ACP

Autoridad Del Canal De Panama

Oficina de Proyectos de Capacidad del Canal

Panama Canal

Work Order No.7 Study of Variatio and Trends in th Historical Rainfa and Runoff Data the Gatun Lake Watershed

Contract Number CC-5-536

VOLUME 1: MAIN REPORT

December 2001

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AUTORIDAD DEL CANAL DE PANAMA
Oficina de Proyectos de Capacidad del Canal

THE PANAMA CANAL

Study of Variations and Trends in the Historical Rainfall and Runoff Data in the Gatun Lake Watershed

CONTRACT NO. CC-3-536
Work Order 7

DECEMBER 2001

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Work Order No. 7
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EXECUTIVE SUMMARY

STUDY OF VARIATIONS AND TRENDS IN THE HISTORICAL RAINFALL AND RUNOFF DATA IN THE GATUN LAKE WATERSHED

E.0 EXECUTIVE SUMMARY

This report on the Study of Variations and Trends in the Historical Rainfall and Runoff Data in the Gatun Watershed is organized into two volumes. Volume 1 is the main report. Volume 2 includes seven appendices. The main report includes a description of the methodology used together with a summary of results and supporting tables and exhibits. Definitions of terms and abbreviation used in the report are provided after the Table of Contents. Appendix A includes references cited in the text. Historic data, inventory of rainfall and stream gauging stations, filled-in data with time series and mass curve plots, fill-in computer program input-output files, input-output files and detailed results of stochastic model, and synthetic flow series with computer input-output files are provided in appendices B to G, respectively. A summary of the report is discussed below.

E.1 Hydrometeorological Data

Monthly hydrometeorological data (rainfall and streamflow) were provided by the Autoridad Del Canal De Panama (ACP, the Panama Canal Authority). The rainfall and stream gauging stations for which detailed statistical analyses were made are listed in Table E-1. Data for climatic indices for El Nino and annual number of sunspots were obtained through the Internet.

The study area was divided into three basins :

- Madden Lake: watershed area draining into Madden Lake
- Gatun Downstream: watershed area between Madden Dam and Gatun Dam draining into Gatun Lake
- Gatun Total: total watershed area upstream from Gatun Dam including the drainage area upstream from Madden Dam

Monthly basin average rainfall over each of the above basins and flow generated from each basin were estimated. Statistical analyses were also performed for each of the three rainfall and three streamflow time series.

E.2 Review of Rainfall and Streamflow Data

E.2.1 Rainfall Data

The rainfall data collection system and instrumentation are well maintained. A tipping bucket rain gauge along with a float-operated storage gauge is installed on each station. Simultaneous observations from the two gauges over the past years were nearly the same except in a few cases. Currently, the meteorologist of ACP uses observation from either of the gauges based on observations on nearby stations and his knowledge of the operation of the gauges. It is suggested that ACP may discontinue the use of the storage gauge. The observation from a tipping bucket gauge can be reviewed and checked by comparing observations at nearby stations.

Table E-1

RAINFALL AND STREAM GAUGING STATIONS

A.	**Rainfall Stations**		
1.	Agua Clara	15.	Gatun
2.	Alhajuela	16.	Guacha
3.	Balboa Heights	17.	Hodges Hill
4.	Borro Colorado	18.	Humedad
5.	Candelaria	19.	Limon Bay
6.	Cano	20.	Monte Lirio
7.	Chico	21.	Peluca
8.	Ciento	22.	Pedro Miguel
9.	Chorro	23.	Racies
10.	Cascadas	24.	Rio Piedras
11.	Canones	25.	Salamanca
12.	Empire Hills	26.	San Miguel
13.	Escandalosa	27.	Santa Rosa
14.	Gamboa		
B.	**Stream Gauging Stations**		
1.	Gatun River at Ciento		
2.	Boqueron River at Peluca		
3.	Pequeni River at Candelaria		
4.	Chagres River at Chico		
5.	Trinidad River at Chorro		
6.	Ciri Grande River at Canones		

It is a general worldwide practice that a non-recording rain gauge is installed with a recording gauge to provide a check on the total rainfall measured by the recording gauge. The non-recording gauge provides data in case of malfunctioning of the recording gauge. We recommend that this practice may be followed in the Gatun watershed. Because of the remoteness of gauge locations, the non-recording gauge should have sufficient capacity to collect rainfall for about two weeks. All stations will have to be visited twice a month.

E.2.2 Stream Gauging Stations

The stations are well maintained and are operating satisfactorily. However, discharge-measuring procedures require significant improvement. Currently, all measurements are made from an overhead cableway. It is highly desirable that low flow measurements should be made by the wading method where feasible. The hydrographer should make discharge measurements by wading, up to a maximum feasible river stage.

The practice of taking depth and velocity observations at about three verticals across the width of a river during low flows and about six or seven verticals during high flows should be discontinued. The depth and velocity observations should be made at a minimum of 20 to 25 verticals across the river. However, the distance between two adjacent verticals should not be less than one meter for measurement from a cableway and 0.5 meter for wading measurements.

A review of measurements from a cableway indicated that due to drag on the sounding weights, vertical angles were observed. Corrections to observed depths are required due to the drag and depend upon the vertical angles. There are two types of corrections – air line and wet line. The vertical angle should be avoided by using heavy sounding weights consistent with the flow condition in the river. If an appropriate weight is not available, air line correction should be avoided using the procedures of United States Geological Survey, Water Resources Division (USGS). Reference to these procedures is given in the main report.

It was noticed that during a year, daily discharges at a gauging station were computed using the rating curve (stage-discharge relationship) updated in the previous years. The current year measurements were not used in the computation of daily discharges. These measurements were used at the end of the year or later when a revision was made to the rating curve. At that time the previously compute discharges were, probably, revised. This practice is quite common when there is a stable hydraulic control. In that case, the revised values are not significantly different from the first estimates. However, in the case of shifting control stations, the difference could be quite significant. All gauging stations in Gatun watershed have shifting channel controls. Since ACP is computing daily flows on a continuous basis, it is recommended that "shift adjustment" procedure of the USGS should be used. The procedure is discussed in the reference given in the report.

An inventory of rainfall and stream gauging stations is provided as Appendix C. This includes description of location, instruments, period of record, etc., for each station. A photograph of a station layout with instruments is provided where available.

E3 Extension of Rainfall Series

Five rainfall stations (Alhajuela, Balboa Heights, Gatun, Pedro Miguel and Gamboa) had complete monthly data for the period from 1911 to 2000. This period of 90 years was selected as a common period for all stations. Monthly historic rainfall data at all other stations (given in Appendix B) were filled-in and extended for this period using a FILLIN computer program developed by Texas Water Resources Development Board. The original program could handle 25 stations and 50 years of monthly data. The program was revised for 30 stations and 100 years of monthly data.

The extended and filled-in series were checked using mass curves and chronological time series plots. The filled-in and extended data were consistent with the historic data. The filled-in data and the plots are given in Appendix D.

E.4 Extension of Streamflow Series

Based on the monthly streamflow data at the six stations, a common period of 1941 to 2000 (60 years) was selected. The data were filled-in and /or extended using the FILLIN computer program discussed above. The plots of mass curves and flow time series showed that the filled-in/extended data were consistent with the historical data. Appendix D shows the historic data, filled-in data and plots.

E.5 Basin Average Rainfall

Monthly basin average rainfall series were computed for the 90-year period for Madden Lake, Gatun Downstream and Gatun Total basins. The Thiessen method was used to derive the station weights of pertinent stations relative to each basin. The generated series were compared with the series provided by ACP. Long-term mean annual rainfall values estimated by MWH were about 2.3, 2.5 and 2.6 percent higher than that estimated by ACP for Madden Lake, Gatun Downstream and Gatun Total, respectively. Comparisons were also made using double mass curves and scattered diagrams. The two sets (by MWH and ACP) were not significantly different.

E.6 Basin Inflows

Monthly inflow series were generated for Madden Lake, Gatun Downstream and Gatun Total basins. Madden Lake basin was divided into five sub-basins. The inflow to Madden Lake was the sum of flows of Chagres, Pequeni, Boqueron, intervening area and runoff from rainfall falling directly over the lake area. The flows for the intervening area were computed by transposing the combined flows of Chagres, Pequeni and Boqueron multiplied by a combined drainage area-mean annual rainfall ratio.

For estimating the monthly flows from Gatun Downstream, the basin was divided into eight sub-basins, three gauged sub-basins, four intervening areas and the lake area. Flows for the intervening areas were estimated by transposing the gauged flows multiplied by combined drainage area-mean annual rainfall ratios. The inflow was the sum of flows from seven sub-basins plus the runoff from rainfall directly falling over the lake area. The generated series were compared with the series provided by ACP. Long-term mean annual runoff values estimated by MWH were nearly equal for Madden Lake, about 9 percent higher for Gatun Downstream and about 5 percent higher for Gatun Total. Comparisons were also made using double mass curves and scattered diagrams. The two sets (by MWH and ACP) were not significantly different.

The above analysis provides a procedure that can be used when the flows at the gauging stations become available. An alternate method was developed to compute the inflows from basin average rainfalls. Linear regression equations were developed for Madden Lake and Gatun Downstream. The equations are given below:

Madden Lake

$$\text{Flow}(t) = 13.3 + 0.18\,\text{Rainfall}(t) + 0.08\,\text{Rainfall}(t-1),$$

Correlation coefficient = 0.84

where flow is in m^3/s , rainfall is basin average rainfall in mm and "t" in the month.

Gatun Downstream

$$\text{Flow}(t) = -6.7 + 0.38\,\text{Rainfall}(t) + 0.17\,\text{Rainfall}(t-1),$$

Correlation coefficient = 0.91

E.7 Statistical Analysis of Time Series

Linear trend analysis was made for all 27 rainfall stations. Detailed statistical analysis were made to test the consistency and homogeneity of the annual series given in Table E-2.

Table E-2

ANNUAL SERIES TESTED FOR CONSISTENCY AND HOMOGENEITY

Rainfall Series	Runoff Series
Madden Lake	Inflow to Madden Lake
Gatun Downstream	Inflow from Gatun Downstream
Gatun Total	Inflow from Gatun Total
Agua Clara	Ciri Grande River
Alhajuela	Trinidad River
Balboa Heights	Chagres River
Borro Colorado	Pequeni River
Chico	Boqueran River
Chorro	Gatun River
Gamboa	
Gatun	
Monte Lirio	
Pedro Miguel	
Salamanca	
San Miguel	

The tests were performed for randomness (auto correlation and modified Pormanteau tests), trend (linear correlation and Mann-Kendall & Abelson-Tukey tests) and one-population test using means and standard deviations of two sub-sets of each series. Final conclusions after careful review of all data. Statistical test results and plots are summarized in Table E-3.

A series was judged to be consistent if no jump was identified and the series was from the same population. A series was judged to be homogeneous if the trend was insignificant.

This study did not find any consistent decrease in rainfall since 1971 that could be attributed to change in instrumentation or environment at a station, physical changes in watershed or climatic factors. Actually, in most cases a decreasing trend was observed from late 1960's, which after 1985 became an increasing trend. Two sub-sets of a few series indicated that the means or standard deviations were significantly different at 95 percent level of confidence and, therefore, the data after 1971 could be from a different population. However, this statistically based conclusion was not considered valid because three El Nino episodes of 1976-77, 1982 and 1997-98 were very severe and resulted in significantly low mean annual flows. This is a short-term effect and cannot form a basis to show that the decreasing trends observed on some rainfall and runoff stations would continue. However, similar episodes may affect the rainfall and flows again.

Table E-3

SUMMARY OF CONSISTENCY AND HOMOGENEITY TESTS

Rainfall Station	Random	Trend	Rate	Consistent	Homogeneous
Agua Clara	Yes	significant, increasing,	6mm/yr	Yes	No
Alhajuela	Yes	insignificant, decreasing	1mm/yr	Yes	Yes
Balboa Heights	Yes	significant, increasing	2mm/yr	Yes	No
Borro Colorado	Yes	insignificant, decreasing	2mm/yr	Yes	Yes
Chico	Yes	insignificant, decreasing	2mm/yr	Yes	Yes
Chorro	Yes	insignificant, decreasing	3mm/yr	Yes	Yes
Gamboa	Yes	insignificant, increasing	1mm/yr	Yes	Yes
Gatun	Yes	insignificant, decreasing	3mm/yr	Yes	Yes
Monte Lirio	Yes	significant, decreasing	4mm/yr	Yes	No
Pedro Miguel	Yes	insignificant, increasing	1mm/yr	Yes	Yes
Salamanca	Yes	insignificant, increasing	2mm/yr	Yes	Yes
San Miguel	No	insignificant, increasing	1mm/yr	Yes	Yes
Madden Lake	Yes	insignificant, increasing	1mm/yr	Yes	Yes
Gatun Downstream	Yes	insignificant, decreasing	3mm/yr	Yes	Yes
Gatun Total	Yes	insignificant, decreasing	2mm/yr	Yes	Yes
Streamflow Stations					
Gatun – Ciento	Yes	insignificant, decreasing	5 l/s/yr	Yes	Yes
Boqueron – Peluca	Yes	insignificant, decreasing	5 l/s/yr	Yes	Yes
Pequeni – Candelaria	Yes	insignificant, decreasing	13 l/s/yr	Yes	Yes
Charges – Chico	Yes	insignificant, decreasing	24 l/s/yr	Yes	Yes
Trinidad – Chorro	Yes	insignificant, decreasing	18 l/s/yr	Yes	Yes
Ciri Grande – Canones	Yes	insignificant, decreasing	26 l/s/yr	Yes	Yes
Madden Lake	Yes	insignificant, decreasing	1 l/s/yr	Yes	Yes
Gatun Downstream	Yes	insignificant, decreasing	152 l/s/yr	Yes	Yes
Gatun Total	Yes	insignificant, decreasing	153 l/s/yr	Yes	Yes

E.8 Stochastic Model

A number of available stochastic models were reviewed to select an appropriate model that would fit the hydrologic time series of Gatun watershed and, when fitted to the series, would provide monthly forecasts a few months ahead of their occurrence. Based on this review, the periodic autoregressive (PAR) model developed by K.W. Hipel and A.I. McLeod of Canada was considered to be most suitable. The model was fitted to six time series - monthly basin average rainfall for Madden Lake, Gatun Downstream and Gatun Total, and monthly inflows from these three basins.

Monthly data for the period 1911 to 1995 was used to develop model parameters for the rainfall series. The data for last 5 years, 1996 to 2000, was used for verification of the parameters. The results are given in Appendix F. In case of inflow series, the model parameters were developed using 1941 to 1997 data and last three years, 1998-2000 were used for model verification. The results are also given in Appendix F.

The modeling results were generally quite good except that some of the high monthly rainfall and monthly inflows were not properly reproduced. The low and medium flows showed good fit. Appendix F provides comparisons of historical and simulated rainfall and flows.

E.9 Synthetic Time Series

HEC-4 computer model developed by the United States Army, Corps of Engineers, Hydrologic Engineering Center, was used to generate synthetic time series. Ten series, of 100 years period each, were generated for three series of basin average rainfall and three inflow series. The program used the monthly rainfall series of 90 years, and monthly inflow series of 60 years as input to generate the synthetic sequences. In the generation process, the means and standard deviations of the input series are maintained. Results are presented in Appendix G.

E.10 Effect of El Nino

All available data/information on the indices qualifying El Nino southern oscillation (ENSO) were obtained. The indices included: sea surface temperatures (SST) and its anomalies, southern oscillation index (SOI, difference between sea level pressures observed at Tahiti and at Darwin) and outgoing long wave radiation (OLR). Major El Nino episodes since 1525 were identified qualitatively and since 1951 on a quantitative basis. The regions of measurements of these indices were identified.

From the locations of the regions relative to the location of Gatun watershed, it was determined that a correlation, if any, would be between the ENSO indices observed in El Nino 3 region, North Atlantic region and SOI. However, actual data showed that there was no correspondence between the low flows in Gatun (or high flows) and the SST of North Atlantic and SOI. The SST recorded in the region of El Nino 3 could have some relationship.

To assess the effect of El Nino on the rainfall/runoff in the Gatun watershed, the long-term mean annual rainfall and runoff were compared with the annual rainfall/runoff recorded during the El Nino years. In all cases the recorded rainfall or runoff were significantly low. For the major episodes the data is given in Table E-4.

Table E-4

PERCENT DECREASES IN ANNUAL RAINFALL AND RUNOFF

Rainfall station	1930 Episode	1957 Episode	1976 Episode	!977 Episode	1982 Episode	1997 Episode
Madden Lake	22.3	28.8	37.8	18.7	27.4	33.4
Gatun Downstream	20.5	14.6	27.6	15.0	24.3	38.2
Gatun Total	21.1	19.3	30.9	16.3	25.4	36.7
Runoff Station						
Madden Lake	------	33.8	30.9	20.6	18.1	36.8
Gatun Downstream	------	37.4	31.5	25.6	23.5	49.3
Gatun Total	------	35.9	31.2	23.6	21.3	44.3

Similar comparison was made on a monthly basis for 1976-77, 1982-83 and 1997-98, the most severe episodes since 1951 for which the monthly data for ENSO indices were available. Table E-5 shows the comparison. Most affected months were of dry and transitional seasons as shown in the table.

Table E-5

PERCENTAGE DECREASES IN MONTHLY RAINFALL AND RUNOFF

Months and Year	Madden Lake	Gatun Downstream	Gatun Total
Average Rainfall			
Nov 76	41	47	45
Dec	86	67	74
Jan 77	0	46	39
Feb	76	65	68
Mar	46	78	66
Apr	70	73	71
Nov 82	62	58	59
Dec	75	85	83
Jan 83	59	69	71
Feb	47	88	74
Mar	29	75	60
Jul 97	52	31	39
Aug	55	42	46
Sep	16	19	18
Oct	28	42	38
Nov	25	39	38
Dec	86	83	84
Jan 98	55	83	79
Feb	44	44	45
Mar	22	13	17
Basin Inflow	Madden Lake	Gatun Downstream	
Dec 76	67	61	
Jan 77	42	52	
Feb	32	45	
Mar	31	55	
Apr	55	71	
May	53	40	
Jun	48	47	
Jul	35	46	
Nov 82	35	42	
Dec	61	72	
Jan	41	59	
Feb	43	52	
Mar	42	54	
Apr	44	38	
Jul 97	49	54	
Aug	55	66	
Sep	41	51	
Oct	36	49	
Nov	56	46	
Dec	67	75	
Jan 98	61	71	
Feb	50	61	
Emar	61	58	

E.11 Effect of Sunspots

Variations in sunspot numbers offer only a general indicator of solar activity. However, there is a strong association between sunspots and Earth's weather and climate. Amount of annual rainfall at many places in the world, shows dependence on the 11-year sunspot cycle. There is a reasonable trend for greater than average rainfall during solar maximum years in the equatorial latitude region (between 20° north and 20° south). In contrast to this, there are studies that have shown that increase in sunspots may decrease air temperature and decrease rainfall. However, orographic effects and other climatic indices may override any solar cycle influence.

E.12 Analysis of Droughts

Monthly runoff series of Madden Lake (drainage area draining into the lake), Gatun Downstream (drainage area between Madden Dam and Gatun Dam) and Gatun Total (drainage area upstream of Gatun Dam including the drainage area upstream from Madden Dam) were used. The period of record was 60 years from 1941 to 2000. The magnitudes of volume corresponding to selected duration and return periods are given in Table E-6.

The table also includes the driest and wettest period of record.

E.13 Global Warming

An extensive literature search was made to determine the effect of global warming on the water supply. There is no clear trend of the effects of global warming at various locations in the world. Rising temperatures could produce more than normal rainfall at some places and less than normal rainfall at other places. In the Gatun watershed at Balboa Heights (Balboa FAA), an increasing trend in temperature showed increase in rainfall. Since long-term temperature data were not available at other stations this trend could not be confirmed. Additional studies are required.

E.14 Conclusions and Recommendations

The conclusions and recommendations given in Section 19.0 are provided below for reference.

1. Hydrometeorological data collection and transmission system of ACP are well maintained.

Table E-6

RUNOFF VOLUMES (MCM) FOR SELECTED DURATIONS AND RETURN PERIODS

Duration in Months

Return Period (yr)	3	6	12	18	24	30	36
Madden Lake							
Driest	100	430	1309	2054	3387	3952	8266
Wettest	1432	2281	3478	5015	5990	7438	5340
10	135	500	1630	2450	3730	4790	6400
25	114	445	1480	2160	3500	4300	5500
50	110	425	1350	2060	3400	4000	5300
75	100	410	1250	2000	3300	3800	5100
Gatun D/s							
Driest	73	429	1599	2347	4375	5412	7255
Wettest	2419	3916	5447	7865	8971	11797	12942
10	127	533	2616	3404	5655	6745	9182
25	100	477	2104	2917	4839	5800	8223
50	80	440	1800	2500	4400	5600	7600
75	73	410	1700	2300	4100	5300	7100
Gatun Total							
Driest	223	868	2908	4426	8476	9364	12708
Wettest	3399	5629	8582	12057	16071	18115	20225
10	249	1061	4020	5860	10250	11800	15350
25	234	970	3580	5070	8500	10250	14050
50	230	900	3100	4700	8200	9400	13000
75	225	860	2800	4300	7900	8900	12000

2. Use of storage rainfall gauges may be discontinued. Instead a non-recording rain gauge should be installed at each meteorological station to provide a check on the tipping bucket gauge.

3. Stream gauging procedures should be improved. Wading discharge measuring method should be introduced for low flow measurements where feasible. The number of observation points for depth and velocities should be increased. The observations should be made at 20 to 25 verticals across the river. However, the minimum distance between the verticals should be 0.5 meter for wading and 1.0 meter for measurements from an overhead cableway.

4. Air line corrections should be avoided as discussed in the report.

5. Time series analysis indicated that all rainfall and runoff series are consistent and homogeneous. The decreasing trends shown are insignificant at 95 percent confidence level.

6. Long-term rainfall and runoff data at various locations in the watershed can be used for further analysis of canal lockages. There is no need to treat the data to correct for decreasing trend.

7. El Nino has a negative effect on the rainfall and runoff series. Depending upon the severity of an episode, the rainfall or runoff could be as low as 10 to 20 percent of normal values on monthly basis. Worst affected months are November through February / march.

8. A decreasing trend since 1971 (indicated by mass curves at some stations) could be due to most severe El Nino episodes of 1976-77, 1982-83 and 1997-98. These episodes affected the mean and standard deviation of the annual series from 1971 to 2000.

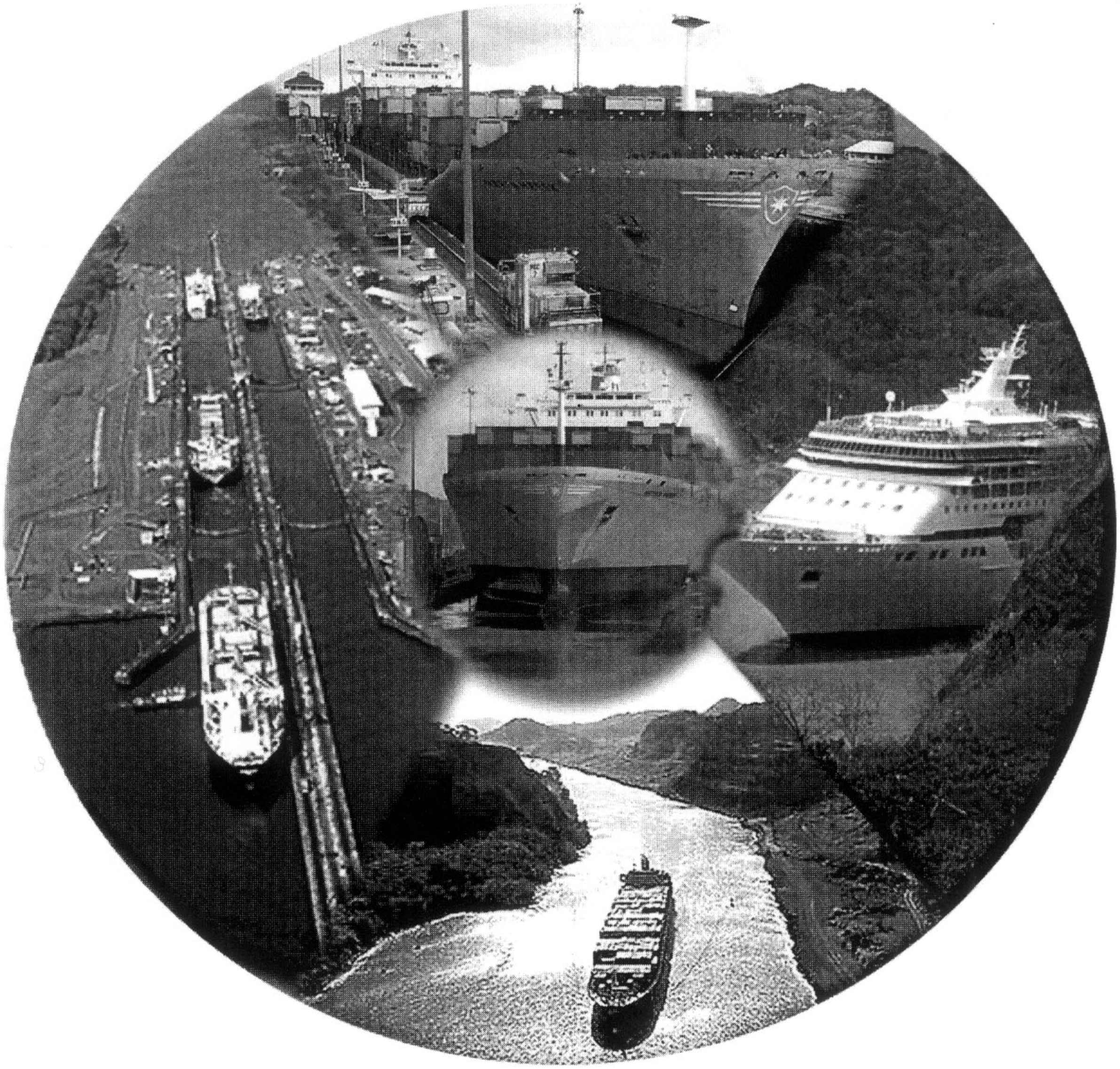
9. There is no reason to believe that slightly decreasing trend from early 1970's was due to any change in instrumentation, environment or observation techniques.

10. An increasing trend in number of sunspots from mid 1960's and decreasing trend since mid 1980's, may also be responsible for a slight decreasing trend since early 1970's.

11. There is an increasing trend in temperatures at the four selected stations. This could produce an increasing trend in the rainfall. Rainfall data at Balboa Heights confirms that but it must be confirmed by analyzing other stations.

12. A more detailed study may be initiated to analyze El Nino effect on hydrologic series and relation between El Nino, intertropical convergence zone and sunspots.

MAIN REPORT



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Prepared for

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Oficina de Proyectos de Capacidad del Canal

By

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December 2001

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DEFINITION OF TERMS

Basin-Average Rainfall — Rainfall considered uniformly distributed over a basin, derived from point rainfall measured at a number of stations in the basin.

Coefficient of Variation — This is equal to standard deviation divided by mean of a sample.

cfs — Cubic feet per second.

Climate — Long-term manifestation of weather.

cms or m^3/s — Cubic meters per second.

Coefficient of Skew — This parameter represents lack of symmetry in a sample. A positive skew indicates more observations of higher magnitudes than the mean of the sample, and a negative skew shows more observations of lower magnitudes than the mean.

Consistency — Also called "stationarity." A time series is consistent (or stationary) if it remains in equilibrium about a constant mean value, that is, the statistical properties (mean and variance) of the time series do not change with absolute time. The series is divided into sub-sets and mean and standard deviation of each set are determined. If the values of these parameters are same for each sub-set at a selected confidence level, the series is consistent.

Correlation — The degree of association of the variables involved is called correlation and defined by the parameters of correlation, covariance and correlation coefficient.

Correlation Coefficient — Correlation coefficient between two variables X and Y is defined the ratio between covariance and product of standard deviation of X and Y.

Covariance — Covariance of two variables X and Y is defined as expected value of the product of X and Y minus product of expected value of X and expected value of Y, that is, Cov(X,Y) = E(XY)-E(X)E(Y).

Drainage Area — Also called as drainage basin or watershed, is an area at a point of interest from which surface runoff is carried to that point by a single drainage system.

El Nino	El Nino is named after a Peruvian Christmas festival where the warming of the waters off Peru is said to occur near the birthday of "The Boy" (El Nino), or Christ child. Meteorologists thus named the phenomenon as "El Nino Southern Oscillation" or ENSO.
Gauging Station	A particular site on a stream where systematic observations of gauge height and discharge are obtained. The station is equipped with water level sensor (manual or automatic continuous) and facility for discharge measurements.
Homogeneity	If the means and standard deviation of the series do not change along a line, that is, there is no trend in the series, the series is called homogeneous.
Hydrology	Hydrology is the science that treats the waters of the earth, their occurrence, circulation, and distribution, their chemical and physical properties, and their reaction with their environment, including their relation to living things.
hPa	Sea level pressure anomaly, 200 millibar (high level), 800 millibar (low level).
Inconsistency	Jumps in a time series make it inconsistent or non-stationary. Jumps are created by sudden changes that are either man-made or they occur by various kind of changes in nature.
Isohyet	A line drawn through geographical points recording equal amounts of rainfall during a given time period or for a particular storm.
Isohyetal Map	A map containing a set of isohyets.
Isthmus	A narrow strip of land, bordered by water on both sides, which connects two large bodies of land.
ITCZ	Intertropical convergence zone (also called equatorial trough) is the zone located in the tropical region where the trade wind trajectories converge from northern and southern hemispheres.
Long-Wave Radiation	Radiation with wavelength greater than 4 microns.

La Nina	The cooling of the eastern Pacific waters, reverse of El Nino, is named as La Nina, "the Girl."
Mass Curve	A curve of cumulative values of rainfall or flow plotted against time.
mcm	Million cubic meters.
Mean	Arithmetic mean of a sample of observations is usually referred to as the mean of the sample. This is equal to sum of the observations divided by the number of observations.
Meteorology	The science concerned with the atmosphere and its phenomena, temperatures, wind, clouds, precipitation, etc., and their variations.
Precipitation	Precipitation is the discharge of water, in liquid or solid state, out of the atmosphere, generally upon a land or water surface. The term is also commonly used to designate the quantity of water that is precipitated. The term precipitation includes rainfall, snow, hail and sleet.
OLR	Outgoing long-wave radiation anomaly.
Range	The difference between the largest and the smallest values of a specific data set.
Rainfall	The quantity of water that falls as rain only.
Rain Gauge	Instrument for measuring the depth of water from precipitation (or rainfall) that is assumed to be distributed over a horizontal, impervious surface and not subjected to evaporation.
Recording Rain Gauge	A rain gauge that automatically records the amount of precipitation (or rainfall) collected as a function of time.
Regression	A curve fitted to all mean values of Y (mean or expected value of Y for a given interval of X around X_i) is called regression of Y versus X.
Runoff	The portion of precipitation (or rainfall) on the land that ultimately reaches the selected point on a stream.

Sensor	The part of a measuring instrument that responds directly to changes in environment.
SLP	Sea level pressure
SOI	Southern oscillation index, this is equal to the sea level pressure at Tahiti minus the sea level pressure at Darwin. This could be as anomaly (simple difference) or standardized by the mean annual standard deviation. When the number is positive, La-Nina (or ocean cooling) occurs. If the number is negative, El-Nino (or ocean warming) occurs.
SST	Sea surface temperature, SST anomalies (departures from the 1971-2000 adjusted OI climatology) are recorded at four locations in the Pacific (Nino 1+2 over 0-10S and 90W-80W, Nino 3 over 5N-5S and 150W-90W, Nino 3.5 over 5N-5S and 170W-120W and Nino 4 over 5N-5S and 160E-150W), in the North Atlantic over 5N-20N and 60W-30W, and in the South Atlantic over 0-20S and 30W-10E. For global indications of SST, the measurements are reported over 10N-10S and 0W-360W.
Standard Deviation	This represents a measure of variability of observations in a sample. The square of standard deviation is called "variance".
Time Series	A time series is a sequence of observations arrayed in order of their occurrence. An observation can be a quantity either observed at discrete times, averaged over a time interval or recorded continuously with time. Hydrologic time series are sequences of daily, monthly or annual rainfall, streamflow, sediment transport, etc.
Trend	Trends are linear or non-linear slow changes in mean, variance, coefficient of variation and serial correlation coefficients of a time series. These render a time serious non-homogeneous.
Variance	It is square of the standard deviation.
Watershed	An area draining to a lake or a specified point on a stream, it lies upstream of the point and is enclosed by a hydrologic surface drainage divide, also called drainage area or drainage basin.
Watershed Divide	A ridge of section of high ground between watersheds, also called drainage divide.

Weather The state of the atmosphere, mainly with respect to its effects upon life and human activities. As distinguished from climate, weather consists of the short-term (minutes to months) variations of the atmosphere.

1.0 Introduction

1.0 INTRODUCTION

This study entitled "Study of Variations and Trends in the Historical Rainfall and Runoff Data in the Gatun Lake Watershed" was authorized by the Autoridad Del Canal De Panama (ACP, the Panama Canal Authority) in June 2001. The study is a part of the ACP's program to conserve and manage its water resources to meet transit demands to lock ships across the Isthmus. The numbers of transits have increased. ACP has determined that water availability is limited and may not be sufficient to meet future demands, especially in dry years. New sources of water have been investigated at pre-feasibility and feasibility levels to determine their contributions into the existing system in order to provide increased traffic service. However, ACP also considered it necessary to understand the reliability of the existing water resources and determine the long-term characteristics of the water supply in terms of potential decrease, frequency and occurrence of droughts and climatic factors affecting the existing resources. This study was made to provide answers to these concerns of the ACP.

The report is organized in two volumes. Volume 1 is the main report. The appendices are given in Volume 2. The main report is divided into sections and subsections. Tables and exhibits are numbered with reference to a section. Tables summarizing the results are provided in the text. Large tables and tables showing computations are labeled as exhibits. The references cited in the report are given in Appendix A. All computer input and output files are provided as appendices B to G.

1.1 Objective and Scope

The study was essentially the evaluation of the accuracy of the hydrologic and meteorological data and analysis of rainfall and runoff time series. The analysis was performed to identify and categorize the variations and possible existence of cyclic, short and/or long-term trends in the time series that might affect the supply of water to the Canal System, define the magnitude, duration and frequency of occurrence of low flow periods and determine climatic conditions affecting the time series. Fifteen rainfall and nine runoff series were selected for the analysis. These included:

A: Runoff Series

- Inflow to Madden Lake
- Inflow to Gatun Lake from drainage basin downstream from Madden Lake, designated as Gatun Downstream
- Inflow to Gatun Lake from total drainage area including area upstream from Madden Lake, designated as Gatun Total
- Ciri Grande River at Canonas
- Trinidad River at Chorro
- Chagres River at Chico

- Pequeni River at Candelaria
- Boqueron River at Peluca
- Gatun River at Ciento

B: Rainfall Series

- Basin average rainfall over the basin above Madden Dam
- Basin average rainfall over Gatun Downstream (the basin between Madden Dam and Gatun Dam)
- Basin average rainfall over Gatun Total (the total basin above Gatun Dam)
- Agua Clara rain gauge
- Alhajuela rain gauge
- Balboa Heights rain gauge
- Borro Colorado rain gauge
- Chico rain gauge
- Chorro rain gauge
- Gamboa rain gauge
- Gatun rain gauge
- Monte Lirio gauge
- Pedro Miguel rain gauge
- Salamanca rain gauge
- San Miguel rain gauge

Various work tasks performed for the study included:

- Collect hydrologic and meteorological data
- Review the data for quality and accuracy and resolve any issue affecting the accuracy of the data to establish a uniform record base for the time series analysis
- Prepare an inventory of the stations describing location, history, period of record and any environmental issue at each station
- Perform initial tests on the data to check consistency, homogeneity and outliers
- Extend rainfall and runoff time series to a common period of record
- Compute basin average rainfall for the basins above Madden Dam, Gatun Downstream and Gatun Total.
- Test the extended time series for autocorrelation, randomness, consistency and trends
- Perform test to verify whether the statistical properties of recent rainfall and runoff data (since 1971) are significantly different from the statistical properties of the data prior to 1971

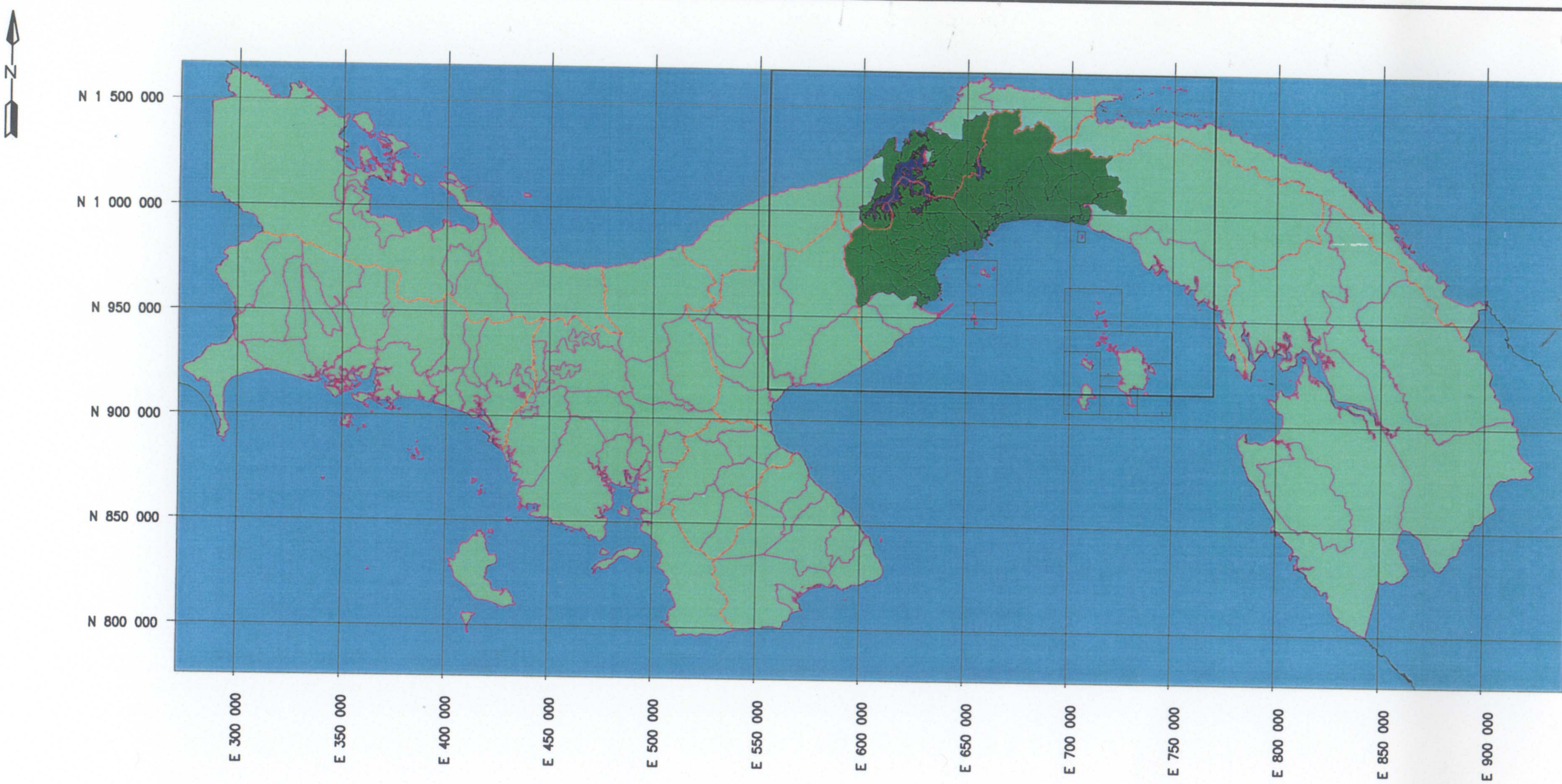
- Select an appropriate stochastic model, fit the model to three inflows and three basin average rainfall series as defined above, verify the model and develop a prediction model.
- Generate ten synthetic series each of 100-year period for three inflows to lakes and three basin average rainfall series as defined above
- Perform drought analysis of 3-, 6-, 12-, 18-, 24-, 30- and 36-month durations
- Determine volumes for the driest, wettest, and for 10, 25, 50 and 75 return periods corresponding to 3-, 6-, 12-, 18-, 24-, 30- and 36-month durations.
- Define the effects of El Nino on the water supply.
- Define the effects of sunspots on the long-term trends in the rainfall and runoff series.
- Make a qualitative assessment of climatic change in the Gatun watershed.

1.2 Location of Study Area

The study area is located between latitudes 8° 40' and 9° 30' north, and longitudes 79°14' and 80°08' west. The drainage area at Gatun Dam is about 3,320 km^2 including Gatun Lake surface area of about 425 km^2 and about 1,030 km^2 area above Madden Dam. The surface area of Madden Lake is about 41 km^2. Exhibit 1.1 shows the location of the study area.

1.3 Units of Measurements

ACP is collecting hydrological and meteorological data in both English and SI units. Most of the data colleted were in English units. All such data were converted into SI units for the analysis. The study used the SI units. Therefore, all results and basic data are presented in SI units.



LEGEND:

Province Boundary

District Boundary

Corregimiento Boundary

Lakes

Study Area

25 0 25 50 75 100 125 150 175 200 Kilometers

AUTORIDAD DEL CANAL DE PANAMA
Oficina de Proyectos de Capacidad del Canal

ACP

CONTRACT NO. CC-3-536

STUDY OF HYDROLOGIC SERIES IN GATUN LAKE WATERSHED

Study Area Location Map

MWH MONTGOMERY WATSON HARZA	FECHA: DECEMBER, 2001	EXHIBIT: 1.1

2.0 Panama Canal Complex

2.0 PANAMA CANAL COMPLEX

The Panama Canal is a 50-mile long waterway Canal connecting the Atlantic and Pacific Oceans across the Isthmus of Panama. It raises ships 85 feet above sea level in three steps. A three-step lock, Gatun Lock, at the north end of the Canal, raises and lowers ships in approximately equal steps for travel southbound across Gatun Lake. The ships travel 23 miles across Gatun Lake and then 8 miles through the Gaillard-Cut. Pedro Miguel Locks lower the ships one step for travel across Miraflores Lake, a distance of about one mile. Miraflores Locks lower the ships in two steps to the level of the Pacific Ocean. These locks are about 6 miles inland. A spillway with eight gates controls water levels in Miraflores Lake.

Gatun Dam, a concrete gravity structure with a 14-gate spillway and an earthen embankment west of Gatun Locks, controls water levels in the Gatun Lake. In addition to navigation, the lake provides water for municipal use.

Madden Dam is located about 12 miles east of the Canal. It is a high head dam located on the Chagres River. It provides water storage for navigation in the Panama Canal by releasing water to Gatun Lake, for flood control and for municipal water supply.

Both dams have hydropower facilities. The power is used to meet the demands of the Authority and Canal's operating facilities.

3.0 Topography and Drainage

3.0 TOPOGRAPHY AND DRAINAGE

The drainage basin above Gatun Dam is located between latitudes 8°40' and 9°30' north, and between longitudes 79°14' and 80°08' west. The overall drainage basin controlled by Gatun Dam is about 3,320 km^2. Of this, about 1,030 km^2 area is controlled by Madden Dam.

Madden Lake is located on the Chagres River. There are two main tributaries, Boqueron River and Pequeni River, entering Madden Lake. Stream gauging stations are located on Chagres (drainage area 414 km^2), Pequeni (drainage area 135 km^2) and Boqueron (drainage area 91 km^2). Mean annual discharges for the period from 1941 to 2000 were derived to be about 30.1, 13.9 and 7.6 m^3/s, respectively.

The Chagres River rises at an elevation of about 1,000 meters and flows in a general southwest direction. There are a number of small tributaries joining the river. Median elevation of the basin above the gauging station is about 460 meters. The Boqueron and Pequeni rivers rise at elevations of about 650 and 750 meters, respectively. The median elevations are about 250 and 290 meters, respectively.

There are a number of tributaries directly draining into Gatun Lake. All releases from Madden Lake (except municipal releases) enter Gatun Lake. Major tributaries joining Gatun Lake are Gatun River, Trinidad River and Ciri Grande River. Stream gauging stations are located on Gatun (drainage area 117 km^2), Trinidad (drainage area 173 km^2) and Ciri Grande (drainage area 186 km^2). Mean annual discharges for the period 1941 to 2000 were derived to be about 6.9, 6.7 and 9.3 m^3/s, respectively.

Mean annual inflows for the period 1941 to 2000 (60 years) were computed for Madden Lake, from the basins Gatun Downstream and Gatun Total. The values were about 75.1, 109.7 and 184.8 m^3/s, respectively.

4.0 Climate

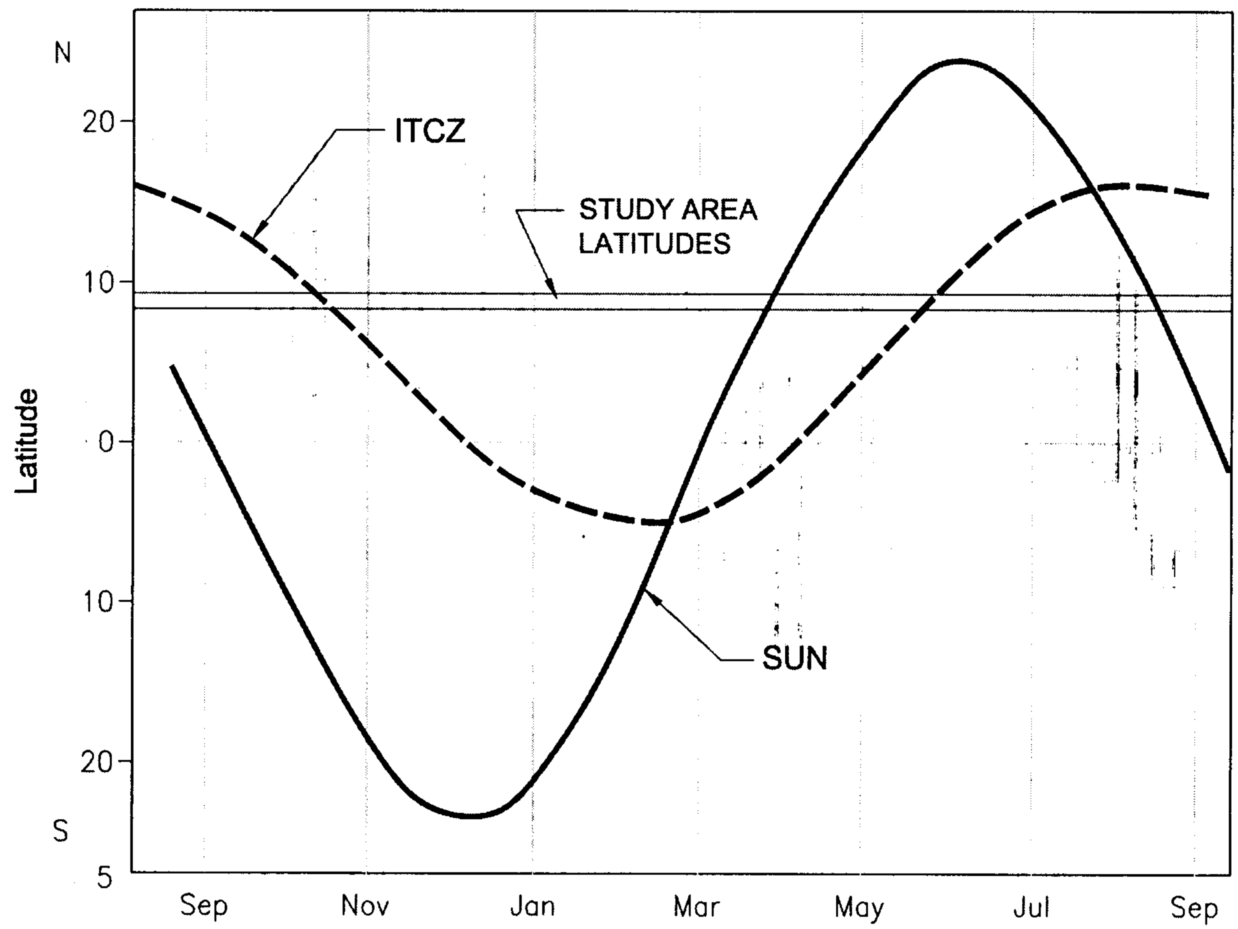
4.0 CLIMATE

The general climate of Panama is tropical with wet and dry seasons induced by the annual movement of the intertropical convergence zone (ITCZ). During the dry season, generally the months of February, March and April, the ITCZ is located south of Panama near the equator. In March or April, the ITCZ starts its northward movement and generally reaches Panama in late May or early June. Its passage results in heavy rainfall over a major portion of Panama. When the ITCZ is well north of Panama, occasionally, the strength of the rainy season subsides and starting from late June through July or sometimes August, a secondary dry season occurs (La Fortuna Project, 1976). However, based on the investigations by Espinosa (Espinosa, Jorge A.; June 1998), this second dry season may also be caused by a reinforcement of the system of high pressure of the Atlantic that affects the Caribbean region. This second dry season is also known as "Veranillo de San Juan" in Panama. This is because the "Veranillo's" or short summer's onset is generally around the Saint Day of San Juan, which is June 24 (Espinosa, Jorge A., June 1998).

