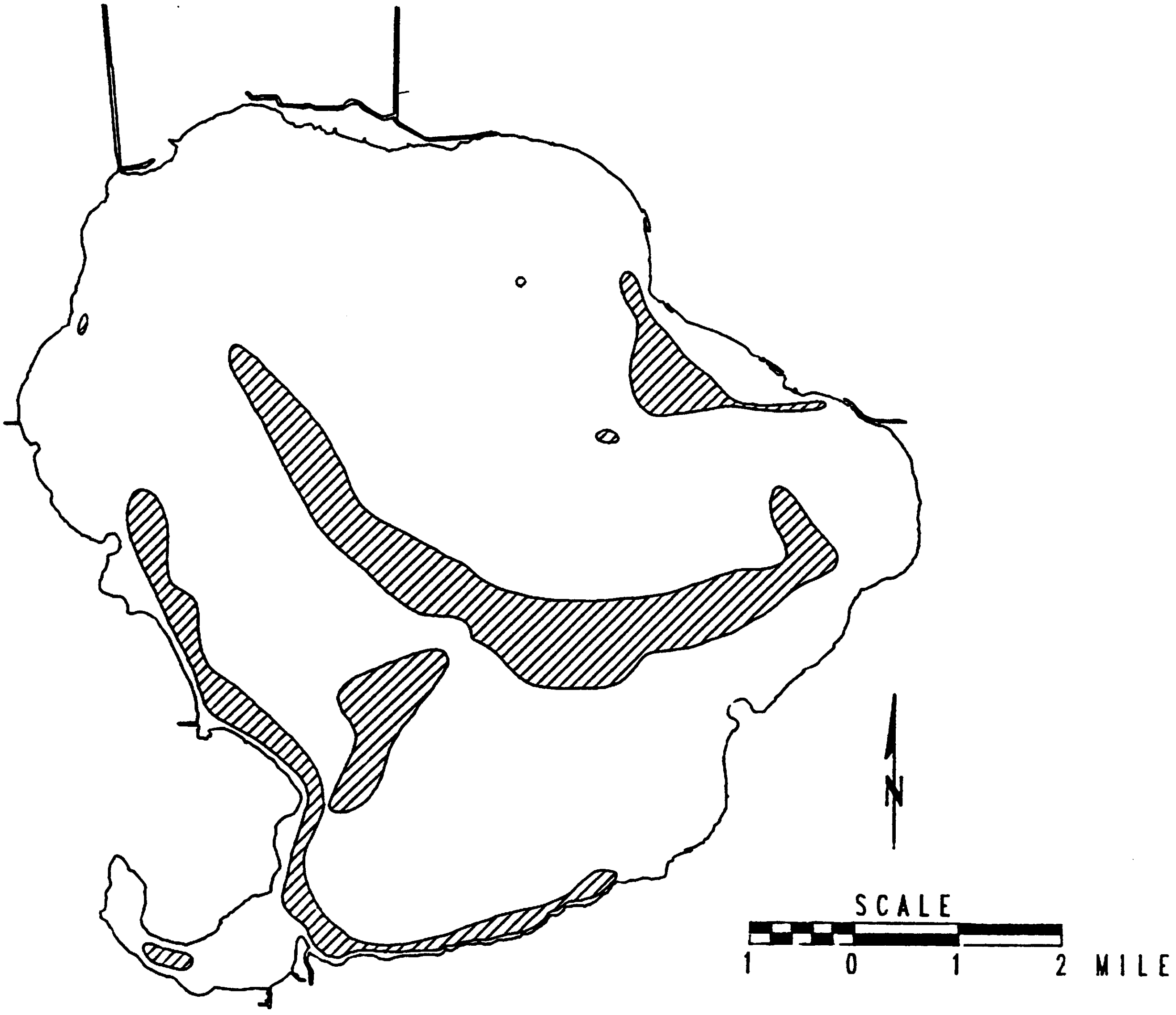


Figure 5.9 Sediment Exposure (unshaded area) in Lake Apopka at Elevation 60 ft. NGVD (Rao et al., in prep.)

5.3 POTENTIAL ECOLOGICAL EFFECTS OF DRAWDOWN AND ENHANCED FLUCTUATION TO LAKE APOPKA AND THE DOWNSTREAM OKLAWAHA CHAIN OF LAKES

Information from the Literature Review and past studies specific to Lake Apopka were used to predict both the in-lake and downstream ecological effects of a drawdown or enhanced fluctuation.

