PANAMA CANAL RESERVOIR SYSTEM
(HEC-5 Model for the Existing System)

Introduction

The Hydrologic Engineering Center (HEC) has developed an HEC-5 reservoir system model for the Panama Canal Commission (PCC). The work was performed in support of the Canal Capacity Study, under a PCC Work Order No. GS-13. The Existing System Model (Base Model) will be used to evaluate the capability of the present PCC system and to evaluate the effectiveness of proposed alternatives to improve the system capability and reliability.

The *HEC-5, Simulation of Flood Control and Water Conservation Systems* computer program performs a sequential simulation of reservoir operations given a time-series of flow. The reservoirs are defined by their storage and outflow capability. Also, the reservoir storage is allocated to operational zones (Levels) that define their usage. In the simplest form, the flood control zone is only used to store excess inflow, the conservation zone is used to store water to meet future demands, and the inactive zone (dead storage) is where no releases can be made. Water demands include minimum flow goals, diversions, and hydroelectric power generation. Reservoirs are linked to other reservoirs and control points (non-reservoir locations) using routing reaches. A combination of reservoirs, control points and connecting routing reaches then define a reservoir system model. The program capabilities and input requirements are defined in the HEC-5 User's Manual (HEC, 1998).

HEC-5 is a generalized program operational on PC-DOS and Unix computers. The data defining the reservoir system, operational goals, and flow are assembled in an input data file. The file is processed by the program to determine the reservoir releases and resulting flow and storage throughout the system. The results are written to an ASCII output file and HEC-DSS random-access file based on input specifications. Data written to a DSS file can be tabulated, graphically displayed, and processed using utility programs to develop summary statistics or to perform data manipulations. The HEC-DSS package of programs are documented in the *HEC-DSS User's Guide and Utility Manuals* (HEC, 1995).

The HEC-5 Base Model for the existing PCC system is described in this report. A diagram of the model is shown in Figure 1. The initial model included Madden and Gatun Reservoirs, diversions from both reservoirs for municipal and industrial (M&I) water supply, and separate diversions for lockage at Gatun and Pedro Miguel. The model was simplified to combine the flow for locks and municipal water supply as one diversion from Gatun. The single diversion applied to Gatun allows the program to short the diversion when the specified minimum pool elevation at Gatun is reached. Outflow from Gatun is linked to the Caribbean Sea. A model overview, data sources and simulation results are presented in the following sections.

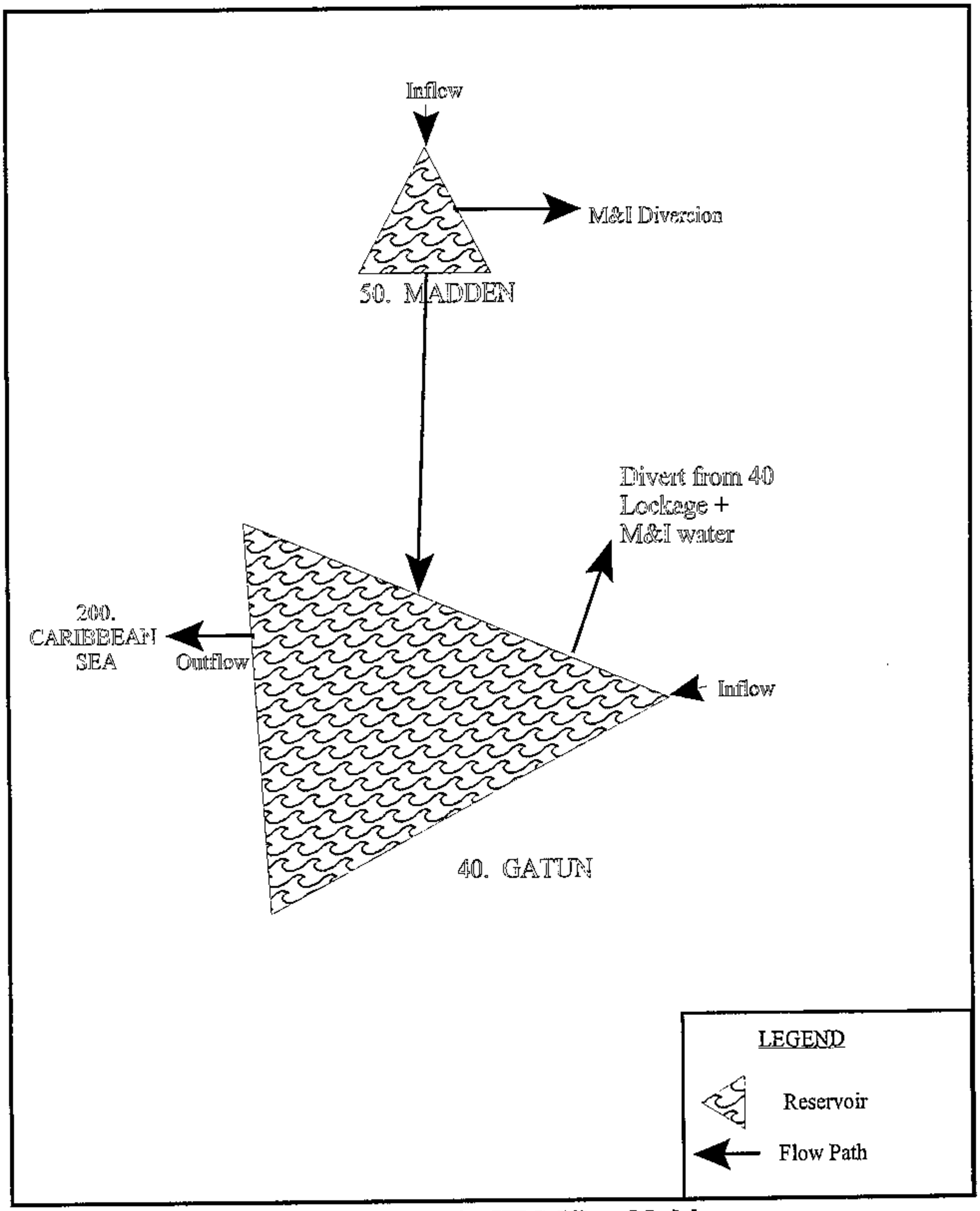

Figure 1. PCC Existing System Diagram for HEC-5 Base Model

Base Model Data

The Base Model represents the existing Panama Canal water supply system. Madden and Gatun Reservoirs are the primary elements of the system. HEC-5 can only process one diversion from each reservoir. The municipal water supply and the lockage for Gatun and Pedro Miguel were combined into one diversion from Gatun. The initial use of "dummy"[1] reservoirs to handle the water use in separate accounts was abandoned to simplify the model and to better control the minimum pool elevation at Gatun. The multiple diversions through dummy reservoirs did not allow the program to maintain a control of a minimum pool elevation at Gatun. The diversions from the "dummy" reservoirs continue to draw water from Gatun below Level 1.

All data are in foot-pound units (US Customary). The simulation time-interval is one month. However, this model could operate at time steps as small as one-hour. Given the monthly time-step, the seasonally varying data are all defined over the 12 months. There is no river-reach routing data required for the monthly time step.

The average-monthly flow data are input to Madden and Gatun. The inflow is assigned as incremental-local flow, which means that the inflow to Gatun only represents the catchment not controlled by Madden. The flow data are read from an HEC-DSS file. The appropriate DSS records are assigned by their pathname[2].

Madden Reservoir

The model begins with Madden Reservoir (Location 50) which receives basin inflow, provides M&I water supply, and releases flow to Gatun. Reservoir releases are assumed to pass through the hydroelectric facility and energy generation is computed up to the limits of power capacity. The outflow from Madden is "routed" to Gatun Reservoir. The channel capacity was set to 50,000 cfs based on operation manual information; however, that value should not be a controlling factor in the monthly simulation.

Elevation-Storage. HEC-5 defines the reservoir with a set of storage-based relationships. Reservoir outflow capacity, elevation, and area are defined as a function of storage. The elevation-storage data were taken from the DSS record /PCC/MAD/ELEV-CAPAC///OBS/ and were converted from million cubic feet to acre-feet (43,560 $feet^2$/ acre). The elevation-area data came from the DSS record /PCC/MAD/ELEV-AREA///OBS/ and were converted from square miles to acres (640 $acres/mi^2$). The data between elevation 190 and 270 feet were input on a

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[1] *"Dummy" reservoirs are reservoirs without storage. Without storage, the reservoir does not store water; therefore, total outflow must equal total inflow. Adding dummy reservoirs allows HEC-5 to perform a variety of different modeling options at a single location.*

[2] *Pathname is the label used to identify a record in a DSS file. The pathname is a unique six-part label used to define every record in the file. See Chapter 3 of the DSS Overview for general information on pathnames (HEC, 1995)*

two-foot interval. When comparing evaporation computations at Madden, there were periods when the difference was larger than expected. It was noted that the pool area varied more in the range of 200 to 220 feet; therefore, data were input on one-foot intervals in that range. The data were not defined below elevation 190; so values were estimated by extrapolating the given curves. The lower values were input for elevations: 140, 160, and 180 feet. Also, areas above elevation 264 were not defined; so, they were estimated by extrapolation.

Outflow Capacity. The outflow capacity is a constraint on releases in HEC-5. The program does not simulate gate openings. It only ensures that the release at any time does not exceed the maximum outflow capacity of the reservoir. The outflow capacity was derived by adding the maximum outflow capability for each outlet set from Tables 5-2, 5-3, and 6-2, which defined the capacity at Madden (PCC, 1992).

Reservoir Guide-Curve. The guide curve for the top-of-conservation is defined by the target storage at the end of each month. The reservoir guide curve has changed over the years. Since this analysis is for the existing system, the current guide-curve was used in the model. The data were taken from the spreadsheet file RULECURVES.XLS, Rule Curves for Madden Lake, and the column labeled 1979-1998. The elevation values were used to look up the storage values from the elevation-storage data described above.

Reservoir Evaporation. The evaporation for Madden is the computed reservoir evaporation, in inches, provided by PCC. Each period of evaporation is read from a DSS record /PCC/MAD/EVAP///MON/OBS/.

Hydropower Data. The total installed capacity is 36 mW, based on three 12 mW units. The overload capacity was assumed to be one. The tailwater elevation was set at 89 feet, based on tailwater data from unit testing. This value could be based on release if the data are available. The efficiency was set at 83%, based on turbine testing data and an assumed generator efficiency of 96%. No hydropower requirements were specified. That means the program will not release for hydropower requirements, but will compute energy generated when releases are made for other purposes. A leakage value of 20 cfs was used. The program will pass 20 cfs as a minimum and that flow will not be used for energy computation.

M&I Diversions. The municipal and industrial water supply is diverted from Madden to nowhere (the diverted flow leaves the system). Average monthly values for the 5-year period 1993 to 1997 were used, assuming that the recent average best represents the current demand.

Gatun Reservoir

Gatun (Location 40) is the next location below Madden. The input flow data to Gatun is the uncontrolled flow downstream from Madden. The total inflow is the sum of Madden releases and input flow data. The release from Gatun routes to the Caribbean Sea. As with Madden, the reservoir releases will be used to generate electrical energy. Flow diversion from Gatun includes municipal water supply and combined lockage for Gatun and Pedro Miguel Locks.

Elevation-Storage. HEC-5 defines the reservoir with a set of storage-based relationships. Reservoir outflow capacity, elevation, and area are defined as a function of storage. The elevation-storage data were taken from the DSS record /PCC/GAT/ELEV-CAPAC///OBS/ and were converted from million cubic feet to acre-feet (43,560 $feet^2$/ acre). The elevation-area data came from the DSS record /PCC/GAT/ELEV-AREA///OBS/ and were converted from square miles to acres (640 acres/mi^2). The data between elevation 77 and 90 feet were input on a one-foot interval. The data were not defined below elevation 77 or above 90 feet, so that data was estimated by extrapolating the given curves. The lower values were input for elevations: 40, 50, 60, and 70. Also, data above elevation 90 were entered on five-foot intervals up to 105 feet.

Outflow Capacity. The outflow capacity is a constraint on releases in HEC-5. The program does not simulate gate openings. It only ensures that the release at any time does not exceed the maximum outflow capacity of the reservoir. The outflow capacity was take from the data in STONEYGAT.XLS for all 14 gates open from an elevation of 78 to 92 feet. Outflow capacity for elevations 70 and 77 feet were estimated using the weir equation and a coefficient of 3.0. Outflow for elevations 95, 100 and 105 feet were extrapolated without concern because the model should never reach those elevations. If a flood analysis were to be performed, then these data should be revised to be more realistic.

Reservoir Guide-Curve. The guide curve for the top-of-conservation is defined by the target storage at the end of each month. The reservoir guide curve has changed over the years. Since this analysis is for the existing system, the current guide curve was used in the model. The data were taken from the spreadsheet file RULECURVES.XLS, Rule Curves for Gatun Lake, and the column labeled 1980-1998. The elevation values were used to look up the storage values from the elevation-storage data described above.

Reservoir Evaporation. The evaporation for Gatun is the computed reservoir evaporation, in inches, provided by PCC. Each period of evaporation is read from a DSS record /PCC/GAT/EVAP///MON/OBS/.

Hydropower Data. The total installed capacity is 24 mW, based on three 3 mW and three 5 mW generators. The overload capacity was assumed to be one. The tailwater elevation was set at 9 feet, based on tailwater data from unit testing. This value could be based on release if the data are available. The efficiency was set at 85%, based on turbine testing data and an assumed generator efficiency of 96%. No hydropower requirements were specified. That means the program will not release for hydropower requirements, but will compute energy generated when releases are made for other purposes. A leakage value of 27 cfs was used. The program will pass 27 cfs as a minimum and that flow will not be used for energy computation.

Gatun and Pedro Miguel Locks. The diversions from Gatun include the combined flow for lockage.

M&I Diversions. The diversion from Gatun for municipal and industrial water supplies are included with the flow for locks as the diversion from Gatun. Average monthly values for the 5-year period 1993 to 1997 were used.

Flow Data

The only date-specific change required in the reservoir system data (T1 - ED Records) are the starting storage values for each reservoir. The flow data used in this simulation is the HEC computed flow data (F part = COMP-HEC) merged with the earlier "OBS" data. The flow data report describes the computation process and final results.

The first record for the flow data (BF) defines the number of simulation periods, the starting date for the data, and the time interval in hours. A value of 720 hours is used to indicate monthly data. Following the BF Record, ZR Records are used to read the essential time-series data from an HEC-DSS file. The DSS record is associated with an HEC-5 data record by defining the pathname parts for each DSS record to be read. For the Base Model simulation, that data represents the incremental inflow to Madden and Gatun. An End-of-Job record (EJ) indicates the end of the flow-data set and an End-of-Run record (ER) indicates the end of the model data.

Base Model Validation

To validate the model configuration and data, a simulation was performed with the outflow and the inflow defined. To accomplish this, the initial Base Model was used with the 5-year average monthly diversion data "commented out"[3] and the diversion type changed to indicate that the diversion data are input for each time period (QD Records). The evaporation (EV Records) was assigned to the PCC evaporation data in inches-month. For comparison purposes, the "historic" evaporation in cubic-feet-per-second were input as observed flow data (NQ Records) and the HEC-5 User Table 1 was set up to output the HEC-5 computed evaporation along with the historic values, as well as their difference. This provides a direct comparison of the HEC-5 evaporation with the PCC computed values. The reservoir outflows were set equal to the outflow data in the DSS file by using QA Records.

With all the inflow and outflow defined, the simulation should yield the same results as historically recorded. The simulated pool elevations should be the same as the historic values. A simulation run was made for the period of January 1970 to December 1997. The resulting pool elevation plots are shown in Figure 2 for Madden and Figure 3 for Gatun. For both reservoirs, the validation model elevations are essentially the same as the observed elevations. Therefore, the model configuration is consistently accounting for the water in the system. A review of the evaporation computation indicates the HEC-5 simulation values are generally within two cubic-feet-per-second (CFS) of the values computed from historic pool elevations. Exhibit 1 provides an HEC-5 input data listing and tabulated results for the validation model.

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[3] *HEC-5 supports input data comments identified by 'C ' in columns 1 and 2. Comments are ignored as input data and are only used to annotate the model data. Input data can be made inactive by changing the record identifier to 'C ' (comment out).*

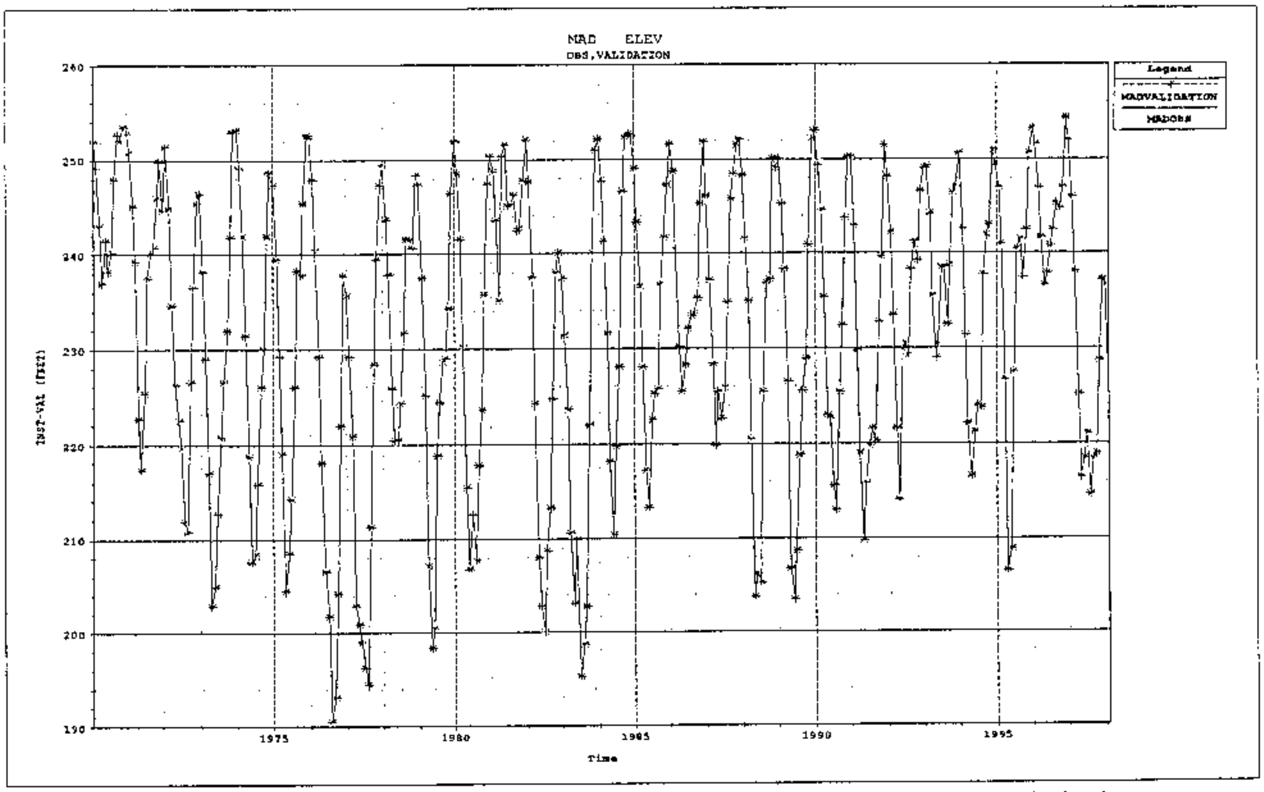

Figure 2. Madden Pool Elevation 1970 - 1997 (Observed and Validation Simulation)

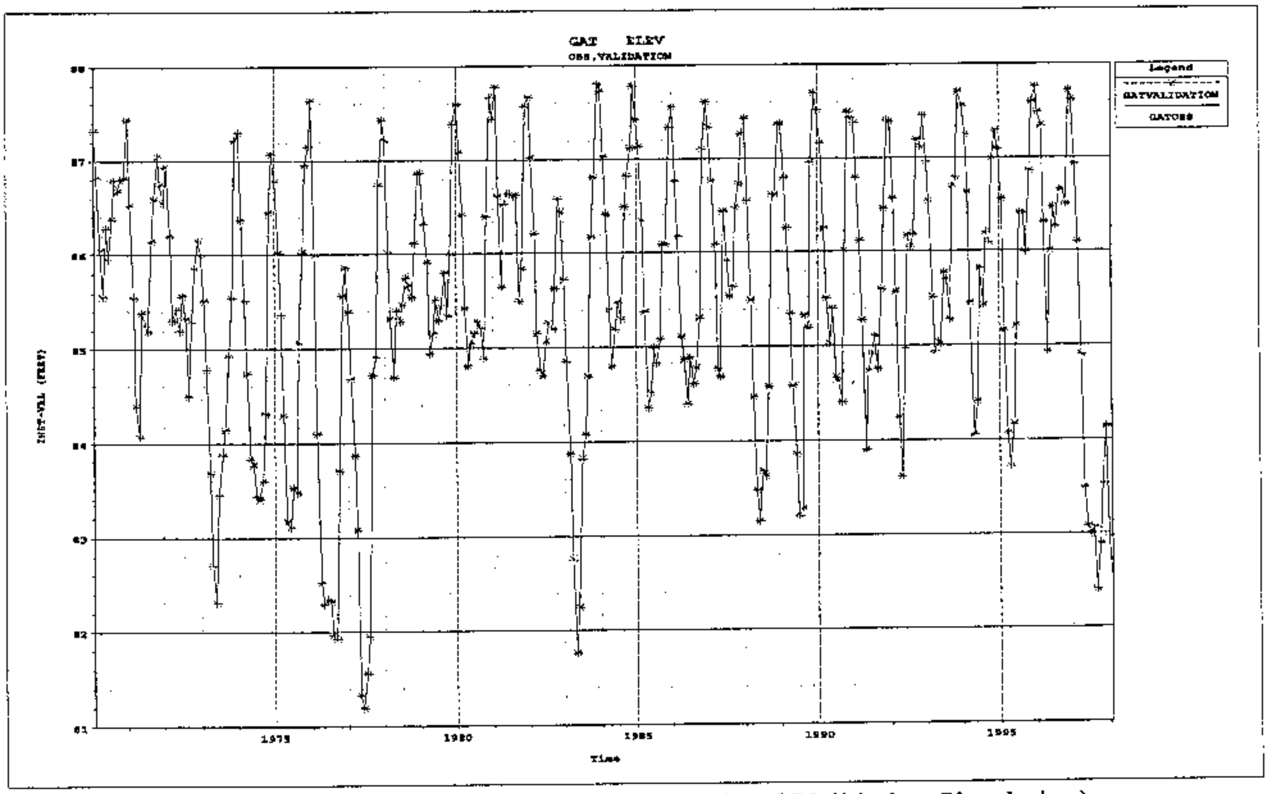

Figure 3. Gatun Pool Elevation 1970 - 1997 (Observed and Validation Simulation)

Base Model Calibration

After the model configuration was tested in the validation phase, the model was modified to remove the references to the specified outflow. The historic evaporation and diversion data were still used. The model was run for the period January 1980 through July 1998 and the program was allowed to make the release determination for each period. The calibration focused on this period because the reservoir guide curves in the model are applicable to that period. The calibration model input data and example output are provided in Exhibit 2. The adjustments made to the data model and a summary of the results follows.

The initial model results looked good, comparing the simulated and historic pool elevations for Madden and Gatun. The simulated results closely followed the input reservoir guide curve. The historic pool elevations deviated from the guide curves more often and Madden historically released more water to Gatun than the simulation. The next phase of model development was calibration to better simulate the existing system's operation.

Reservoir Operational Levels. During the calibration phase, the reservoir physical data (e.g., storage-elevation-outflow relations) generally remain the same. The data-model adjustments take the form of added HEC-5 operational data to cause the program to make decisions that better emulate the actual operation. Three modifications were made to improve the tandem operation between Madden and Gatun Reservoirs.

The first modification was developed to allow both reservoirs to carry water in the flood storage zone while limiting releases to maximum generation capacity. This was achieved by restricting the reservoir's operational channel capacity to the estimated penstock capacity. Penstock capacity was estimated from observations of releases made during 1996. During 1996, PCC provided data shows that storage was retained throughout the year in both reservoirs.

During six months of 1996, historic reservoir spills were made. The second modification was made to better simulate this spill operation. The top-of-flood control guide curve for both reservoirs was revised to follow a monthly variable "Spill Curve" provided by the PCC. The spill curve is input as Level 5 in the model. The reservoir levels are shown in Table 1 for Madden Reservoir and Table 2 for Gatun Reservoir. Figures 4 and 5 provide graphical displays for the two reservoirs.

The top-of-conservation (Level 4) is the PCC operation guide curve, as described under Base Model Data. The simulation will try to keep the reservoir at that level and only deviate when there is too much water to release or when a downstream demand requires a release from conservation storage.

The third modification was developed to enhance tandem operation when storage is in the conservation zone. This was achieved by adding an additional monthly-variable curve between the top-of-conservation level and the buffer storage level. This curve was developed by examining recent operation periods when both reservoirs were drawing down together. The

"Tandem Balancing Operation Curve" is Level 3 in the model.

Reservoir Minimum Outflow. Madden minimum releases went to zero during some months, while the historic operation always released 500 cfs or more. To maintain a release from Madden, the minimum desired flow was set to 500 cfs. This will be the minimum release down to elevation 190.0, the top-of-buffer pool elevation. No minimum release was set at Gatun.