In late summer or early autumn, the ITCZ starts its southward migration and it passes over Panama in late October or early November. During the months of October through December and occasionally in January heavy rainfall occurs over Panama. However, major storms have occurred in November and December. When the ITCZ has moved well south of Panama, the dry season is established again. Monthly average positions of the ITCZ are shown on Exhibit 4.1 (source Riehl, H., 1979). The position of study area is also located on this exhibit. There could be significant variations from this average position from year to year. In general, the wet season is characterized by mild humid winds from a southerly direction while less humid, but somewhat stronger, northerly winds are more typical of the dry season (La Fortuna Project, 1976).

It has been observed in Panama that the presence of El Nino affects the regular movement of the ITCZ. This results in below normal rainfall in some parts of Panama and above normal rainfall in other parts. Estoque (Estoque, M.A., et al., 1985) studied the effect of El Nino on the rainfall in Panama. They listed thirteen episodes of El Nino for the period from 1920 to 1983, and compared the annual rainfall during an El Nino with the long-term mean annual rainfall. The results indicated that El Nino produced below normal rainfall in most of the regions of Panama except some basin located north of the Cordillera in the Atlantic coastal region.

Basin average annual rainfall amounts were calculated for the basin upstream from Madden Lake, Gatun Downstream and Gatun Total for the period from 1911 to 2000 (90 years). The values are about 2837, 2576 and 2663 mm, respectively.



LEGEND:

ITCZ = INTERTROPICAL CONVERGENCE ZONE

AUTORIDAD DEL CANAL DE PANAMA
Oficina de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
STUDY OF HYDROLOGIC SERIES IN GATUN LAKE WATERSHED

Annual March of Sun's Zenith Position and ITCZ

MWH MONTGOMERY WATSON HARZA

FECHA: DECEMBER, 2001

EXHIBIT: 4.1

5.0 Hydrometeorological Data Collected

5.0 HYROMETEOROLOGICAL DATA COLLECTED

Rainfall and runoff data for the stations within the Gatun Lake basin were provided by ACP. These data are given in Appendix B. ACP also provided hydrological data for the stations outside the basin. Climatic indices for El Nino and sunspot data were retrieved through the Internet.

Rainfall stations with period of record are listed in Exhibit 5.1. Exhibit 5.2 shows the list of stream gauging stations. The type of data collected at each station is listed on Exhibit 5.3.

Other data and information collected includes:

1. List of hydrometeorological stations including names, latitudes, longitudes and elevations.

2. Report – Panama Canal Watershed Runoff Trend Analysis by Carlos Vargas, June 1992.

3. Report – Analysis of Rainfall Data in the Panama Canal for Presence of a Trend by Mike Hart, May 1992.

4. Article – International Variability of Caribbean Rainfall, ENSO and Atlantic Ocean, by Gianni, Kunir and Cane, Journal of Climate, Vol 13, Jan 2000.

5. Article – ENSO and Natural Variability in the Flows of Tropical Rivers by Kishan N. Amarasekra, Robert F. Lee, Earle R. Williams and Elfaith A.B. Eltahir. Journal of Hydrology 200 (1997) 24-39.

6. Mean Annual Rainfall Map of Gatun Watershed.

7. Map of Water Yield of Sub-Basins of Gatun Watershed.

LIST OF RAINFALL STATIONS IN GATUN LAKE WATERSHED
WITH PERIOD OF RECORD
(including Area above Maddan Lake)

Station Name	Station ID	Latitude North (deg-min-sec)	Longitude West (deg-min-sec)	Elevation (meters)	Period of Record
Agua Clara	ACL	09-21-52	79-42-22	460.0	May 1910 to Ju 1921, Dec 1921 to Jan 1927, Jun 1945 to Aug 1947, Nov 1947 to Aug 1963, Oct-Nov 1963, Jan-Apr 1963, Jan-Feb 1965, May-Jul 1965, Oct 1965, Jan 1966 to Jul 1971, Oct 1971 to Dec 2000.
Alhajuela	ALA	09-12-23	79-37-14	39.5	Jul 1899 to Apr 1904, Jun 1904 to Dec 2000.
Amador	AST	08-55-00	79-32-05	1.5	
Arca Sonia	ARC	09-11-36	79-30-54	265.0	Mar 1999 to Dec 2000.
Balboa Heights	BHT	08-57-34	79-35-15	30.5	Jul 1898 to Dec 1901, Jun 1905 to Dec 2000.
Boro Colorado	BCI	09-09-55	79-50-11	33.5	Apr 1925 to Dec 2000.
Candelaria	CDL	09-22-58	79-30-59	97.5	Sep 1933 to Apr 1934, Jul 1934 to Jan 1962, Nov-Dec 1964, Feb-Jul 1963, Nov 1963 to May 1964, Oct 1964 to Dec 2000.
Cano	CNO	09-04-35	79-49-22	33.0	Jan 1912 to Jun 1959, Feb 1970, May-Aug 1970, Feb 1971 to Dec 2000.
Canones	CAN	08-56-56	80-03-45	103.5	Sep 1947 to Jul 1959, Mar 1970 to Dec 2000.
Cascadas	CAS	09-04-53	79-40-48	47.0	Feb-Oct 1967, Dec 1967, Jan-Feb 1968, Jul 1968 to Mar 1969, Apr-Oct 1970, Apr-Jul 1971, Dec 1971 to Dec 2000.
Cerro Cama	CCA	09-01-36	79-54-21	120.0	Apr-Dec 2000.
Chamon	CHM	09-20-31	79-19-06	640.0	Jan-Dec 2000.
Chico	CHI	09-15-49	79-30-35	103.5	Oct 1932 to Feb 1933, Apr 1933 to Jan 1962, Oct-Dec 1964, Apr 1966 to Apr 1967, Jul 1967 to Dec 2000.
Chorro	CHR	08-58-32	79-59-25	42.5	Sep 1947 to Jul 1960, Nov 1960 to to Sep 1963, Dec 1963, Jan 1964, Jan-Mar 1965, May 1965 to Aug 1966, Oct 1966 to Dec 2000.
Ciento	CNT	09-17-52	79-43-41	38.0	Apr 1947 to Sep 1962, Jan-Sep 1963, Nov-Dec 1963, Jan 1964, Mar-May 1964, Oct-Nov 1964, Sep-Dec 1965, Jan 1966, Apr 1966, Jun-Jul 1966, Oct 1966 to Apr 1971, jun 1971 to Feb 1974, May 1974 to Dec 2000.
Coco Solo	CSO				Sep 1980 to Dec 1995.
Cristobal		09-21-00	79-54-00	12.0	Mar 1881 to Mar 1888, Jan 1890 to Sep 1979.
Diablo Heights	DHT	08-57-56	79-34-24	4.5	Jan 1983 to Dec 2000.
Dos Bocas	DBK	09-27-09	79-25-52	228.0	May-Dec 2000.
Empire Hill	EMH	09-03-29	79-39-53	61.0	Apr-Jun 1883, Aug-Sep 1883, Dec 1883, Jun 1905 to Mar 1927, Jan 1962 to Sep 1964, Dec 1978 to dec 2000.
Escandalosa	ESC	09-25-25	79-34-42	480.0	Jan-Apr 1948, Oct 1948 to Nov 1959, Jun1960, Jan 1961 to Apr 1962, Dec 1962 to Jan 1965, May-Dec 1965, Mar 1966, Jun-Aug 1966, Nov 1966 to Apr 1969, Mar 1970 to Dec 2000.
Esperanza	EZA	09-24-35	79-21-08		Jan 1999 to Dec 2000.
FAA	FAA	08-58-08	79-32-58	10.0	Apr 1978 to Dec 2000.
Frijolito	FTO	09-13-08	79-42-58	349.0	
Gamboa	GAM	09-06-44	79-41-38	31.5	Jun-Dec 1881, Mar-Dec 1882, Apr 1883 to Jan 1895, Apr-May 1895, Jul 1895, Apr-Jul 1896, Jan 1897 to Dec 2000.
Gasparillal	GAS	08-51-46	80-00-56	346.0	Oct-Dec 2000.
Gatun	GAT	09-16-06	79-55-14	30.5	Jan 1905 to Dec 2000.
Gatun West	GTW	09-15-47	79-55-45	33.0	Jan 1999 to Dec 2000.
Gold Hill	GOL	09-02-34	79-38-35	180.0	

LIST OF RAINFALL STATIONS IN GATUN LAKE WATERSHED
WITH PERIOD OF RECORD
(including Area above Maddan Lake)

Station Name	Station ID	Latitude North (deg-min-sec)	Longitude West (deg-min-sec)	Elevation (meters)	Period of Record
Guacha	GUA	09-10-37	79-56-20	29.0	Dec 1959 to Jul 1960, Dec 1960 to Aug 1961, Apr-Dec 1963, Feb 1965, May 1965 to Mar 1966, Jan 1968 to Jan 1970, Jan -Oct 1970, Dec 1971 to Dec 2000.
Hodges Hills	HHI	09-02-39	79-39-05	70.0	Jan 1968 to Dec 2000.
Humedad	HUM	09-02-54	80-02-21	30.5	Aug 1925 to Dec 1927, Jan-Mar 1961, Dec 1961, Sep-Nov 1966 Jan 1967 to Dec2000.
Jagua	JAG	08-44-14	80-02-50	545.5	Jan 1999 to Dec 2000.
Limon Bay	LMB	09-21-20	79-54-53	3.0	Jan-Dec 1997, Jul 1998 to Dec 2000
Limpio	LIM	09-19-41	79-28-07	684.0	Jan 1999, Jul-Sep 1999
Mirafloras	MIR	09-00-51	79-36-36	20.0	Jan 1999 to Dec 2000.
Monte Lirio	MLR	09-14-28	79-51-12	33.5	Dec 1907 to Feb 1960, Apr-May 1960, Oct 1960 to Apr 1964, Sep 1964, Apr 1965 to Jan 1966, Mar-Dec 1966, Mar 1967 to Mar 1970, May 1970 to Dec 2000.
Nuevo Vigia	NVG				
Peluca	PEL	09-22-48	79-33-40	106.5	Oct 1933 to Feb 1962, Feb-May 1963, Aug-Dec 1963, Mar-Apr 1964, Nov 1964, Jul 1965 to Aug 1971, Oct 1971 to Dec 2000.
Pedro Miguel	PMG	09-01-22	79-37-02	30.5	Jan 1908 to Dec 2000.
Rio Piedras	RPD	09-16-55	79-23-53	149.5	May 1985 to Dec 2000.
Raises	RAI	09-05-31	79-59-16	33.5	Jan 1941, Jun 1941 to Dec 1961, Apr 1962 to Mar 1963, Sep-Oct 1963, Nov 1964 to Jul 1965, Oct 1955 to May 1970, Oct-Nov 1970, Jan 1971 to Dec 2000.
San Miguel	SMG	09-25-12	79-30-15	520.0	Apr 1941 to Dec 1959, Feb-Aug 1960, Nov 1960 to Jun 1961, Feb-Nov 1963, Feb-Apr 1964, Dec 1964 to Apr 1967, Aug 1967 to Dec 1969, Feb-Apr 1970, Jan 1971 to Dec 2000.
Salamanca	SAL				Jan-Dec 1900, Apr 1921 to Nov 1962, Jan 1963 to May 1964, Aug-Oct 1964, Feb-Mar 1965, May 1965, Oct 1965 to May 2000.
Santa Rosa	SRO	09-11-09	79-39-15	27.5	Jan 1986 to Dec 2000.
Vistamares	VTM	09-14-04	79-24-05	968	Jan 1999 to Dec 2000.

Exhibit 5.2

LIST OF STREAM GAGING STATIONS IN GATUN LAKE WATERSHED WITH PERIOD OF RECORD

Station Name	Period of Record
1. Ciri Grande River at Los Canones	Jul-Aug 1947, Nov 1947 to Dec 1958, Feb-May 1959, Aug 1978 to Dec 1983, Mar-Oct 1984, Dec 1984, Mar-Oct 1985 Jan-Oct 1986, Jan 1987 to Dec 1998
2. Trinidad River at Chorro	Apr 1947, Nov 1947 to Jul 1966, Oct 1966 to Jun 1969, Oct 1969 to Oct 1972, Dec 1972 to Jul 1985, Sep 1985 to Dec 1998
3. Charges River at Chico	Mar 1933 to Jun 1934, Oct 1934 to Oct 1966, Dec 1966 to Dec 1967, Jan 1971, Jul 1971 to Mar 1975, Jun 1975 to Oct 1986, Dec 1986 to Dec 1998
4. Pequeni River at Candelaria	Sep-Dec 1933, Feb 1934 to Feb 1971. May 1971 tp Dec 1998
5. Boqueron River at Peluca	Sep 1933 to Aug 1964, Nov 1964 to May 1965, Sep 1965 to Jun 1998
6. Gatun River at Ciento	May 1943, Aug 1943 to Jun 1945 Apr 1946 to Feb 1947, Apr-May 1947, Sep 1947 to Jul 1964, Oct 1964 to May 1965, Aug 1965, Oct-Dec 1965, Jan 1971 to Aug 1974, Oct 1974 to Feb 1975, Apr 1975, Jun 1975 to May 1990, Jul 1990 to Jul 1998

Exhibit 5.3

TYPE OF HYDROMETRIC AND METEOROLOGICAL DATA COLLECTED IN GATUN LAKE WATERSHED

No.	Station Name	Code	Station ID	Latitude North (deg-min-sec)	Longitude West (deg-min-sec)	Elevation (meters)	Type of Observations
1	Agua Clara	50	ACL	09-21-52	79-42-22	460.0	rainfall
2	Alhajuela	55	ALA	09-12-23	79-37-14	39.5	rainfall, river stage, discharge measurements
3	Amador	02	AST	08-55-00	79-32-05	1.5	rainfall
4	Arca Sonia	77	ARC	09-11-36	79-30-54	265.0	rainfall
5	Balboa Heights	60	BHT	08-57-34	79-35-15	30.5	rainfall
6	Boro Colorado	04	BCI	09-09-55	79-50-11	33.5	rainfall
7	Candelaria	51	CDL	09-22-58	79-30-59	97.5	rainfall, river stage, discharge measurements, sediment samples
8	Cano	59	CNO	09-04-35	79-49-22	33.0	rainfall
9	Canones	21	CAN	08-56-56	80-03-45	103.5	rainfall, river stage, discharge measurements, sediment samples
10	Cascadas	30	CAS	09-04-53	79-40-48	47.0	rainfall
11	Cerro Cama	78	CCA	09-01-36	79-54-21	120.0	rainfall
12	Chamon	79	CHM	09-20-31	79-19-06	640.0	rainfall
13	Chico	53	CHI	09-15-49	79-30-35	103.5	rainfall, river stage, discharge measurements, sediment samples
14	Chorro	48	CHR	08-58-32	79-59-25	42.5	rainfall, river stage, discharge measurements, sediment samples
15	Ciento	52	CNT	09-17-52	79-43-41	38.0	rainfall, river stage, discharge measurements, sediment samples
16	Coco Solo		CSO				rainfall
17	Cristobal			09-21-00	79-54-00	12.0	rainfall
18	Diablo Heights	06	DHT	08-57-56	79-34-24	4.5	rainfall
19	Dos Bocas	81	DBK	09-27-09	79-25-52	228.0	rainfall
20	Empire Hill	64	EMH	09-03-29	79-39-53	61.0	rainfall
21	Escandalosa	14	ESC	09-25-25	79-34-42	480.0	rainfall
22	Esperanza	71	EZA	09-24-35	79-21-08		rainfall
23	FAA	63	FAA	08-58-08	79-32-58	10.0	rainfall,wind velocity, direction and gust, relative humidity, air temperature, solar radiation, barometric pressure
24	Frijolito	69	FTO	09-13-08	79-42-58	349.0	rainfall
25	Gamboa	16	GAM	09-06-44	79-41-38	31.5	lake level, rainfall, wind velocity, direction and gust, relative humidity, air temperature, solar radiation, barometric pressure.
26	Gasparillal	22	GAS	08-51-46	80-00-56	346.0	rainfall
27	Gatun	54	GAT	09-16-06	79-55-14	30.5	lake level and rainfall
28	Gatun West	09	GTW	09-15-47	79-55-45	33.0	lake level, rainfall, wind velocity, direction and gust, relative humidity, air temperature, solar radiation, barometric pressure
29	Gold Hill	24	GOL	09-02-34	79-38-35	180.0	rainfall
30	Guacha	46	GUA	09-10-37	79-56-20	29.0	lake level and rainfall
31	Hodges Hills	41	HHI	09-02-39	79-39-05	70.0	rainfall
32	Humedad	43	HUM	09-02-54	80-02-21	30.5	rainfall
33	Jagua	67	JAG	08-44-14	80-02-50	545.5	rainfall,wind velocity, direction and gust, relative humidity, air temperature, solar radiation, barometric pressure
34	Limon Bay	70	LMB	09-21-20	79-54-53	3.0	rainfall,wind velocity, direction and gust, relative humidity, air temperature, solar radiation, barometric pressure
35	Limpio	20	LIM	09-19-41	79-28-07		lake level and rainfall
36	Miraflores	58	MIR	09-00-51	79-36-36	20.0	lake level and rainfall
37	Monte Lirio	42	MLR	09-14-28	79-51-12	33.5	rainfall
38	Nuevo Vigia	25	NVG				lake level and rainfall
39	Peluca	45	PEL	09-22-48	79-33-40	106.5	rainfall, river stage, discharge measurements, sediment samples
40	Pedro Miguel	61	PMG	09-01-22	79-37-02	30.5	lake level, rainfall,relative humidity, air temperature, solar radiation
41	Rio Piedras	66	RPD	09-16-55	79-23-53	149.5	rainfall and river stage
42	Raises	44	RAI	09-05-31	79-59-16	33.5	lake level and rainfall
43	San Miguel	49	SMG	09-25-12	79-30-15	520.0	rainfall
44	Salamanca		SAL				rainfall
45	Santa Rosa	08	SRO	09-11-09	79-39-15	27.5	river stage and rainfall
46	Vistamares	68	VTM	09-14-04	79-24-05	968	rainfall,wind velocity, direction and gust, relative humidity, air temperature, solar radiation, barometric pressure
47	Cocle Del Norte	32	CON	08-53-09	80-33-26	12.2	rainfall, river stage, discharge measurements, sediment samples
48	Indio West	31	INW	08-58-33	80-10-39	9.1	rainfall, river stage, discharge measurements, sediment samples
49	Toabre	33	TOA	08-55-01	80-30-03	13.7	rainfall, river stage, discharge measurements, sediment samples

6.0 Review of Hydrometeorological Data

6.0 REVIEW OF HYDROMETEOROLOGICAL DATA

The period of record and missing data for the stations within Gatun Watershed were identified. Preliminary checking of a few historic rainfall and runoff time series was made by simple mass curves and chronological plots. No apparent significant change in mass curve slopes or trends in the data were observed. However, detailed statistical procedures were used to confirm this as discussed in the subsequent sections.

During the field visit, the field and office procedures used in data collection and reduction, were reviewed. Based on the information collected in the field, an inventory of rainfall and stream gauging stations was prepared and is presented as Appendix C. The inventory includes a review of the history of each station and identifies any change in the location, instrumentation and environment at the station that could have affected the consistency of the data. The inventory also includes:

- Location of station: latitude, longitude and elevation.
- History of station: date of installation, instrumentation, and change in location and environment over the record period. For the stream gauging stations, the hydraulic characteristics defining the stage-discharge relationships are discussed.
- Period of record.

6.1 Stream Gauging Stations

The instrumentation at these stations is well maintained. All stream gauging stations are connected to a central computer at Balboa Heights via VHF communication system.

Hydraulic conditions at the stations are reasonably good. The stage-discharge relationships (rating curves) are controlled by the channel conditions. At nearly all of the sites the channel controls are likely to change depending upon the magnitude of a flood. The rating curves for the previous years show significant change from year to year.

The method of discharge measurements is satisfactory and provides from reasonably fair to good measurements but does not follow the standard discharge measuring procedures of the United States Geological Survey, Water Resources Division (USGS). It is recommended that the discharge measurements should be made using the following procedures:

- Depth and velocity observations should be made at 20 to 25 verticals. The number of verticals may be restricted due to relatively narrow stream widths. Minimum distance between two verticals should be one meter (not less than one meter) when making a measurement from a cableway. When wading measurements are made, the minimum distance should be 0.5 meter.

- Currently discharge measurements are made from a cableway for low and high flows. Measurements during low flow (up to a depth at which a measurement can be made safely), must be made by wading where feasible.

- Proper sounding weights should be used to avoid vertical angle, and air-line and wet-line corrections to the observed depth. If a proper weight is not available at the site, the air-line correction should be avoided using tags on the sounding line. This method is explained in USGS Water Supply Paper 2175, Volume 1 (Rantz and others, 1982).

- Preparation of rating curves was checked during the field visit. The procedures used are reasonable but should be improved to follow the guidelines given in Volume 2 of Water Supply Paper 2175.

- From the date when a rating curve becomes applicable up to the date when sufficient number of discharge measurements become available to revise the previous rating curve, the daily discharges should be computed using the concept of shift adjustment (Chapter 10, Volume 2, Water Supply Paper 2175).

6.2 Rainfall Stations

Rainfall stations and other climatological stations are well maintained. The rainfall data are transmitted to the base station at Balboa heights.

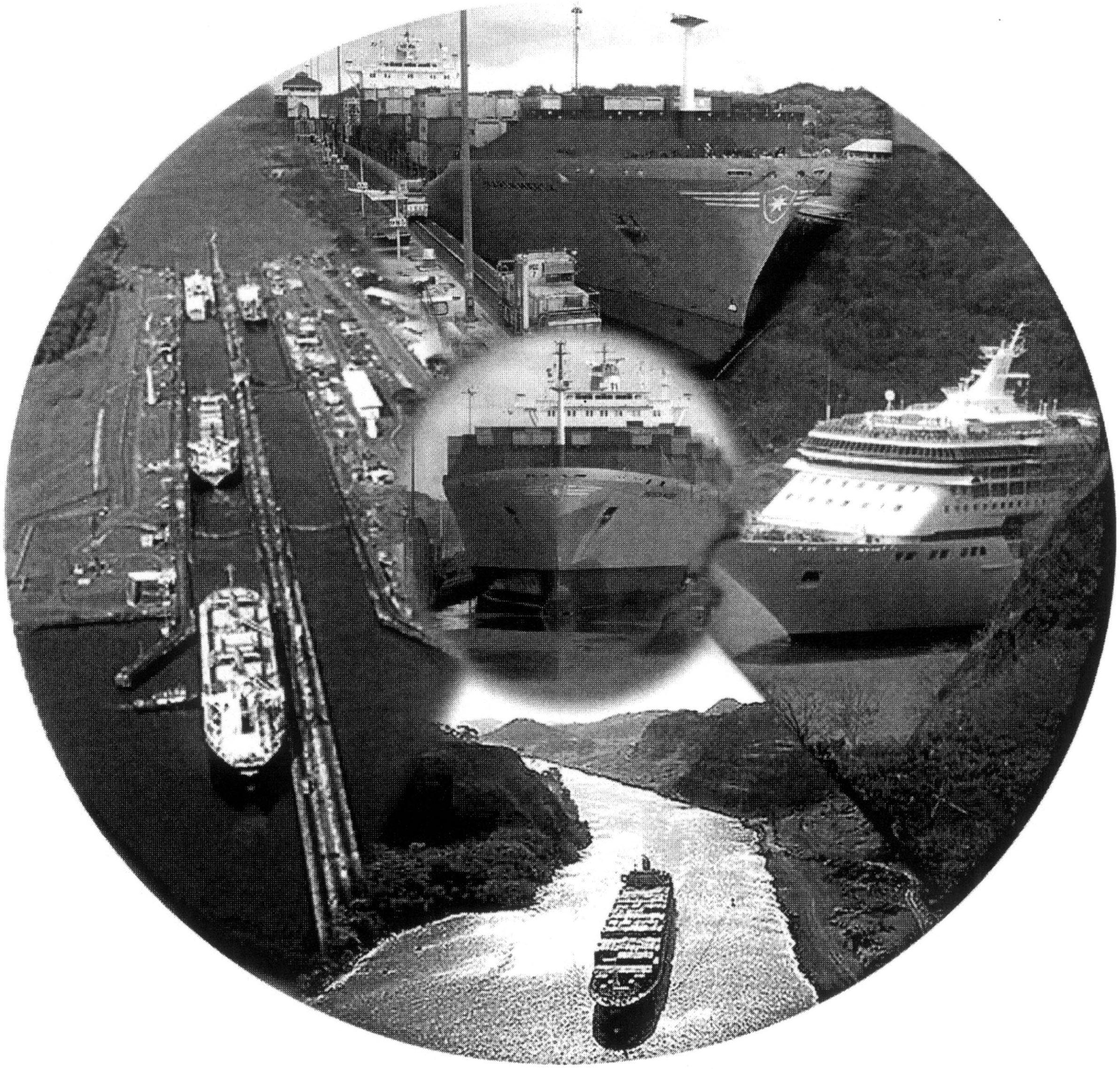
Two types of rain gauges are installed on nearly all stations, a tipping bucket rain gauge from Novalynx of 12-inch collector diameter and one mm per tip, and a storage type gauge also of 12-inch collector diameter. Both gauges are installed on the roof of the instrument house. The details of the gauges are discussed in Appendix C. The Appendix also describes the field and office studies made by ACP to adopt a one mm per tip gauge.

The signal from the tipping bucket is divided into two signals at the terminal strip, one going into a data storage devise from VAISALA/HANDAR (on site record) and the other signal going into the Climatronics telecommunication hub installed by SUTRON. The hub sends the data via VHF to the ACP Administrative Building in Balboa.

Rainfall data received from the storage and tipping bucket gauges are often nearly equal but some times there are significant differences in the two observations. In such cases, the ACP meteorologist decides to use one or the other observation based on a review of data at nearby stations and based on his experience with the instruments.

The above procedure is reasonable and can be continued if desired by ACP. However, based on the review of simultaneous measurements by two gauges over more than a year, it is recommended to use the tipping bucket rain gauge of one mm per tip. To provide a check on the operation of the gauge, a standard non-recording 12-inch diameter rain gauge with sufficient capacity to store rainfall for about two weeks during the rainy season, should be installed on all tipping bucket rain gauge stations. The rainfall collected in the non-recording rain gauge should be measured twice in a month, at the middle of the month and at end of the month. Apart from providing a check on the working of the tipping bucket rain gauge, this will give good quality monthly rainfall data.

7.0 General Study Methodology



7.0 GENERAL STUDY METHODOLOGY

The historic rainfall data for stations with more than 5 years of data were reviewed keeping in mind the effect of ITCZ and El Nino as discussed under "Climate." The rainfall data are strongly related to the movement of ITCZ. A delay in the arrival of ITCZ resulted in less than normal rainfall. Similarly, the rainfall was below normal in nearly all of the El Nino episodes.

Reports on trend analyses of rainfall by Michael S. Hart (May 1992) and runoff by Carlos A. Vargas (June 1992) identified changes in rainfall and runoff regimes starting from 1971. Based on a preliminary review of rainfall and streamflow series, it was determined that the inconsistency or trend (non-homogeneity) in the series was not so significant to warrant special treatment including adjustments to current or past conditions. There was a change in most of the series starting from early 1970's. This inconsistency and non-homogeneity in the data might possibly be due to man-made changes in the watershed, shift in the methodology of data analysis or some sort of climatic change. However, based on the assumption that some change might have occurred in early 1970's, one-population concept with two sub-sets was tested. The monthly rainfall and streamflow data prior to 1971 was considered as one set and the data from 1971 to 2000 was considered as the second set.

After the review of the available rainfall data, it was decided to use a common period of 90 years, from 1911 to 2000, for the monthly rainfall series. A common period of 60 years, from 1941 to 2000, was adopted for the streamflow series.

Each series was tested for inconsistency and significance of trend. More than one method was used as discussed in the subsequent sections. Conclusions were made as to whether a series was consistent and homogeneous or not. All tests were made at 95 percent confidence level. The series that were judged to be inconsistent or with significant trends were tested against the consistent and homogeneous series. The purpose was to assess the applicability of the series for further use.

Monthly basin average rainfall series were developed for the basins upstream from Madden Lake, Gatun Downstream and Gatun Total. The Thiessen method was applied and extended series at appropriate rainfall stations for the period from 1911 to 2000, were used.

Monthly inflow series were developed for Madden Lake and Gatun Downstream by transposing the extended monthly flows at the stream gauging stations. Monthly inflows for Gatun Total were obtained as sum of the Madden Lake inflows and flows from Gatun Downstream. Regression analysis was performed to correlate basin average rainfall and runoff.

Ten synthetic rainfall and flow series sets, each of 100-year period, were developed for each of three basin average rainfall series and three inflow series discussed above. The HEC-4 computer program was used to generate synthetic series.

The effect of El Nino on the annual and monthly rainfall and runoff data was evaluated for all El Nino episodes since 1951. The data prior to 1951 are not available. Decreases in the rainfall and runoff as percentages of mean annual or mean monthly values were calculated. These data were used to assess the severity of an episode. Correlation was also attempted between climatic indices of El Nino and the annual flows.

Analysis was made to evaluate any correlation between sunspots and rainfall and/or runoff series. Long-term trends in the sunspots cycles were also evaluated. A detailed review was made of long-term climatic change in the region of Central America. Only qualitative conclusions could be made.

8.0 Extension of Rainfall Series To a Common Period

8.0 EXTENSION OF RAINFALL SERIES TO A COMMON PERIOD

8.1 Procedures

Historic rainfall time series were used to fill-in the missing months and extend all of the monthly rainfall series to a common period. Rainfall data at selected stations were filled-in and/or extended for the period from 1911 to 2000 (90 years). This 90-year period was selected to have two sub-series of 60 years and 30 years. This is because the previous reports (Vargas and Hart, 1992) identified the early 1970's as the year when potential change in rainfall and runoff regimes occurred. This gives a 30-year period up to 2000. Two sub-series of 60 years and 30 years provided a better procedure to test the consistency and homogeneity of the whole series.

Complete 90-years of data were available for Alhajuela, Balboa Heights, Gamboa, Gatun and Pedro Miguel. For other stations, the data for some months and/or years were missing. The data at these stations were filled-in and extended to the common period. Exhibits 5.1 and 8.1 show the periods of historic record. Table 8.1 gives the percent of filled-in data.

Three computer programs were reviewed to fill-in and extend the data. The HEC-4 computer program developed by the United States Army, Corps of Engineers can fill-in and extend the data. The program is dimensioned for 10 stations and 100 years of record. A computer program "Stochastic Optimization & Simulation Techniques for Management of Regional Water Resources System, Volume II B FILLIN –1 Program," developed by Texas Water Development Board, 1970, can fill-in and extend the data. The program is dimensioned for 25 stations and 50 years of record. The third computer program, "Applied Stochastic Technique," developed by the United States Bureau of Reclamation cannot fill-in the data. The program can only extend the data.

Both the HEC-4 and FILLIN programs use nearly same statistical procedures. After the review, it was decided to use the FILLIN program developed by the Texas Water Development Board.

8.2 Description of Model

FILLIN program was developed by System Engineering Division of the Texas Water Development Board in Austin Texas. The original program was dimensioned to handle up to a combination of 25 streamflow, rainfall, and evaporation stations with a maximum period of 50 years. The program was modified in the current study to handle up to 30 stations and maximum record length of 100 years.

Table 8.1

PERCENTAGES OF FILLED-IN DATA
RAINFALL STATIONS

Station	Percent Filled	Station	Percent Filled
Agua Clara	18.2	Gatun	0.0
Alhajuela	0.0	Guacha	72.2
Balboa Heights	0.0	Hodges Hill	74.9
Borro Colorado	15.8	Humedad	71.1
Candelaria	26.6	Limon Bay	2.7
Cano	12.4	Monte Lirio	1.9
Chico	27.4	Peluca	39.4
Ciento	42.6	Pedro Miguel	0.0
Chorro	42.4	Racies	23.3
Cascadas	75.4	Rio Piedras	93.7
Canones	72.5	Salamanca	2.4
Empire Hills	57.5	San Miguel	48.7
Escandalosa	56.2	Santa Rosa	94.4
Gamboa	0.0		

The program computes the statistical parameters of the multi-site monthly data set (i.e., means, standard deviations, single lag-one correlations, and multi-site spatial correlations) and creates a filled data set. The filled-in data set has a record length equal to the longest record length of the original data set. The program is designed to preserve, in the filled-in portions of the data, the mean, standard deviation, the spatial correlations, and lag-one correlations between the original unfilled portions of the multi-site data set.

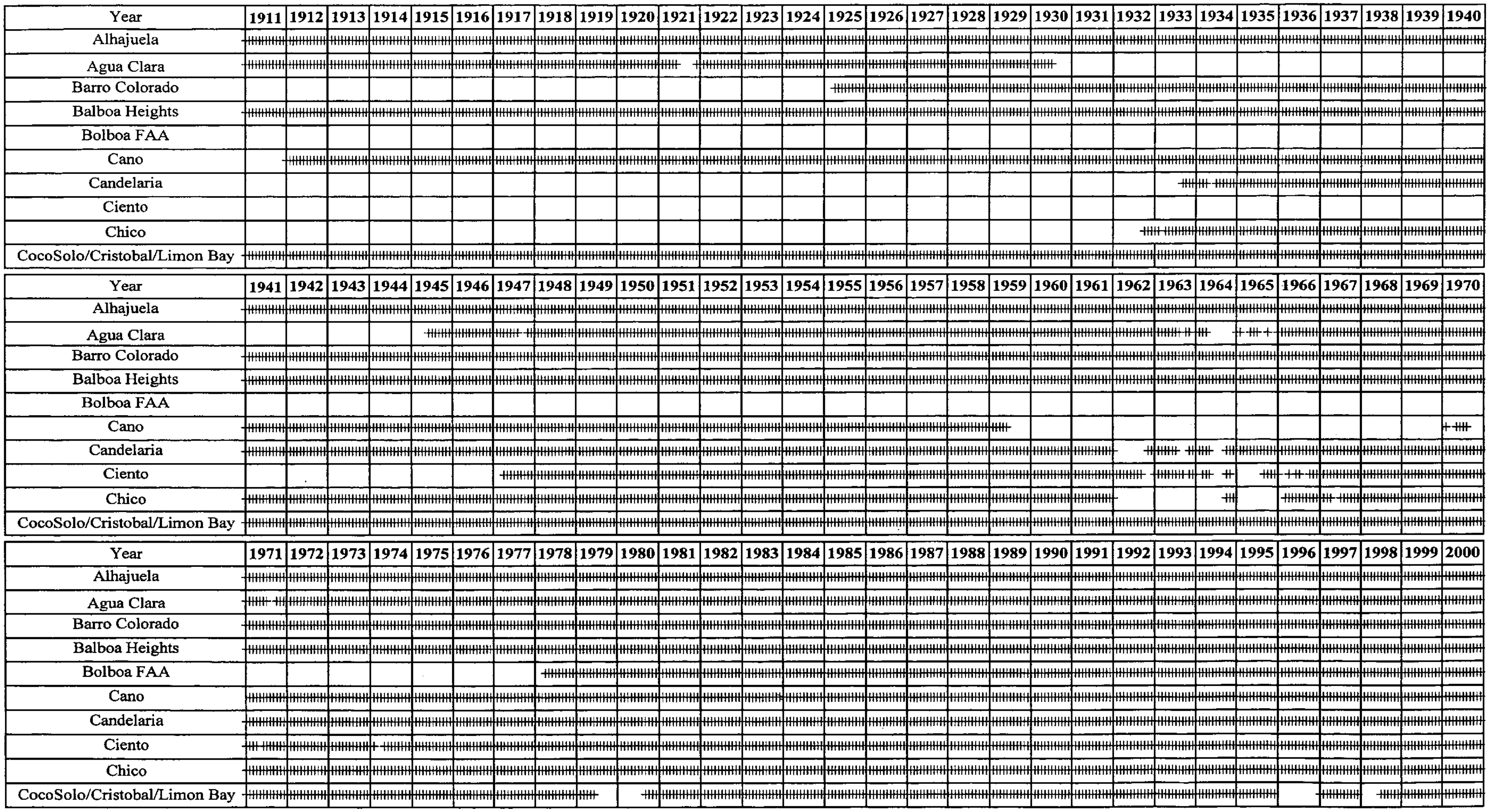
There are mainly three phases of the fill-in procedure: data preparation and statistical analysis, data fill-in, and report preparation. Phase one includes reordering of the data set, performing a logarithmic transformation, computing the monthly mean and standard deviation, and performing a normalizing transformation by subtracting its mean and dividing the remainder by the standard deviation. Phase two of data fill-in includes developing coefficients for linear estimator equations, estimating each missing data, and adjusting the filled-in data. Phase three is used to conduct reverse normalizing transformation and reverse logarithmic transformation and reorder the sites and print output of filled historic hydrologic time series.

Filled-in monthly flows for all rainfall stations are given in Appendix D. Input and output files of the FILLIN program are given in Appendix E.

8.3 Evaluation of Filled Data

Mass curves and chronological plots drawn for all stations (see Appendix D) do not show any discontinuity for the filled-in periods. The mass curves were continuous with no significant change in slope. Therefore, the filled-in data was judged to be of the same quality as the historical data.

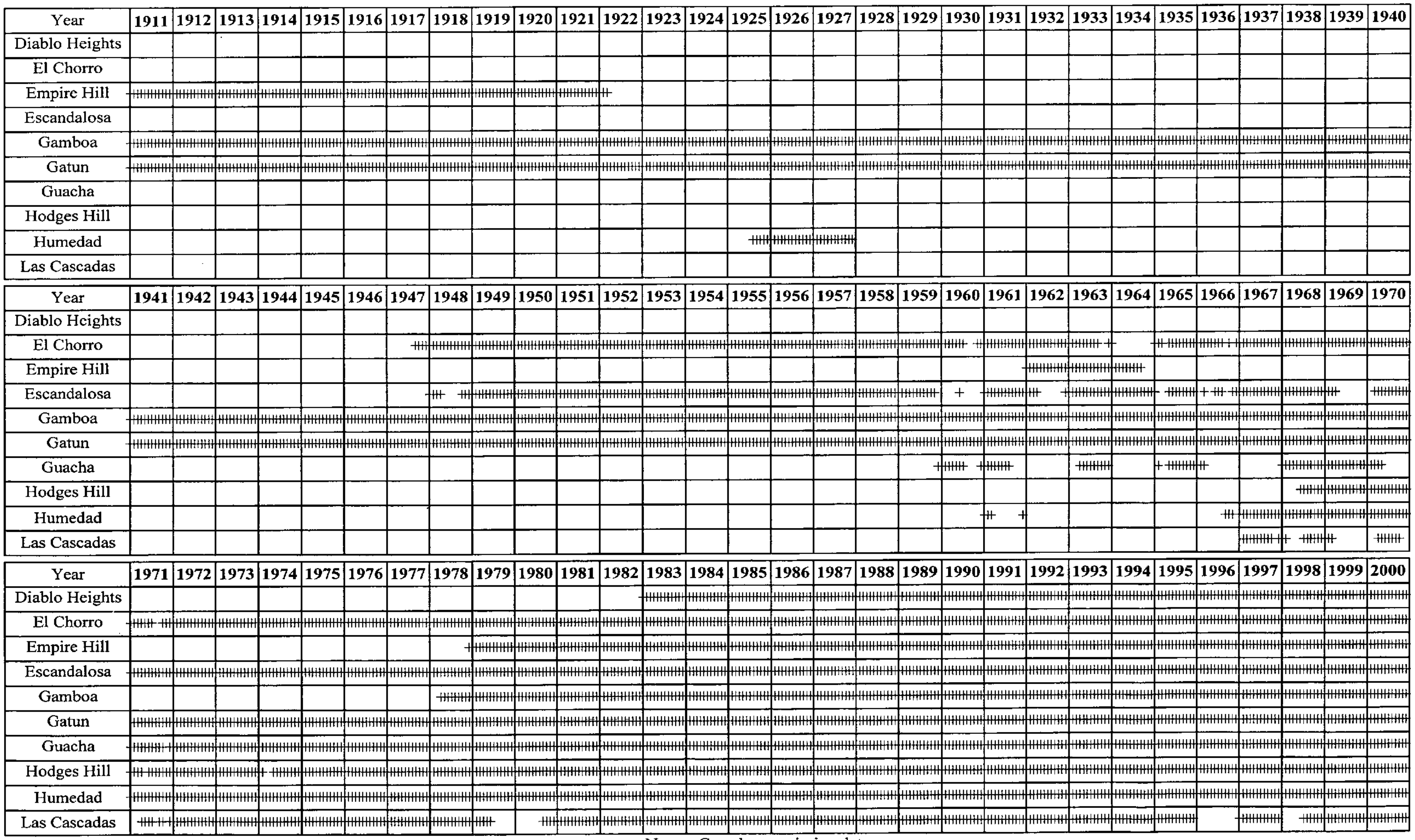
RAINFALL STATIONS WITH PERIOD OF RECORD



Note: Gap shows missing data.

Data prior to 1911 not included.

RAINFALL STATIONS WITH PERIOD OF RECORD



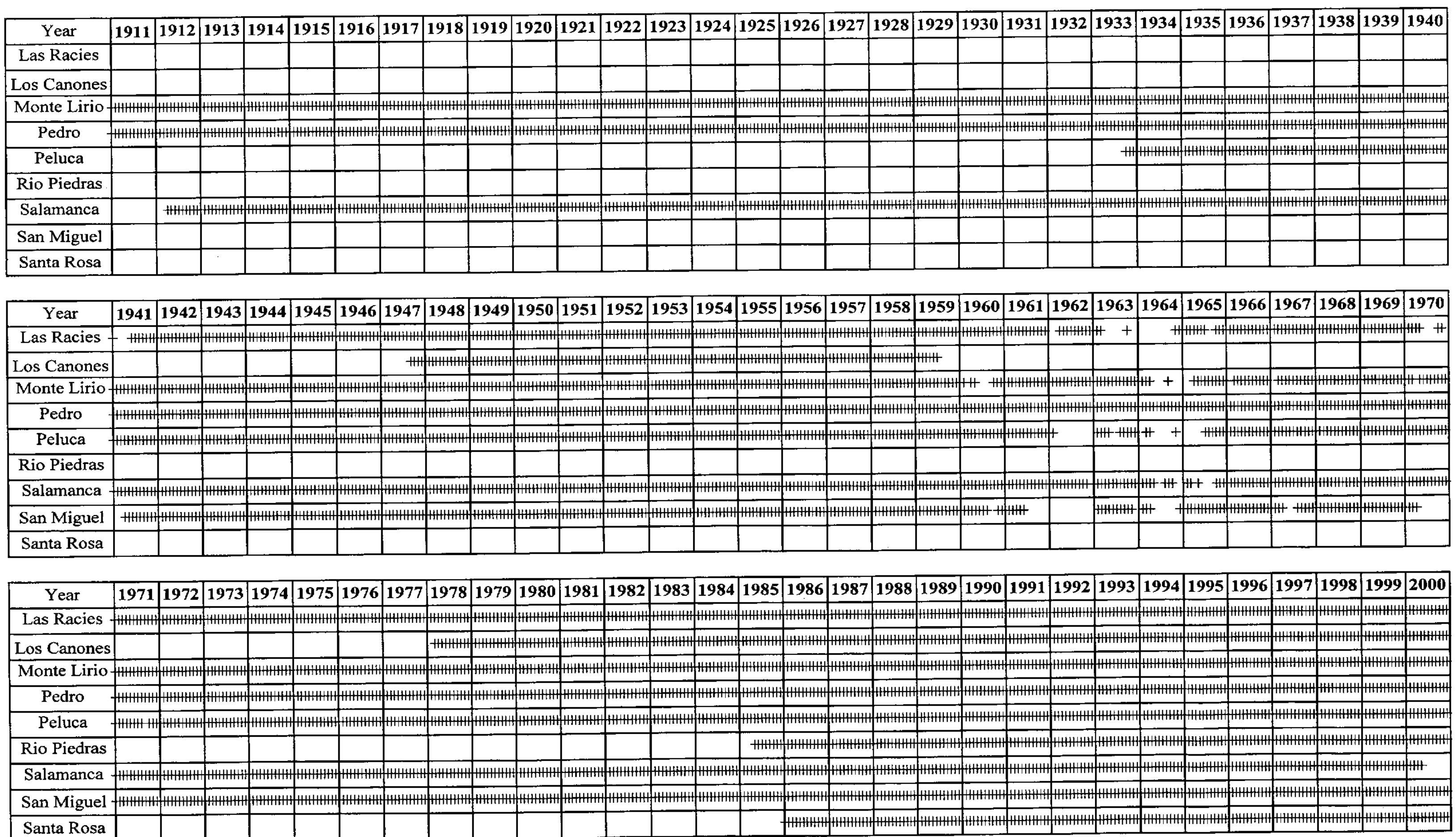
Note: Gap shows missing data.

Data prior to 1911 not included.

Exhibit 8.1

Sheet 3 of 3

RAINFALL STATIONS WITH PERIOD OF RECORD



Note: Gap shows missing data.

Data prior to 1911 not included.

9.0 Extension of Streamflow Series To a Common Period

9.0 EXTENSION OF STREAMFLOW SERIES TO A COMMON PERIOD

The FILLIN program, developed for monthly rainfall data was used to fill-in missing data in the historical streamflow time series. Exhibits 5.2 and 9.1 show the period of record for each station.