In order to assess potential ecologic effects to the downstream Chain of Lakes, it is necessary to address potential hydrologic and hydraulic impacts on this system. Based on past studies (Camp, Dresser, and McKee 1976), there is approximately 3.65 x 10^9 cfs of available storage in the Oklawaha Chain (disregarding Lake Apopka) if these lakes are allowed to drop lower than their current operating level during a four month drawdown period. This amount of storage capacity, however, would be sufficient for only the 63 feet NGVD drawdown scenario. It should be pointed out that downstream storage capacity for all the drawdown discharge water from Lake Apopka is necessary only if back pumping refill water into Lake Apopka is used. Ross, Saarinen, Bolton & Wilder (RSB&W) (1978) report that an eight-month drawdown schedule to reach 58 ft. NGVD would result in downstream lake levels remaining within historically managed limits. If refill of Lake Apopka is accomplished by backpumping stored discharge water from the downstream lakes, then lake levels in these downstream lakes will be higher than normal during the Lake Apopka drawdown and throughout the holddown period. This may increase the risk of downstream flooding during periods of heavy rains, even though no flooding may result from the drawdown or water level fluctuation itself (RSB&W 1978). A detailed water budget of the Oklawaha Chain of Lakes should therefore be made during the design and planning stages for a drawdown.

Another engineering aspect of a Lake Apopka drawdown which can affect ecological aspects is increased water flow velocity in the channels connecting the Chain of Lakes. Excessive velocities are a public safety hazard and can also cause channel scour, causing serious maintenance problems and increased downstream turbidity (RSB&W 1978). Velocities in each of the connecting channels must be examined carefully during engineering feasibility studies of a Lake Apopka drawdown or enhanced fluctuation.

5.3.1 Potential Effects on Littoral Zone Habitat and Fish Production

In-lake Effects

Each of the four enhanced water level fluctuation schedules described in Section 5.2 would result in exposure of some amount of Lake Apopka bottom sediment. During the exposure period, it is expected that extensive germination of littoral zone and terrestrial plant species will occur on the newly exposed sediments (see Section 4.1 and 4.4), particularly cattails (Typha sp.) (Fox et al. 1977). Increased littoral zone vegetation persisting after refill frequently results in temporarily increased macroinvertebrate production, fish spawning, and refuge areas for gamefish and forage fish species.

In Lake Apopka, all four lake level fluctuation scenarios would likely result in littoral zone habitat improvement and temporarily increased gamefish species populations, if sufficient stock remains in the lake to benefit from the increased food source and spawning sites. Due to the different amount of exposed sediments during each scenario, however, it is expected that these benefits would be different for each scenario. Drawdown to 63 ft. NGVD would expose only 8.6 percent (2640 acres) of the total lake area, primarily in a narrow strip around the edge (Figure 5.6). Drawdown to 62 ft. NGVD would expose 6980 acres (22.7%), and thus would most likely result in more vegetated littoral zone habitat (Figure 5.7). Drawdown to 61 and 60 ft. NGVD would expose areas that have been inundated for many years (Figures 5.8 and 5.9) and possibly do not have the viable seedbanks important for germination and growth during dewatering. Without further seedbank studies, the effects of drawdown on revegetation in the deeper parts of Lake Apopka remain unclear.

The establishment of littoral zone vegetation lasting several years or longer after a drawdown may require some degree of littoral zone sediment consolidation (Lantz et al. 1964; Wegner and Williams 1974 (a,b); Tarver 1980). If so, then macrophyte establishment and concomitant fisheries production benefits will require drawdowns to at least two feet below the elevation to which sediment consolidation is desired (Sheffield and Kuhrt 1969). This suggests that most of Lake Apopka would have to be drained (over 90% of its volume) to achieve a potential fisheries benefit in 10% of the lake's surface area which would last several years. The impact such a drastic reduction in lake volume would have on existing fish populations in Lake Apopka is unknown.

Regardless of the amount of littoral zone habitat that may become available as a result of drawdown, recent fisheries surveys indicate that gamefish (especially largemouth bass) populations are near extinction in the lake (FGFWFC, 1982(b); 1984). A stocking program concurrent with the refill period and possibly using adult fish may be necessary to achieve the full benefits which sportfish populations have experienced in many Florida lakes after drawdown.

Downstream Effects

During the gravity or pump down segment and holddown segment of a Lake Apopka water level fluctuation schedule, the downstream Chain of Lakes may be maintained near maximum pool water level elevation. If natural inflow is used to refill Lake Apopka, then downstream lake elevations may be near their maximum for a short period only. However, if refill water is to be stored in the downstream lakes and back pumped into Lake Apopka as refill water, a longer period of high water levels would result. If the duration of the high water elevation is sufficient (perhaps 6 months or greater in these downstream lakes), some littoral zone species requiring water level fluctuation for optimal growth and reproduction (such as Carex sp., Eleocharis sp.) may not survive. Conversely, other plant species (especially aquatic species) may become more abundant (Greening and Gerritsen 1987; Gerritsen and Greening 1989). The extent of ecological changes in littoral zone habitat of downstream lakes is dependent upon many factors, including existing conditions in the downstream water bodies, duration of increased water level and timing of water level manipulation.

