APPENDIX N

Upper Kissimmee River Basin Model Technical Memorandum

TECHNICAL MEMORANDUM

Upper Kissimmee Chain of Lakes Routing Model

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I. INTRODUCTION

The UKISS computer model was developed in 1981 by the SFWMD to simulate the operation of the Upper Kissimmee Chain of Lakes, Florida. The model serves as a management tool to predict the lake conditions so that alternative management schemes, aimed at achieving specific objectives, can be evaluated.

The model area covers a chain of nine lakes (Lakes Alligator, Myrtle, Hart, Gentry, East Tohopekaliga, Tohopekaliga, Cypress, Hatchineha, and Kissimmee) in the upper portion of the Kissimmee River Basin. The lakes are interconnected with canals and outlet control structures that are rigidly regulated (Figure 1). The lake discharges are affected by tailwater conditions and the watershed inflows to the lakes are poorly defined. The hydrologic and hydraulic conditions are unique and at the time of the model's development, existing routing models were inadequate to handle the unusual conditions.

II. MODEL OVERVIEW

The Upper Kissimmee Chain of Lakes Routing Model (KROUTE) is a continuous simulation model designed to simulate the operation of the lake system in the Upper Kissimmee River Basin. The study area covers Lakes Alligator, Myrtle, Hart and Mary Jane, Gentry, East Tohopekaliga and Tohopekaliga, Cypress, Hatchineha, and Kissimmee. The model is capable of simulating the management of the system according to predetermined regulation schedules, structure operational criteria, and rainfall conditions.

Level pool storage routing is used to route the flow through the system. Storage routing is similar to a water budget computation. Both use the same mass balance equation:

$$Q_{in} + Q_{lake} - Q_{out} + P - E \pm DSTOR + ADJ = 0 \qquad \text{<1>}$$

Where

Q_{in} = Structure inflows from upper lake

Q_{lake} = Watershed inflows

Q_{out} = Structure outflow to lower lake

P = Lake precipitation

E = Lake evaporation

$DSTOR$ = Change in lake storage

ADJ = Inflow adjustment (all unestimated flows and errors of water budget).

In the water budget computation, all components except ADJ in Equation 1 are known historical data. Equation 1 is used to quantify the unknown term, ADJ, so as to evaluate the uncertainties of the water budget.

In storage routing, all components are unknown except rainfall, which is predetermined. Evaporation, E, and watershed inflows, Q_{lake}, are estimated as a function of rainfall. In lakes where the inflows are adequately gaged, ADJ is nearly zero and can be neglected; otherwise ADJ must be estimated or included in the watershed inflow term Q_{lake}. The structure inflow term, Q_{in}, is Q_{out} in the next upstream lake from the previous routing step. Equation 1 is used to determine the unknown quantities Q_{out} and DSTOR; but since both unknowns are a function of the lake stage, lake stage is the only real unknown.

Routing is performed in daily time steps beginning from the uppermost lake (Lake Alligator) to the lowermost lake (Lake Kissimmee). The lake outflow term, Q_{out}, is affected hydraulically by the lower lake stage (backwater effect), and management constraints described by the lake regulation schedules and gate operation criteria. Due to backwater effect, an iteration technique is used to balance the headwater and tailwater stage relationship because the tailwater stage in the current time step is unknown.

Watershed inflows to the lakes are estimated as direct runoff and base flow. Direct runoff is estimated by a District modified Soil Conservation Service method. Base flow is estimated by an empirical formula which relates potential base flow to actual base flow using water table depth as a dependent variable. Both direct runoff and base flow are dependent on the water table depth. A soil moisture accounting procedure was developed to continuously predict the effective water table elevation.

The model provides three operational modes: “simulation,” “calibration,” and “forecasting.” The three modes differ in the way the lake inflows are obtained. In “simulation,” historical rainfall and watershed inflows are input. The model simulates the structure flows and stages and is suitable for evaluating situations where only the management variables change. In ”calibration,” historical rainfall is input and all other flows are predicted. An optimization option is provided to assist in calibrating the parameters. In “forecasting,” rainfall is specified and the model predicts all inflows as a function of rainfall.

Complimentary to the routing program (KROUTE) are a water budget computation program (KBUDGET) and a plotting program (KPLOT). The water budget program is used to verify the historical data and to preprocess the input data files needed to calibrate the routing program.

The Windows implementation of the SFWMD computer model (UKISS-WIN) incorporates both KBUDGET and KROUTE in a single executable program. KPLOT and Input/Output will be replaced by VB (Visual Basic) or MS-Access graphing utilities.

Calibration of the model involves the calibration of the watershed parameters. In short term forecasting the results are good; in long term forecasting moderately large deviations at times are observed. The major uncertainty of the model lies in the difficulties of accurately forecasting the watershed inflows.

III THEORETICAL ASSUMPTIONS AND LIMITATIONS

Major assumptions and limitations of the model are presented below.

1. A primary assumption of the routing model is that level pool conditions exist. The assumption is valid as long as the flow through the lake is small relative to the storage. The assumption is reasonable under normal flow conditions but is slightly violated under heavy discharge conditions.

2. The model simulates the management of the system according to a set of management rules. These rules are expressed in regulation schedules, gate operation criteria, and established rules governing the operation of the structures. As long as the operation follows the established rules, the simulation of the management is possible. Under unusual conditions, the operation may differ from the established rules and thus explains the inability of the routing model to simulate those events.

3. The model runs in daily time steps and generates daily average flows and stages. The time step resolution is adequate for most applications except for extreme storm events where instantaneous peak stages and flows are important. Nevertheless, an examination of the recorded lake hydrographs suggests that, due to the large size of the lakes, the instantaneous stages are not significantly different from the daily averages. The errors introduced are probably small in comparison to random fluctuation of the lake stages due to wind effects and other disturbances.

4. For certain applications where only the management variables change, historical rainfall and inflow data are used. The implicit assumption is that a change in the management will not change the historical hydrologic variables.

5. In forecasting applications, rainfall is specified to be uniformly distributed over time and space for the month of forecast. This is a scenario, rather than a model assumption, and can be modified. The assumption is more acceptable for dry than for wet conditions.

IV. DESCRIPTION OF THE MODEL STUDY AREA

The model covers a nine-lake system in the upper portion of the Kissimmee River Basin. The lakes are interconnected with canals and control structures that are rigidly regulated. Alligator Lake is the uppermost lake with no definable surface water inflows. Outflow from Alligator Lake can be made north through a chain of small lakes to East Lake Tohopekaliga, or south through Lake Gentry to Lake Cypress; however, because of the limited capacity of the lakes north of Alligator Lake, discharges have been made primarily south.

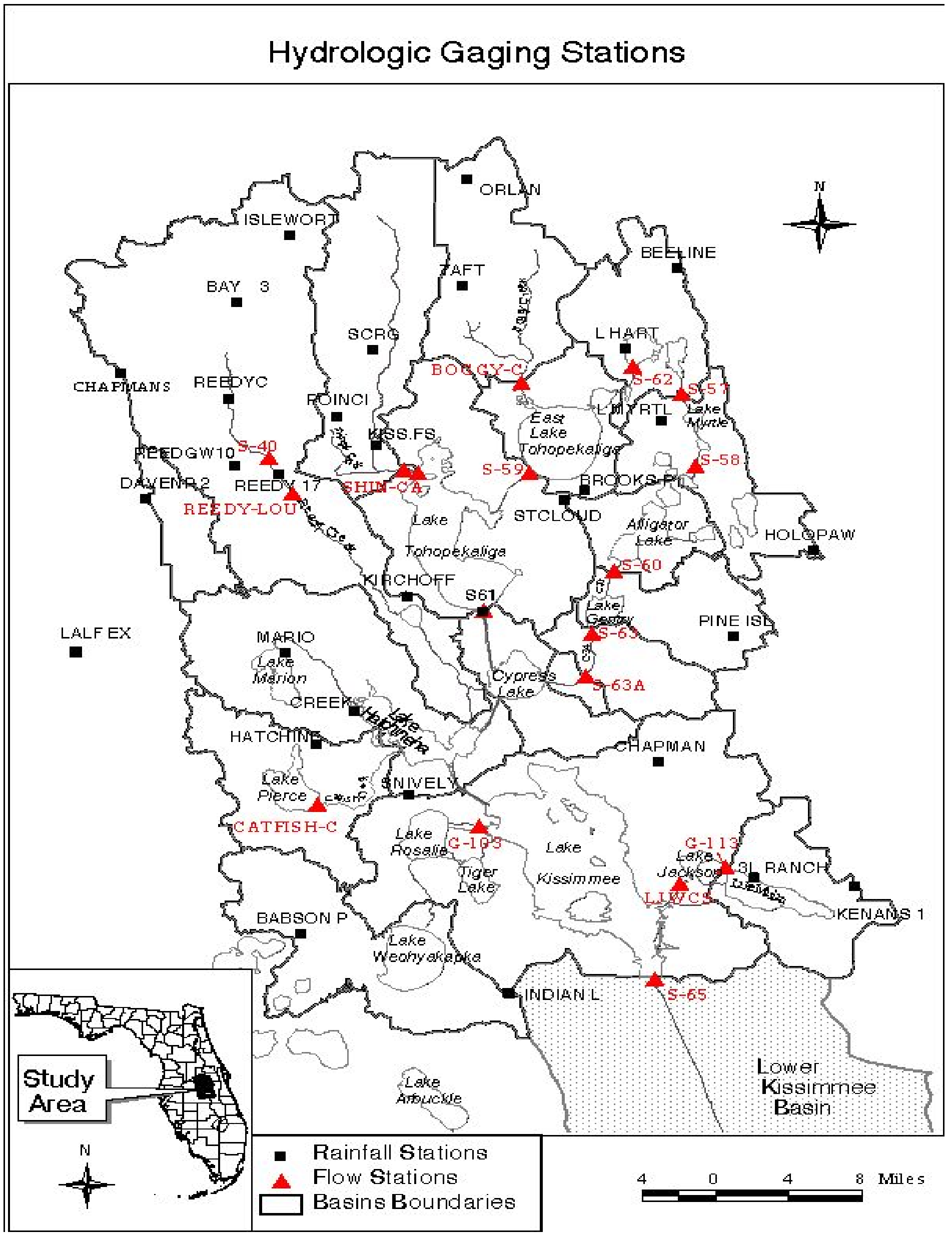


Figure 1. Hydrologic Station Map

North of Alligator Lake (which includes Lakes Alligator, Brick, Coon, Trout, Center and Lizzie) are the Lake Myrtle-Preston system (which includes Lakes Joel, Preston and Myrtle) and the Lake Hart-Mary Jane system, and to the south is the Lake Gentry system. These systems consist of one to five small lakes, and together they make up the headwater portion of the chain. As a group, these small lakes generate only a small portion of the flow in the chain and their influence in the lower lakes is relatively small.

East Lake Tohopekaliga is the first of five major lakes in the chain. The largest inflow to East Lake Tohopekaliga is from Boggy Creek. Second largest is the inflow from Lake Hart through S-62. East Lake Tohopekaliga discharges to Lake Tohopekaliga, which is the second largest lake in the chain. Shingle Creek, which drains to Lake Tohopekaliga, is the largest tributary in the chain.

Lake Cypress receives inflows from both Lake Tohopekaliga and Lake Gentry. There is a stage drop of approximately ten feet between Lakes Gentry and Cypress; and Structures 63 and 63A are used to step down the pools. Lakes Cypress, Hatchineha, and Kissimmee constitute the lower three lake system. They can be considered as a system because their stages tend to be equalized since there are no restricting structures in the connecting canals (C-36 and C-37). At times of high stage, the lower three lakes are connected by swamps, making it difficult, to identify the boundaries.

Reedy Creek is the largest tributary inflow to the lower three lake systems. Reedy Creek splits into two branches near Lake Cypress. One branch enters Lake Cypress and the other, known as Dead River, enters Lake Hatchineha. The major portion of the flow (approximately 70%) enters Lake Hatchineha. Catfish Creek, which connects Lake Pierce with Lake Hatchineha, is another important tributary to the lower three-lake system. Lake Hatchineha also receives inflow from Marion Creek and London Creek from the north, which drains a moderately large area undergoing intensive urban development.

Lake Kissimmee is the largest lake in the chain. Four other medium sized lakes drain into Lake Kissimmee, including Lake Rosalie, Lake Tiger, Lake Marian, and Lake Jackson. With the exception of Lake Tiger, however, these lakes contribute little flow to Lake Kissimmee because earth dams were constructed at their outlets. Inflows from the drainage areas of the lower three lakes, though important, are poorly gaged.

The Kissimmee Chain of Lakes are shallow; average depths range from 13 ft in Lake Alligator to 8 ft in Lake Kissimmee. Geologically, the lakes cut into the surficial aquifer, which has a thickness ranging from 50 to 100 ft in the study area. The surficial aquifer is made up of a relatively homogeneous silty fine to medium sand. Permeability is estimated to be low. Although direct seepage to the lake is normally small in comparison to other inflows, at time of drought, seepage may become important.

V. DESCRIPTION OF MODEL COMPONENTS

A. Control Structure Characteristics

The Kissimmee Chain of Lakes is interconnected with canals and discharge control structures that are rigidly regulated. The control structures consist of gated culverts and gated spillways and are summarized in Table 1. Several structures have special operational characteristics and require special treatment.

Lake Alligator has two outlet structures. At the north end is the S-58 gated culvert, and at the south end is the S-60 gated spillway. The S-58 culvert has seldom been used because of the limited capacity of the small lakes and canals north of Lake Alligator. An assumption is made that the S-58 structure will be operated only when the capacity of S-60 is inadequate to lower the stage at Lake Alligator to regulation schedule within a day.

Table 1 – Control Structures Parameters

Structure	Type	Crest EL MSL	Length (Ft)	Diameter (Ft)	Design Q (cfs)	Remarks
S-57	Culvert	52.5(invert)	80	4.5	170*	Seldom operated
S-58	Culvert	54.5(invert)	70	4.5	160*	
S-59	Spillway	49.1	18	NA	590	Weir below structure
S-60	Spillway	55.0	12	NA	450	
S-61	Spillway	36.9	27	NA	1570	
S-62	Spillway	55.3	14	NA	410	
S-63	Spillway	54.0	15	NA	715	
S-63A	Spillway	49.4	30	NA	2000	Automatic gate
S-65	Spillway	39.3	81	NA	11000**	

Note: * Based on an analysis of the historical data, maximum allowable discharges of 230 cfs and 110 cfs are assigned to S-57 and S-58 as additional operational constraints.

** The design capacity for S-65 has been increased to 18,000 cfs with added 2 gates in 2001.

Structure 58 (S-58) is located in C-32, which connects Lakes Trout and Joel about 3700 feet downstream from Trout Lake.

S-58 is a double-barreled corrugated metal pipe culvert with discharge controlled by stem operated vertical lift gates. Operation of the gates is manually controlled in accordance with the seasonal operational criteria.

The culvert structure maintains water control stages in C-32 and Lakes Alligator, Lizzie, Coon, Center and Trout; passes up to 30 percent of the standard project flood; and passes sufficient discharge during low-flow periods to meet irrigation demands downstream.

During floods the culvert structure is used, together with S-60, to assist in regulating and maintaining water levels from 62.0 ft to 64.0 ft. NGVD, in the lake upstream from the structure as shown on the regulation schedule. The design capacity of the structure is 160 cfs.

To meet structural stability requirements, the maximum allowable hydrostatic head on the structure should not be allowed to exceed 2.0 ft with a headwater elevation of 64.0 ft and a tailwater elevation of 62.0 ft, NGVD.

Structure 57 (S-57) is located in C-30, connecting Lakes Myrtle and Mary Jane, about 6200 feet downstream from Lake Myrtle.

S-57 is a double-barreled corrugated metal pipe culvert, with discharge controlled by stem operated vertical lift gates. Operation of the gates is manually controlled in accordance with the seasonal operational criteria.

The culvert structure is used to maintain scheduled stages in Lakes Myrtle, Preston and Joel upstream from the structure; passes up to 30 percent of the standard project flood; and passes sufficient discharge during low-flow periods to satisfy irrigation demands downstream.

The culvert structure normally maintains seasonal water control stages of from 60.0 to 62.0 ft, NGVD upstream from the structure, as shown on the regulation schedule. When the lake stage rises above schedule and above normal inflows are anticipated, releases up to design capacity of 170 cfs can be made.

To meet structural and stability requirements, the maximum allowable hydrostatic head on the structure should not be allowed to exceed 2.2 ft with a headwater elevation of 59.0 ft, and a tailwater elevation of 56.8 ft, NGVD.

Structure 62 (S-62) is located in C-29 at the outlet of Lake Hart which discharges into Lake Ajay.

S-62 is a reinforced concrete, gated spillway with discharge controlled by a vertical lift gate. Operation of the gate is manually controlled in accordance with the seasonal operational criteria.

The spillway structure is used to maintain scheduled stages in Lakes Hart and Mary Jane upstream from the structure; passes up to 30 percent of the standard project flood, restricts discharge during floods to that which will not cause damaging velocities or stages downstream; and passes sufficient discharge during low-flow periods to satisfy irrigation demands downstream.

The spillway gate should be operated during floods to assist in regulating water levels in lakes Hart and Mary Jane seasonally between 59 to 61 ft, NGVD as shown on the regulation schedule. When the lake stage is over 0.5 feet from the prescribed level, maximum releases can be made. The design capacity of the structure is 640 cfs.

To meet structural and stability requirements, the maximum allowable hydrostatic head on the structure should not be allowed to exceed 7.2 ft with a headwater elevation of 66.6 ft, NGVD and a tailwater elevation of 59.4 ft, NGVD.

Structure 60 (S-60) is located in C-33 between Lakes Alligator and Gentry about 1,500 feet upstream from County Road 534 and 3,700 feet downstream from Alligator Lake.

S-60 is a reinforced concrete, gated spillway with discharge controlled by a stem operated, vertical lift gate. Operation of the gate is manually controlled in accordance with seasonal operational criteria.

The spillway structure maintains desirable water-control stages in C-33 and Alligator Lake; passes up to 30 percent of the standard project flood without exceeding desirable stages; restricts discharge during floods to that which will not cause damaging velocities or stages downstream; and passes sufficient discharge during low-flow periods to maintain stages and satisfy irrigation demands downstream.

The spillway structure normally maintains a seasonal desirable water-control stage of 62.0 to 64.0 ft, NGVD upstream from the structure as shown on the regulation schedule. S-60 and S-58 both discharge from Alligator Lake, consequently discharges from both structures must be considered in establishing release schedules.