The common period for runoff was taken to be from 1941 to 2000 (60 years). The data for the Boqueron and Pequeni rivers had only one or two months missing. These were filled-in based on the general flow pattern for these stations. FILLIN program was then used to fill-in and extend the data at other stations. Monthly filled-in data are given in Appendix D following the rainfall data. FILLIN program input and output files are given in Appendix E following the rainfall files. Table 2 shows the percentages of filled-in data.

Table 9.1

PERCENTAGES OF FILLED-IN DATA
STREAM GAUGING STATIONS

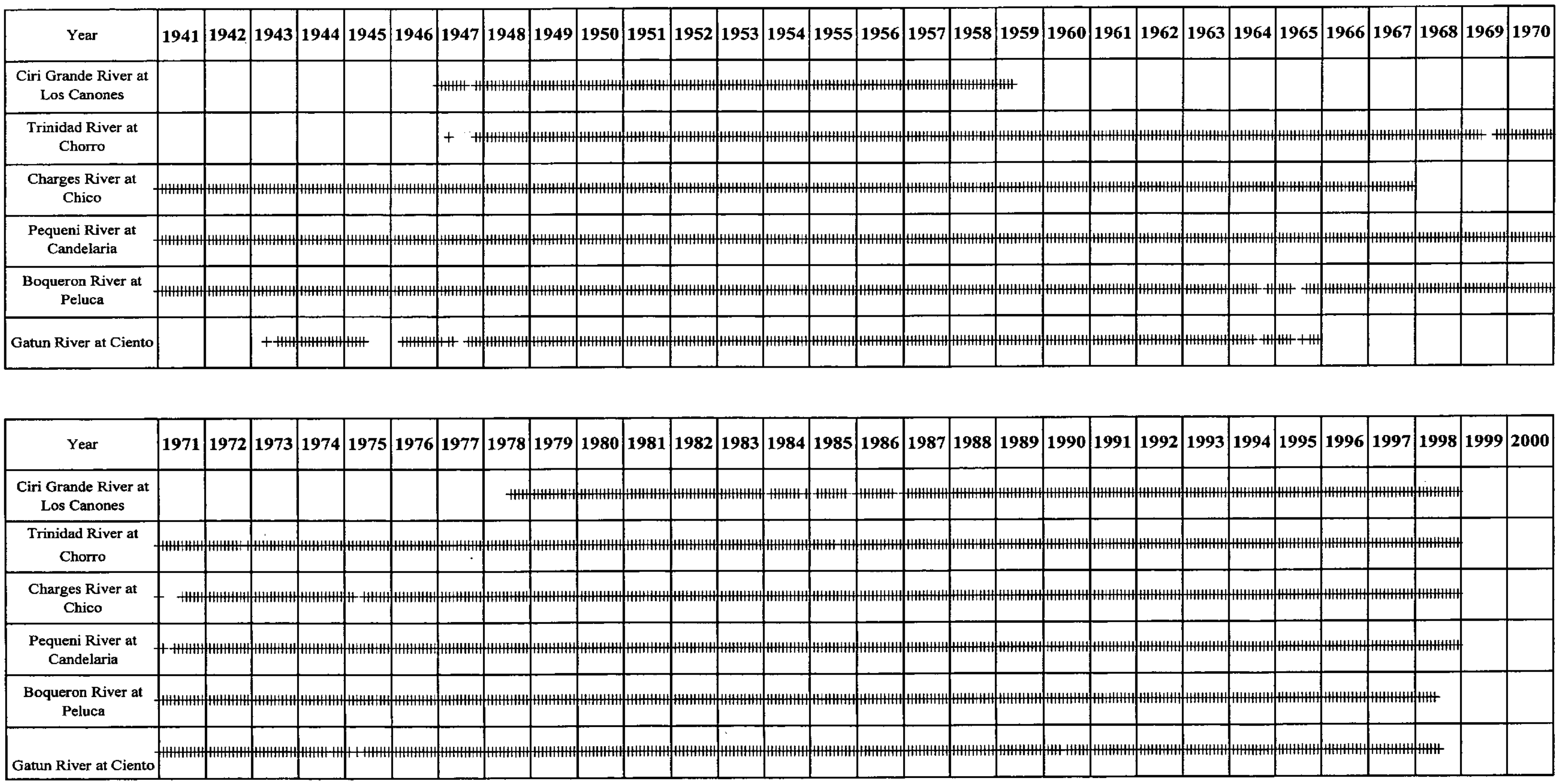
Stream Gauging Station	Percentages
Gatun River at Ciento	15.4
Boqueron River at Peluca	0.8
Pequeni River at Candelaria	0.7
Chagres River at Chico	6.3
Trinidad River at Chorro	12.5
Ciri Grande River at Canones	45.0

9.1 Evaluation of Filled Data

Mass curves and chronological plots drawn for all stations (see Appendix D) do not show any discontinuity for the filled-in periods. The mass curves were continuous with no significant change in slope. Therefore, the filled-in data was judged to be of the same quality as the historical data.

Exhibit 9.1

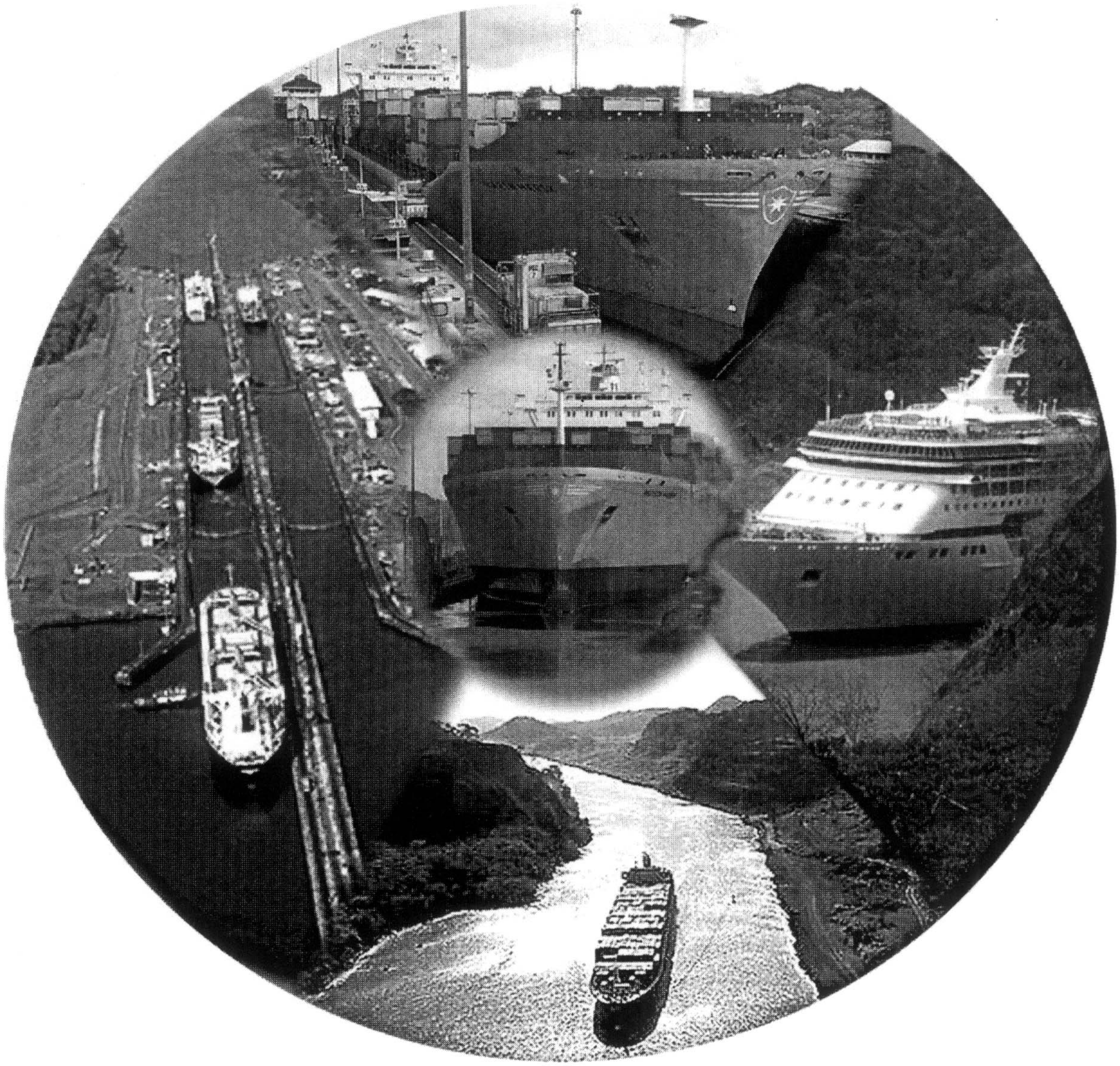
STREAM GAGING STATIONS WITH PERIOD OF RECORD



Note: Gap shows missing data.

Data prior to 1941 not included.

10.0 Computation of Monthly Basin Average Rainfall



10.0 COMPUTATION OF MONTHLY BASIN AVERAGE RAINFALL

Long-term monthly rainfall data (from January 1911 to December 2000) were generated at 27 rainfall stations using historic rainfall data at each station and the FILLIN computer program as discussed under Section 8.0, "Extension of Rainfall Series to a Common Period." Using these data, monthly basin average rainfall series for the period from 1911 to 2000 were computed for (1) drainage basin Madden Upstream, about 1,030 km^2 including the lake area, (2) drainage basin downstream from Madden Lake (designated as Gatun downstream, about 2,290 km^2 including lake area and (3) total drainage basin above Gatun Lake (designated as Gatun total), about 3,320 km^2 including both lakes. Either of the following three approaches could be used to determine the basin-average rainfall:

- Average of the monthly rainfall recorded at the stations within the selected basin.
- The Thiessen method. This method assumes that at any point in the basin (or outside but close to the watershed divide), the rainfall is the same as that at the nearest rain gauge, therefore, the depth recorded at a given gauge is applied out to a distance halfway to the next station in any direction. The relative weights for the gauges are determined from the corresponding areas of application in a Thiessen polygon network, the boundaries of the polygon being formed by the perpendicular bisectors of the lines joining adjacent gauges (Chow, et al., 1988).
- Using monthly isohyetal patterns.

First approach was used by ACP in their analysis of rainfall data. The number of stations used for averaging varied within the 1911-2000 period. During early years a few stations were used. The approach assigned equal weights to all stations irrespective of their physical location. Thus the stations located close to one another were assigned same weights as assigned to stations well distributed in the basin. The method provides approximate basin average rainfall, and is used for a quick estimate.

The isohyetal approach is very reliable but requires extensive work. Preparation of about 1,080 (12 months*90 years) isohyetal patterns was not feasible. The method was not considered.

Thiessen method provides reasonably accurate estimate of basin average rainfall. The method was used in this study. The Thiessen polygons were drawn on a map as shown on Exhibit 10.1. The stations representing the rainfall within a polygon are underlined on this exhibit. Five dummy stations (A, B, C, El Cacao and Ciri Grande) were included to represent rainfall at relatively high altitudes.

10.1 Drainage Basin Madden Lake

Three dummy stations (A, B and C) and eight regular rainfall stations were used. Table 10.1 shows the drainage area and relative station weights. Monthly rainfall data at the dummy stations were computed using the "normal ratio method" (Chow, 1964). However, only one station closest to the dummy station was used.

Monthly rainfall data at Dummy A were computed as (mean annual rainfall at Dummy A/mean annual rainfall at Rio Piedras) * (monthly rainfall at Rio Piedras). The mean annual rainfalls were derived from the mean annual isohyetal map provided by ACP (see Exhibit 10.2). The ratio was about 1.078. Similarly, the monthly rainfall data for Dummy B and C were based on the monthly rainfall series at Sam Miguel and Chico, respectively. The ratios were about 1.20 and 1.05, respectively.

Monthly rainfall data at each station were multiplied by the respective station weight and the products at 11 stations were added to obtain basin average rainfall for that month. Table 10.1 shows the station weights used. Basin average monthly rainfall data are shown on Exhibit 10.3. Exhibit 10.4 shows the annual series for Madden Lake with 5-year moving average and a linear trend line. Exhibit 10.5 shows the corresponding mass curve.

Table 10.1

STATION WEIGHTS FOR COMPUTING BASIN AVERAGE RAINFALL MADDEN LAKE BASIN

Station	Area, km^2	Weight
Dummy A	144	14.0
Rio Piedras	219	21.2
Dummy C	47	4.6
Chico	172	16.7
Candelaria	70	6.8
Dummy B	125	12.1
San Miguel	50	4.9
Escandalosa	47	4.6
Peluca	55	5.3
Salamanca	55	5.3
Alhajuela	47	4.6
	1030	100.0

10.2 Drainage Basin Gatun Downstream

This basin included three dummy stations (Dummy C, El Cacao and Ciri Grande) and twenty regular rainfall stations. Table 10.2 shows the drainage areas and relative station weights. The rainfall data for Empire Hill, Hodges Hill and Pedro Miguel were averaged to represent one station with its relative weight. This was done because the three stations are located close to one another. There is another nearby station, Cascadas. This station has nearly the same period of historic record as Empire Hill but with more missing data. Being close to Empire Hill, the station was judged to be represented by Empire Hill. The station was not used in averaging the rainfall.

Table 10.2

STATION WEIGHTS FOR COMPUTING BASIN AVERAGE RAINFALL GATUN DOWNSTREAM BASIN

Station	Area, km^2	Weight
El Cacao (dummy station)	128	5.6
Ciri Grande (dummy station)	116	5.0
Chorro	200	8.7
Canones	148	6.5
Humedad	94	4.1
Raices	113	4.9
Cano	278	12.1
Guacha	103	4.5
Barro Colorado	122	5.3
Gatun	28	1.2
Monte Lirio	125	5.5
Crystoball, Coco Solo, Limon Bay (one series)	16	0.7
Ciento	138	6.0
Santa Rosa	106	4.6
Gamboa	148	6.5
Pedro Miguel, Hodges Hill, Empire Hill (average)	164	7.2
Alhajuela	70	3.1
Salamanca	31	1.4
Agua Clara	86	3.7
Chico	19	0.8
Dummy C	11	0.5
Escandalosa	39	1.7
Peluca	9	0.4
	2292	100.0

The monthly rainfall series at Crystoball, Coco Solo and Limon Bay were combined to form one series, represented at Coco Solo.

Monthly rainfall data at Dummy El Cacao were computed as (mean annual rainfall at Dummy El Cacao/mean annual rainfall at Canonas) * (monthly rainfall at Canonas). The mean annual rainfalls were derived from the mean annual isohyetal map provided by ACP (see Exhibit 10.2). The ratio was about 0.974. The monthly rainfall data for

Dummy Ciri Grande were also based on the monthly rainfall series at Canonas. The ratio was about 1.26.

Monthly rainfall data at each station were multiplied by the respective station weight and the products at 23 stations were added to obtain basin average rainfall for that month. Exhibit 10.6 shows the basin average monthly rainfall data. Exhibit 10.7 shows the annual series with 5-year moving average and a linear trend line. Exhibit 10.8 shows the corresponding mass curve.

10.3 Drainage Basin Gatun Total

The procedure for computing the basin average rainfall for Gatun Total (the total drainage basin) was the same as discussed for the two basins above. All 23 regular rainfall stations and five dummy stations were used in the computations. The drainage areas and relative station weights for the stations are given in Table 10.3. Exhibit 10.9 shows the monthly basin average rainfall. Exhibit 10.10 shows the annual series with 5-year moving average and a linear trend line, and Exhibit 10.11 shows the corresponding mass curve.

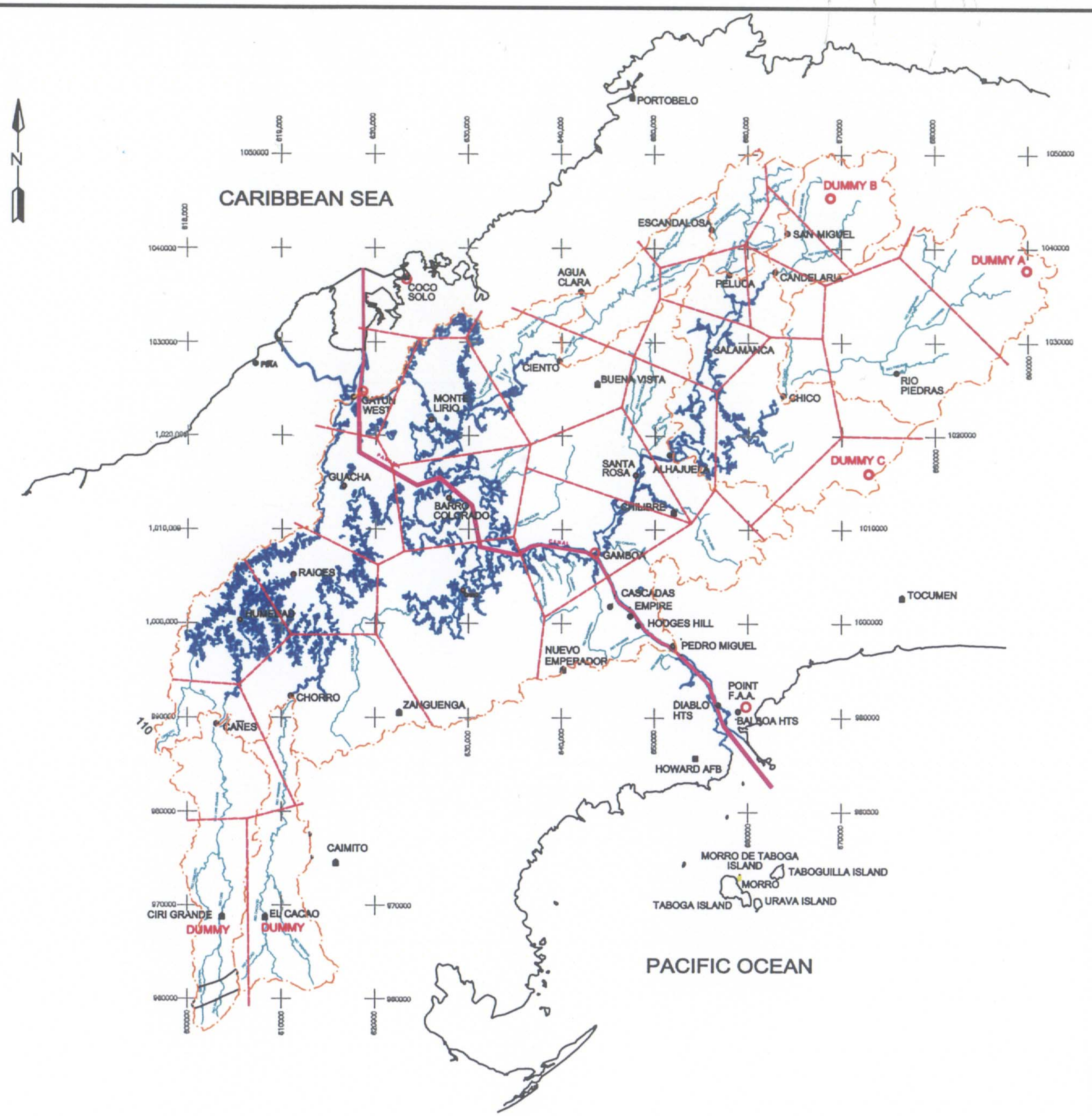
10.4 Comparison with ACP's Estimates

ACP provided monthly basin average rainfall data for the three basins discussed above. A comparison was made between annual basin average rainfall amounts estimated by MWH and ACP using double mass curves and scatter diagrams (see Exhibits 10.12 to 10.17). On a long-term basis MWH's estimates are about 2.3, 2.5 and 2.2 percent higher for Madden, Gatun Downstream and Gatun Total respectively, than that estimated by ACP. Double mass curves do not show any significant change in slopes.

Table 10.3

STATION WEIGHTS FOR COMPUTING BASIN AVERAGE RAINFALL GATUN DOWNSTREAM BASIN

Station	Area, km^2	Weight
El Cacao (dummy)	133	4.0
Ciri Grande (dummy)	117	3.5
Chorro	203	6.1
Canones	148	4.5
Humedad	94	2.8
Raices	117	3.5
Cano	281	8.5
Guacha	102	3.1
Barro Colorado	125	3.8
Gatun	31	0.9
Monte Lirio	125	3.8
Crystoball, Coco Solo, Limon Bay (one series)	16	0.5
Ciento	141	4.2
Santa Rosa	109	3.3
Gamboa	148	4.5
Pedro Miguel, Hodges Hill, Empire Hill (average)	164	4.9
Alhajuela	109	3.3
Salamanca	86	2.6
Agua Clara	86	2.6
Chico	188	5.6
Dummy C	63	1.9
Escandalosa	86	2.6
Peluca	63	1.9
Rio Piedras	219	6.6
Dummy A	141	4.2
Dummy B	117	3.5
Candelaria	63	1.9
San Miguel	47	1.4
	3320	100.0



LEYENDA:

- ESTACIONES METEOROLOGICAS, ACP
- ESTACIONES DE PRECIPITACION, ACP
- ESTACIONES DE PRECIPITACION, ETESA
- ESTACIONES DE PRECIPITACION, FUERZA AEREA, E.U.A.
- LIMITE DE CUENCA
- LIMITE DE SUBCUENCA

5 Kms. 0 10 Kms. 20 Kms.

ESCALA GRAFICA

AUTORIDAD DEL CANAL DE PANAMA
Oficina de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536

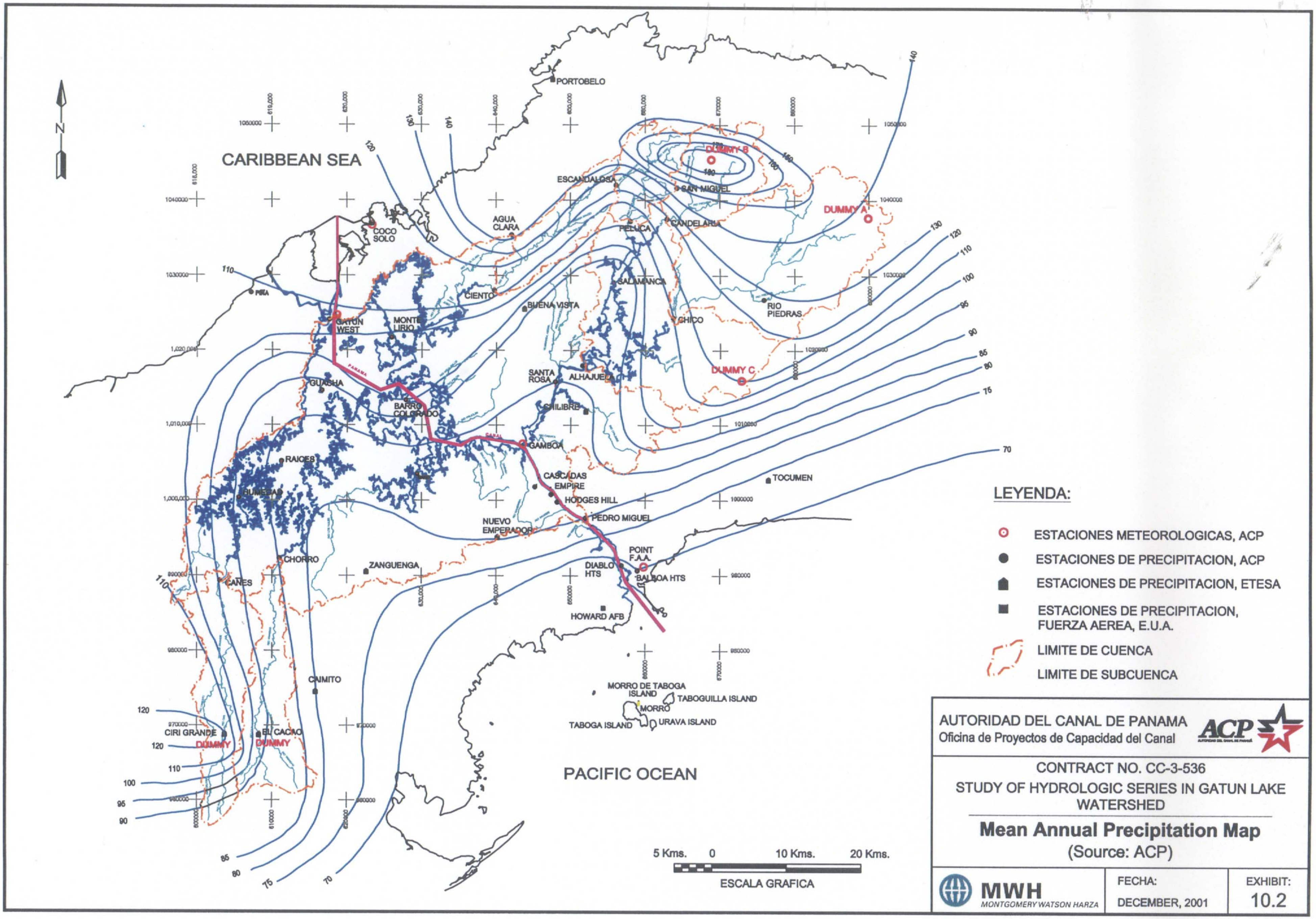
STUDY OF HYDROLOGIC SERIES IN GATUN LAKE WATERSHED

Thiessen Polygon Network

MWH MONTGOMERY WATSON HARZA

FECHA: DECEMBER, 2001

EXHIBIT: 10.1


N
CARIBBEAN SEA
PACIFIC OCEAN
PORTOBELO
ESCANDALOSA
SAN MIGUEL
CANDELARIA
PELUCA
DUMMY B
DUMMY A
DUMMY C
AGUA CLARA
COCO SOLO
CIENTO
BUENA VISTA
SALAMANCA
CHICO
RIO PIEDRAS
GATUN WEST
MONTE LIRIO
GUACHA
BARRO COLORADO
SANTA ROSA
ALHAJUELA
CHILIBRE
GAMBOA
RAICES
CASCADAS
EMPIRE
HODGES HILL
TOCUMEN
NUEVO EMPERADOR
PEDRO MIGUEL
CHORRO
ZANGUENGA
CAÑES
DIABLO HTS
POINT F.A.A.
BALBOA HTS
HOWARD AFB
CAIMITO
CIRI GRANDE
EL CACAO
DUMMY
MORRO DE TABOGA ISLAND
TABOGUILLA ISLAND
MORRO
TABOGA ISLAND
URAVA ISLAND
5 Kms. 0 10 Kms. 20 Kms.
ESCALA GRAFICA
LEYENDA:
ESTACIONES METEOROLOGICAS, ACP
ESTACIONES DE PRECIPITACION, ACP
ESTACIONES DE PRECIPITACION, ETESA
ESTACIONES DE PRECIPITACION, FUERZA AEREA, E.U.A.
LIMITE DE CUENCA
LIMITE DE SUBCUENCA
AUTORIDAD DEL CANAL DE PANAMA
Oficina de Proyectos de Capacidad del Canal
ACP
CONTRACT NO. CC-3-536
STUDY OF HYDROLOGIC SERIES IN GATUN LAKE WATERSHED
Mean Annual Precipitation Map
(Source: ACP)
MWH
MONTGOMERY WATSON HARZA
FECHA:
DECEMBER, 2001
EXHIBIT:
10.2

MADDEN LAKE
BASIN AVERAGE MONTHLY RAINFALLS IN MM

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1911	54	75	36	169	397	245	129	190	318	523	307	83	2527
1912	49	30	5	83	268	299	241	261	266	409	407	126	2445
1913	41	30	13	20	414	340	244	288	355	322	301	148	2518
1914	17	20	37	68	209	289	131	325	496	400	355	146	2493
1915	19	168	42	349	229	403	502	333	265	375	463	223	3373
1916	45	72	17	288	286	269	417	260	299	442	303	102	2800
1917	2	4	14	53	319	297	437	384	309	259	529	187	2793
1918	105	42	40	184	411	405	321	231	310	354	233	33	2669
1919	100	40	17	339	198	218	253	319	427	332	261	199	2703
1920	50	23	49	103	261	306	492	332	265	443	289	56	2669
1921	29	74	26	207	292	349	390	469	455	496	278	268	3333
1922	168	51	34	98	399	344	125	219	265	344	345	300	2691
1923	49	36	12	47	232	342	251	226	335	654	274	139	2597
1924	42	66	14	193	363	280	505	416	423	215	241	84	2843
1925	96	25	9	144	201	465	373	260	288	460	260	162	2742
1926	12	35	41	104	262	476	398	369	353	369	360	349	3126
1927	80	117	86	240	471	352	613	223	325	248	416	498	3670
1928	83	27	120	51	229	340	323	378	310	424	449	221	2955
1929	7	51	47	48	250	334	333	375	267	333	305	128	2479
1930	80	25	41	204	345	177	317	164	315	222	219	94	2204
1931	81	36	146	39	493	357	293	246	386	431	818	253	3578
1932	92	8	42	158	311	271	198	328	305	564	644	240	3161
1933	125	22	57	82	369	324	430	305	311	178	461	237	2900
1934	34	4	27	77	417	252	305	256	309	391	433	205	2710
1935	76	64	22	64	396	346	585	409	298	328	1093	396	4078
1936	65	18	7	82	420	197	308	309	367	376	349	74	2573
1937	154	30	22	60	302	288	338	284	374	381	504	500	3238
1938	37	51	30	209	665	411	281	494	329	309	286	496	3600
1939	27	1	28	15	138	352	162	332	372	341	485	213	2466
1940	72	35	18	58	256	199	233	308	282	316	358	70	2205
1941	41	120	86	78	313	377	277	291	324	550	365	82	2904
1942	30	19	73	97	310	334	230	319	307	415	190	268	2593
1943	87	63	49	118	346	348	210	292	384	331	241	441	2908
1944	42	29	23	213	271	320	287	442	274	498	268	369	3033
1945	29	11	10	111	309	360	435	442	218	238	310	238	2710
1946	18	11	21	36	349	330	429	195	377	257	218	259	2499
1947	8	32	16	81	120	318	215	320	245	269	234	238	2096
1948	30	8	10	33	209	264	422	234	236	284	364	93	2187
1949	9	12	14	63	245	488	367	324	322	364	374	110	2691
1950	17	41	10	137	325	372	536	386	263	188	354	354	2983
1951	33	164	14	162	327	219	258	383	361	361	259	158	2698
1952	40	8	2	114	333	311	392	371	438	520	234	432	3194
1953	238	42	59	108	413	161	297	238	197	375	359	204	2691
1954	32	70	32	75	392	383	423	346	382	309	459	258	3162
1955	265	27	75	22	174	291	348	470	254	240	607	220	2993
1956	238	88	105	134	464	307	437	312	276	339	433	163	3296
1957	24	34	7	25	233	191	166	191	193	387	415	155	2019
1958	123	56	63	37	288	338	369	274	310	242	321	114	2532

MADDEN LAKE
BASIN AVERAGE MONTHLY RAINFALLS IN MM

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1959	21	10	7	85	190	368	231	330	416	358	306	454	2777
1960	111	23	56	243	461	267	372	317	266	336	301	545	3297
1961	30	8	16	160	244	512	242	319	355	340	239	159	2623
1962	58	16	28	113	359	217	291	338	267	369	310	235	2602
1963	129	74	19	277	345	392	403	455	301	218	279	66	2959
1964	4	15	14	122	190	398	364	383	266	416	398	104	2672
1965	43	11	8	29	293	252	231	280	347	388	469	248	2598
1966	88	21	36	286	381	263	322	343	390	418	577	444	3568
1967	51	32	54	247	268	525	392	293	329	363	423	232	3209
1968	9	66	75	46	348	308	285	306	233	453	323	133	2586
1969	65	22	70	132	309	157	270	360	365	189	294	367	2601
1970	384	89	68	291	457	202	300	389	347	297	356	418	3597
1971	79	31	118	12	346	394	430	353	325	367	333	51	2838
1972	296	40	21	232	306	370	159	204	293	357	240	120	2637
1973	43	27	8	21	294	271	341	306	296	358	517	205	2687
1974	32	156	35	56	166	313	258	210	346	325	330	100	2328
1975	26	25	24	36	411	381	406	343	298	556	353	335	3194
1976	42	29	38	123	203	199	72	233	323	257	214	32	1765
1977	81	11	22	40	235	221	189	370	291	447	277	122	2306
1978	30	57	64	277	401	345	329	332	296	307	357	104	2900
1979	9	28	29	238	186	227	376	252	192	308	405	331	2582
1980	118	95	24	55	254	340	203	322	225	301	333	235	2503
1981	177	54	69	620	304	355	362	296	204	260	299	301	3300
1982	81	19	12	100	196	268	320	186	256	428	137	57	2061
1983	30	24	29	163	310	236	173	226	409	475	345	485	2906
1984	45	58	11	20	196	325	305	467	228	377	317	88	2437
1985	63	27	69	53	203	366	280	206	383	281	201	322	2454
1986	62	10	48	248	299	334	146	224	339	492	295	72	2569
1987	43	57	12	416	514	309	423	359	411	442	497	179	3663
1988	20	117	44	58	401	317	528	449	353	517	321	125	3250
1989	64	128	18	30	184	286	414	348	238	373	396	210	2690
1990	78	13	52	45	326	152	274	352	353	561	282	218	2708
1991	30	48	70	120	362	259	285	246	393	304	437	95	2648
1992	35	20	25	173	523	405	299	426	300	329	272	158	2966
1993	97	14	180	267	313	561	220	197	434	426	262	146	3115
1994	39	37	85	44	416	404	255	348	251	363	511	91	2843
1995	95	11	49	104	301	479	418	380	282	295	364	345	3124
1996	383	127	109	202	454	394	248	367	305	328	536	325	3778
1997	32	57	17	86	300	271	153	144	267	262	271	31	1889
1998	33	25	32	150	407	302	400	379	394	300	370	391	3183
1999	92	151	96	216	367	492	399	352	340	329	411	815	4061
2000	133	43	41	126	301	461	246	433	341	482	252	660	3520
Mean	73	45	41	132	317	324	318	317	318	364	360	228	2837
Max	384	168	180	620	665	561	613	494	496	654	1093	815	4078
Min	2	1	2	12	120	152	72	144	192	178	137	31	1765
Sd.Dev	74	38	33	104	97	86	109	79	63	95	135	150	457
Skew	2.46	1.58	1.63	1.69	0.55	0.34	0.25	0.04	0.27	0.48	2.40	1.23	0.42
CV	1.01	0.85	0.82	0.79	0.31	0.27	0.34	0.25	0.20	0.26	0.37	0.66	0.16

MADDEN LAKE ANNUAL BASIN AVERAGE RAINFALLS

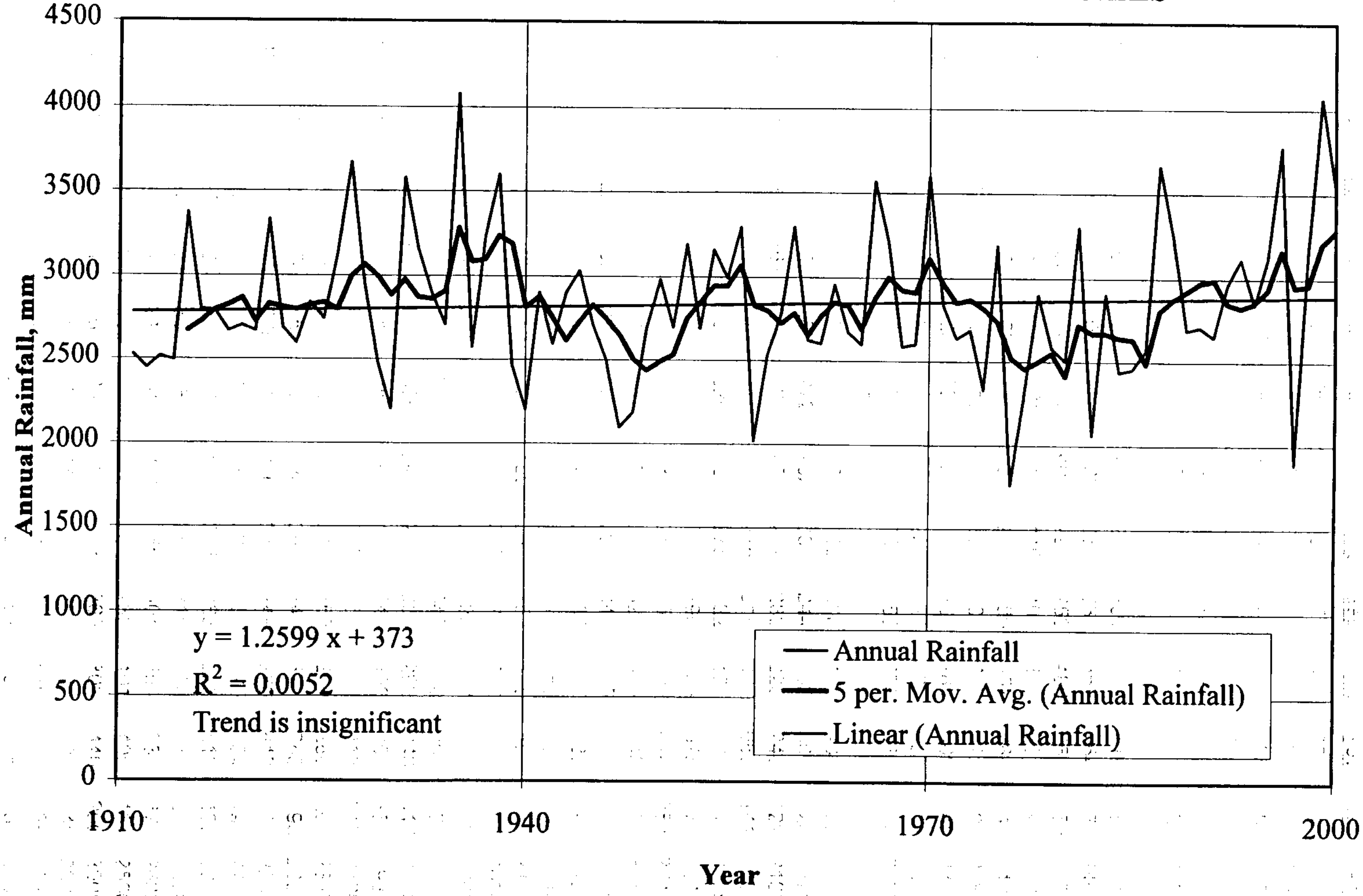


Exhibit 10.4

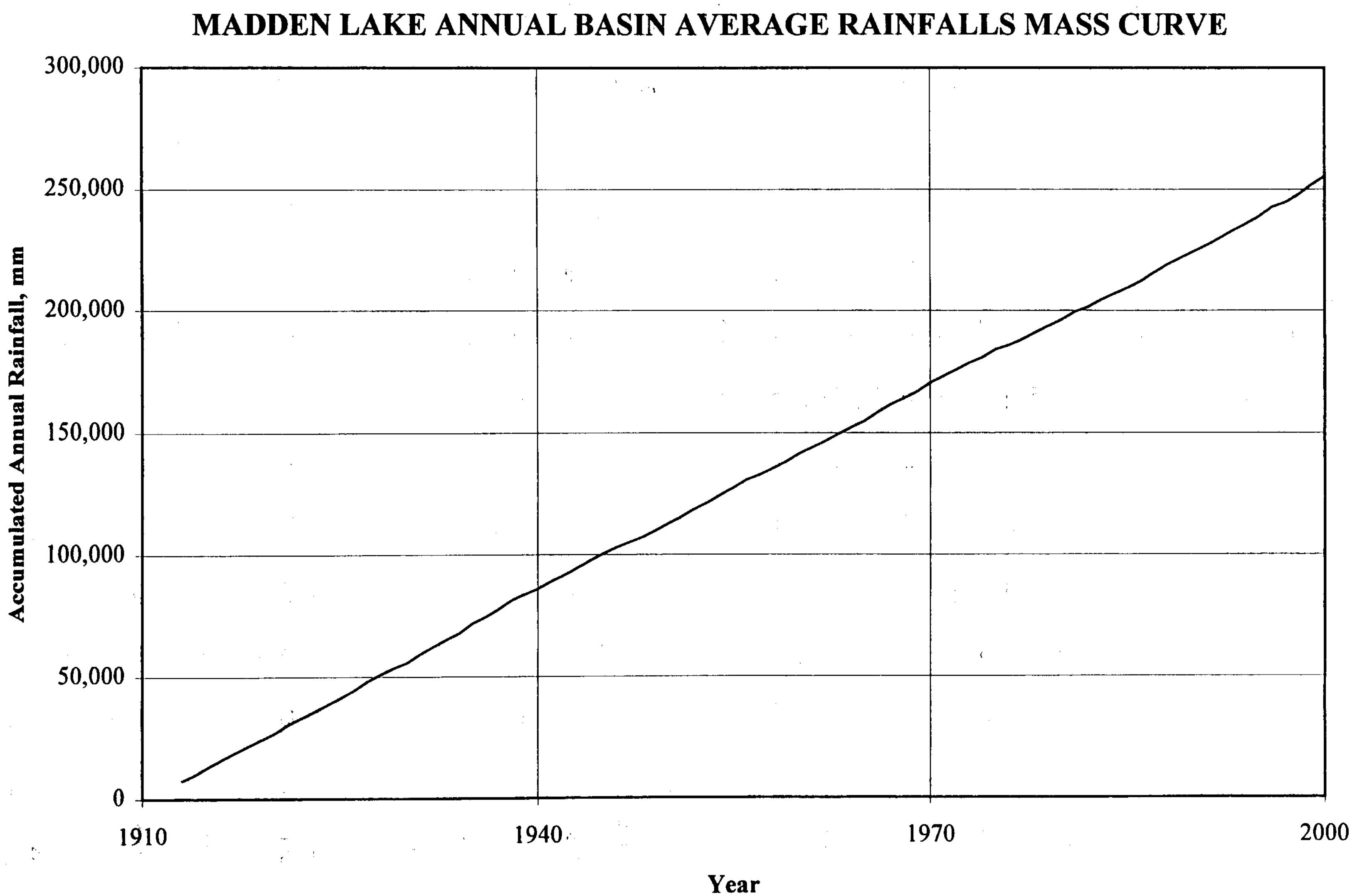

MADDEN LAKE ANNUAL BASIN AVERAGE RAINFALLS MASS CURVE
300,000
250,000
200,000
150,000
100,000
50,000
0
Accumulated Annual Rainfall, mm
1910
1940
1970
2000
Year

Exhibit 10.5

GATUN DOWNSTREAM
BASIN AVERAGE MONTHLY RAINFALLS IN MM

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1911	44	43	38	135	451	275	177	190	230	456	289	33	2360
1912	23	50	20	62	253	255	257	288	320	457	393	213	2592
1913	90	40	9	71	373	253	243	374	343	268	352	163	2579
1914	29	21	23	67	301	360	122	287	414	385	418	165	2592
1915	60	155	43	315	227	321	347	231	292	393	343	190	2917
1916	61	72	56	147	326	243	299	278	272	478	371	130	2732
1917	48	26	9	96	297	296	336	349	344	313	646	244	3004
1918	111	15	26	154	356	221	165	250	297	439	211	59	2303
1919	72	22	19	249	208	236	222	227	298	374	265	163	2353
1920	32	20	23	38	193	242	360	274	255	495	247	54	2235
1921	45	65	24	106	242	283	321	383	377	345	310	238	2739
1922	189	40	10	33	347	268	137	252	286	362	257	220	2400
1923	52	23	13	30	246	308	185	261	288	757	340	77	2578
1924	13	68	32	174	309	340	383	274	341	313	481	171	2899
1925	87	23	14	95	181	274	338	214	333	412	371	89	2432
1926	18	33	10	11	209	407	367	358	360	381	533	284	2971
1927	87	42	35	209	393	385	354	230	298	249	366	233	2878
1928	78	36	97	84	270	330	240	436	307	390	421	195	2883
1929	13	24	51	51	302	244	230	348	233	330	307	124	2257
1930	64	28	12	143	272	182	232	239	268	226	249	134	2049
1931	66	23	102	73	316	281	364	201	282	339	601	92	2740
1932	87	34	27	168	287	340	239	251	185	438	679	209	2943
1933	77	13	31	40	240	246	233	208	281	250	627	287	2532
1934	56	12	31	116	333	237	198	262	376	412	404	317	2754
1935	100	80	23	88	318	306	537	302	328	302	874	343	3602
1936	29	14	28	96	379	187	268	290	337	417	312	87	2446
1937	93	18	20	101	332	233	248	286	390	359	401	628	3110
1938	41	20	22	87	423	456	277	389	302	376	391	402	3186
1939	22	5	25	39	158	256	144	229	343	322	581	264	2388
1940	68	40	28	33	233	207	186	284	266	347	279	57	2029
1941	92	85	32	57	228	272	282	354	325	430	327	131	2616
1942	59	30	78	129	309	280	234	273	357	507	216	447	2920
1943	80	52	59	141	389	359	254	290	339	275	391	404	3031
1944	68	34	22	182	376	231	222	413	229	437	323	349	2888
1945	49	10	17	79	308	209	274	331	270	288	456	396	2687
1946	52	15	29	37	239	190	308	223	341	272	307	264	2274
1947	12	42	29	71	164	307	234	288	380	415	246	172	2360
1948	49	5	13	33	295	186	327	296	252	278	439	79	2252
1949	18	9	13	55	291	383	254	326	300	379	544	235	2806
1950	19	43	21	95	261	385	373	280	265	283	581	418	3025
1951	52	114	15	169	292	176	234	242	287	355	333	237	2507
1952	66	22	5	112	301	270	221	203	246	424	233	349	2453
1953	164	20	27	88	297	170	270	256	244	411	416	141	2505
1954	34	31	21	125	351	350	404	355	354	300	431	174	2928
1955	243	28	33	27	292	334	245	348	275	292	485	249	2849
1956	186	47	86	94	397	195	381	236	278	439	328	108	2776
1957	20	11	7	10	269	219	232	300	277	392	314	149	2200
1958	111	84	75	80	279	244	273	256	264	348	202	134	2350