Changes in littoral zone plant species composition may affect fish production (see Section 4.1). The approximately 4 to 8 month period during which downstream water levels might be at maximum regulation levels (if refill by back pumping is utilized) will likely result in additional growth of aquatic plant species and increased fishery food resources. However, Dooris and Courser (1976) report that lack of water level fluctuation in regulated lakes in Central and South Florida has been implicated as a major cause of accelerated accumulation of unconsolidated bottom sediments, declines in dissolved oxygen, nutrient enrichment, vegetational changes, and reduction of fish and wildlife populations. Thus, the potential effects on fish production of possibly maintaining maximum regulation pool elevations for 4 to 8 months in these downstream lakes remains unclear.

5.3.2 Potential Effects on Macroinvertebrates

In-Lake Effects

Similar to fish populations, many macroinvertebrate species become more abundant in response to increased littoral zone vegetation (see Section 4.2). Therefore, as with sport fisheries, all four enhanced water level fluctuation scenarios are expected to result in temporarily increased abundances of those invertebrate species associated with littoral zone vegetation. However, the littoral zone habitat response to the various scenarios is not necessarily a simple function of amount of sediment exposure (see Section 5.3.1). Existing benthic species may be severely affected or eliminated during drawdown due to desiccation (see Section 4.2). A current benthic survey would be necessary to estimate potential effects on existing benthic macroinvertebrate communities in various areas of Lake Apopka which may be exposed during water level drawdown.

Downstream Effects

If high or excessive flow velocities in the channels connecting the Chain of Lakes cannot be avoided during the initial pump down period, dislodgement of sessile organisms inhabiting the channels may occur (RSB&W 1978). The extent and severity of potential effects to macroinvertebrates will be partially determined by characteristics of existing species and the velocity and duration of increased flow.

5.3.3 Potential Effects on Water Quality

In-Lake Effects

Water level drawdown for each of the four scenarios is not expected to result in improved water quality in Lake Apopka (TP, TN, or chlorophyll a concentration), primarily due to observed decreased water quality, both during drawdown and after refill, in most Florida lake drawdowns (see Section 4.3). Nutrient regeneration from dried or partially dried sediments may affect water quality after refill (see Section 4.5). Water quality in the refilled lake may also be affected by the source(s) of refill water.

If water from Lake Apopka is simply stored in the downstream Chain of Lakes during drawdown and is then back pumped into the lake during refill, water quality in the refilled lake will not improve, and may even decline (see Section 4.3). If groundwater (seepage and Apopka Springs) and rainfall are principal sources of refill, lower TP and TN concentrations may be possible in the refilled lake, but this scenario may require an unacceptable length of time for refill. A detailed water budget study is necessary to examine these different scenarios for refill. Regardless of the source(s) of refill water, external loadings (especially from the muck farms surrounding the northern sections of Lake Apopka) must be halted to obtain significant or lasting water quality improvements.

Downstream Effects

As noted in Section 5.1, the upstream lakes (Apopka and Beauclair) are the most eutrophic and have the poorest water quality within the Chain of Lakes. However, all lakes within the primary Chain are considered eutrophic or highly eutrophic (Brezonik et al. 1981), with the exceptions of Lake Harris (mesotrophic to eutrophic) and Lake Yale (mesotrophic) [Fulton et al. 1989;

Cooke et al. 1986]. RSB&W (1978) concluded that there would be short term downstream water quality impacts as a result of a Lake Apopka drawdown but that "the low quality water of Lake Apopka is to be discharged into a series of downstream lakes and canals with waters of poor quality". RSB&W (1978) therefore concluded that these impacts would be minimal. Similar predictions were made by the U.S. EPA (1979) in their FEIS examining the feasibility of a Lake Apopka drawdown: "The water quality of downstream lakes may be temporarily degraded due to increased nutrient levels and reduced dissolved oxygen concentrations", but, after refill "water quality will improve in Lake Apopka, thereby restoring and enhancing lake ecosystems. Similar effects will occur in downstream lakes as restored Apopka water flushes through the Chain of Lakes" (U.S. EPA 1979). Additional references to downstream effects of lake drawdown were not found during the Literature Review.