The maximum water level differential should not exceed 7 feet with the headwater not exceeding elevation 68.0 ft, NGVD.

Structure 59 (S-59) is located in C-31 between East Lake Tohopekaliga and Lake Tohopekaliga at the outlet of East Lake Tohopekaliga.

S-59 is a reinforced concrete, gated spillway with discharge controlled by a vertical lift gate. Operation of the gate is manually controlled in accordance with seasonal operational criteria.

S-59 is the outlet structure for East Lake Tohopekaliga. The spillway structure normally maintains desirable water-control stages in the lake upstream from the structure; passes up to 30 percent of the standard project flood without exceeding desirable stages; restricts discharges during floods to that which will not cause damaging velocities or stages downstream; and passes sufficient discharge during low-flow periods to maintain stages and satisfy irrigation demands.

Downstream of S-59 a sheet pile weir was constructed to influence the tailwater of the structure. The crest of the weir is elevation 50.83 ft. A submerged weir equation is used in the model to adjust the tailwater stage at S-59 from the lake stage.

To meet structural and stability requirements, the maximum differential hydrostatic head on the structure should not be allowed to exceed 8 feet when the headwater is below 62.8 ft, NGVD. If the headwater should ever exceed 62.8 ft, NGVD, the allowable differential head will be reduced.

Structure 61 (S-61) is located in C-35 at the south shore (outlet) of Lake Tohopekaliga.

S-61 is a reinforced concrete, gated spillway with discharge controlled by a vertical lift gate, and a reinforced concrete lock structure with two pairs of sector gates. Operation of the spillway gate is manually controlled in accordance with seasonal operational criteria.

The spillway structure normally maintains desirable water-control stages in Lake Tohopekaliga upstream from the structure during low-flow periods; passes up to 30 percent of the standard project flood without exceeding desirable stages; and passes sufficient discharge during low-flow periods to maintain stages and satisfy irrigation demands downstream. The lock structure permits passage of vessels with a draft of less than 6 feet between the Kissimmee River (C-38) and Lake Tohopekaliga.

The gate in the spillway should be operated to permit water levels in Lake Tohopekaliga to fluctuate seasonally between 52 ft and 55 ft, NGVD as shown on the regulation schedule.

To meet structural and stability requirements, the maximum differential hydrostatic head on the structure should not be allowed to exceed 10 ft when the headwater is below 55.0 ft, NGVD. When the headwater is between 55.0 and 59.9 ft, the maximum differential head should not be allowed to exceed 6 ft. If the headwater should ever exceed 59.9 ft the allowable differential will be reduced.

Structure 63 (S-63) is located in C-34 about 2000 feet downstream from Lake Gentry.

S-63 is a reinforced concrete gated spillway with discharge controlled by a stem operated vertical lift gate. Operation of the gate is manually controlled in accordance with the seasonal operation criteria.

The spillway structure maintains desirable water-control stages in C-34 and Lake Gentry upstream from the structure during low-flow periods; passes up to 30 percent of the standard project flood without exceeding desirable stages; restricts discharge during floods to that which will not cause damaging velocities or stages downstream; and passes sufficient discharge during low-flow periods to maintain stages and satisfy irrigation demands downstream.

The spillway structure normally maintains a seasonal desirable water-control stage of 59.5 to 61.5 ft, NGVD upstream from the structure as shown on the regulation schedule. When the lake is within 0.5 ft of the schedule, forecasts should be made and releases initiated to return the lake to schedule within 15 days. When the lake stage is considerably above schedule and large inflows are anticipated, releases up to the design capacity of 715 cfs can be made.

Structure 63A (S-63A) is an automatic spillway located below S-63.

Both structures control the outflow from Lake Gentry and together allow a stepped drop of ten feet between Lake Gentry and Lake Cypress. It is assumed that discharges at S-63 and S-63A are the same and therefore only S-63 flow is modeled. Structure 63A maintains, automatically, an optimum headwater pool of 56.5 msl. The model uses this 56.5 msl to calculate the flow through S-63 and is assumed to be unchanged.

Spillway S-65 (S-65) is the outlet of the chain.

S-65 can discharge up to 11,000 cfs. Under actual operation, however, the discharge at S-65 has rarely exceeded 6000 cfs. In day-to-day operations, the District determines the maximum allowable discharge at S-65 based on the amount of inflow experienced on the previous day. Based on statistical analyses of the historical data, two assumptions were made:

First, the tailwater stage at S-65 is fixed at 46.3 msl, which is the historical mean stage maintained by S-65A. The design tailwater elevation (46.3 ft NGVD) will be different after the completion of Kissimmee River restoration projects due to back filling of C-38. Therefore, the tailwater stage at S-65 will need to reflect this change, especially for simulation cases where the simulation duration covers both exiting and restoration conditions.

Second, the maximum discharge at S-65 is limited to 3000 cfs and 5000 cfs, respectively, under dry and wet conditions. These two values are based on past flow through S-65 prior to 1980. With additional flow data and climatic changes in the 1980-90s, the value may not be the same. The model should treat these two values as input and use 3000 cfs and 5000 cfs as default values. Under Kissimmee River Restoration Project, the maximum S-65 discharge has increased up to 18,000 cfs instead of 11,000 cfs. Two additional gates spillways have been added to existing S-65 structure. The probability of ever being able to discharge 18,000 cfs for extended period is remote. Only under an extreme or nearly catastrophic event would there be sufficient head across the structure (ie. Lake Kissimmee stages greater than 56 ft.) to discharge 18,000 cfs to the Low Basin.

Wet conditions are defined as having antecedent monthly rainfall exceeding eight inches. Baffle blocks were installed below S-65 in 1986. The dry condition discharge constraint was raised to 6000 cfs on an interim basis until the model is extended to the lower basin whereby the boundary condition will be shifted from S-65 to S-65E.

B. Regulation Schedules

The lakes are regulated by rigid hard-coded schedules. The regulation schedules represent the management aspect of the system aimed at optimizing flood control, water conservation, and environmental enhancement. The trend of the regulation schedules generally reaches the minimum and maximum at the beginning and end of the wet season to prepare for flood control and water conservation, respectively. Regulation schedules are, nevertheless, subjective rules that change every few years.

In the routing model, the actual regulation schedules for the years under simulation are entered as breakpoint data in a separate input file (TAPE4). Since its original inception the model has been used to develop a new regulation schedule for Lakes Kissimmee, Hatchineha and Cypress to meet some of the requirements for the restoration of Kissimmee River. This new regulation schedule contains a set of complex zones for flow releases and discharge variations with the program code designed specifically for the new regulation schedule for Lake Kissimmee. Any deviation of flow releases at any time during the year requires code changes if the deviations were not originally coded in the model. It is necessary to develop a generic routine capable of handling any possible regulation schedule changes relating the parameters; flow, stage and time for each lake system.

C. Gate Operation Criteria

The maximum allowable gate opening for each spillway is governed by the “Riprap Control” criteria, so named because the objective is to prevent excessive velocity damage to the riprap around the structures. The criteria were established by the US Army Corps of Engineers and presented in charts such as that shown in Table 2. The family of curves can be fitted by the following equation, which appears to be the same general form of equation used to calculate flow through a weir under submerged conditions.

$$GO = A\,(HW - TW)^{B}\,TW^{C} + D \qquad <2>$$

where

GO = Maximum allowable gate opening in ft
HW = Headwater elevation
TW = Tailwater elevation
A,B,C,D = Constant coefficients as shown in Table 2

Table 2 – Riprap Control Coefficients

	A	***B***	***C***	***D***
S-59	$0.38\text{x}10^{-8}$	-0.22083	5.41927	-3.673
S-60	$2.2588896\text{x}10^{-14}$	-0.51706295	8.2136768	0.
S-61	0.002954	-.15463	2.24833	-10.82
S-62	$1.7404157\text{x}10^{-22}$	-.59052612	12.743331	0.
S-63	0.022745	-.21273	1.6471	-8.246
S-65	0.36587777	-.55682769	.95236956	0.

Gated culvert structures S-57 and S-58 do not have gate operation criteria and this presents difficulties in simulating their operation. Their discharge capacities, however, are relatively small and S-58 has seldom been operated. Based on an analysis of the historical data, maximum allowable discharges of 230 and 100 cfs are assigned to S-57 and S-58 as additional operational constraints.

D. Structure and Canal Flow Equations

The flow equations for the control structures and Canals C-36 and C-37 are summarized in Table 3. Though the flow equations for the structures incorporate all flow conditions, under normal operation submerged controlled flow predominates. Stream flow gaging data were used to calibrate the spillway flow equations. Since most of the measurements were taken under submerged controlled flow conditions, only this type of flow was calibrated. The fitted coefficients are shown in Table 3. Calibrated values of some coefficients exceeded the theoretical range, which can be attributed to datum errors and other unknown noise in the original data.

Canals C-36 and C-37 are the open channels connecting Lakes Cypress and Hatchineha, and Lakes Hatchineha and Kissimmee. Because there are no control structures along C-36 and C-37, the stages in the lower three lakes tend to be equalized. The flow rating equations for C-36 and C-37 (Table 3) were established from stream flow gaging data taken in 1983 and 1984. The flow equations shown in Table 3 are in essence a Manning Equation using both the stage and water surface slope as independent variables.

$$Q = A\,(HW - TW)^{B}\,(HW - C)^{D} \qquad <3>$$

where

Q = Discharge in cfs

HW = Upper lake stage in ft msl

TW = Lower lake stage in ft msl

A,B,C,D = Calibrated coefficients shown in Table 3.

Table 3 – Structure and Canal Flow Equations

Spillway

Flow Type	Flow Equation	Criteria
Free weir flow	$Q1 = 3.28AL(HW-CEL)^{1.5}$	$TW<CEL$ and $Q1<Q2$
Free control flow	$Q2 = 0.75ALxGO[64.4(HW-CEL-0.5GO)]^{0.5}$	$TW<CEL$ and $HW>1.1(CEL+GO)$
Submerged weir flow	$Q3 = 0.9AL(TW-CEL)[64.4(HW-TW)]^{0.5}$	$TW>CEL$ and $Q3<Q4$
Submerged control	$Q4 = (\alpha\ GO + \beta)(AL)(GO)[64.4(HW-52)]^{0.5}$	$TW>CEL$ and $Q4<Q3$

where

$Q1,Q2,Q3,Q4$ = Flow in cfs under four different flow conditions

AL = Spillway length in ft

HW = Headwater elevation in msl

CEL = Spillway crest elevation in msl

GO = Gate opening in ft obtained from Equation <2> and Table 2

α, β = Calibrated flow coefficients shown below:

	S-59	S-60	S-61	S-62	S-63	S-65
α	.1033	0	.0253	0	0	.0375
β	.58	.73	.59	.75	.75	.76

Gated Culvert

Flow Type	Flow Equation	Criteria
Open channel flow	$Q1 = (1.49/n)(AR)(SLOPE)^{0.5}$	$HW<TOP$
Orifice flow	$Q2 = 0.75A[64.4(HW-TW)]^{0.5}$	$HW>TOP$ and $TW<TOP$
Full pipe flow	$Q3 = (1.49/n)(AR)(SLOPE)^{0.5}$	$HW>TOP$ and $TW>TOP$

where

$Q1,Q2,Q3$ = Flow in cfs under three different flow conditions

TOP = Top elevation of pipe in msl

n = Manning n (0.024 for all culverts)

AR = Linearized conveyance coefficient

= $(1.72y/d = 0.373)(3.142)(A)(d/4)^{0.6667}$

y = Mean depth of flow in ft

d = Diameter of pipe in ft

A = Cross sectional area of pipe in ft^2

$SLOPE$ = Sloper of water surface

= $(HW-TW)/L$

HW = Headwater elevation is msl

TW = Tailwater elevation in msl

L = Length of pipe in ft

Canal 36 and 37

C-36: $Q = 35.61885873(HW-TW-.19)^{.5511796(}HW-35.07)^{1.6667}$

C-37: $Q = 87.07430164(HW-TW+.12)^{.4976433}(HW-42.12)^{1.6667}$

The rating equations compute the instantaneous flow rate, and since the model runs in daily time steps, there may occasionally be a time resolution problem. In order to assure the conservation of mass, the computed total daily discharge is compared with the allowable storage release (which is estimated as the storage above the regulation schedule plus the expected inflows) and the smaller of the two is selected. If the allowable storage release is less than zero, no discharge will be made. Since there are no control structures in C-36 and C-37, the allowable storage release at Lakes Cypress or Hatchineha is calculated as the storage above the downstream lake stage plus the expected inflows. If the allowable storage release is negative due to higher stage in the downstream lake, reverse (negative) flow is permitted.

In summary, therefore, by combining gate operation criteria (Equation 2), flow rating equations (Table 3), and lake regulation schedules, the management of the system can be simulated.

E. Rainfall and Evaporation

In forecasting, rainfall is a predetermined quantity specified by the user. Evaporation is predicted as a function of rainfall. Both rainfall and evaporation are distributed uniformly throughout the lakes unless specified otherwise. Evaporation is predicted by the following frequency correlation equation:

$$E_d = C\{E_m - (R_m - RN_m)S_E/S_R\}/N_m \qquad <4>$$

where :

E_d = Estimated daily lake evaporation in inches
C = Pan to lake coefficient (0.8 used as default value)
E_m = Normal pan evaporation for calendar month, m, in inches
S_E = Standard deviation of pan evaporation (1.7094 used)
S_R = Standard deviation of rainfall (2.4755 used)
R_m = Total rainfall for calendar month m in inches
RN_m = Normal rainfall for calendar month, m, in inches
N_m = Number of days in calendar month, m

Assuming both follow the same probability distribution, the above equation equates the frequency occurrence of rainfall and evaporation; that is, a one in ten year rainfall in any month will generate a one in ten year evaporation in the same month. Furthermore, the relationship is inverse; that is, the smaller the amount of rainfall, the greater the evaporation.

Historical rainfall and pan evaporation data were used in model calibration. Rainfall input to the lakes is based on a weighted average rainfall from stations around the lakes as listed in Table 4. The Rainfall stations used to develop average rainfall over each lake are based on available long-term rainfall stations close to the lake. Table 4 is no longer valid due to some of the rainfall stations no longer in service. The data from Table 4a now supercedes that from Table 4.

Evaporation is assumed to be uniformly distributed throughout the lakes in the chain. A 0.8 pan to lake coefficient is used. The 0.8 coefficient was calibrated from a water budget analysis of East Tohopekaliga for the drought period of October 1981 to April 1982, however, further analysis based on 30 years of water budget data has indicated that a different value should be used. Therefore, this value will be an input data and use 0.8 as default value.

Table 4 – Rainfall Station Weighting Factors

LAKE NAME	Rainfall Station	Weighting Factor
Lake Kissimmee (1970-1999)	Chapman (MRF23)	0.25
	Snively (MRF24)	0.25
	S65 (MRF27)	0.25
	Indian L (MRF28)	0.25
Lake Hatchineha (1970-1999)	Snively (MRF24)	0.4
	Mario (MRF205)	0.25

	Kirchoff (MRF17)	0.20
	S61 (MRF18)	0.15
Lake Cypress (1970-1999)	S61 (MRF18)	0.34
	Chapman (MRf23)	0.33
	Snively (MRF24)	0.33
Lake Tohopekaliga (1970-1999)	St. Cloud (MRF12)	0.25
	Kiss. FS (MRF162)	0.25
	S61 (MRF18)	0.25
	Kirchoff (MRF17)	0.25
East Lake Tohopekaliga (1970-1991)	L Myrtle (MRF8)	0.34
	Taft (MRF4)	0.33
	St. Cloud (MRF12)	0.33
East Lake Tohopekaliga (1992-1999)	St. Cloud (MRF12)	0.50
	Taft (MRF4)	0.40
	Beeline (MRF3)	0.10
Lake Gentry (1970-1999)	S61 (MRF18)	0.50
	Pine Isle (MRF19)	0.50
Lake Myrtle (1970-1991)	L Myrtle (MRF8)	0.60
	St. Cloud (MRF12)	0.30
	Pine Isle (MRF19)	0.10
Lake Myrtle (1992-1999)	St. Cloud (MRF12)	0.50
	Pine Isle (MRF19)	0.25
	Beeline (MRF3)	0.25
Lake Alligator (1970-1991)	Pine Isle (MRF19)	0.30
	St. Cloud (MRF12)	0.40
	L Myrtle (MRF8)	0.30
Lake Alligator (1992-1999)	St. Cloud (MRF12)	0.60
	Pine Isle (MRF19)	0.40
Lake Hart (1970-1991)	Beeline (MRF3)	0.40
	L Myrtle (MRF8)	0.40
	Taft (MRF4)	0.20
Lake Hart (1992-1999)	Beeline (MRF3)	0.50
	Taft (MRF4)	0.25
	St. Cloud (MRF12)	0.25

F. Watershed Inflows

Some modifications were made to the watershed inflow calculations. The modification had to do with the way the model computed daily runoff from the various sub-basins. The inflow module consists of a set of routines that will compute runoff, at daily time steps, over a long period. For each time step, the required daily data is supplied to the inflow routine. The routine will use the data to maintain a soil moisture balance for the basin, and compute the depth of surface runoff for the current time step.

For the purposes of this document, the module is divided into four parts:

1. Soil moisture balance,
2. Computation of surface runoff,
3. Computation of ET, and

4. Miscellaneous computations.

Soil Moisture Balance:

The soil moisture balance is very much like that used by Fan (1986). The main difference is the computation of ET. Computing a soil moisture deficit, for each time step performs the balance:

$$SMD_I = SMD_{I-1} + ET + B_f - [P - R_o]$$

Where:

SMD_I = soil moisture deficit, in inches, for time step I;

ET = evapotranspiration, in inches;

B_f = base flow or seepage, in inches;

P = precipitation, in inches; and

R_o = excess rainfall, in inches;

Estimation of ET is discussed below. The base flow term, B_f, is computed using

$$B_f = [K_{bf}/H_{max}]\{H_{max} - SMD/12n\}$$

Where:

K_{bf} = a coefficient representing the maximum rate at which the water can fall, inches per time step;

n = soil porosity, inches per inch; and

H_{max} = water table depth below which base flow ceases, feet;

When the water table depth, given by SMD/12n, is less than H_{max} . However, if the water table depth is greater then H_{max}, base flow is zero.