GATUN DOWNSTREAM
BASIN AVERAGE MONTHLY RAINFALLS IN MM

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1959	17	3	6	66	210	266	217	245	314	291	251	552	2437
1960	112	19	112	252	327	303	302	243	249	400	374	465	3158
1961	33	12	17	116	197	367	208	325	363	379	299	181	2495
1962	65	24	18	75	328	231	267	285	300	274	328	301	2495
1963	163	48	17	144	260	295	308	430	317	262	355	105	2704
1964	21	12	19	131	314	341	318	299	290	374	410	122	2652
1965	114	16	17	39	272	203	186	278	288	471	574	134	2592
1966	66	26	28	116	302	265	308	348	331	297	575	372	3035
1967	48	22	30	134	228	352	301	271	265	339	390	100	2479
1968	5	86	55	30	293	308	197	340	259	394	314	56	2338
1969	56	19	22	106	270	184	277	340	356	342	349	256	2577
1970	227	58	65	181	327	218	306	313	257	321	500	418	3192
1971	142	50	68	17	373	260	254	319	271	304	308	30	2395
1972	168	41	30	220	215	282	139	198	320	338	211	113	2274
1973	59	15	4	35	238	294	250	219	311	369	460	123	2379
1974	10	26	24	38	197	316	301	220	272	500	394	97	2395
1975	18	25	46	29	279	273	282	353	281	498	358	368	2810
1976	32	16	5	120	220	222	88	201	360	337	196	69	1865
1977	38	12	7	28	258	191	176	378	265	409	324	103	2189
1978	45	30	62	265	253	273	308	316	248	310	281	67	2458
1979	9	25	7	238	246	282	281	287	228	283	280	151	2319
1980	126	55	6	40	301	264	259	287	182	290	306	179	2295
1981	203	35	82	359	363	345	308	294	175	320	497	342	3323
1982	144	18	14	112	234	204	194	201	254	390	153	30	1949
1983	22	4	8	74	257	241	204	222	323	298	321	259	2233
1984	75	69	15	50	252	269	188	385	310	410	384	47	2453
1985	68	26	22	19	245	303	230	246	305	245	240	250	2199
1986	36	11	37	164	171	252	160	212	266	447	204	61	2021
1987	21	36	5	224	354	232	270	298	444	475	295	192	2846
1988	8	32	8	39	269	263	260	313	356	385	311	164	2407
1989	21	62	25	22	175	185	255	284	212	348	353	177	2119
1990	50	6	42	72	344	178	265	259	395	463	288	209	2570
1991	25	22	91	60	354	240	247	202	347	266	354	94	2302
1992	25	11	9	167	364	311	245	298	342	280	274	132	2456
1993	90	19	83	170	239	322	224	213	415	373	376	161	2685
1994	52	9	54	41	273	307	167	269	250	333	404	46	2205
1995	115	17	20	131	330	348	320	296	259	312	389	258	2795
1996	339	89	93	75	325	301	223	262	295	317	416	127	2862
1997	24	22	3	28	237	225	178	164	242	210	223	35	1592
1998	12	19	28	187	270	304	281	276	247	282	271	351	2528
1999	72	66	94	154	215	353	226	412	328	275	445	529	3171
2000	123	21	9	97	271	371	208	292	222	436	214	391	2655
Mean	70	34	32	104	284	275	258	285	298	362	368	206	2576
Max	339	155	112	359	451	456	537	436	444	757	874	628	3602
Min	5	3	3	10	158	170	88	164	175	210	153	30	1592
Sd.Dev	59	26	26	71	61	61	70	59	53	82	124	131	349
Skew	1.88	1.92	1.36	1.14	0.22	0.37	0.63	0.47	0.22	1.27	1.23	0.94	0.17
CV	0.84	0.77	0.82	0.69	0.22	0.22	0.27	0.21	0.18	0.23	0.34	0.64	0.14

GATUN DOWNSTREAM
ANNUAL BASIN AVERAGE RAINFALLS

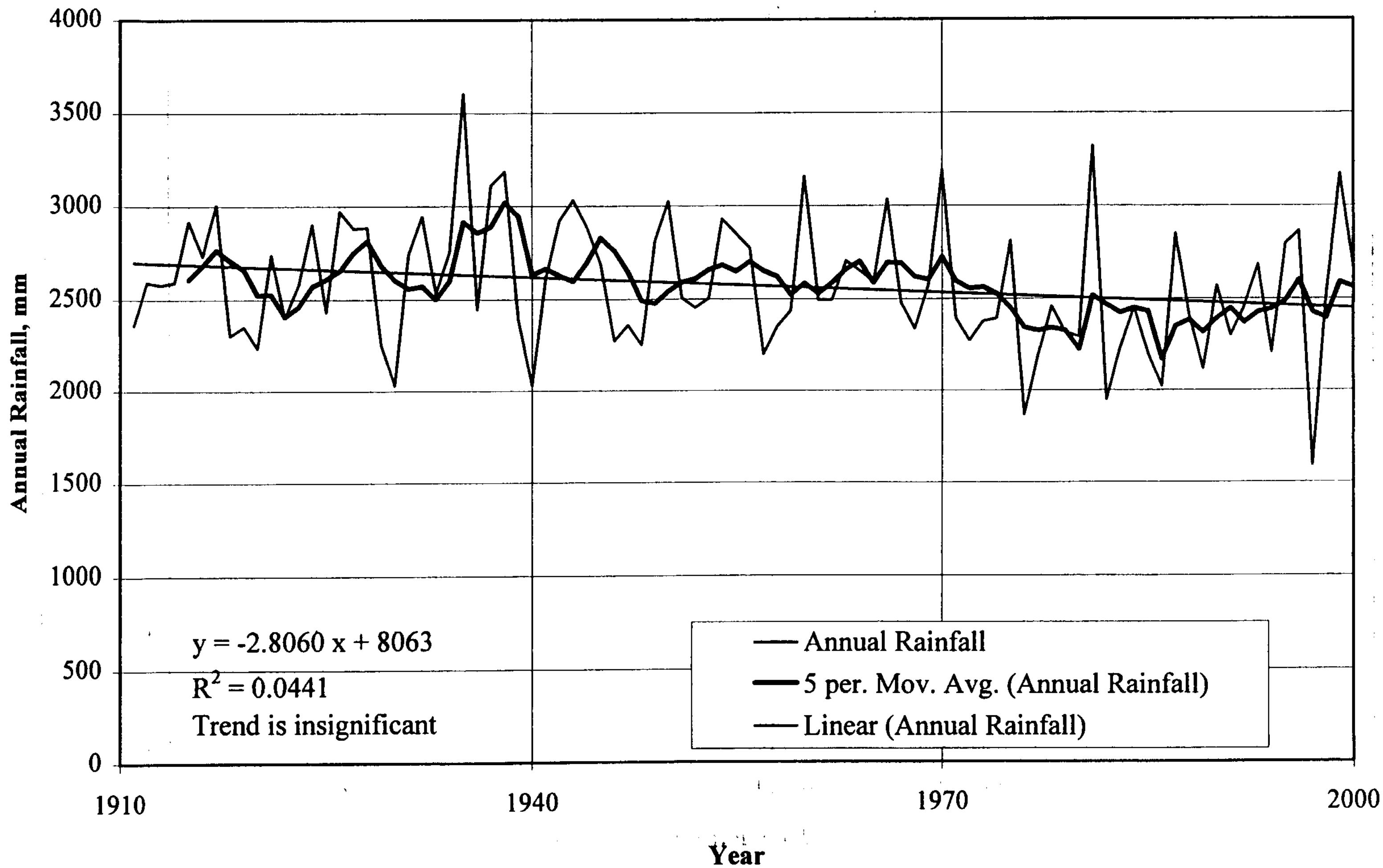


Exhibit 10.7

GATUN DOWNSTREAM
ANNUAL BASIN AVERAGE RAINFALLS MASS CURVE

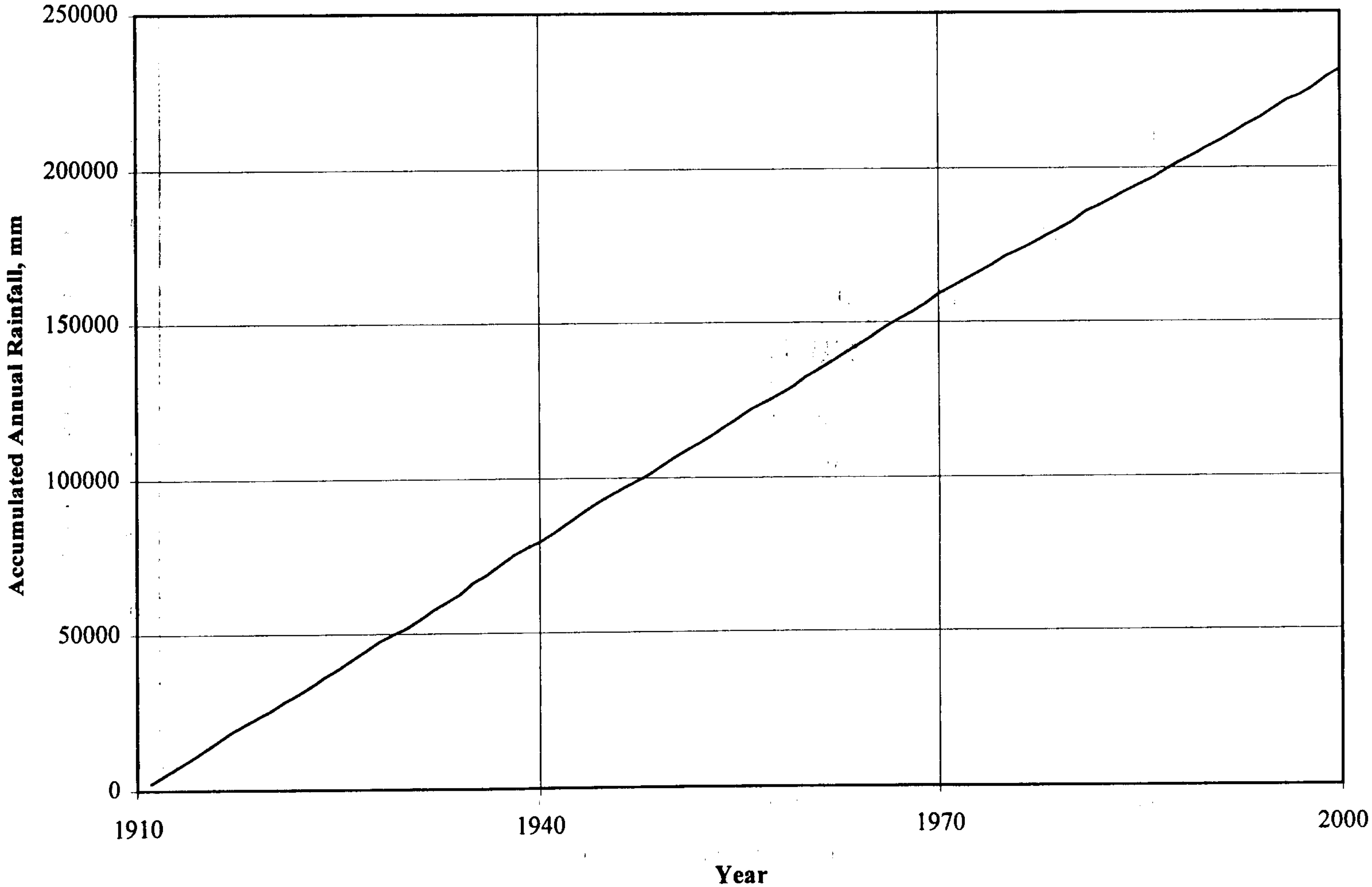


Exhibit 10.8

Exhibit 10.9

GATUN TOTAL
BASIN AVERAGE MONTHLY RAINFALL IN MM

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1911	47	53	38	145	435	267	163	190	257	477	295	48	2415
1912	31	44	15	69	258	269	253	280	304	444	398	187	2553
1913	75	37	11	56	386	280	244	349	347	285	338	159	2565
1914	26	20	27	67	274	339	125	299	440	390	400	160	2567
1915	47	159	42	326	228	346	395	263	285	388	380	201	3061
1916	56	72	44	190	314	251	335	273	280	468	351	122	2757
1917	34	19	11	83	304	297	367	360	334	297	611	227	2945
1918	109	23	31	163	373	277	213	245	301	414	218	51	2419
1919	81	27	19	277	205	231	232	255	338	362	264	174	2464
1920	38	21	31	58	214	262	401	292	259	480	261	55	2371
1921	41	68	25	137	257	304	342	410	401	392	301	248	2925
1922	183	43	17	52	363	292	133	243	280	357	284	245	2493
1923	51	27	13	35	242	319	205	250	302	727	321	96	2589
1924	22	68	27	181	326	323	421	318	366	284	409	145	2888
1925	90	24	12	110	188	333	349	228	320	427	338	112	2531
1926	16	34	19	39	226	428	377	362	359	378	481	304	3022
1927	85	65	50	218	417	375	434	228	307	249	382	314	3125
1928	79	34	104	74	258	334	266	419	308	401	430	203	2910
1929	11	32	50	50	287	272	262	357	244	332	307	126	2329
1930	69	27	21	162	294	181	258	217	283	225	240	122	2100
1931	70	27	116	63	371	304	343	215	314	368	668	141	3000
1932	88	26	31	166	294	320	227	275	222	477	670	219	3015
1933	92	15	39	53	280	270	293	237	290	228	578	273	2648
1934	50	10	30	105	359	242	231	260	356	406	414	284	2746
1935	93	76	23	81	342	318	553	335	320	310	943	360	3754
1936	40	15	22	92	393	190	281	296	347	405	324	83	2489
1937	112	21	21	89	324	250	276	286	386	367	433	590	3155
1938	40	29	24	124	497	443	279	422	311	356	360	432	3318
1939	23	4	26	32	152	286	150	261	352	328	554	249	2417
1940	69	39	25	41	241	205	200	292	271	338	304	61	2086
1941	77	96	49	64	254	305	281	336	325	467	339	116	2708
1942	50	27	77	120	310	297	233	288	342	480	209	394	2827
1943	82	55	56	134	376	356	241	291	353	292	346	416	2999
1944	60	32	22	192	345	259	242	423	243	456	307	356	2938
1945	43	11	15	89	309	255	323	365	254	273	413	349	2700
1946	41	14	26	36	273	232	345	215	352	269	280	263	2347
1947	11	39	25	74	151	311	228	298	340	371	243	193	2285
1948	43	6	12	33	269	210	356	278	248	280	417	83	2237
1949	15	10	13	58	277	416	289	326	307	375	494	198	2777
1950	19	42	18	108	281	381	423	313	265	255	513	400	3018
1951	47	129	15	167	303	189	242	285	310	358	311	213	2570
1952	58	18	4	113	311	283	274	255	304	454	234	375	2683
1953	187	27	37	94	333	168	279	251	230	401	400	161	2566
1954	33	43	24	110	364	361	411	353	363	303	440	200	3005
1955	250	28	46	25	257	322	276	385	269	277	523	241	2898
1956	202	59	92	106	418	230	399	259	278	410	361	125	2939
1957	22	18	7	14	259	211	212	267	252	391	345	151	2149
1958	115	75	72	67	282	273	303	262	278	316	239	129	2410

GATUN TOTAL
BASIN AVERAGE MONTHLY RAINFALL IN MM

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1959	18	5	6	72	204	298	222	271	345	312	268	523	2545
1960	112	20	95	250	368	292	323	266	255	382	353	491	3207
1961	32	10	17	129	212	412	219	324	361	368	281	174	2539
1962	63	18	5	6	72	204	298	222	271	345	312	268	2085
1963	523	112	20	95	250	368	292	323	266	255	382	353	3239
1964	491	32	10	17	129	212	412	219	324	361	368	281	2855
1965	174	63	21	21	87	338	227	275	302	291	303	323	2426
1966	282	25	31	168	327	264	313	347	349	334	577	395	3412
1967	49	25	38	168	240	406	329	278	285	347	401	140	2706
1968	6	80	61	35	310	309	224	331	252	413	317	79	2418
1969	59	20	37	114	283	176	275	347	360	296	333	291	2590
1970	275	67	66	215	367	213	305	337	285	315	458	419	3322
1971	123	45	83	16	365	301	307	330	288	323	316	36	2534
1972	207	41	28	224	243	309	145	200	312	344	220	115	2388
1973	55	19	5	31	255	287	278	246	307	366	478	148	2477
1974	16	65	27	43	188	316	288	218	295	448	376	98	2379
1975	21	25	39	31	320	306	320	350	287	517	357	359	2932
1976	35	20	15	121	215	215	84	211	349	313	202	58	1839
1977	51	12	12	32	251	200	180	376	273	421	311	109	2228
1978	41	39	63	269	298	295	315	321	263	310	305	78	2597
1979	9	26	14	239	229	266	311	277	218	291	318	206	2403
1980	124	67	12	44	287	287	242	298	195	294	315	197	2363
1981	195	41	78	439	346	348	325	296	185	303	438	330	3323
1982	125	18	13	109	223	224	233	197	255	402	148	38	1986
1983	24	10	14	101	273	240	195	224	350	353	329	328	2442
1984	66	66	13	41	236	287	224	411	285	401	364	59	2453
1985	66	27	36	29	232	323	246	234	329	256	229	273	2281
1986	44	11	40	190	210	277	156	216	289	461	232	64	2191
1987	28	42	7	283	403	256	317	317	435	466	357	189	3100
1988	12	58	19	45	309	280	342	355	356	426	315	153	2668
1989	34	82	23	25	178	216	304	304	220	356	367	188	2296
1990	59	8	45	64	339	170	269	288	383	494	287	212	2617
1991	26	30	85	78	357	246	259	216	362	278	380	94	2411
1992	28	14	14	169	413	340	262	338	330	295	274	140	2616
1993	92	18	112	200	262	395	223	208	421	390	342	157	2821
1994	48	17	64	42	317	337	194	294	251	343	437	60	2403
1995	109	16	29	123	322	388	350	322	267	307	382	285	2899
1996	353	101	98	114	365	330	231	294	299	320	453	188	3145
1997	26	33	7	45	257	240	170	158	250	226	238	34	1685
1998	18	21	29	176	312	304	318	308	292	288	301	364	2732
1999	78	92	95	173	262	396	279	395	332	292	435	617	3446
2000	126	28	19	106	281	399	220	335	259	451	226	474	2923
Mean	84	38	35	109	287	290	278	292	304	362	364	219	2663
Max	523	159	116	439	497	443	553	423	440	727	943	617	3754
Min	6	4	4	6	72	168	84	158	185	225	148	34	1685
Sd.Dev.	92	29	27	80	75	64	78	59	51	80	119	132	377
Skew	2.82	1.66	1.37	1.36	-0.16	0.21	0.42	0.25	0.27	1.11	1.77	0.82	0.22
CV	1.10	0.75	0.78	0.73	0.26	0.22	0.28	0.20	0.17	0.22	0.33	0.60	0.14

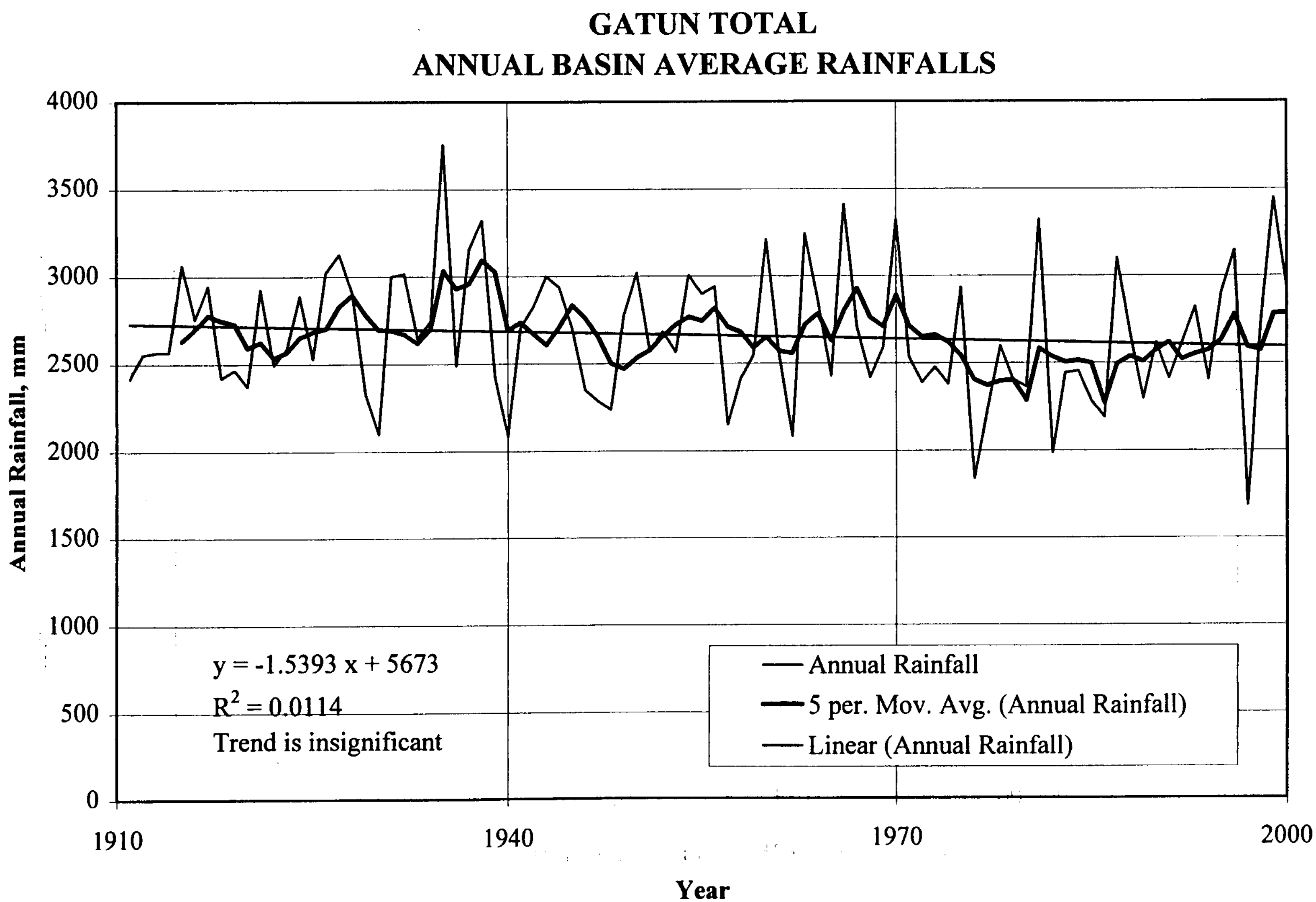


Exhibit 10.10

GATUN TOTAL
ANNUAL BASIN AVERAGE RAINFALLS MASS CURVE

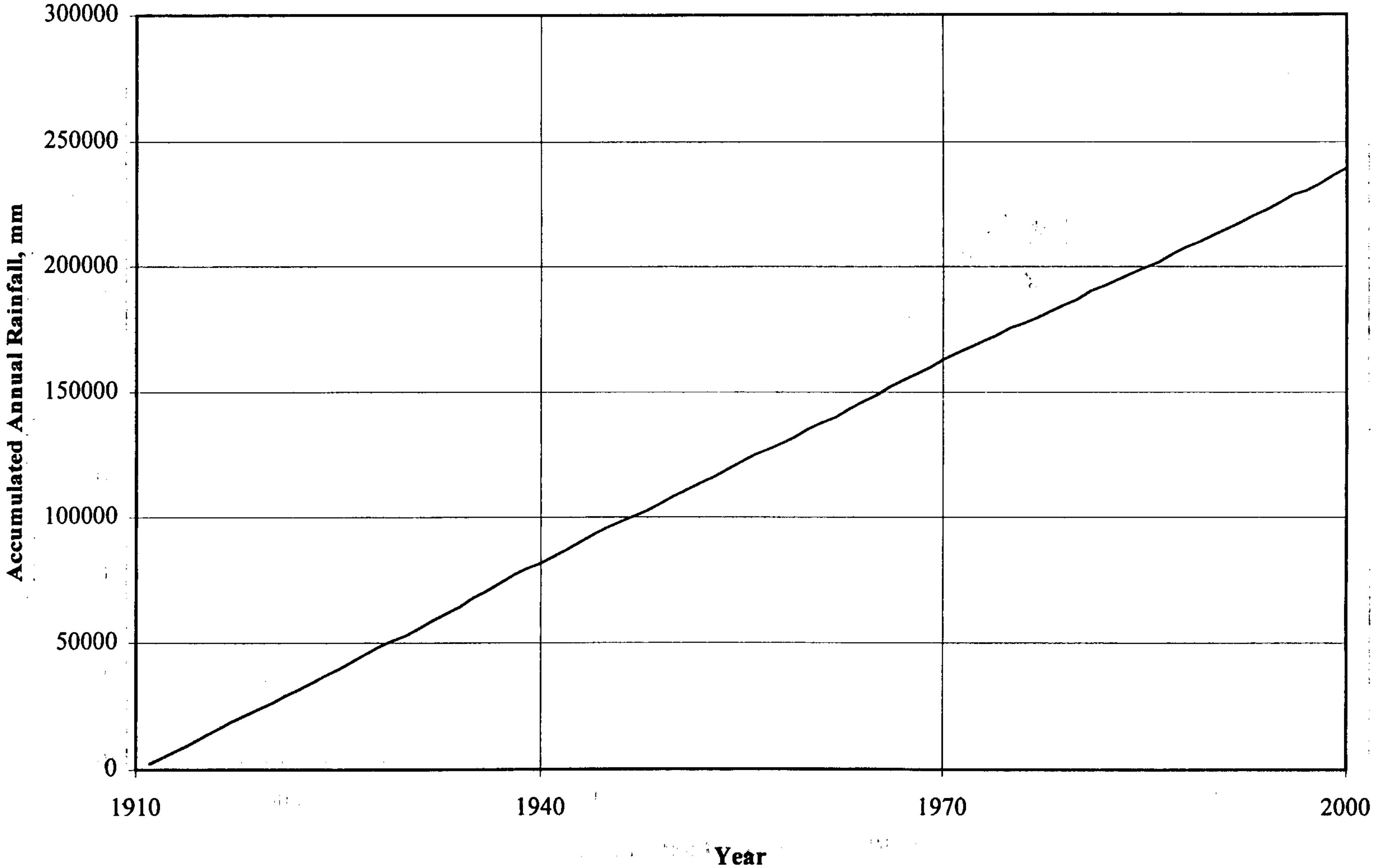


Exhibit 10.11

MADDEN LAKE ANNUAL BASIN AVERAGE RAINFALLS
DOUBLE MASS CURVE MWH VS ACP
PERIOD: 1911-2000

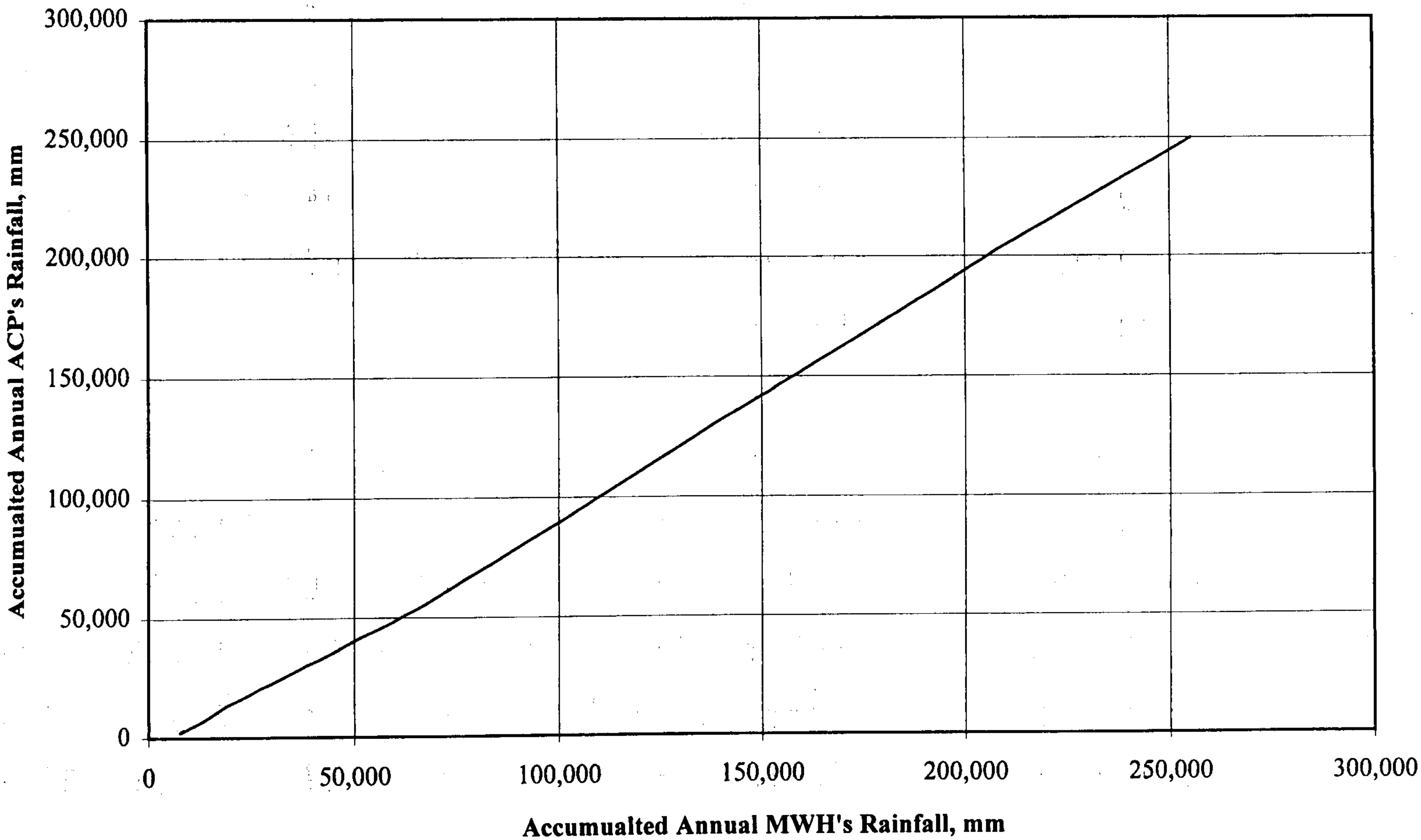


Exhibit 10.12

MADDEN LAKE ANNUAL BASIN AVERAGE RAINFALLS
SCATTERED DIAGRAM MWH VS ACP
PERIOD: 1911-2000

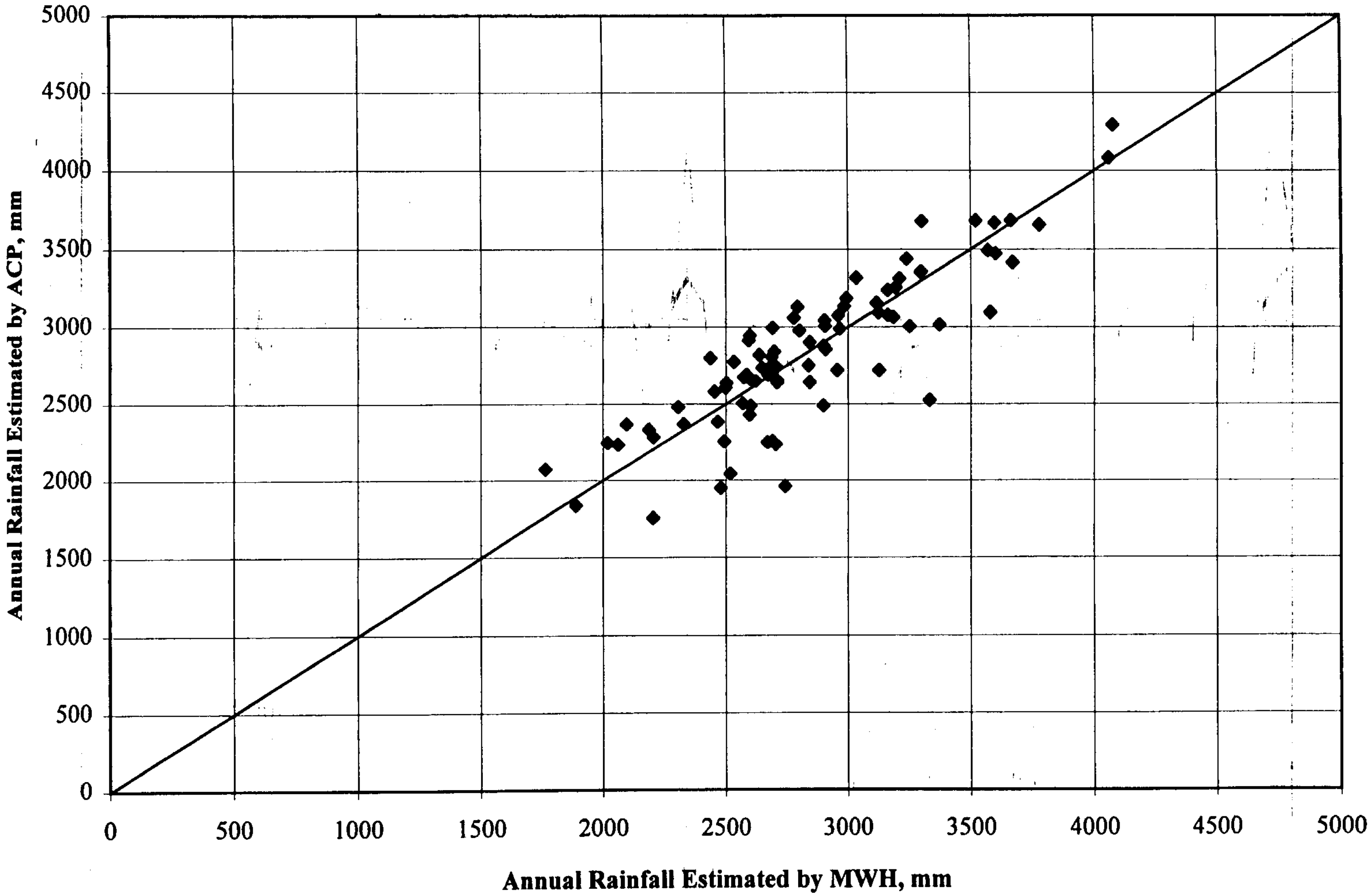


Exhibit 10.13

GATUN DOWNSTREAM BASIN AVERAGE ANNUAL RAINFALLS
DOUBLE MASS CURVE MWH VS ACP
PERIOD: 1911-2000

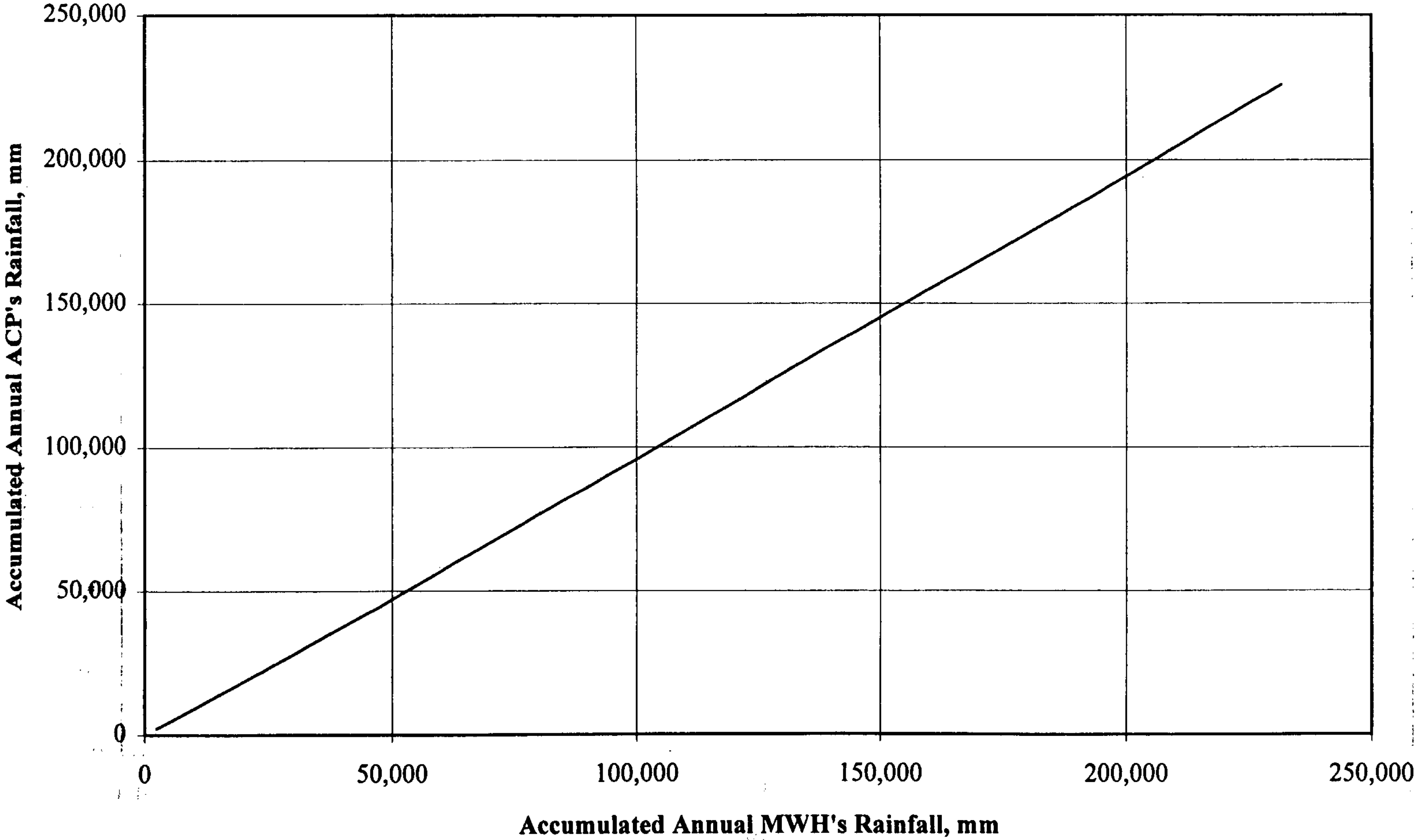


Exhibit 10.14

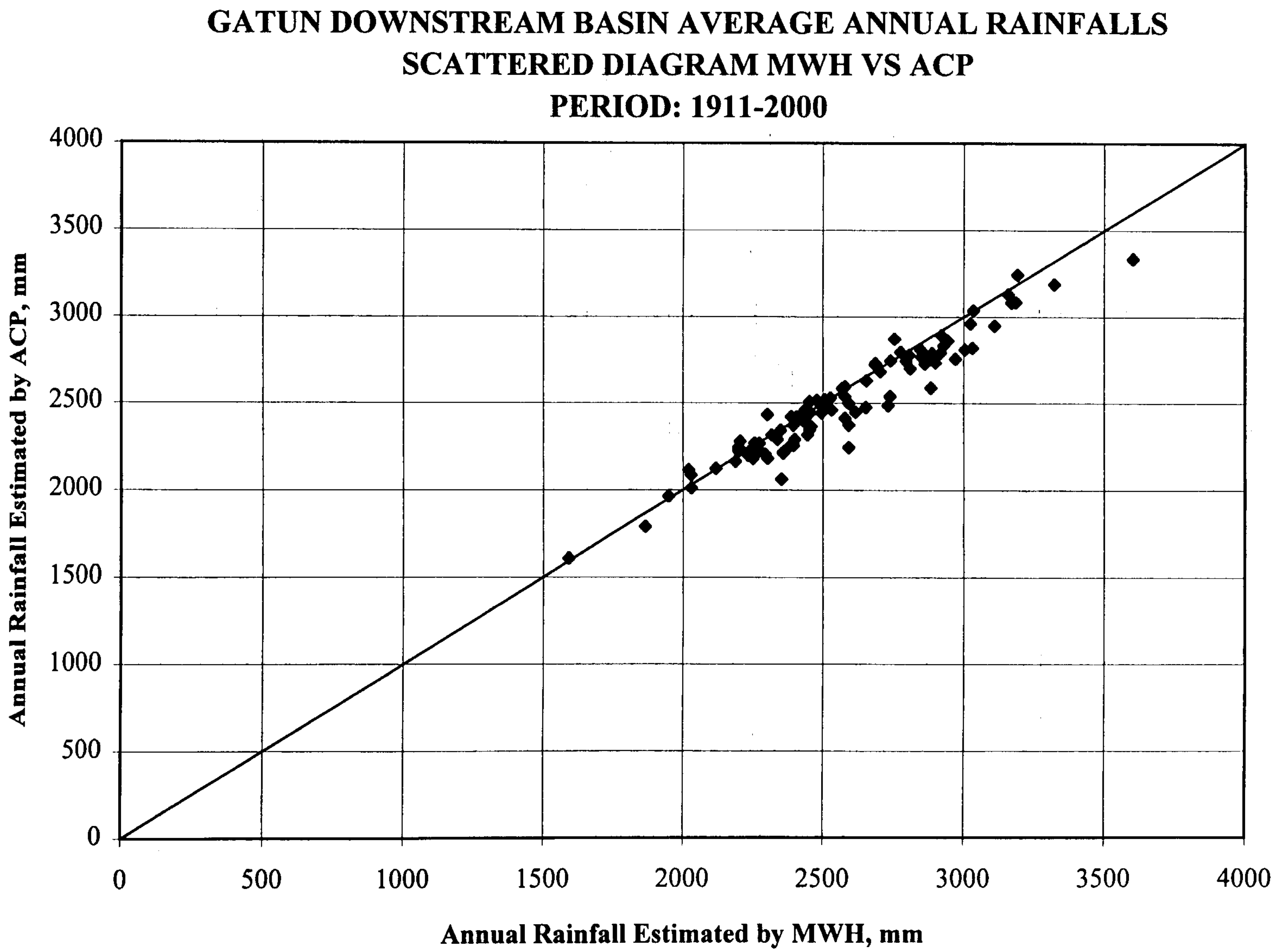


Exhibit10.15

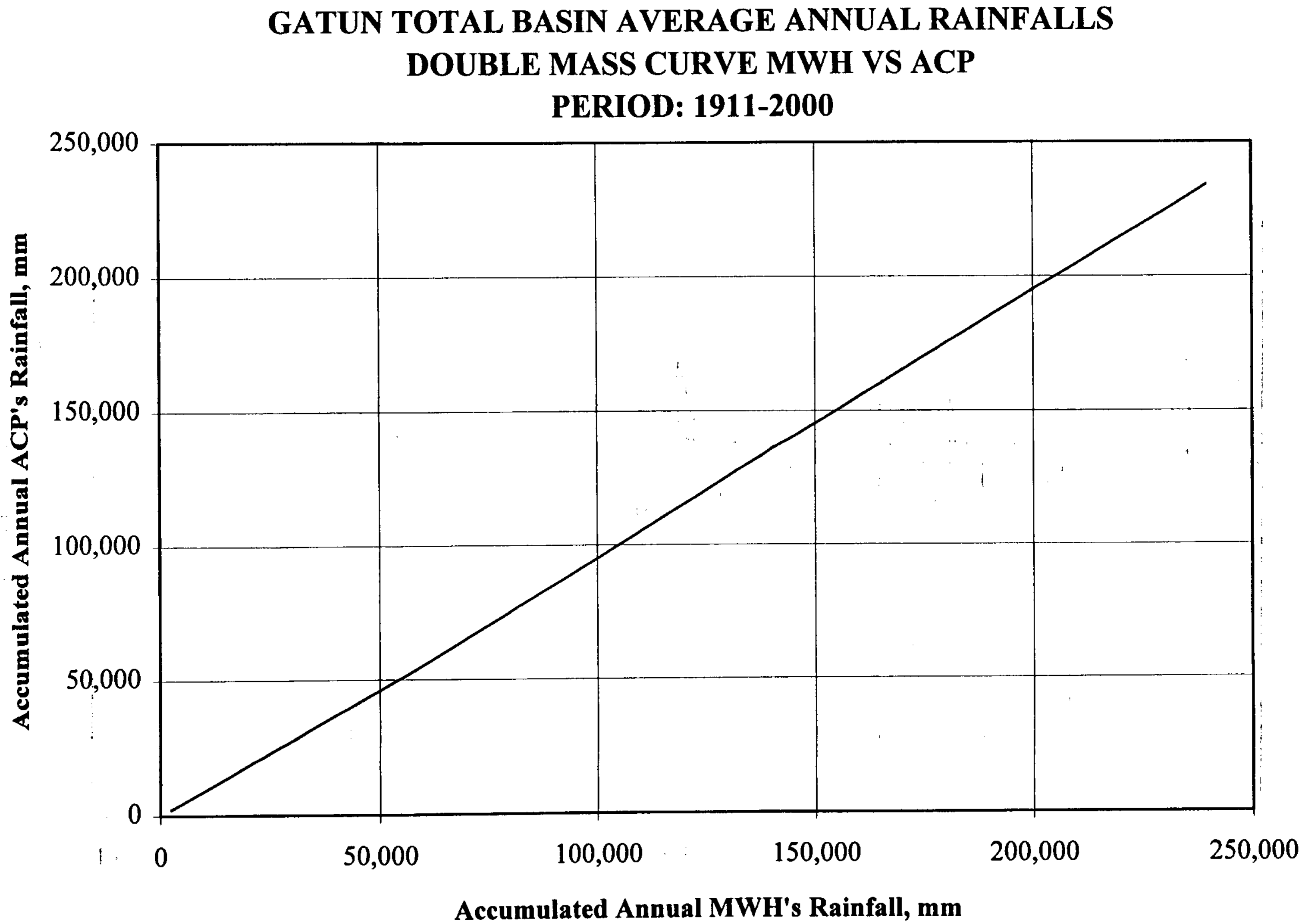


Exhibit 10.16

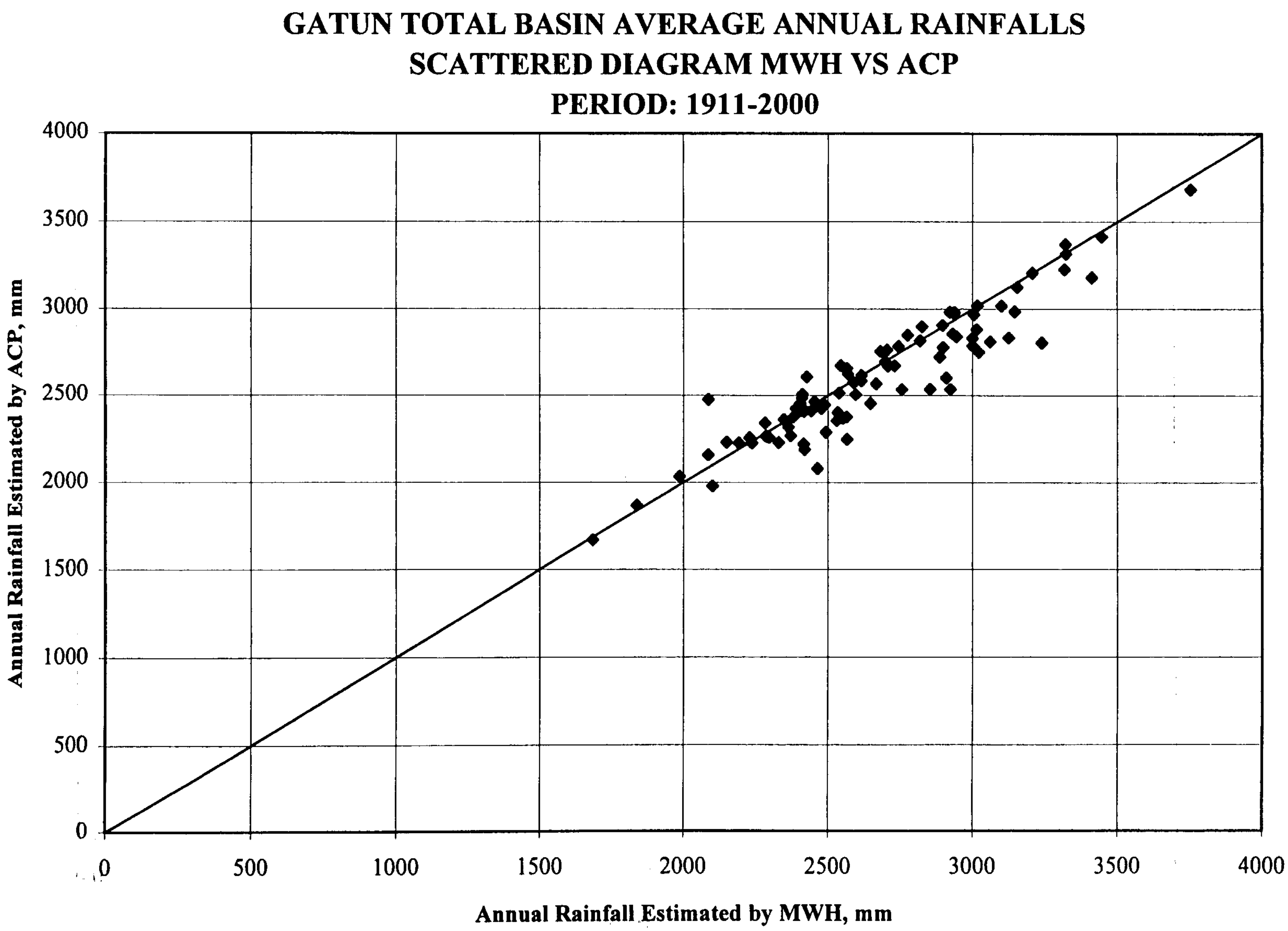
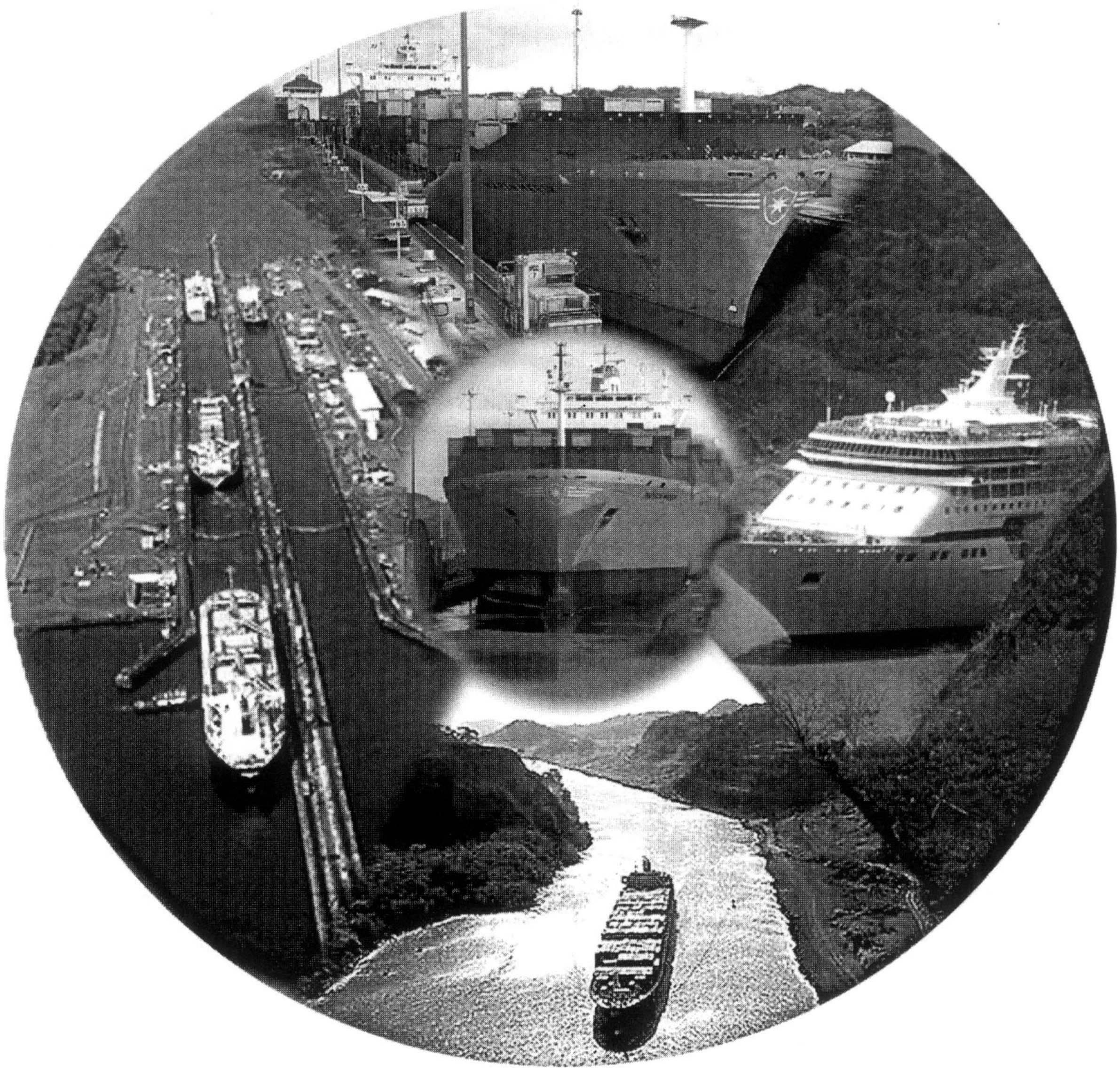


Exhibit 10.17

11.0 Computation of Monthly Inflows



11.0 COMPUTATIONS OF MONTHLY INFLOWS

Six stream gauging stations exist in Gatun Lake watershed. Three of these – Chagres River at Chico, Pequeni River at Caldelaria and Boqueran River at Peluca, flow into Madden Lake. The drainage area controlled by these rivers is about 640 km^2 compared to the total area of 1,030 km2 (including 41 km^2 lake area) at Madden Dam.