However, the conclusion that downstream water quality effects of a Lake Apopka drawdown will be minimal and short-term appears to be ecologically naive, given the enormous amount of nutrient-laden water which would be released during any of the four enhanced fluctuation or drawdown schedule scenarios. Existing water quality in downstream Lakes Dora, Eustis, Griffin, Harris, and Yale is significantly higher (with regards to Secchi disk transparency, phosphorus forms, total organic nitrogen and average Trophic State Index) than in Lakes Apopka and Beauclair (Brezonik et al. 1981). Increased discharge from Apopka and Beauclair will therefore result in greater nutrient loading to these lakes than exists under current "baseflow" conditions. For example, during the residence time of Lake Apopka drawdown water in each of the downstream lakes, macrophytes, algae, and microfauna and flora both in the water column and associated with the lake sediment surface will likely have sufficient time to assimilate additional dissolved nitrogen and phosphorus, adding to that lake's nutrient load. The detailed water budget suggested earlier should include an assessment of potential nutrient loadings to each downstream lake, based on the discharge rate of Lake Apopka water, anticipated residence time in each lake, and nutrient concentrations of both discharge water (this concentration may change as drawdown proceeds) and receiving waters.

A simplified assessment of nutrient loading to downstream lakes from water discharged from Lake Apopka during each of the four drawdown scenarios and under current conditions is presented here. Average water column nutrient and suspended solids concentrations in Lake Apopka are taken from 1989 SJRWMD monitoring data. The mass of total phosphorus (TP), total Kjeldahl nitrogen (TKN), and total suspended solids (TSS) in each one-foot layer of water in Lake Apopka during normal baseflow conditions is shown in Table 5.2.

In addition to the mass of suspended solids and nutrients presently found in each water layer being discharged downstream during a drawdown (Table 5.2), additional nutrients and sediments will become resuspended in the water column from the flocculent unconsolidated muck layer on the lake bottom during a drawdown (RSB&W 1978). These resuspended sediments and their associated nutrients will also be discharged during a drawdown. RSB&W (1978) estimated the increase in water column suspended sediment concentrations caused by lowering the elevation of Lake Apopka during a drawdown. Their estimates were used along with data on nutrient concentrations in the unconsolidated sediment layer in Lake Apopka (SJRWMD sediment chemistry data) to estimate the additional mass of sediments and nutrients (from drawdown-induced resuspension) which would be discharged downstream by lowering the lake by one-foot intervals (Table 5.3).

The estimated downstream sediment and nutrient loading for each of the four drawdown scenarios is shown in Table 5.4(a). These estimates include the suspended solids and nutrients presently in each discharged water layer (Table 5.2) and the resuspended sediments and nutrients in each water layer resulting from the lowering of lake levels during the drawdown (Table 5.3).

Under current baseflow conditions, the average discharge from Lake Apopka is estimated to be 48.7 cfs (J. Shuman, personal communication, May 1990). The estimated monthly export of suspended solids and nutrients under baseflow conditions is:

TSS	2.71×10^{11}mg (298.5 tons)
TP	6.80×10^{8} mg (0.75 tons)
TKN	1.59×10^{10} mg (17.5 tons)

Assuming a four-month discharge period for each drawdown scenario, the additional sediments and nutrients discharged downstream due to the drawdown is estimated to be the difference between baseflow nutrient and sediment discharge (shown above for a one-month period) and the estimates for downstream sediment and nutrient loading during each drawdown (Table 5.4(a)). These estimates for the increase in sediment and nutrient loading for each of the four drawdown scenarios are shown in Table 5.4(b). Downstream loading of nutrients and sediments during any drawdown scenario will be significantly greater than that observed during baseflow conditions. Depending on the drawdown scenario, downstream sediment export is estimated to be 95 to 413 times greater than under baseflow conditions; downstream total phosphorus export is estimated to be 42 to 167 times greater than during baseflow conditions; and total Kjeldahl nitrogen downstream export is estimated to be 57 to 233 times greater than during baseflow conditions.

Table 5.2. Mass of total phosphorus (TP), total Kjeldahl nitrogen (TKN), and suspended solids (TSS) in each water layer (by elevation) during baseflow conditions. Average water column nutrient concentrations are: 0.19 mg/l for TP, 4.44 mg/l for TKN, and 75.75 mg/l for TSS (source: SJRWMD 1989 monitoring data).

WATER LAYER (FT NGVD)	VOLUME (1) (ECT 1989)	TOTAL MASS OF TP (mg)	TOTAL MASS OF TP (tons)	TOTAL MASS OF TKN (mg)	TOTAL MASS OF TKN (tons)	TOTAL MASS OF TSS (mg)	TOTAL MASS OF TSS (tons)
66-65	3.76E+10	7.15E+09	7.9	1.67E+11	184.1	2.85E+12	3142.1
65-64	3.69E+10	7.02E+09	7.7	1.64E+11	180.8	2.80E+12	3087.0
64-63	3.57E+10	6.77E+09	7.5	1.58E+11	174.2	2.70E+12	2976.8
63-62	3.20E+10	6.09E+09	6.7	1.42E+11	156.6	2.43E+12	2679.1
62-61	2.27E+10	4.31E+09	4.8	1.01E+11	111.4	1.72E+12	1896.3
61-60	1.07E+10	2.03E+09	2.2	4.74E+10	52.3	8.09E+11	891.9