Madden Minimum Elevation for Downstream Operation. Madden Reservoir's minimum elevation for downstream operation is 190.0 feet. Below that elevation, only M&I water demands are to be met. In the HEC-5 model, Madden operates to "balance" with Gatun and the M&I water is modeled as a diversion. The tandem operation is usually carried down to the Level 1, the top-of-inactive storage. To model Madden, a new program feature was used. The priority option (J2 Record, field 4) was set to 132, indicating that tandem operation will stop at the Buffer Level (Code = 128) and the water supply diversion will be made down to Level 1 (Code = 4). When the pool elevation drops to 190 feet (Buffer Level), the program will cease tandem operation, only the 20 cfs leakage should continue. However, the diversions from Madden for M&I water supply will continue until the reservoir drops to the inactive pool elevation of 160 feet.

Reservoir Hydropower Releases. To better simulate the hydropower releases during periods of full reservoir storage, the penstock capacity at Madden was set to 3,624 cfs based on a review of historic hydropower releases. Also, the channel capacity was set to 3,624 cfs to keep the program from "dumping"[4] excess water. At Gatun, the penstock capacity and the channel capacity were set to 4,550 cfs based on historic generation flow rates.

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[4]*When the pool level is above the reservoir guide curve, the program will release excess water subject to the limitations of outlet capacity and the downstream channel capacity. For monthly operations, the release will rarely be limited by the outlet capacity; therefore, the water in excess of the conservation storage will be released (dumped) to keep the reservoir at the top-of-conservation pool. Setting the channel capacity to the maximum generation flow rate will keep the reservoir from releasing more than the energy generation rate as long as there is available flood storage.*

Table 1. Madden Reservoir Guide Curves

Month	Level 1 Elevation	Level 2 Elevation	Level 3 Elevation	Level 4 Elevation	Level 5 Elevation	Level 6 Elevation
January	160.0	190.0	224.0	249.0	255.0	270.0
February	160.0	190.0	204.0	243.0	255.0	270.0
March	160.0	190.0	198.0	233.0	245.0	270.0
April	160.0	190.0	198.0	221.0	245.0	270.0
May	160.0	190.0	198.0	217.0	245.0	270.0
June	160.0	190.0	198.0	215.0	245.0	270.0
July	160.0	190.0	200.0	217.0	245.0	270.0
August	160.0	190.0	210.0	222.0	245.0	270.0
September	160.0	190.0	220.0	228.0	245.0	270.0
October	160.0	190.0	230.0	236.0	248.0	270.0
November	160.0	190.0	240.0	247.0	251.0	270.0
December	160.0	190.0	237.0	252.0	255.0	270.0

Note: Level 2 = Buffer, Level 3 = Balancing, Level 4 = Operational Guide, and Level 5 = Spill

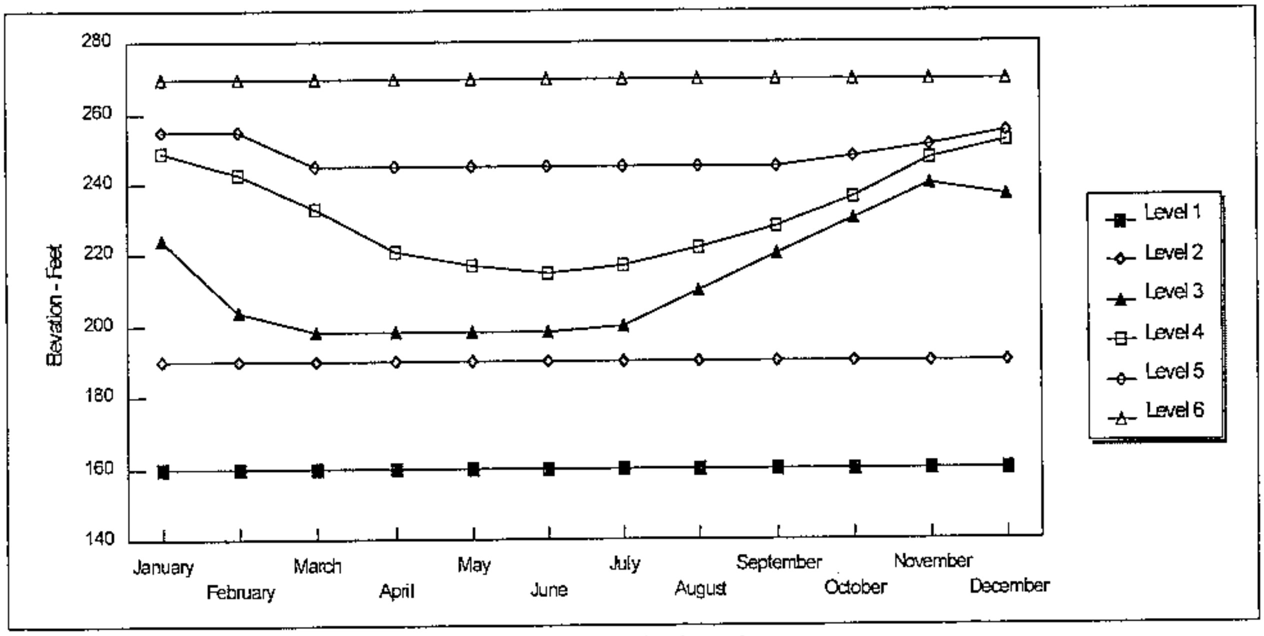

Figure 4. Madden Reservoir Guide Curves for Six Levels

Table 2. Gatun Reservoir Guide Curves

Month	Level 1 Elevation	Level 2 Elevation	Level 3 Elevation	Level 4 Elevation	Level 5 Elevation	Level 6 Elevation
January	70.0	81.5	82.5	87.0	87.75	105.
February	70.0	81.5	82.0	86.3	87.75	105.
March	70.0	81.5	82.0	85.4	87.75	105.
April	70.0	81.5	82.0	84.7	87.75	105.
May	70.0	81.5	82.0	84.7	86.5	105.
June	70.0	81.5	82.0	84.7	86.5	105.
July	70.0	81.5	82.0	84.7	86.5	105.
August	70.0	81.5	82.0	84.7	86.5	105.
September	70.0	81.5	82.0	85.0	86.5	105.
October	70.0	81.5	82.0	85.9	86.8	105.
November	70.0	81.5	83.0	87.3	87.4	105.
December	70.0	81.5	83.0	87.5	87.5	105.

Note: Level 2 = Buffer, Level 3 = Balancing, Level 4 = Operational Guide, and Level 5 = Spill

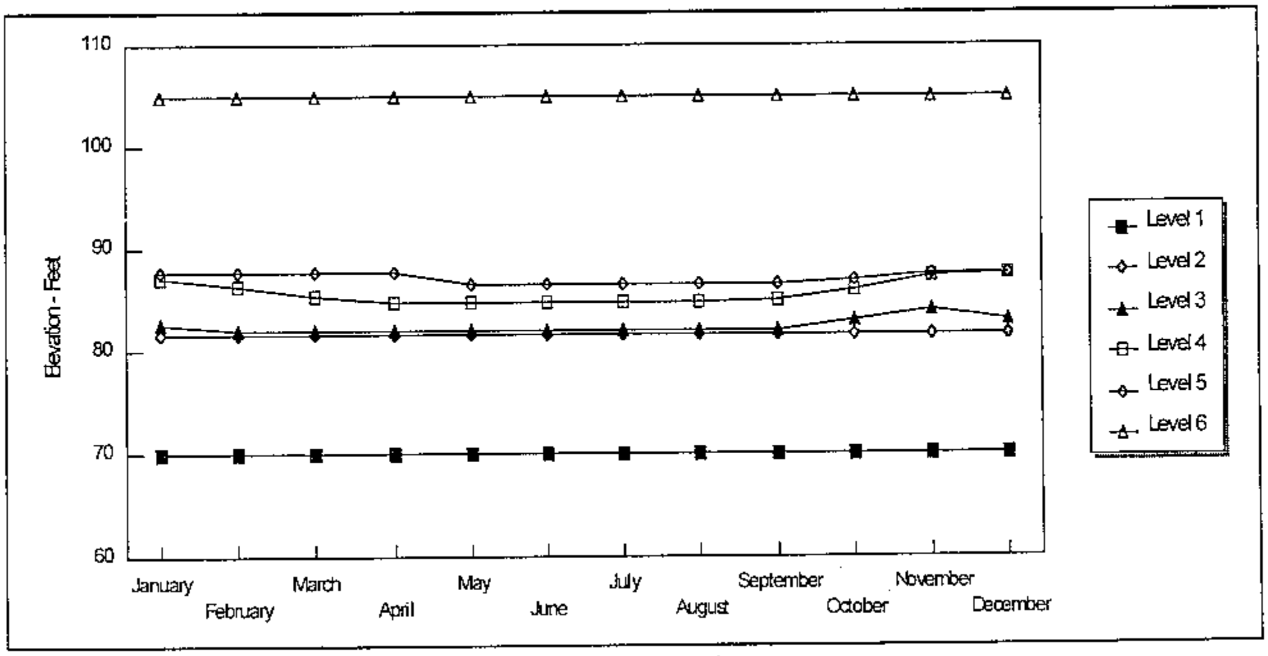

Figure 5. Gatun Reservoir Guide Curves for Six Levels

Base Model Calibration Results

The model calibration focused on the period January 1980 through July 1998 because that was the appropriate period for the "current" operational guide curves. This period will be referred to as the "calibration period." If the reservoirs' operation can be reasonably simulated during this period, it is assumed that the model represents the current operational policy. Once satisfied that this is true, the period of record can be processed. A summary of the results from this calibration simulation is described. Exhibit 2 provides a listing of the input data, graphical displays of pool elevations and reservoir releases, and tables listing simulated and observed data for pool elevations and reservoir releases.

The flow data used in the simulation is the HEC computed average-monthly inflow with correction for evaporation effects. The evaporation in inches, computed by PCC was input as time-series data. The evaporation in cfs computed by HEC-5 was compared to that computed from the observed pool elevations. Generally, the difference was less than two cfs, with most differences less than one cfs.

The demand data were all historic data. The calibration run was repeatedly performed, making the adjustments previously described. Key output data were written to an HEC-DSS file. The primary focus of the output review was the simulated versus observed pool elevations for the two reservoirs. The resulting pool elevations for the calibration period are shown in Figure 6 for Madden Reservoir and Figure 7 for Gatun Reservoir.

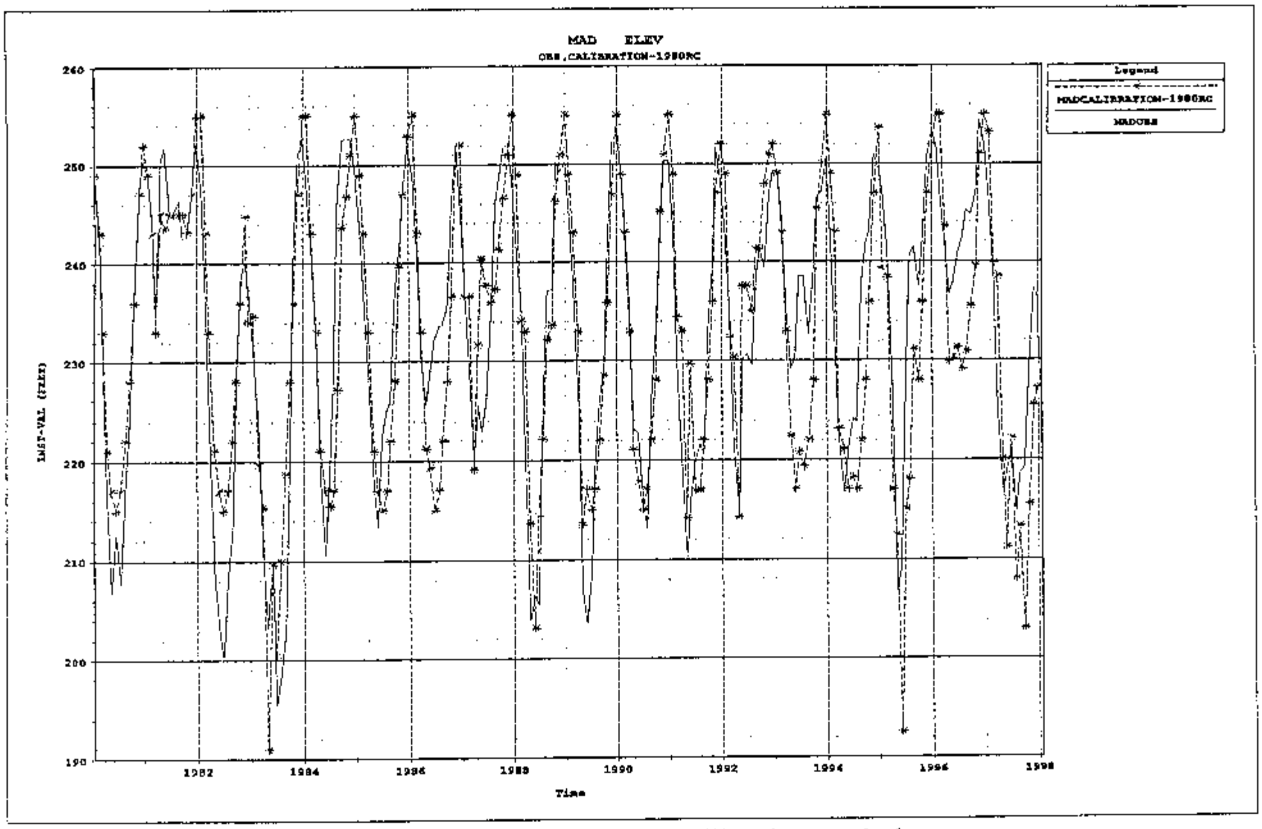

Figure 6. Madden Pool Elevation for 1980 - 1998 Calibration Period

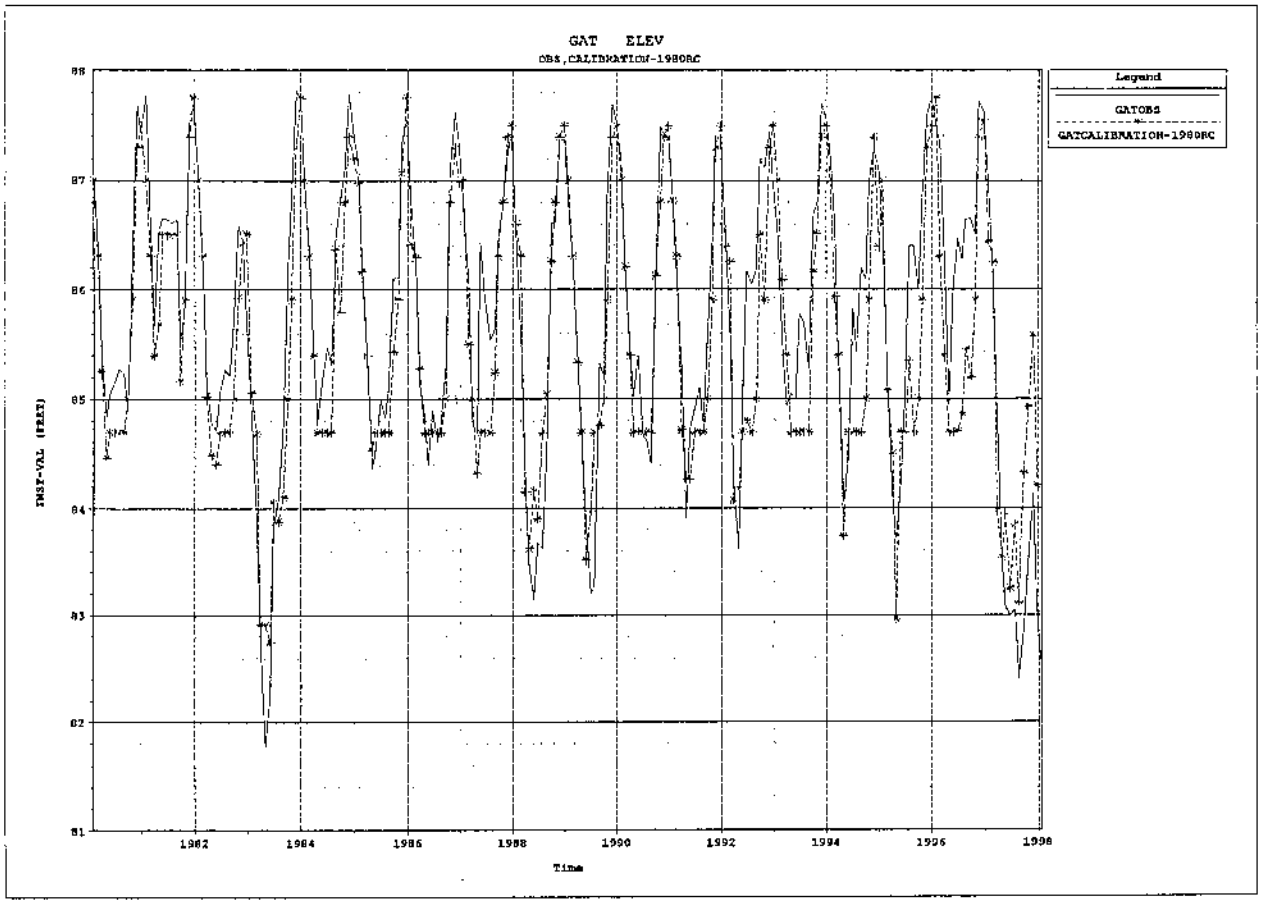

Figure 7. Gatun Pool Elevation for 1980 - 1998 Calibration Period

The simulation at this point appears reasonable. Several factors must be considered when comparing the pool elevations. The first is the human element in historic operation. Guide curves are general goals. The simulation treats them more rigidly and tries to follow the curve, if possible. For example, during actual operations an early release may be made from a reservoir because there is an unusual demand or perceived threat such as a major storm approaching. The monthly simulation cannot know about, or respond to, these unique events.

A second factor is the use of average monthly data. Average data always minimizes the extremes. Maximum and minimum daily flows are averaged with other daily values during the month. The resulting average data is less severe. Also, the simulation evaluation only considers the state of the system once a month. Therefore, an entire month will elapse before the next decision is made. The tandem operation of Madden releasing water to "balance" with Gatun will tend to lag the actual operation, which will tend to move the water between the two sooner.

One factor that will tend to improve the appearance of the computed pool elevations is the fact that a large reservoir's elevation is not as sensitive to small changes in storage. This is particularly true for Lake Gatun. Therefore, there can be larger differences in storage that look like small differences in elevation.

Another method of comparing results from the calibration run is the pool-elevation duration curves for the observed and simulated data. Figures 8 and 9 present the results for the calibration periods for Madden and Gatun Reservoirs, respectively. The analysis shows the percent of time in a year, that a specific pool elevation is exceeded. Data from 1998 is not included because it was less than a full year. From this analysis, one can see that the simulation tended to keep Madden and Gatun near the levels recorded historically.

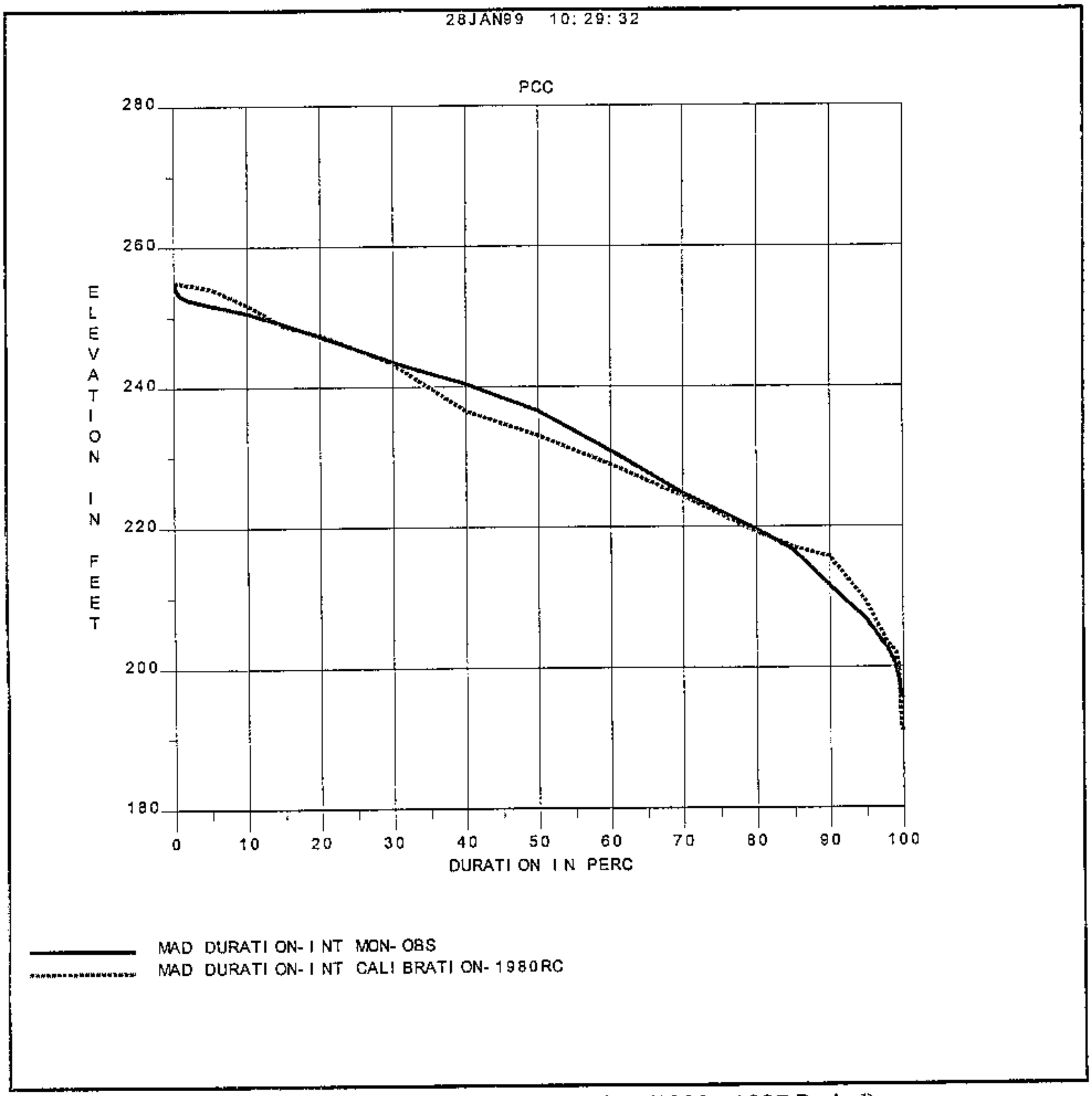

Figure 8. Madden Interpolated Pool Elevation-Duration (1980 - 1997 Period)

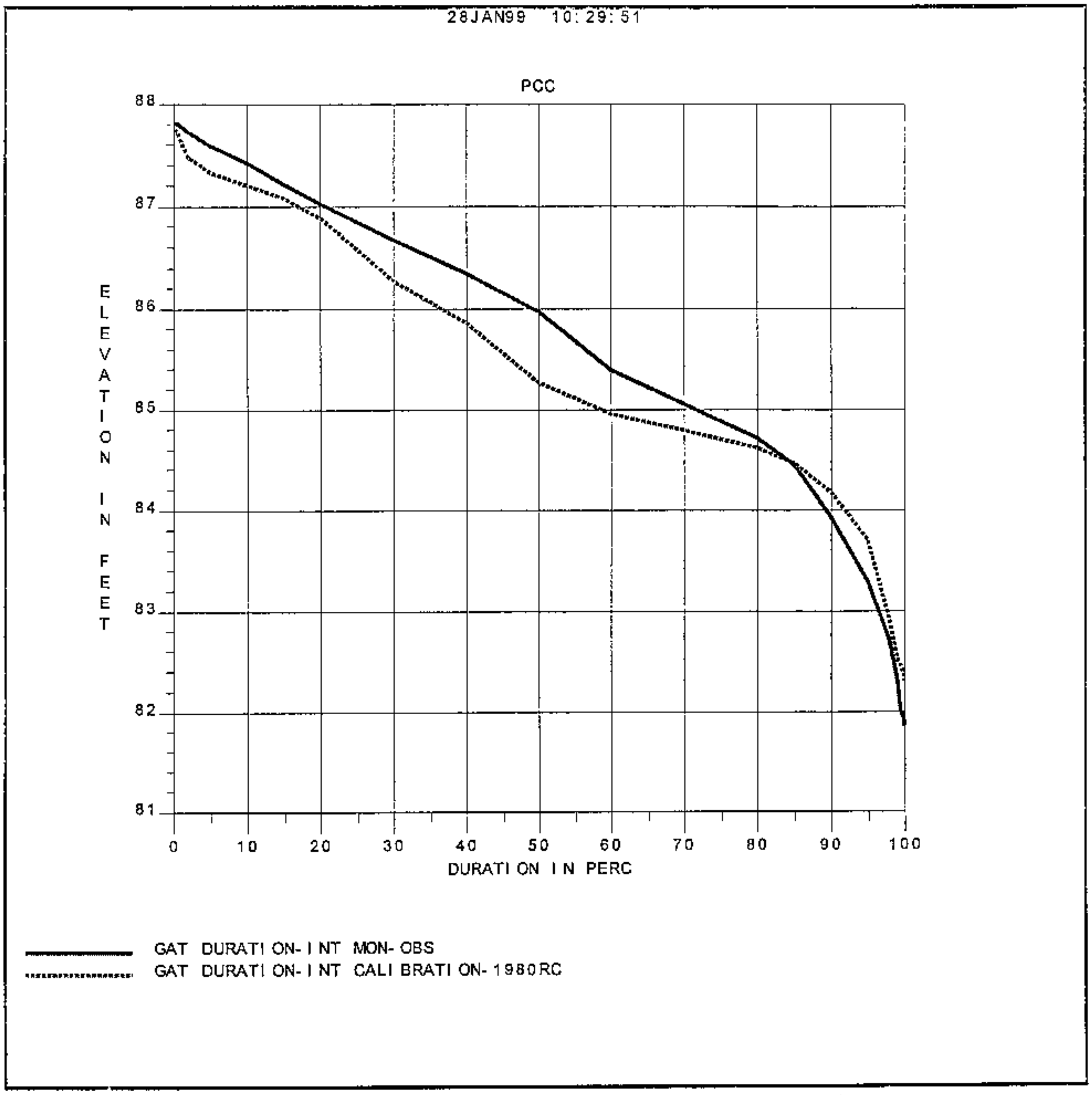

Figure 9. Gatun Interpolated Pool Elevation-Duration (1980 - 1997 Period)

Base Model Simulation

For the base model simulation, the diversion data were returned to the five-year (1993 - 1997) average-monthly values. The starting pool elevation was set to the guide curve elevation for December. This should be a good assumption because the pool is usually full by the end of December. The simulation period was set to start in January 1914 and continue 1015 months through July 1998 (84.5 years). The simulation results show how the system would perform given the current reservoir guide curve and current water demands for water supply and lockage. Exhibit 3 provides an input listing and a summary table of the results. The following sections present proposed evaluation criteria and results from the Base Model simulation.