Excess rainfall, R_o, is estimated using the SCS runoff equation using the soil moisture deficit as the available storage:

$$R_o = \frac{(P - 0.2SMD)^2}{P + 0.8SMD}$$

Surface Runoff Computation:

Fan (1986) assumed that during a time step surface runoff was equal to the excess rainfall, R_o, as calculated above. This yields large peak outflows of very short duration. This module uses an imaginary linear reservoir to compute instantaneous outflow rates at the end of each time step:

$$Q_I = \frac{\{R_o/K_{ro} + Q_{I-1}(1 - \Delta t/2K_{ro})\}}{1 + \Delta t/2K_{ro}}$$

where:

Q_I = runoff rate, in inches per hour, at the end of time step I;

Δt = time step, in hours (usually 24); and

K_{ro} = linear reservoir routing coefficient, in hours;

The value return by the module routine is the runoff depth, O, in inches, for the time step, or

$$\bullet = \Delta t \{(Q_I + Q_{I-1})/2\}$$

Evapotranspiration Computation:

Evapotranspiration is estimated using the methodology implemented and used by the CREAMS model (Knisel, 1980). This method is a modified form of the Ritchie method (Ritchie, 1972). The modifications made to the Ritchie method are not extensive, but they are important. The CREAMS manual by Knisel provides only limited documentation of the method.

The inflow module uses a truncated form of the Penman equation to estimate potential evapotranspiration. In this form, the radiation term is simplified and the advection term is ignored:

$$ET_p = 1.28 \Delta H_o [\Delta + \Gamma]$$

Where:

ET_p = potential evapotranspiration, in millimeters per day;

Δ = change in saturation vapor pressure with temperature,

$$= \frac{T_K}{T_K^{\,2}\ \exp[\,(21.255-5304)/\ T_K\,]}$$

T_K = mean daily temperature, in degree Kelvin;

Γ = the psychrometric constant or 0.68;

H_o = net radiation or $(1 - \alpha)R_{so}$ /58.3;

α = crop albedo or = 0.23

R_{so} = total (long-wave) incoming solar radiation, in calories/cm;

1.28 = a constant to convert calories per square centimeter to inches of water per day.

Actual ET is estimated as the sum of two components; soil evaporation and plant ET. Estimation of soil evaporation is a complicated algorithm. Ritchie (1972) presented a flow chart of the procedure, which is probably the best description available. The estimation is based on the concept of soil evaporation having two "stages": (1) early after rainfall, when surface soil layers are relatively wet, and (2) after topmost soil layers are dry. In stage 1, there is little resistance so soil evaporation proceeds at a potential rate:

$$E_s = E_{sp} = \begin{cases} ET_p \exp(-0.4LAI) & \text{for } K_{wc} >= \exp(-0.45LAI) \\ ET_p\ K_{wc} & \text{for } K_{wc} < \exp(-0.4LAI) \end{cases}$$

Where:

E_{sp} = potential soil evaporation, mm/day;

LAI = leaf area index ; and

K_{wc} = "winter cover factor"

Inclusion of the "winter cover factor" is one of the major differences between the Ritchie method presented by Ritchie and that used in the CREAMS model. The factor is retained in the runoff module.

"Stage 2" soil evaporation begins when a specified amount of "stage 1" evaporation has occurred. This upper limit of stage 1 evaporation is given by Knisel (1980) as

$$U = 9.0 \exp[\alpha_s - 3.0]$$

Where:

U = upper limit of stage 1 soil evaporation, mm;

α_s = a soil coefficient = 4.5 for loamy soils, 3.5 for clay soils, 3.3 for sandy soils.

The module currently sets α_s to 3.3 for sandy soils; this can be changed at runtime.

Stage 2 soil evaporation is estimated using a decay function, where the evaporation rate is a function of time

$$E_s = \alpha_s [\sqrt{t} - \sqrt{(t - 1)}]$$

Where: t is time, in days, since stage2 soil evaporation started.

Plant evapotranspiration is estimated using the equation:

$$ET_{plant} = [LAI/3]\, ET_p \quad \text{for } LAI \le 3.0$$
$$ET_p - E_s \quad \text{for } LAI > 3.0$$

The estimate of total ET is the sum of plant ET and soil evaporation, or potential ET if it is less than the sum.

Miscellaneous Computations:

Fitting Monthly Data. The inflow module is generally used for daily estimations of runoff, so daily temperature, radiation and leaf area index must be supplied to the module. Unfortunately consistent daily values of these quantities are rarely available, but monthly values may be more available. Sets of routines, which will form daily estimate temperature, radiation, and leaf area index from available monthly values are contained in the module.

Given twelve monthly values the forfit routine will fit a truncated Fourier Series of the form

$$X_I = a_0 + a_1 \sin(c_I) + a_2 \cos (c_I)$$

Where:

I = Julian day;

X_I = daily value for day I;

$C = 0.017167;$

And a_0, a_1 , and a_2 are coefficients estimated from the monthly data as

$$a_0 = 1/12 \sum^{12}_{m=1} X_m$$

$$a_1 = 2/12 \sum^{12}_{m=1} \cos [X_m/12]$$

$$a_2 = 2/12 \sum^{12}_{m=1} \sin [X_m/12]$$

where:

X_m = mid month (or monthly mean) value for month m.

Thirteen watersheds are simulated in the model. There are four gaged (Boggy Creek, Shingle Creek, Catfish Creek, and Reedy Creek) and nine ungaged watersheds. Each ungaged watershed represents a combination of several local watersheds that drain to a lake. Watershed inflows in the lakes consist of both direct runoff and base flow. In continuous simulation, base flow can be more important than direct runoff because it occurs continuously. The model simulates direct runoff and base flow separately.

Direct runoff is simulated by a District-modified Soil Conservation Service Direct Runoff Formula. Routing of the direct runoff (rainfall excess) is not performed because the watershed time of concentrations are smaller than a one day time step.

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \qquad <5>$$

where

Q = Direct runoff volume in inches

P = Precipitation in inches

S = Soil moisture deficit in inches

Base flow simulation is based on the concept of potential and actual base flow. The actual base flow is linearly related to the water table depth.

$$B = SCOEF \frac{(HMAX-WT)}{(HMAX)} \qquad <6>$$

where

B = Base flow in inches

$SCOEF$ = Potential base flow in inches

$HMAX$ = Depth at which base flow ceases (5 to 10 ft)

WT = Water table depth

In the above equation *SCOEF* represents the potential base flow when the water table is near the land surface; *HMAX* represents the effective depth at which the base flow ceases. This corresponds to a situation when the water table has effectively fallen below the streambeds. The formulation of the base flow is analogous to the formulation of the watershed evapotranspiration loss.

$$ET = PET \frac{(ROOT-WT)}{(ROOT)} \tag{7}$$

where

ET = Watershed evapotranspiration in inches

PET = Potential ET in inches = PCOEF x EVAP

$PCOEF$ = Pan coefficient at PET (0.7 to 0.9)

$EVAP$ = Pan evaporation in inches

$ROOT$ = Deep root zone in feet below which ET ceases (5 to 10 ft)

WT = Water table depth in feet

To evaluate Equations 5, 6 and 7 the knowledge of the water table depth *WT* and soil moisture deficit *S* is needed. Assuming a constant storage coefficient of 0.2 and including a unit conversion factor, the water table depth *WT* (in feet) can be related to *S* (in inches) by a factor of 2.4. Thus only *S* needs to be quantified. A soil moisture accounting procedure is formulated to continuously monitor *S*.

$$S_t = S_{t-1}+ET-P+Q+B \tag{8}$$

where

S_t = Soil moisture deficit (in) at time step t

S_{t-1} = Soil moisture deficit (in) at previous time step, t-1

ET = Watershed evapotranspiration loss in inches from Equation 7

P = Precipitation in inches

Q = Direct runoff in inches from Equation 5

B = Base flow in inches from Equation 6

In summary, the watershed discharge is modeled as the summation of direct runoff and base flow from Equations 5 and 6 which, in turn, are functions of the soil moisture deficit *S* determined by Equations 7 and 8. The procedure described requires the calibration of four parameters: *SCOEF*, *HMAX*, *PCOEF* and *ROOT*. The base flow parameters (*SCOEF* and *HMAX*) are primarily a function of the drainage density and aquifer characteristics; the *ET* parameters (*PCOEF* and *ROOT*) are primarily a function of the land use and soil type. An optimization procedure is provided to assist in calibrating the parameters and is described below.

The current approach is a lumped parameter approach; that is, each watershed is treated as a unit and the parameters are effective parameters for the entire watershed. Thus, although the procedure is physically based and has the ability to reflect changes in the physical conditions, statistical elements are introduced in the process of calibration and the procedure can only be viewed as partly deterministic.

G. Stage-Area /Stage Volume Relationships

Polynomial equations were fitted to the stage-area and stage-volume data and the coefficients are shown in Table 5. Polynomial fitting is suitable for interpolation only; extrapolation beyond the range of data used to calibrate the equation can be erroneous. The following linear extrapolation equation is used to project the area above the maximum surveyed stage.

$$AREA = A_{(hmax)} + DA_{(hmax)} x [h - hmax] \qquad <9>$$

where

AREA = Lake area in acres

$A_{(h)}$ = Stage area function

= $D1(h)^4+D2(h)^3+D3(h)^2+D4(h)+D5$

h = Stage in ft msl (>hmax)

D1 to D5= coefficients for area rating

$DA_{(h)}$ = $dA_{(h)}/dh$

= $4(D1)(h)^3+3(D2)(h)^2+2(D3)(h)+D4$

hmax = Maximum stage used in polynomial fitting in ft msl

Similarly, linear extrapolation is used to project the volume above the maximum surveyed stage using the following equation.

$$VOL = V_{(hmax)} + (AREA + AREA_{(hmax)})/2\,[h-hmax] \quad <10>$$

where

AREA = Lake area in acres (from equation 9)

VOL = Lake volume in acre-ft

$V_{(h)}$ = Stage volume function

= $C1(h)^4+C2(h)^3+C3(h)^2+C4(h)+C5$

h = Stage in ft msl (>hmax)

C1 to C5= coefficients for area rating

hmax = Maximum stage used in polynomial fitting in ft msl

Table 5 – Stage-Area/Stage-Volume Relationships

$$AREA = D1(h)^4+D2(h)^3+D3(h)^2+D4(h)+D5 \quad <11>$$

$$VOL = C1(h)^4+C2(h)^3+C3(h)^2+C4(h)+C5 \quad <12>$$

where

AREA = Lake area in acres

VOL = Lake volume in acre-ft

h = Stage in ft msl

C1 to C5 = coefficients for stage volume rating

D1 to D5 = coefficients for stage area rating

hmax = Maximum stage used in polynomial fitting in ft msl

hmin = Minimum stage used in polynomial fitting in ft msl

	Alligator	**Myrtle**	**Hart**	**Gentry**	**E. Toho**	**Toho**	**Cypress**	**Hatchineha**	**Kissimmee**
C1	-4.4642004	3.0002689	0.21157913	2.9258007	2.829373	0	.43142302	-1.5127289	14.023537
C2	1238.5192	-707.76736	-41.567386	-702.73697	-649.2139	24.71876	-91.027331	284.80337	-2683.7603
C3	-126982.37	62675.634	3097.0676	63312.71	56075.09	-3310.8	7294.9886	-19506.905	193335.42
C4	5724291.8	-2468063.4	-102266.56	-2534177.8	-2148076	161410.9	-258747.85	578132.96	-6183331
C5	-95950501	36452945	1244906.4	38012042	30728530	-2828022	3400561.1	-6250583	73906134
D1	-22.3861	2.0264439	0.29565288	1.5462534	-0.263521	-1.661901	0	0	0
D2	5641.0255	-481.925	-67.473332	-366.74399	64.99214	367.9039	1.7256921	-6.0509156	56.094148
D3	-532464.04	42983.139	5783.8343	32608.56	-5948.022	-30441.02	-273.08199	854.41011	-8051.2809
D4	22314593	-1703871.9	-220443.89	-1288094.7	240362.1	1117249	14589.977	-39013.81	386670.84
D5	-350337540	25327409	3150674.3	19073801	-3617802	-15345700	-258747.85	578132.96	-6183331
H max	65	65	64	65	65	60	58	55	58
H min	59.5	58	56	57	50	49	43	45	42.5

For projection below the minimum surveyed stage, the following equations are used. The formulation is empirical and the objective is to avoid negative area projection.

$$AREA = A_{(hmin)} \text{ x } (h/hmin)^{1.5}$$

$$VOL = V_{(hmin)} \text{ x } (h/hmin)^{1.5}$$

where

AREA = Lake area in acres

VOL = Lake volume in acre-ft

$A_{(h)}$ = Area function

$V_{(h)}$ = Volume function

h = Stage in ft msl (<hmin)

hmin = Minimum stage used in polynomial fitting in ft msl

When using regression equations, especially those with large coefficients, it is important to take into account the numerical resolution of the compiler. Using 4 byte precision the numerical accuracy is approximately $X \pm 2^{-22}$. (All compilers conforming to the IEEE floating point standard will uphold this approximation.) To demonstrate by example:

say, for Lake Alligator

Stage = 63.83

D1 = -22.3861

D2 = 5641.0255

D3 = -532464.04

D4 = 22314593

D5 = -350337540

then

Stage = 63.83 ± 0.0000038146972656250000

D1 = -22.3861 ± 0.0000019073486328125000

etc…

and the Area calculated using equation 11 is a value between 7065.255 and 8211.165. To the compiler these values are indistinguishable. (In this particular example the compiler returned a value of 7638.21 versus the actual value of 7830.916.)

The raw data was examined by comparing the measured areas with those calculated from the polynomial coefficients. The measured volume was also compared with the volume calculated from the polynomial coefficients and also with the volume calculated using equation 13.

$$VOL = h/3 (A1 + A2 + sqrt(A1 \times A2)) \qquad <13>$$

where

VOL = Lake volume in acre-ft

h = Lake stage

$A1$ = Lake area in acres at stage 1

$A2$ = Lake area in acres at stage 2

The polynomials obtained from regression analysis generally provided good correlation with the measured data. The major errors would appear to be due to rounding errors in the manual calculation of the (measured) volume. Table 6 below shows the error (in %) comparing the measured area to that calculated from the polynomial coefficients and also the error comparing the volume calculated using equation 13 with the measured volume and the volume calculated from the polynomial coefficients.

Table 6 – Area and Volume Percentage Error

	Area Min. Error	Area Max Error	Area Ave. Error	Measured Volume Min. Error	Measured Volume Max. Error	Measured Volume Ave. Error	Polynomial Volume Min. Error	Polynomial Volume Max. Error	Polynomial Volume Ave. Error
Alligator	-16.4	10.1	-0.21	0.0	1.1	0.42	-3.1	1.3	0.27
Myrtle	-4.6	3.4	-0.39	0.0	8.9	3.71	0.3	8.4	3.63
Hart	-0.8	0.3	-0.04	-0.4	1.1	0.04	-0.2	0.2	0.00
Gentry	-1.2	1.8	-0.08	0.0	0.7	0.24	-0.0	0.9	0.22
E. Toho	-1.5	1.1	-0.31	-0.6	0.2	-0.14	-2.4	0.2	-0.96
Toho	-1.4	0.8	-0.19	-0.2	0.5	0.12	-1.2	0.6	0.12
Cypress	-10.8	8.1	1.55	-0.6	1.9	0.43	1.5	6.2	3.61
Hatchineha	-62.3	15.1	-11.47	0.0	2.9	0.83	1.5	63.7	11.72
Kissimmee	-27.8	3.1	-0.13	-2.55	0.40	-0.03	2.1	10.0	3.85

This analysis suggests that although the polynomial fit is adequate in most cases, the magnitude of numerical error able to be introduced within the compiler reduces modeling confidence to the point where consideration should be given to replacing the stage-area and stage-volume function with a simple linear interpolation routine.

The lack of either, the original raw data used to generate the rating curves for the lake discharge structures, or the availability of the data in electronic form, makes a rigorous analysis futile. Errors are introduced interpolating data from the graphs provided, which make a statistical analysis worthless. However a number of spot-checks of the results for each discharge structure has shown the results generated by the software appear to fall on the curves provided. This procedure does not suffer from the same compiler-introduced residual errors, however consideration should still be given to replacing the Gate Operation Criteria (equation 2) with a similar interpolation routine to that suggested for the stage/volume relationship. This would allow for the user to modify the discharge relationship without the need to modify source code.

H. Routing Procedures

Routing proceeds from the uppermost lake (Alligator) to the lowermost lake (Kissimmee) by solving the mass balance equation in daily time steps. The mass balance equation is rewritten below with the unknowns placed on the left side of the equation.

$$DSTOR+Q_{out} = Q_{in}+P-E+ADJ+Q_{lake} \qquad <14>$$

where

Q_{in} = Inflows from upper lake structure

Q_{lake} = Watershed inflows

P = Lake precipitation

E = Lake evaporation

ADJ = Inflow adjustment term - all un-estimated flows and errors of water budget

$DSTOR$ = Change in lake storage

Q_{out} = Outflow to lower lake

The model can operate in three different modes. Each routing mode differs in the way the terms on the right side of Equation 14 are determined:

- **Simulation Mode:** All terms on the right side of Equation 14 are input from historical records. The model routes the flow through the lakes and simulates only the management aspect of the system. In other words, the model predicts the structure flows and lake stages based on historical hydrologic input. This mode is suitable for evaluating situations where only the management variables change, such as in evaluating a change in the regulation schedules. The implicit assumption is that a change in the management variables will not affect the historical hydrologic variables.

- **Forecasting Mode:** All terms on the right side of Equation 14, except rainfall, are predicted using rainfall as a conditional dependent variable. Rainfall is predetermined. Variation of the management rules, such as the regulation schedules, can also be input as additional conditional variables. This mode is most general, as the ultimate objective of a routing model is to be able to forecast under any conditions.

- **Calibration Mode:** This mode is essentially the same as the previous one except that historical rainfall is used. This mode is used to calibrate and verify the forecasting capability of the model by comparing historical to model results. An optimization operation is provided to aide in the calibration of the parameters.

On the left side of Equation 14, the unknowns *DSTOR* and Q_{out} are both a function of the lake stage and thus stage is the only unknown. However, Q_{out} is dependent on both the current and lower lake stages due to backwater effect and constraints imposed by management rules. Since the tailwater (lower lake) stage is unknown a priori in the current time step, an iteration technique is used to converge the estimated and computed stages. The process is accomplished by first estimating Q_{out} from the stages in the last time step, computing the storage change *DSTOR* from Equation 14, and then updating the stages from the following equation:

$$h_t = h_{t-1} + DSTOR / AREA_{(ht)} \qquad <15>$$

where

h_t = Stage in current time step in ft msl

h_{t-1} = Stage in last time step in ft msl

$DSTOR$ = Computed storage change from Equation <14> in acre-ft

$AREA_{(ht)}$ = Lake surface area in acres from rating equation as a function of h_t

The updated stages are used to revise Q_{out} and DSTOR by Equation 14 and a small number of iterations per time step are needed to converge the stages.