Table 5.3. Additional mass (above baseflow conditions, see Table 5.2) of suspended solids (TSS), total phosphorus (TP), and total Kjeldahl nitrogen (TKN) discharged downstream due to in-lake sediment resuspension during drawdown, by one-foot changes in lake elevation. Average unconsolidated sediment nutrient concentrations are: 0.97 mg TP and 23.69 mg TKN per gram dry weight of sediment (source: SJRWMD 1989 data).

DRAWDOWN ELEVATION CHANGE (FT NGVD)	VOLUME DISCHARGED (1)	ADDITIONAL TSS CONC. IN LAYER DISCHARGED (1) (mg/l)	ADDITIONAL MASS OF TSS IN LAYER DISCHARGED (mg)	ADDITIONAL MASS OF TSS IN LAYER DISCHARGED (tons)	ADDITIONAL MASS OF TP IN LAYER DISCHARGED (mg)	ADDITIONAL MASS OF TP IN LAYER DISCHARGED (tons)	ADDITIONAL MASS OF TKN IN LAYER DISCHARGED (mg)	ADDITIONAL MASS OF TKN IN LAYER DISCHARGED (tons)
66-65	3.76E+10	25	9.400E+11	1036.4	9.118E+08	1.0	2.227E+10	24.6
65-64	3.69E+10	50	1.845E+12	2034.1	1.790E+09	2.0	4.371E+10	48.2
64-63	3.57E+10	2575	9.193E+13	101350.1	8.917E+10	98.3	2.178E+12	2401.0
63-62	3.20E+10	4425	1.416E+14	156114.0	1.374E+11	151.4	3.355E+12	3698.3
62-61	2.27E+10	5925	1.345E+14	148283.5	1.305E+11	143.8	3.186E+12	3512.8
61-60	1.07E+10	5925	6.340E+13	69895.7	6.150E+10	67.8	1.502E+12	1655.8

(1) Source: RSB&W (1978).

Table 5.4(a). Estimated downstream sediment and nutrient loading for each of the four drawdown scenarios. Estimates include sediments and nutrients in each discharged water layer (see Table 5.2) and resuspended sediments and nutrients in each water layer which is discharged during drawdown (see Table 5.3).

DRAWDOWN SCENARIO	TOTAL VOLUME DISCHARGED (l)	MASS OF TSS DISCHARGED (mg)	MASS OF TSS DISCHARGED (tons)	MASS OF TP DISCHARGED (mg)	MASS OF TP DISCHARGED (tons)	MASS OF TKN DISCHARGED (mg)	MASS OF TKN DISCHARGED (tons)
63 FT NGVD	1.10E+11	1.03E+14	113667.8	1.13E+11	125.0	2.73E+12	3013.1
62 FT NGVD	1.42E+11	2.47E+14	272427.8	2.57E+11	283.1	6.23E+12	6868.6
61 FT NGVD	1.65E+11	3.83E+14	422588.3	3.92E+11	431.7	9.52E+12	10495.8
60 FT NGVD	1.76E+11	4.48E+14	493368.8	4.55E+11	501.9	1.11E+13	12237.8

Table 5.4(b). Estimated increase in downstream sediment and nutrient loading (above baseflow) for each drawdown scenario. Discharge for each drawdown scenario is assumed to be over a 4-month (120 day) period. Baseflow discharge is assumed to be 48.7 cfs; see Table 5.2 for baseflow discharge nutrient concentrations.

DRAWDOWN SCENARIO	ADDITIONAL VOLUME DISCHARGED BY DRAWDOWN (l)	ADDITIONAL MASS OF TSS DISCHARGED BY DRAWDOWN (mg)	ADDITIONAL MASS OF TSS DISCHARGED BY DRAWDOWN (tons)	ADDITIONAL MASS OF TP DISCHARGED BY DRAWDOWN (mg)	ADDITIONAL MASS OF TP DISCHARGED BY DRAWDOWN (tons)	ADDITIONAL MASS OF TKN DISCHARGED BY DRAWDOWN (mg)	ADDITIONAL MASS OF TKN DISCHARGED BY DRAWDOWN (tons)
63 FT NGVD	9.57E+10	1.02E+14	112477.1	1.11E+11	122.0	2.67E+12	2943.1
62 FT NGVD	1.28E+11	2.46E+14	271237.1	2.54E+11	280.1	6.17E+12	6798.6
61 FT NGVD	1.51E+11	3.82E+14	421397.6	3.89E+11	428.7	9.46E+12	10425.8
60 FT NGVD	1.62E+11	4.46E+14	492178.1	4.52E+11	498.9	1.10E+13	12167.7