Evaluation Criteria

Evaluation criteria are measures of performance that summarize the simulation results for each system purpose. The existing system simulated operation will define the basis for comparison (Base Model). The defined system purposes are: canal navigation, M&I water supply, and hydroelectric energy. The system's ability to meet these operational goals must be effectively summarized in the criteria. Additionally, there should be criteria that "measure" the systems overall performance. In earlier analyses of the Columbia River System (HEC, 1993), four indices were proposed.

1. *Penalty (or Value)* is the raw economic impact derived from the economic functions used in HEC-PRM. These value functions can be applied to the output from an HEC-5 simulation. If the functions are in equivalent dollars, the total value can be derived as the sum of all individual values.

2. *Reliability* is the frequency that performance fails to meet a particular purposes's target. In HEC-5 terms, this would be Shortage. A reliability of 100% implies that the monthly target is always met.

3. *Resiliency* is a measure of a system's ability to recover from failure. The resiliency index was defined as the number of recoveries divided by the number of failing months. Resiliency of 100% implies that the system always recovers, that is the system does not fail to meet a target in two successive months.

4. *Vulnerability* indicates the magnitude of typical failures, when they occur. The average deviation from a performance target was used. The deviation is the difference between the target (e.g., diversion schedule) and the actual value. For storage, the average difference between the guide curve and the simulated pool elevation could be an indicator of vulnerability. The smaller the average the better, assuming the guide curve is the ideal reservoir state.

An additional summary statistic, that is applicable to the goals of this system, is a duration analysis. The pool elevation-duration for a reservoir provides a summary indicating the percent of time the pool is above the range of possible pool elevations. For Gatun, this would be another indicator of vulnerability because the pool elevation has a direct impact on navigation. The use of average monthly flow in this analysis will tend to minimize the extremes; therefore, the elevation duration from simulation will be less reliable at the highest and lowest ends of the range of occurrence. The elevation-duration for the 1914 - 1997 Base Simulation is shown in Figures 10 and 11 for Madden and Gatun, respectively. The observed elevation data are limited to the period 1966 - 1997.

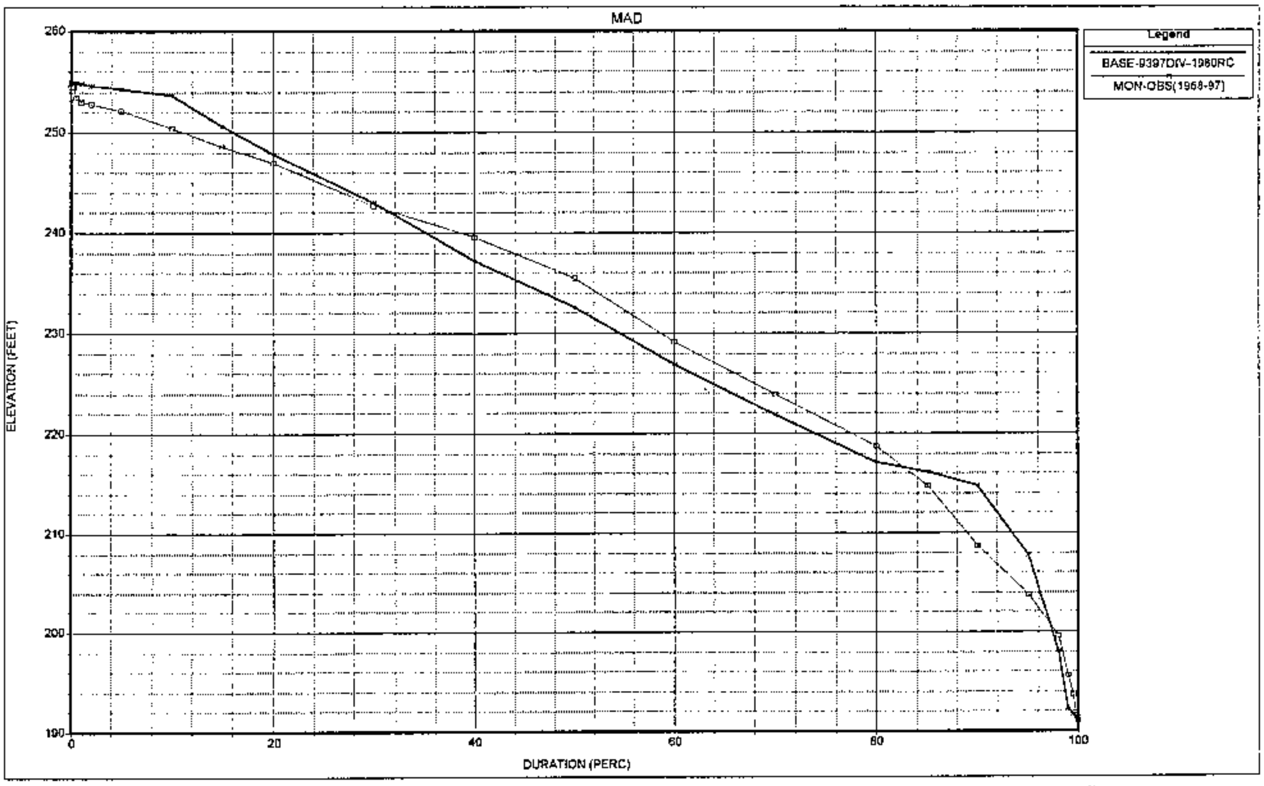

Figure 10. Madden Pool Elevation-Duration (dark = simulated and grey = observed)

Navigation

Navigation is the primary purpose and deserves the most attention. In the model simulation, navigation is modeled by a specified diversion schedule from Gatun, which also includes M&I water. The pool elevation at Gatun is critical for maintaining navigation depth as well as water supply for lockage. For the Base Model, Gatun's elevation for Level 1 was set at 70 feet. Under this condition all diversions are met; however, the minimum pool drops below 81.5 feet, the minimum desired for navigation depth.

The pool elevation-duration for Gatun shows the annual percent chance the pool will exceed an elevation. Figure 11 shows the duration curve for Gatun for the 1914 - 1997 simulation period. Setting the minimum elevation at 81.5 feet to maintain navigation depth will show how much diversion shortage occurs and the resulting reliability indicators could be applied. This option was simulated (GAT81-5.DAT) and the results show three years with shortage for a total of 8,972.88 cfs-month. The worse period was Spring of 1998 when Gatun was down to minimum pool for three months. Madden diversions were always met.

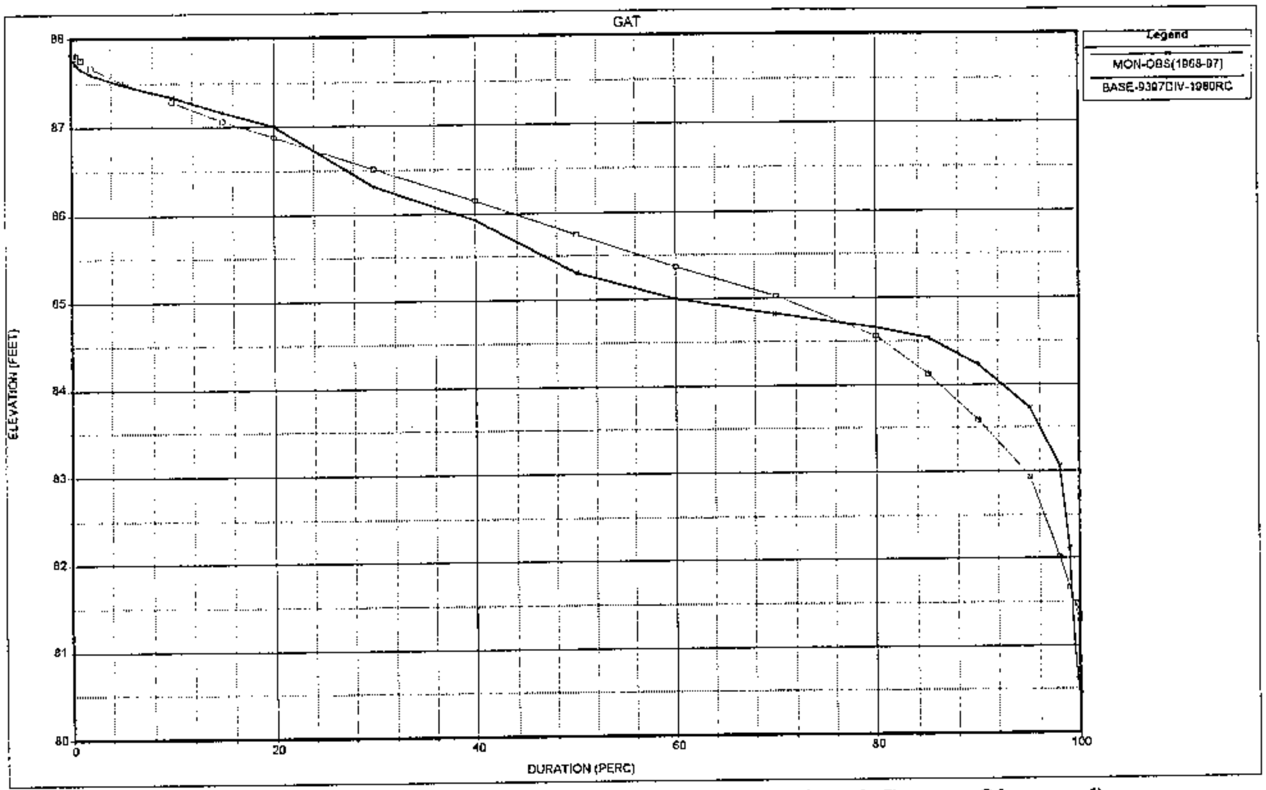

Figure 11. Gatun Pool Elevation-Duration (Dark = Simulated and Grey = Observed)

M&I Water Supply

Water supply is modeled with a monthly demand from Madden and Gatun. In the Base model, the water supply from Gatun is included in the diversion for lockage. All demands are met in the Base Model simulation.

Hydropower

Simulated hydropower energy in the Base Model is not based on a demand; it is incidental. However, hydropower has considerable value as a commercial product to sell or as a cost saving by displacing fuel cost for equivalent energy production. Economic value can be applied, if available, or the total energy produced could be a sufficient indicator for energy. The average annual energy generated at Madden and Gatun is shown for the Base Model simulation in Exhibit 3, Table 2.

Total System

Total System Value. If all value functions for each operational goal were in commensurate economic units (dollars), then the total system value would provide an overall performance indicator. In terms of economic investment, this would balance the trade-offs among purposes. The values used in the HEC-PRM model could be applied, once they were converted to flow in cubic-feet-per-second.

Percent Time Ideal Storage. A primary indicator of the system "health" is the percent of time the reservoir storage is within an acceptable range. Since all purposes are met from storage, the greater percent of time the two reservoirs are within a specified "ideal" storage range the better the system is ready to meet operation goals.

Guide-Curve Deviation. As described under vulnerability, the average deviation from a target is an indicator of vulnerability. Assuming that the guide curve is the ideal state for the system, the closer the reservoirs keep to the curve the better. Figure 12 shows the Elevation-Duration for the Guide Curve along with the simulation results for Gatun pool elevations. For the Base Model, the pool elevation is near or above the guide curve 60% of the year.

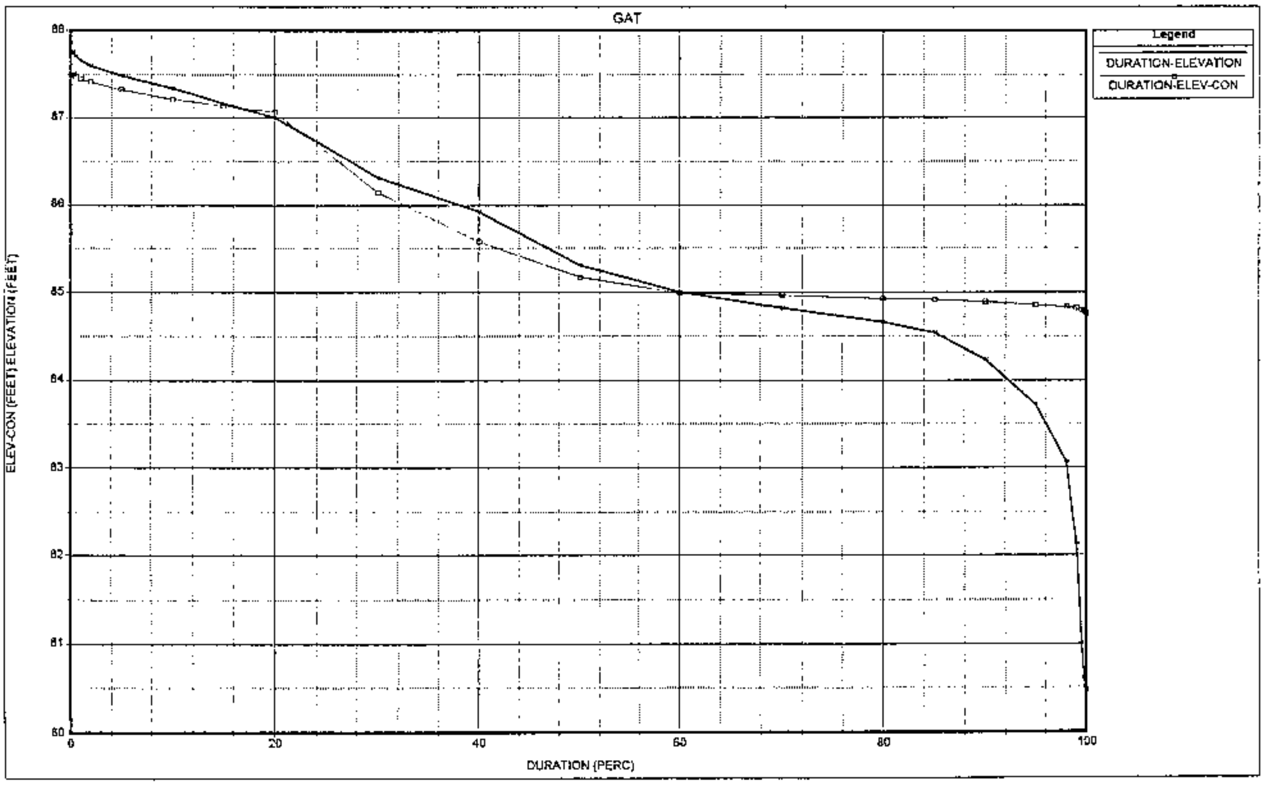

Figure 12. Gatun Elevation-Duration (Dark = Simulated and Grey = Guide Curve)

References

HEC, 1993. "Columbia River Reservoir System Analysis: Phase II," Project Report 21, Hydrologic Engineering Center, Davis, CA, December 1993.

HEC, 1995. "HEC-DSS, User's Guide and Utility Manuals," Hydrologic Engineering Center, Davis, CA, March 1995.

HEC, 1998. "HEC-5 User's Manual," Hydrologic Engineering Center, Davis, CA, October 1998.

PCC, 1992. "Flood Control Manual," Panama Canal Commission, September 1992.

Exhibit 1. PCC VALIDATION MODEL

The validation run was performed with the initial HEC-5 model for the Base System. The model data were modified to specify historic inflows and outflows, plus reservoir evaporation in inches, for the period of January 1970 to December 1997. (See ZR Records at the end of the input file.) With the inflow and outflow defined, the resulting reservoir storage and elevations should check with the historic data. If the results are the same, the validation run will demonstrate that the model data are appropriately configured and the program accounting for system flow and storage is correct. The following tables show the HEC-5 input data file (Table 1) and a tabulation listing from the HEC-DSS file for the simulated and observed pool elevations for Madden and Gatun (Table 2). The validation run demonstrates that the model data are appropriately configured.

Table 1. Input Data Listing for Validation Simulation
(HEC-5 filename = PCCVALID.DAT)

```
T1     Panama Canal Capacity Study  1970 - 1997
T2     Validation Model:  Existing System with historic lockage, div, & release
T3     Model developed by HEC, September 1998 & Revised January 1999
J1      0       1       5       3       4       2
J2     24     1.0               4
J3      4                                      -1
C   Evaporation data from PCC Evaporation computations (*User 1 compares evap)
J8 50.10    50.12    50.13    50.22    40.10    40.12    40.13    40.22
J8 50.09    50.10    50.21    50.02    50.00    40.09    40.10    40.21    40.02    40.00
JZ 40.09    40.10    40.22    40.11    40.16    50.09    50.10    50.22    50.11    50.16
JZ 50.03    50.30    40.03    40.30    40.21    50.21

C ============== Lake Madden ==============================================
C  5.  Top-of-dam       = Elev. 270
C  4.  Top-of-flood     = Elev. 260
C  3.  Top-of-conserv.  = Monthly varying, Elevations from Fig 5.1
C  2.  Top-of-buffer    = Elev. 190 (M&I only)
C  1.  Top-of-inactive  = Elev. 160 (no basis)
C  Starting Elev. from Dec 1969 Observed data
RL     50 -252.30
RL      1       50      -1            16000
RL      2       50      -1           127250
C         ELEV:                         249      243      233      221      217      215
RL      3       50       0           611478   541116   434890   324950   292650   277430
C         ELEV:                         217      222      228      236      247      252
RL      3                            292650   333360   386640   465290   587580   648140
RL      4       50      -1           751400
RL      5       50      -1           886750
RO      1       40
C  Reservoir storage from path = /MADDEN/MAD/ELEV-CAPAC///OBS/ converted to
C  Reservoir areas from path =  /MADDEN/MAD/ELEV-AREA///OBS/  converted to a
C  Storage & area values below Elev. = 190 are extrapolated
C  Areas above Elev = 264.0 are extrapolated
C  Reservoir maximum outflow from Tables 5-2 + 5-3 + 6-2 (FLOOD CONTROL MANUAL)
RS    -44        0     16.0     54.4   127.25   136.89   146.51   156.70   167.29   178.35
RS189.92   202.07   214.76   227.92   241.53   255.58   270.04   284.96   300.50   316.67
RS333.36   350.57   368.30   386.64   405.56   425.00   444.90   465.29   486.22   507.78
RS529.87   552.52   575.78   599.47   623.58   648.14   673.26   698.85   724.91   751.40
RS778.33   805.62   832.67   859.71   886.75
RQ     44     1000    10000    15000    20000    22000    23000    24000    25000    26000
RQ 26300    26500    27000    27300    27500    27800    28000    28300    28500    28800
RQ 29000    29300    29500    29800    30000    30100    34100    41100    50400    60700
```

```
RQ 74000    88000  103700  120800  139300  159200  180600  203500  227700  253600
RQ281000   310000  340700  373100  407100
RA    44        0    1600    3840    4608    4800    4992    5184    5376    5568
RA  6016     6272    6528    6720    6848    7104    7293    7616    7936    8198
RA  8480     8762    9043    9318    9587    9856   10125   10394   10630   10912
RA 11168    11424   11680   11936   12179   12422   12666   12909   13146   13376
RA 13606    13837   14080   14304   14528
RE    44      140     160     180     190     192     194     196     198     200
RE   202      204     206     208     210     212     214     216     218     220
RE   222      224     226     228     230     232     234     236     238     240
RE   242      244     246     248     250     252     254     256     258     260
RE   262      264     266     268     270
C ======  Evaporation rates are PCC computed historic for Lake Madden
C ======  Power data for Madden Hydropower - no power requirements
P1    50   36000       1              89              .83
P2    20
PR
PR
CP    50   50000
IDMAD
RT    50      40

C ======  Municipal diversion from Lake Madden ================================
C     Diversions are from /PCC/MAD/FLOW-DIV//MON/COMP-HEC/
DR    50                                              -5               1.0
C     Diversions are M&I 5 year average (1993 - 1997)
C     12      185     188     190     190     191     188     188     187     187
C    180      182     183

C ============== Lake Gatun ==============================================
C  5.  Top-of-dam      = Elev. 105.0
C  4.  Top-of-flood    = Elev.  88.0
C  3.  Top-of-conserv. = Monthly varying, Elevations from Fig 5.1
C  2.  Top-of-buffer   = Elev.  82.0
C  1.  Top-of-inactive = Elev.  77.0 (no basis)
C  Starting elevation from Dec 1969 Observed data
RL    40  -87.43
RL     1      40      -1          3393300
RL     2      40      -1          3880300
C        ELEV:                         87    86.3    85.4    84.7    84.7    84.7
RL     3      40       0          4399800 4325160 4230070 4156820 4156820 4156820
C        ELEV:                       84.7    84.7      85    85.9    87.3    87.5
RL     3      40                  4156820 4156820 4188100 4282800 4432050 4453580
RL     4      40      -1          4507600
RL     5      40      -1          6384700
RO
C   Reservoir storage from path = /GATUN/GAT/ELEV-CAPAC///OBS/ converted to
C   Reservoir maximum outflow from StoneyGAT.xls, data for 14 gates ELEV=78'-92'
C   Reservoir areas from path =   /GATUN/GAT/ELEV-AREA///OBS/ converted to a
C   data below elev. 77 and above 90 was extrapolated
RS   -21        0   833.7  1781.7  2729.7  3393.3  3488.1  3584.2  3681.6  3780.3
RS3880.3   3981.6  4084.2  4188.1  4293.3  4399.8  4507.6  4616.7  4727.2  5279.7
RS5832.2   6384.7
RQ    21        0       0       0    1890   42790   58878   69463   80672   92479
RQ104860   117796  131268  145260  159756  174743  190208  206139  222525  300000
RQ350000   400000
RA    21        0   56544   70404   84264   93966   95352   96740   98127   99414
RA100702   101990  103277  104566  105853  107141  108382  109670  110957  117392
RA123827   130262
RE    21       40      50      60      70      77      78      79      80      81
RE    82       83      84      85      86      87      88      89      90      95
RE   100      105
C ======  Evaporation rates are PCC computed for Gatun
C ======  Power data for Gatun - no power requirements
P1    40   24000       1               9              .85
P2    27
PR
PR
```

```
CP    40   99999
IDGAT
RT    40     200

C ======  Diversion data includes Total Lockage and M&I water supply
C ======  Data for validation from: /PCC/GAT/FLOW-DIV/MON/COMP-HEC/
DR    40                                                   -5             1.0
C ======  Comment out: Diversions are 5-year average (1993 - 1997)
C     12     3326     3325     3333     3233     3088     2943     2941     2983     2899
C   3092     2965     3081
C
C ============== CARIBBEAN SEA = LAST NODE ===================================
CP   200  999999
IDCARIBBEAN SEA
RT   200
ED
BF     2     336                70010100                720                       1900
C ===== OBSERVED DATA SPECIFIED FOR JAN 1970 TO DEC 1997 =====================
C ===== PCC EVAPORATION INPUT IN INCHES
ZR=EV40 A=PCC B=GAT C=EVAP F=OBS
ZR=EV50 A=PCC B=MAD C=EVAP F=OBS
C ===== COMPUTED EVAPORATION INPUT AS OBSERVED FLOW TO COMPARE WITH HEC-5 VALUES
ZR=NQ40 A=PCC B=GAT C=FLOW-EVAP F=COMP-HEC
ZR=NQ50 A=PCC B=MAD C=FLOW-EVAP F=COMP-HEC
C ===== COMPUTED INCREMENTAL INFLOW ==========================================
ZR=IN40 A=PCC B=GAT C=FLOW-IN-INC F=COMP-HEC
ZR=IN50 A=PCC B=MAD C=FLOW-IN F=COMP-HEC
C ===== TOTAL RESERVOIR RELEASES (HYDROPOWER + SPILL + LEAKAGE) ===============
ZR=QA40 A=PCC B=GAT C=FLOW-OUT F=COMP-HEC
ZR=QA50 A=PCC B=MAD C=FLOW-OUT F=COMP-HEC
C ===== DIVERSIONS AT GAT FOR MUNI AND LOCKAGE; MAD IS MUNI ONLY ==============
ZR=QD40 A=PCC B=GAT C=FLOW-LOCKS+MUNI F=COMP-HEC
ZR=QD50 A=PCC B=MAD C=FLOW-MUNI F=COMP-HEC
C ===== OUTPUT WRITTEN WITH F PART = VALIDATION ==============================
ZW  F=VALIDATION
EJ
ER
```

The observed pool elevations and the computed elevations from the HEC-5 validation simulation are plotted in Figure 1 for Madden Reservoir and Figure 2 for Gatun Reservoir. The tabulated elevations are shown in Table 2.