One particular feature of the model is that it can handle missing records. Missing records are signaled by "?" tags in the input files. When a user-specified missing gap is encountered, the model will skip the routing computation, reinitialize the stages to historical at the end of the gap, but continue soil moisture accounting throughout. This provision removes major noise in the input data so that they will not be included in the calibration.

I. Parameter Optimization Procedures

A univariant gradient search procedure is used to aid in the calibration of the watershed parameters. For ungaged watersheds where stream flow data are unavailable. The objective function f(x) is defined as the sum of square deviations of the observed and computed stages of the receiving lakes. For gaged watersheds, f(x) is defined as the sum of square deviations of the logarithmic transformed flows, where x is one of the watershed parameters (SCOEF, HMAX, PCOEF and ROOT) to be adjusted. The adjustment ∂x for x is obtained from the following formula:

$$\partial x = \propto [-f(x) / f(x)] \qquad <16>$$

where

∂x = Adjustment for x

x = Parameter value

= One of 52 parameters: SCOEF, HMAX, PCOEF or ROOT in thirteen watersheds

$\propto$ = Adjustment factor between 0 and 1

$f(x)$ = Objective function value from model run

= $\Sigma\, [h_{obs} - h_{sim}(x)]^2$ or

$\Sigma [\log Q_{obs} - \log Q_{sim}(x)]^2$

h_{obs}, h_{sim} = Observed and simulated stages of receiving lakes for ungaged watersheds

Q_{obs}, Q_{sim} = Observed and simulated flows for gaged watersheds

$f(x)$ = Gradient (Partial derivative) of f(x) with respect to parameter x.

Since it is not possible to evaluate f(x) analytically, the gradient (partial derivative) f(x) is determined numerically from the following equation:

$$f(x) = [f(x) - f^*(x)]/[x - x^*] \qquad <17>$$

where

$f(x)$ = Objective function value from current model run

$f^*(x)$ = Objective function value from previous model run

x = Parameter value of x at current run

= $x^* + \partial x^*$

x^* = Parameter value of x at previous run

∂x^* = Adjustment for x in previous run.

Each adjustment iteration requires running the routing model for the entire simulation period (1970 to 1980) one time to renew the objective function value. The new value f(x) and the old value f*(x) are used to calculate the gradient f(x) by Equation 17, which is then used to determine a new adjustment ∂x for x by Equation 16. Each parameter is adjusted independently by keeping the other parameters constant. To minimize interaction among the watersheds, optimization proceeds from the most upstream watershed to the downstream ones.

VI MODEL USAGE

The model can operate in three different modes, which have been described in detail in Section V. Briefly a “simulation” mode reads in historical hydrologic data directly and is suitable for evaluating the management components of the system. A “calibration” mode reads in the historical rainfall; all other terms are predicted using rainfall as the dependent variable. An optimization option is provided to aid in the calibration of the parameters. A “forecasting” mode is essentially the same as the “calibration” mode except that rainfall is predetermined by the user.

All three routing modes are included in one version of the routing program KROUTE. A brief description of the subroutines in KROUTE is summarized in Table 7. Complimentary to KROUTE are a water budget program KBUDGET and a, now obsolete, plotting program KPLOT. The input and output file requirements for all three programs are listed in Table 8. Files are attached or created dynamically in the programs so that the user need not explicitly manage the files.

The water budget computation program (now subroutine) KBUDGET serves two purposes. One is to verify the historical data, which can be achieved by examining the water budget results. Another is to preprocess the input data files for KROUTE. The water budget function is used only initially and is not required in routine application of the routing program.

Table 7 – Subroutine Functions

KROUTE	This main program initializes data, attaches or creates input data files dynamically, and performs routing from lake to lake.
BUILDF	Builds input data file NTAPE5 for “forecasting” run according to user specified rainfall scenario and initial stage conditions.
INFLOW	Computes watershed discharges, evaporation, and performs soil moisture accounting needed for base flow and direct runoff simulation.
OPT	Performs optimization for watershed parameters by a gradient search technique.
STORAGE	Calculates stage area and stage storage relationships from rating equations.
DISCH	Computes flow from spillway, culvert, and canal rating equations.
BLOCK DATA	Contains lake, structure, and miscellaneous parameter data needed for other subroutines.

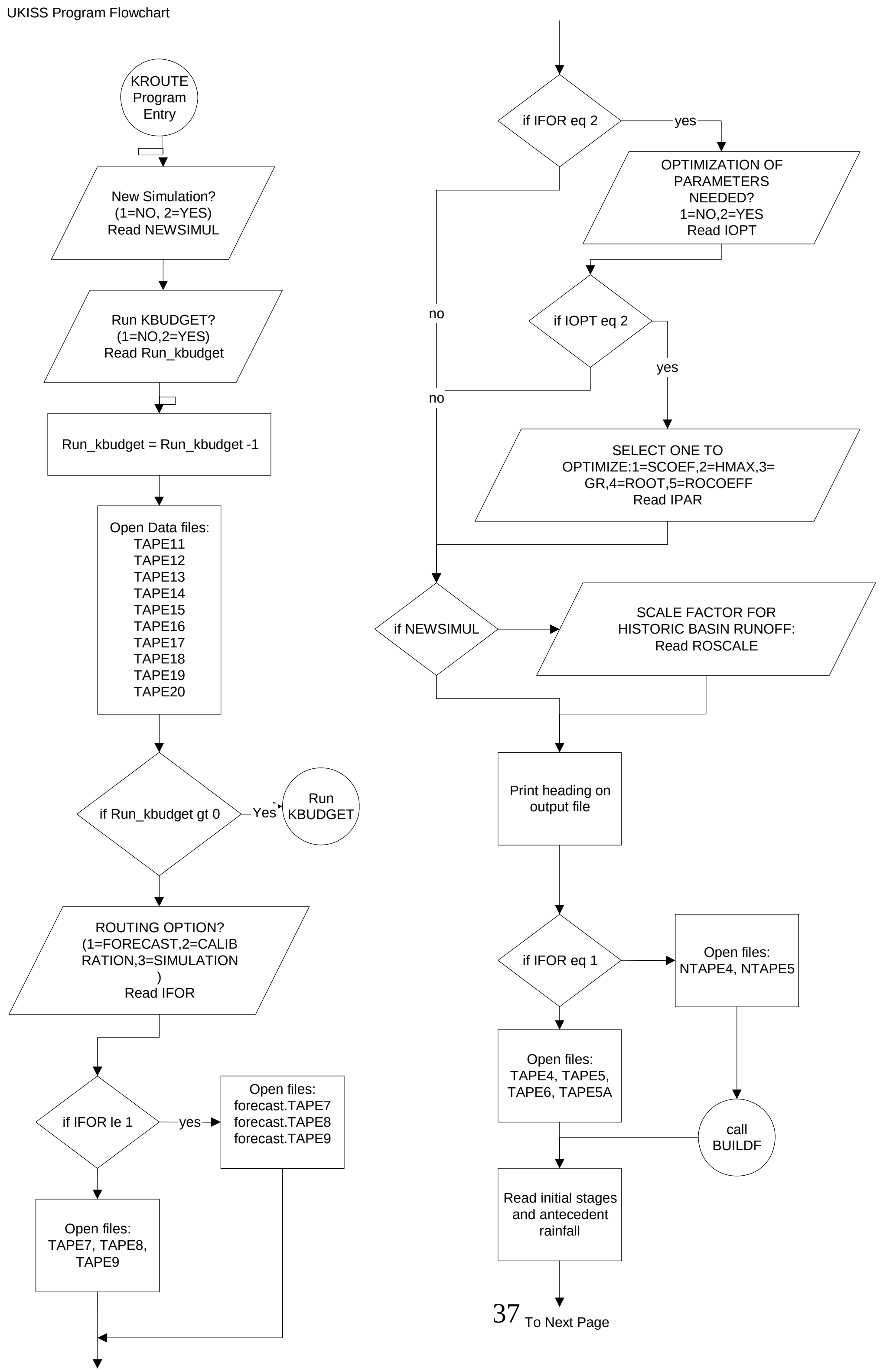
One particular feature of the routing program is that it can handle missing records. Missing records are indicated by “?” tags in the input data records (column 3 of TAPE5 and TAPE6). When a missing gap is encountered, the model will skip the routing computation, initialize the stages to historical, but continue soil moisture accounting throughout. This provision removes major noise from the input data so that they will not be included in the calibration. Missing records or records with errors can be detected by inspecting the water budget results from KBUDGET runs. If a missing gap is small, the gap is filled in by an interpolation or correlation method otherwise a “?” tag is inserted thus allowing the routing program to skip computation.

Table 8 – Input and Output Data Files

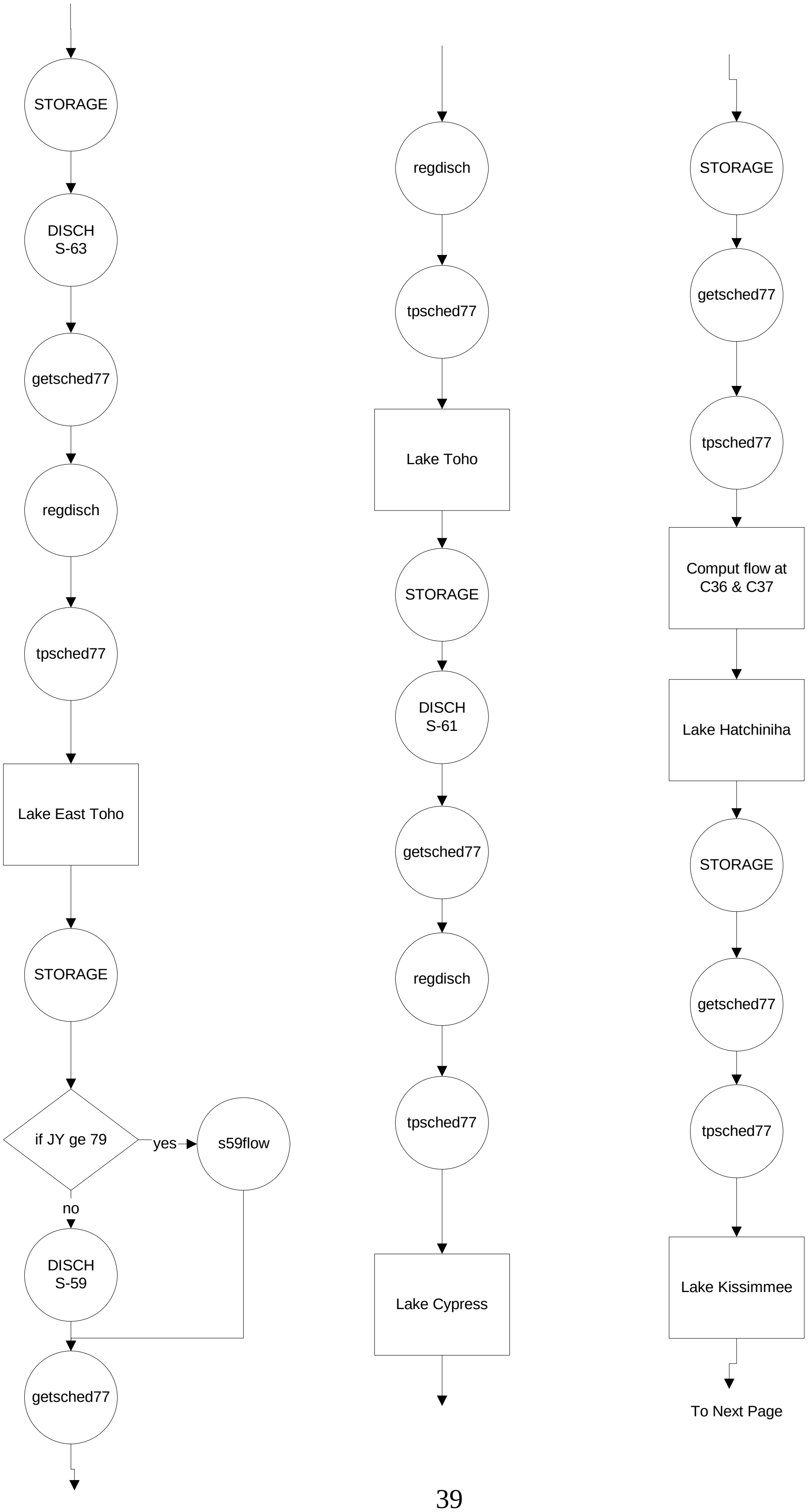
Program	Input Files	Contents	Output Files	Contents
KBUDGET	Tape1	Raw hydrologic data	Tape5	Input data for KROUTE
	Tape2	Raw hydrologic data	Tape6	Input data for KROUTE
KROUTE	Tape4	Regulation schedules	Tape7	Output stages
	Ntape4	Current regulation schedules	Tape8	Output stages
	Tape5	From KBUDGET run	Tape9	Output flows
	Tape6	From KBUDGET run	Tape11-19	Detailed output by lakes
KPLOT (superceded)	Tape2	Raw hydrologic data		
	Tape8	From KROUTE run		
	Tape9	From KROUTE run		

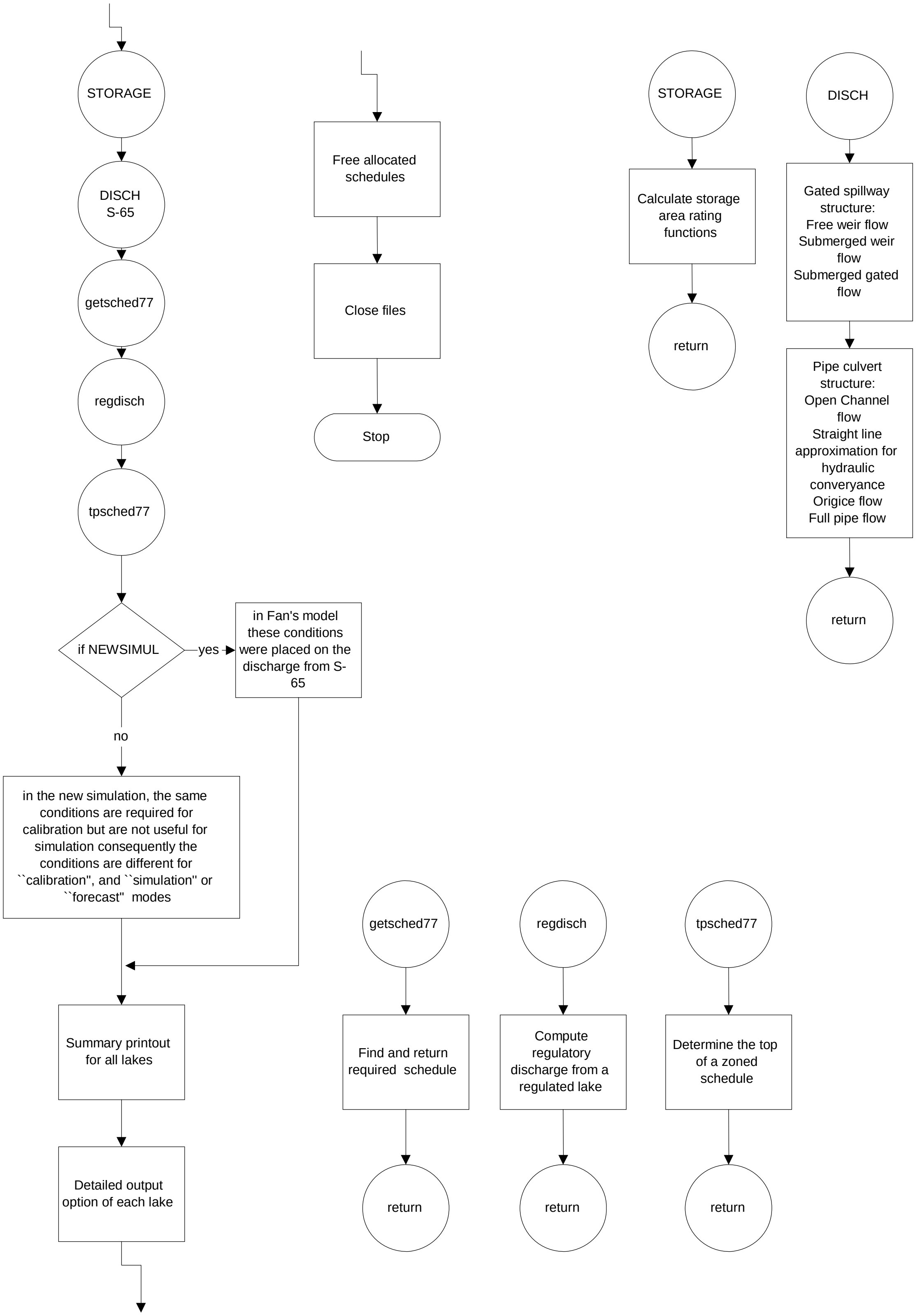
APPENDIX A: MODEL FLOW CHART

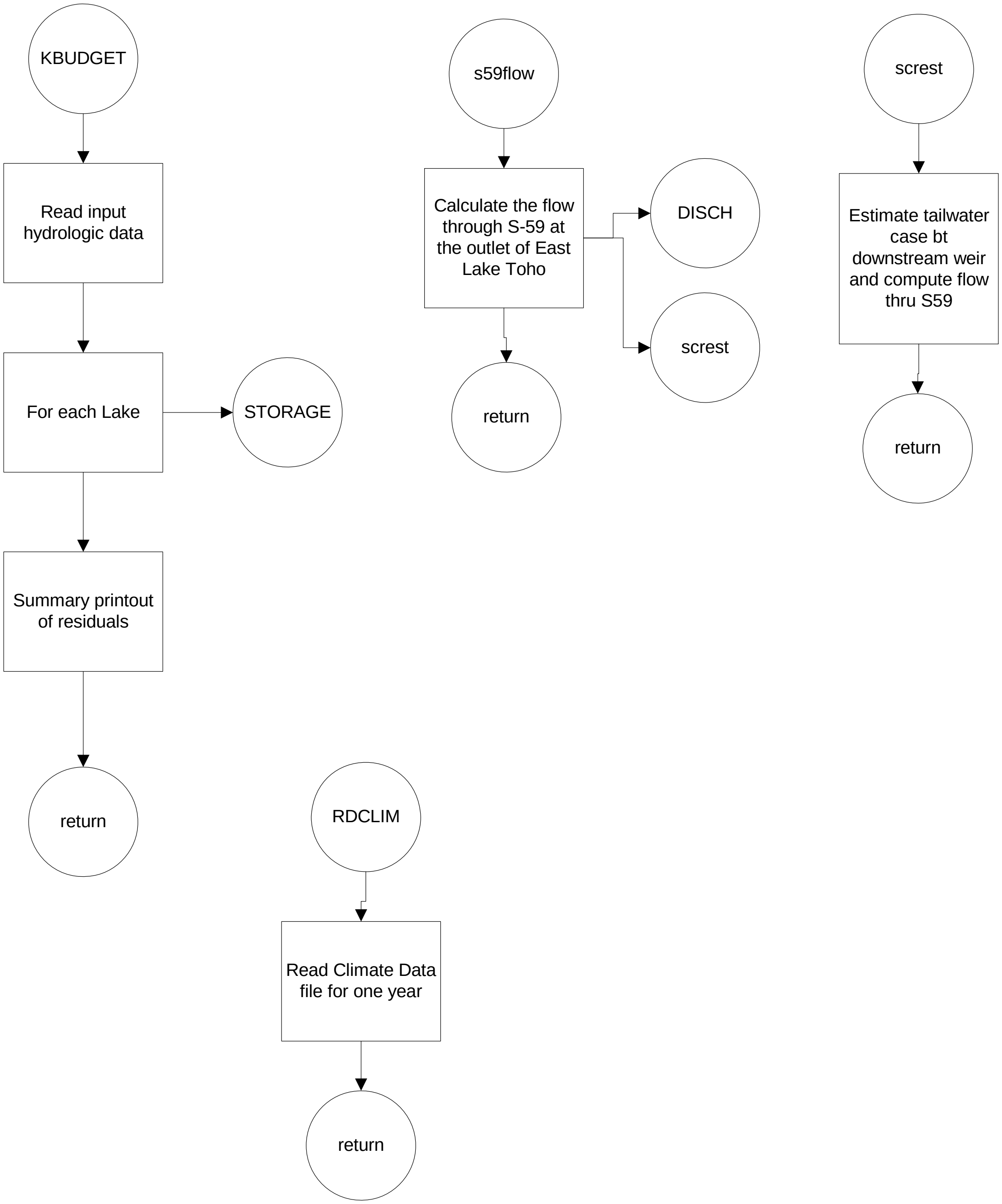
The flow chart for the KROUTE and KBUDGET programs is shown below.