The other three rivers – Gatun River at Chico, Trinidad River at El Chorro and Ciri Grande at Canones, join Gatun Lake. The drainage area controlled by these rivers is about 476 km^2 compared to a total area of about 2,290 km^2 (including 425 km^2 lake area) between Madden Dam and Gatun Dam.

ACP provided the drainage areas for the sub-basins and lakes. The areas of all sub-basins except the lake areas were checked by a planimeter.

Historic monthly rainfall data at six stream gauging stations were extended to a common period from 1941 to 2000. This is discussed under Section 9.0 "Extension of Streamflow Series to a Common Period."

ACP provided a map indicating unit yields in liter per second per square kilometer for the sub-basins of Gatun watershed. The variation was judged to be primarily due to variation in rainfall over the watershed. During the field visit, the land use and land cover in the watershed appeared to be nearly the same except that the density of the cover was controlled by the rainfall. Therefore, it was decided to transpose the measured flows at the stream gauging stations to unmeasured sub-basins using combined ratios of drainage areas and mean annual rainfall. The basin average mean annual rainfall amounts were derived from the map prepared by ACP (see Exhibit 10.2).

11.1 Madden Lake

The drainage basin upstream from Madden Lake was sub-divided into five sub-basins (see Exhibit 11.1):

1. Chagres River at Chico.
2. Pequeni River at Caldelaria.
3. Boqueran at Peluca.
4. Intervening area from gauging stations up to Madden Dam, excluding area of Madden Lake.
5. Area of Madden Lake.

The sub-division of the intervening area into smaller units was evaluated. In the preparation of specific yield map by ACP, the intervening area was divided into more than one sub-basin. A study of the land use and topographic maps showed that the area could be considered as one sub-basin. This will not affect the accuracy of the results.

Monthly flows of Chagres, Pequeni and Boqueran were added and transposed to the intervening area using a combined ratio of drainage area and mean annual rainfall (see Table 11.1). Mean annual rainfall amounts were estimated from the map prepared by ACP. Average rainfall over the lake was the mean of the station rainfall at Alhajuela, Salamanca and Chico. Since monthly time steps were used, the flows from the five sub-basins were added to derive the monthly inflows to Madden Lake (no routing effect). Exhibit 11.2 shows the monthly inflows. Exhibits 11.3 and 11.4 show the annual time series and mass curves.

11.2 Gatun Downstream

The drainage basin contributing to Gatun Lake excluding the basin upstream from Madden Lake, was divided into eight sub-basins (see Exhibit 11.5):

1. Gatun River at Ciento.
2. Intervening area of Gatun River between Ciento and Gatun Lake.
3. Intervening area, east and north-east of Gatun Lake, contributing to Gatun Lake between Madden and Gatun lakes.
4. Intervening area south of Gatun Lake including area downstream from El Chorro gauging station.
5. Intervening area south of Gatun Lake between Canonas stream gauging station and Gatun Lake.
6. Area upstream from El Chorro gauging station.
7. Area upstream from Canones gauging station.
8. Lake area.

Monthly flows for sub-basins 2 and 3 were estimated by transposing the flows of sub-basin 1 using a combined drainage area and rainfall ratio (see Table 11.2). The monthly flows for sub-basins 4 and 5 were based on the flows of the Trinidad River at El Chorro. Average rainfall over Gatun Lake was computed as the average of rainfall amounts at

Gatun, Monte Lirio, Guacha, Las Racies, Borro Colorado, El Chorro, Cano and Gamboa. This was converted into runoff. The sum of the flows from the eight sub-basins was the inflow to Gatun Lake (no routing effect because of monthly time steps). Exhibit 11.6 shows the estimated monthly flows. The time series and mass curve, based on annual flows, are shown on Exhibits 11.7 and 11.8, respectively.

11.3 Gatun Total

Monthly Flows from the total watershed area above Gatun Lake, were computed as the sum of the Madden inflows and inflows from the downstream area. The flows are given on Exhibit 11.9. Exhibits 11.10 and 11.11 show the annual time series and mass curve.

11.4 Comparison with ACP's Estimates

The three inflow series computed above were compared with the inflow series provided by ACP. The comparison was made using double mass curve graphs and scatter diagrams of annual flows (see Exhibits 11.12 to 11.17).

The MWH estimate of Madden inflows is nearly the same as that of ACP. The long-term mean annual flows are about 75.1 (MWH) and 75.2 (ACP) m^3/s. The long-term mean annual inflow from the downstream area estimated by MWH is about 9 percent higher than that estimated by ACP. This difference could be due to negative inflows estimated by ACP. The long-term mean annual flow estimated by MWH for the total area is about 5 percent higher than that by ACP.

11.5 Rainfall – Runoff Relationships

As discussed above, the inflows to Madden Lake and flows from Gatun Downstream basin were computed by transposition. An attempt was made to check correlations between the basin average rainfall and these flows. For Madden inflows the following regression equation was developed:

$$\text{Flow}(t) = 13.3 + 0.18\ \text{Rainfall}(t) + 0.08\ \text{Rainfall}(t-1)$$

where flow is in m^3/s (computed by transposition method) and rainfall (basin average) is in mm, and "t" is the month for which flow is desired. The correlation coefficient was about 0.84. This equation can be used as an alternative to the transposition method when only basin average rainfall is available.

Table 11.1

RUNOFF COMPUTATIONS – MADDEN LAKE

Sub-basin No.	Drainage Area (km^2)	Annual Basin Average Rainfall (in)	Annual Basin Average Rainfall (mm)
1	414	133.5	3391
2	135	156.3	3970
3	91	137.4	3489
1+2+3	640	138.9	3527
4	348	100.3	2547
5	41	Rainfall average of Alhajuela, Salamanca and Chico	

Monthly flows for sub-basins 1, 2 and 3 are available.

Monthly flows for sub-basin 4
(sum of sub-basins 1, 2 and 3) * (348/640) * (2547/3527)
transposition factor 0.392666

Runoff from lake area
($41X10^6$) * (monthly rainfall / 1000) / (no. of days in a month * 24 * 3600)
(monthly rainfall / no. of days) * (0.475)

A similar relationship developed for the Gatun Downstream basin is:

Flow (t) = -6.7 + 0.38 Rainfall (t) + 0.17 Rainfall (t-1)

In this case the correlation coefficient was about 0.91. A comparison of flows computed by the above equations and the flows derived by transposition is shown on Exhibits 11.18 and 11.19 for Madden Lake and Gatun Downstream, respectively.

Table 11.2

RUNOFF COMPUTATIONS - GATUN DOWNSTREAM

Sub-basin No.	Drainage Area (km^2)	Annual Basin Average Rainfall (in)	Annual Basin Average Rainfall (mm)
1	117	119.2	3028
2	132	113.1	3970
3	528	89.0	3489
4	549	80.8	3527
5	180	89.9	2547
6	173	89.3	2268
7	186	101.5	2579
8	425	Rainfall over lake, average of 8 stations: Gatun, Monte Lirio, Guacha, Las Racies, Borro Colorado, El Chorro, Gamboa	

Monthly flows for sub-basins 1, 6 and 7 are available.

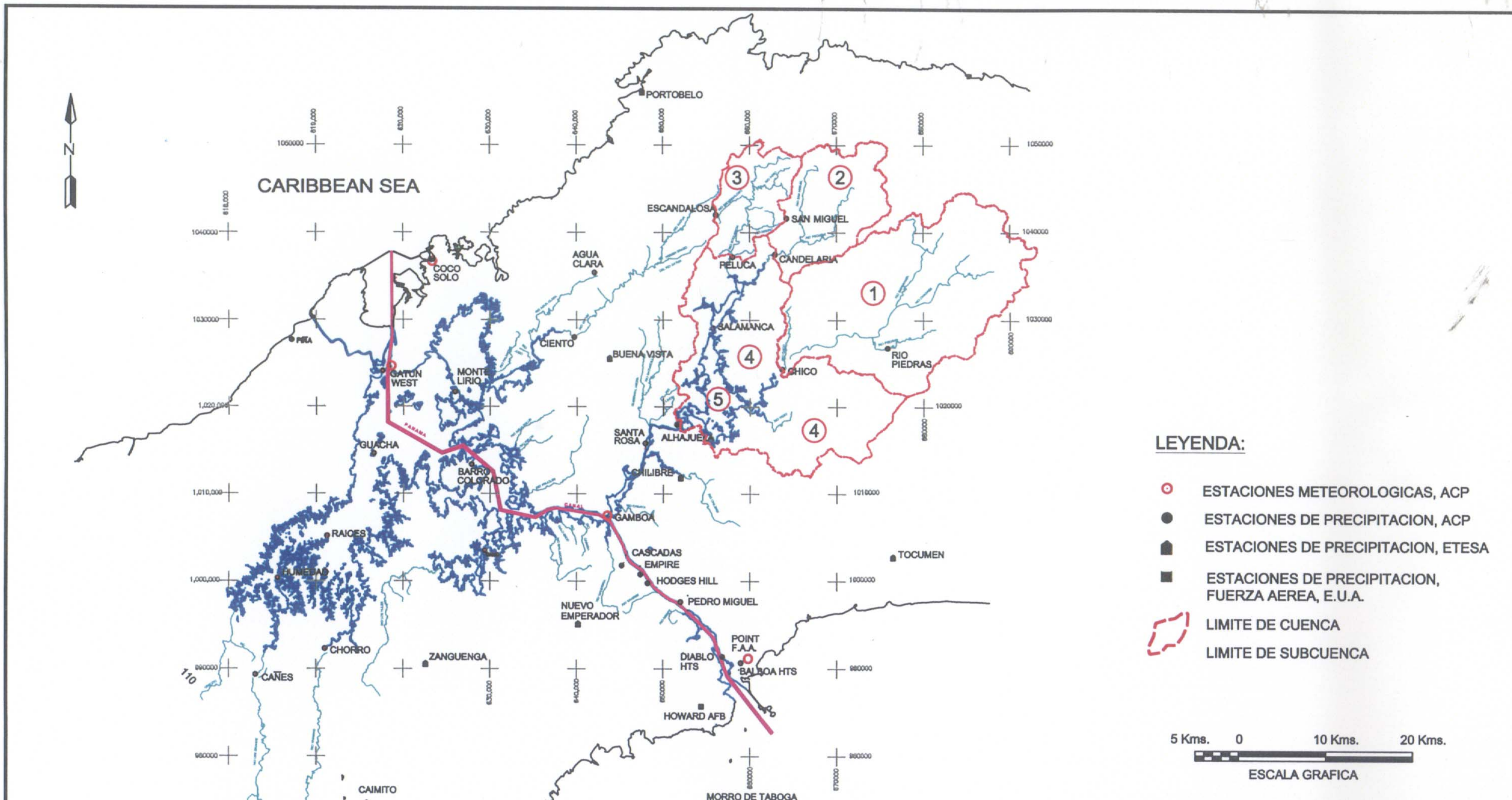
Sub-basin 2 flows – Sub-basin 1 flows * (132/117) * (2872/3028)
transposition factor 1.070081

Sub-basin 3 flows – Sub-basin 1 flows * (528/117) * (2117/3028)
transposition factor 3.155099

Sub-basin 4 flows – Sub-basin 6 flows * (549/173) * (2052/2268)
transposition factor 2.87118

Sub-basin 5 flows – Sub-basin 6 flows * (180/173) * (2283/2268)
transposition factor 1.0473

Runoff from lake area
$(425X10^6)$ * (monthly rainfall / 1000) / (no. of days in a month * 24 * 3600)
(monthly rainfall / no. of days) * (4.92)



AUTORIDAD DEL CANAL DE PANAMA
Oficina de Proyectos de Capacidad del Canal

ACP

CONTRACT NO. CC-3-536
STUDY OF HYDROLOGIC SERIES IN GATUN LAKE WATERSHED

Sub-basins Draining into Madden Lake

MWH
MONTGOMERY WATSON HARZA

FECHA:	EXHIBIT:
DECEMBER, 2001	11.1

Exhibit 11.2

MADDEN LAKE
MONTHLY INFLOWS IN CMS

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1941	34.0	54.0	41.4	26.4	62.7	106.1	81.0	103.0	90.6	188.1	157.7	98.5	87.0
1942	44.2	33.2	36.0	63.3	54.3	96.0	88.7	88.2	101.8	130.9	90.7	88.8	76.3
1943	65.8	45.1	32.7	39.4	85.1	101.2	74.8	93.3	89.2	103.4	95.8	193.5	84.9
1944	56.0	47.5	23.0	41.5	108.2	79.7	108.0	121.8	93.2	148.4	146.7	257.0	102.6
1945	64.0	36.3	23.2	23.1	69.1	77.2	89.7	108.6	89.9	82.7	78.1	151.8	74.5
1946	40.6	28.0	19.0	25.1	63.3	77.4	116.5	93.7	85.7	73.4	68.3	165.1	71.3
1947	44.6	30.0	18.0	23.4	40.5	74.9	102.7	98.1	75.9	78.7	82.0	97.7	63.9
1948	36.5	19.8	13.9	13.8	38.8	61.3	104.3	78.4	73.9	89.7	108.9	65.1	58.7
1949	32.1	19.9	14.2	18.3	62.7	109.9	131.4	117.5	97.0	112.5	139.2	130.6	82.1
1950	43.6	39.4	23.7	47.5	104.8	81.0	163.2	118.4	80.9	66.0	123.1	159.0	87.5
1951	45.6	105.0	54.1	49.3	73.5	78.4	76.6	71.5	76.1	70.6	73.4	78.4	71.1
1952	42.5	27.1	18.3	24.8	61.8	62.9	91.8	109.8	91.7	123.5	75.4	134.3	72.0
1953	99.9	65.9	29.3	29.5	96.2	67.8	82.6	76.4	68.9	79.2	105.5	83.6	73.7
1954	39.8	29.6	26.3	33.3	66.1	90.1	98.0	107.8	89.2	62.6	159.4	160.4	80.2
1955	148.1	38.4	27.9	22.4	42.7	45.8	82.8	131.9	74.2	61.7	189.2	101.7	80.6
1956	140.5	50.2	47.0	47.3	119.3	92.9	145.7	82.1	85.3	94.0	189.2	108.4	100.2
1957	37.2	24.7	18.0	15.2	36.7	37.4	33.7	42.0	47.8	77.9	136.0	89.8	49.7
1958	86.1	36.0	27.7	19.0	48.4	53.2	73.0	70.9	82.7	70.5	89.9	72.4	60.8
1959	31.5	19.9	15.3	23.9	48.1	59.3	55.2	60.9	104.4	86.5	163.9	227.7	74.7
1960	123.6	28.2	22.1	68.0	80.4	81.3	82.4	77.7	70.8	81.5	95.0	227.6	86.6
1961	50.5	23.3	18.3	28.0	48.6	102.0	80.3	82.0	72.3	93.8	99.8	71.1	64.2
1962	40.5	24.1	19.2	21.1	69.1	56.0	96.7	112.7	89.3	90.5	99.1	74.9	66.1
1963	89.7	40.2	26.1	55.1	108.6	102.2	112.8	115.2	111.1	79.9	102.1	53.5	83.0
1964	30.9	23.3	19.6	36.0	69.9	117.6	83.0	74.4	75.0	68.4	96.5	50.0	62.0
1965	41.6	28.9	24.0	21.2	58.7	96.2	70.6	68.4	95.4	114.9	131.4	125.0	73.0
1966	59.7	35.6	27.2	82.7	102.2	78.5	78.9	75.6	95.3	95.7	208.2	182.7	93.5
1967	70.5	40.4	29.7	73.9	108.8	116.0	121.3	82.8	84.8	70.9	103.0	97.3	83.3
1968	30.5	28.5	21.5	23.8	58.6	57.6	74.9	91.5	95.3	85.7	83.0	50.1	58.4
1969	30.0	29.4	24.0	43.6	70.7	49.4	61.3	85.0	78.9	67.0	87.1	213.0	69.9
1970	147.1	35.4	33.9	82.2	111.8	80.8	89.7	104.0	103.0	120.7	119.8	173.8	100.2
1971	87.0	40.7	30.6	21.0	55.4	110.6	132.4	95.2	77.5	77.8	92.0	48.9	72.4
1972	175.2	39.1	23.4	55.6	66.6	67.0	48.1	61.6	73.5	84.8	83.8	57.6	69.7
1973	29.0	19.0	11.1	10.2	48.3	68.8	81.4	84.1	68.6	80.6	157.1	107.9	63.9
1974	59.0	28.5	20.0	15.4	33.3	53.6	64.7	77.3	69.1	93.9	109.5	64.0	57.4
1975	25.9	16.0	11.9	10.8	64.4	88.7	123.5	146.7	87.7	110.3	132.6	151.7	80.8
1976	55.3	29.7	24.5	34.3	51.5	53.4	35.8	41.0	59.5	90.4	109.8	37.9	51.9
1977	34.5	23.1	17.0	17.7	35.6	41.4	56.6	81.1	73.1	138.3	106.7	90.0	59.6
1978	29.8	27.7	20.5	70.2	94.8	99.8	96.2	114.8	79.2	78.4	99.1	52.7	71.9
1979	26.1	19.3	14.5	52.0	47.3	67.3	67.0	83.0	67.0	71.8	102.0	121.7	61.6
1980	73.3	42.9	22.6	23.6	62.4	90.2	49.9	56.0	55.6	78.1	97.7	98.5	62.6
1981	58.9	40.5	34.3	247.8	115.2	88.3	112.9	91.8	61.7	81.1	105.6	160.5	99.9
1982	73.2	32.9	20.5	30.0	49.5	47.6	86.0	85.4	73.7	118.2	74.9	45.9	61.5
1983	34.8	19.2	14.2	21.8	91.5	65.9	61.2	62.7	75.5	95.4	101.8	219.2	71.9
1984	53.9	34.2	19.5	13.5	44.2	81.1	93.4	149.2	100.6	113.5	123.9	79.0	75.5
1985	38.1	26.6	26.4	20.0	55.0	91.8	67.0	56.6	98.5	81.3	77.6	128.1	63.9
1986	39.9	24.4	23.5	63.2	121.9	89.0	73.2	65.8	102.2	120.7	138.1	58.0	76.7
1987	26.5	25.9	16.1	83.8	162.1	96.3	91.2	109.0	125.5	98.6	148.0	68.2	87.6
1988	28.8	31.7	19.6	16.0	57.3	51.6	132.7	151.4	85.9	123.5	100.2	75.9	72.9
1989	43.3	44.0	25.0	17.3	50.4	84.8	102.6	106.3	74.7	132.0	152.1	82.7	76.2
1990	75.2	41.8	33.9	42.5	154.2	56.5	55.7	98.0	101.7	133.1	123.7	121.9	86.5
1991	40.0	26.1	31.3	25.4	97.3	58.0	55.7	63.5	108.6	77.4	157.7	74.7	68.0
1992	34.8	21.6	18.0	39.7	143.5	104.5	88.7	138.3	103.3	77.5	115.9	78.9	80.4
1993	59.6	28.9	39.8	77.1	85.4	112.4	84.4	63.9	98.4	143.2	108.9	82.3	82.0
1994	32.2	21.5	17.1	14.9	73.5	109.1	91.8	106.5	83.7	83.7	151.4	63.2	70.7
1995	35.8	19.0	12.0	19.4	54.3	97.5	118.2	89.0	71.5	71.8	104.0	138.4	69.2
1996	167.8	64.1	54.7	46.3	124.1	104.5	99.0	105.4	74.6	87.4	202.6	211.5	111.8
1997	53.7	39.4	20.9	17.7	78.7	74.4	44.5	41.0	49.6	60.3	51.0	38.3	47.5
1998	23.2	16.8	9.7	37.9	84.6	60.7	88.8	95.5	85.9	77.4	78.9	132.0	66.0
1999	72.2	54.2	40.1	57.1	78.7	96.2	120.9	130.5	96.0	93.4	122.2	317.2	106.5
2000	112.9	45.1	30.0	17.4	65.9	117.5	75.0	87.6	89.4	119.9	84.2	187.4	86.0
Mean	59.1	33.9	24.6	39.0	75.3	80.3	87.5	91.4	84.0	94.4	115.2	116.3	75.1
Max	175.2	105.0	54.7	247.8	162.1	117.6	163.2	151.4	125.5	188.1	208.2	317.2	111.8
Min	23.2	16.0	9.7	10.2	33.3	37.4	33.7	41.0	47.8	60.3	51.0	37.9	47.5
Sd. Dev	36.8	14.6	9.7	34.1	30.1	21.6	26.7	25.9	15.3	25.6	34.4	61.2	13.9
Skew	1.70	2.30	1.19	4.09	0.97	-0.08	0.40	0.30	-0.01	1.25	0.84	1.06	0.52
CV	0.62	0.43	0.39	0.87	0.40	0.27	0.31	0.28	0.18	0.27	0.30	0.53	0.19

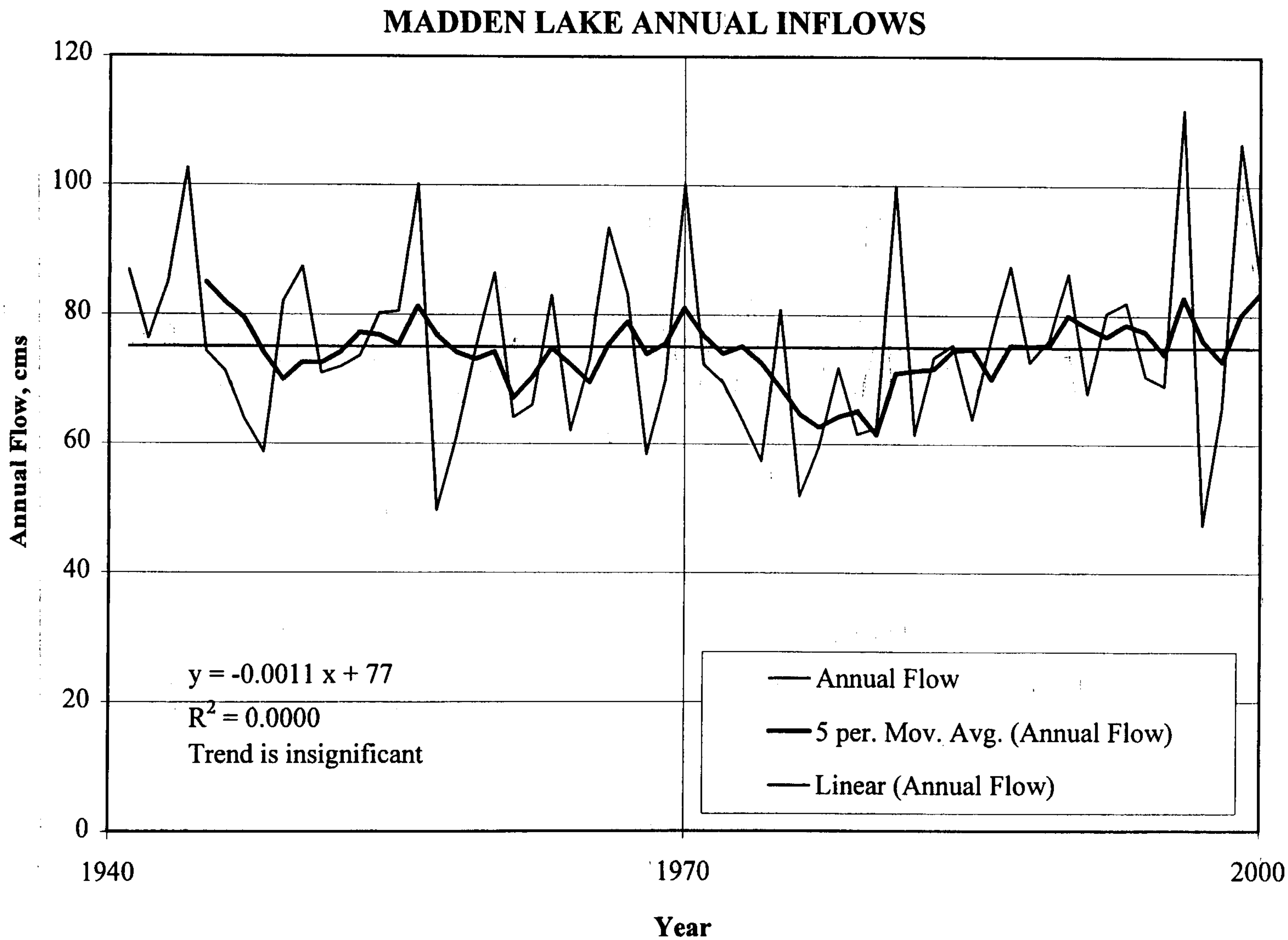

MADDEN LAKE ANNUAL INFLOWS
120
100
80
60
40
20
0
Annual Flow, cms
1940
1970
2000
Year
y = -0.0011 x + 77
R² = 0.0000
Trend is insignificant
Annual Flow
5 per. Mov. Avg. (Annual Flow)
Linear (Annual Flow)

Exhibit 11.3

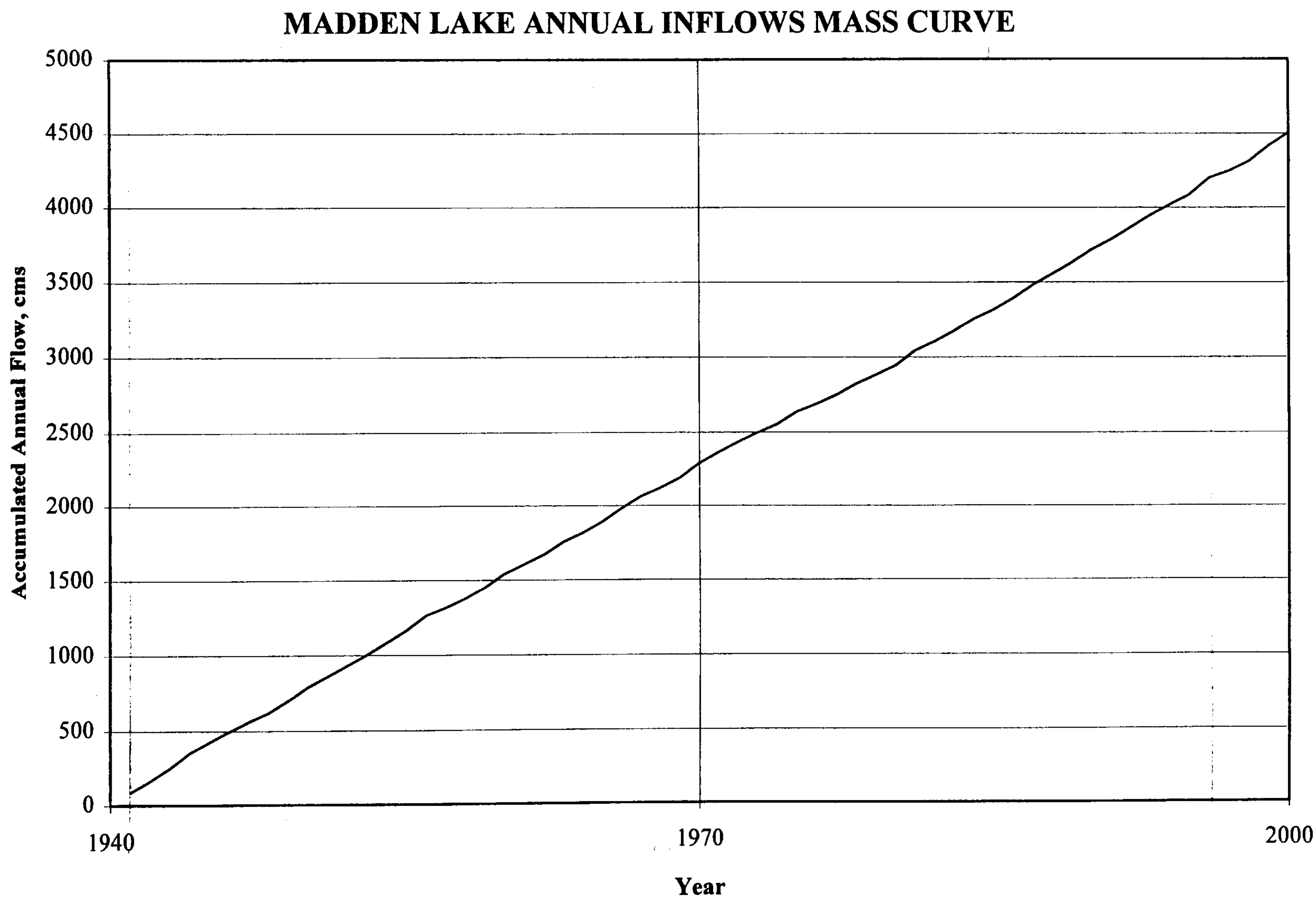
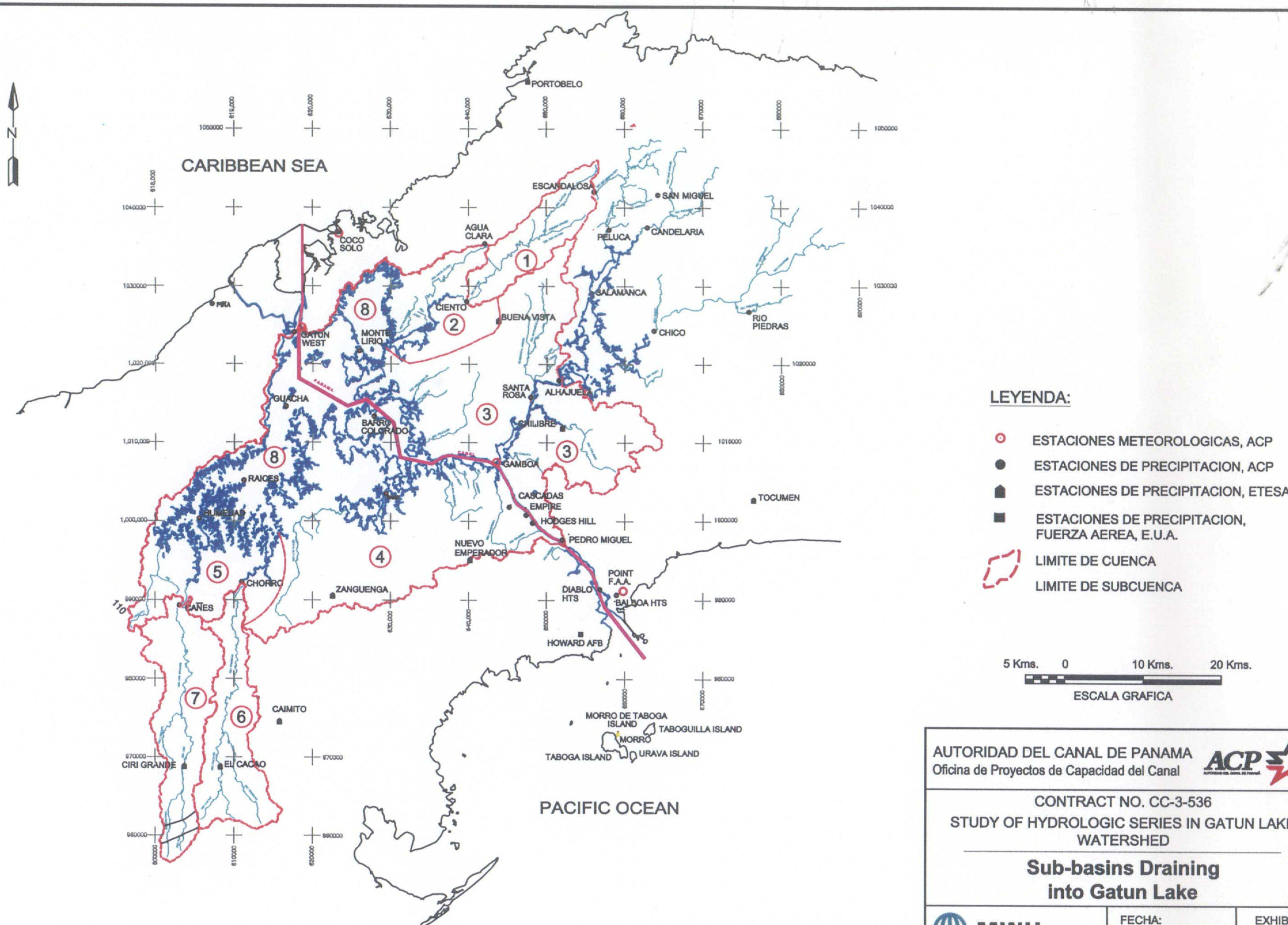

MADDEN LAKE ANNUAL INFLOWS MASS CURVE
Accumulated Annual Flow, cms
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1940
1970
2000
Year

Exhibit 11.4



AUTORIDAD DEL CANAL DE PANAMA
Oficina de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
STUDY OF HYDROLOGIC SERIES IN GATUN LAKE WATERSHED

Sub-basins Draining into Gatun Lake

MWH
MONTGOMERY WATSON HARZA

FECHA:	EXHIBIT:
DECEMBER, 2001	11.5

Exhibit 11.6

GATUN DOWNSTREAM
MONTHLY INFLOWS IN CMS

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1941	57.5	57.7	32.0	33.6	72.4	120.5	124.8	174.0	175.7	278.3	205.5	114.9	120.6
1942	56.9	52.0	40.0	36.9	74.2	142.6	175.2	176.2	221.4	257.4	199.6	154.1	132.2
1943	37.4	43.4	36.3	44.6	115.9	146.7	102.2	112.0	111.0	153.7	220.6	249.6	114.5
1944	80.3	31.3	17.6	55.2	138.6	110.9	117.5	174.9	152.5	261.4	186.5	228.8	129.6
1945	58.9	31.8	18.4	25.4	81.7	102.6	105.1	107.4	141.5	236.3	257.2	293.6	121.7
1946	57.2	22.2	23.3	21.0	63.3	72.9	139.9	102.0	138.9	141.7	115.9	176.9	89.6
1947	54.7	30.2	26.3	27.9	69.5	102.9	112.6	134.3	150.7	178.4	145.4	103.8	94.7
1948	51.0	24.1	15.2	13.2	67.4	54.9	118.8	115.1	105.0	121.4	220.0	64.5	80.9
1949	27.8	14.2	11.1	13.6	65.8	156.2	135.4	147.3	170.0	193.8	338.5	193.6	122.3
1950	43.8	32.8	19.9	25.9	94.3	147.1	161.0	167.4	121.6	159.5	293.7	273.7	128.4
1951	57.9	59.4	24.6	47.2	101.2	85.9	103.6	132.0	142.6	169.3	188.5	127.2	103.3
1952	47.9	26.9	16.5	28.5	70.1	104.0	104.5	103.7	133.0	217.0	138.6	236.3	102.2
1953	105.5	48.5	28.0	33.8	109.0	80.3	126.8	111.4	114.0	229.5	236.3	110.3	111.1
1954	46.3	30.4	16.6	31.6	120.4	111.9	225.4	185.7	173.7	173.5	281.9	140.6	128.2
1955	145.9	38.3	22.7	16.7	67.9	122.4	103.4	168.6	155.4	177.6	285.7	151.9	121.4
1956	119.6	39.9	32.3	33.9	126.6	117.3	171.1	105.6	146.7	248.5	206.4	86.1	119.5
1957	23.7	13.8	8.3	6.1	59.9	53.6	54.2	90.3	87.1	172.9	172.8	81.1	68.7
1958	60.3	53.1	32.0	30.0	82.7	84.9	106.9	121.1	132.4	157.3	118.1	79.5	88.2
1959	30.9	17.0	11.4	20.5	55.0	70.8	67.4	78.7	120.3	173.1	185.5	295.5	93.8
1960	72.8	23.4	36.5	71.2	122.0	126.9	109.6	111.5	96.2	171.9	202.7	347.6	124.4
1961	46.3	22.3	14.5	33.0	46.6	130.7	99.5	120.4	145.5	213.2	196.3	124.1	99.4
1962	49.0	23.6	16.1	24.7	125.6	109.5	143.5	164.0	150.5	159.8	179.0	130.2	106.3
1963	95.2	33.3	18.8	39.2	110.1	145.2	152.5	218.9	175.8	221.4	324.3	83.4	134.8
1964	35.0	15.9	11.3	29.0	111.1	201.7	258.3	232.9	215.7	276.6	325.4	103.6	151.4
1965	64.6	30.5	18.5	13.1	78.6	91.8	82.7	124.5	121.3	288.6	428.6	216.1	129.9
1966	73.0	26.7	17.1	52.5	110.1	131.7	110.3	139.6	130.7	193.5	316.5	187.5	124.1
1967	52.6	30.1	22.2	39.6	109.6	179.3	160.2	152.4	170.7	233.9	232.2	128.5	125.9
1968	44.4	34.5	23.0	12.4	75.1	101.2	83.0	132.5	128.3	182.2	171.5	71.9	88.3
1969	49.7	23.7	16.6	29.8	66.2	67.2	96.0	136.4	173.8	175.1	203.2	181.5	101.6
1970	122.4	40.0	36.9	54.2	139.3	104.0	113.7	154.6	140.7	231.1	234.3	283.1	137.9
1971	131.9	47.5	38.8	22.3	114.2	120.8	134.4	173.9	156.0	186.0	217.7	57.0	116.7
1972	101.5	36.0	22.8	72.6	71.6	123.9	67.0	72.5	140.0	157.8	127.2	99.7	91.1
1973	44.9	30.6	9.9	15.3	70.7	160.3	161.6	145.8	205.5	187.3	312.3	128.9	122.8
1974	52.9	31.9	26.0	17.8	51.9	92.6	115.8	108.2	123.8	285.7	238.9	104.3	104.1
1975	31.5	24.2	15.6	12.1	61.8	87.4	128.9	194.3	155.7	250.6	322.9	231.7	126.4
1976	62.2	31.7	18.4	33.0	64.0	75.3	31.2	52.1	125.9	189.9	160.0	57.5	75.1
1977	30.7	17.7	10.2	10.4	54.2	59.1	63.2	152.7	127.8	195.1	167.5	90.9	81.6
1978	39.0	25.7	26.3	103.6	105.0	134.6	145.5	184.1	151.6	186.1	226.3	103.4	119.2
1979	43.6	24.1	17.8	59.7	82.0	121.7	111.2	148.1	145.5	198.7	166.1	94.7	101.1
1980	96.5	43.9	20.8	20.6	92.0	123.4	94.3	131.4	95.9	166.7	176.0	127.9	99.1
1981	97.5	48.2	45.5	178.0	224.3	218.8	195.6	173.1	127.8	190.4	317.8	267.5	173.7
1982	110.7	51.8	32.2	44.4	71.2	83.7	80.4	72.6	105.5	189.8	123.6	41.1	83.9
1983	26.0	15.3	10.5	22.3	72.4	81.5	63.9	89.1	158.8	156.3	155.2	189.6	86.7
1984	75.7	40.6	18.1	18.3	86.4	114.2	121.0	227.1	214.8	263.8	263.0	96.5	128.3
1985	51.3	32.9	25.2	21.6	74.7	104.7	84.7	103.7	171.4	144.4	140.1	182.3	94.7
1986	45.0	26.1	21.8	55.9	56.6	108.9	77.1	88.8	108.9	256.3	171.3	67.0	90.3
1987	30.5	26.7	13.1	84.7	131.1	95.5	119.7	143.3	174.7	263.4	202.9	107.6	116.1
1988	32.2	22.4	11.3	15.1	73.1	84.7	124.8	178.6	197.2	253.6	184.0	121.2	108.2
1989	46.4	39.2	25.3	21.6	56.1	68.4	114.3	149.8	121.4	167.5	227.5	152.0	99.1
1990	69.5	34.6	32.6	31.8	103.7	98.9	109.8	130.2	229.8	271.1	199.4	151.5	121.9
1991	43.7	29.3	44.5	28.9	114.9	85.1	92.2	86.9	146.6	152.4	190.2	90.9	92.1
1992	57.9	24.0	13.2	42.5	134.7	139.9	111.7	143.6	201.4	145.5	143.9	103.9	105.2
1993	64.5	38.7	44.9	67.0	72.2	119.5	121.3	94.4	191.8	187.7	235.6	122.4	113.3
1994	48.9	25.1	26.8	22.1	89.4	110.3	77.3	95.1	114.6	163.6	211.6	65.0	87.5
1995	55.5	20.1	15.2	31.1	103.6	144.0	155.6	153.7	135.7	154.3	212.1	137.6	109.9
1996	238.1	63.7	48.8	33.1	126.5	153.1	153.6	181.5	170.8	189.2	257.7	151.5	147.3
1997	45.6	29.8	15.1	15.1	65.3	68.4	53.9	46.9	72.9	101.0	115.1	37.8	55.6
1998	18.5	12.5	9.6	48.0	69.8	80.3	103.1	120.0	119.3	167.1	121.4	192.0	88.5
1999	63.2	32.9	30.5	37.9	97.3	169.8	118.6	208.3	186.2	166.4	272.3	339.7	143.6
2000	109.7	36.6	18.4	27.2	77.1	145.7	85.2	121.7	124.6	183.9	136.4	185.1	104.3
Mean	63.9	32.2	22.9	36.0	90.0	112.5	116.4	136.1	147.4	197.0	213.4	148.6	109.7
Max	238.1	63.7	48.8	178.0	224.3	218.8	258.3	232.9	229.8	288.6	428.6	347.6	173.7
Min	18.5	12.5	8.3	6.1	46.6	53.6	31.2	46.9	72.9	101.0	115.1	37.8	55.6
Sd. Dev	36.6	11.8	10.2	26.7	30.7	34.9	40.2	41.5	34.5	44.5	66.5	75.0	21.6
Skew	2.29	0.68	0.78	3.01	1.56	0.69	0.95	0.19	0.41	0.46	0.79	0.90	0.19
CV	0.57	0.37	0.44	0.74	0.34	0.31	0.35	0.31	0.23	0.23	0.31	0.50	0.20