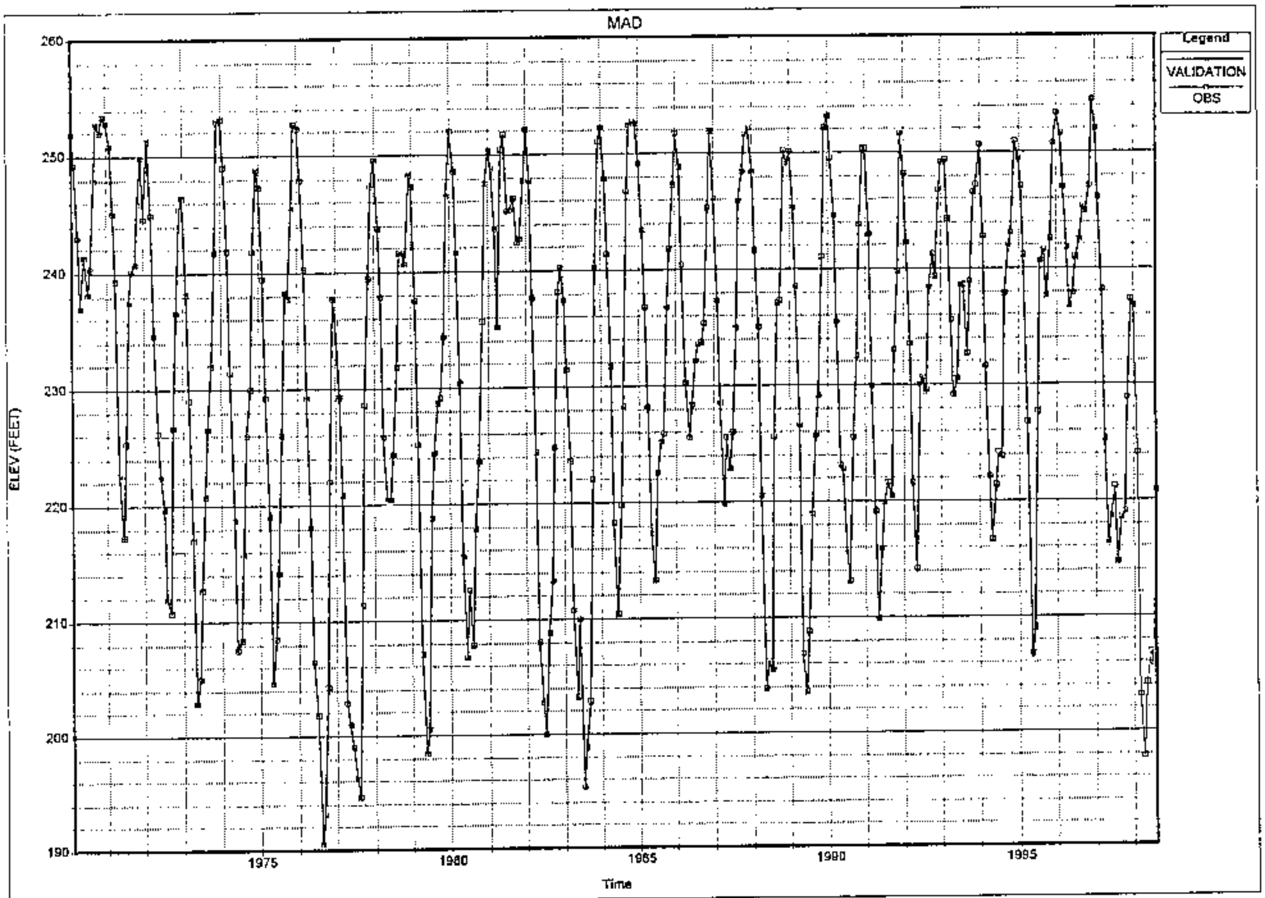

Figure 1. Madden Pool Elevation, Observed and Validation Simulated (1970 - 1997)
(All inflow and outflow specified from historic data)

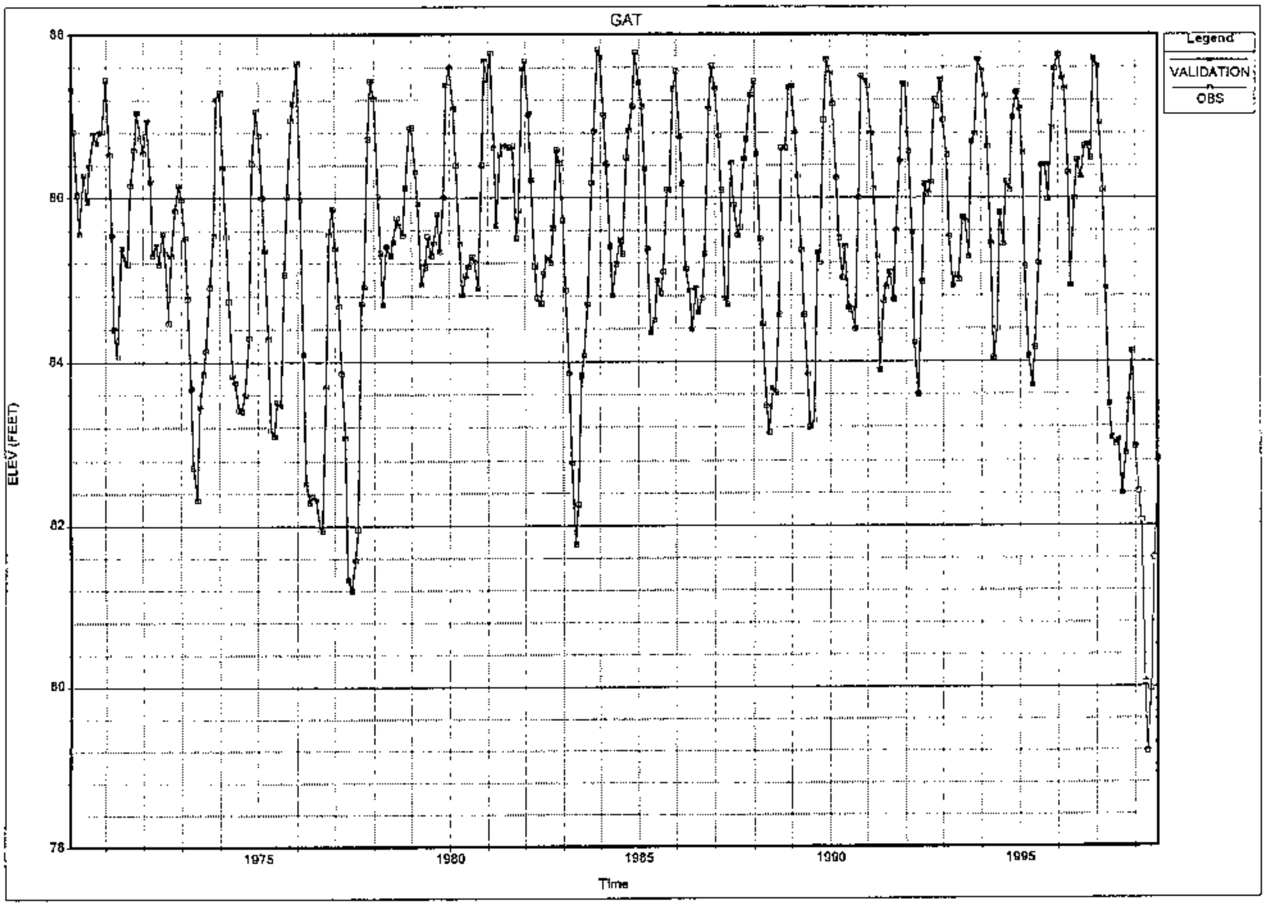

Figure 2. Gatun Pool Elevation, Observed and Validation Simulated (1970 - 1997)
(All inflow and outflow specified from historic data)

Table 2. Madden and Gatun Reservoir Elevations
(Observed and Validation Model using Historic Demand and Release Data)

Date	MAD ELEVATION OBSERVED (Feet)	MAD ELEVATION VALIDATION (Feet)	GAT ELEVATION OBSERVED (Feet)	GAT ELEVATION VALIDATION (Feet)
31Jan1970	251.93	251.93	87.32	87.32
28Feb1970	249.24	249.24	86.82	86.82
31Mar1970	242.98	242.98	86.05	86.05
30Apr1970	236.96	236.97	85.55	85.55
31May1970	241.44	241.44	86.28	86.28
30Jun1970	238.22	238.22	85.95	85.95
31Jul1970	240.29	240.29	86.38	86.38
31Aug1970	247.94	247.94	86.79	86.79
30Sep1970	252.77	252.76	86.68	86.68
31Oct1970	252.08	252.08	86.80	86.80
30Nov1970	253.48	253.47	86.81	86.81
31Dec1970	252.86	252.85	87.44	87.44
31Jan1971	250.85	250.84	86.52	86.52
28Feb1971	245.12	245.11	85.54	85.54
31Mar1971	239.34	239.33	84.40	84.40
30Apr1971	222.73	222.72	84.06	84.06
31May1971	217.35	217.34	85.39	85.39
30Jun1971	225.36	225.35	85.26	85.26
31Jul1971	237.51	237.51	85.19	85.19
31Aug1971	240.13	240.14	86.15	86.15
30Sep1971	240.73	240.73	86.59	86.59
31Oct1971	246.02	246.03	87.04	87.04
30Nov1971	249.86	249.87	86.74	86.74
31Dec1971	244.64	244.65	86.55	86.55
31Jan1972	251.34	251.36	86.94	86.94
29Feb1972	244.91	244.93	86.20	86.20
31Mar1972	234.59	234.61	85.30	85.30
30Apr1972	226.21	226.23	85.42	85.42
31May1972	222.44	222.47	85.19	85.19
30Jun1972	219.63	219.66	85.56	85.56
31Jul1972	211.90	211.93	85.32	85.32
31Aug1972	210.80	210.81	84.49	84.49
30Sep1972	226.63	226.64	85.29	85.29
31Oct1972	236.55	236.56	85.85	85.85
30Nov1972	245.48	245.49	86.15	86.15
31Dec1972	246.40	246.42	85.99	85.99
31Jan1973	238.13	238.15	85.51	85.51
28Feb1973	229.00	229.01	84.78	84.78
31Mar1973	217.04	217.06	83.68	83.68
30Apr1973	202.87	202.89	82.71	82.71
31May1973	205.01	205.04	82.31	82.31
30Jun1973	212.72	212.75	83.45	83.45
31Jul1973	220.73	220.75	83.86	83.86
31Aug1973	226.57	226.59	84.14	84.14
30Sep1973	231.97	231.99	84.92	84.92
31Oct1973	241.77	241.79	85.54	85.54
30Nov1973	252.95	252.97	87.21	87.21
31Dec1973	253.16	253.17	87.29	87.29
31Jan1974	249.08	249.10	86.37	86.37
28Feb1974	241.87	241.89	85.52	85.52

Date	MAD ELEVATION OBSERVED (Feet)	MAD ELEVATION VALIDATION (Feet)	GAT ELEVATION OBSERVED (Feet)	GAT ELEVATION VALIDATION (Feet)
31Mar1974	231.42	231.44	84.74	84.74
30Apr1974	218.76	218.79	83.83	83.83
31May1974	207.57	207.60	83.76	83.76
30Jun1974	208.34	208.36	83.43	83.43
31Jul1974	215.73	215.74	83.40	83.40
31Aug1974	226.03	226.05	83.60	83.60
30Sep1974	230.00	230.01	84.30	84.30
31Oct1974	241.86	241.87	86.44	86.44
30Nov1974	248.66	248.67	87.06	87.06
31Dec1974	247.32	247.34	86.77	86.77
31Jan1975	239.47	239.49	86.01	86.01
28Feb1975	229.21	229.23	85.36	85.36
31Mar1975	219.00	219.02	84.29	84.29
30Apr1975	204.57	204.60	83.17	83.17
31May1975	208.45	208.47	83.10	83.10
30Jun1975	214.23	214.24	83.52	83.52
31Jul1975	226.03	226.03	83.47	83.47
31Aug1975	238.23	238.24	85.07	85.07
30Sep1975	237.79	237.80	86.02	86.02
31Oct1975	245.46	245.47	86.95	86.95
30Nov1975	252.65	252.66	87.15	87.15
31Dec1975	252.37	252.38	87.64	87.64
31Jan1976	247.88	247.89	85.99	85.99
29Feb1976	240.32	240.33	84.10	84.10
31Mar1976	229.29	229.30	82.52	82.52
30Apr1976	218.11	218.11	82.29	82.29
31May1976	206.50	206.50	82.35	82.35
30Jun1976	201.80	201.79	82.32	82.32
31Jul1976	190.53	190.51	81.97	81.97
31Aug1976	193.14	193.11	81.93	81.93
30Sep1976	204.25	204.24	83.70	83.70
31Oct1976	222.02	222.01	85.56	85.56
30Nov1976	237.75	237.75	85.86	85.86
31Dec1976	235.69	235.69	85.39	85.39
31Jan1977	229.21	229.20	84.68	84.68
28Feb1977	220.84	220.83	83.87	83.87
31Mar1977	202.94	202.92	83.08	83.08
30Apr1977	200.99	200.95	81.33	81.33
31May1977	199.00	198.96	81.19	81.19
30Jun1977	196.38	196.34	81.56	81.56
31Jul1977	194.57	194.53	81.95	81.95
31Aug1977	211.37	211.33	84.72	84.72
30Sep1977	228.56	228.52	84.92	84.92
31Oct1977	239.48	239.45	86.73	86.73
30Nov1977	247.35	247.32	87.43	87.43
31Dec1977	249.59	249.57	87.22	87.22
31Jan1978	243.73	243.71	86.02	86.02
28Feb1978	237.90	237.88	85.32	85.32
31Mar1978	225.81	225.78	84.70	84.70
30Apr1978	220.42	220.39	85.40	85.40
31May1978	220.42	220.38	85.29	85.29
30Jun1978	224.32	224.28	85.47	85.47
31Jul1978	231.79	231.76	85.75	85.75
31Aug1978	241.61	241.58	85.67	85.67
30Sep1978	241.60	241.57	85.54	85.54
31Oct1978	240.62	240.59	86.12	86.12
30Nov1978	248.30	248.28	86.85	86.85
31Dec1978	247.35	247.33	86.86	86.86

Date	MAD ELEVATION OBSERVED (Feet)	MAD ELEVATION VALIDATION (Feet)	GAT ELEVATION OBSERVED (Feet)	GAT ELEVATION VALIDATION (Feet)
31Jan1979	237.49	237.47	86.33	86.33
28Feb1979	225.15	225.12	85.92	85.92
31Mar1979	207.08	207.04	84.95	84.95
30Apr1979	198.40	198.35	85.16	85.16
31May1979	200.56	200.50	85.52	85.52
30Jun1979	218.79	218.75	85.30	85.30
31Jul1979	224.46	224.42	85.45	85.45
31Aug1979	228.75	228.71	85.80	85.80
30Sep1979	229.10	229.06	85.35	85.35
31Oct1979	234.38	234.34	86.00	86.00
30Nov1979	246.43	246.40	87.39	87.39
31Dec1979	252.02	251.99	87.60	87.60
31Jan1980	248.59	248.57	87.09	87.09
29Feb1980	241.64	241.62	86.41	86.41
31Mar1980	230.46	230.43	85.43	85.43
30Apr1980	215.53	215.49	84.82	84.82
31May1980	206.79	206.74	85.05	85.05
30Jun1980	212.57	212.53	85.16	85.16
31Jul1980	207.80	207.75	85.28	85.28
31Aug1980	217.81	217.77	85.22	85.22
30Sep1980	223.70	223.66	84.89	84.89
31Oct1980	235.74	235.70	86.40	86.39
30Nov1980	247.50	247.46	87.68	87.67
31Dec1980	250.34	250.30	87.45	87.44
31Jan1981	248.82	248.78	87.77	87.76
28Feb1981	243.65	243.62	86.62	86.61
31Mar1981	235.16	235.12	85.66	85.65
30Apr1981	250.39	250.35	86.54	86.53
31May1981	251.69	251.65	86.65	86.64
30Jun1981	245.18	245.14	86.64	86.63
31Jul1981	245.30	245.26	86.61	86.60
31Aug1981	246.29	246.26	86.63	86.62
30Sep1981	242.51	242.47	85.51	85.50
31Oct1981	242.79	242.75	85.85	85.84
30Nov1981	247.77	247.74	87.58	87.57
31Dec1981	252.18	252.16	87.67	87.66
31Jan1982	247.69	247.67	87.03	87.02
28Feb1982	237.61	237.58	86.22	86.21
31Mar1982	224.36	224.33	85.16	85.15
30Apr1982	208.08	208.04	84.77	84.76
31May1982	202.81	202.76	84.71	84.70
30Jun1982	200.04	200.00	85.07	85.06
31Jul1982	208.83	208.78	85.27	85.26
31Aug1982	213.30	213.25	85.21	85.20
30Sep1982	224.86	224.81	85.64	85.63
31Oct1982	238.12	238.08	86.59	86.58
30Nov1982	240.22	240.19	86.44	86.43
31Dec1982	237.44	237.40	85.72	85.71
31Jan1983	231.54	231.50	84.87	84.86
28Feb1983	223.67	223.63	83.87	83.86
31Mar1983	210.72	210.67	82.76	82.75
30Apr1983	203.26	203.15	81.77	81.76
31May1983	209.95	209.86	82.25	82.24
30Jun1983	195.40	195.27	83.83	83.82
31Jul1983	198.84	198.71	84.08	84.07
31Aug1983	202.87	202.74	84.70	84.69
30Sep1983	222.05	221.96	86.18	86.17
31Oct1983	240.19	240.12	86.82	86.81

Date	MAD ELEVATION OBSERVED (Feet)	MAD ELEVATION VALIDATION (Feet)	GAT ELEVATION OBSERVED (Feet)	GAT ELEVATION VALIDATION (Feet)
30Nov1983	251.07	251.01	87.81	87.80
31Dec1983	252.26	252.21	87.73	87.72
31Jan1984	247.86	247.81	87.02	87.02
29Feb1984	241.39	241.33	86.42	86.41
31Mar1984	231.69	231.63	85.40	85.39
30Apr1984	218.23	218.16	84.81	84.80
31May1984	210.47	210.38	85.19	85.18
30Jun1984	219.80	219.72	85.48	85.47
31Jul1984	228.24	228.17	85.31	85.30
31Aug1984	246.77	246.71	86.49	86.48
30Sep1984	252.50	252.45	86.83	86.83
31Oct1984	252.76	252.71	87.12	87.12
30Nov1984	252.60	252.55	87.78	87.77
31Dec1984	249.19	249.14	87.42	87.41
31Jan1985	243.39	243.33	87.13	87.13
28Feb1985	236.74	236.68	86.35	86.34
31Mar1985	228.20	228.14	85.38	85.37
30Apr1985	217.28	217.20	84.36	84.35
31May1985	213.35	213.28	84.52	84.51
30Jun1985	222.59	222.52	84.99	84.99
31Jul1985	225.32	225.25	84.83	84.83
31Aug1985	225.91	225.85	85.09	85.09
30Sep1985	236.75	236.69	86.10	86.10
31Oct1985	241.80	241.75	86.10	86.10
30Nov1985	247.33	247.28	87.34	87.34
31Dec1985	251.69	251.65	87.55	87.55
31Jan1986	248.79	248.75	86.76	86.76
28Feb1986	240.39	240.35	86.17	86.17
31Mar1986	230.32	230.27	85.12	85.12
30Apr1986	225.61	225.55	84.87	84.87
31May1986	228.37	228.32	84.40	84.40
30Jun1986	232.17	232.11	84.90	84.90
31Jul1986	233.53	233.47	84.61	84.61
31Aug1986	233.75	233.69	84.78	84.78
30Sep1986	235.38	235.31	85.31	85.31
31Oct1986	245.37	245.32	87.10	87.10
30Nov1986	251.94	251.89	87.61	87.61
31Dec1986	246.12	246.07	87.34	87.34
31Jan1987	237.26	237.20	86.77	86.77
28Feb1987	228.52	228.46	86.09	86.09
31Mar1987	219.90	219.83	84.77	84.77
30Apr1987	225.54	225.45	84.69	84.69
31May1987	222.86	222.77	86.44	86.44
30Jun1987	225.99	225.91	85.91	85.91
31Jul1987	235.00	234.92	85.54	85.54
31Aug1987	245.95	245.89	85.64	85.64
30Sep1987	248.43	248.37	86.48	86.48
31Oct1987	251.61	251.55	86.73	86.73
30Nov1987	252.13	252.08	87.26	87.26
31Dec1987	248.40	248.35	87.43	87.43
31Jan1988	241.66	241.60	86.54	86.54
29Feb1988	235.03	234.96	85.50	85.50
31Mar1988	220.53	220.45	84.46	84.46
30Apr1988	203.92	203.81	83.47	83.47
31May1988	206.26	206.16	83.15	83.15
30Jun1988	205.45	205.34	83.68	83.68
31Jul1988	225.62	225.52	83.62	83.62
31Aug1988	237.07	236.99	84.57	84.57

	MAD ELEVATION OBSERVED	MAD ELEVATION VALIDATION	GAT ELEVATION OBSERVED	GAT ELEVATION VALIDATION
Date	(Feet)	(Feet)	(Feet)	(Feet)
30Sep1988	237.32	237.24	86.61	86.61
31Oct1988	250.17	250.10	86.61	86.61
30Nov1988	249.15	249.08	87.36	87.36
31Dec1988	250.15	250.09	87.37	87.37
31Jan1989	245.29	245.23	86.80	86.80
28Feb1989	238.50	238.43	86.26	86.26
31Mar1989	226.52	226.43	85.36	85.36
30Apr1989	206.91	206.80	84.58	84.58
31May1989	203.59	203.43	83.86	83.86
30Jun1989	208.81	208.67	83.20	83.20
31Jul1989	218.89	218.77	83.28	83.28
31Aug1989	225.71	225.61	85.33	85.33
30Sep1989	229.14	229.04	85.20	85.20
31Oct1989	241.03	240.94	86.95	86.95
30Nov1989	252.20	252.12	87.69	87.69
31Dec1989	253.09	253.00	87.52	87.52
31Jan1990	249.52	249.43	87.16	87.16
28Feb1990	244.66	244.57	86.25	86.25
31Mar1990	235.48	235.38	85.51	85.51
30Apr1990	223.09	222.97	85.02	85.02
31May1990	222.79	222.67	85.40	85.40
30Jun1990	215.76	215.62	84.67	84.67
31Jul1990	213.12	212.97	84.63	84.63
31Aug1990	225.48	225.36	84.41	84.41
30Sep1990	232.51	232.40	86.01	86.01
31Oct1990	243.86	243.77	87.49	87.49
30Nov1990	250.31	250.22	87.43	87.43
31Dec1990	250.31	250.23	87.37	87.37
31Jan1991	243.02	242.93	86.79	86.79
28Feb1991	229.89	229.79	86.11	86.11
31Mar1991	219.14	219.02	85.28	85.28
30Apr1991	209.90	209.77	83.90	83.90
31May1991	215.88	215.78	84.74	84.74
30Jun1991	219.87	219.77	84.91	84.91
31Jul1991	221.57	221.48	85.10	85.10
31Aug1991	220.43	220.34	84.76	84.76
30Sep1991	232.97	232.88	85.60	85.60
31Oct1991	239.77	239.69	86.46	86.46
30Nov1991	251.64	251.56	87.40	87.40
31Dec1991	248.19	248.12	87.38	87.38
31Jan1992	242.30	242.22	86.57	86.57
29Feb1992	233.60	233.51	85.57	85.57
31Mar1992	221.62	221.51	84.24	84.24
30Apr1992	214.16	214.02	83.61	83.61
31May1992	230.05	229.94	84.97	84.97
30Jun1992	230.69	230.58	86.17	86.17
31Jul1992	229.52	229.41	86.05	86.05
31Aug1992	238.43	238.33	86.19	86.19
30Sep1992	241.33	241.23	87.20	87.20
31Oct1992	239.35	239.25	87.12	87.12
30Nov1992	246.79	246.70	87.45	87.45
31Dec1992	249.18	249.09	86.96	86.96
31Jan1993	249.36	249.27	86.53	86.53
28Feb1993	244.34	244.25	85.52	85.52
31Mar1993	235.58	235.48	84.93	84.93
30Apr1993	229.17	229.05	85.05	85.05
31May1993	230.59	230.48	85.01	85.01
30Jun1993	238.62	238.51	85.77	85.77

Date	MAD. ELEVATION OBSERVED (Feet)	MAD. ELEVATION VALIDATION (Feet)	GAT. ELEVATION OBSERVED (Feet)	GAT ELEVATION VALIDATION (Feet)
31Jul1993	238.59	238.49	85.71	85.71
31Aug1993	232.71	232.60	85.28	85.28
30Sep1993	238.95	238.85	86.69	86.69
31Oct1993	246.53	246.44	86.79	86.79
30Nov1993	247.22	247.12	87.70	87.70
31Dec1993	250.67	250.58	87.55	87.55
31Jan1994	242.82	242.72	87.24	87.24
28Feb1994	231.60	231.49	86.63	86.63
31Mar1994	222.16	222.03	85.45	85.45
30Apr1994	216.66	216.52	84.05	84.05
31May1994	221.36	221.23	84.41	84.41
30Jun1994	224.14	224.01	85.82	85.82
31Jul1994	223.87	223.74	85.43	85.43
31Aug1994	237.85	237.74	86.20	86.20
30Sep1994	242.01	241.91	86.09	86.09
31Oct1994	243.09	242.99	86.99	86.99
30Nov1994	250.95	250.86	87.29	87.29
31Dec1994	249.46	249.37	87.09	87.09
31Jan1995	247.10	247.00	86.56	86.56
28Feb1995	241.17	241.07	85.16	85.16
31Mar1995	226.81	226.69	84.07	84.07
30Apr1995	206.73	206.56	83.71	83.71
31May1995	209.04	208.87	84.17	84.17
30Jun1995	227.59	227.47	85.21	85.21
31Jul1995	240.60	240.50	86.40	86.40
31Aug1995	241.57	241.47	86.40	86.40
30Sep1995	237.62	237.52	85.99	85.99
31Oct1995	242.60	242.50	86.86	86.86
30Nov1995	250.76	250.67	87.59	87.59
31Dec1995	253.34	253.25	87.76	87.76
31Jan1996	251.58	251.49	87.48	87.48
29Feb1996	247.04	246.95	87.34	87.34
31Mar1996	241.79	241.70	86.31	86.31
30Apr1996	236.76	236.66	84.93	84.93
31May1996	237.90	237.81	86.00	86.00
30Jun1996	240.93	240.83	86.47	86.47
31Jul1996	242.52	242.43	86.27	86.27
31Aug1996	245.39	245.30	86.64	86.64
30Sep1996	244.93	244.84	86.66	86.66
31Oct1996	247.11	247.03	86.50	86.50
30Nov1996	254.51	254.43	87.71	87.71
31Dec1996	251.99	251.91	87.62	87.62
31Jan1997	246.10	246.02	86.93	86.93
28Feb1997	238.20	238.11	86.10	86.10
31Mar1997	225.31	225.20	84.90	84.90
30Apr1997	216.42	216.29	83.49	83.49
31May1997	218.59	218.45	83.07	83.07
30Jun1997	221.13	220.99	82.99	82.99
31Jul1997	214.73	214.57	83.05	83.05
31Aug1997	218.50	218.36	82.40	82.40
30Sep1997	219.08	218.93	82.89	82.89
31Oct1997	228.77	228.64	83.51	83.51
30Nov1997	237.31	237.20	84.13	84.13
31Dec1997	236.74	236.63	82.96	82.96

Exhibit 2. PCC CALIBRATION MODEL

The calibration model data were developed by modifying the HEC-5 model from the Validation run. The calibration model was run with the historic inflow and demand data. The evaporation is computed using PCC evaporation data in inches. The period of January 1980 to July 1998 was simulated because that was the period when the current reservoir guide curves were applicable.