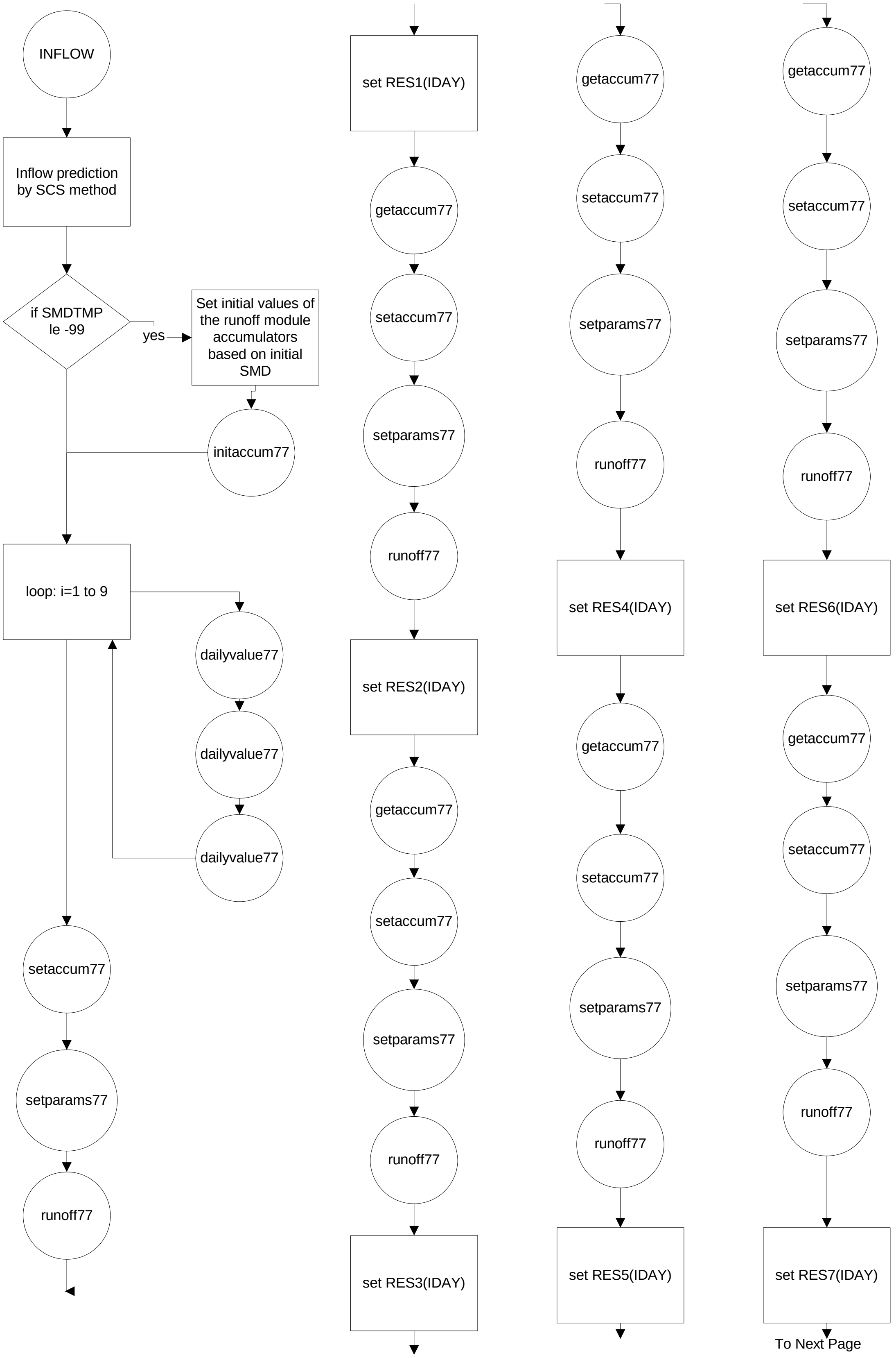


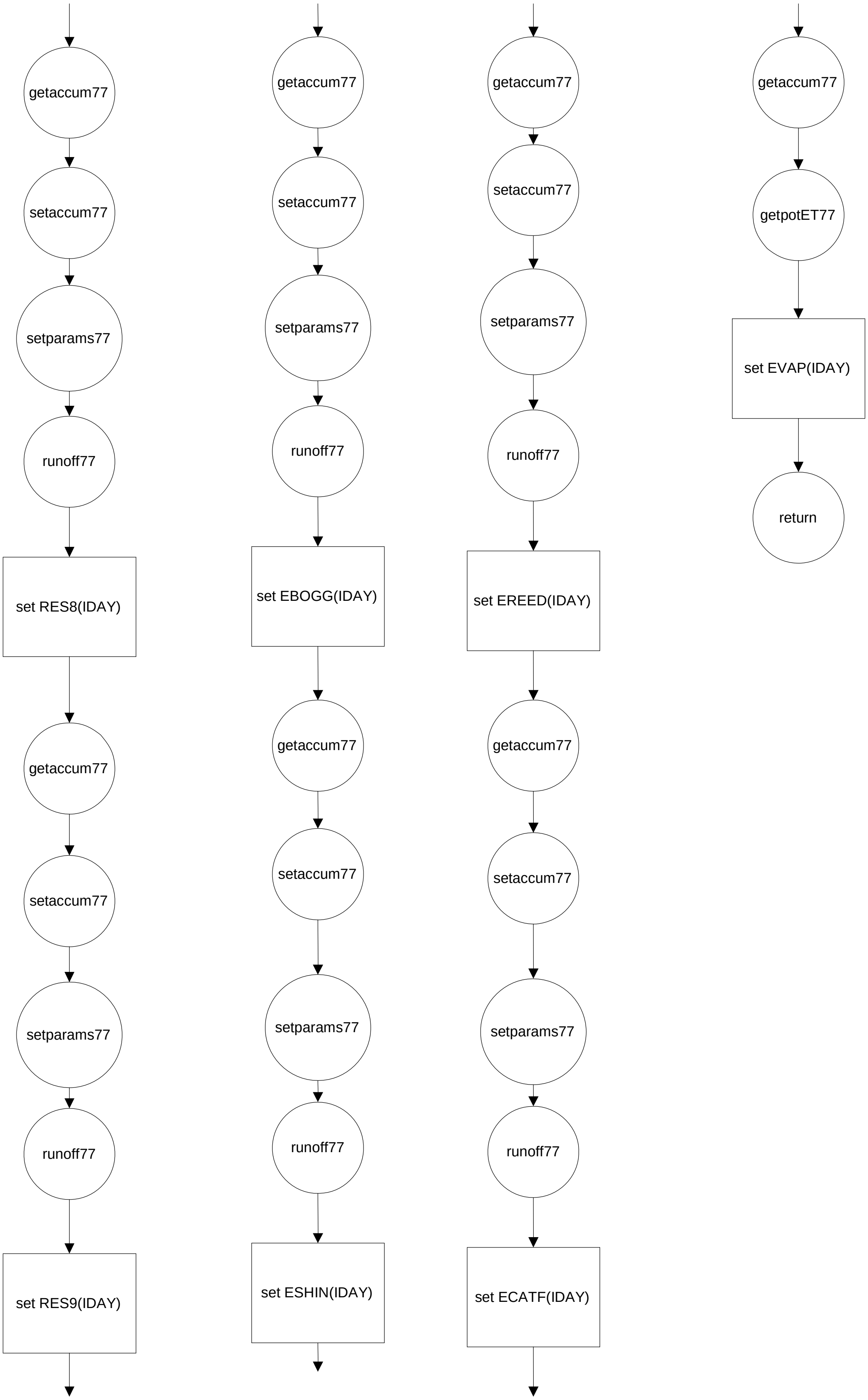

Global Initialization
Initialize lake stages for next year's simulation
Read lake regulation schedule
rdsched77
Read input hydrologic data
RDCLIM
Place the observed local inflows where they can be saved and used
INFLOW
Loop: For each day, read input hydrologic data
Iterate lake stages per time step
Lake Alligator
STORAGE
DISCH S-58
DISCH S-60
getsched77
regdisch
tpsched77
Lake Myrtle & Mary Jane
STORAGE
DISCH S-57
getsched77
regdisch
tpsched77
Lake Hart & Mary Jane
STORAGE
DISCH S-62
getsched77
regdisch
tpsched77
Lake Gentry
To Next Page

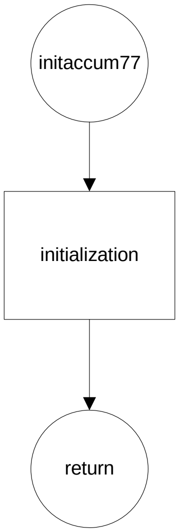

STORAGE
DISCH
S-63
getsched77
regdisch
tpsched77
Lake East Toho
STORAGE
if JY ge 79
yes
s59flow
no
DISCH
S-59
getsched77
regdisch
tpsched77
Lake Toho
STORAGE
DISCH
S-61
getsched77
regdisch
tpsched77
Lake Cypress
STORAGE
getsched77
tpsched77
Comput flow at
C36 & C37
Lake Hatchiniha
STORAGE
getsched77
tpsched77
Lake Kissimmee
To Next Page

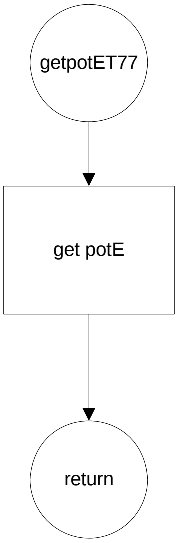

STORAGE
DISCH
S-65
getsched77
regdisch
tpsched77
if NEWSIMUL
yes
in Fan's model these conditions were placed on the discharge from S-65
no
in the new simulation, the same conditions are required for calibration but are not useful for simulation consequently the conditions are different for ``calibration'', and ``simulation'' or ``forecast'' modes
Summary printout for all lakes
Detailed output option of each lake
Free allocated schedules
Close files
Stop
STORAGE
Calculate storage area rating functions
return
DISCH
Gated spillway structure:
Free weir flow
Submerged weir flow
Submerged gated flow
Pipe culvert structure:
Open Channel flow
Straight line approximation for hydraulic converyance
Origice flow
Full pipe flow
return
getsched77
Find and return required schedule
return
regdisch
Compute regulatory discharge from a regulated lake
return
tpsched77
Determine the top of a zoned schedule
return

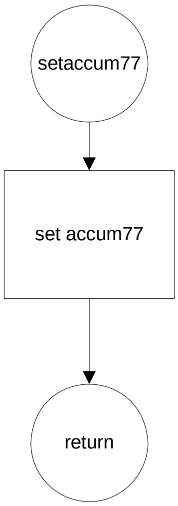

KBUDGET
Read input hydrologic data
For each Lake
STORAGE
Summary printout of residuals
return
s59flow
Calculate the flow through S-59 at the outlet of East Lake Toho
DISCH
screst
return
screst
Estimate tailwater case bt downstream weir and compute flow thru S59
return
RDCLIM
Read Climate Data file for one year
return

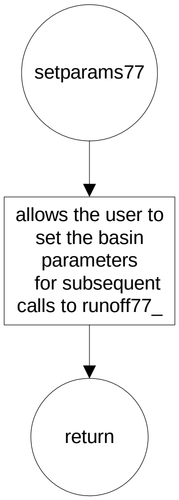

INFLOW
Inflow prediction by SCS method
if SMDTMP le -99
yes
Set initial values of the runoff module accumulators based on initial SMD
initaccum77
loop: i=1 to 9
dailyvalue77
dailyvalue77
dailyvalue77
setaccum77
setparams77
runoff77
set RES1(IDAY)
getaccum77
setaccum77
setparams77
runoff77
set RES2(IDAY)
getaccum77
setaccum77
setparams77
runoff77
set RES3(IDAY)
getaccum77
setaccum77
setparams77
runoff77
set RES4(IDAY)
getaccum77
setaccum77
setparams77
runoff77
set RES5(IDAY)
getaccum77
setaccum77
setparams77
runoff77
set RES6(IDAY)
getaccum77
setaccum77
setparams77
runoff77
set RES7(IDAY)
To Next Page

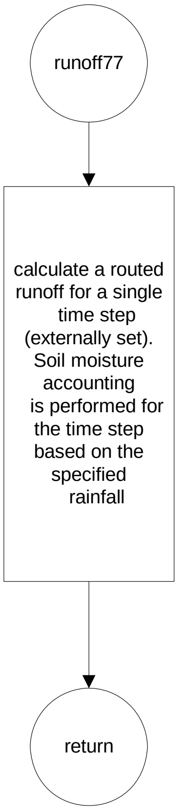

getaccum77
setaccum77
setparams77
runoff77
set RES8(IDAY)
getaccum77
setaccum77
setparams77
runoff77
set RES9(IDAY)
getaccum77
setaccum77
setparams77
runoff77
set EBOGG(IDAY)
getaccum77
setaccum77
setparams77
runoff77
set ESHIN(IDAY)
getaccum77
setaccum77
setparams77
runoff77
set EREED(IDAY)
getaccum77
setaccum77
setparams77
runoff77
set ECATF(IDAY)
getaccum77
getpotET77
set EVAP(IDAY)
return

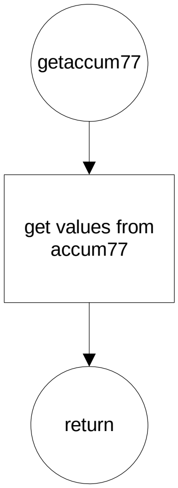

initaccum77
initialization
return

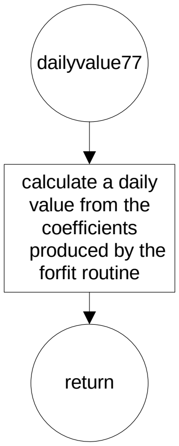

getpotET77
get potE
return

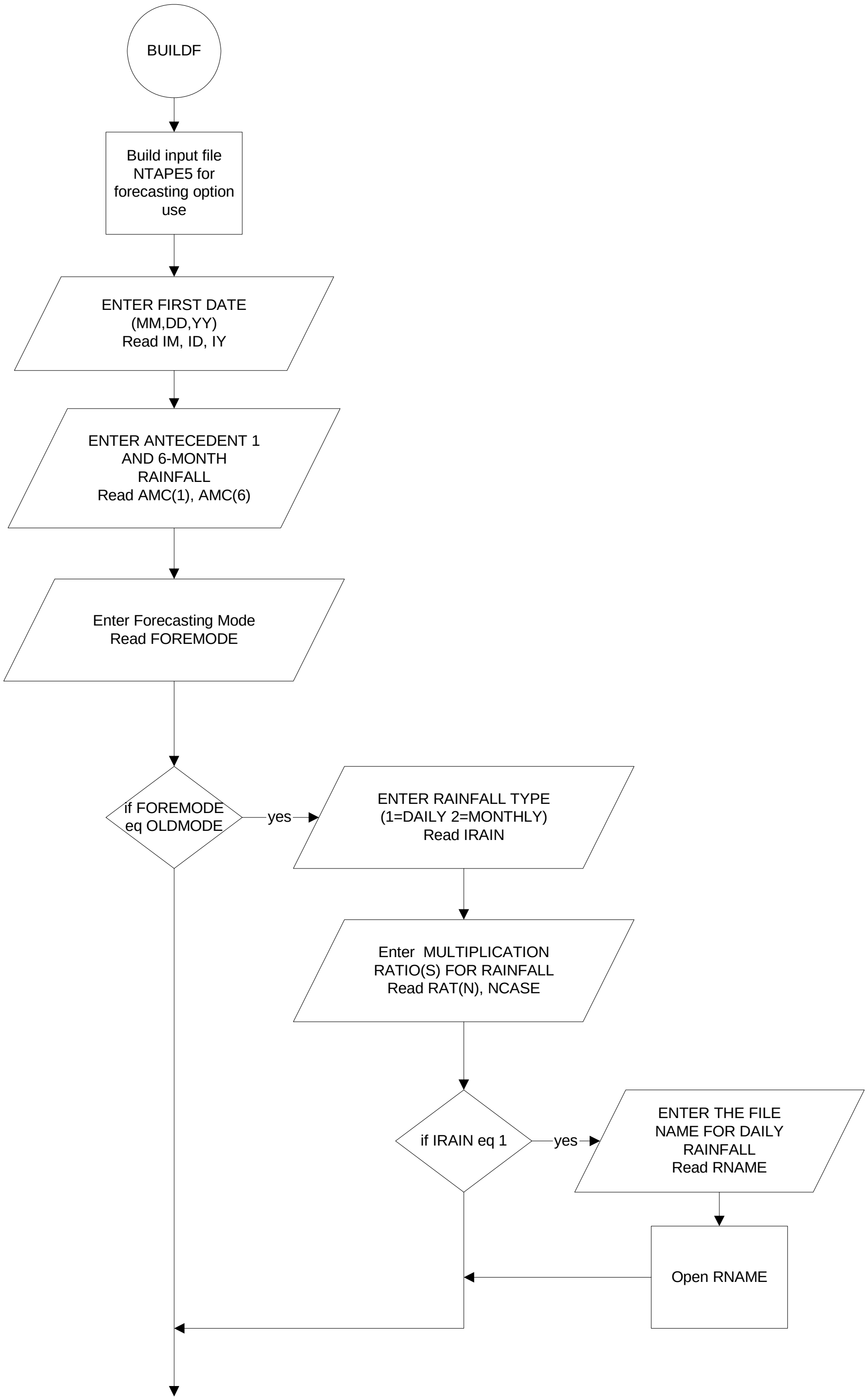

setaccum77
set accum77
return


setparams77
allows the user to set the basin parameters for subsequent calls to runoff77_
return