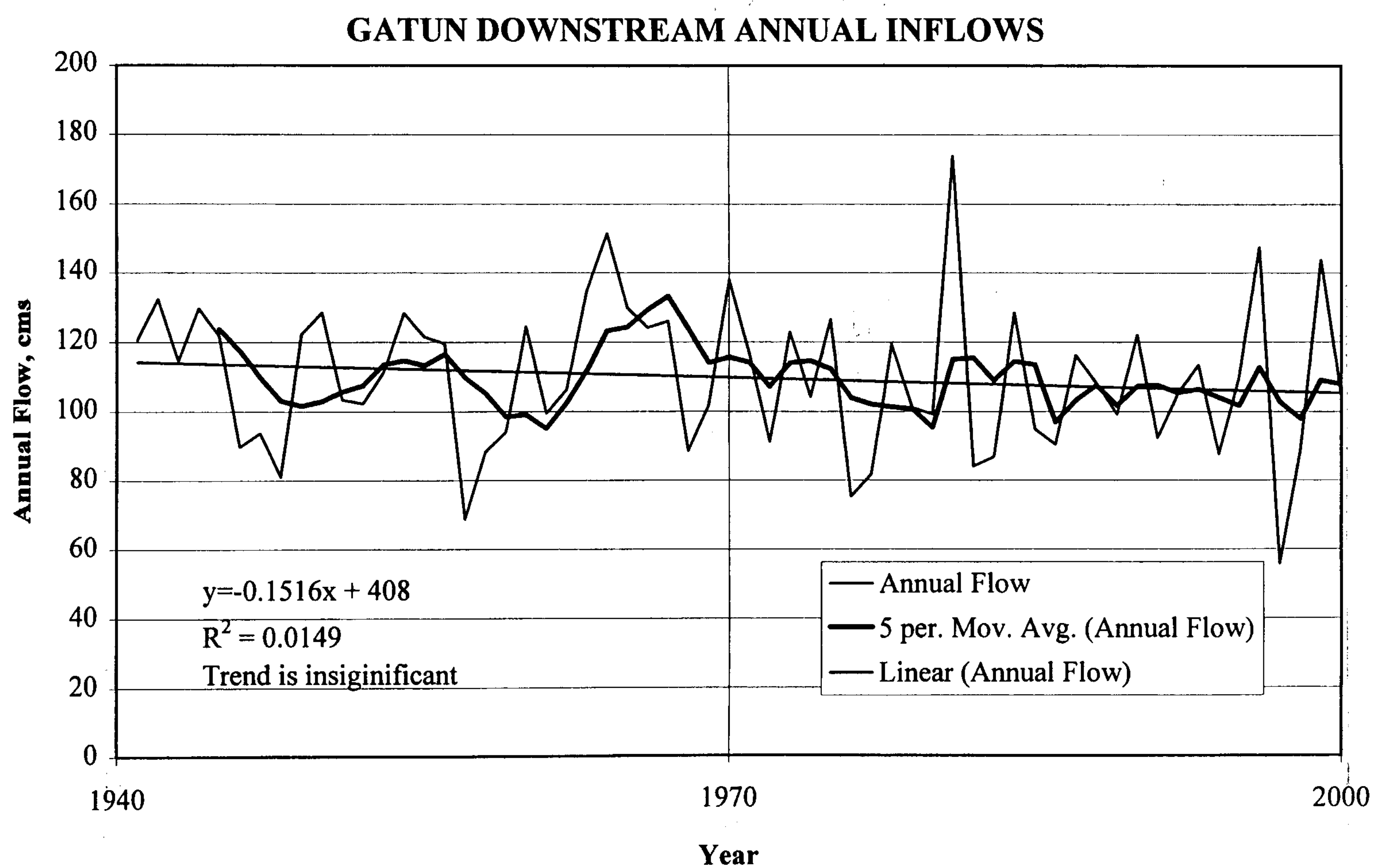
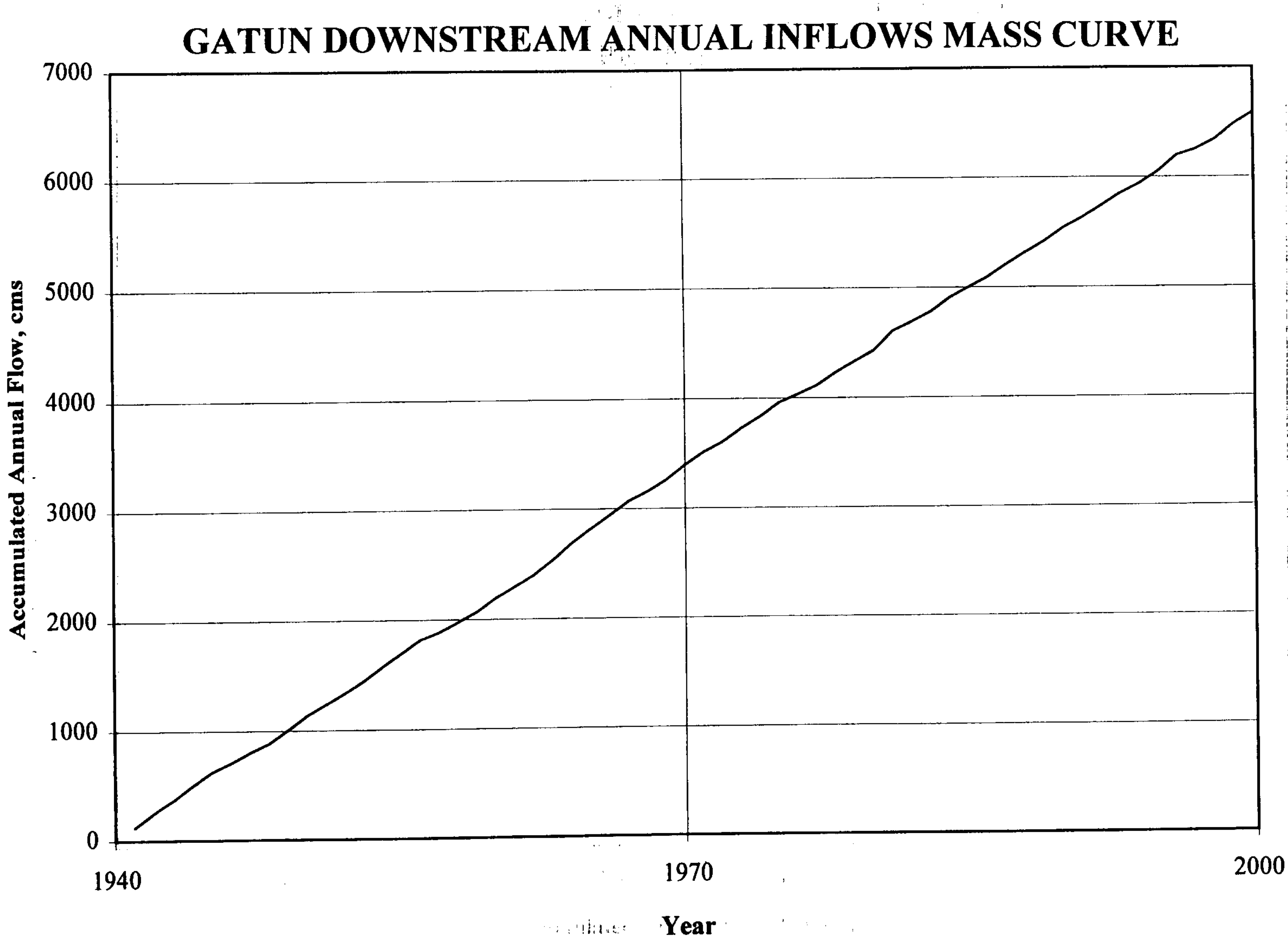

GATUN DOWNSTREAM ANNUAL INFLOWS
200
180
160
140
120
100
80
60
40
20
0
Annual Flow, cms
y=-0.1516x + 408
R2 = 0.0149
Trend is insiginificant
Annual Flow
5 per. Mov. Avg. (Annual Flow)
Linear (Annual Flow)
1940
1970
2000
Year

Exhibit 11.7



GATUN DOWNSTREAM ANNUAL INFLOWS MASS CURVE
7000
6000
5000
4000
3000
2000
1000
0
Accumulated Annual Flow, cms
1940
1970
2000
Year

Exhibit 11.8

Exhibit 11.9

GATUN TOTAL
MONTHLY FLOWS IN CMS

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1941	91.5	111.8	73.4	60.0	135.1	226.6	205.7	277.0	266.4	466.4	363.2	213.4	207.5
1942	101.1	85.3	76.0	100.2	128.5	238.6	263.9	264.3	323.2	388.3	290.4	242.9	208.6
1943	103.2	88.5	69.0	84.0	201.0	247.9	177.0	205.3	200.3	257.1	316.3	443.1	199.4
1944	136.3	78.7	40.6	96.7	246.8	190.6	225.6	296.7	245.6	409.8	333.2	485.9	232.2
1945	122.9	68.0	41.5	48.5	150.9	179.8	194.8	216.0	231.4	319.0	335.3	445.4	196.1
1946	97.8	50.2	42.3	46.1	126.6	150.3	256.3	195.7	224.7	215.1	184.1	342.0	160.9
1947	99.3	60.2	34.3	51.3	110.0	177.7	215.3	232.4	226.6	257.1	227.4	201.5	157.8
1948	87.6	44.0	29.1	26.9	106.2	116.1	223.2	193.5	178.9	211.2	328.9	129.6	139.6
1949	59.9	34.0	25.3	32.0	128.5	266.1	266.8	264.8	267.0	306.2	477.7	324.2	204.4
1950	87.3	72.1	43.6	73.3	199.0	228.1	324.2	285.9	202.5	225.4	416.7	432.7	215.9
1951	103.4	164.5	78.7	96.5	174.7	164.3	180.2	203.5	218.7	239.9	261.9	205.7	174.3
1952	90.4	54.1	34.8	53.3	131.9	166.9	196.2	213.5	224.7	340.5	214.0	370.6	174.2
1953	205.4	114.4	57.3	63.3	205.2	148.0	209.4	187.8	182.8	308.7	341.8	194.0	184.8
1954	86.1	60.1	42.9	64.9	186.5	202.0	323.4	293.5	262.9	236.1	441.3	301.0	208.4
1955	294.0	76.7	50.6	39.1	110.7	168.2	186.2	300.5	229.5	239.3	474.9	253.6	201.9
1956	260.2	90.1	79.3	81.2	245.9	210.2	316.8	187.7	232.0	342.4	395.6	194.5	219.7
1957	61.0	38.5	26.3	21.3	96.6	91.0	87.9	132.3	134.9	250.8	308.7	171.0	118.4
1958	146.4	89.1	59.7	49.0	131.1	138.1	179.9	192.0	215.1	227.9	208.0	151.9	149.0
1959	62.4	36.9	26.8	44.4	103.1	130.2	122.6	139.6	224.7	259.6	349.4	523.3	168.6
1960	196.5	51.6	58.5	139.2	202.5	208.2	192.0	189.3	167.1	253.4	297.7	575.2	210.9
1961	96.8	45.6	32.8	61.0	95.2	232.8	179.8	202.4	217.8	307.0	296.1	195.2	163.5
1962	89.5	47.7	35.2	45.8	194.7	165.6	240.3	276.7	239.8	250.3	278.1	205.1	172.4
1963	184.9	73.4	44.9	94.3	218.6	247.4	265.3	334.1	286.9	301.2	426.4	136.9	217.9
1964	65.9	39.2	30.8	65.0	181.0	319.3	341.3	307.3	290.7	345.0	421.9	153.6	213.4
1965	106.2	59.4	42.5	34.3	137.3	187.9	153.3	192.9	216.7	403.5	560.0	341.0	202.9
1966	132.6	62.3	44.4	135.2	212.2	210.2	189.2	215.2	225.9	289.2	524.6	370.2	217.6
1967	123.0	70.5	51.9	113.4	218.4	295.3	281.4	235.2	255.5	304.8	335.2	225.8	209.2
1968	74.9	62.9	44.5	36.2	133.7	158.8	157.9	224.0	223.6	267.9	254.5	122.0	146.8
1969	79.8	53.1	40.7	73.4	136.9	116.5	157.3	221.3	252.7	242.1	290.3	394.5	171.5
1970	269.5	75.4	70.8	136.4	251.1	184.8	203.4	258.6	243.8	351.8	354.0	456.9	238.0
1971	218.9	88.2	69.4	43.4	169.6	231.5	266.8	269.0	233.5	263.8	309.8	105.9	189.1
1972	276.7	75.1	46.2	128.3	138.2	190.8	115.0	134.1	213.5	242.6	211.1	157.4	160.7
1973	73.9	49.6	21.0	25.5	119.1	229.2	242.9	229.9	274.1	268.0	469.4	236.8	186.6
1974	111.9	60.4	46.1	33.2	85.2	146.2	180.5	185.5	192.9	379.6	348.4	168.3	161.5
1975	57.4	40.2	27.5	22.8	126.1	176.1	252.4	341.0	243.4	360.9	455.6	383.4	207.2
1976	117.5	61.4	42.9	67.3	115.4	128.7	67.0	93.1	185.4	280.3	269.8	95.4	127.0
1977	65.2	40.8	27.2	28.2	89.8	100.5	119.8	233.8	200.9	333.4	274.2	180.9	141.2
1978	68.8	53.4	46.8	173.8	199.7	234.4	241.7	298.9	230.8	264.6	325.3	156.1	191.2
1979	69.7	43.4	32.3	111.7	129.3	189.0	178.2	231.1	212.5	270.6	268.1	216.4	162.7
1980	169.8	86.8	43.4	44.1	154.4	213.6	144.2	187.4	151.6	244.8	273.7	226.4	161.7
1981	156.4	88.7	79.9	425.7	339.5	307.1	308.5	265.0	189.5	271.5	423.4	428.0	273.6
1982	183.9	84.7	52.7	74.4	120.7	131.3	166.4	158.0	179.2	308.0	198.5	87.0	145.4
1983	60.7	34.5	24.6	44.1	163.9	147.4	125.0	151.8	234.3	251.7	257.1	408.9	158.7
1984	129.6	74.8	37.6	31.7	130.6	195.3	214.4	376.3	315.4	377.3	387.0	175.5	203.8
1985	89.3	59.5	51.5	41.6	129.8	196.4	151.8	160.3	269.9	225.7	217.6	310.4	158.7
1986	84.9	50.5	45.4	119.0	178.5	198.0	150.4	154.6	211.1	377.0	309.4	124.9	167.0
1987	57.0	52.6	29.2	168.5	293.2	191.8	210.8	252.3	300.3	362.0	350.8	175.8	203.7
1988	61.0	54.1	30.9	31.2	130.4	136.3	257.5	330.0	283.1	377.2	284.3	197.1	181.1
1989	89.7	83.2	50.3	38.9	106.5	153.2	216.9	256.1	196.1	299.5	379.7	234.7	175.4
1990	144.7	76.5	66.5	74.3	257.9	155.4	165.6	228.2	331.6	404.2	323.1	273.4	208.4
1991	83.8	55.4	75.8	54.2	212.2	143.1	147.8	150.5	255.2	229.8	347.9	165.5	160.1
1992	92.7	45.6	31.2	82.2	278.2	244.4	200.4	281.9	304.7	222.9	259.8	182.8	185.6
1993	124.1	67.6	84.7	144.1	157.6	231.9	205.7	158.3	290.2	330.9	344.5	204.7	195.4
1994	81.1	46.7	44.0	36.9	162.9	219.5	169.1	201.6	198.3	247.3	363.0	128.2	158.2
1995	91.3	39.1	27.2	50.5	157.9	241.5	273.8	242.7	207.2	226.1	316.1	276.0	179.1
1996	405.9	127.9	103.5	79.4	250.7	257.6	252.6	286.9	245.4	276.6	460.3	362.9	259.1
1997	99.3	69.2	36.1	32.7	143.9	142.8	98.5	87.9	122.4	161.3	166.0	76.0	103.0
1998	41.7	29.2	19.2	85.9	154.4	141.0	191.9	215.6	205.3	244.5	200.3	324.0	154.4
1999	135.3	87.1	70.5	95.0	176.0	266.0	239.4	338.8	282.2	259.8	394.6	656.9	250.1
2000	222.7	81.7	48.4	44.6	143.0	263.2	160.2	209.3	214.0	303.8	220.6	372.6	190.3
Mean	123.0	66.1	47.3	75.0	165.2	192.8	203.9	227.5	231.4	291.4	328.6	264.9	184.8
Max	405.9	164.5	103.5	425.7	339.5	319.3	341.3	376.3	331.6	466.4	560.0	656.9	273.6
Min	41.7	29.2	19.2	21.3	85.2	91.0	67.0	87.9	122.4	161.3	166.0	76.0	103.0
Sd. Dev	70.2	24.6	18.5	59.5	55.0	51.6	60.4	62.3	43.9	61.7	88.0	130.5	33.3
Skew	1.85	1.39	0.84	3.73	0.97	0.29	0.17	0.08	0.08	0.64	0.42	0.88	0.18
CV	0.57	0.37	0.39	0.79	0.33	0.27	0.30	0.27	0.19	0.21	0.27	0.49	0.18

GATUN TOTALANNUAL INFLOWS

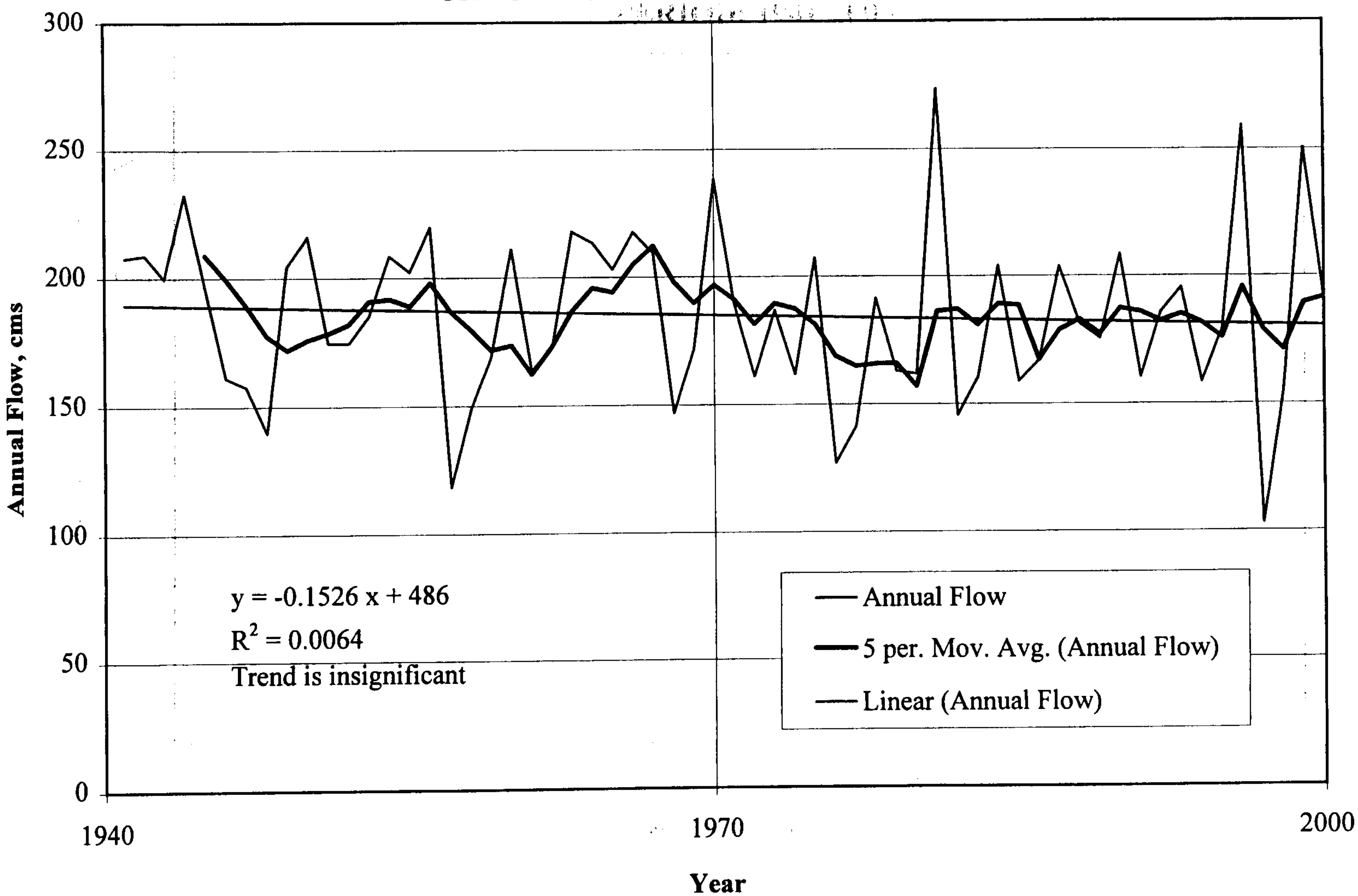


Exhibit 11.10

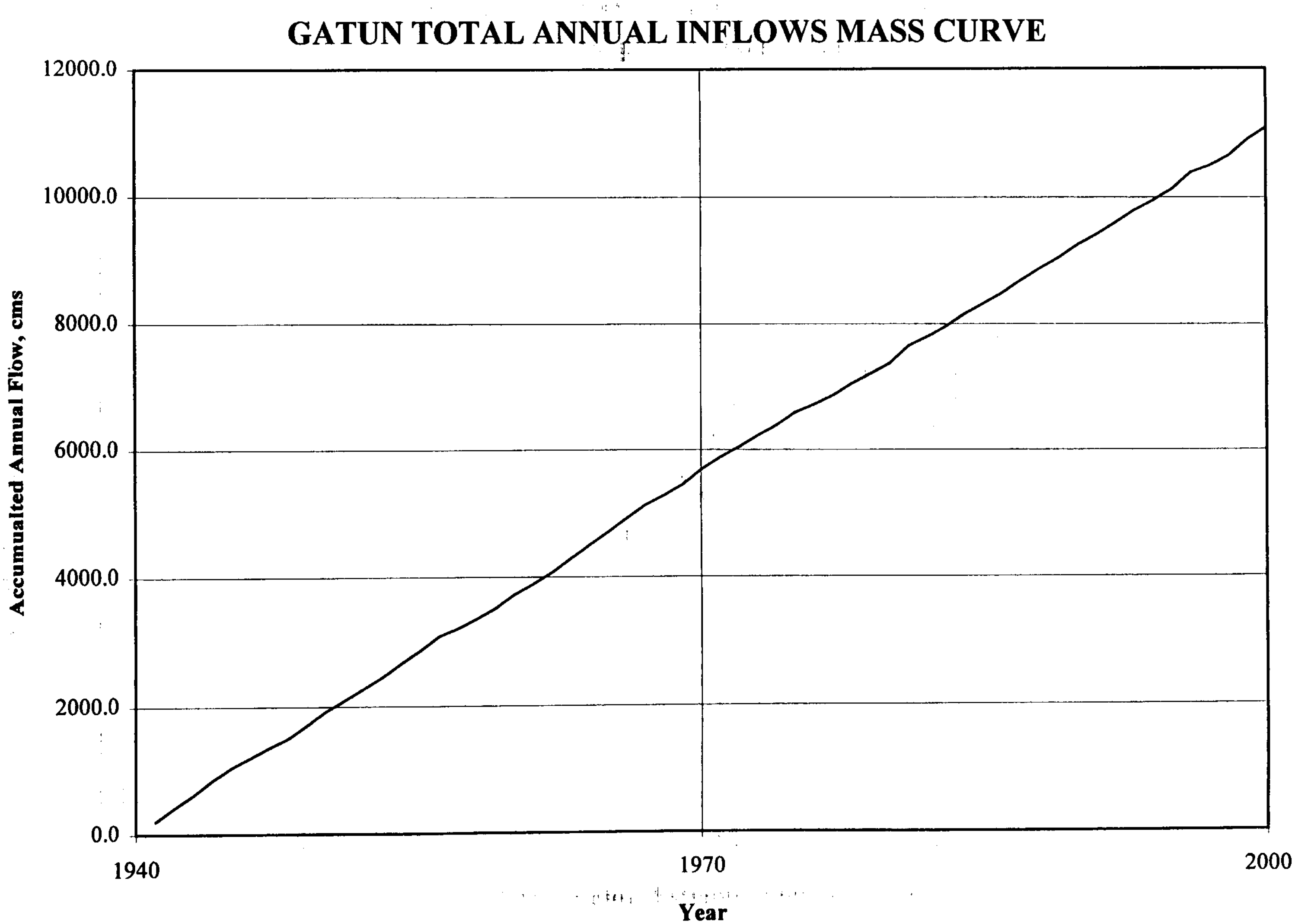


Exhibit 11.11

MADDEN LAKE ANNUAL INFLOWS
DOUBLE MASS CURVE MWH VS ACP
PERIOD: 1941-2000

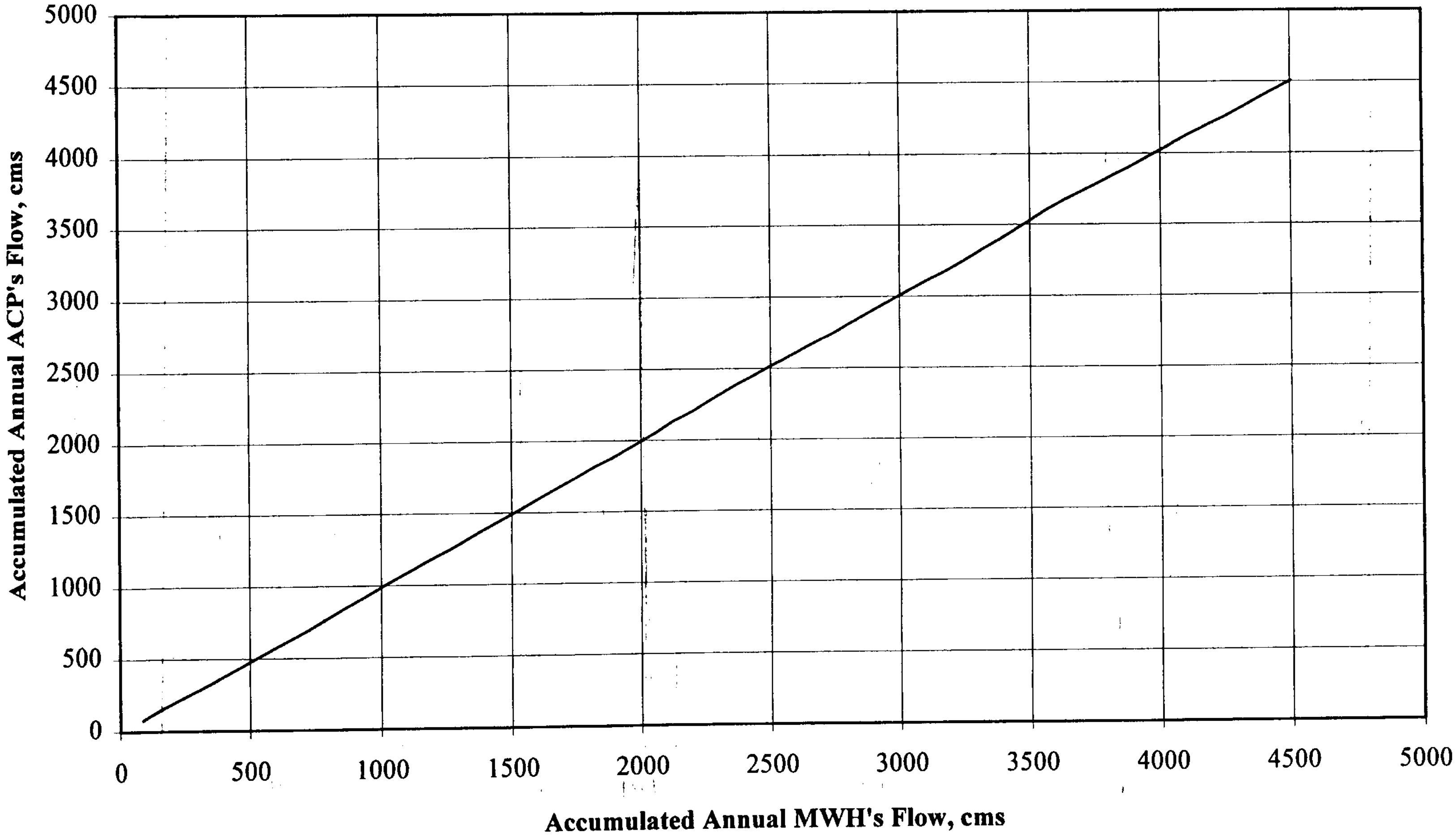


Exhibit 11.12

MADDEN LAKE ANNUAL INFLOWS
SCATTERED DIAGRAM MWH VS ACP
PERIOD: 1941-2000

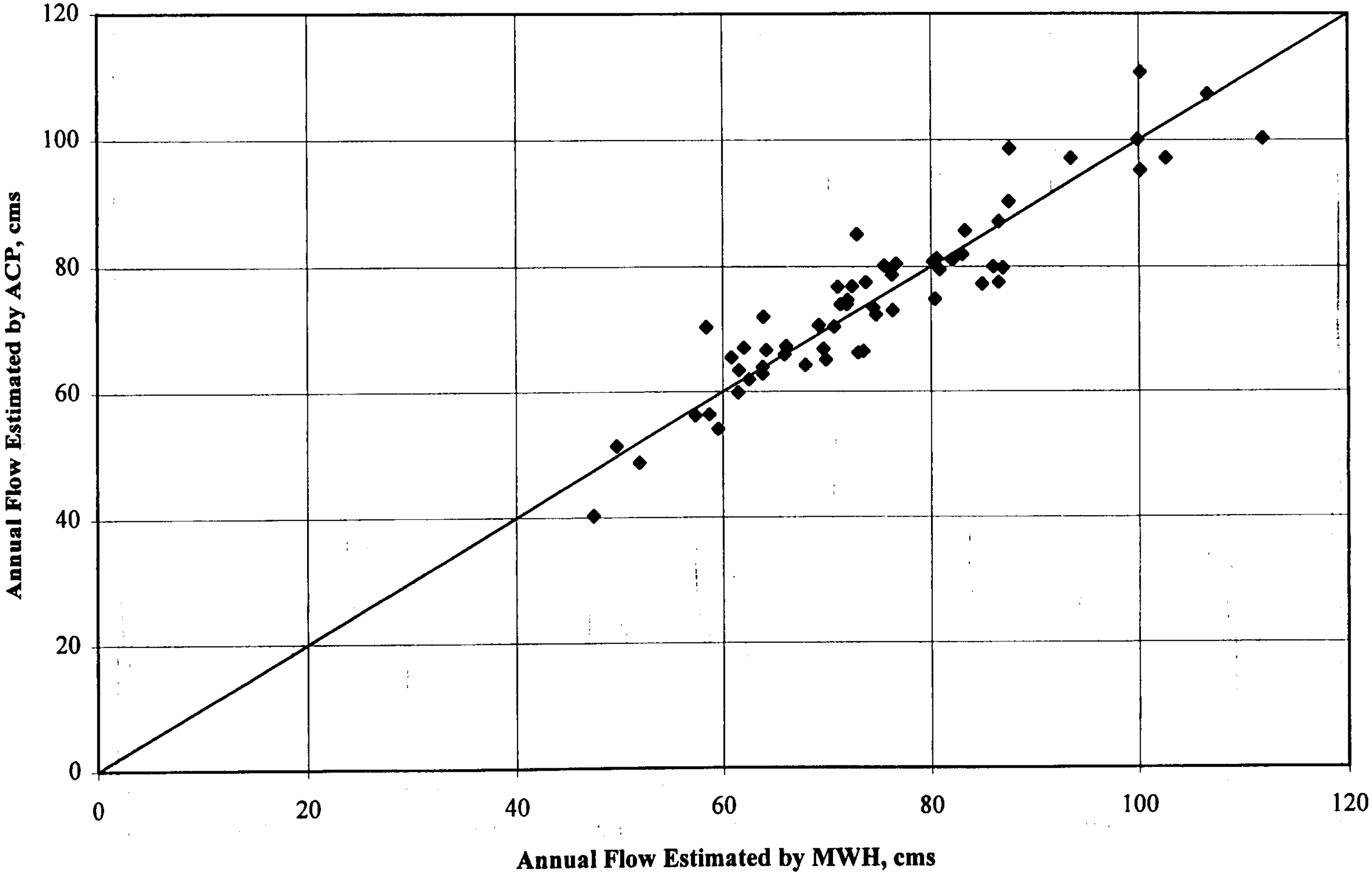


Exhibit 11.13

GATUN DOWNSTREAM ANNUAL INFLOWS
DOUBLE MASS CURVE MWH VS ACP
PERIOD: 1941-2000

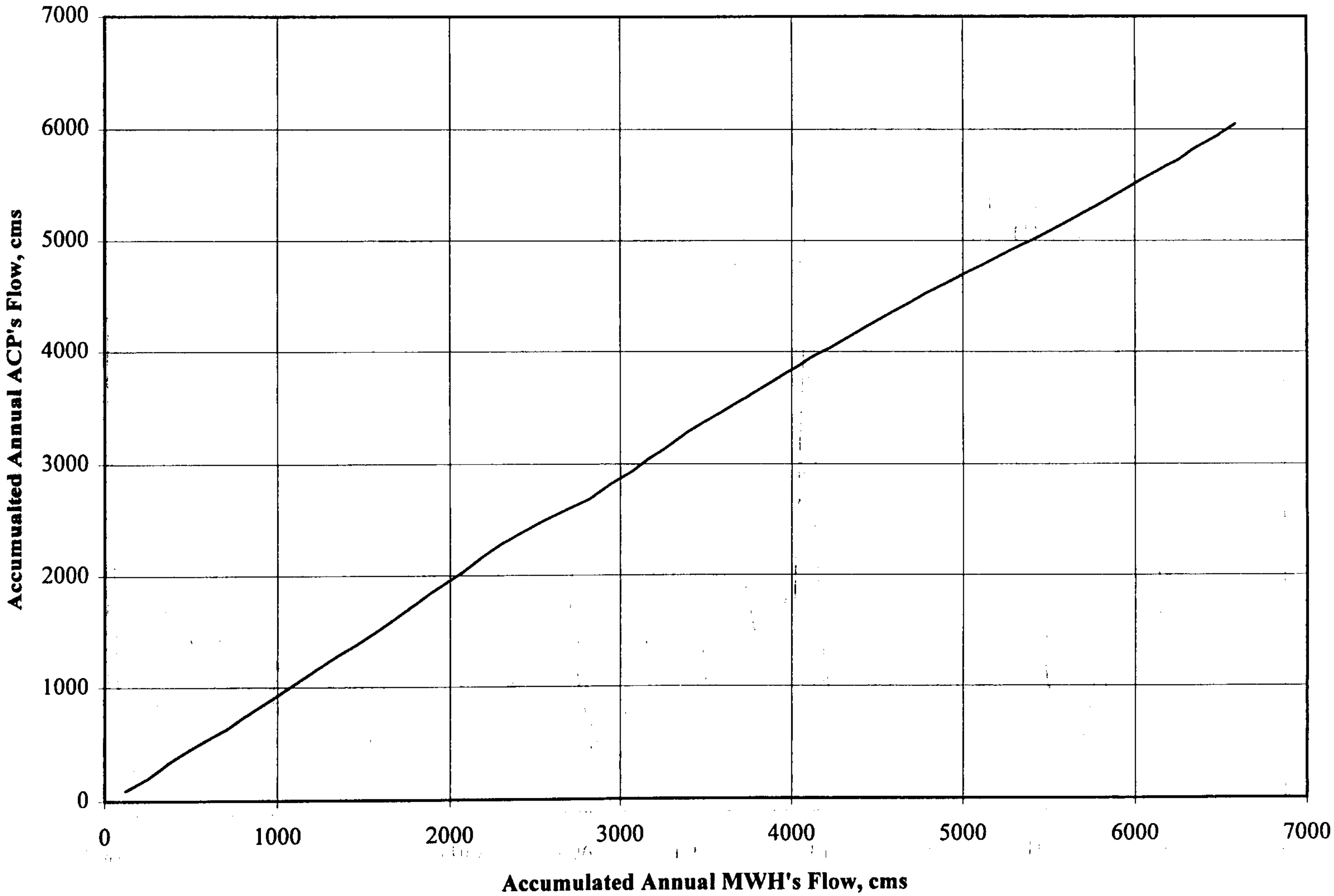


Exhibit 11.14

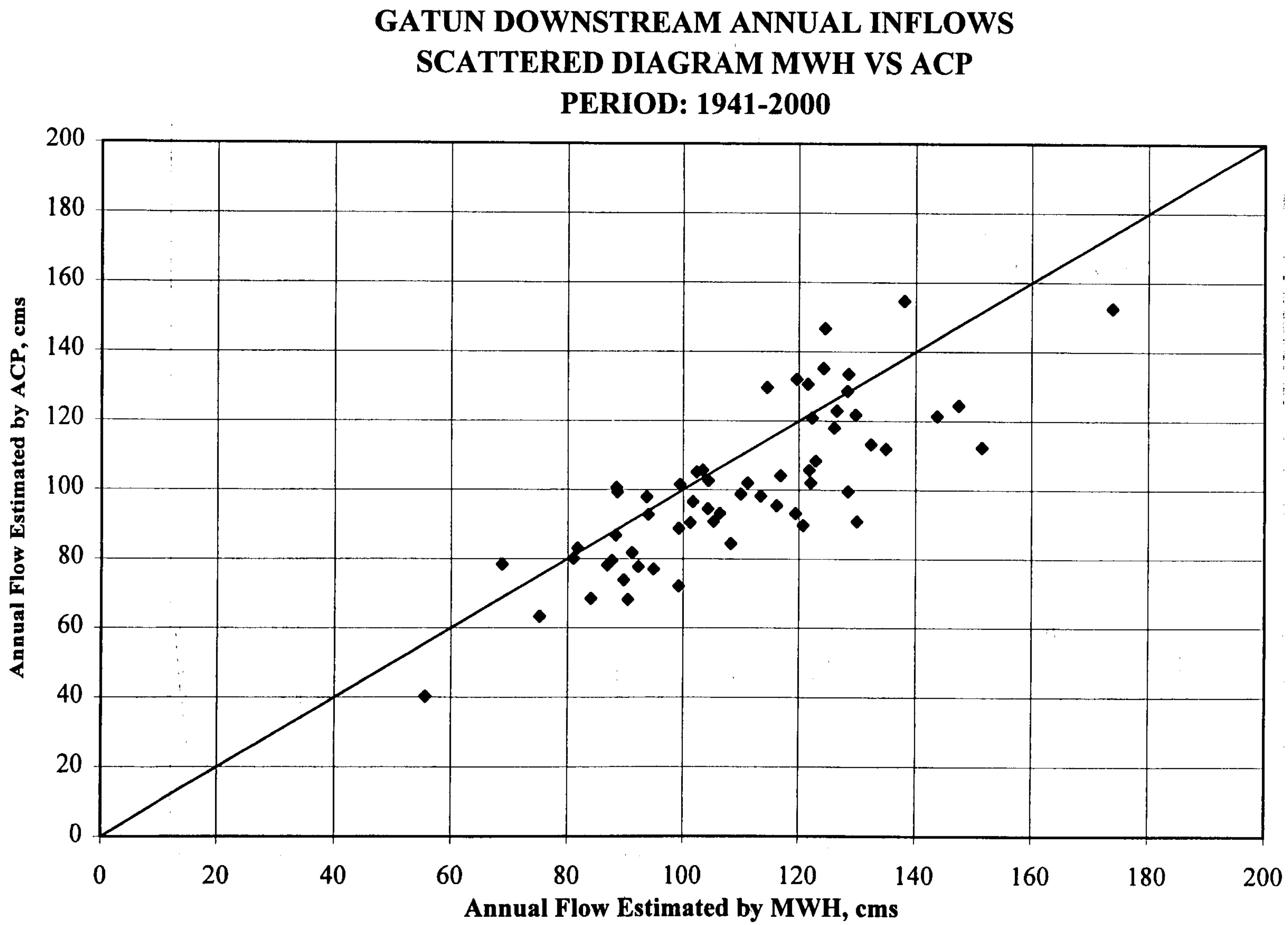


Exhibit 11.15

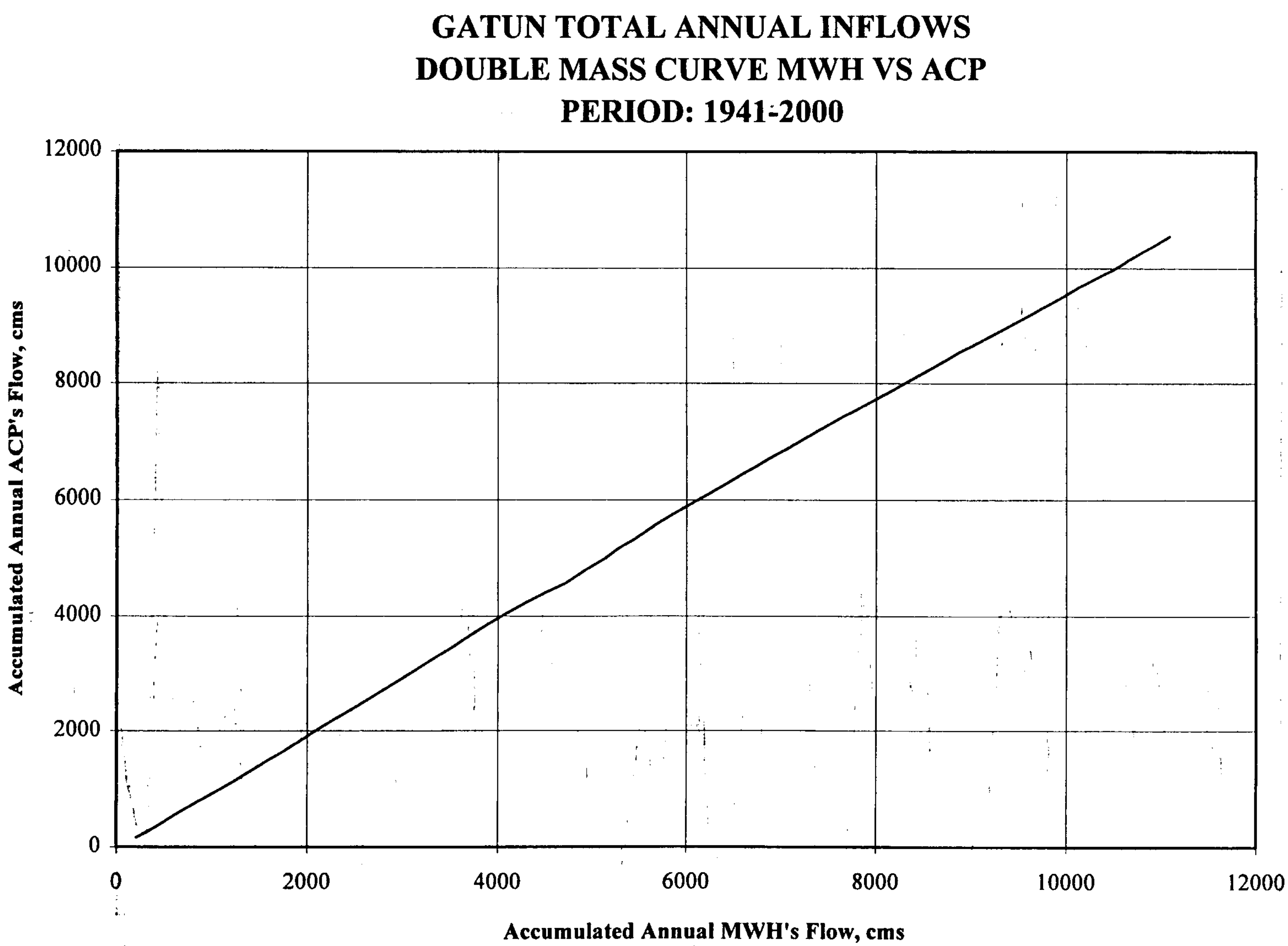
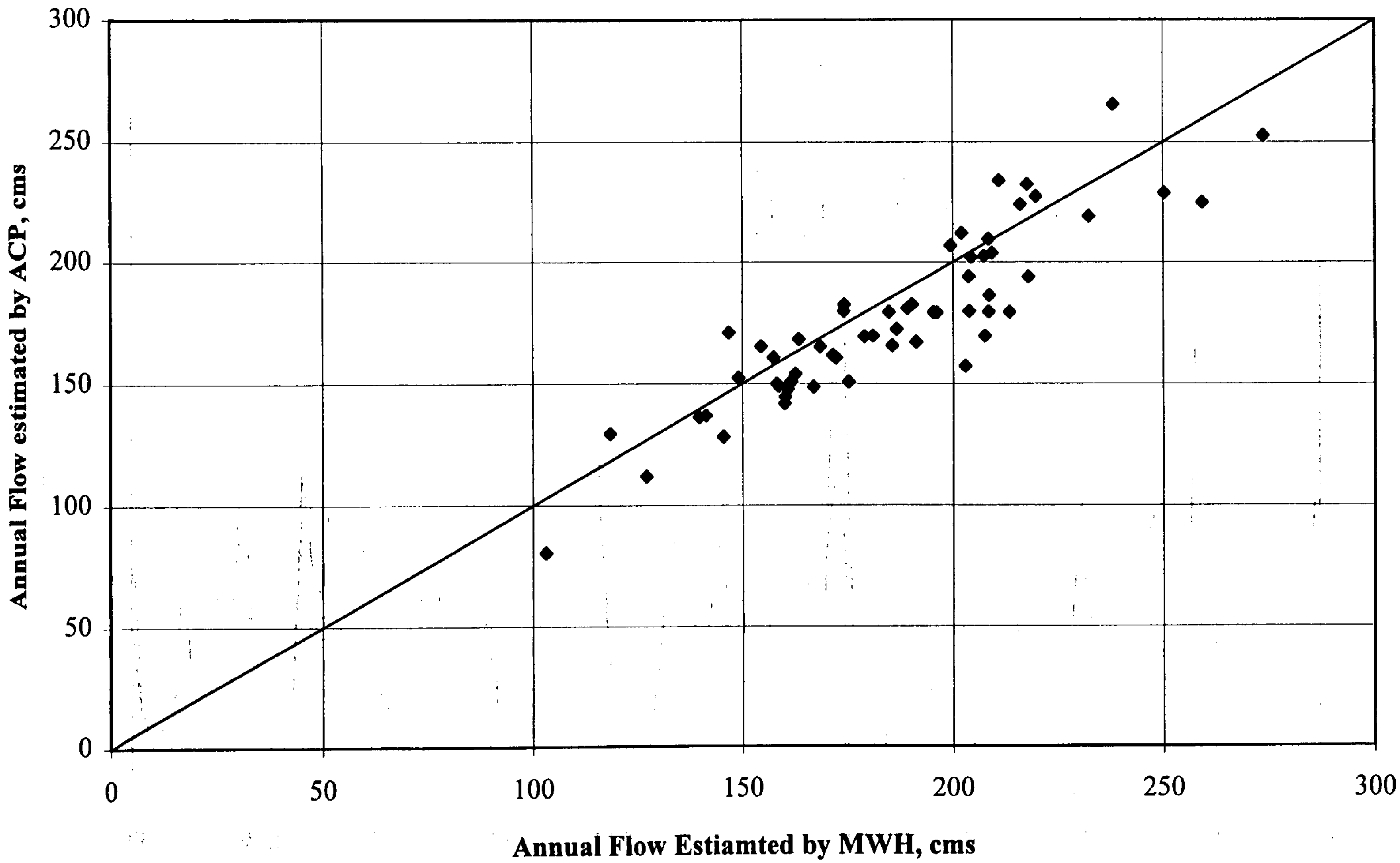