The validation model data were modified to add an additional level to the reservoir guide curves to better balance Madden with Gatun. The storage - outflow - area - elevation data for Madden (RS, RQ, RA, RE Records) were modified to define data on a one-foot interval between elevations 200 and 220 because the area changes varied more in that range. Level 1 (Inactive Pool) at Gatun was set to 70.0 feet; Level 2 (Buffer Pool) was set to 81.5; and the Level 3 (Balancing Guide Curve) minimum elevation was set to 82.0 feet, based on the goal of maintaining the pool elevation near 81.5 feet for navigation.

The maximum channel capacities for the reservoirs were set to match the maximum hydropower release. The limited channel capacity causes the simulation to store water in the flood pool during high flow months, which better match the historic data. The minimum release at Madden was set to 500 CFS, which matches the historic minimum and forces Madden to always release if above elevation 190 feet. Table 1 shows the input data file for the Calibration Model.

The computed reservoir elevations and releases were plotted along with historic data to illustrate the calibrated model results. For comparison, the results were plotted by decade with Madden and Gatun results on the same page. Figures 1 and 2 show the elevation results for 1980 to 1990 and Figures 3 and 4 show the results for 1990 through July 1998. The reservoir releases are similarly compared, by decades, in Figures 5 through 8. Tables 2 and 3 provide a listing of the observed and simulated pool elevations and reservoir release data, respectively.

HEC-5 computed evaporation, in cubic feet per second, is plotted along with the HEC-DSS computed values based on observed pool elevations and PCC evaporation rates. Figure 9 shows the evaporation comparison for Madden and Figure 10 shows the comparison for Gatun.

A final comparison is the total system storage plot in Figure 11. The total system storage was computed by adding together the reservoir storage for Madden and Gatun for historic storage as well as for calibration simulation storage. Then the difference was computed by subtracting the simulation totals from the historic totals. The resulting plot shows the difference between historic total system storage and calibration model simulated results. Values above zero mean that the historic system storage is greater than the calibration simulation storage. The display indicates that, during the middle of the year, recent reservoir operation tends to keep more water in storage than the amount suggested by the guide curve. *(Note: The year marker on the plot is January of that year).*

Table 1. Input Data Listing for Calibration Simulation
(HEC-5 filename = PCCCALIB.DAT)

```
T1     Panama Canal Capacity Study  Jan.1980 - July 1998
T2     Calibration Model: Existing System with Historic Lockage & Municipal Qs
T3     Model developed by HEC, December  1998 and Revised January 1999
J1      0       1       6       4       5       2
J2     24     1.0             132
J3      4                                       -1
C   Evaporation from PCC computed values input as EV data
J8 40.12   40.32   40.10   40.13   50.13   50.10   50.32   50.12
J8 40.22   40.02   40.00   50.22   50.02   50.00
JZ 40.09   40.10   40.22   40.11   40.16   50.09   50.10   50.22   50.11   50.16
JZ 40.03   40.30   40.31   50.03   50.30   50.31   40.21   50.21
C ============= Lake Madden ==========================================
C  6.  Top-of-dam      = Elev. 270
C  5.  Top-of-flood    = Monthly varying, Based on Spill Curve
C  4.  Top-of-conserv. = Monthly varying, Elevations from Fig 5.1
C  3.  Tandem Operation= Monthly varying, Based on Previous Operations
C  2.  Top-of-buffer   = Elev. 190 (M&I only)
C  1.  Top-of-inactive = Elev. 160
C  Starting Elevation for December 1979
RL     50 -252.02
RL      1      50      -1           16000
RL      2      50      -1          127250
C        ELEV:                        224     204     198     198     198     198
RL      3      50       0          350570  202070  167290  167290  167290  167290
C        ELEV:                        200     210     220     230     240     237
RL                                 178350  241530  316670  405560  507780  475755
C        ELEV:                        249     243     233     221     217     215
RL      4      50       0          611478  541116  434890  324950  292650  277430
C        ELEV:                        217     222     228     236     247     252
RL                                 292650  333360  386640  465290  587580  648140
C   Madden Spill Curve from PCC OPERDATA.BAS dated 6-23-94
RL      5      50       0          685996  685996  685996  564096  564096  564096
RL                                 564096  564096  564096  599470  635790  685996
RL      6      50      -1          886750
RO      1      40
C  Reservoir storage from path = /PCC/MAD/ELEV-CAPAC(ACFT)///OBS/
C  Reservoir areas from path =  /PCC/MAD/ELEV-AREA(ACRES)///OBS/
C  Storage & area values below Elev. = 190 are extrapolated
C  Areas above Elev = 264.0 are extrapolated
C  Reservoir maximum outflow from Tables 5-2 + 5-3 + 6-2 PCC FC MANUAL (9/1992)
RS    -54       0    16.0    54.4  127.25  136.89  146.51  156.70  167.29  178.35
RS184.07 189.992 195.914 202.066 208.356 214.761 221.281 227.916 234.665 241.529
RS248.51 255.579 262.764 270.041 277.433 284.963 292.654 300.505 308.517 316.667
RS333.36 350.573 368.297 386.639 405.556 425.000 444.904 465.289 486.226 507.782
RS529.87 552.525 575.781 599.472 623.577 648.140 673.255 698.852 724.908 751.400
RS778.33 805.624 832.668 859.711 886.754
RQ     54    1000   10000   15000   20000   22000   23000   24000   25000   26000
RQ  26150   26300   26400   26500   26750   27000   27150   27300   27400   27500
RQ  27650   27800   27900   28000   28150   28300   28400   28500   28650   28800
RQ  29000   29300   29500   29800   30000   30100   34100   41100   50400   60700
RQ  74000   88000  103700  120800  139300  159200  180600  203500  227700  253600
RQ281000  310000  340700  373100  407100
RA     54       0    1600    3840    4608    4800    4992    5184    5376    5568
RA   5792    6016    6144    6272    6400    6528    6624    6720    6784    6848
RA   6976    7104    7168    7296    7488    7616    7744    7936    8064  8198.4
RA   8480  8761.6  9043.2  9318.4  9587.2    9856 10124.8 10393.6 10630.4   10912
RA  11168   11424   11680   11936 12179.2 12422.4 12665.6 12908.8 13145.6   13376
RA  13606   13837   14080   14304   14528
RE     54     140     160     180     190     192     194     196     198     200
RE    201     202     203     204     205     206     207     208     209     210
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RE   211     212     213     214     215     216     217     218     219     220
RE   222     224     226     228     230     232     234     236     238     240
RE   242     244     246     248     250     252     254     256     258     260
RE   262     264     266     268     270
C   Evaporation rates are read from DSS file for Madden
C   Hydropower Data
P1    50  36000    1.05             89             .83
C   Penstock Capacity Based on Hydro-Met data for Maximum Discharge @ elev = 252
P2    20    3624
PR
PR
C  = Channel Capacity Based on Limiting Non-spill Releases to Power Operation ==
C  = Minimum flow set to 500 cfs based on historic minimum ===================
CP    50    3624     500
IDMAD
RT    50      40

C ============== Municipal Diversion from Lake Madden =======================
C  Historic Demands:  A=PCC B=MAD C=FLOW-MUNI F=COMP-HEC
DR    50                                              -5            1.0
C ============== Comment out: Diversions are 5 year average (1993 - 1997)
C     12     185     188     190     190     191     188     188     187     187
C    180     182     183

C ============== Lake Gatun ==================================================
C  6.  Top-of-dam      = Elev. 105.0
C  5.  Top-of-flood    = Monthly varying, Based on Spill Curve
C  4.  Top-of-conserv. = Monthly varying, Elevations from Fig 5.1
C  3.  Tandem Operation= Monthly varying, Based on Previous Operations
C  2.  Top-of-buffer   = Elev.  81.5
C  1.  Top-of-inactive = Elev.  70.0 based on Jorge note of 14 Oct 1998
C  Starting elevation for December 1979
RL    40  -87.60
RL     1      40      -1         2729700
RL     2      40      -1         3830250
C        ELEV:                      82.5    82.0    82.0    82.0    82.0    82.0
RL     3      40       0         3930740 3880230 3880230 3880230 3880230 3880230
C        ELEV:                      82.0    82.0    82.0    83.0    84.0    83.0
RL                               3880230 3880230 3880230 3981590 4084210 3981590
C        ELEV:                        87    86.3    85.4    84.7    84.7    84.7
RL     4      40       0         4399800 4325160 4230070 4156820 4156820 4156820
C        ELEV:                      84.7    84.7      85    85.9    87.3    87.5
RL                               4156820 4156820 4188100 4282800 4432050 4453580
C   Gatun Spill Curve from PCC OPERDATA.BAS dated 6-23-94
C        ELEV:                     87.75   87.75   87.75   87.75    86.5    86.5
RL     5      40       0         4480570 4480570 4480570 4480570 4346420 4346420
C        ELEV:                      86.5    86.5    86.5    86.8    87.4    87.5
RL                               4346420 4346420 4346420 4378440 4442800 4480570
RL     6      40      -1         6384700
RO
C   Reservoir storage from path = /PCC/GAT/ELEV-CAPAC(ACFT)///OBS/
C   Reservoir maximum outflow from StoneyGAT.xls, data for 14 gates ELEV=78'-92'
C   Reservoir areas from path =   /PCC/GAT/ELEV-AREA(ACRES)///OBS/
C   data below elev. 77 and above 90 was extrapolated
RS   -21       0   833.7  1781.7  2729.7  3393.3  3488.1  3584.2  3681.6  3780.3
RS3880.2  3981.6  4084.2  4188.1  4293.3  4399.8  4507.6  4616.7  4727.2  5279.7
RS5832.2  6384.7
RQ    21       0       0       0    1890   42790   58878   69463   80672   92479
RQ104860  117796  131268  145260  159756  174743  190208  206139  222525  300000
RQ350000  400000
RA    21       0   56544   70404   84264   93966   95353   96740   98127   99414
RA100702  101990  103277  104566  105853  107141  108382  109670  110957  117392
RA123827  130262
RE    21      40      50      60      70      77      78      79      80      81
RE    82      83      84      85      86      87      88      89      90      95
RE   100     105
C ====== Hydropower Data
P1    40   24000       1               9             .85
```

```
C   Penstock Capacity Estimated from Operation Data Sheets
P2    27    4550
PR
PR
C    Channel Capacity Based on Limiting Non-spill Releases to Power Operation
CP    40    4550
IDGAT
RT    40     200
C    Diversion Data include Total Lockage and M&I water supply
C    Data for calibration from:  A=PCC B=GAT C=FLOW-LOCKS+MUNI F=COMP-HEC
DR    40                                                   -5           1.0
C    Comment out: Diversions are 5 year average for Total Lockage and M&I
C      12     3326     3325     3333     3233     3088     2943     2941     2983     2899
C   3092     2965     3081

C ============= Caribbean Sea ==========================================
CP   200  999999
IDCARIBBEAN SEA
RT   200

ED
BF      2      223                   80010100              720                       1900
C ===== PCC EVAPORATION INPUT IN INCHES ======================================
ZR=EV40 A=PCC B=GAT C=EVAP F=OBS
ZR=EV50 A=PCC B=MAD C=EVAP F=OBS
C ===== OBSERVED POOL ELEVATIONS READ AS OBSERVED FLOW FOR COMPARISON =========
ZR=NQ40 A=PCC B=GAT C=ELEV F=OBS
ZR=NQ50 A=PCC B=MAD C=ELEV F=OBS
C ===== INFLOW INCREMENTAL COMPUTED BY HEC ===================================
ZR=IN40 A=PCC B=GAT C=FLOW-IN-INC F=COMP-HEC
ZR=IN50 A=PCC B=MAD C=FLOW-IN F=COMP-HEC
C ===== DIVERSIONS FOR MUNICIPAL AND LOCKAGE =================================
ZR=QD40 A=PCC B=GAT C=FLOW-LOCKS+MUNI F=COMP-HEC
ZR=QD50 A=PCC B=MAD C=FLOW-MUNI F=COMP-HEC
ZW   A=PCC   F=CALIBRATION-1980RC
EJ
ER
```

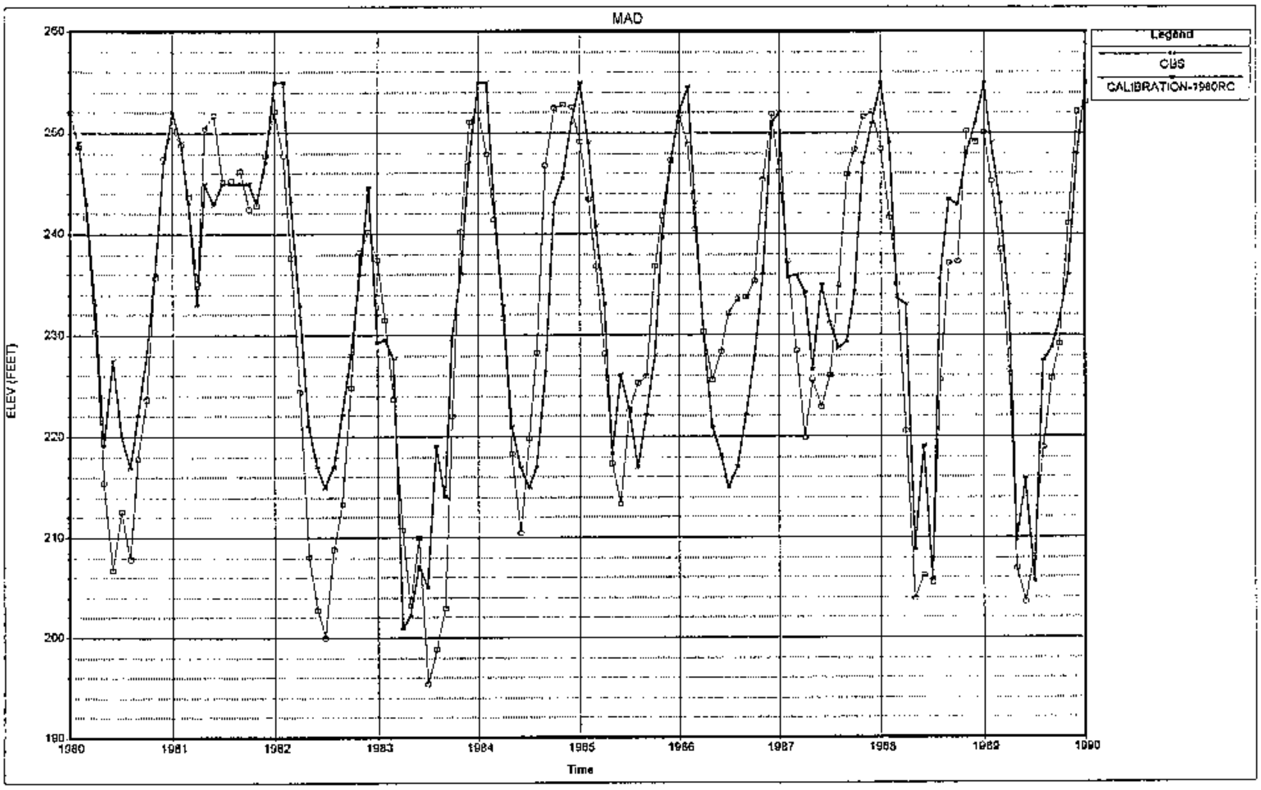

Figure 1. Madden Pool Elevation, Observed and Calibration (1980 - 1990)

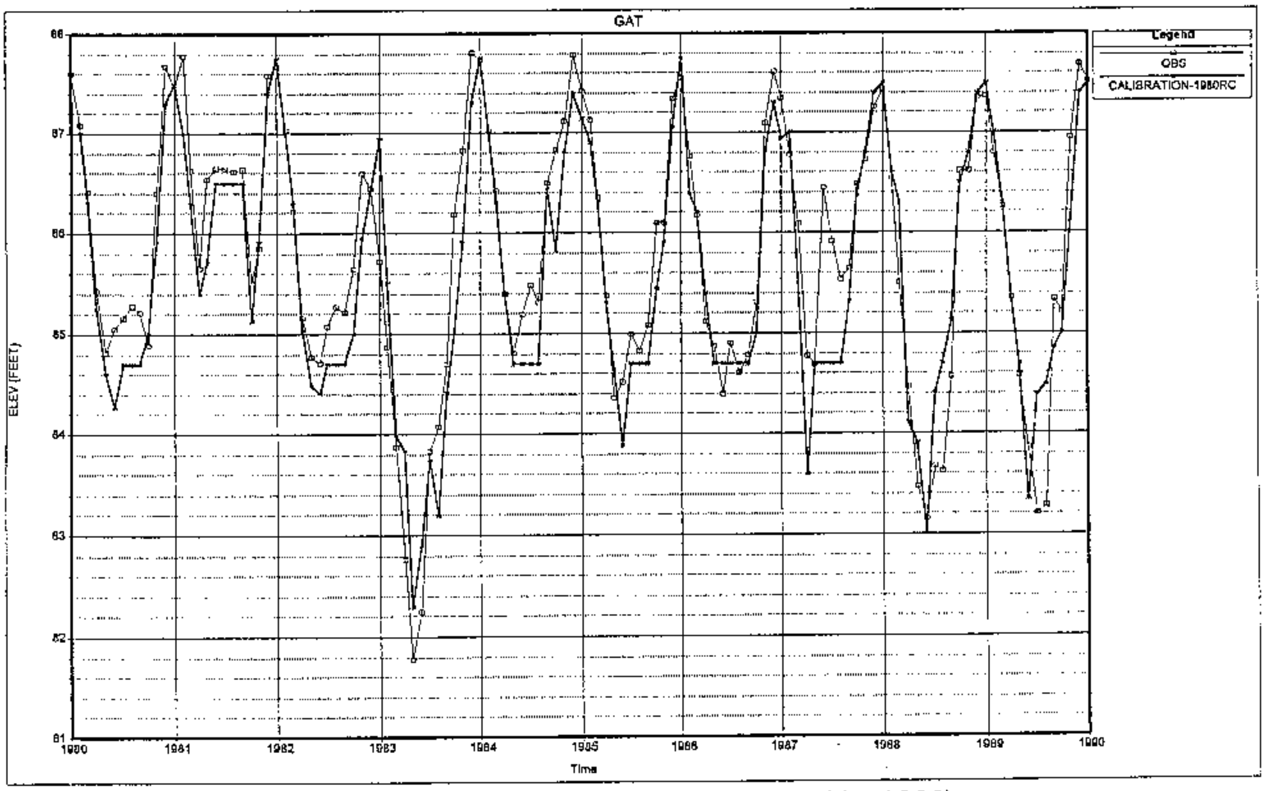

Figure 2. Gatun Pool Elevation, Observed and Calibration (1980 - 1990)

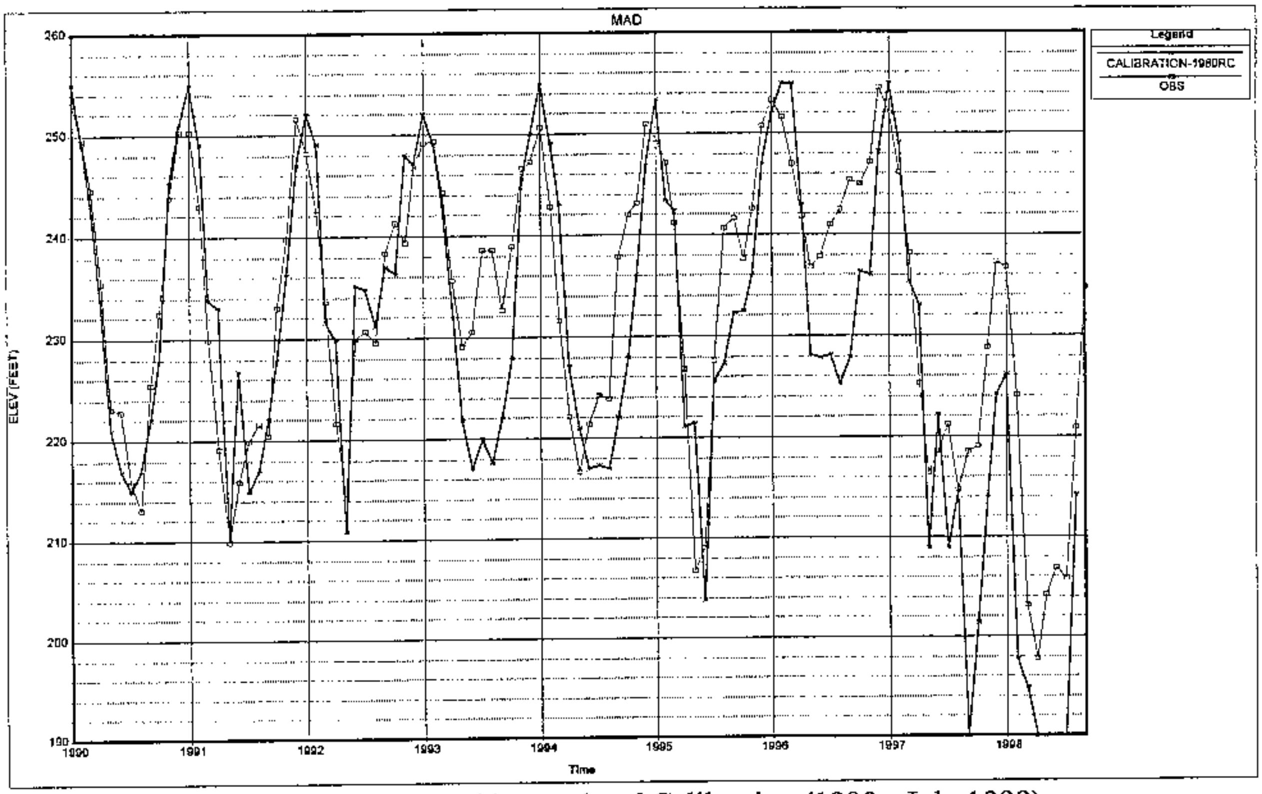

Figure 3. Madden Pool Elevation, Observed and Calibration (1990 - July 1998)