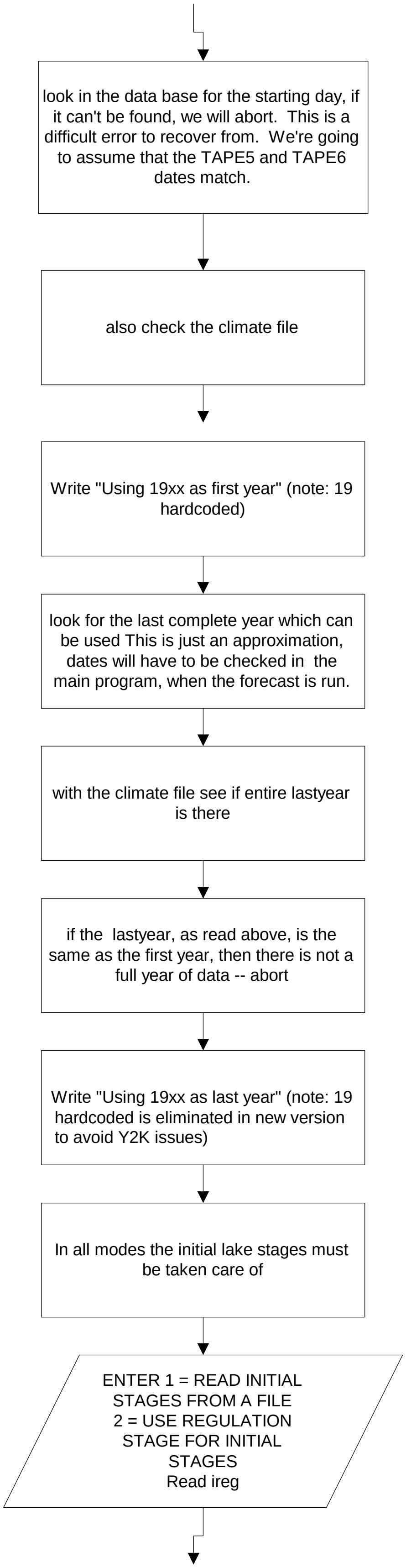

runoff77
calculate a routed runoff for a single time step (externally set). Soil moisture accounting is performed for the time step based on the specified rainfall
return

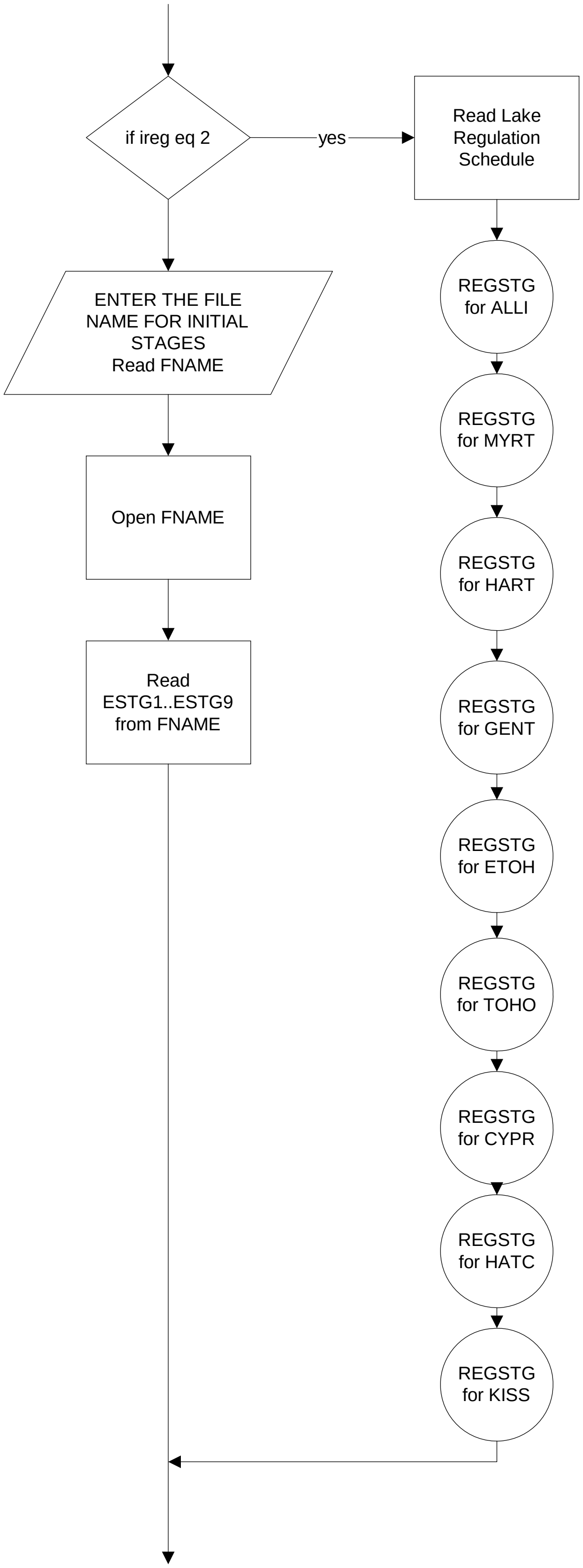

getaccum77
get values from accum77
return

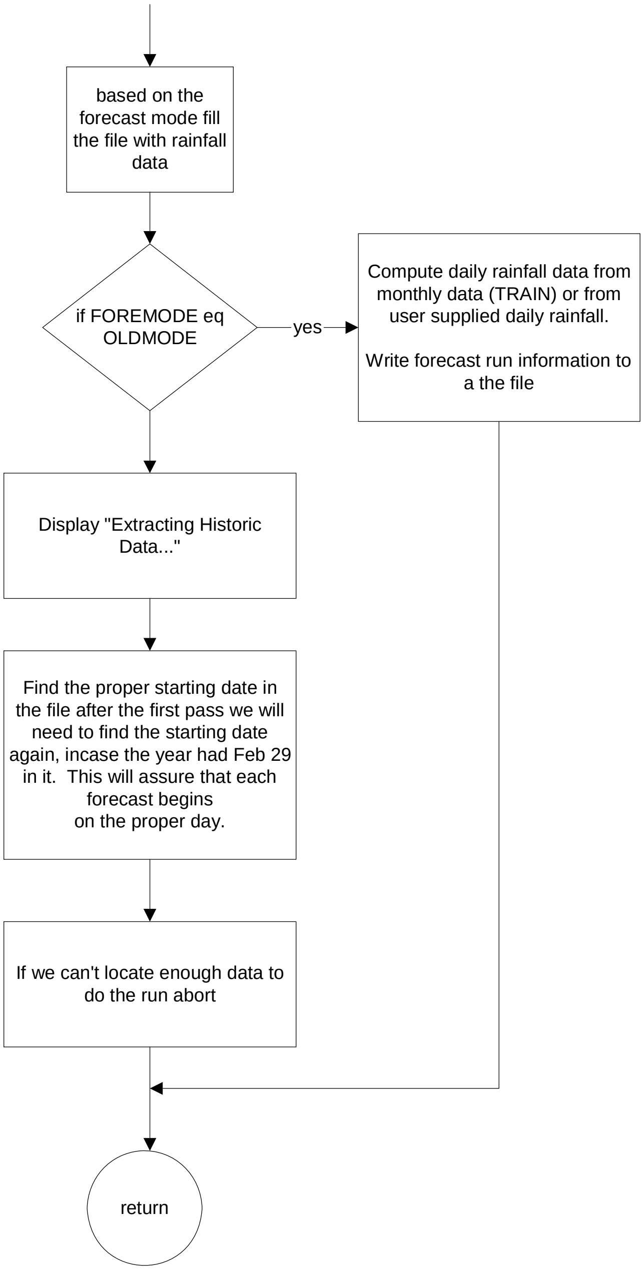

dailyvalue77
calculate a daily value from the coefficients produced by the forfit routine
return

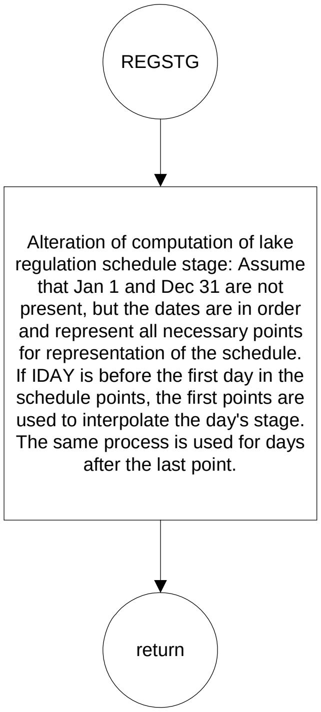

BUILDF
Build input file NTAPE5 for forecasting option use
ENTER FIRST DATE (MM,DD,YY) Read IM, ID, IY
ENTER ANTECEDENT 1 AND 6-MONTH RAINFALL Read AMC(1), AMC(6)
Enter Forecasting Mode Read FOREMODE
if FOREMODE eq OLDMODE
yes
ENTER RAINFALL TYPE (1=DAILY 2=MONTHLY) Read IRAIN
Enter MULTIPLICATION RATIO(S) FOR RAINFALL Read RAT(N), NCASE
if IRAIN eq 1
yes
ENTER THE FILE NAME FOR DAILY RAINFALL Read RNAME
Open RNAME


Enter name of TAPE5 Database Read FNAME
if FNAME not blank
yes
Open FNAME
no
Open RNAME
Display name of TAPE5 database file
Enter name of TAPE6 Database Read FNAME
if FNAME not blank
yes
Open FNAME
no
Open RNAME
Display name of TAPE6 database file
Enter name of TAPE5A Database Read FNAME
if FNAME not blank
yes
Open FNAME
no
Open RNAME
Display name of TAPE5A database file
if FOREMODE eq MULTI_YR
FIRST YEAR TO USE: Read firstyear
LAST YEAR TO USE: Read lastyear
if FOREMODE eq HISTORIC_YR
HISTORIC YEAR TO USE: Read firstyear
firstyear = mod(firstyear,100) lastyear = firstyear


look in the data base for the starting day, if it can't be found, we will abort. This is a difficult error to recover from. We're going to assume that the TAPE5 and TAPE6 dates match.
also check the climate file
Write "Using 19xx as first year" (note: 19 hardcoded)
look for the last complete year which can be used This is just an approximation, dates will have to be checked in the main program, when the forecast is run.
with the climate file see if entire lastyear is there
if the lastyear, as read above, is the same as the first year, then there is not a full year of data -- abort
Write "Using 19xx as last year" (note: 19 hardcoded is eliminated in new version to avoid Y2K issues)
In all modes the initial lake stages must be taken care of
ENTER 1 = READ INITIAL STAGES FROM A FILE 2 = USE REGULATION STAGE FOR INITIAL STAGES Read ireg


if ireg eq 2
yes
Read Lake Regulation Schedule
ENTER THE FILE NAME FOR INITIAL STAGES Read FNAME
Open FNAME
Read ESTG1..ESTG9 from FNAME
REGSTG for ALLI
REGSTG for MYRT
REGSTG for HART
REGSTG for GENT
REGSTG for ETOH
REGSTG for TOHO
REGSTG for CYPR
REGSTG for HATC
REGSTG for KISS


based on the forecast mode fill the file with rainfall data
if FOREMODE eq OLDMODE
yes
Compute daily rainfall data from monthly data (TRAIN) or from user supplied daily rainfall.
Write forecast run information to a the file
Display "Extracting Historic Data..."
Find the proper starting date in the file after the first pass we will need to find the starting date again, incase the year had Feb 29 in it. This will assure that each forecast begins on the proper day.
If we can't locate enough data to do the run abort
return


REGSTG
Alteration of computation of lake regulation schedule stage: Assume that Jan 1 and Dec 31 are not present, but the dates are in order and represent all necessary points for representation of the schedule. If IDAY is before the first day in the schedule points, the first points are used to interpolate the day's stage. The same process is used for days after the last point.
return

APPENDIX B

Survey data for these lakes was obtained from hand-written Stage/Area/Volume tables. Additional new survey data for Lakes Cypress, Hatchineha, and Kissimmee at two contour elevations (52.5 and 54.0 feet, NGVD is also included. No survey data for Lake Kissimmee is available beyond 54ft NGVD. The "measured area" data used in the table for this lake between elevations 54 and 55 ft is that obtained from the polynomial coefficients.

L. Alligator

Stage ft msl	Area (measured)	Area (from Polynomial)	Volume (measured)	Volume (from Area)	Volume (from Polynomial)
59	4600	3845	29500	29500	28592
59.1	4640	4082	29990	29962	29264
59.2	4680	4291	30480	30428	29917
59.3	4720	4472	30970	30898	30552
59.4	4760	4628	31460	31372	31170
59.5	4800	4762	31950	31850	31772
59.6	4840	4874	32440	32332	32360
59.7	4880	4967	32930	32818	32934
59.8	4920	5042	33420	33308	33496
59.9	4960	5102	33910	33802	34046
60	5000	5148	34400	34300	34585
60.1	5020	5181	34910	34801	35115
60.2	5050	5204	35420	35304	35636
60.3	5080	5217	35930	35811	36150
60.4	5100	5223	36440	36320	36658
60.5	5120	5222	36950	36831	37160
60.6	5150	5216	37460	37344	37657
60.7	5180	5207	37970	37861	38150
60.8	5200	5194	38480	38380	38641
60.9	5220	5181	38990	38901	39130
61	5250	5168	39500	39424	39618
61.1	5270	5156	40030	39950	40106
61.2	5290	5145	40560	40478	40594
61.3	5310	5138	41090	41008	41085
61.4	5330	5135	41620	41540	41578
61.5	5350	5137	42150	42074	42075
61.6	5370	5144	42680	42610	42576
61.7	5390	5158	43210	43148	43082
61.8	5410	5180	43740	43688	43594
61.9	5430	5209	44270	44230	44113
62	5450	5246	44800	44774	44639
62.1	5470	5293	45370	45320	45174
62.2	5480	5349	45940	45868	45718
62.3	5500	5415	46510	46417	46272
62.4	5520	5492	47080	46968	46837
62.5	5540	5580	47650	47521	47413
62.6	5550	5678	48220	48075	48001
62.7	5570	5788	48790	48631	48603

62.8	5590	5909	49360	49189	49218
62.9	5600	6042	49930	49749	49847
63	5620	6187	50500	50310	50491
63.1	5870	6344	51200	50884	51152
63.2	6130	6512	51900	51484	51828
63.3	6380	6692	52600	52110	52522
63.4	6630	6883	53300	52760	53233
63.5	6880	7086	54000	53436	53963
63.6	7140	7299	54700	54137	54712
63.7	7390	7524	55400	54863	55480
63.8	7640	7758	56100	55615	56269
63.9	7900	8003	56800	56392	57078
64	8150	8258	57500	57194	57909
64.1	8510	8521	58480	58027	58762
64.2	8870	8793	59460	58896	59638
64.3	9230	9073	60440	59801	60537
64.4	9590	9360	61420	60742	61459
64.5	9950	9653	62400	61719	62406
64.6	10310	9952	63380	62732	63377
64.7	10670	10256	64360	63781	64374
64.8	11030	10564	65340	64866	65397
64.9	11390	10875	66320	65987	66445
65	11750	11188	67300	67144	67521
65.1	11960	11501	68570	68329	68624
65.2	12160	11815	69840	69535	69754
65.3	12360	12127	71110	70761	70913
65.4	12570	12437	72380	72007	72100
65.5	12780	12743	73650	73275	73316
65.6	12980	13044	74920	74563	74561
65.7	13180	13339	76190	75871	75837
65.8	13390	13626	77460	77199	77142
65.9	13600	13903	78730	78549	78479
66	13800	14169	80000	79919	79846
66.1	14030	14423	81500	81310	81245
66.2	14260	14663	83000	82725	82675
66.3	14490	14887	84500	84162	84137
66.4	14720	15093	86000	85623	85632
66.5	14950	15280	87500	87106	87160
66.6	15180	15446	89000	88613	88720
66.7	15410	15589	90500	90142	90314
66.8	15640	15706	92000	91695	91941
66.9	15870	15797	93500	93270	93603
67	16100	15858	95000	94869	95298