Exhibit 11.16

GATUN TOTAL ANNUAL INFLOWS
SCATTERED DIAGRAM MWH VS ACP
PERIOD: 1941-2000



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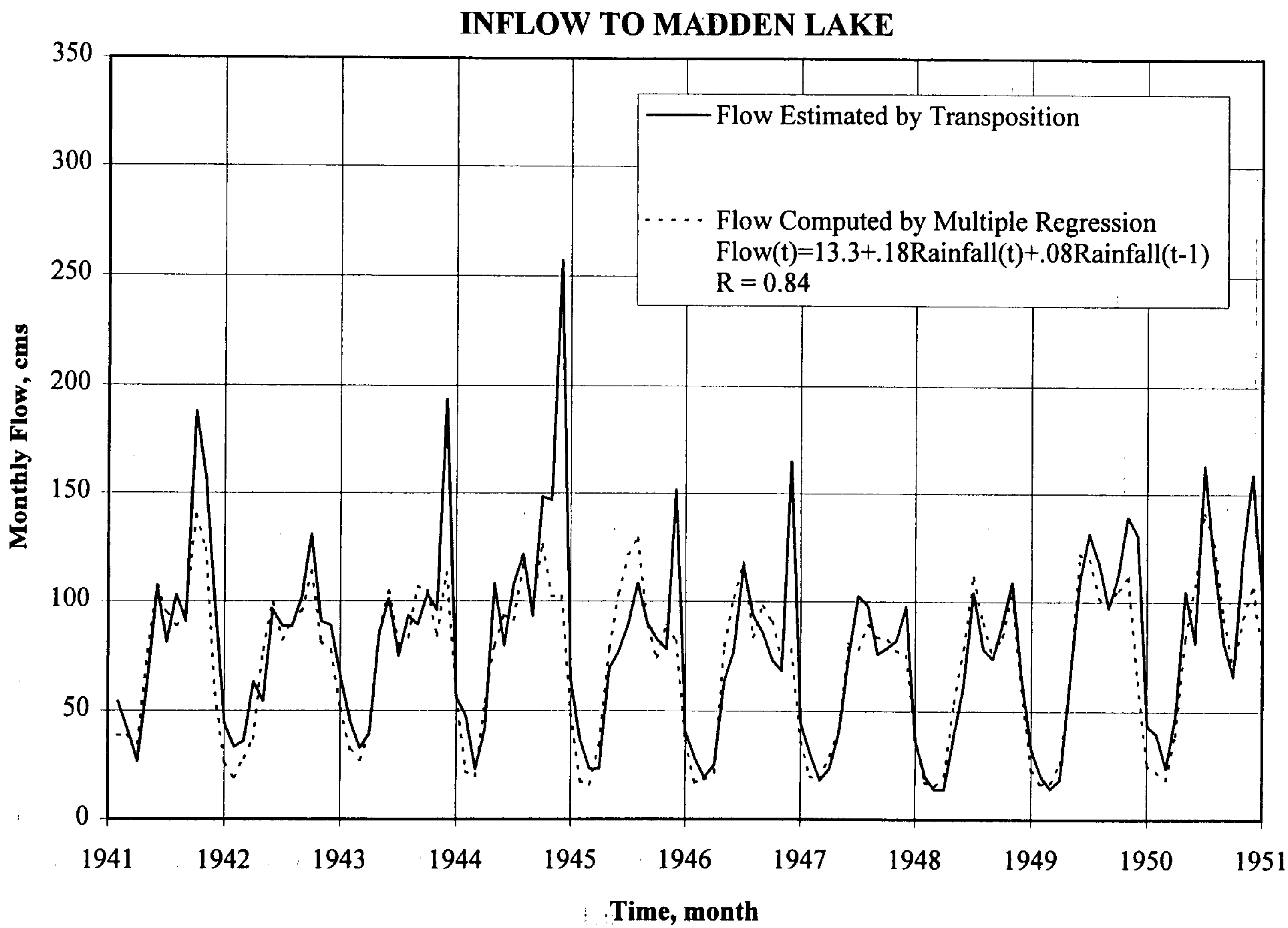


Exhibit 11.18
Sheet 1 of 6

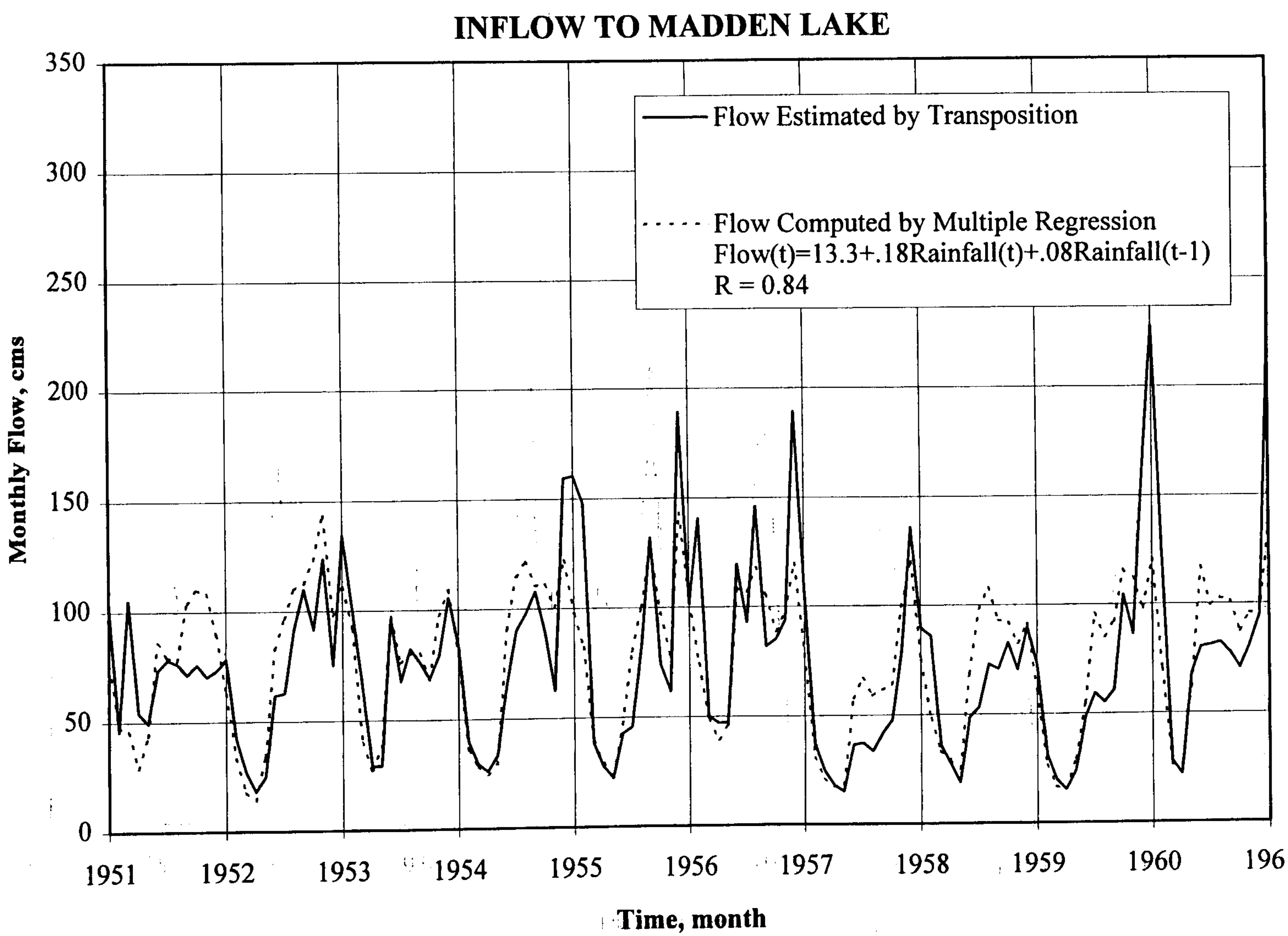


Exhibit 11.18
Sheet 2 of 6

INFLOW TO MADDEN LAKE

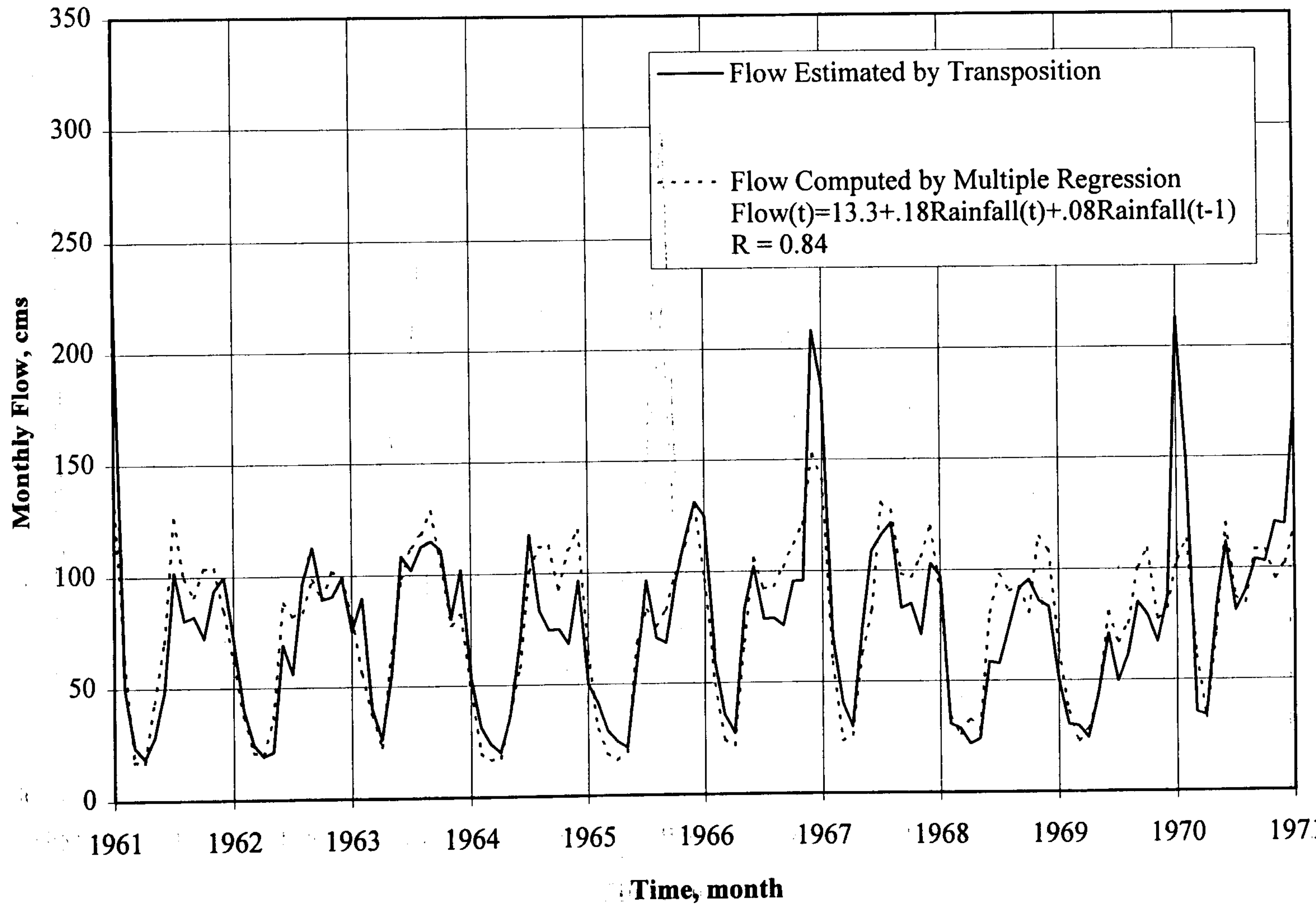


Exhibit 11.18
Sheet 3 of 6

INFLOW TO MADDEN LAKE

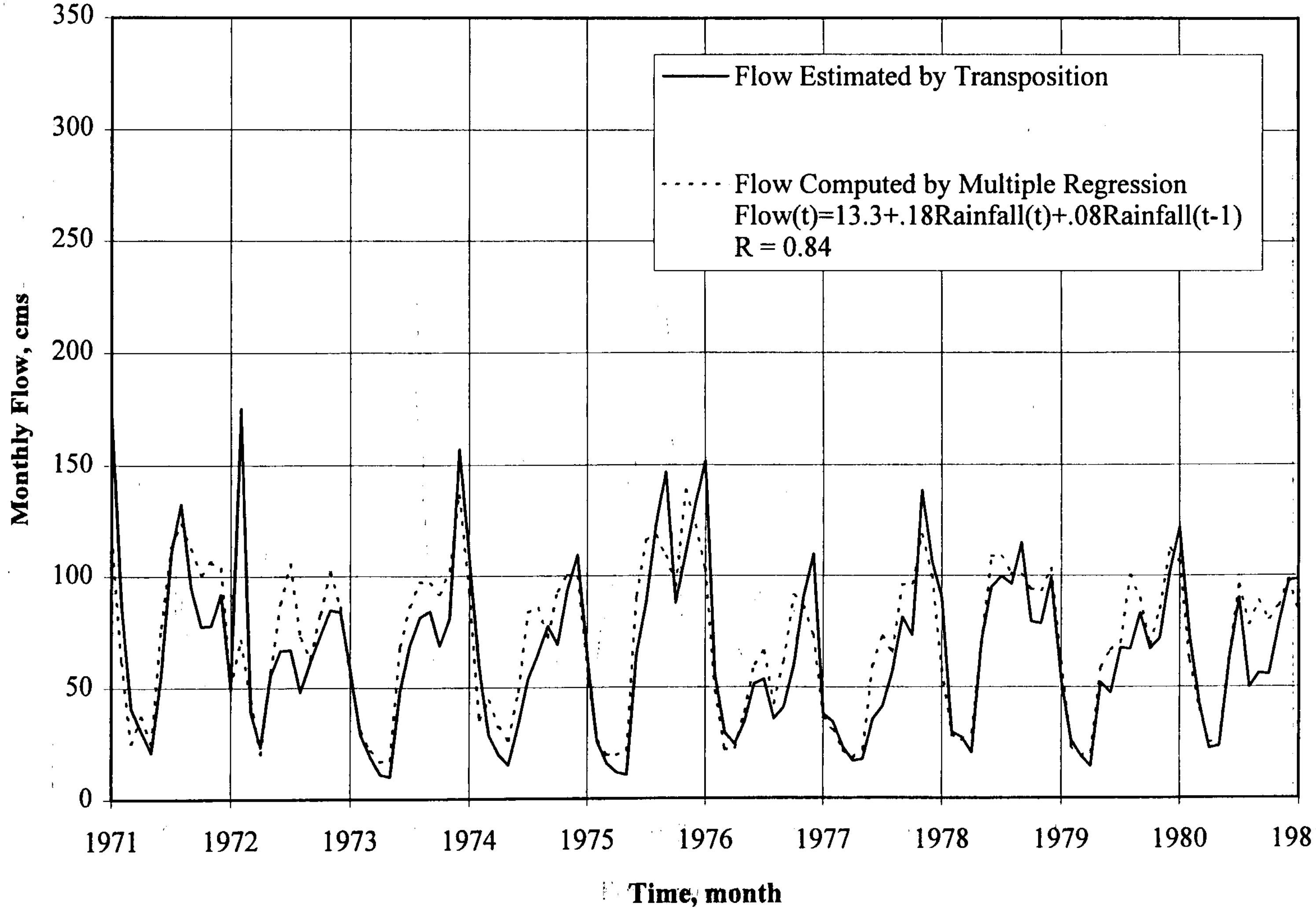


Exhibit 11.18
Sheet 4 of 6

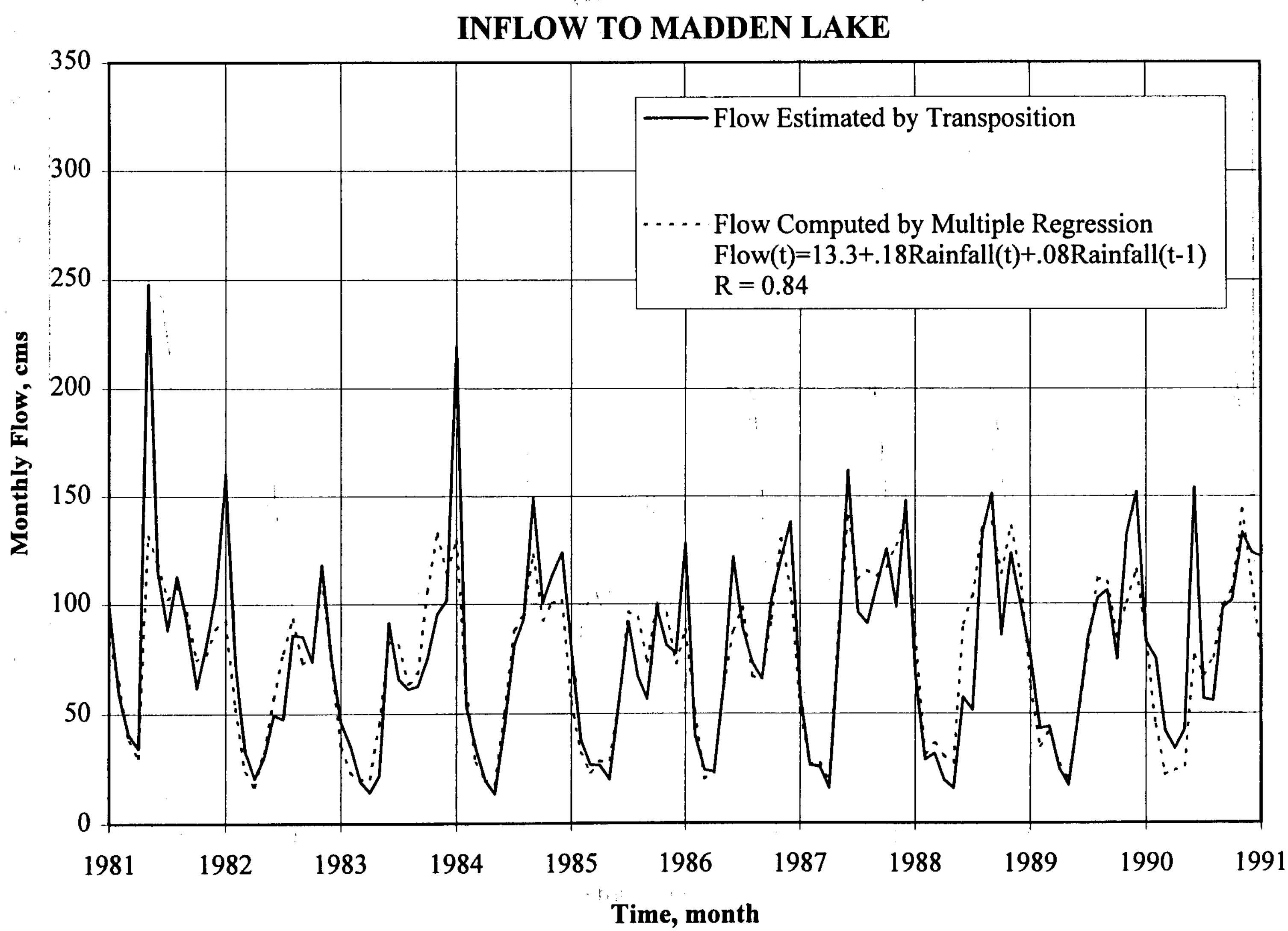


Exhibit 11.18
Sheet 5 of 6

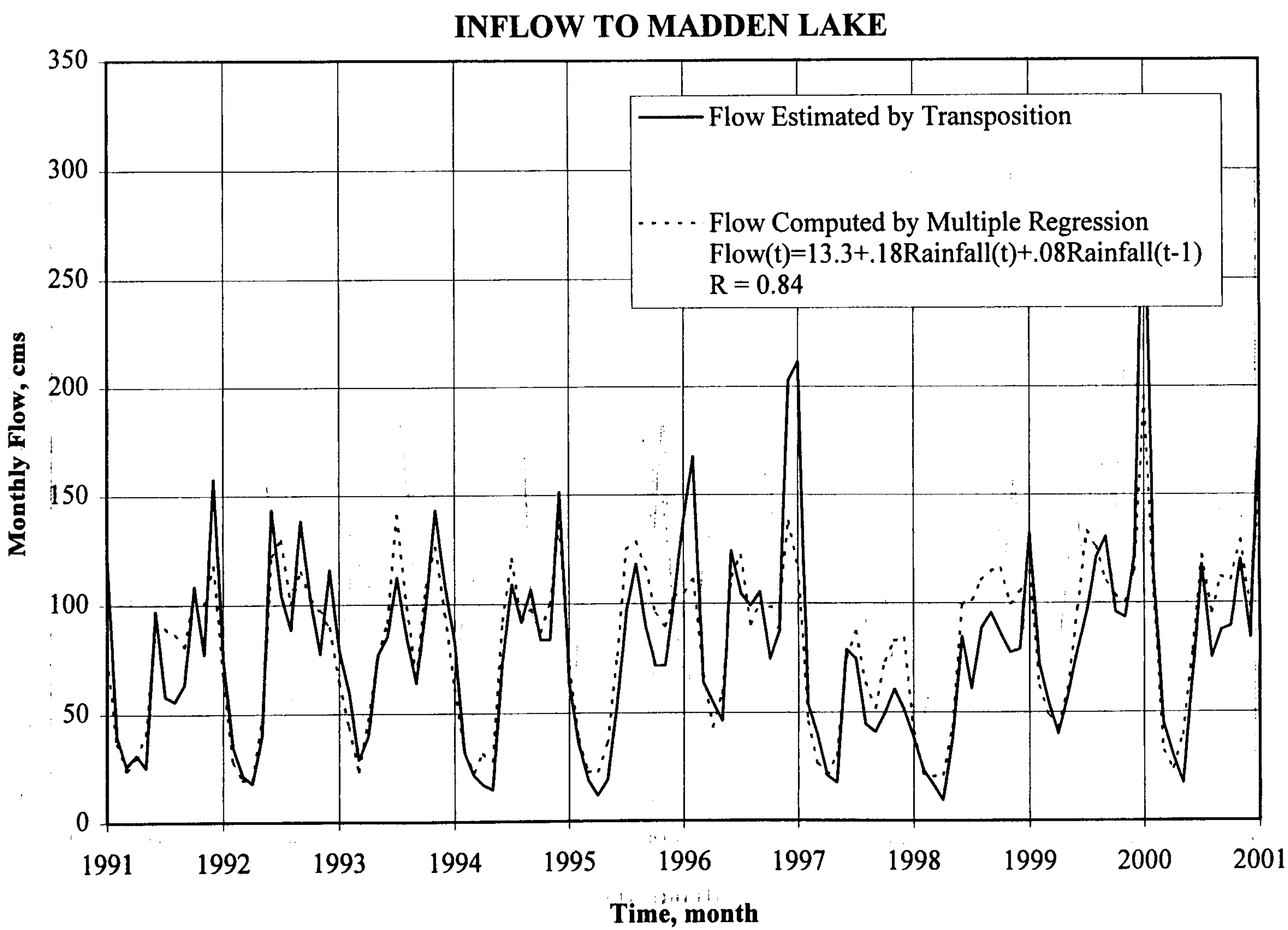


Exhibit 11.18
Sheet 6 of 6

INFLOW TO GATUN DOWNSTREAM

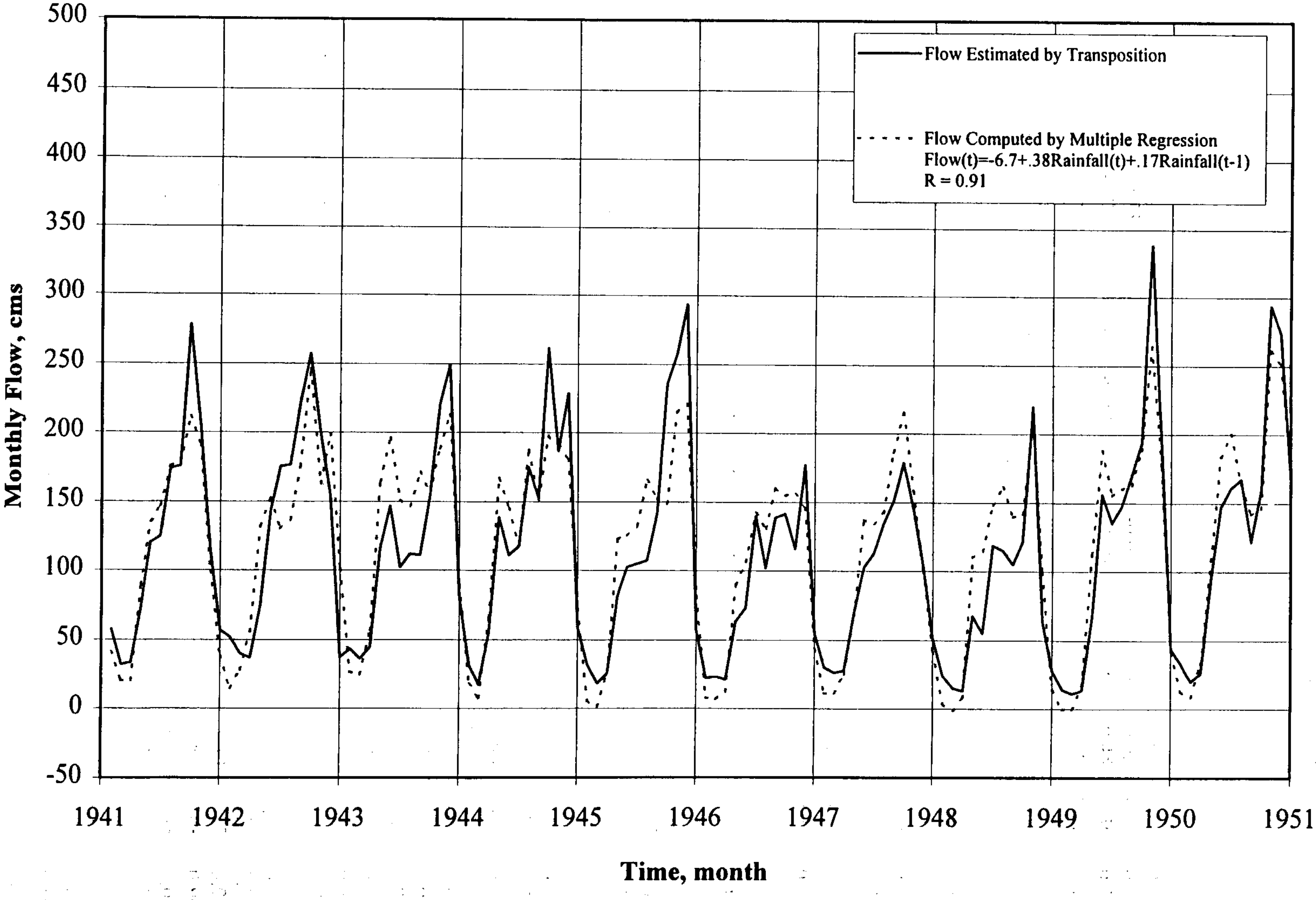


Exhibit 11.19
Sheet 1 of 6

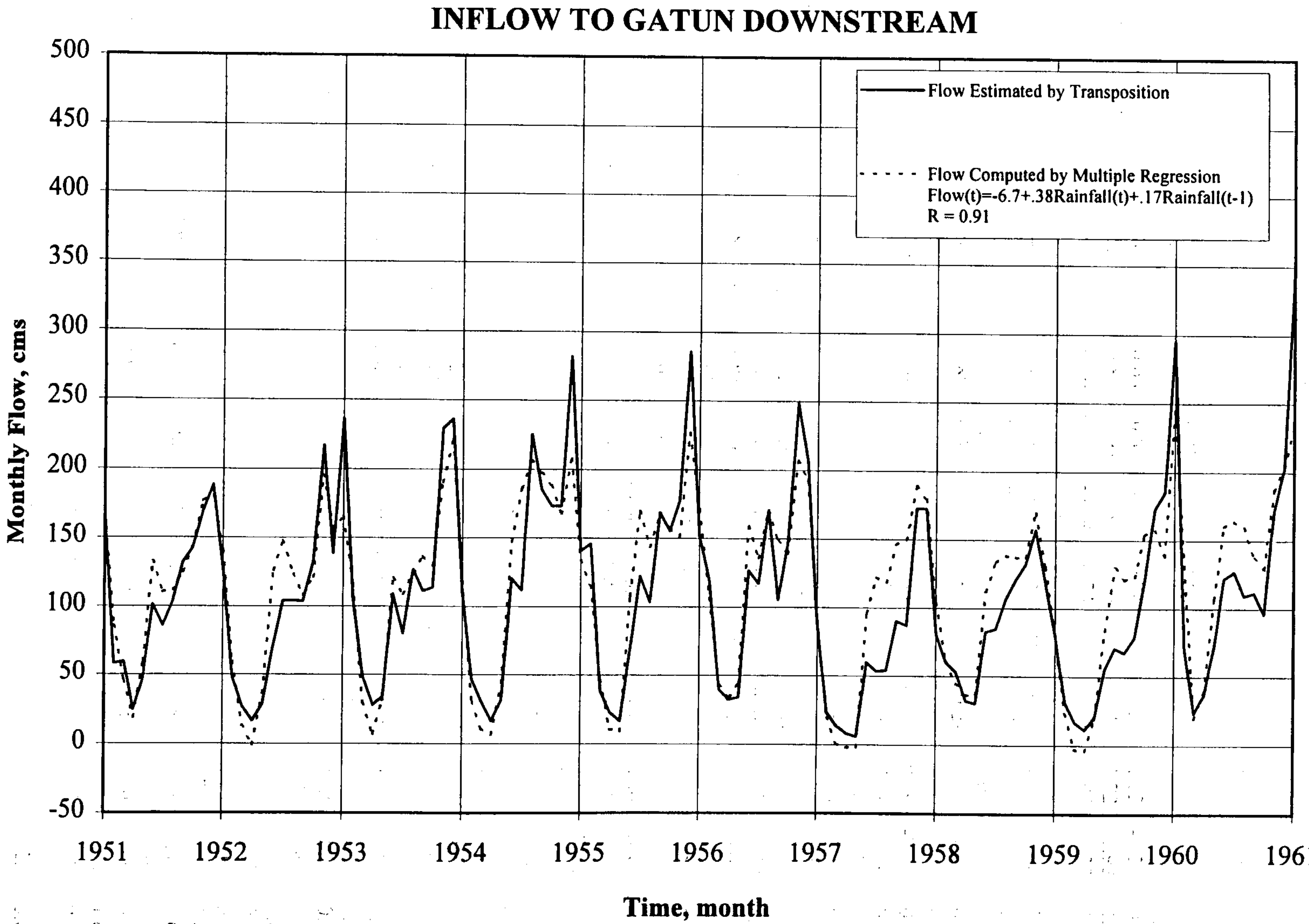


Exhibit 11.19
Sheet 2 of 6

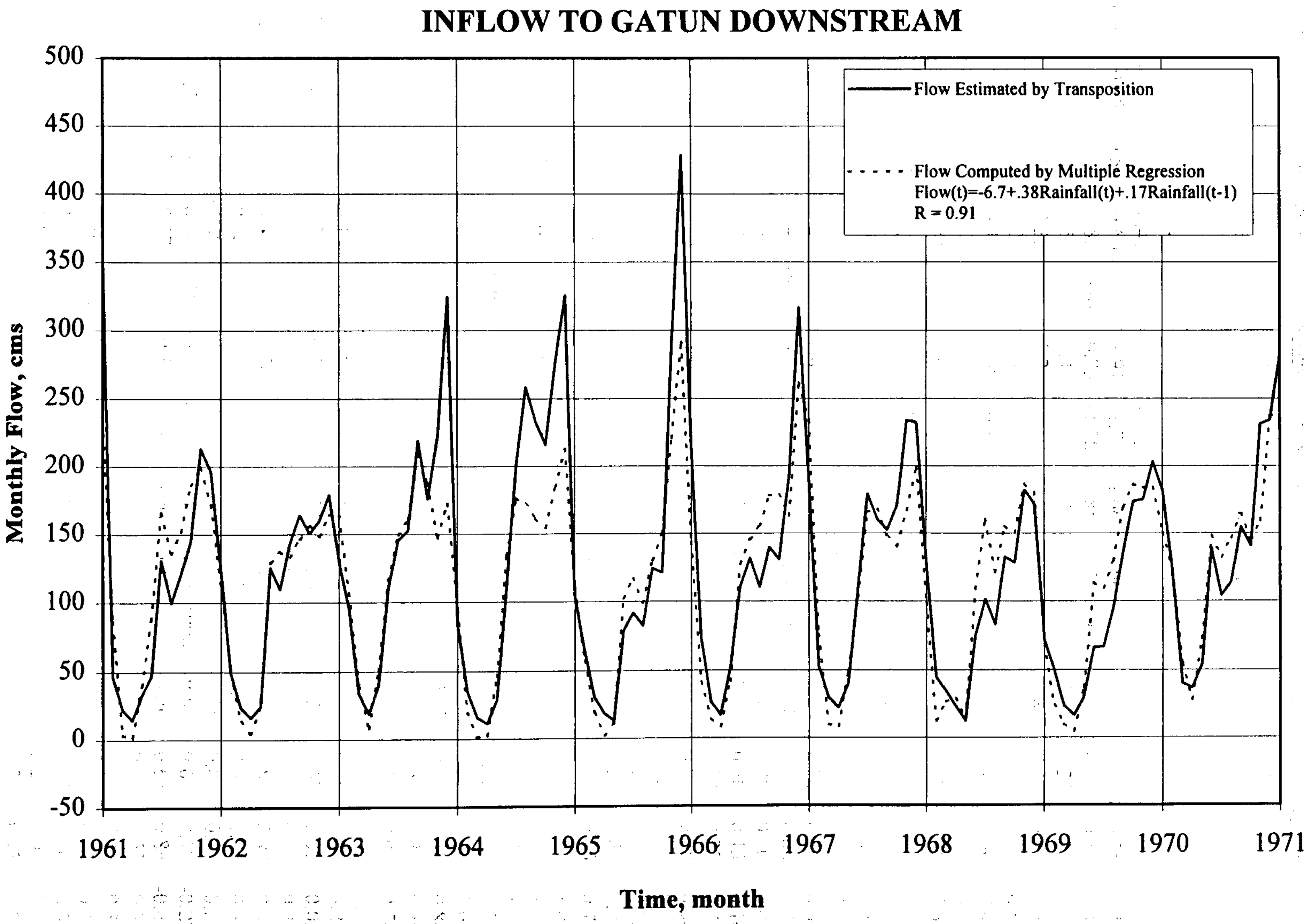


Exhibit 11.19
Sheet 3 of 6

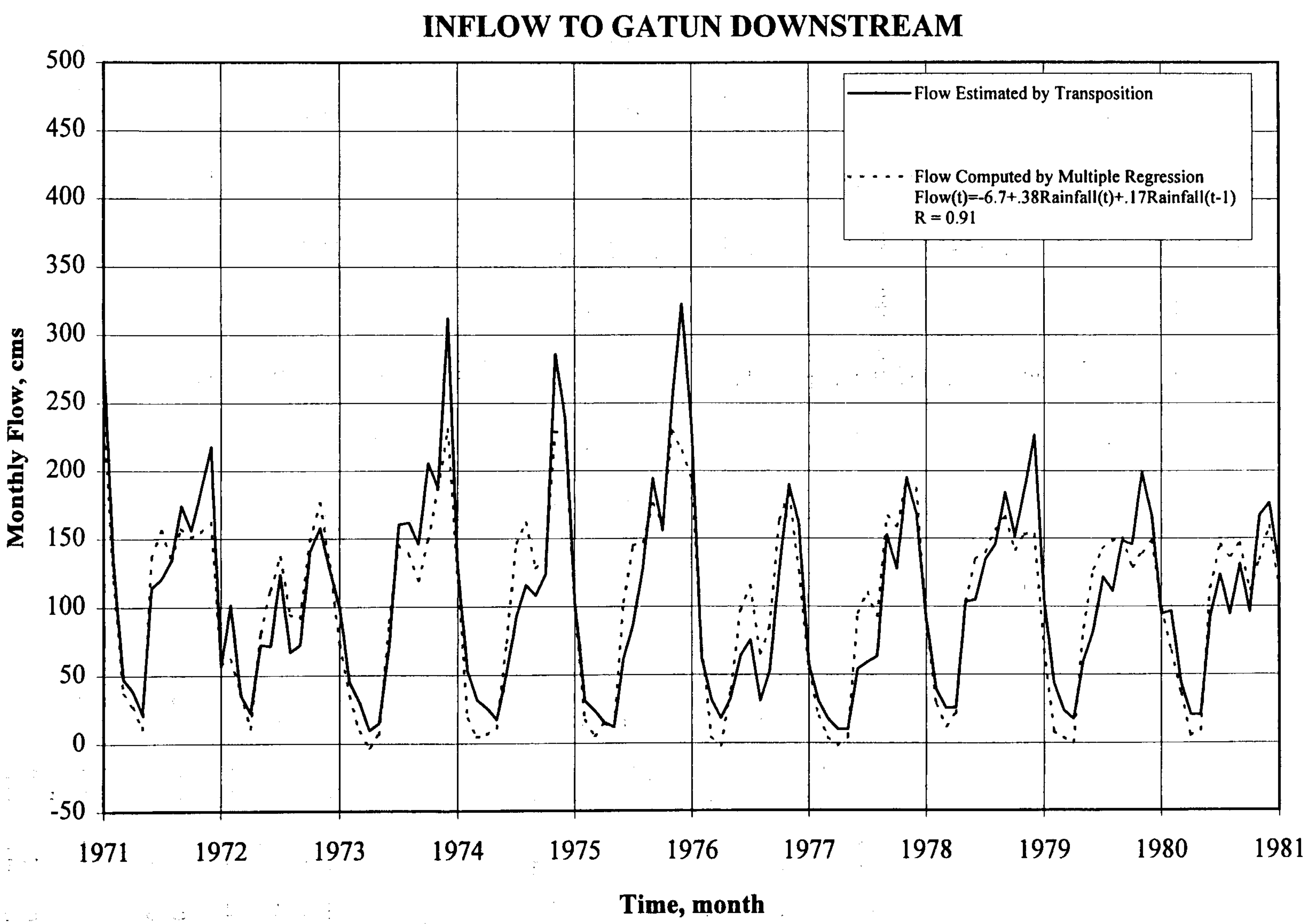


Exhibit 11.19
Sheet 4 of 6

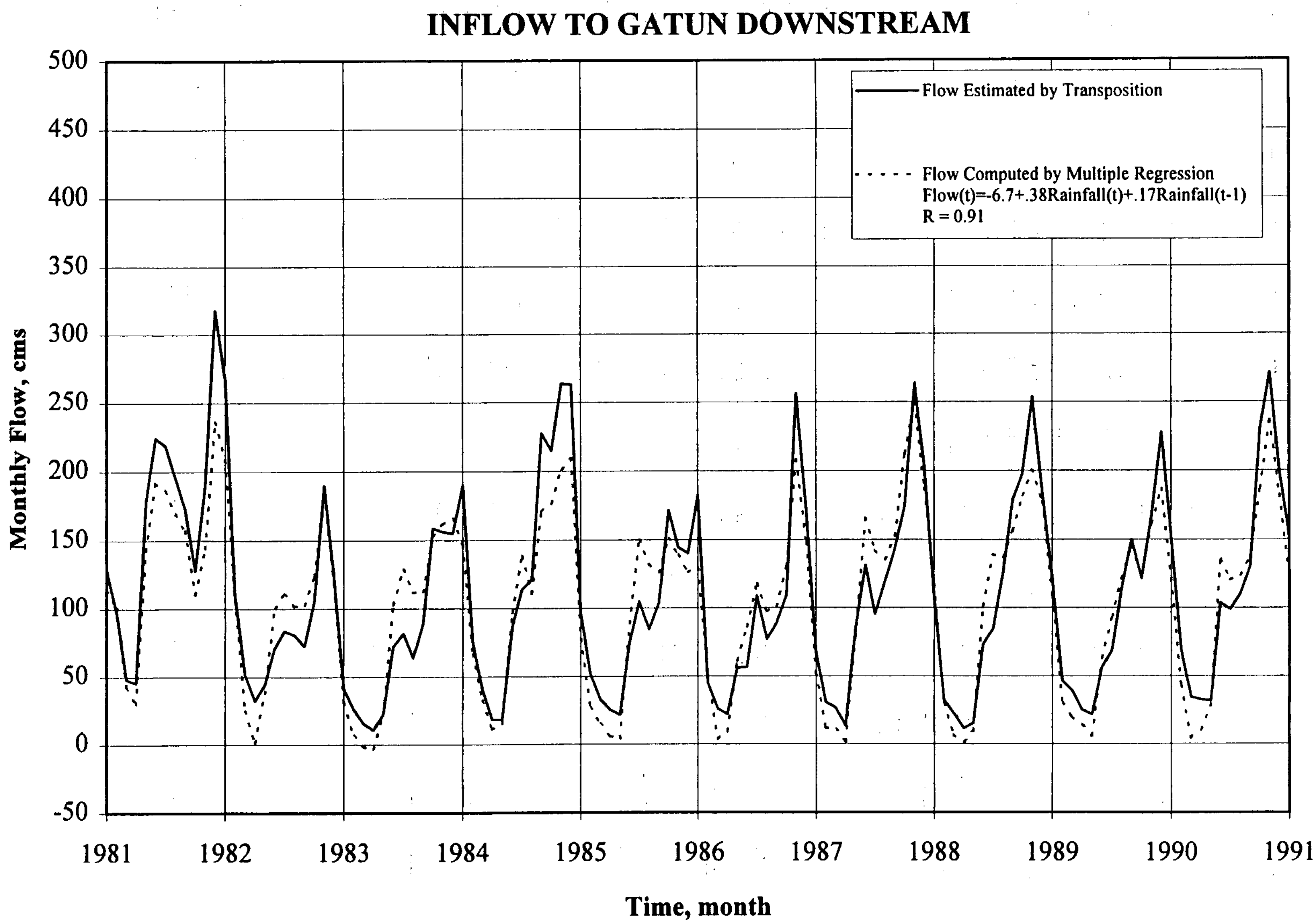


Exhibit 11.19
Sheet 5 of 6

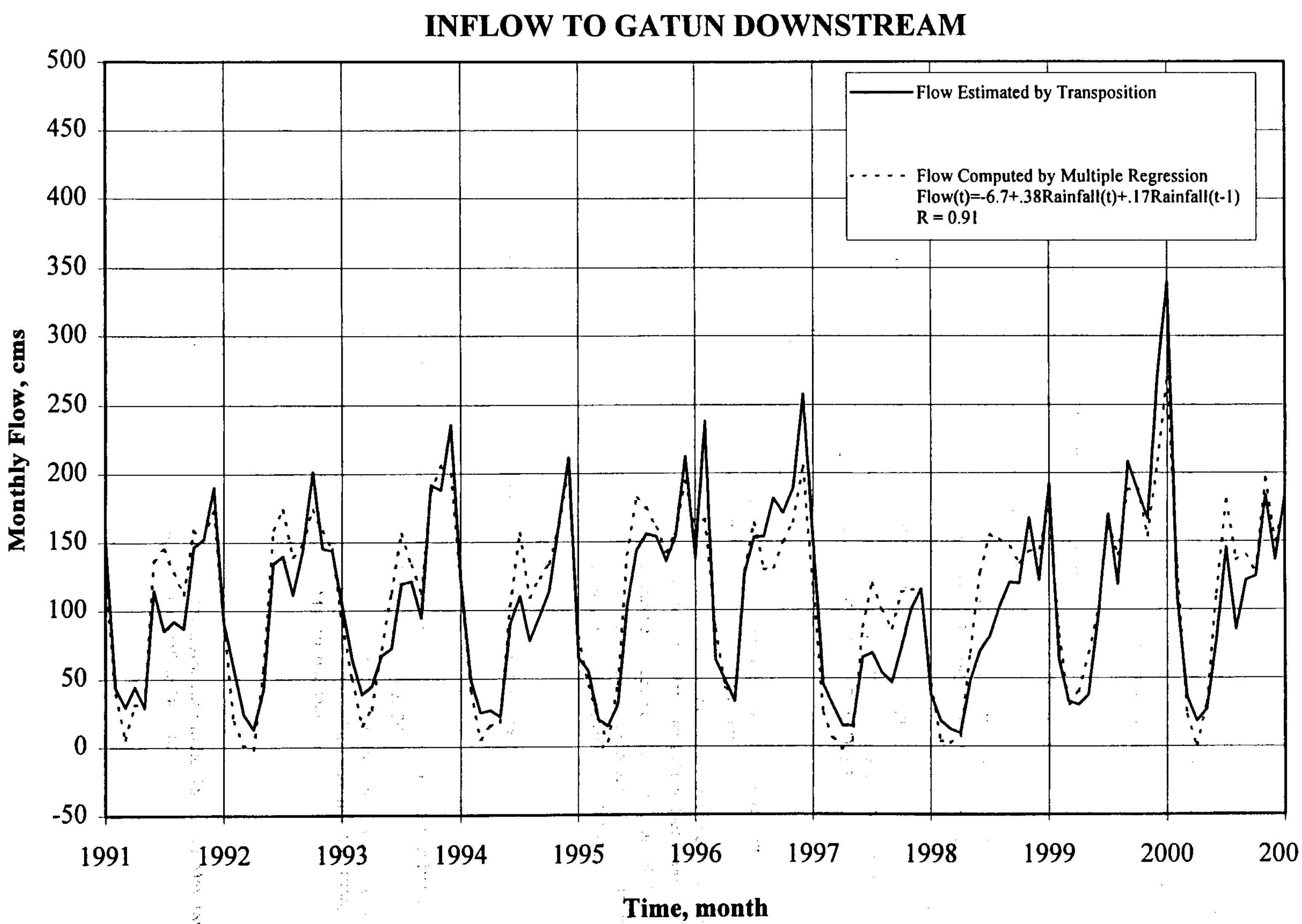


Exhibit 11.19
Sheet 6 of 6

12.0 Statistical Analyses of Time Series

12.0 STATISTICAL ANALYSES OF TIME SERIES

A time series is a sequence of values collected over time on a particular hydrologic variable (rainfall, flow or temperature). A value can be a quantity either observed at discrete times, averaged over a time interval or recoded continuously with time. A series is considered consistent (or stationary) if it remains in equilibrium about a constant mean value, that is, the statistical properties of the series do not change with absolute time. Jumps in a time series make it inconsistent or non-stationary (see Exhibit 12.1). Jumps are created by sudden changes that are either man-made (closure of a new dam, beginning or cessation of pumping of ground water, diversion for various uses, etc.) or they occur by various kinds of catastrophic natural events such as earthquakes or large forest fires. These are usually indicated by changes in mean, variance, skew coefficient and coefficient of variation.

Trends are linear or non-linear slow changes in the mean, variance, and serial correlation coefficients of a time series. These render a time series non-homogeneous (see Exhibit 12.2). These can result from gradual natural or man-induced changes in the hydrologic environment producing the time series. Changes in watershed conditions over a period of several years result in corresponding changes in streamflow characteristics that show up as trends in the series. Testing for trends also checks the homogeneity of the series.

Analyses of consistency and trend (homogeneity) were performed on the selected annual rainfall and runoff series. The results of each analysis are documented below. The following series were analyzed.