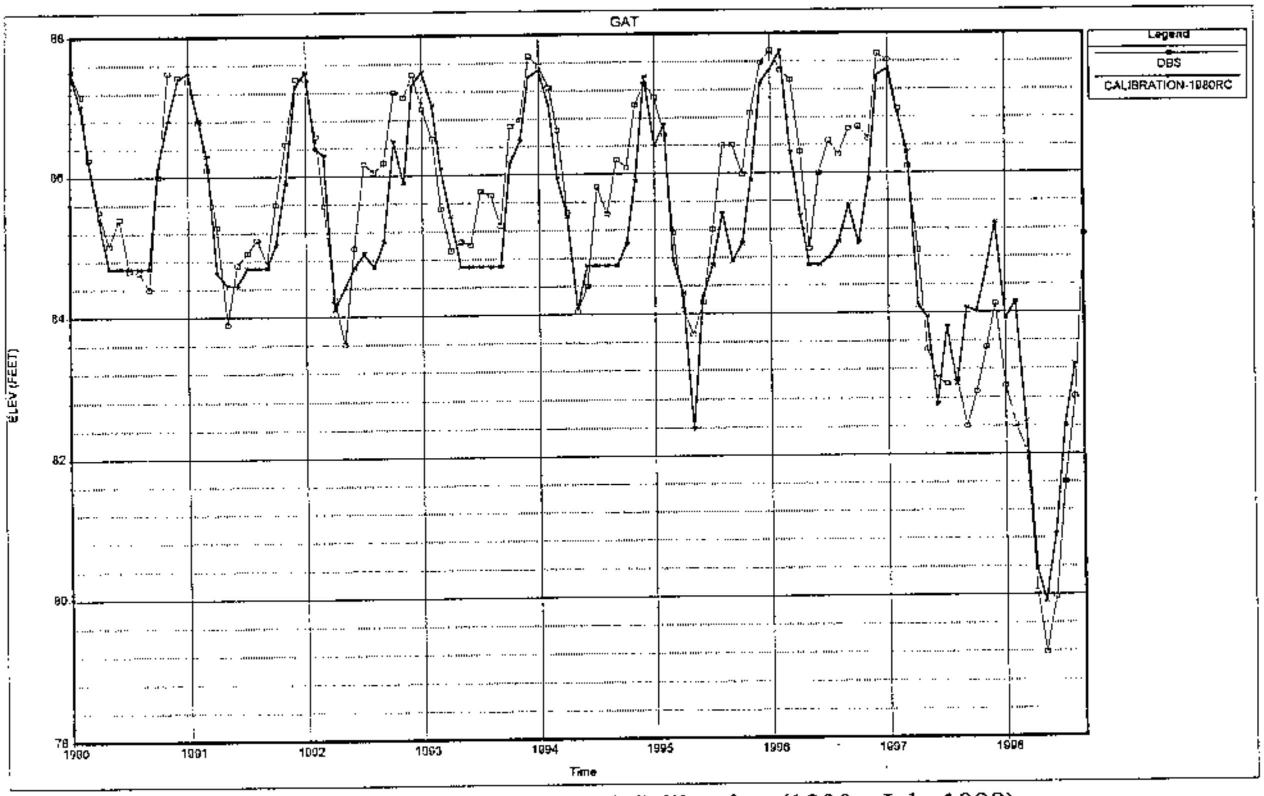

Figure 4. Gatun Pool Elevation, Observed and Calibration (1990 - July 1998)

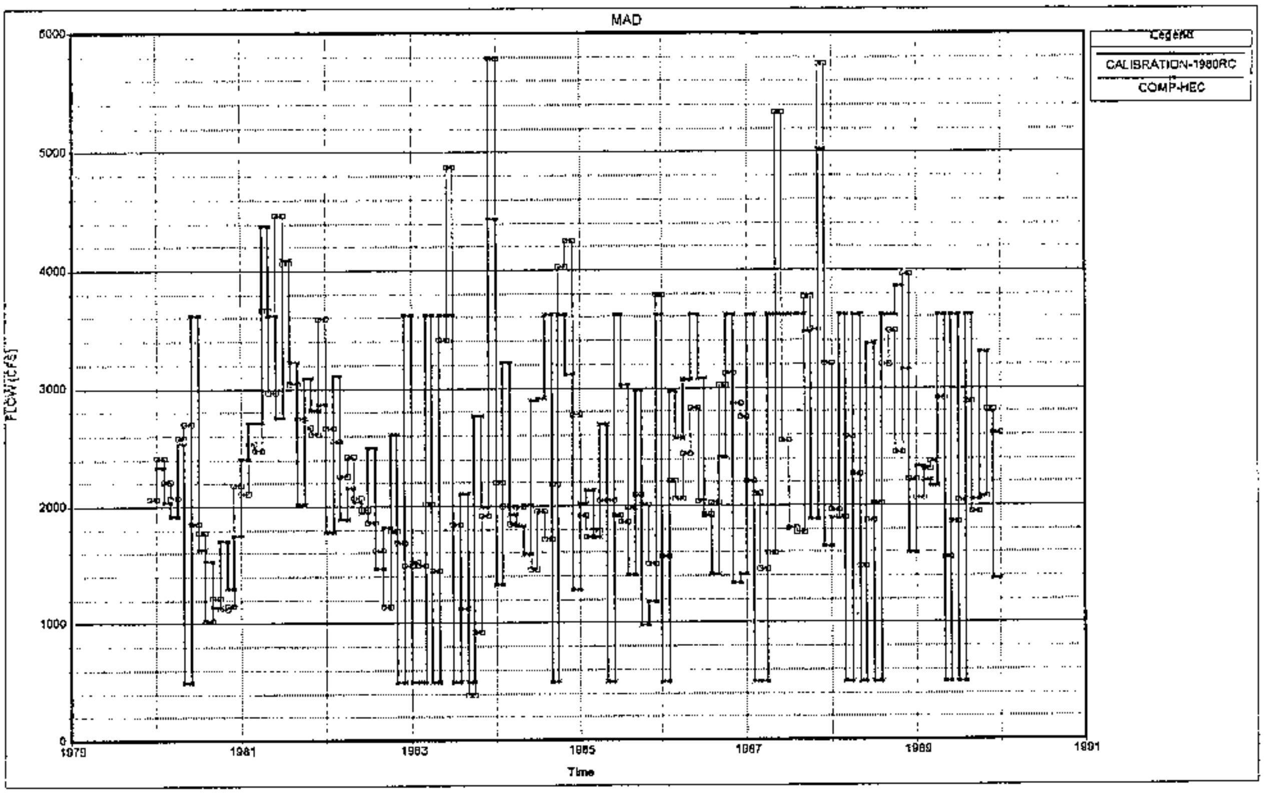

Figure 5. Madden Releases, Observed and Calibration (1980 - 1990)

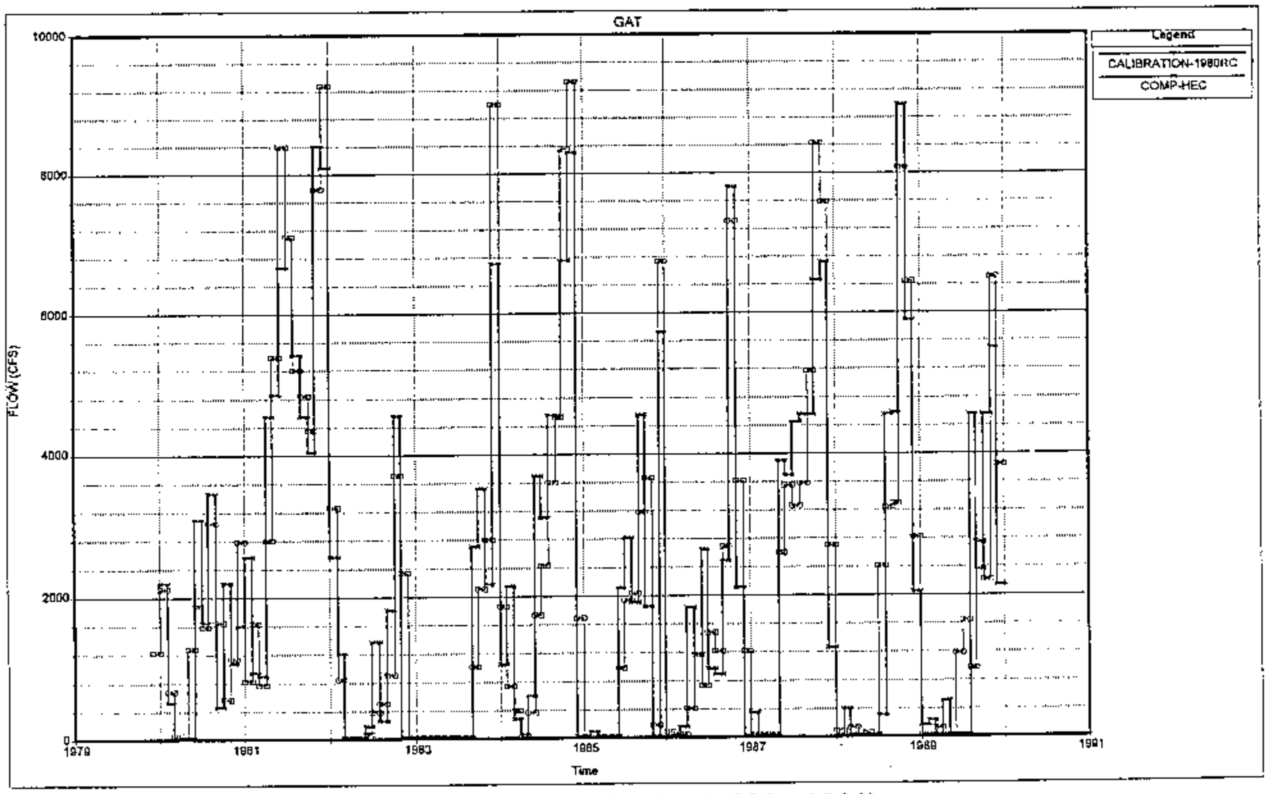

Figure 6. Gatun Releases, Observed and Calibration (1980 - 1990)

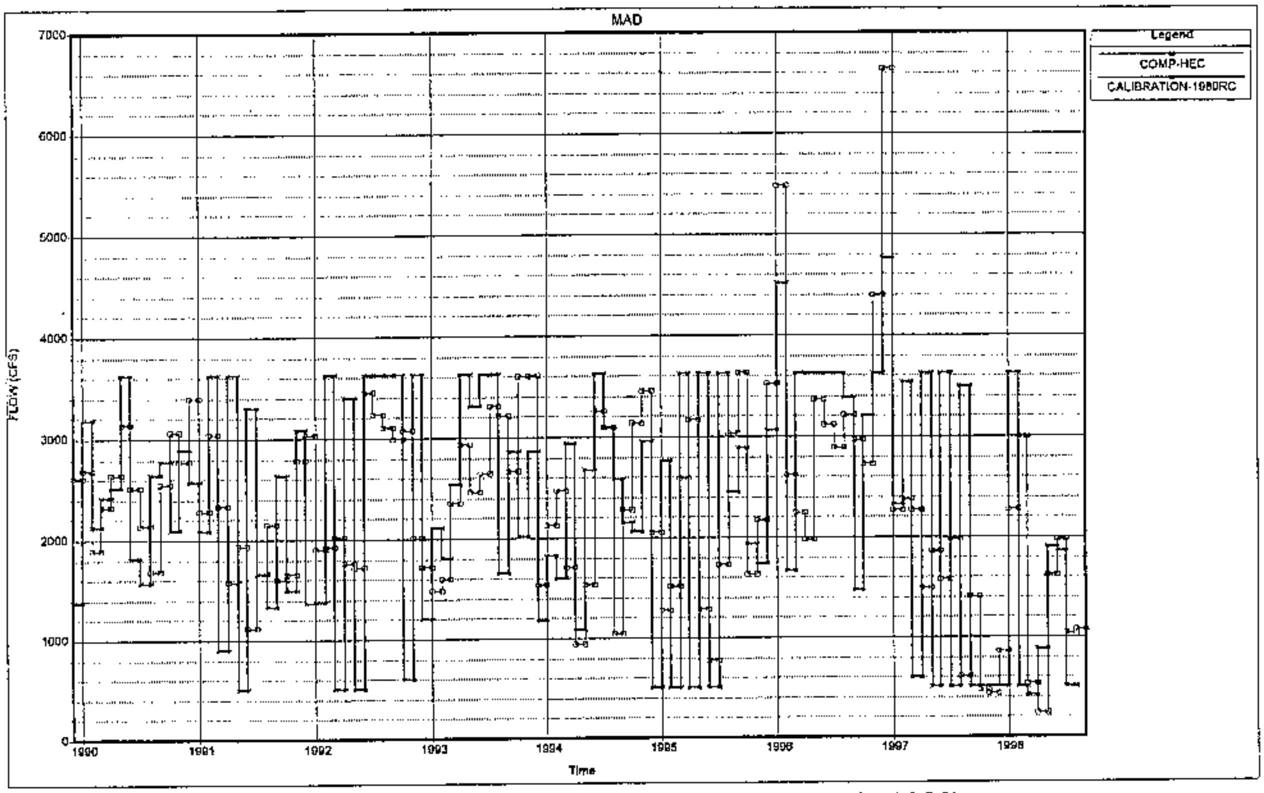

Figure 7. Madden Releases, Observed and Calibration (1990 - July 1998)

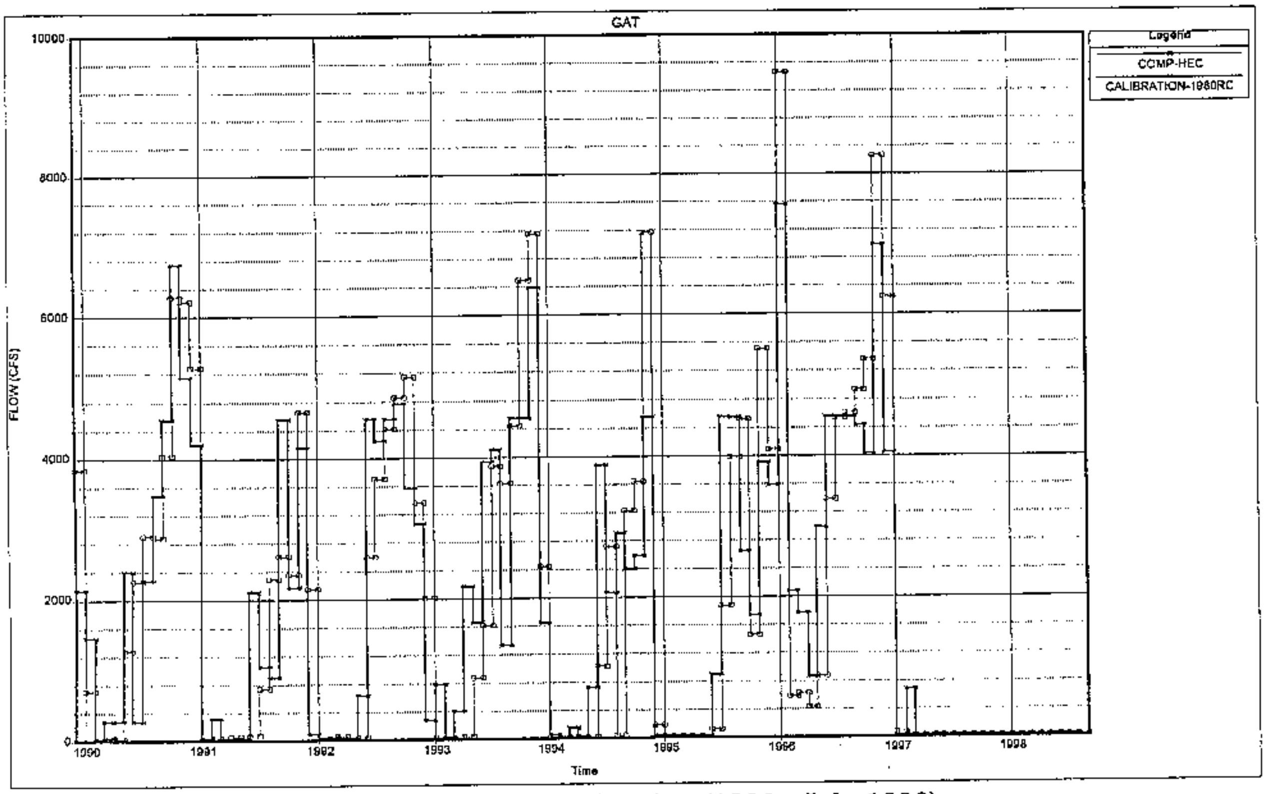

Figure 8. Gatun Releases, Observed and Calibration (1990 - July 1998)

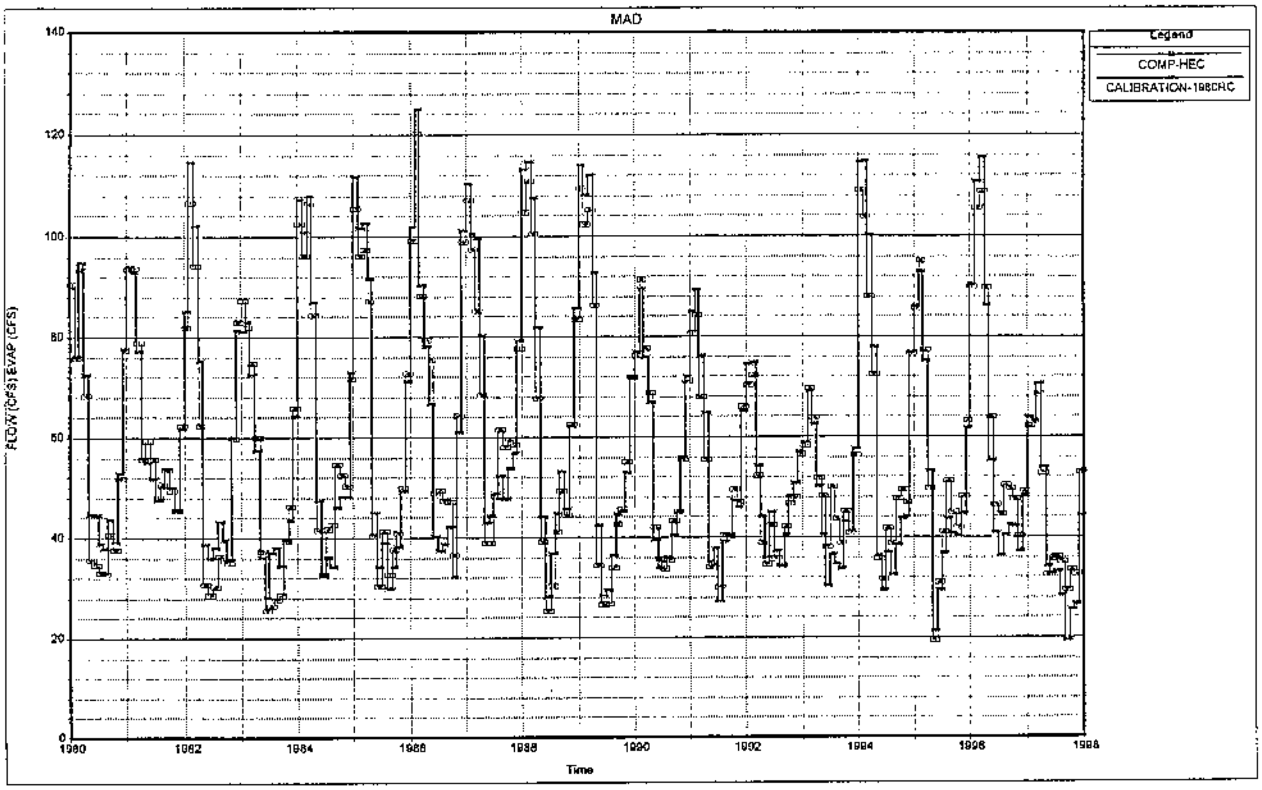

Figure 9. Madden Reservoir Evaporation, Computed and Calibration (1980 - July 1998)

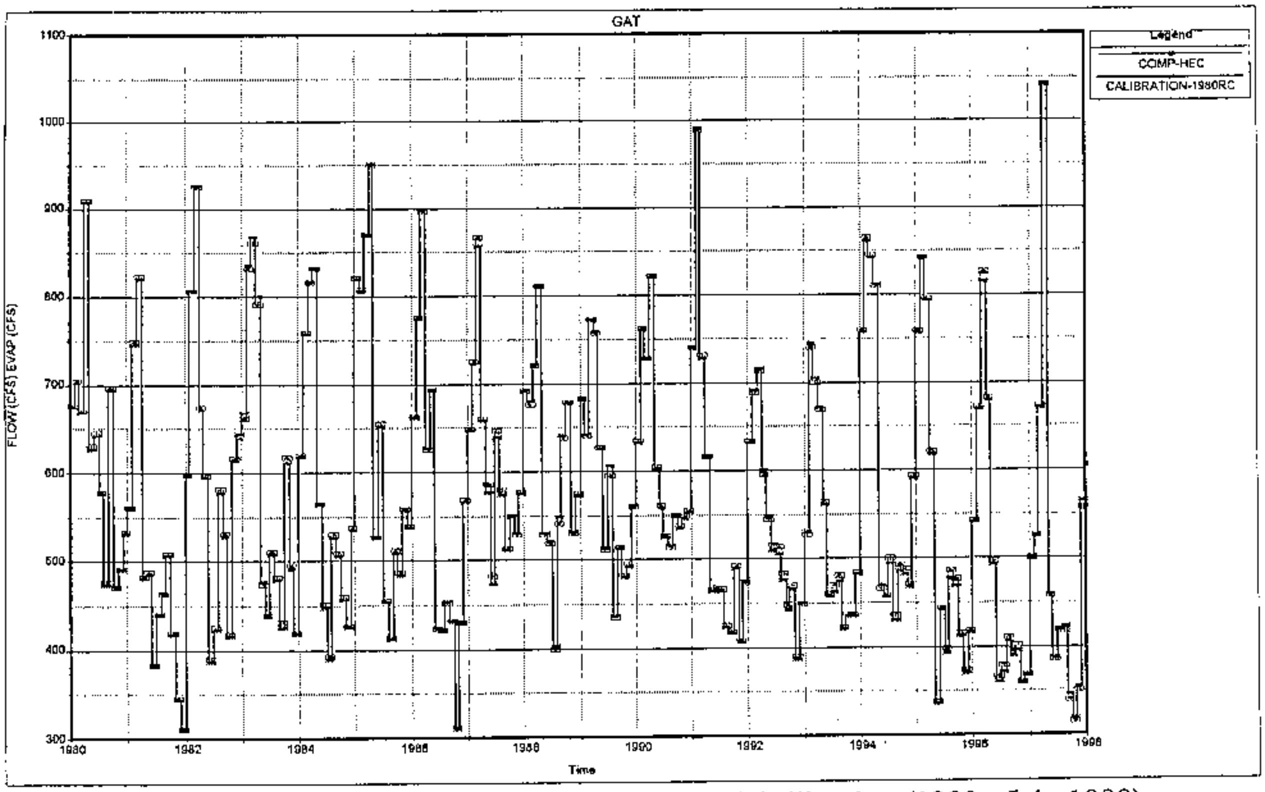

Figure 10. Gatun Reservoir Evaporation, Computed and Calibration (1980 - July 1998)

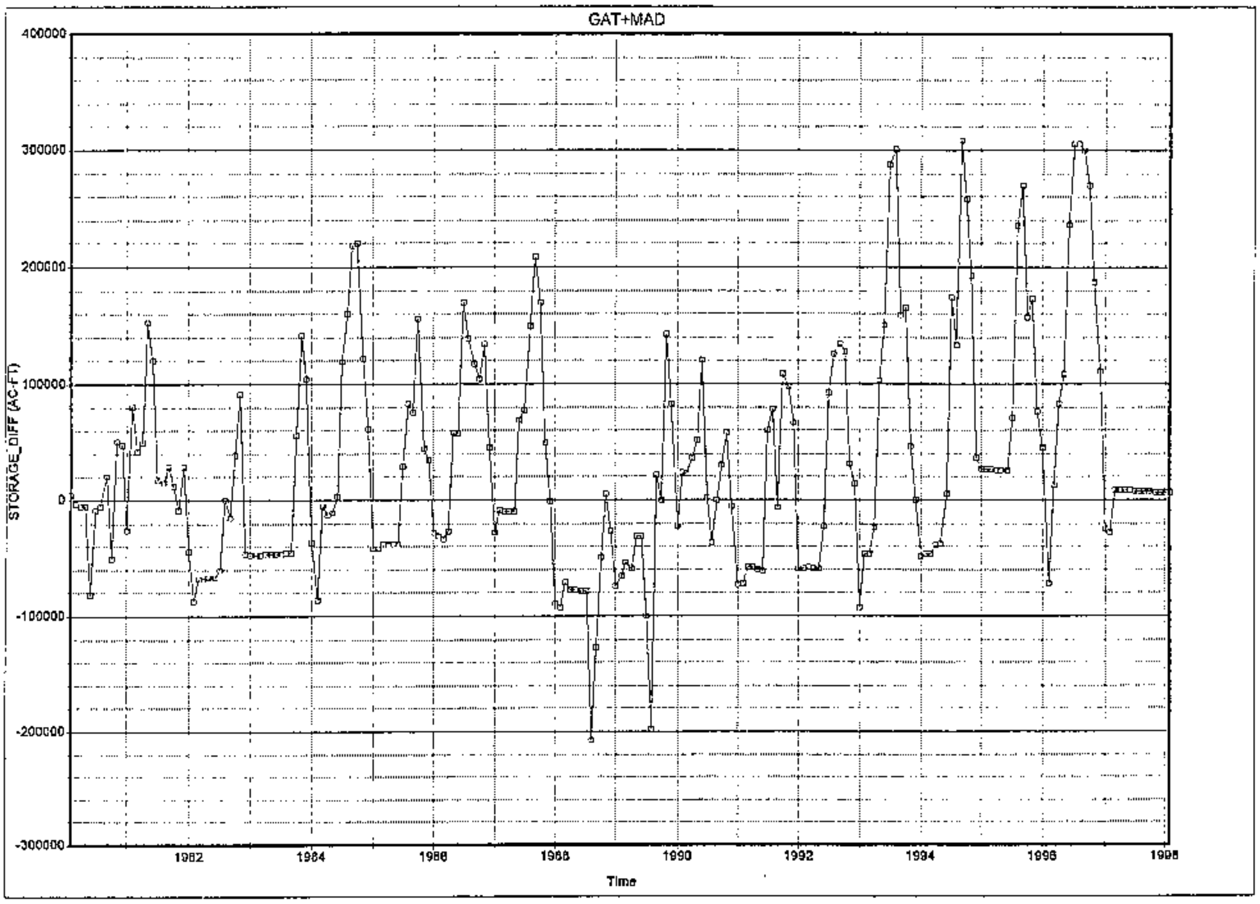

Figure 11. System (Madden + Gatun) Storage Difference (Observed - Calibration)