			L. Myrtle		
Stage ft msl	**Area (measured)**	**Area (from Polynomial)**	**Volume (measured)**	**Volume (from Area)**	**Volume (from Polynomial)**
57.5	960	962	4200	4200	4211
57.6	975	970	4300	4297	4310
57.7	980	979	4400	4394	4411
57.8	995	990	4500	4493	4515
57.9	1000	1000	4650	4593	4620
58	1020	1012	4750	4694	4726
58.1	1035	1024	4850	4797	4835
58.2	1045	1037	4950	4901	4945
58.3	1060	1050	5100	5006	5056
58.4	1075	1064	5180	5113	5169
58.5	1085	1078	5250	5221	5283
58.6	1100	1092	5400	5330	5399
58.7	1115	1107	5500	5441	5516
58.8	1125	1121	5650	5553	5635
58.9	1140	1136	5750	5666	5754
59	1150	1151	5850	5780	5875
59.1	1170	1167	6000	5896	5997
59.2	1180	1182	6150	6014	6121
59.3	1190	1198	6250	6132	6246
59.4	1205	1213	6350	6252	6372
59.5	1220	1229	6500	6373	6499
59.6	1230	1244	6650	6496	6628
59.7	1245	1260	6750	6620	6759
59.8	1255	1276	6850	6745	6890
59.9	1275	1292	7000	6871	7024
60	1300	1308	7200	7000	7159
60.1	1320	1325	7350	7131	7295
60.2	1335	1341	7450	7264	7434
60.3	1350	1358	7550	7398	7574
60.4	1375	1375	7700	7534	7716
60.5	1390	1392	7900	7672	7860
60.6	1410	1410	8000	7812	8006
60.7	1430	1428	8150	7954	8155
60.8	1450	1446	8300	8098	8305
60.9	1475	1465	8400	8245	8459
61	1500	1485	8550	8393	8615
61.1	1515	1505	8750	8544	8773
61.2	1545	1526	8950	8697	8935
61.3	1570	1548	9100	8853	9100
61.4	1590	1571	9250	9011	9268
61.5	1610	1595	9400	9171	9439
61.6	1640	1619	9650	9333	9614
61.7	1660	1646	9800	9498	9793
61.8	1695	1673	10000	9666	9975
61.9	1725	1702	10200	9837	10162
62	1750	1732	10350	10011	10353
62.1	1800	1764	10600	10188	10549
62.2	1830	1798	10750	10370	10750

62.3	1860	1834	11000	10554	10955
62.4	1900	1871	11250	10742	11166
62.5	1940	1911	11400	10934	11382
62.6	1985	1954	11650	11131	11605
62.7	2025	1998	11850	11331	11833
62.8	2070	2046	12100	11536	12067
62.9	2110	2096	12300	11745	12308
63	2150	2149	12600	11958	12556
63.1	2200	2206	12850	12175	12811
63.2	2250	2265	13100	12398	13073
63.3	2300	2328	13350	12625	13343
63.4	2360	2395	13700	12858	13622
63.5	2420	2466	13900	13097	13908
63.6	2490	2541	14250	13343	14203
63.7	2550	2620	14500	13595	14507
63.8	2625	2703	14800	13854	14821
63.9	2700	2791	15100	14120	15144
64	2800	2885	15350	14395	15477
64.1	3010	2983	15750	14685	15820
64.2	3190	3086	16150	14995	16175
64.3	3350	3195	16650	15322	16540
64.4	3460	3310	17000	15663	16917
64.5	3580	3431	17350	16015	17305
64.6	3700	3558	17750	16379	17706
64.7	3800	3692	18200	16754	18120
64.8	3890	3832	18650	17138	18547
64.9	3980	3980	19100	17532	18987
65	4090	4135	19450	17935	19441

L. Hart

Stage ft msl	Area (measured)	Area (from Polynomial)	Volume (measured)	Volume (from Area)	Volume (from Polynomial)
56	2120	2121	11250	11250	11259
56.1	2145	2146	11480	11463	11477
56.2	2170	2170	11700	11679	11696
56.3	2195	2195	11920	11897	11918
56.4	2220	2220	12150	12118	12141
56.5	2245	2245	12380	12341	12366
56.6	2270	2270	12600	12567	12594
56.7	2295	2296	12820	12795	12824
56.8	2320	2322	13050	13026	13055
56.9	2345	2347	13280	13259	13289
57	2370	2374	13500	13495	13526
57.1	2400	2400	13750	13733	13764
57.2	2425	2426	14000	13975	14005
57.3	2455	2453	14250	14219	14248
57.4	2480	2480	14500	14465	14494
57.5	2510	2507	14750	14715	14742
57.6	2540	2534	15000	14967	14992

57.7	2565	2562	15250	15223	15245
57.8	2595	2589	15500	15481	15501
57.9	2620	2617	15750	15741	15759
58	2650	2645	16000	16005	16020
58.1	2680	2673	16280	16271	16283
58.2	2705	2702	16560	16541	16550
58.3	2735	2731	16840	16813	16819
58.4	2760	2760	17120	17087	17091
58.5	2790	2789	17400	17365	17365
58.6	2820	2818	17680	17645	17643
58.7	2845	2848	17960	17929	17924
58.8	2875	2878	18240	18215	18208
58.9	2900	2909	18520	18503	18494
59	2930	2939	18800	18795	18784
59.1	2965	2970	19100	19090	19077
59.2	2995	3001	19400	19388	19374
59.3	3030	3033	19700	19689	19673
59.4	3060	3065	20200	19993	19976
59.5	3095	3098	20300	20301	20282
59.6	3130	3130	20600	20612	20592
59.7	3160	3164	20900	20927	20905
59.8	3195	3197	21200	21245	21222
59.9	3230	3231	21500	21566	21542
60	3260	3266	21800	21890	21866
60.1	3300	3301	22150	22218	22194
60.2	3340	3337	22500	22550	22525
60.3	3375	3373	22850	22886	22861
60.4	3415	3410	23200	23226	23200
60.5	3455	3447	23550	23569	23543
60.6	3495	3485	23900	23917	23890
60.7	3535	3523	24250	24268	24241
60.8	3570	3562	24600	24623	24596
60.9	3610	3602	24950	24982	24955
61	3650	3643	25300	25345	25319
61.1	3695	3684	25690	25713	25687
61.2	3735	3726	26080	26084	26059
61.3	3780	3769	26470	26460	26435
61.4	3820	3813	26860	26840	26817
61.5	3865	3857	27250	27224	27202
61.6	3910	3903	27640	27613	27592
61.7	3950	3949	28030	28006	27987
61.8	3995	3997	28420	28403	28386
61.9	4040	4045	28810	28805	28791
62	4080	4094	29200	29211	29200
62.1	4135	4145	29630	29622	29614
62.2	4190	4196	30060	30038	30033
62.3	4250	4249	30490	30460	30457
62.4	4305	4302	30920	30888	30886
62.5	4360	4357	31350	31321	31320
62.6	4420	4414	31780	31760	31760
62.7	4470	4471	32210	32204	32205

62.8	4530	4530	32640	32654	32655
62.9	4585	4590	33070	33110	33111
63	4640	4652	33500	33571	33572
63.1	4710	4715	34000	34039	34039
63.2	4780	4779	34500	34513	34511
63.3	4885	4845	35000	34997	34990
63.4	4925	4913	35500	35487	35473
63.5	4995	4982	36000	35983	35963
63.6	5065	5053	36500	36486	36459
63.7	5135	5125	37000	36996	36961
63.8	5210	5200	37500	37513	37469
63.9	5280	5276	38000	38038	37983
64	5350	5354	38500	38569	38503

L. Gentry

Stage ft msl	Area (measured)	Area (from Polynomial)	Volume (measured)	Volume (from Area)	Volume (from Polynomial)
57	1440	1447	9600	9600	9690
57.1	1450	1452	9750	9744	9816
57.2	1460	1458	9900	9890	9946
57.3	1465	1465	10050	10036	10078
57.4	1475	1472	10200	10183	10214
57.5	1480	1479	10350	10331	10353
57.6	1490	1487	10500	10479	10494
57.7	1500	1495	10650	10629	10638
57.8	1510	1504	10800	10779	10784
57.9	1515	1513	10950	10931	10932
58	1525	1521	11100	11083	11082
58.1	1530	1530	11260	11235	11234
58.2	1540	1539	11410	11389	11388
58.3	1545	1548	11560	11543	11543
58.4	1555	1557	11720	11698	11699
58.5	1560	1566	11880	11854	11857
58.6	1570	1574	12030	12010	12016
58.7	1580	1583	12180	12168	12177
58.8	1585	1591	12340	12326	12338
58.9	1590	1600	12500	12485	12500
59	1600	1608	12650	12644	12662
59.1	1610	1616	12820	12805	12826
59.2	1615	1623	12980	12966	12990
59.3	1625	1631	13140	13128	13155
59.4	1630	1638	13310	13291	13320
59.5	1640	1645	13480	13454	13486
59.6	1650	1652	13640	13619	13652
59.7	1655	1658	13800	13784	13819
59.8	1665	1665	13970	13950	13986
59.9	1670	1671	14140	14117	14154
60	1680	1677	14300	14284	14322
60.1	1690	1683	14480	14453	14490

60.2	1695	1689	14650	14622	14658
60.3	1700	1695	14820	14792	14827
60.4	1710	1701	15000	14962	14996
60.5	1715	1706	15180	15134	15166
60.6	1720	1712	15350	15305	15336
60.7	1730	1718	15520	15478	15507
60.8	1735	1724	15700	15651	15678
60.9	1740	1731	15880	15825	15849
61	1750	1737	16050	15999	16021
61.1	1755	1744	16220	16175	16194
61.2	1760	1751	16400	16350	16368
61.3	1765	1759	16580	16527	16542
61.4	1770	1767	16750	16703	16717
61.5	1775	1776	16920	16881	16893
61.6	1780	1786	17100	17058	17071
61.7	1785	1796	17280	17237	17249
61.8	1790	1807	17450	17415	17429
61.9	1795	1819	17620	17595	17610
62	1800	1832	17800	17774	17793
62.1	1825	1847	17990	17956	17978
62.2	1850	1862	18180	18139	18164
62.3	1875	1879	18370	18326	18352
62.4	1900	1897	18560	18514	18543
62.5	1925	1917	18750	18706	18736
62.6	1950	1939	18940	18899	18931
62.7	1975	1962	19130	19096	19129
62.8	2000	1988	19320	19294	19329
62.9	2025	2015	19510	19496	19533
63	2050	2045	19700	19699	19740
63.1	2090	2076	19930	19906	19950
63.2	2130	2111	20160	20117	20164
63.3	2170	2148	20390	20332	20382
63.4	2210	2188	20620	20551	20603
63.5	2250	2230	20850	20774	20830
63.6	2290	2276	21080	21001	21060
63.7	2330	2325	21310	21232	21296
63.8	2370	2377	21540	21467	21536
63.9	2410	2433	21770	21706	21782
64	2450	2493	22000	21949	22033
64.1	2540	2556	22290	22199	22290
64.2	2625	2624	22580	22457	22553
64.3	2710	2696	22870	22724	22823
64.4	2800	2772	23160	22999	23099
64.5	2880	2853	23450	23283	23383
64.6	2975	2938	23740	23576	23673
64.7	3060	3029	24030	23878	23972
64.8	3150	3125	24320	24188	24278
64.9	3240	3226	24610	24508	24592
65	3325	3333	24900	24836	24915

L. East Tohopekaliga

Stage ft msl	Area (measured)	Area (from Polynomial)	Volume (measured)	Volume (from Area)	Volume (from Polynomial)
52.0	9,300	9,226	59,500	59,500	58,242
52.1	9,370	9,302	60,450	60,433	59,113
52.2	9,440	9,377	61,400	61,374	59,998
52.3	9,510	9,450	62,350	62,321	60,896
52.4	9,580	9,522	63,300	63,276	61,807
52.5	9,650	9,592	64,250	64,237	62,730
52.6	9,720	9,661	65,200	65,206	63,666
52.7	9,790	9,728	66,150	66,181	64,614
52.8	9,860	9,794	67,100	67,164	65,573
52.9	9,930	9,859	68,050	68,153	66,544
53.0	10,000	9,923	69,000	69,150	67,526
53.1	10,060	9,986	70,000	70,153	68,518
53.2	10,120	10,047	71,000	71,162	69,521
53.3	10,180	10,108	72,000	72,177	70,535
53.4	10,240	10,167	73,000	73,198	71,558
53.5	10,300	10,226	74,000	74,225	72,590
53.6	10,360	10,284	75,000	75,258	73,632
53.7	10,420	10,341	76,000	76,297	74,683
53.8	10,480	10,397	77,000	77,342	75,743
53.9	10,540	10,453	78,000	78,393	76,811
54.0	10,600	10,508	79,000	79,450	77,888
54.1	10,660	10,562	80,150	80,513	78,973
54.2	10,720	10,616	81,300	81,582	80,065
54.3	10,780	10,669	82,450	82,657	81,166
54.4	10,840	10,722	83,600	83,738	82,274
54.5	10,900	10,775	84,750	84,825	83,389
54.6	10,960	10,827	85,900	85,918	84,511
54.7	11,020	10,879	87,050	87,017	85,640
54.8	11,080	10,930	88,200	88,122	86,775
54.9	11,140	10,981	89,350	89,233	87,918
55.0	11,200	11,032	90,500	90,350	89,066
55.1	11,240	11,083	91,600	91,472	90,221
55.2	11,280	11,134	92,700	92,598	91,381
55.3	11,320	11,185	93,800	93,728	92,548
55.4	11,360	11,236	94,900	94,862	93,720
55.5	11,400	11,287	96,000	96,000	94,898
55.6	11,440	11,337	97,100	97,142	96,081
55.7	11,480	11,388	98,200	98,288	97,269
55.8	11,520	11,439	99,300	99,438	98,463
55.9	11,560	11,491	100,400	100,592	99,662
56.0	11,600	11,542	101,500	101,750	100,865
56.1	11,640	11,594	102,650	102,912	102,074
56.2	11,670	11,646	103,800	104,077	103,288
56.3	11,700	11,698	104,950	105,246	104,506
56.4	11,740	11,751	106,100	106,418	105,729
56.5	11,780	11,804	107,250	107,594	106,956
56.6	11,810	11,857	108,400	108,773	108,188

56.7	11,840	11,911	109,550	109,956	109,424
56.8	11,880	11,965	110,700	111,142	110,665
56.9	11,920	12,020	111,850	112,332	111,910
57.0	11,950	12,076	113,000	113,525	113,160
57.1	12,020	12,132	114,280	114,724	114,414
57.2	12,080	12,188	115,560	115,929	115,672
57.3	12,140	12,245	116,840	117,140	116,934
57.4	12,210	12,303	118,120	118,357	118,201
57.5	12,280	12,362	119,400	119,582	119,472
57.6	12,340	12,421	120,680	120,813	120,747
57.7	12,400	12,481	121,960	122,050	122,026
57.8	12,470	12,542	123,240	123,293	123,310
57.9	12,540	12,604	124,520	124,544	124,598
58.0	12,600	12,666	125,800	125,801	125,891
58.1	12,670	12,729	127,070	127,064	127,187
58.2	12,740	12,793	128,340	128,335	128,489
58.3	12,810	12,858	129,610	129,612	129,794
58.4	12,880	12,924	130,880	130,897	131,105
58.5	12,950	12,991	132,150	132,188	132,420
58.6	13,020	13,058	133,420	133,487	133,739
58.7	13,090	13,127	134,690	134,792	135,064
58.8	13,160	13,197	135,960	136,105	136,393
58.9	13,230	13,267	137,230	137,424	137,727
59.0	13,300	13,339	138,500	138,751	139,067
59.1	13,390	13,412	139,900	140,085	140,411
59.2	13,480	13,485	141,300	141,429	141,761
59.3	13,570	13,560	142,700	142,781	143,116
59.4	13,660	13,636	144,100	144,143	144,477
59.5	13,750	13,713	145,500	145,513	145,843
59.6	13,840	13,791	146,900	146,893	147,216
59.7	13,930	13,870	148,300	148,281	148,594
59.8	14,020	13,951	149,700	149,679	149,978
59.9	14,110	14,032	151,100	151,085	151,369
60.0	14,200	14,115	152,500	152,501	152,766

			L. Tohopekaliga		
Stage ft msl	Area (measured)	Area (from Polynomial)	Volume (measured)	Volume (from Area)	Volume (from Polynomial)
49	13500	13609	40500	40500	40019
49.1	13720	13802	41950	41861	41522
49.2	13940	13989	43400	43244	43032
49.3	14160	14171	44850	44649	44549
49.4	14380	14347	46300	46076	46073
49.5	14600	14518	47750	47525	47603
49.6	14780	14684	49200	48994	49141
49.7	14960	14846	50650	50481	50687
49.8	15140	15003	52100	51986	52239
49.9	15370	15157	53550	53511	53800
50	15500	15306	55000	55055	55368
50.1	15620	15452	56600	56611	56944
50.2	15740	15594	58200	58179	58528
50.3	15850	15733	59800	59758	60121
50.4	15980	15869	61400	61350	61722
50.5	16100	16002	63000	62954	63331
50.6	16220	16133	64600	64570	64949
50.7	16340	16261	66200	66198	66576
50.8	16460	16387	67800	67838	68212
50.9	16580	16510	69400	69490	69857
51	16700	16632	71000	71154	71511
51.1	16805	16752	72750	72829	73175
51.2	16910	16870	74500	74515	74848
51.3	17015	16987	76250	76211	76531
51.4	17120	17103	78000	77918	78224
51.5	17225	17217	79750	79635	79927
51.6	17330	17331	81500	81363	81640
51.7	17435	17444	83250	83101	83364
51.8	17540	17556	85000	84850	85097
51.9	17645	17668	86750	86609	86842
52	17750	17780	88500	88379	88597
52.1	17855	17891	90350	90159	90363
52.2	17960	18002	92200	91950	92140
52.3	18065	18113	94050	93751	93929
52.4	18170	18224	95900	95563	95728
52.5	18275	18336	97750	97385	97540
52.6	18380	18448	99600	99218	99362
52.7	18445	18561	101450	101059	101197
52.8	18590	18674	103300	102911	103044
52.9	18695	18788	105150	104775	104902
53	18800	18902	107000	106650	106773
53.1	18940	19018	108950	108537	108657
53.2	19080	19135	110900	110438	110553
53.3	19220	19253	112850	112353	112461
53.4	19360	19371	114800	114282	114382
53.5	19500	19492	116750	116225	116317