Sediment transport downstream has been a larger concern than downstream water quality effects in past drawdown studies. As the lake is lowered, suspended solids concentrations will increase in Lake Apopka due to sediment resuspension. A partial drawdown of Lake Apopka in 1971 resulted in sharp increases (25 to 100 percent) in total suspended solids concentrations in Lake Griffin, 4 months after initiation of the Lake Apopka drawdown (RSB&W 1978); however, normal levels were reached after discharge ended. Increased sediment transport rates will increase sedimentation rates in downstream lakes and can potentially affect water quality in these lakes due to nutrient release from the flocculent sediment material. In addition, this increased sediment concentration could cause problems downstream with turbidity, increased nutrient concentrations, increased algae blooms, and increased biochemical oxygen demand (BOD). Since the sediment is primarily organic in nature, it would exert a significant BOD downstream.

The RSB&W (1978) study called for sedimentation basins at the outfall to Lake Apopka to allow sediments to settle out prior to discharge downstream. In addition, a dredging operation on the Apopka-Beauclair Canal was recommended to remove silt in the canal and reduce the chances of transporting silt downstream. The possibility of short-term discharges of high sediment loads was evaluated. RSB&W (1978) concluded that, although the organically rich sediments could result in high BOD downstream resulting in dissolved oxygen sags, the shallowness of the lakes, and high algal productivity of oxygen would result in little or no dissolved oxygen sags.

However, results of the simplified assessment shown here indicate that large amounts of TP and TKN will be discharged to downstream water bodies. As mentioned above, the additional nutrient loading from discharge water and sediments during drawdown to the downstream lakes should be examined more thoroughly once hydrologic and hydraulic modeling for specific drawdown scenarios is considered.

5.3.4 Potential Effects on Macrophytes

As described in Section 5.3.1, all four water level fluctuation scenarios will likely result in extensive germination of littoral zone and terrestrial plant species on the exposed sediments and will probably be directly positively related to the amount of sediment exposed during drawdown. However, the macrophyte species which occur in the seedbank at 63 feet NGVD may be different from which occur at 61 feet NGVD. Due to the depth and unconsolidated nature of the bottom sediments in deeper parts of Lake Apopka (Conrow et al. 1989), seeds found in these areas may not be as viable as those located in shallow areas. The seedbank potential in Lake Apopka at different topographic depths is unknown at this time.

However, it is known that cattails will be one (if not the only) dominant macrophyte species to become established on exposed sediment during lowered water level (Fox et al. 1977) and that they will likely require some sort of physical management. The FGFWFC routinely builds an herbicide spray program into their lake drawdown management plans (Williams 1985). Several studies, however, have concluded that herbicide treatments are only briefly effective, can stimulate nutrient release, increase algal productivity, and promote oxygen depletion in the refilled lake (Cooke 1983). The decayed vegetation also adds to the organic matter in the lake sediment, thus negating some of the benefits of the completed drawdown.

Mechanical harvesting may benefit lakes because biomass removal can remove nutrients as well. In a demonstration project in Lake Okeechobee, mechanically harvesting hydrilla resulted in a phosphorus removal rate of approximately 10 lbs. phosphorus per acre of harvested plants, and cattails are expected to have similar or higher nutrient content per unit biomass as hydrilla. Cost per acre for hydrilla removal was $375 to $500 in 1987 (Gremillion et al. 1987). A major complication of any large-scale macrophyte harvesting program is the problem of macrophyte disposal after harvesting. Enormous amounts of biomass could potentially be generated by a Lake Apopka harvesting program, requiring either a high capacity landfill or an effective reuse program. Potential uses of harvested cattails can include methane production, animal feed production, and compost or mulch production. Mulch production was found to be the only viable reuse option for harvested hydrilla from Lake Okeechobee (Greening and Mericas 1990).

One potentially effective method to help with cattail control is to sow a fast growing cover crop on exposed sediments before cattails have a chance to become fully established. During drawdown of Lake Talquin in northern Florida, millet was seeded in the exposed areas to help the drying process and to help prevent establishment of undesirable vegetation species (D. Moxley, personal communication, January 1990).

Downstream Effects

Potential downstream effects of water level drawdown in Lake Apopka on macrophytes are expected to be primarily related to the increased water level within the downstream lakes, and are addressed in Section 5.3.1.