Table 2. Madden and Gatun Reservoir Elevations
(Observed and Calibration Model using Historic Demand Data)

Date	MADDEN ELEV. OBSERVED Feet	MADDEN ELEV. CALIBRATION Feet	GATUN ELEV. OBSERVED Feet	GATUN ELEV. CALIBRATION Feet
31Jan1980	248.59	249.00	87.09	87.00
29Feb1980	241.64	242.99	86.41	86.30
31Mar1980	230.46	232.99	85.43	85.25
30Apr1980	215.53	219.09	84.82	84.61
31May1980	206.79	227.57	85.05	84.27
30Jun1980	212.57	220.00	85.16	84.70
31Jul1980	207.80	217.00	85.28	84.70
31Aug1980	217.81	222.00	85.22	84.70
30Sep1980	223.70	228.00	84.89	85.00
31Oct1980	235.74	236.00	86.40	85.90
30Nov1980	247.50	247.00	87.68	87.30
31Dec1980	250.34	252.00	87.45	87.50
31Jan1981	248.82	249.00	87.77	87.00
28Feb1981	243.65	242.99	86.62	86.30
31Mar1981	235.16	232.99	85.66	85.40
30Apr1981	250.39	245.00	86.54	85.70
31May1981	251.69	242.91	86.65	86.50
30Jun1981	245.18	245.00	86.64	86.50
31Jul1981	245.30	245.00	86.61	86.50
31Aug1981	246.29	245.00	86.63	86.50
30Sep1981	242.51	245.00	85.51	85.13
31Oct1981	242.79	243.04	85.85	85.90
30Nov1981	247.77	247.00	87.58	87.40
31Dec1981	252.18	255.00	87.67	87.75
31Jan1982	247.69	255.00	87.03	87.00
28Feb1982	237.61	242.99	86.22	86.30
31Mar1982	224.36	232.99	85.16	85.03
30Apr1982	208.08	220.99	84.77	84.48
31May1982	202.81	217.00	84.71	84.41
30Jun1982	200.04	215.00	85.07	84.70
31Jul1982	208.83	217.00	85.27	84.70
31Aug1982	213.30	222.00	85.21	84.70
30Sep1982	224.86	228.00	85.64	85.00
31Oct1982	238.12	236.00	86.59	85.94
30Nov1982	240.22	244.54	86.44	86.42
31Dec1982	237.44	229.21	85.72	86.93
31Jan1983	231.54	229.55	84.87	85.50
28Feb1983	223.67	227.66	83.87	83.98
31Mar1983	210.72	200.94	82.76	83.83
30Apr1983	203.26	202.19	81.77	82.29
31May1983	209.95	207.09	82.25	82.89
30Jun1983	195.40	205.01	83.83	83.74
31Jul1983	198.84	218.99	84.08	83.19
31Aug1983	202.87	214.12	84.70	84.40
30Sep1983	222.05	229.67	86.18	85.00

Date	MADDEN ELEV. OBSERVED Feet	MADDEN ELEV. CALIBRATION Feet	GATUN ELEV. OBSERVED Feet	GATUN ELEV. CALIBRATION Feet
31Oct1983	240.19	236.00	86.82	85.90
30Nov1983	251.07	247.00	87.81	87.30
31Dec1983	252.26	255.00	87.73	87.75
31Jan1984	247.86	255.00	87.02	87.00
29Feb1984	241.39	242.99	86.42	86.30
31Mar1984	231.69	232.99	85.40	85.40
30Apr1984	218.23	220.99	84.81	84.70
31May1984	210.47	217.00	85.19	84.70
30Jun1984	219.80	215.00	85.48	84.70
31Jul1984	228.24	217.00	85.31	84.70
31Aug1984	246.77	226.36	86.49	86.44
30Sep1984	252.50	243.05	86.83	85.82
31Oct1984	252.76	245.54	87.12	86.80
30Nov1984	252.60	250.99	87.78	87.40
31Dec1984	249.19	255.00	87.42	87.14
31Jan1985	243.39	249.00	87.13	86.91
28Feb1985	236.74	240.76	86.35	86.30
31Mar1985	228.20	232.99	85.38	85.30
30Apr1985	217.28	218.28	84.36	84.64
31May1985	213.35	225.99	84.52	83.89
30Jun1985	222.59	222.72	84.99	84.70
31Jul1985	225.32	217.00	84.83	84.70
31Aug1985	225.91	222.00	85.09	84.70
30Sep1985	236.75	228.00	86.10	85.44
31Oct1985	241.80	239.70	86.10	85.90
30Nov1985	247.33	247.00	87.34	87.05
31Dec1985	251.69	252.18	87.55	87.75
31Jan1986	248.79	254.56	86.76	86.39
28Feb1986	240.39	242.99	86.17	86.21
31Mar1986	230.32	230.02	85.12	85.40
30Apr1986	225.61	220.99	84.87	84.70
31May1986	228.37	218.18	84.40	84.70
30Jun1986	232.17	215.00	84.90	84.70
31Jul1986	233.53	217.00	84.61	84.70
31Aug1986	233.75	222.00	84.78	84.70
30Sep1986	235.38	228.00	85.31	85.00
31Oct1986	245.37	236.05	87.10	86.80
30Nov1986	251.94	250.99	87.61	87.30
31Dec1986	246.12	252.00	87.34	86.94
31Jan1987	237.26	235.71	86.77	87.00
28Feb1987	228.52	235.91	86.09	85.49
31Mar1987	219.90	234.15	84.77	83.60
30Apr1987	225.54	226.54	84.69	84.70
31May1987	222.86	235.00	86.44	84.70
30Jun1987	225.99	231.31	85.91	84.70
31Jul1987	235.00	228.71	85.54	84.70
31Aug1987	245.95	229.40	85.64	85.32
30Sep1987	248.43	234.28	86.48	86.35
31Oct1987	251.61	246.89	86.73	86.80
30Nov1987	252.13	250.99	87.26	87.40
31Dec1987	248.40	255.00	87.43	87.50

Date	MADDEN ELEV. OBSERVED Feet	MADDEN ELEV. CALIBRATION Feet	GATUN ELEV. OBSERVED Feet	GATUN ELEV. CALIBRATION Feet
31Jan1988	241.66	249.00	86.54	86.60
29Feb1988	235.03	233.63	85.50	86.30
31Mar1988	220.53	232.97	84.46	84.11
30Apr1988	203.92	208.86	83.47	83.90
31May1988	206.26	219.04	83.15	83.01
30Jun1988	205.45	205.88	83.68	84.41
31Jul1988	225.62	235.56	83.62	84.70
31Aug1988	237.07	243.42	84.57	85.12
30Sep1988	237.32	242.88	86.61	86.50
31Oct1988	250.17	248.00	86.61	86.80
30Nov1988	249.15	250.99	87.36	87.40
31Dec1988	250.15	255.00	87.37	87.50
31Jan1989	245.29	249.00	86.80	87.00
28Feb1989	238.50	242.99	86.26	86.30
31Mar1989	226.52	232.99	85.36	85.34
30Apr1989	206.91	209.73	84.58	84.70
31May1989	203.59	215.77	83.86	83.35
30Jun1989	208.81	205.56	83.20	84.37
31Jul1989	218.89	227.40	83.28	84.49
31Aug1989	225.71	228.72	85.33	84.85
30Sep1989	229.14	231.37	85.20	85.00
31Oct1989	241.03	236.00	86.95	86.11
30Nov1989	252.20	247.93	87.69	87.40
31Dec1989	253.09	255.00	87.52	87.50
31Jan1990	249.52	249.00	87.16	87.00
28Feb1990	244.66	242.99	86.25	86.21
31Mar1990	235.48	232.99	85.51	85.40
30Apr1990	223.09	220.99	85.02	84.70
31May1990	222.79	217.04	85.40	84.70
30Jun1990	215.76	215.00	84.67	84.70
31Jul1990	213.12	217.00	84.63	84.70
31Aug1990	225.48	222.00	84.41	84.70
30Sep1990	232.51	228.00	86.01	86.14
31Oct1990	243.86	245.22	87.49	86.80
30Nov1990	250.31	250.99	87.43	87.40
31Dec1990	250.31	255.00	87.37	87.50
31Jan1991	243.02	249.00	86.79	86.81
28Feb1991	229.89	233.71	86.11	86.30
31Mar1991	219.14	232.99	85.28	84.64
30Apr1991	209.90	210.37	83.90	84.44
31May1991	215.88	226.80	84.74	84.45
30Jun1991	219.87	215.00	84.91	84.70
31Jul1991	221.57	217.00	85.10	84.70
31Aug1991	220.43	222.00	84.76	84.70
30Sep1991	232.97	228.00	85.60	85.02
31Oct1991	239.77	236.19	86.46	85.90
30Nov1991	251.64	247.00	87.40	87.30
31Dec1991	248.19	252.00	87.38	87.50
31Jan1992	242.30	249.00	86.57	86.39
29Feb1992	233.60	231.62	85.57	86.30
31Mar1992	221.62	229.83	84.24	84.10

	MADDEN ELEV. OBSERVED	MADDEN ELEV. CALIBRATION	GATUN ELEV. OBSERVED	GATUN ELEV. CALIBRATION
Date	Feet	Feet	Feet	Feet
30Apr1992	214.16	210.85	83.61	84.41
31May1992	230.05	235.19	84.97	84.70
30Jun1992	230.69	234.75	86.17	84.90
31Jul1992	229.52	231.20	86.05	84.70
31Aug1992	238.43	236.95	86.19	85.06
30Sep1992	241.33	236.37	87.20	86.50
31Oct1992	239.35	248.00	87.12	85.90
30Nov1992	246.79	247.00	87.45	87.30
31Dec1992	249.18	252.00	86.96	87.50
31Jan1993	249.36	249.00	86.53	87.00
28Feb1993	244.34	242.99	85.52	86.10
31Mar1993	235.58	232.99	84.93	85.40
30Apr1993	229.17	221.69	85.05	84.70
31May1993	230.59	217.00	85.01	84.70
30Jun1993	238.62	219.98	85.77	84.70
31Jul1993	238.59	217.64	85.71	84.70
31Aug1993	232.71	222.00	85.28	84.70
30Sep1993	238.95	228.00	86.69	86.16
31Oct1993	246.53	245.45	86.79	86.48
30Nov1993	247.22	249.89	87.70	87.40
31Dec1993	250.67	255.00	87.55	87.50
31Jan1994	242.82	249.00	87.24	87.00
28Feb1994	231.60	242.99	86.63	85.94
31Mar1994	222.16	227.09	85.45	85.40
30Apr1994	216.66	220.99	84.05	84.08
31May1994	221.36	217.00	84.41	84.70
30Jun1994	224.14	217.28	85.82	84.70
31Jul1994	223.87	217.00	85.43	84.70
31Aug1994	237.85	222.00	86.20	84.70
30Sep1994	242.01	228.00	86.09	85.00
31Oct1994	243.09	236.00	86.99	85.90
30Nov1994	250.95	247.00	87.29	87.39
31Dec1994	249.46	253.36	87.09	86.39
31Jan1995	247.10	243.41	86.56	86.71
28Feb1995	241.17	242.38	85.16	84.78
31Mar1995	226.81	221.12	84.07	84.29
30Apr1995	206.73	221.45	83.71	82.38
31May1995	209.04	203.74	84.17	84.25
30Jun1995	227.59	225.63	85.21	84.70
31Jul1995	240.60	227.35	86.40	85.44
31Aug1995	241.57	232.27	86.40	84.76
30Sep1995	237.62	232.43	85.99	85.00
31Oct1995	242.60	236.00	86.86	85.90
30Nov1995	250.76	247.00	87.59	87.30
31Dec1995	253.34	252.00	87.76	87.50
31Jan1996	251.58	255.00	87.48	87.75
29Feb1996	247.04	255.00	87.34	86.30
31Mar1996	241.79	242.94	86.31	85.40
30Apr1996	236.76	228.22	84.93	84.70
31May1996	237.90	227.83	86.00	84.70
30Jun1996	240.93	228.19	86.47	84.80

	MADDEN ELEV. OBSERVED	MADDEN ELEV. CALIBRATION	GATUN ELEV. OBSERVED	GATUN ELEV. CALIBRATION
Date	Feet	Feet	Feet	Feet
31Jul1996	242.52	225.27	86.27	85.02
31Aug1996	245.39	227.80	86.64	85.54
30Sep1996	244.93	236.34	86.66	85.00
31Oct1996	247.11	236.00	86.50	85.90
30Nov1996	254.51	248.22	87.71	87.40
31Dec1996	251.99	255.00	87.62	87.50
31Jan1997	246.10	249.00	86.93	86.87
28Feb1997	238.20	235.36	86.10	86.30
31Mar1997	225.31	232.99	84.90	84.12
30Apr1997	216.42	208.90	83.49	83.94
31May1997	218.59	222.16	83.07	82.70
30Jun1997	221.13	208.92	82.99	83.81
31Jul1997	214.73	214.61	83.05	82.99
31Aug1997	218.50	190.00	82.40	84.06
30Sep1997	219.08	201.43	82.89	84.02
31Oct1997	228.77	214.05	83.51	84.64
30Nov1997	237.31	224.24	84.13	85.28
31Dec1997	236.74	226.11	82.96	83.91
31Jan1998	224.08	197.76	82.41	84.16
28Feb1998	203.11	194.84	82.06	82.45
31Mar1998	197.72	190.00	80.04	80.37
30Apr1998	204.20	190.00	79.19	79.91
31May1998	206.89	190.00	79.97	80.85
30Jun1998	205.80	190.00	81.60	82.40
31Jul1998	220.88	214.18	82.81	83.26

Table 3. Madden and Gatun Reservoir Releases
(COMP-HEC = "Observed" and CALIBRATION Model using Historic Demand Data)

Date	MADDEN COMP-HEC CFS	MADDEN CALIBRATION CFS	GATUN COMP-HEC CFS	GATUN CALIBRATION CFS
31Jan1980	2410.98	2331.57	2112.57	2194.54
29Feb1980	2215.08	2035.25	669.16	525.49
31Mar1980	2073.84	1915.46	64.71	27.00
30Apr1980	2583.27	2530.16	27.00	27.00
31May1980	2704.44	500.00	1272.89	27.00
30Jun1980	1856.42	3624.00	1870.36	3092.07
31Jul1980	1780.75	1628.19	1584.27	1637.87
31Aug1980	1018.73	1529.64	3043.73	3455.44
30Sep1980	1219.07	1143.42	1645.83	464.47
31Oct1980	1120.28	1704.18	571.35	2203.38
30Nov1980	1155.80	1299.61	1137.72	1079.52
31Dec1980	2180.62	1751.64	2783.12	1600.56
31Jan1981	2113.04	2409.34	829.34	2563.91
28Feb1981	2536.12	2709.30	1632.90	930.55
31Mar1981	2475.57	2710.88	767.37	897.14
30Apr1981	3668.15	4381.74	2800.92	4550.00
31May1981	2971.01	3624.00	5384.67	4854.42
30Jun1981	4465.99	2755.17	8400.45	6672.08
31Jul1981	4068.31	4091.69	7104.73	7076.60
31Aug1981	3040.83	3230.25	5202.48	5427.26
30Sep1981	2749.55	2016.70	4844.90	4550.00
31Oct1981	2671.58	3086.63	4352.72	4033.48
30Nov1981	2616.45	2819.57	7789.73	8409.59
31Dec1981	3596.01	2868.62	9282.52	8099.29
31Jan1982	2666.73	1775.43	3260.65	2563.66
28Feb1982	2549.76	3103.81	851.65	1194.00
31Mar1982	2256.41	1888.23	31.11	27.00
30Apr1982	2423.55	2152.88	27.00	27.00
31May1982	2070.48	2039.94	32.60	27.00
30Jun1982	1971.39	1947.54	77.15	179.07
31Jul1982	1862.14	2500.35	386.92	1368.36
31Aug1982	1623.57	1465.79	510.87	254.75
30Sep1982	1144.61	1811.40	903.93	1808.52
31Oct1982	1788.22	2612.44	3698.97	4550.00
30Nov1982	1690.91	500.00	2338.34	27.00
31Dec1982	1494.01	3624.00	30.73	27.00
31Jan1983	1518.66	500.00	33.72	27.00
28Feb1983	1491.15	500.00	27.41	27.00
31Mar1983	2018.21	3624.00	27.00	27.00
30Apr1983	1445.93	500.00	27.00	27.00
31May1983	3412.32	3624.00	27.00	27.00
30Jun1983	4872.24	3624.00	27.00	27.00
31Jul1983	1840.12	500.00	27.00	27.00
31Aug1983	1120.66	2099.11	27.00	27.00
30Sep1983	386.51	500.00	1008.87	2701.75
31Oct1983	921.66	2763.73	2102.12	3519.23
30Nov1983	1916.22	1994.56	2797.06	2161.68

Date	MADDEN COMP-HEC CFS	MADDEN CALIBRATION CFS	GATUN COMP-HEC CFS	GATUN CALIBRATION CFS
31Dec1983	5792.47	4433.07	8998.40	6710.87
31Jan1984	2200.78	1324.56	1851.60	1046.52
29Feb1984	2003.16	3218.25	735.01	2134.54
31Mar1984	1847.21	1928.71	396.25	270.69
30Apr1984	1994.15	1828.99	30.86	58.61
31May1984	1996.93	1580.70	368.62	599.51
30Jun1984	1456.73	2892.58	1742.28	3694.01
31Jul1984	1955.86	2915.16	2432.17	3104.89
31Aug1984	1712.43	3624.00	3586.96	4550.00
30Sep1984	2183.19	500.00	4510.02	4550.00
31Oct1984	4031.72	3624.00	8349.88	6753.07
30Nov1984	4246.46	3115.76	9317.12	8300.37
31Dec1984	2778.36	1279.82	1695.53	27.00
31Jan1985	1918.52	2014.75	35.59	27.00
28Feb1985	1730.07	2132.70	28.24	98.65
31Mar1985	1786.73	1730.55	27.00	27.00
30Apr1985	2048.93	2690.61	28.93	27.00
31May1985	2048.45	500.00	27.75	27.00
30Jun1985	1918.92	3624.00	986.49	2102.17
31Jul1985	1865.88	3019.06	1934.48	2817.05
31Aug1985	1980.50	1406.85	2031.18	1900.77
30Sep1985	2090.99	2973.83	3179.78	4550.00
31Oct1985	2008.50	980.46	3653.42	1842.48
30Nov1985	1505.34	1184.05	182.86	27.00
31Dec1985	3786.05	3624.00	6737.35	5723.20
31Jan1986	1564.58	500.00	92.71	27.00
28Feb1986	2211.22	2969.40	59.24	27.00
31Mar1986	2051.81	2569.23	52.01	158.24
30Apr1986	2444.00	3066.35	417.43	1830.68
31May1986	2829.51	3624.00	1164.62	1162.98
30Jun1986	2038.90	3074.07	733.40	2642.21
31Jul1986	1927.11	1911.50	1468.91	962.27
31Aug1986	2023.81	1406.22	1213.90	883.39
30Sep1986	3026.94	2414.19	2692.89	2487.01
31Oct1986	3126.70	3624.00	7310.82	7804.62
30Nov1986	2865.68	1339.60	3614.58	2111.53
31Dec1986	2757.45	1412.79	1213.90	27.00
31Jan1987	2212.35	3624.00	40.44	355.82
28Feb1987	2104.16	500.00	51.39	27.00
31Mar1987	1453.69	500.00	35.96	27.00
30Apr1987	1593.30	3624.00	47.06	35.67
31May1987	5340.71	3624.00	2602.42	3892.09
30Jun1987	2548.93	3624.00	3553.62	3693.07
31Jul1987	1806.14	3624.00	3252.06	4442.07
31Aug1987	1767.31	3624.00	3578.00	4550.00
30Sep1987	3772.31	3472.81	5180.93	4550.00
31Oct1987	3493.71	1875.72	8426.79	6468.73
30Nov1987	5742.22	5020.78	7583.71	6734.72
31Dec1987	3205.11	1647.21	2698.00	1262.77
31Jan1988	1958.84	1890.74	85.99	27.00
29Feb1988	1898.59	3624.00	27.80	400.84

Date	MADDEN COMP-HEC CFS	MADDEN CALIBRATION CFS	GATUN COMP-HEC CFS	GATUN CALIBRATION CFS
31Mar1988	2584.22	500.00	141.25	27.00
30Apr1988	2269.23	3624.00	40.12	27.00
31May1988	1484.31	500.00	57.62	27.00
30Jun1988	1866.84	3370.93	36.65	27.00
31Jul1988	2021.57	500.00	2419.10	309.39
31Aug1988	3198.39	3624.00	3243.47	4550.00
30Sep1988	3481.03	3624.00	3285.49	4584.01
31Oct1988	2452.79	3865.84	8086.29	8979.74
30Nov1988	3965.60	3147.79	6444.05	5893.94
31Dec1988	2220.57	1599.02	2818.59	2040.03
31Jan1989	2067.12	2332.29	27.75	173.35
28Feb1989	2314.15	2208.40	29.89	230.62
31Mar1989	2375.51	2168.08	128.55	27.00
30Apr1989	2909.66	3624.00	37.03	502.43
31May1989	1560.10	500.00	27.00	27.00
30Jun1989	1859.51	3624.00	1182.86	27.00
31Jul1989	2046.58	500.00	1645.50	27.00
31Aug1989	2882.16	3624.00	970.85	4550.00
30Sep1989	1944.77	2047.98	2728.39	2350.90
31Oct1989	2073.46	3298.08	2205.91	4550.00
30Nov1989	2820.93	2792.28	6508.48	5502.00
31Dec1989	2615.58	1376.48	3843.83	2130.73
31Jan1990	2688.38	3183.94	713.60	1455.56
28Feb1990	1897.48	2129.01	35.27	27.00
31Mar1990	2321.75	2421.31	46.79	272.17
30Apr1990	2642.68	2521.38	36.26	283.57
31May1990	3143.13	3624.00	1269.16	2402.00
30Jun1990	2516.53	1822.17	2257.32	281.89
31Jul1990	2136.19	1569.83	2900.36	2267.58
31Aug1990	1686.29	2650.41	2878.70	3468.46
30Sep1990	2548.16	2771.44	4043.59	4550.00
31Oct1990	3059.50	2097.61	6275.50	6736.84
30Nov1990	2769.23	2891.92	6219.51	5153.12
31Dec1990	3392.53	2575.27	5288.35	4191.16
31Jan1991	2280.30	2089.01	27.75	27.00
28Feb1991	3042.07	3624.00	46.84	305.14
31Mar1991	2336.31	901.84	39.32	27.00
30Apr1991	1583.66	3624.00	60.95	27.00
31May1991	1936.82	500.00	54.26	27.00
30Jun1991	1120.69	3297.91	70.60	2109.88
31Jul1991	1669.49	1654.59	730.78	1040.98
31Aug1991	2147.02	1331.67	2288.80	897.49
30Sep1991	1606.81	2633.14	2607.63	4550.00
31Oct1991	1651.57	1491.90	2342.93	2164.98
30Nov1991	2785.43	3090.93	4652.00	4141.63
31Dec1991	3034.11	1367.92	2150.66	99.53
31Jan1992	1897.99	1375.86	27.37	27.00
29Feb1992	1925.73	3624.00	27.40	49.31
31Mar1992	2020.45	500.00	55.75	27.00
30Apr1992	1765.76	3399.85	40.50	27.00
31May1992	1717.65	500.00	40.07	628.63