53.6	19640	19613	118700	118182	118264
53.7	19750	19736	120650	120151	120225
53.8	19920	19861	122600	122135	122199
53.9	20060	19987	124550	124134	124187
54	20200	20114	126500	126147	126189
54.1	20330	20243	128550	128173	128204
54.2	20460	20374	130600	130213	130233
54.3	20590	20507	132650	132265	132277
54.4	20720	20641	134700	134331	134335
54.5	20850	20778	136750	136409	136407
54.6	20980	20916	138800	138501	138494
54.7	21110	21056	140850	140605	140596
54.8	21240	21198	142900	142723	142713
54.9	21370	21342	144950	144853	144844
55	21500	21488	147000	146997	146991
55.1	21675	21636	149200	149155	149153
55.2	21850	21786	151400	151332	151331
55.3	22025	21938	153600	153525	153525
55.4	22200	22092	155800	155737	155734
55.5	22375	22248	158000	157965	157959
55.6	22550	22406	160200	160212	160200
55.7	22725	22566	162400	162475	162458
55.8	22900	22728	164600	164757	164732
55.9	23075	22892	166800	167055	167022
56	23250	23058	169000	169372	169329
56.1	23405	23226	171400	171704	171653
56.2	23560	23395	173800	174053	173994
56.3	23715	23567	176200	176416	176352
56.4	23870	23741	178600	178796	178728
56.5	24025	23916	181000	181190	181121
56.6	24180	24093	183400	183601	183531
56.7	24335	24272	185800	186026	185959
56.8	24490	24452	188200	188468	188405
56.9	24645	24634	190600	190924	190869
57	24800	24817	193000	193397	193351
57.1	24990	25002	195600	195886	195852
57.2	25180	25189	198200	198395	198371
57.3	25370	25376	200800	200922	200909
57.4	25560	25565	203400	203469	203465
57.5	25750	25755	206000	206034	206040
57.6	25940	25947	208600	208619	208635
57.7	26130	26139	211200	211222	211248
57.8	26320	26332	213800	213845	213881
57.9	26510	26526	216400	216486	216534
58	26700	26720	219000	219147	219206
58.1	26900	26916	221800	221827	221898
58.2	27100	27111	224600	224527	224609
58.3	27300	27308	227400	227247	227341
58.4	27500	27504	230200	229987	230094
58.5	27700	27701	233000	232747	232866
58.6	27900	27897	235800	235527	235659

58.7	28100	28094	238600	238327	238473
58.8	28300	28290	241400	241147	241308
58.9	28500	28486	244200	243987	244164
59	28700	28681	247000	246846	247041
59.1	28890	28876	250000	249726	249939
59.2	29100	29070	253000	252625	252858
59.3	29290	29263	256000	255545	255799
59.4	29490	29455	259000	258484	258762
59.5	29690	29645	262000	261443	261747
59.6	29880	29834	265000	264421	264754
59.7	30080	30022	268000	267419	267783
59.8	30280	30208	271000	270437	270834
59.9	30480	30392	274000	273475	273908
60	30675	30573	277000	276533	277004

L. Cypress

Stage ft msl	Area (measured)	Area (from Polynomial)	Volume (measured)	Volume (from Area)	Volume (from Polynomial)
43	830	897	465	465	477
44	1465	1526	1613	1598	1696
45	2010	2064	3351	3328	3498
45.1	2057	2113	3576	3531	3707
45.2	2104	2161	3800	3739	3921
45.3	2151	2209	4025	3952	4139
45.4	2198	2256	4249	4169	4363
45.5	2245	2302	4474	4392	4591
45.6	2292	2347	4698	4618	4823
45.7	2339	2392	4923	4850	5060
45.8	2386	2436	5147	5086	5301
45.9	2433	2479	5372	5327	5547
46	2480	2522	5596	5573	5797
46.1	2516	2563	5862	5823	6051
46.2	2552	2604	6128	6076	6310
46.3	2588	2645	6394	6333	6572
46.4	2624	2685	6660	6594	6839
46.5	2660	2724	6926	6858	7109
46.6	2696	2762	7192	7126	7383
46.7	2732	2800	7458	7397	7662
46.8	2768	2837	7724	7672	7943
46.9	2804	2874	7990	7951	8229
47	2840	2909	8256	8233	8518
47.1	2863	2945	8551	8518	8811
47.2	2885	2980	8847	8805	9107
47.3	2908	3014	9142	9095	9407
47.4	2930	3047	9437	9387	9710
47.5	2953	3080	9733	9681	10016
47.6	2975	3113	10028	9977	10326
47.7	2998	3145	10323	10276	10639
47.8	3020	3176	10618	10577	10955

47.9	3043	3207	10914	10880	11274
48	3065	3238	11209	11185	11596
48.1	3099	3268	11532	11494	11922
48.2	3132	3297	11855	11805	12250
48.3	3166	3326	12178	12120	12581
48.4	3199	3355	12501	12438	12915
48.5	3233	3383	12825	12760	13252
48.6	3266	3411	13148	13085	13592
48.7	3300	3438	13471	13413	13934
48.8	3333	3465	13794	13745	14279
48.9	3367	3491	14117	14079	14627
49	3400	3517	14440	14418	14977
49.1	3429	3543	14795	14759	15330
49.2	3458	3568	15149	15104	15686
49.3	3487	3593	15504	15451	16044
49.4	3516	3617	15858	15801	16405
49.5	3545	3642	16213	16154	16768
49.6	3574	3665	16567	16510	17133
49.7	3603	3689	16922	16869	17501
49.8	3632	3712	17276	17231	17871
49.9	3661	3735	17631	17595	18243
50	3690	3758	17985	17963	18618
50.1	3722	3780	18365	18333	18994
50.2	3754	3802	18744	18707	19374
50.3	3786	3824	19124	19084	19755
50.4	3818	3845	19503	19464	20138
50.5	3851	3866	19883	19848	20524
50.6	3883	3887	20262	20235	20912
50.7	3915	3908	20642	20624	21301
50.8	3947	3929	21021	21018	21693
50.9	3979	3949	21401	21414	22087
51	4011	3970	21780	21813	22483
51.1	4077	3990	22109	22218	22881
51.2	4143	4009	22540	22629	23281
51.3	4209	4029	22971	23046	23683
51.4	4274	4049	23403	23470	24087
51.5	4340	4068	23834	23901	24493
51.6	4406	4087	24265	24338	24900
51.7	4472	4106	24696	24782	25310
51.8	4538	4126	25128	25233	25722
51.9	4604	4145	25559	25690	26135
52	4670	4163	25990	26154	26551
52.1	4800	4182	26464	26627	26968
52.2	4931	4201	26950	27114	27387
52.3	5062	4220	27450	27613	27808
52.4	5193	4238	27962	28126	28231
52.5	5324	4257	28488	28652	28656
52.6	5449	4275	29027	29190	29082
52.7	5574	4294	29578	29742	29511
52.8	5698	4312	30142	30305	29941
52.9	5823	4331	30718	30881	30373

53	5948	4349	31306	31470	30807
53.1	6073	4368	31907	32071	31243
53.2	6198	4387	32521	32684	31681
53.3	6322	4405	33147	33310	32120
53.4	6447	4424	33785	33949	32562
53.5	6572	4443	34436	34600	33005
53.6	6697	4462	35100	35263	33450
53.7	6822	4481	35775	35939	33898
53.8	6946	4500	36464	36627	34347
53.9	7071	4519	37165	37328	34798
54	7196	4538	37878	38042	35250
54.1	7695	4558	38622	38786	35705
54.2	8194	4577	39417	39580	36162
54.3	8692	4597	40261	40424	36621
54.4	9191	4617	41155	41318	37081
54.5	9690	4637	42099	42262	37544
54.6	10189	4657	43093	43256	38009
54.7	10688	4677	44136	44300	38475
54.8	11186	4698	45230	45394	38944
54.9	11685	4719	46374	46537	39415
55	12184	4740	47567	47730	39888
55.1	13225	4761	48837	49001	40363
55.2	14267	4783	50211	50375	40840
55.3	15308	4804	51690	51853	41320
55.4	16350	4827	53272	53436	41801
55.5	17392	4849	54959	55123	42285
55.6	18433	4871	56750	56914	42771
55.7	19475	4894	58645	58809	43259
55.8	20516	4918	60645	60808	43750
55.9	21558	4941	62748	62912	44243
56	22600	4965	64956	65119	44738

L. Hatchineha

Stage ft msl	Area (measured)	Area (from Polynomial)	Volume (measured)	Volume (from Area)	Volume (from Polynomial)
45	3450	1302	8242	8242	13491
45.1	3526	1415	8625	8591	13627
45.2	3601	1529	9008	8947	13774
45.3	3677	1643	9390	9311	13932
45.4	3752	1757	9773	9682	14102
45.5	3828	1873	10156	10061	14284
45.6	3903	1989	10539	10448	14477
45.7	3979	2105	10922	10842	14682
45.8	4054	2222	11304	11244	14898
45.9	4130	2340	11687	11653	15126
46	4205	2458	12070	12069	15366
46.1	4278	2576	12527	12494	15618
46.2	4351	2694	12984	12925	15881
46.3	4424	2813	13441	13364	16156

46.4	4497	2933	13898	13810	16444
46.5	4570	3052	14355	14263	16743
46.6	4643	3172	14812	14724	17054
46.7	4716	3291	15269	15192	17377
46.8	4789	3411	15726	15667	17712
46.9	4862	3531	16183	16150	18060
47	4935	3652	16640	16639	18419
47.1	4997	3772	17165	17136	18790
47.2	5059	3892	17689	17639	19173
47.3	5121	4012	18214	18148	19568
47.4	5183	4132	18738	18663	19976
47.5	5245	4252	19263	19184	20395
47.6	5307	4372	19787	19712	20826
47.7	5369	4491	20312	20246	21269
47.8	5431	4610	20836	20786	21724
47.9	5493	4729	21361	21332	22191
48	5555	4848	21885	21884	22670
48.1	5604	4967	22465	22442	23161
48.2	5653	5085	23045	23005	23663
48.3	5702	5202	23625	23573	24178
48.4	5751	5319	24205	24146	24704
48.5	5800	5436	24785	24723	25241
48.6	5849	5552	25365	25306	25791
48.7	5898	5668	25945	25893	26352
48.8	5947	5783	26525	26485	26924
48.9	5996	5897	27105	27082	27508
49	6045	6011	27685	27684	28104
49.1	6077	6124	28306	28290	28710
49.2	6109	6236	28926	28900	29328
49.3	6141	6348	29547	29512	29958
49.4	6173	6458	30167	30128	30598
49.5	6205	6568	30788	30747	31249
49.6	6237	6677	31408	31369	31912
49.7	6269	6785	32029	31994	32585
49.8	6301	6892	32649	32623	33269
49.9	6333	6998	33270	33254	33963
50	6365	7103	33890	33889	34668
50.1	6431	7207	34676	34529	35384
50.2	6497	7310	35463	35176	36110
50.3	6563	7412	36249	35829	36846
50.4	6629	7513	37036	36488	37592
50.5	6696	7612	37822	37154	38348
50.6	6762	7710	38608	37827	39114
50.7	6828	7807	39395	38507	39890
50.8	6894	7902	40181	39193	40676
50.9	6960	7997	40968	39886	41471
51	7026	8089	41754	40585	42275
51.1	7142	8181	42374	41293	43088
51.2	7258	8271	43134	42013	43911
51.3	7374	8359	43894	42745	44742
51.4	7490	8446	44654	43488	45583

51.5	7606	8531	45414	44243	46432
51.6	7723	8615	46174	45009	47289
51.7	7839	8697	46934	45787	48154
51.8	7955	8777	47694	46577	49028
51.9	8071	8856	48455	47378	49910
52	8187	8933	49215	48191	50799
52.1	9264	9008	49796	49063	51696
52.2	10342	9081	50776	50043	52601
52.3	11420	9152	51864	51131	53512
52.4	12497	9222	53059	52326	54431
52.5	13575	9289	54362	53629	55357
52.6	13896	9355	55736	55003	56289
52.7	14218	9419	57142	56409	57228
52.8	14539	9480	58580	57846	58173
52.9	14860	9540	60049	59316	59124
53	15182	9597	61552	60818	60080
53.1	15503	9652	63086	62353	61043
53.2	15824	9705	64652	63919	62011
53.3	16146	9756	66251	65517	62984
53.4	16467	9804	67881	67148	63962
53.5	16788	9850	69544	68811	64945
53.6	17110	9894	71239	70506	65932
53.7	17431	9936	72966	72233	66923
53.8	17752	9975	74725	73992	67919
53.9	18074	10012	76516	75783	68918
54	18395	10046	78340	77606	69921
54.1	18453	10077	80182	79449	70927
54.2	18511	10106	82030	81297	71937
54.3	18569	10133	83884	83151	72949
54.4	18627	10157	85744	85011	73963
54.5	18686	10178	87610	86877	74980
54.6	18744	10197	89481	88748	75999
54.7	18802	10212	91358	90625	77019
54.8	18860	10225	93241	92508	78041
54.9	18918	10236	95130	94397	79064
55	18976	10243	97025	96292	80088
55.1	19339	10247	98941	98208	81113
55.2	19701	10249	100893	100160	82137
55.3	20064	10248	102881	102148	83162
55.4	20426	10243	104905	104172	84187
55.5	20788	10236	106966	106233	85211
55.6	21151	10225	109063	108330	86234
55.7	21513	10212	111196	110463	87256
55.8	21876	10195	113366	112633	88276
55.9	22238	10175	115571	114838	89295
56	22600	10152	117813	117080	90311

			L. Kissimmee		
Stage	**Area**	**Area**	**Volume**	**Volume**	**Volume**

ft msl	**(measured)**	**(from Polynomial)**	**(measured)**	**(from Area)**	**(from Polynomial)**
42	14245	10288	44185	44185	52464
43	17500	16574	58500	60030	66045
44	21000	21230	79430	79253	85069
45	24300	24592	102000	101883	108074
45.1	24600	24870	104573	104328	110547
45.2	24899	25139	107145	106803	113047
45.3	25199	25399	109718	109308	115574
45.4	25498	25650	112290	111843	118127
45.5	25798	25893	114863	114407	120704
45.6	26097	26129	117435	117002	123305
45.7	26397	26356	120008	119627	125930
45.8	26696	26577	122580	122281	128576
45.9	26996	26790	125153	124966	131245
46	27295	26997	127725	127680	133934
46.1	27456	27198	130553	130418	136644
46.2	27616	27393	133380	133171	139373
46.3	27777	27582	136208	135941	142122
46.4	27937	27767	139035	138727	144890
46.5	28098	27946	141863	141528	147675
46.6	28258	28121	144690	144346	150479
46.7	28419	28291	147518	147180	153299
46.8	28579	28458	150345	150030	156137
46.9	28740	28622	153173	152896	158991
47	28900	28782	156000	155778	161861
47.1	29038	28939	158930	158675	164747
47.2	29175	29094	161859	161585	167649
47.3	29313	29246	164789	164510	170566
47.4	29450	29397	167718	167448	173498
47.5	29588	29546	170648	170400	176445
47.6	29725	29695	173577	173365	179407
47.7	29863	29842	176507	176345	182384
47.8	30000	29989	179436	179338	185376
47.9	30138	30135	182366	182345	188382
48	30275	30282	185295	185365	191403
48.1	30388	30430	188366	188398	194438
48.2	30500	30578	191436	191443	197489
48.3	30613	30727	194507	194498	200554
48.4	30725	30878	197577	197565	203634
48.5	30838	31031	200648	200643	206730
48.6	30950	31186	203718	203733	209840
48.7	31063	31344	206789	206833	212967
48.8	31175	31504	209859	209945	216109
48.9	31288	31668	212930	213068	219268
49	31400	31835	216000	216203	222443
49.1	31535	32006	219232	219349	225635
49.2	31669	32182	222463	222510	228844
49.3	31804	32362	225695	225683	232072
49.4	31939	32546	228927	228871	235317
49.5	32074	32737	232159	232071	238581
49.6	32208	32932	235390	235285	241864

49.7	32343	33134	238622	238513	245168
49.8	32478	33342	241854	241754	248491
49.9	32612	33556	245085	245008	251836
50	32747	33777	248317	248276	255203
50.1	33072	34006	251585	251567	258592
50.2	33398	34242	254854	254891	262004
50.3	33723	34486	258122	258247	265441
50.4	34048	34738	261390	261635	268902
50.5	34374	34999	264659	265056	272388
50.6	34699	35269	267927	268510	275902
50.7	35024	35548	271195	271996	279443
50.8	35349	35837	274463	275515	283012
50.9	35675	36136	277732	279066	286610
51	36000	36445	281000	282650	290239
51.1	36591	36765	285183	286279	293900
51.2	37182	37095	289054	289968	297593
51.3	37773	37437	292924	293715	301319
51.4	38365	37791	296794	297522	305081
51.5	38956	38156	300665	301388	308878
51.6	39547	38534	304535	305313	312712
51.7	40138	38925	308406	309298	316585
51.8	40729	39328	312276	313341	320498
51.9	41320	39745	316147	317443	324451
52	41911	40175	320017	321605	328447
52.1	45548	40619	345147	325977	332487
52.2	45602	41078	349705	330534	336571
52.3	45656	41552	354268	335097	340703
52.4	45710	42040	358836	339665	344882
52.5	45765	42544	363410	344239	349111
52.6	46234	43063	368010	348839	353391
52.7	46704	43598	372657	353486	357724
52.8	47173	44150	377350	358180	362112
52.9	47642	44719	382091	362920	366555
53	48111	45304	386879	367708	371056
53.1	48581	45907	391713	372543	375616
53.2	49050	46527	396595	377424	380238
53.3	49519	47166	401523	382353	384922
53.4	49988	47823	406499	387328	389672
53.5	50458	48498	411521	392350	394487
53.6	50927	49193	416590	397419	399372
53.7	51396	49907	421706	402536	404327
53.8	51865	50640	426869	407699	409354
53.9	52335	51394	432079	412909	414455
54	52804	52168	437336	418165	419633
54.1	54251	52963	442689	423518	424890
54.2	55699	53779	448186	429015	430227
54.3	57147	54616	453828	434658	435646
54.4	58594	55475	459615	440444	441151
54.5	60042	56356	465547	446376	446742
54.6	61489	57260	471623	452453	452423
54.7	62937	58186	477845	458674	458195

54.8	64385	59135	484211	465040	464060
54.9	65832	60108	490721	471550	470022
55	67280	61104	497377	478206	476083
55.1	68517	62125	504166	484996	482244
55.2	69754	63170	511080	491909	488509
55.3	70991	64240	518117	498946	494879
55.4	72228	65334	525278	506107	501357
55.5	73465	66455	532562	513392	507947
55.6	74702	67601	539971	520800	514649
55.7	75939	68773	547503	528332	521468
55.8	77176	69971	555158	535988	528405
55.9	78413	71197	562938	543767	535463
56	79650	72449	570841	551670	542645