5.3.5. Potential Effects on Sediment Characteristics

In-lake Effects

A three to seven month exposure period should result in some surface organic muck consolidation (see Section 4.5). However, this "cap" of semi-consolidated sediment and germinated vegetation may become dislodged from underlying unconsolidated sediments upon refill, creating "floating islands" of vegetation (Section 4.5). Vince Williams, FGFWFC, believes that, due to the capillary or "wicking" effects within drying sediments, water level must be as much as 6 feet below the muck level to be completely effective for long-term consolidation which does not become dislodged upon refill (V. Williams, personal communication, December 1989). Observations on the effects of drawdown or enhanced fluctuation within Florida lakes further indicates that sediment must be exposed for a minimum of seven months to prevent the "floating cap" phenomenon (Section 4.5).

Several microcosm experiments have shown that nutrient release from dried sediments may be higher than from undried sediments. Actual drawdowns in Florida lakes support these results (reviewed in Sections 4.3 and 4.5). Additional information is required to evaluate fully the potential effect of water level drawdown on Lake Apopka sediments.

Downstream Effects

The Literature Review did not reveal any reference to potential downstream effects of lake level drawdown on sediments. Physical effects are expected to include an increase in sedimentation rates and sediment depth in downstream lakes as a result of sediment resuspension in Lake Apopka during drawdown and increased discharge. Increased nutrient loading to downstream lake sediments may also result from the influx of nutrient-laden Lake Apopka water and suspended sediments (see discussion in Section 5.3.3).

5.3.6 Other Potential Effects

Other potential ecological effects of water level drawdown in Lake Apopka have been reviewed by RSB&W (1978) and U.S. EPA (1979), and include the following:

- Terrestrial vegetation (including trees) around the lake perimeter may be affected by prolonged drawdown;
- Highly turbid discharge water can interfere with the activities of sight-feeding aquatic organisms and can clog the apparatus of many filter-feeding organisms;
- During the drawdown, increased nutrient loads downstream may cause algae blooms;
- Chlorinated hydrocarbons stored in Lake Apopka sediments could kill some downstream biota if these chemicals are discharged in high enough concentrations;
- A large migration of alligators from the de-watered lake, with the attendant public complaints, could be expected during a water level drawdown;
- Fish may die as they become extremely concentrated in the remaining pools of water;

- Increased littoral zone macrophyte biomass will compete with phytoplankton for available nutrients and thus reduce algal blooms in the lake;

- Forested wetlands adjacent to the lake may experience increased growth of new seedlings due to the fluctuating water levels;

- Fish-eating birds and other water fowl will experience increased food supply as fish are concentrated in the remaining water and exposed sediment becomes vegetated.

6.0 CONCLUSIONS

Drawdown and Enhanced Fluctuation as a Lake Management and Restoration Technique

(1) With some exceptions, lake drawdown or enhanced water level fluctuation results in increased fish production and littoral zone habitat enhancement, increased macrophyte-associated macroinvertebrate populations, and short-term control of nuisance vegetation in cold climates. Drawdown or enhanced water level fluctuation generally does not result in long-term improved water quality (TP, TN, or chlorophyll a concentrations) or nuisance macrophyte control in warm climates (including Florida). Significant sediment consolidation occurs only following long (>7 months) desiccation periods.

(2) Lake drawdown or enhanced fluctuation is effective for improving sportfish populations (as total numbers, densities, and growth), primarily due to improved littoral zone habitat. Germination and growth of littoral zone and terrestrial plant species on exposed sediments during water level drawdown provide food, spawning sites, and habitat for many species of fish and macroinvertebrates. Other factors include a concentration of forage fish in remaining water during drawdown, an increase in invertebrate littoral zone organisms, and an increase in suitable spawning sites after refill. Sportfish populations in Florida lakes may remain high for two to six years before returning to pre-drawdown levels.

(3) Due to increased littoral zone habitat, macrophyte-associated macroinvertebrates exhibit temporarily increased densities after refill. However, benthic species which inhabit lake sediments exposed during

water level drawdown can suffer reduced densities or elimination during dewatering.

(4) Lake drawdown or enhanced water level fluctuations can result in temporary (<1 year) improvements in water quality (decreased TP, TN, and chlorophyll a concentrations). However, all lakes in Florida reporting water quality information showed higher nutrient concentrations during and after drawdown when compared to periods prior to water level reduction. Increased nutrient concentrations during drawdown have been attributed to release of nutrients from the exposed sediments during exposure to oxygen and increased microbial activity. Upon reinundation, terrestrial plants which germinate on the exposed sediment are flooded and die, and can release additional nutrients into the water column.

(5) Drawdown or enhanced water level fluctuation is effective for annual control of some nuisance macrophyte species (especially pondweed, coontail, and milfoil) in cold climates. Winter drawdown in northern states results in exposure, desiccation, freezing and ice scour, causing temporary reduction of susceptible species populations. However, freeze-tolerant nuisance species can become established as a result of reduced competition for space.