	MADDEN COMP-HEC	MADDEN CALIBRATION	GATUN COMP-HEC	GATUN CALIBRATION
Date	CFS	CFS	CFS	CFS
30Jun1992	3447.47	3624.00	2601.07	4550.00
31Jul1992	3233.86	3624.00	3703.82	4240.63
31Aug1992	3105.42	3624.00	4402.00	4550.00
30Sep1992	2989.91	3624.00	4856.86	4762.14
31Oct1992	3075.18	602.35	5139.00	3566.07
30Nov1992	2008.81	3623.85	3358.02	3063.14
31Dec1992	1723.63	1202.82	2007.66	280.05
31Jan1993	1480.95	2111.92	27.00	783.36
28Feb1993	1606.47	1805.10	29.48	27.00
31Mar1993	2359.46	2535.51	27.75	391.81
30Apr1993	2937.44	3624.00	43.98	2169.70
31May1993	2459.52	3309.21	873.40	1657.84
30Jun1993	2646.16	3624.00	1614.96	3938.03
31Jul1993	3308.90	3624.00	3878.18	4097.43
31Aug1993	3211.08	1655.36	3619.44	1333.19
30Sep1993	2671.62	2863.03	4436.72	4550.00
31Oct1993	3601.24	2024.97	6492.42	4550.00
30Nov1993	3617.22	2864.25	7163.19	6397.38
31Dec1993	1542.18	1180.51	2447.85	1649.00
31Jan1994	2131.71	1830.91	28.12	61.49
28Feb1994	2475.77	1607.03	27.00	27.00
31Mar1994	1706.08	2936.71	27.00	147.18
30Apr1994	940.91	1081.60	27.00	27.00
31May1994	1538.07	2679.87	30.73	728.81
30Jun1994	3258.04	3624.00	1023.91	3872.79
31Jul1994	3094.22	3096.04	2723.76	2063.50
31Aug1994	1037.77	2580.75	39.32	2910.22
30Sep1994	2274.24	2149.88	3233.02	2395.19
31Oct1994	3140.15	2064.68	3634.38	2584.14
30Nov1994	3447.08	2958.28	7171.67	4550.00
31Dec1994	2057.04	500.00	178.21	27.00
31Jan1995	1281.57	2761.84	31.11	27.00
28Feb1995	1513.88	500.00	27.00	27.00
31Mar1995	2594.30	3624.00	27.00	27.00
30Apr1995	3174.32	500.00	32.79	27.00
31May1995	1288.67	3624.00	31.85	27.00
30Jun1995	778.49	500.00	121.14	887.88
31Jul1995	1735.58	3624.00	1874.00	4550.00
31Aug1995	3035.23	2452.79	3972.64	4550.00
30Sep1995	3630.34	2887.20	4523.53	2644.91
31Oct1995	1638.88	1940.17	1459.20	1728.73
30Nov1995	2175.09	1740.77	5517.74	3896.55
31Dec1995	3529.56	3067.60	4085.02	3573.28
31Jan1996	5488.93	4515.52	9460.24	7557.16
29Feb1996	2621.37	1661.96	582.56	2066.35
31Mar1996	2248.94	3624.00	631.09	1772.20
30Apr1996	1982.96	3624.00	429.01	862.07
31May1996	3361.17	3624.00	880.87	2977.78
30Jun1996	3123.01	3624.00	3378.85	4550.00
31Jul1996	2890.74	3619.76	4538.65	4550.00
31Aug1996	3213.32	3384.59	4612.95	4550.00

	MADDEN COMP-HEC	MADDEN CALIBRATION	GATUN COMP-HEC	GATUN CALIBRATION
Date	CFS	CFS	CFS	CFS
30Sep1996	2968.30	1473.42	4931.32	4428.91
31Oct1996	2728.71	3208.58	5355.18	4023.00
30Nov1996	4393.46	3624.00	8266.20	6991.66
31Dec1996	6648.21	4768.77	6244.52	4032.62
31Jan1997	2273.21	2327.95	72.92	27.00
28Feb1997	2381.52	3536.26	29.07	680.67
31Mar1997	2266.86	599.88	27.00	27.00
30Apr1997	1491.06	3624.00	31.63	27.00
31May1997	1862.89	500.00	29.24	27.00
30Jun1997	1581.34	3624.00	34.72	27.00
31Jul1997	1977.51	500.00	27.37	27.00
31Aug1997	614.01	3489.37	27.00	27.00
30Sep1997	1409.27	500.00	27.77	27.00
31Oct1997	477.74	500.00	27.00	27.00
30Nov1997	445.93	500.00	27.00	27.00
31Dec1997	858.93	500.00	27.00	27.00
31Jan1998	2284.04	3624.00	27.00	27.00
28Feb1998	2998.67	500.00	27.41	27.00
31Mar1998	538.59	423.95	27.00	27.00
30Apr1998	249.17	883.92	27.00	27.00
31May1998	1619.84	1907.51	27.00	27.00
30Jun1998	1973.32	1861.59	27.00	27.00
31Jul1998	1044.49	500.00	27.00	27.00

Exhibit 3. PCC BASE MODEL

The PCC Base Model is the Calibration Model modified to use the five-year (1993 - 1997) average diversions, rather than the historical values used in calibration. The simulation period runs from January 1914 through July 1998. Note that evaporation depths were not defined in the DSS file until March 1918, so the first four years have no computed evaporation. Table 1 is a listing of the HEC-5 input file PCCBASE.DAT.

Table 1. Input Data Listing for Base Model Simulation

```
T1     Panama Canal Capacity Study  Jan.1914 - July 1998
T2     Base Model: Existing System with Average Lockage & Municipal Qs
T3     Model developed by HEC, December  1998 and Revised January 1999
J1      0       1       6       4       5       2
J2     24     1.0             132
J3      4                                       -1
C   Evaporation from PCC computed values input as EV data
J850.163  50.323  40.163  40.323  50.221  40.221  50.222  40.222  40.033  40.314
J8 40.32   40.10   40.12   40.13   50.13   50.12   50.10   50.32
JZ 40.09   40.10   40.22   40.11   40.16   50.09   50.10   50.22   50.11   50.16
JZ 40.03   40.30   40.31   50.03   50.30   50.31   40.21   50.21
C ============= Lake Madden ==============================================
C  6.  Top-of-dam       = Elev. 270
C  5.  Top-of-flood     = Monthly varying, Based on Spill Curve
C  4.  Top-of-conserv. = Monthly varying, Elevations from Fig 5.1
C  3.  Tandem Operation= Monthly varying, Based on Previous Operations
C  2.  Top-of-buffer    = Elev. 190 (M&I only)
C  1.  Top-of-inactive = Elev. 160
C  Starting Storage at December Top-of-Conservation
RL    50  -252.0
RL     1      50      -1          16000
RL     2      50      -1         127250
C        ELEV:                      224     204     198     198     198     198
RL     3      50       0         350570  202070  167290  167290  167290  167290
C        ELEV:                      200     210     220     230     240     237
RL                               178350  241530  316670  405560  507780  475755
C        ELEV:                      249     243     233     221     217     215
RL     4      50       0         611478  541116  434890  324950  292650  277430
C        ELEV:                      217     222     228     236     247     252
RL                               292650  333360  386640  465290  587580  648140
C   Madden Spill Curve from PCC OPERDATA.BAS dated 6-23-94
RL     5      50       0         685996  685996  685996  564096  564096  564096
RL                               564096  564096  564096  599470  635790  685996
RL     6      50      -1         886750
RO     1      40
C  Reservoir storage from path = /PCC/MAD/ELEV-CAPAC(ACFT)///OBS/
C  Reservoir areas from path =  /PCC/MAD/ELEV-AREA(ACRES)///OBS/
C  Storage & area values below Elev. = 190 are extrapolated
C  Areas above Elev = 264.0 are extrapolated
C  Reservoir maximum outflow from Tables 5-2 + 5-3 + 6-2 PCC FC MANUAL (9/1992)
RS    -54       0    16.0    54.4  127.25  136.89  146.51  156.70  167.29  178.35
RS184.07 189.992 195.914 202.066 208.356 214.761 221.281 227.916 234.665 241.529
RS248.51 255.579 262.764 270.041 277.433 284.963 292.654 300.505 308.517 316.667
RS333.36 350.573 368.297 386.639 405.556 425.000 444.904 465.289 486.226 507.782
RS529.87 552.525 575.781 599.472 623.577 648.140 673.255 698.852 724.908 751.400
RS778.33 805.624 832.668 859.711 886.754
RQ    54    1000   10000   15000   20000   22000   23000 . 24000   25000   26000
RQ 26150   26300   26400   26500   26750   27000   27150   27300   27400   27500
RQ 27650   27800   27900   28000   28150   28300   28400   28500   28650   28800
RQ 29000   29300   29500   29800   30000   30100   34100   41100   50400   60700
RQ 74000   88000  103700  120800  139300  159200  180600  203500  227700  253600
```

```
RQ281000   310000   340700   373100   407100
RA    54        0     1600     3840     4608     4800     4992     5184     5376     5568
RA  5792     6016     6144     6272     6400     6528     6624     6720     6784     6848
RA  6976     7104     7168     7296     7488     7616     7744     7936     8064   8198.4
RA  8480   8761.6   9043.2   9318.4   9587.2     9856  10124.8  10393.6  10630.4    10912
RA 11168    11424    11680    11936  12179.2  12422.4  12665.6  12908.8  13145.6    13376
RA 13606    13837    14080    14304    14528
RE    54      140      160      180      190      192      194      196      198      200
RE   201      202      203      204      205      206      207      208      209      210
RE   211      212      213      214      215      216      217      218      219      220
RE   222      224      226      228      230      232      234      236      238      240
RE   242      244      246      248      250      252      254      256      258      260
RE   262      264      266      268      270
C    Evaporation rates are read from DSS file for Madden ====================
C == Hydropower Data
P1    50   36000     1.05               89               .83
C    Penstock Capacity Based on Hydro-Met data for Maximum Discharge @ elev = 25
P2    20     3624
PR
PR
C  = Channel Capacity Based on Limiting Non-spill Releases to Power Operation ==
C  = Minimum flow set to 500 cfs based on historic minimum ===================
CP    50     3624      500
IDMAD
RT    50       40

C ============== Municipal Diversion from Lake Madden ======================
DR    50                                                      1               1.0
C ============== Diversions are 5 year average (1993 - 1997)
QD    12      185      188      190      190      191      188      188      187      187
QD   180      182      183

C ============== Lake Gatun ===============================================
C  6.  Top-of-dam        = Elev. 105.0
C  5.  Top-of-flood      = Monthly varying, Based on Spill Curve
C  4.  Top-of-conserv. = Monthly varying, Elevations from Fig 5.1
C  3.  Tandem Operation= Monthly varying, Based on Previous Operations
C  2.  Top-of-buffer     = Elev.  81.5
C  1.  Top-of-inactive = Elev.  70.0 based on Jorge note of 14 Oct 1998
C  Starting elevation for December Top-of-Conservation
RL    40   -87.5
RL     1       40       -1          2729700
RL     2       40       -1          3830250
C        ELEV:                         82.5     82.0     82.0     82.0     82.0     82.0
RL     3       40        0          3930740  3880230  3880230  3880230  3880230  3880230
C        ELEV:                         82.0     82.0     82.0     83.0     84.0     83.0
RL                                  3880230  3880230  3880230  3981590  4084210  3981590
C        ELEV:                           87     86.3     85.4     84.7     84.7     84.7
RL     4       40        0          4399800  4325160  4230070  4156820  4156820  4156820
C        ELEV:                         84.7     84.7       85     85.9     87.3     87.5
RL                                  4156820  4156820  4188100  4282800  4432050  4453580
C   Gatun Spill Curve from PCC OPERDATA.BAS dated 6-23-94
C        ELEV:                        87.75    87.75    87.75    87.75     86.5     86.5
RL     5       40        0          4480570  4480570  4480570  4480570  4346420  4346420
C        ELEV:                         86.5     86.5     86.5     86.8     87.4     87.5
RL                                  4346420  4346420  4346420  4378440  4442800  4480570
RL     6       40       -1          6384700
RO
C   Reservoir storage from path = /PCC/GAT/ELEV-CAPAC(ACFT)///OBS/
C   Reservoir maximum outflow from StoneyGAT.xls, data for 14 gates ELEV=78'-92'
C   Reservoir areas from path =   /PCC/GAT/ELEV-AREA(ACRES)///OBS/
C   data below elev. 77 and above 90 was extrapolated
RS   -21        0    833.7   1781.7   2729.7   3393.3   3488.1   3584.2   3681.6   3780.3
RS3880.2   3981.6   4084.2   4188.1   4293.3   4399.8   4507.6   4616.7   4727.2   5279.7
RS5832.2   6384.7
RQ    21        0        0        0     1890    42790    58878    69463    80672    92479
RQ104860   117796   131268   145260   159756   174743   190208   206139   222525   300000
RQ350000   400000
```

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RA    21        0    56544   70404   84264   93966   95353   96740   98127   99414
RA100702  101990  103277  104566  105853  107141  108382  109670  110957  117392
RA123827  130262
RE    21       40      50      60      70      77      78      79      80      81
RE    82       83      84      85      86      87      88      89      90      95
RE   100      105
C == Hydropower Data
P1    40   24000       1              9              .85
C   Penstock Capacity Estimated from Operation Data Sheets
P2    27    4550
PR
PR
C    Channel Capacity Based on Limiting Non-spill Releases to Power Operation
CP    40    4550
IDGAT
RT    40     200
C    Diversion Data include Total Lockage and M&I water supply
DR     40                                                1              1.0
C    Diversions are 5 year average (1993 - 1997)
QD    12    3326    3325    3333    3233    3088    2943    2941    2983    2899
QD  3092    2965    3081

C ============== Caribbean Sea ================================================
CP   200  999999
IDCARIBBEAN SEA
RT   200

ED
BF     2    1015                14010100             720                    1900
C ===== PCC EVAPORATION INPUT IN INCHES =======================================
ZR=EV40 A=PCC B=GAT C=EVAP F=OBS
ZR=EV50 A=PCC B=MAD C=EVAP F=OBS
C ===== INFLOW INCREMENTAL COMPUTED BY HEC ====================================
ZR=IN40 A=PCC B=GAT C=FLOW-IN-INC F=COMP-HEC
ZR=IN50 A=PCC B=MAD C=FLOW-IN F=COMP-HEC
ZW   A=PCC   F=BASE-9397DIV-1980RC
EJ
ER
```

The J8/JZ records were modified to show simulation results for evaluation parameters. The first J8 table is an annual summary for the simulation period. Table 2 shows an Annual Summary of the results from the output file PCCBASE.OUT. The average annual energy production and spill are shown for Madden and Gatun, followed by the maximum and minimum pool elevations for both reservoirs. Finally, the average annual diversion and sum of shortages are shown for Gatun. Notice that no shortages occur during the simulation. Summary data for the annual summary is shown at the end of the table. The minimum pool elevation was 190.0 feet for Madden and 77.81 feet for Gatun.

Table 2. Annual Summary

Year	MAD Energy G Avg	MAD Q-Spill Avg	GAT Energy G Avg	GAT Q-Spill Avg	MAD EOP Elev Max	GAT EOP Elev Max	MAD EOP Elev Min	GAT EOP Elev Min	GAT Diversio Avg	GAT Div Shor Sum
1914	15102.41	0.00	8964.54	315.99	255.00	87.50	210.09	84.27	3100.75	0.00
1915	20812.53	0.50	15663.51	661.87	255.00	87.50	219.39	84.83	3100.75	0.00
1916	17661.12	7.16	11287.94	595.09	255.00	87.50	215.00	84.70	3100.75	0.00
1917	18715.64	345.56	11876.44	1734.93	255.00	87.75	215.00	84.70	3100.75	0.00
1918	17643.79	4.47	10248.29	129.57	255.00	87.30	220.72	84.70	3100.75	0.00
1919	11408.48	13.01	3647.03	0.00	252.00	87.45	212.80	83.69	3100.75	0.00
1920	12835.92	0.00	4189.66	306.92	252.00	87.37	190.00	81.43	3100.75	0.00
1921	14073.90	0.00	7770.65	65.81	252.70	87.50	193.72	83.55	3100.75	0.00
1922	18967.78	45.04	9110.33	200.64	255.00	87.52	215.00	84.32	3100.75	0.00
1923	16313.25	270.15	5349.27	1509.79	255.00	87.43	207.16	83.72	3100.75	0.00
1924	15673.71	0.00	10236.10	285.08	255.00	87.50	215.00	84.25	3100.75	0.00
1925	12671.47	0.00	4960.68	0.00	252.00	87.50	199.12	83.94	3100.75	0.00
1926	11502.42	7.19	6563.46	20.99	252.00	87.50	197.63	82.32	3100.75	0.00
1927	22600.96	268.21	12927.55	892.82	255.00	87.75	217.29	84.70	3100.75	0.00
1928	18293.28	23.11	9363.00	535.81	255.00	87.75	215.00	84.50	3100.75	0.00
1929	13517.81	0.00	4999.91	0.00	255.00	87.30	215.00	83.87	3100.75	0.00
1930	11877.22	14.00	1255.60	0.00	252.00	87.50	205.19	83.41	3100.75	0.00
1931	15981.25	332.69	7364.04	1183.59	255.00	87.50	209.67	83.62	3100.75	0.00
1932	19007.56	183.91	9236.27	1546.71	255.00	87.75	215.00	84.55	3100.75	0.00
1933	14392.06	0.00	5295.85	481.26	255.00	87.75	209.20	83.65	3100.75	0.00
1934	16531.11	18.52	8388.67	764.65	255.00	87.75	215.00	84.45	3100.75	0.00
1935	19566.15	1311.79	11369.52	3396.58	255.00	87.75	215.00	84.64	3100.75	0.00
1936	13279.75	0.00	9182.53	229.95	255.00	87.75	215.00	83.81	3100.75	0.00
1937	18224.72	258.10	9961.44	823.92	255.00	87.75	215.00	84.70	3100.75	0.00
1938	22254.56	432.45	12496.12	1932.84	255.00	87.75	220.99	84.70	3100.75	0.00
1939	12894.30	0.00	4034.26	1742.89	255.00	87.75	199.10	83.17	3100.75	0.00
1940	12511.73	16.62	5081.63	0.00	255.00	87.50	207.41	83.95	3100.75	0.00
1941	18274.65	18.57	8427.70	278.13	255.00	87.75	217.00	83.90	3100.75	0.00
1942	17312.29	0.00	8791.76	390.79	255.00	87.75	215.00	84.70	3100.75	0.00
1943	16886.79	129.85	11565.64	233.74	255.00	87.75	215.00	84.70	3100.75	0.00
1944	20581.26	427.80	11293.63	772.58	255.00	87.75	215.00	84.70	3100.75	0.00
1945	16947.52	36.85	7446.87	188.20	255.00	87.75	215.00	84.12	3100.75	0.00
1946	17029.90	25.10	3768.30	0.00	255.00	87.50	209.59	83.40	3100.75	0.00
1947	14593.67	0.00	7347.27	54.34	252.00	87.75	212.30	83.51	3100.75	0.00
1948	12232.63	0.00	5321.68	206.30	253.95	87.75	197.37	83.65	3100.75	0.00
1949	18782.68	17.13	9359.08	1470.31	255.00	87.75	197.89	83.49	3100.75	0.00

Year	MAD Energy G Avg	MAD Q-Spill Avg	GAT Energy G Avg	GAT Q-Spill Avg	MAD EOP Elev Max	GAT EOP Elev Max	MAD EOP Elev Min	GAT EOP Elev Min	GAT Diversio Avg	GAT Div Shor Sum
1950	21283.21	105.85	11293.98	1319.90	255.00	87.75	215.00	84.70	3100.75	0.00
1951	18076.60	48.29	10849.75	24.95	255.00	87.74	215.00	84.70	3100.75	0.00
1952	17088.01	23.28	7613.44	227.04	254.76	87.50	215.00	84.15	3100.75	0.00
1953	17613.14	14.90	10294.42	343.92	255.00	87.75	215.00	84.70	3100.75	0.00
1954	18805.52	86.13	11057.30	1280.63	255.00	87.75	215.00	84.70	3100.75	0.00
1955	18087.90	223.67	11702.81	1347.45	255.00	87.75	215.00	84.70	3100.75	0.00
1956	22243.85	237.88	14633.52	1213.07	255.00	87.75	222.53	84.70	3100.75	0.00
1957	11689.88	0.00	3966.72	170.61	255.00	87.75	193.22	83.15	3100.75	0.00
1958	14902.13	23.04	7147.69	0.00	255.00	87.50	215.00	84.70	3100.75	0.00
1959	15042.86	176.57	4423.51	77.64	255.00	87.75	200.06	83.06	3100.75	0.00
1960	19196.74	263.76	12868.26	182.35	255.00	87.75	215.00	84.70	3100.75	0.00
1961	15558.77	0.00	9041.10	199.24	255.00	87.75	215.25	84.40	3100.75	0.00
1962	15184.81	7.11	7478.96	49.88	254.35	87.75	215.00	84.04	3100.75	0.00
1963	18837.12	29.46	12370.69	616.15	255.00	87.75	215.00	84.70	3100.75	0.00
1964	15528.44	22.48	10272.00	505.85	254.39	87.75	214.05	83.76	3100.75	0.00
1965	15241.50	0.00	5229.02	924.51	255.00	87.75	206.64	84.09	3100.75	0.00
1966	18900.60	261.69	11131.77	1287.25	255.00	87.75	215.00	84.70	3100.75	0.00
1967	19213.12	21.56	11249.00	453.26	255.00	87.50	217.00	84.70	3100.75	0.00
1968	14384.79	0.00	8073.56	17.41	252.00	87.50	215.00	84.68	3100.75	0.00
1969	12912.77	23.51	5316.11	120.69	253.08	87.75	213.94	84.35	3100.75	0.00
1970	23592.69	315.77	15034.95	1680.53	255.00	87.75	226.13	84.70	3100.75	0.00
1971	16186.75	0.00	10700.48	30.68	255.00	87.30	215.00	84.46	3100.75	0.00
1972	13534.05	27.19	4704.62	0.00	253.45	87.37	214.90	84.28	3100.75	0.00
1973	11521.26	0.00	5837.44	392.13	255.00	87.50	190.00	82.12	3100.75	0.00
1974	10141.49	0.00	5036.20	203.91	255.00	87.50	190.00	83.67	3100.75	0.00
1975	16396.19	5.84	8289.59	1057.28	255.00	87.75	195.03	83.72	3100.75	0.00
1976	9876.64	0.00	1345.04	0.00	255.00	87.30	193.45	83.61	3100.75	0.00
1977	8001.67	0.00	1895.70	0.00	252.00	87.50	190.00	80.42	3100.75	0.00
1978	15062.51	0.00	8265.95	22.30	251.55	87.30	215.00	84.70	3100.75	0.00
1979	12510.63	10.81	5106.99	11.84	252.00	87.50	206.21	83.05	3100.75	0.00
1980	12662.69	0.00	5283.56	0.00	252.00	87.50	215.36	84.31	3100.75	0.00
1981	22678.01	116.82	14491.95	1385.76	255.00	87.75	232.99	85.30	3100.75	0.00
1982	14858.70	0.00	4310.46	15.47	255.00	87.00	215.00	84.69	3100.75	0.00
1983	12110.50	86.80	2047.28	161.38	255.00	87.75	190.00	80.70	3100.75	0.00
1984	16428.14	11.37	8181.27	483.91	255.00	87.40	211.52	84.19	3100.75	0.00
1985	14866.77	23.95	4536.13	88.82	252.00	87.75	203.55	83.12	3100.75	0.00
1986	16427.15	9.68	4685.84	262.73	254.20	87.30	216.78	83.93	3100.75	0.00
1987	20503.14	109.97	9640.37	341.54	255.00	87.50	211.08	84.03	3100.75	0.00
1988	18121.19	24.30	6496.93	404.97	255.00	87.50	201.46	82.54	3100.75	0.00
1989	16655.11	0.00	5174.90	74.46	255.00	87.50	204.49	83.01	3100.75	0.00

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1990	18471.34	0.00	8573.93	289.35	255.00	87.50	215.00	84.34	3100.75	0.00
1991	15078.11	8.16	4648.76	9.68	252.00	87.46	210.13	84.31	3100.75	0.00
1992	17180.45	0.00	7801.98	40.50	252.00	87.50	212.94	83.25	3100.75	0.00
1993	18693.89	0.00	9068.95	168.36	255.00	87.50	217.00	84.70	3100.75	0.00
1994	16259.94	0.00	5958.51	29.70	253.39	87.40	208.45	83.97	3100.75	0.00
1995	16908.56	0.00	7823.17	28.10	252.00	87.50	206.33	82.58	3100.75	0.00
1996	23654.76	325.31	14268.80	610.08	255.00	87.75	226.01	84.70	3100.75	0.00
1997	11984.87	0.00	230.12	0.00	253.58	86.57	196.36	83.36	3100.75	0.00
1998	8633.02	0.00	0.00	0.00	218.21	81.96	190.00	77.81	3169.86	0.00
Sum =	1375748.38	6852.97	669599.69	41107.41	21580.61	7438.97	17861.49	7131.26	263632.84	0.00
Max =	23654.76	1311.79	15663.51	3396.58	255.00	87.75	232.99	85.30	3169.86	0.00
Min =	8001.67	0.00	0.00	0.00	218.21	81.96	190.00	77.81	3100.75	0.00
PMax=	1996.00	1935.00	1915.00	1935.00	1914.00	1917.00	1981.00	1981.00	1998.00	1914.00
Avg =	16185.28	80.62	7877.64	483.62	253.89	87.52	210.14	83.90	3101.56	0.00
PMin=	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00