(6) Lake drawdown or enhanced water level fluctuation does not appear to be successful for nuisance macrophyte control in Florida lakes. Several drawdowns have resulted in large growths of undesirable vegetation (especially cattail and water hyacinth) which must be controlled after refill. Drawdown on Lake Oklawaha provided short-term control of coontail and hydrilla, but increased growth of water hyacinth and

alligatorweed. The year-round growing season in Florida undoubtedly contributes to the difficulties in managing nuisance macrophytes.

(7) Lake drawdown and enhanced fluctuation can be effective for sediment consolidation if the drawdown is for a sufficient length of time and the water level is lowered below the level of the unconsolidated sediments. In Florida lakes, it appears that sediments must be dewatered for approximately seven months before significant sediment consolidation occurs. Periods of dewatering between three and seven months have resulted in the formation of a cap of consolidated sediments overlying unconsolidated muck, which becomes colonized with emergent or terrestrial vegetation during drawdown. Upon lake refill, this cap of consolidated sediment can become dislodged from the unconsolidated sediments below it and float to the surface, causing "floating islands" of vegetation.

(8) Sediment exposure as a result of lowered lake levels can result in increased release of orthophosphate due to more effective oxidation of the sediments. However, experimental desiccation and consolidation of sediments from Lake Apopka indicate that the effect of sediment drying on major nutrient forms appears to be minimal, and leads to only slight changes in nutrient leachability.

Potential Ecological Effects of Drawdown or Enhanced Fluctuation in Lake Apopka

(1) A lake level drawdown to any elevation will result in extensive germination of littoral zone and terrestrial vegetation on the exposed sediments in Lake Apopka. Lake level drawdown from 66 feet NGVD (normal pool) to 63 feet NGVD will expose 8.6 percent (2640 acres) of

the total lake area and lake volume will be reduced by almost 60 percent of normal pool; at 62 feet NGVD, 22.7 percent of the lake will be exposed and lake volume will be reduced by almost 77 percent; at 61 feet NGVD, 56.3 percent of the lake will be exposed, while 89 percent of the original lake volume will have been discharged, and at 60 feet NGVD, 85 percent, or 26,174 acres, would be exposed with 95 percent of the original lake volume having been discharged. Longevity of littoral zone habitat enhancement will likely depend upon the degree of sediment consolidation during exposure.

(2) Increased sportfish populations are expected as a result of increased littoral zone habitat, if sufficient stocks remain in Lake Apopka. The possibility of a concomitant sportfish stocking program should be considered as part of a drawdown or enhanced water level fluctuation program.

(3) If the maximum regulated water level elevations in downstream lakes are maintained during drawdown and hold-down, some shifts could occur in littoral zone plant community composition to include more aquatic species.

(4) Macroinvertebrates in Lake Apopka may be affected by lowered lake level in two ways: (a) increased littoral zone habitat will result in increased abundances and diversity of macrophyte-associated macroinvertebrates, and (b) existing benthic species may be severely affected or eliminated during drawdown due to desiccation.

(5) Excessive velocities in downstream channels during drawdown can result in dislodgement and displacement of some sessile macroinvertebrate species inhabiting these channels.

(6) Water quality (TP, TN, and chlorophyll a concentrations) are not expected to improve during or after water level drawdown, based on observations in other Florida lakes. The source(s) of refill water may influence water quality after completion of the water level fluctuation program.

(7) Previous studies have indicated that discharge of nutrient-laden Lake Apopka water will only temporarily and minimally affect downstream water bodies. However, a simplified assessment of additional nutrient loading to downstream lakes as a result of a Lake Apopka drawdown indicates that nutrient loading would increase an estimated 42 to 233 times above existing baseflow conditions. Nutrient assimilation by downstream macrophytes, phytoplankton, and sediment microorganisms may tie up these nutrients within the lake ecosystem, increasing eutrophication of these lakes. Further evaluation is necessary for a more definitive assessment.

(8) Cattail (Typha) is expected to be the dominant species germinating from the seedbank of exposed sediments in Lake Apopka. Extensive cattail biomass will likely require some sort of management (i.e., herbicide spray, mechanical removal). One method of cattail management may be to seed in a desirable species (such as millet) to help control cattail germination.

(9) A sediment exposure duration of three to seven months may result in a "cap" of consolidated sediments and germinated vegetation, which can become dislodged from underlying unconsolidated sediments upon refill and float to the lake surface. Sediment exposure longer than seven months will likely result in significant sediment consolidation down to within two feet of the holddown lake elevation.

(10) Any effects associated with lake water level drawdown are expected to be relatively short-lived (a maximum of 2 to 6 years), based on observations in other Florida lakes.

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