A: Runoff Series

Inflow to Madden Lake
Inflow to Gatun Lake excluding Madden Lake (Gatun downstream)
Inflow to Gatun Lake including Madden Lake (Gatun total)
Ciri Grande River
Trinidad River
Chagres River
Pequeni River
Boqueran River
Gatun River

B: Rainfall Series

Basin average rainfall – Madden Lake basin
Basin average rainfall – Gatun basin excluding Madden basin (Gatun downstream)

Basin average rainfall – Gatun basin including Madden basin (Gatun Total)
Agua Clara (ACL)
Alhajuela (ALA)
Balboa Heights (BHT)
Borro Colorado (BCI)
Chico (CHI)
Chorro (El Chorro), (CHR)
Gamboa (GAM)
Gatun (GAT)
Monte Lirio (MLR)
Pedro Miguel (PMG)
Salamaca (SAL)
San Miguel (SMG)

In addition to the above stations, trend analyses were also performed on the annual rainfall series for the remaining 15 rainfall stations.

12.1 Consistency

The selected annual rainfall and runoff series were checked at 95 percent confidence level. A stochastic package (Mclead and Hipal, 2001) was used to check the randomness of each series through autocorrelation technique and modified Pormanteau test. The results are summarized in Table 12.1 and Table 12.2, respectively.

In addition to the above tests, annual rainfall series were divided into two sub-series, 1911 to 1970 (60 years) and 1971 to 2000 (30 years). The statistical parameters (mean and standard deviation) of each sub-series were computed and tests were performed to show that the parameters are not (or are) significantly different among themselves. This is essentially a one-population hypothesis testing (Haan, 1979). Means of the sub-series were tested at 95 percent confidence level using a t-distribution. Standard deviations were tested at 95 percent confidence level using an F-distribution. For the runoff series, the 60-year period was divided into two sub-series of 30 years each. The one-population hypothesis was tested using the same procedure as used for the rainfall series. The results are presented on Exhibits 12.3 and 12.4 for rainfall and runoff series, respectively. Table 12.3 summarizes the results.

As per Table 12.3, some of the series passed either the tests for means or the tests for variance or both. The test for means is relatively more important for the detection of jump (inconsistency) in a series. The annual data after 1971 was critically reviewed. It was determined that the difference in the means of the two sub-sets was due to low rainfall during the El Nino episodes of 1972, 1976-77, 1982-83 and 1992. Therefore, in spite of failure of the null hypothesis, the series were assumed to be consistent.

To further support this decision, the rainfall series of Chorro, Chico, Monte Lirio, San Miguel and Salamanca that failed the tests of means, were plotted against the average of the rainfall at Alhajuela, Borro Colorado, Gamboa, Gatun and Pedro Miguel as double mass curves. The selected base stations had complete records for the 90-year period and were consistent. The curves are shown on Exhibits 12.5 to 12.9. These exhibits do not show any significant changes in slopes as to consider these series inconsistent.

Table 12.1

ANNUAL RAINFALL SERIES – TESTS FOR RANDOMNESS AND TREND

Station Name	Series is Random	Series is Random	Trend is Significant	Trend is Significant
	Auto Correlation Lag 1 and 2	Modified Pormanteau Test	Mann-Kendall & Abelson-Tukey Test	Linear Correlation
Agua Clara	Yes	Yes	Yes	Yes
Alhajuela	Yes	Yes	No	No
Balboa Heights	Yes	Yes	No	Yes
Borro Colorado	Yes	Yes	No	No
Chico	Yes	Yes	No	No
Chorro	Yes	Yes	No	No
Gamboa	Yes	Yes	No	No
Gatun	Yes	Yes	No	No
Monte Lirio	Yes	Yes	No	Yes
Pedro Miguel	Yes	Yes	No	No
Salamanca	Yes	Yes	No	Yes
San Miguel	No	No	Yes	Yes
Madden Upstream	Yes	Yes	No	No
Gatun Downstream	Yes	Yes	No	Yes
Gatun Total	Yes	Yes	No	No

Note: For procedures on autocorrelation, Modified Portmanteau statistics, Mann-Kendall statistics and Abelson Tukey statistics, refer to "MHTS Package Reference Manual, Version 1.5," by A.I. Mcleod and K.W. Hipel, 2001.

A few series were also checked using Smirnov-Kolomogoro (S-K) test (Haan, 1979) to show whether the two sub-series were from the same population or not. The results were the same as for the means and variances tests. Therefore, the S-K method was not used for other series.

12.2 Homogeneity (Trends)

Homogeneity of the annual rainfall and inflow series was checked through trend analysis. Two methods were used, Mann-Kendall and Abelson-Tukey tests, and correlation coefficient of linear trends line. The results of the correlation analysis are given on Exhibits 12.10 and 12.11 for rainfall and inflow series, respectively. The summaries are given in Tables 12.1 and 12.2.

12.3 Evaluation of Characteristics of Time Series

Before defining the characteristics of the time series analyzed for this study, it was considered desirable to discuss the result of a study made by Donald M. Windsor (Windsor, 1990) using the annual rainfall series and other climatic data observed at Borro Colorado Island. The conclusions of this study are given below.

"Annual rainfall on Borro Colorado Island averages 2,612 mm (1925-89), 90 percent of which falls in the months of May through November. Rainfall on Borro Colorado Island and seven other sites in the middle of the Isthmus has decreased significantly over time. The only long-term rainfall records without decreasing trend come from coastal sites, suggesting that convective, but not orographic, rainfall has diminished during the last sixty years. Further, annual rainfall appears to be influenced by factors associated with El Nino events. Higher than normal rainfall tends to occur the year before El Nino events and lower than normal rainfall tends to occur the year of such events. Dry-season forest and clearing temperatures on Borro Colorado Island were elevated during each of the three El Nino events occurring in the past 16 years."

The Windsor's statement shows that the rainfall has significantly decreased in the canal watershed. This study could not confirm this statement. The finding of this study is that there are decreasing trends in almost all rainfall and inflow series but these trends are insignificant.

Table 12.2

ANNUAL RUNOFF SERIES – TESTS FOR RANDOMNESS AND TREND

Station Name	Series is Random	Series is Random	Trend is Significant	Trend is Significant
	Auto Correlation Lag 1 and 2	Modified Pormanteau Test	Mann-Kendall & Abelson-Tukey Test	Linear Correlation
Gatun River at Ciento	No	No	No	No
Boqueron River at Peluca	Yes	Yes	No	No
Pequeni River at Candelaria	Yes	Yes	No	No
Charges River at Chico	Yes	Yes	No	No
Trinidad River at Chorro	Yes	Yes	No	No
Ciri Grande River at Canones	Yes	Yes	No	No
Madden Upstream	Yes	Yes	No	No
Gatun Downstream	Yes	Yes	No	Yes
Gatun Total	Yes	Yes	No	No

Note: For procedures on autocorrelation, Modified Portmanteau statistics, Mann-Kendall statistics and Abelson Tukey statistics, refer to "MHTS Package Reference Manual, Version 1.5," by A.I. McLeod and K.W. Hipel, 2001.

12.3.1 Rainfall Series

Mass curves and time series plots prepared for all stations are given in Appendix D. The plots of basin average annual and 5-year moving average rainfall series, trend lines and mass curves were also prepared for the drainage basins of Madden Lake, Gatun Downstream and Gatun Total. Exhibits 10.4, 10.5, 10.7, 10.8, 10.10 and 10.11 show these plots. Table 12.4 shows the general characteristics of annual rainfall series based on the plots. Fifteen rainfall series (as per scope of the study) are discussed below:

Agua Clara (ACL)

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual rainfall series was random. The mass curve shows slight changes in slope at a few points. The 5-year moving average series indicates cyclic high and low flow periods, which are not significant. The series show low annual rainfall during the El Nino episodes.

A linear trend line fitted to the series shows an increasing trend, about 6 mm per year. The trend was tested to be significant at 95 percent confidence level. The trend in the series was also tested to be significant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in early 1970's due to changes in the rainfall sensors. For this purpose, the series was divided into two sub-series of 60 years (1911 to 1970) and 30 years (1971 to 2000). It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. An F-distribution was used to test standard deviations. The means were tested using a t-distribution. The tests indicated that there was no significant difference between the means and standard deviations that would indicate that the two sets were from different populations. Therefore, the series was considered to be consistent and non-homogeneous.

Alhajuela (ALA)

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual rainfall series was random. The mass curve shows slight changes in slope at a few points. The 5-year moving average series indicates cyclic high and low flow periods, which are not significant. The series shows low annual rainfall during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 1.0 mm per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in early 1970's due to changes in the rainfall sensors. For this purpose, the series was divided into two sub-series of 60 years (1911 to 1970) and 30 years (1971 to 2000). It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-

Table 12.3

TESTS FOR CONSISTENCY USING ONE-POPULATION HYPOTHESIS

Rainfall Station	**Series is from same Population based on**		
	Mean	Variance	Result
Agua Clara	Yes	Yes	Yes
Alhajuela	Yes	Yes	Yes
Balboa Heights	Yes	Yes	Yes
Borro Colorado	Yes	No	Yes
Chico	No	Yes	Yes
Chorro	No	Yes	Yes
Gamboa	Yes	No	Yes
Gatun	No	Yes	Yes
Monte Lirio	No	Yes	Yes
Pedro Miguel	Yes	No	Yes
Salamanca	No	Yes	Yes
San Miguel	No	Yes	Yes
Madden Lake	Yes	Yes	Yes
Gatun Downstream	No	Yes	Yes
Gatun Total	Yes	Yes	Yes
Runoff Stations			
Gatun – Ciento	Yes	No	Yes
Boqueron – Peluca	Yes	Yes	Yes
Pequeni-Candelaria	Yes	Yes	Yes
Chagres – Chico	Yes	Yes	Yes
Trinidad – Chorro	Yes	Yes	Yes
Ciri Grande-Canones	Yes	Yes	Yes
Madden Lake	Yes	Yes	Yes
Gatun Downstream	Yes	Yes	Yes
Gatun Total	Yes	Yes	Yes

Table 12.4

CHARACTERISTICS OF RAINFALL SERIES

Station	Characteristics
Agua Clara (ACL)	trend significant, increase 6mm/yr, consistent, non-homogeneous
Alhajuela (ALA)	trend insignificant, decrease 1mm/yr, consistent, homogeneous
Balboa Heights (BHT)	trend significant, increase 2mm/yr, consistent, non-homogeneous
Borro Colorado (BCI)	trend insignificant, decrease 2mm/yr, consistent, homogeneous
Candelaria (CDL)	trend insignificant, decrease 2mm/yr, consistent, homogeneous
Cano (CNO)	trend significant, decrease 4mm/yr, consistent, non-homogeneous
Chico (CHI)	trend insignificant, decrease 2mm/yr, consistent, homogeneous
Ciento (CNT)	trend insignificant, decrease 1mm/yr, consistent, homogeneous
Chorro (CHR)	trend insignificant, decrease 3mm/yr, consistent, homogeneous
Cascadas (CAS)	trend insignificant, decrease 2mm/yr, consistent, homogeneous
Canones (CAN)	trend significant, decrease 6mm/yr, consistent, non-homogeneous
Empire Hills (EMH)	trend insignificant, decrease 0 mm/yr, consistent, homogeneous
Escandalosa (ESC)	trend insignificant, increase 0mm/yr, consistent, homogeneous
Gamboa (GAM)	trend insignificant, increase 1mm/yr, consistent, homogeneous
Gatun (GAT)	trend insignificant, decrease 3mm/yr, consistent, homogeneous
Guacha (GUA)	trend significant, decrease 3mm/yr, consistent, non-homogeneous
Hodges Hill (HHI)	trend insignificant, decrease 2mm/yr, consistent, homogeneous
Humedad (HUM)	trend significant, decrease 4mm/yr, consistent, non-homogeneous
Limon Bay (LMB)	trend insignificant, decrease 4mm/yr, consistent, homogeneous
Monte Lirio (MLR)	trend significant, decrease 4mm/yr, consistent, non-homogeneous
Peluca (PEL)	trend insignificant, decrease 3mm/yr, consistent, homogeneous
Pedro Miguel (PMG)	trend insignificant, increase 1mm/yr, consistent, homogeneous
Racies (RAI)	trend significant, decrease 4mm/yr, consistent, non-homogeneous
Rio Piedras (RPD)	trend significant, increase 6mm/yr, consistent, non-homogeneous
Salamanca (SAL)	trend insignificant, increase 5mm/yr, consistent, homogeneous
San Miguel (SMG)	trend significant, increase 7mm/yr, consistent, non-homogeneous
Santa Rosa (SRO)	trend insignificant, increase 2mm/yr, consistent, homogeneous
Madden Lake	trend insignificant, increase 1mm/yr, consistent, homogeneous
Gatun Downstream	trend insignificant, decrease 3mm/yr, consistent, homogeneous
Gatun Total	trend insignificant, decrease 2mm/yr, consistent, homogeneous

Note: A series was judged to be consistent if no jump and from same population. A series was judged to be homogeneous if the trend was insignificant.

distribution. The tests indicated that there was no significant difference between the means and standard deviations that would indicate that the two sets were from different populations. Therefore, the series was considered to be consistent and homogeneous.

Balboa Heights (BHI)

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual rainfall series was random. The mass curve shows slight changes in slope at a few points. The 5-year moving average series indicates cyclic high and low flow periods, which are not significant. The series shows low annual rainfall during the El Nino episodes.

A linear trend line fitted to the series shows an increasing trend, about 2 mm per year. The trend was tested to be significant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson-Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in the early 1970's due to changes in the rainfall sensors. For this purpose, the series was divided into two sub-series of 60 years (1911 to 1970) and 30 years (1971 to 2000). It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. An F-distribution was used to test standard deviations. The means were tested using a t-distribution. The tests indicated that there was no significant difference between the means and standard deviations that would indicate that the two sets were from different populations. Therefore, the series was considered to be consistent and non-homogeneous.

Borro Colorado (BCI)

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual rainfall series was random. The mass curve shows slight changes in slope at a few points. The 5-year moving average series indicates cyclic high and low flow periods, which are not significant. The series shows low annual rainfall during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 2 mm per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in the early 1970's due to changes in the rainfall sensors. For this purpose, the series was divided into two sub-series of 60 years (1911 to 1970) and 30 years (1971 to 2000). It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was no significant difference between the means that would prove that the two sets were from different populations. The standard deviations of the two sub-sets indicated a significant difference. However, very low annual flows occurred due to three El Nino episodes in the second sub-set which caused the difference in the standard deviations. Therefore, the series was considered to be consistent and homogeneous.

Chico (CHI)

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual rainfall series was random. The mass curve shows slight changes in slope at a few points. The 5-year moving average series indicates cyclic high and low flow periods, which are not significant. The series shows low annual rainfall during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 2 mm per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in the early 1970's due to changes in the rainfall sensors. For this purpose, the series was divided into two sub-series of 60 years (1911 to 1970) and 30 years (1971 to 2000). It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. An F-distribution was used to test standard deviations. The means were tested using a t-distribution. The tests indicated that there was a significant difference between the means and the two sets were from different populations. However, very low annual flows occurred due to three El Nino episodes in the second sub-set that caused difference in the means. The standard deviations did not show a significant difference. Therefore, the series was considered to be consistent and homogeneous.

Chorro (CHR)

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual rainfall series was random. The mass curve shows slight changes in slope at a few points. The 5-year moving average series indicates cyclic high and low flow periods, which are not significant. The series shows low annual rainfall during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 3 mm per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in early 1970's due to changes in the rainfall sensors. For this purpose, the series was divided into two sub-series of 60 years (1911 to 1970) and 30 years (1971 to 2000). It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was a significant difference between the means but no significant difference between standard deviations that would indicate that the two sets were from different populations. The difference between the means was caused by very low annual flows during the 1976-77, 1982 and 1997 El Nino episodes. Therefore, the series was judged to be consistent and homogeneous.

Gamboa (GAM)

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual rainfall series was random. The mass curve shows slight changes in slope at a few points. The 5-year moving average series indicates cyclic high and low flow periods, which are not significant. The series shows low annual rainfall during the El Nino episodes.

A linear trend line fitted to the series shows an increasing trend, about 1.0 mm per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in the early 1970's due to changes in the rainfall sensors. For this purpose, the series was divided into two sub-series of 60 years (1911 to 1970) and 30 years (1971 to 2000). It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was no significant difference between the means but there was a significant difference in the standard deviations. The difference in the standard deviations was caused by very low flows during El Nino in the second sub-set. The series was considered to be consistent and homogeneous.

Gatun (GAT)

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual rainfall series was random. The mass curve shows slight changes in slope at a few points. The 5-year moving average series indicates cyclic high and low flow periods, which are not significant. The series shows low annual rainfall during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 3 mm per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in the early 1970's due to changes in the rainfall sensors. For this purpose, the series was divided into two sub-series of 60 years (1911 to 1970) and 30 years (1971 to 2000). It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was significant difference between the means but no significant difference in the standard deviations. The difference in the means was due to very low annual flows during the 1976-77, 1982 and 1997 El Nino episodes. The series was considered to be consistent and homogeneous.

Monte Lirio (MLR)

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual rainfall series was random. The mass curve shows slight changes in slope at a few points. The 5-year moving average series indicates cyclic high and low flow periods, which are not significant. The series shows low annual rainfall during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 4 mm per year. The trend was tested to be significant at 95 percent confidence level. The trend in the series was tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in early 1970's due to changes in the rainfall sensors. For this purpose, the series was divided into two sub-series of 60 years (1911 to 1970) and 30 years (1971 to 2000). It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was significant difference between the means but no significant difference between the standard deviations. The difference in the means could be due to very low flows during the El Nino episodes of 1976-77, 1982 and 1997. The series was considered to be consistent and non-homogeneous.

Pedro Miguel (PMG)

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual rainfall series was random. The mass curve shows slight changes in slope at a few points. The 5-year moving average series indicates cyclic high and low flow periods, which are not significant. The series shows low annual rainfall during the El Nino episodes.

A linear trend line fitted to the series shows an increasing trend, about 1.0 mm per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in the early 1970's due to changes in the rainfall sensors. For this purpose, the series was divided into two sub-series of 60 years (1911 to 1970) and 30 years (1971 to 2000). It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was no significant difference between the means but significant difference between the standard deviations. The difference in the standard deviation was due to low annual flows during El Nino episodes in the 1971-2000 subset. The series was considered to be consistent and homogeneous.

Salamanca (SAL)

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual rainfall series was random. The mass curve shows slight changes in slope at a few points. The 5-year moving average series indicates cyclic high and low flow periods, which are not significant. The series shows low annual rainfall during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 5 mm per year. The trend was tested to be significant at 95 percent confidence level using correlation coefficient. The trend in the series was tested to be insignificant at 95 percent confidence level when using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in the early 1970's due to changes in the rainfall sensors. For this purpose, the series was divided into two sub-series of 60 years (1911 to 1970) and 30 years (1971 to 2000). It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was a significant difference between the means and but no significant difference in the standard deviations. The low annual flows of 1976-77, 1982 and 1997 caused this difference. The series was judged to be consistent and homogeneous.

San Miguel (SMG)

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual rainfall series was not random. The mass curve shows a significant change in slope around 1943. The 5-year moving average series indicates cyclic high and low flow periods, with significantly low annual flows during 1943 to about 1951. This abrupt decrease in flow and then continuous rise, was not observed in the data from the other stations. The station is located at a higher altitude and the exposure of the station may not have been good during that period. The series shows low annual rainfall during the El Nino episodes.

A linear trend line fitted to the series shows an increasing trend, about 7 mm per year. The trend was tested to be significant at 95 percent confidence level. The trend in the series was also tested to be significant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in the early 1970's due to changes in the rainfall sensors. For this purpose, the series was divided into two sub-series of 60 years (1911 to 1970) and 30 years (1971 to 2000). It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was a significant difference between the means but no significant difference in the standard deviations. The series was considered to be consistent and non-homogeneous.

Madden Lake (Basin Average)

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual rainfall series was random. The mass curve shows slight changes in slope at a few points. The 5-year moving average series indicates cyclic high and low flow periods, which are not significant. The series shows low annual rainfall during the El Nino episodes.

A linear trend line fitted to the series shows an increasing trend, about 1.0 mm per year. The trend was tested to be insignificant at 95 percent confidence level. The rend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in the early 1970's due to changes in the rainfall sensors. For this purpose, the series was divided into two sub-series of 60 years (1911 to 1970) and 30 years (1971 to 2000). It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was no significant difference between the means and standard deviations. The series was judged to be consistent and non-homogeneous.

Gatun Downstream (Basin Average)

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual rainfall series was random. The mass curve shows slight changes in slope at a few points. The 5-year moving average series indicates cyclic high and low flow periods, which are not significant. The series shows low annual rainfall during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 3 mm per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in early 1970's due to changes in the rainfall sensors. For this purpose, the series was divided into two sub-series of 60 years (1911 to 1970) and 30 years (1971 to 2000). It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was a significant difference between the means but no significant difference between standard deviations. The mean annual rainfall during the second sub-set is low due to three most severe El Nino episodes of 1976-77, 1982 and 1997. There was not other reason for low flows during the period. However, the series was judged to be consistent and homogeneous.

Gatun Total (Basin Average)

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual rainfall series was random. The mass curve shows slight changes in slope at a few points. The 5-year moving average series indicates cyclic high and low flow periods, which are not significant. The series shows low annual rainfall during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 2 mm per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in the early 1970's due to changes in the rainfall sensors. For this purpose, the series was divided into two sub-series of 60 years (1911 to 1970) and 30 years (1971 to 2000). It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was no significant difference between the means and standard deviations. The series was judged to be consistent and homogeneous.

12.3.2 Runoff Series

The results of the statistical tests performed for six flows series at the gauging stations and three inflow series to Madden Lake and Gatun Lake, are given in Table 12.5. The time series and mass curves for the stations are given in Appendix D. The plots of time series and mass curves for Madden Lake, Gatun Downstream and Gatun Total are given on Exhibits 11.3, 11.4, 11.7, 11.8, 11.10 and 11.11. The inflow series are discussed below.

Gatun River at Ciento

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual flow series was not random. The mass curve shows a significant change in slope from about 1962 to 1965 when the flow was nearly twice the mean annual flow. The 5-year moving average series indicates a big hump for this period. No reason could be assigned to this from the available data and information. This condition was not noticed on other stations. This could be due to discharge or river stage measuring errors. The series shows low annual runoff during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 5 liter /second per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in early 1970's. For this purpose, the series was divided into two sub-series of 30 years each, 1941 to 1970 and 1971 to 2000. It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was no significant difference between the means but a significant difference in the standard deviations. However, the series was judged to be consistent and homogeneous.

Table 12.5

CHARACTERISTICS OF INFLOW SERIES

Station	Characteristics
Gatun R at Ciento	trend insignificant, decrease 5 liter/s per yr, consistent, homogeneous
Boqueron R at Peluca	trend insignificant, decrease 5 liter/s per yr, consistent, homogeneous
Pequeni R at Candelaria	trend insignificant, decrease 13 liter/s per yr, consistent, homogeneous
Chagres R at Chico	trend insignificant, increase 24 liter/s per yr, consistent, homogeneous
Trinidad R at Chorro	trend insignificant, decrease 18 liter/s per yr, consistent, homogeneous
Ciri Grande R at Canones	trend insignificant, decrease 26 liter/s per yr, consistent, homogeneous
Madden Lake	trend insignificant, decrease 1 liter/s per yr, consistent, homogeneous
Gatun Downstream	trend insignificant, decrease 152 liter/s per yr, consistent, homogeneous
Gatun Total	trend insignificant, decrease 153 liter/s per yr, consistent, homogeneous

Note: A series was judged to be consistent if no jump and from same population. A series was judged to be homogeneous if the trend was insignificant.

Boqueron River at Peluca

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual flow series was random. The mass curve does not show any significant change in slope. The series shows low annual runoff during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 5 liter /second per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in early 1970's. For this purpose, the series was divided into two sub-series of 30 years each, 1941 to 1970 and 1971 to 2000. It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was no significant difference between the means and standard deviations that would indicate that the two sets were from different populations. The series was judged to be consistent and homogeneous.

Pequeni River at Candelaria

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual flow series was random. The mass curve shows no significant change in slope. The 5-year moving average series show some cyclic effect. The series shows low annual runoff during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 13 liter /second per year. The trend was tested to be insignificant at 95 percent confidence level. The rend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in early 1970's. For this purpose, the series was divided into two sub-series of 30 years each, 1941 to 1970 and 1971 to 2000. It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was no significant difference between the means and standard deviations that would indicate that the two sets were from different populations. The series was judged to be consistent and homogeneous.

Chagres River At Chico

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual flow series was random. The mass curve shows no significant change in slope. The 5-year moving average series indicates an insignificant cyclic trend. The series shows low annual runoff during the El Nino episodes.

A linear trend line fitted to the series shows an increasing trend, about 24 liter /second per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in early 1970's. For this purpose, the series was divided into two sub-series of 30 years each, 1941 to 1970 and 1971 to 2000. It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was no significant difference between the means and standard deviations that would indicate that the two sets were from different populations. The series was judged to be consistent and homogeneous.

Trinidad River at Chorro

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual flow series was random. The mass curve shows no significant change in slope. The 5-year moving average series indicates a cyclic behavior. The series shows low annual runoff during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 18 liter /second per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in early 1970's. For this purpose, the series was divided into two sub-series of 30 years each, 1941 to 1970 and 1971 to 2000. It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was no significant difference between the means and standard deviations that would indicate that the two sets were from different populations. The series was judged to be consistent and homogeneous.

Ciri Grande at Canones

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual runoff series was random. The mass curve shows insignificant changes in slope. The 5-year moving average series indicates a cyclic behavior. The series shows low annual runoff during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 26 liter /second per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in the early 1970's. For this purpose, the series was divided into two sub-series of 30 years each, 1941 to 1970 and 1971 to 2000. It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was no significant difference between the means and standard deviations that would indicate that the two sets were from different populations. The series was judged to be consistent and homogeneous.

Madden Lake

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual inflow series was random. The mass curve shows no significant change in slope. The 5-year moving average series indicates a cyclic trend. The series shows low annual inflows during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 1.0 liter /second per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for one population hypothesis to detect and jump in the series in the early 1970's. For this purpose, the series was divided into two sub-series of 30 years each, 1941 to 1970 and 1971 to 2000. It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was no significant difference between the means and standard deviations that would indicate that the two sets were from different populations. The series was judged to be consistent and homogeneous.

Gatun Downstream

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual inflow series was random. The mass curve shows no significant change in slope. The 5-year moving average series indicates a cyclic behavior. The series shows low annual inflows during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 152 liter /second per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

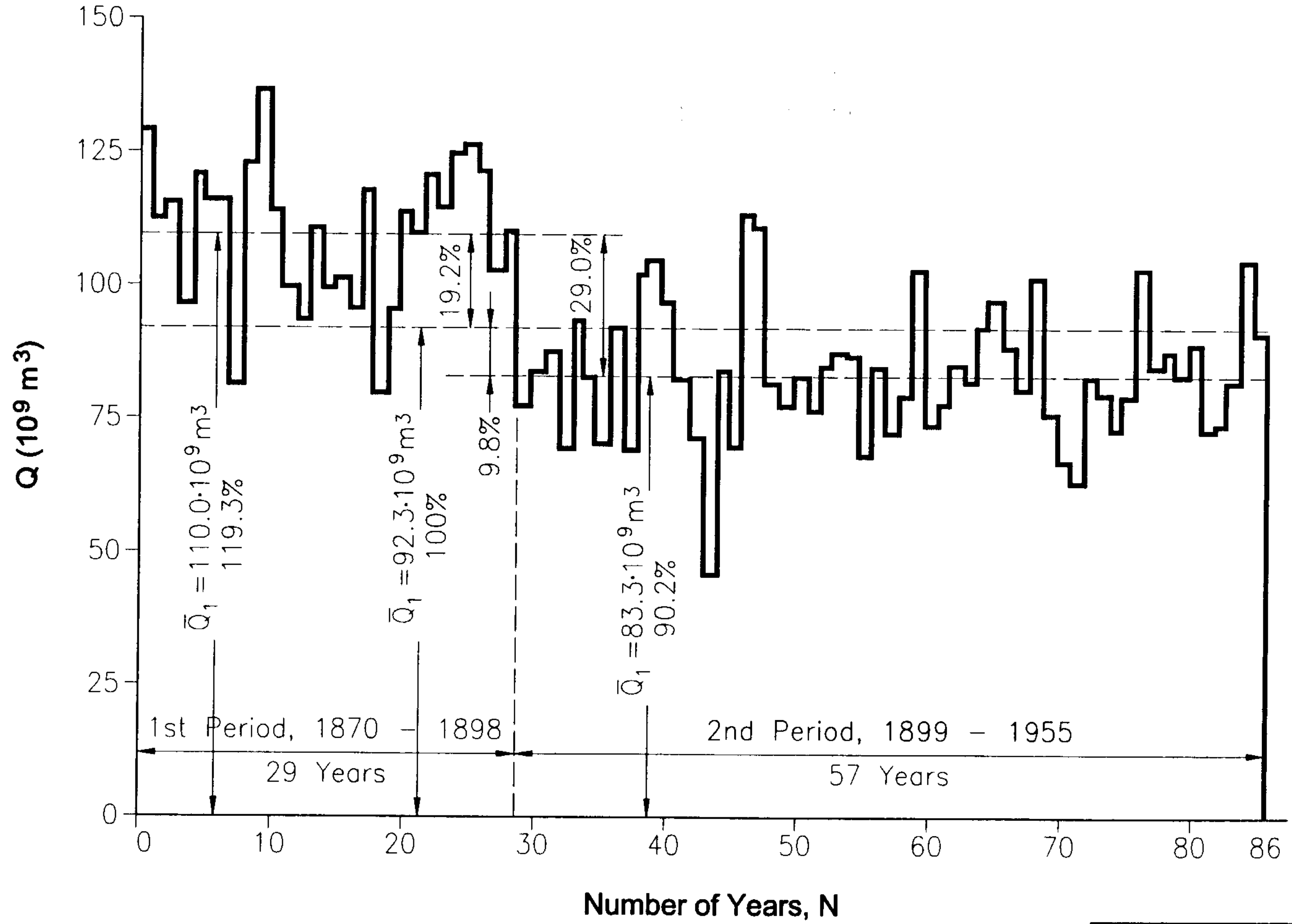
The annual series was tested for the one population hypothesis to detect any jump in the series in early 1970's. For this purpose, the series was divided into two sub-series of 30 years each, 1941 to 1970 and 1971 to 2000. It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was no significant difference between the means and standard deviations that would indicate that the two sets were from different populations. The series was judged to be consistent and homogeneous.

Gatun Total

Modified Portmenteau and autoregressive tests (McLeod and Hipal, 2001) indicated that the annual inflows series was random. The mass curve shows no significant change in slope. The 5-year moving average series indicates some cyclic trend. The series shows low annual inflows during the El Nino episodes.

A linear trend line fitted to the series shows a decreasing trend, about 153 liter /second per year. The trend was tested to be insignificant at 95 percent confidence level. The trend in the series was also tested to be insignificant at 95 percent confidence level using Mann-Kendall and Abelson- Tukey tests (McLeod and Hipal, 2001).

The annual series was tested for the one population hypothesis to detect any jump in the series in early 1970's. For this purpose, the series was divided into two sub-series of 30 years each, 1941 to 1970 and 1971 to 2000. It was hypothesized that the means and standard deviations of two sub-sets of the series were not significantly different from each other at a 95 percent confidence level. The F-distribution was used to test standard deviations. The means were tested using the t-distribution. The tests indicated that there was no significant difference between the means and standard deviations that would indicate that the two sets were from different populations. The series was judged to be consistent and homogeneous.



AUTORIDAD DEL CANAL DE PANAMA
Oficina de Proyectos de Capacidad del Canal

ACP

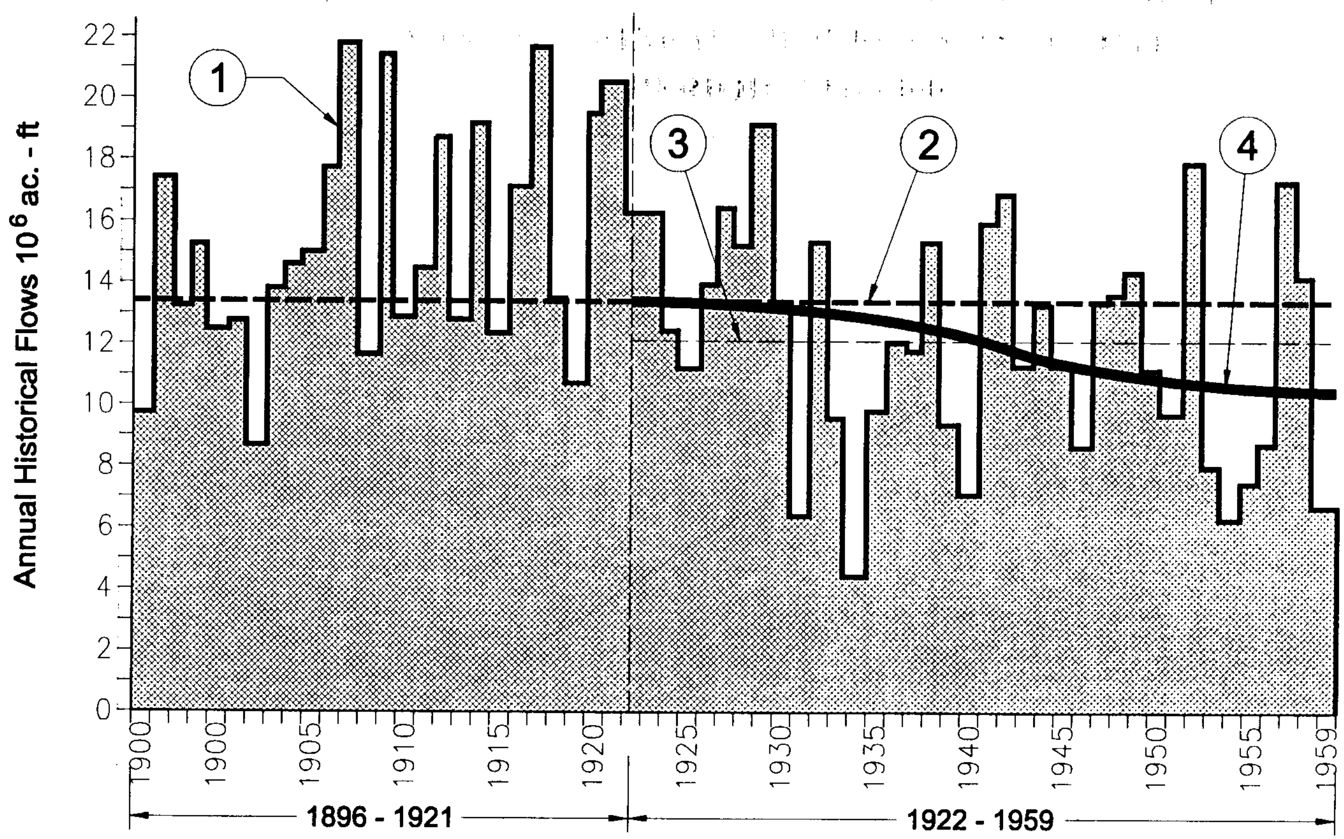
CONTRACT NO. CC-3-536

STUDY OF HYDROLOGIC SERIES IN GATUN LAKE WATERSHED

Example of Inconsistency
Annual Flows of Nile River

MWH
MONTGOMERY WATSON HARZA

FECHA:	EXHIBIT:
DECEMBER, 2001	12.1



LEGEND:

(1) HISTORICAL ANNUAL FLOW RECORD, WITH 1896-1921 PERIOD DATA ESTIMATED FROM OTHER STATIONS BY CORRELATION

(2) ARITHMETIC MEAN FOR THE PERIOD 1896-1959 (64 YEARS)

(3) ARITHMETIC MEAN FOR THE HISTORIC OBSERVED PERIOD, 1922-1959

(4) AN APPROXIMATE NON-HOMOGENEITY TREND IN THE PERIOD 1922-1959

AUTORIDAD DEL CANAL DE PANAMA
Oficina de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
STUDY OF HYDROLOGIC SERIES IN GATUN LAKE WATERSHED

Example of Non-homogeneity
Colorado River at Lee Ferry Arizona

MWH MONTGOMERY WATSON HARZA

FECHA: DECEMBER, 2001

EXHIBIT: 12.2

Exhibit 12.3

TESTING OF ONE-POPULATION HYPOTHESIS
ANNUAL RAINFALL SERIES

A. Testing of Means "t" Test at 95 percent confidence level

If the computed statistics, (difference in the means divided by standard deviation of the differences), is less than the critical value, the hypothesis Ho is accepted, that is, there is no significant difference to prove that the two means are from two different populations

Station Name	Code	First Population 1911 to 1970 $N_1 = 60$ Mean M1	Std. Dev. S1	econd Population 1971 to 2000 $N_2 = 30$ Mean M2	Std. Dev. S2	Difference in Means (absolute values) I M1-M2 I	$S_0 = (S1^2/N_1 + S2^2/N_2)$^0.5	Test Statistic $(M1-M2)/S_0$	Critical t' value	Remarks
Agua Clara	ACL	3482	612	3657	678	175	147	1.19	1.98	Ho accepted, same poulation
Alhajuela	ALA	2387	317	2304	319	83	71	1.17	1.98	Ho accepted, same poulation
Balboa Heights	BHT	1779	240	1860	335	81	69	1.18	1.98	Ho accepted, same poulation
Borro Colorado	BCI	2688	386	2522	600	166	120	1.38	1.98	Ho accepted, same poulation
Chico	CHI	2702	436	2489	397	213	92	2.32	1.98	Ho rejected, different populations
Chorro (or El Chorro)	CHR	2399	399	2158	390	241	88	2.74	1.98	Ho rejected, different populations
Gamboa	GAM	2117	273	2173	430	56	86	0.65	1.98	Ho accepted, same poulation
Gatun	GAT	3111	485	2741	537	370	116	3.18	1.98	Ho rejected, different populations
Monte Lirio	MLR	2862	426	2586	506	276	108	2.57	1.98	Ho rejected, different populations
Pedro Miguel	PMG	2033	278	2012	203	21	52	0.41	1.98	Ho accepted, same poulation
Salamanca	SAL	2438	447	2171	432	267	98	2.73	1.98	Ho rejected, different populations
San Miguel	SMG	3458	640	3795	779	337	164	2.05	1.98	Ho rejected, different populations
Gatun Downstream		2651	316	2425	368	226	79	2.88	1.98	Ho rejected, different populations
Madden Upstream		2840	419	2830	533	10	111	0.09	1.98	Ho accepted, same poulation
Gatun Total		2718	354	2553	403	165	87	1.90	1.98	Ho accepted, same poulation

B. Testing of Standard Deviations "F" Test at 95 percent confidence level

Rainfall Station		Computed Statistics (large S/small S)^2	denominator lowe value mr	numinator higher value n	critical F value	Remarks
Agua Clara	ACL	1.23	59	29	1.94	Ho accepted, same poulation
Alhajuela	ALA	1.01	59	29	1.94	Ho accepted, same poulation
Balboa Heights	BHT	1.95	59	29	1.94	Ho rejected, different populations
Borro Colorado	BCI	2.42	59	29	1.94	Ho rejected, different populations
Chorro (or El Chorro)	CHR	1.05	29	59	1.82	Ho accepted, same poulation
Gamboa	GAM	2.48	59	29	1.94	Ho rejected, different populations
Gatun	GAT	1.23	59	29	1.94	Ho accepted, same poulation
Monte Lirio	MLR	1.41	59	29	1.94	Ho accepted, same poulation
Pedro Miguel	PMG	1.88	29	59	1.82	Ho rejected, different populations
Salamanca	SAL	1.07	29	59	1.82	Ho accepted, same poulation
San Miguel	SMG	1.48	59	29	1.94	Ho accepted, same poulation
Gatun Downstream		1.36	59	29	1.94	Ho accepted, same poulation
Madden Upstream		1.62	59	29	1.94	Ho accepted, same poulation
Gatun Total		1.30	59	29	1.94	Ho accepted, same poulation

m = denominator, degree of freedom, sub-set with smaller variance
n = numinator, degree of freedom, sub-set with larger variance
statistic is $S1^2/S2^2$
F value at 95 percent corresponding to m and n values
Null hypothesis same population

Exhibit 12.4

TESTING OF ONE-POPULATION HYPOTHESIS
ANNUAL INFLOW SERIES

A. Testing of Means "t" Test at 95 percent confidence level

If the computed statistics, (difference in the means divided by the standard deviation of the differences), is less than than the critical value, the hypothesis H_0 is accepted, that is, there is no significant difference to prove that the two means are from two different populations

	First Population 1941 to 1970 $N_1 = 30$		Second Population 1971 to 2000 $N_2 = 30$						
Inflow Station	Mean M1	Standard Deviation S1	Mean M2	Standard Deviation S2	Difference in Means (absolute values) I M1-M2 I	$S_o = (S1^2/N_1 + S2^2/N_2)$^0.5	Test Statistic $(M1-M2)/S_o$	Critical t value	Remarks
Gatun River at Ciento	7.1	2.6	6.6	1.7	0.5	0.567	0.88	2.00	Ho accepted, same population
Boqueron River at Peluca	7.7	1.7	7.5	1.6	0.2	0.426	0.47	2.00	Ho accepted, same population
Pequeni River at Candelaria	14.4	2.4	13.5	2.7	0.9	0.660	1.36	2.00	Ho accepted, same population
Charges River at Chico	30.3	5.6	29.9	6.5	0.4	1.566	0.26	2.00	Ho accepted, same population
Trinidad River at Chorro	6.9	1.7	6.5	2.0	0.4	0.479	0.83	2.00	Ho accepted, same population
Ciri Grande at Canones	9.7	2.1	9.0	2.6	0.7	0.610	1.15	2.00	Ho accepted, same population
Madden Lake	76.4	13.2	73.8	14.7	2.6	3.607	0.72	2.00	Ho accepted, same population
Gatun Downstream	113.2	19.3	106.3	23.6	6.9	5.566	1.24	2.00	Ho accepted, same population
Gatun Total	189.5	29.7	180.0	36.5	9.5	8.591	1.11	2.00	Ho accepted, same population

B. Testing of Standard Deviations "F" Test at 95 percent confidence level

m = deminator, degree of freedom, sub-set with smaller variance

n = numerator, degree of freedom, sub-set with larger variance

statistics is $S1^2/S2^2$

F value is 95 percent correspopnding to m and n values

Null hypothesis, H_0 If computed statistic is less than the critical value, samples from same population

Inflow Station	Computed Statistics (large S/small S)^2	denominator lower value m	numerator higher value n	critical F value	Remarks
Gatun River at Ciento	2.34	29	29	2.03	Ho accepted, same population
Boqueron River at Peluca	1.13	29	29	2.03	Ho accepted, same population
Pequeni River at Candelaria	1.27	29	29	2.03	Ho accepted, same population
Charges River at Chico	1.35	29	29	2.03	Ho accepted, same population
Trinidad River at Chorro	1.38	29	29	2.03	Ho accepted, same population
Ciri Grande at Canones	1.53	29	29	2.03	Ho accepted, same population
Madden Lake	1.24	29	29	2.03	Ho accepted, same population
Gatun Downstream	1.49	29	29	2.03	Ho accepted, same population
Gatun Total	1.51	29	29	2.03	Ho accepted, same population

CHORRO OR EL CHORRO (CHR) VS 5-STATION AVERAGE (ALA, BCI, GAM, GAT, PMG)
ANNUAL RAINFALL DOUBLE MASS CURVE
PERIOD 1911-2000

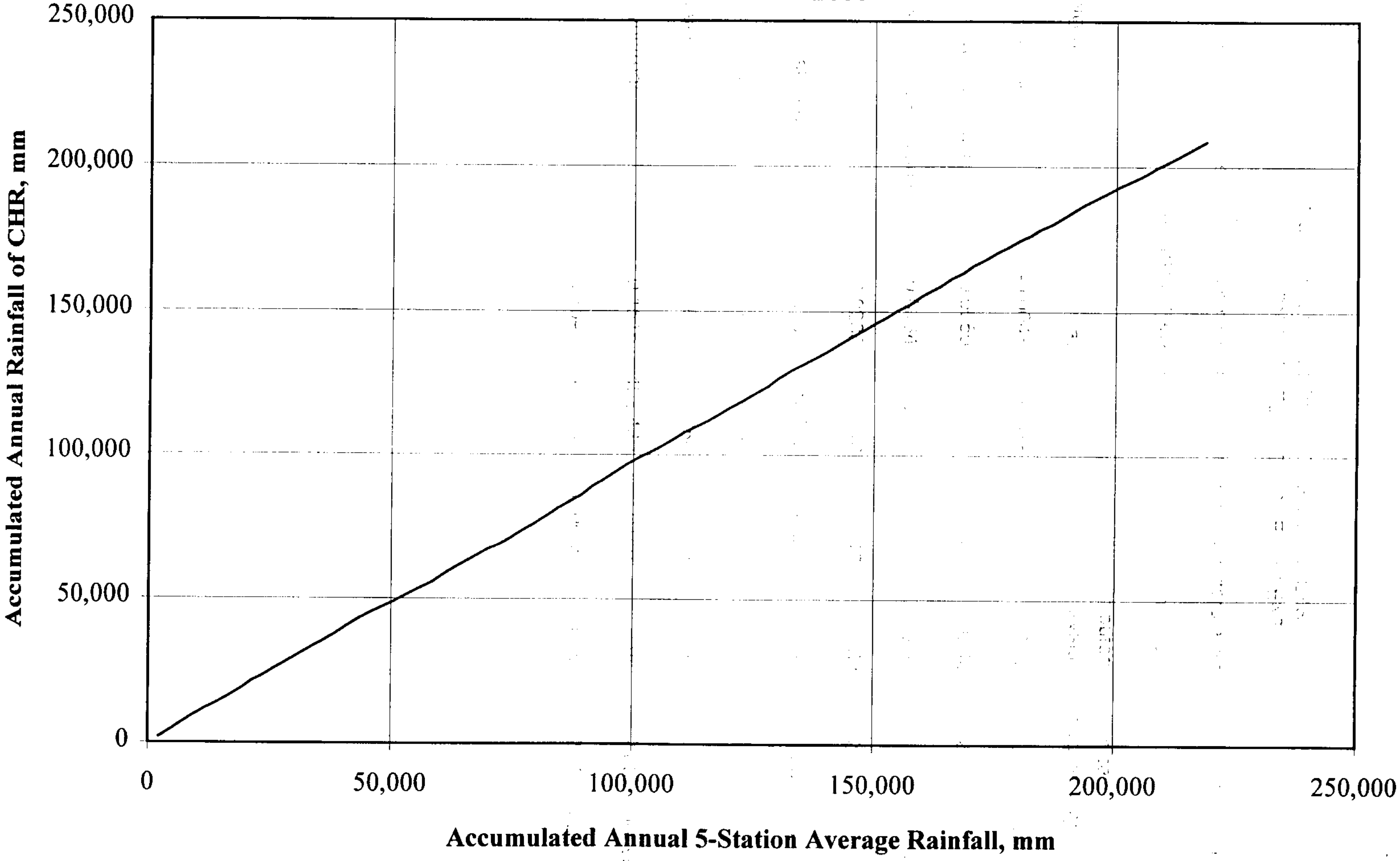


Exhibit 12.5

CHICO (CHI) VS 5-STATION AVERAGE (ALA, BCI, GAM, GAT, PMG)
ANNUAL RAINFALL DOUBLE MASS CURVE
PERIOD 1911-2000

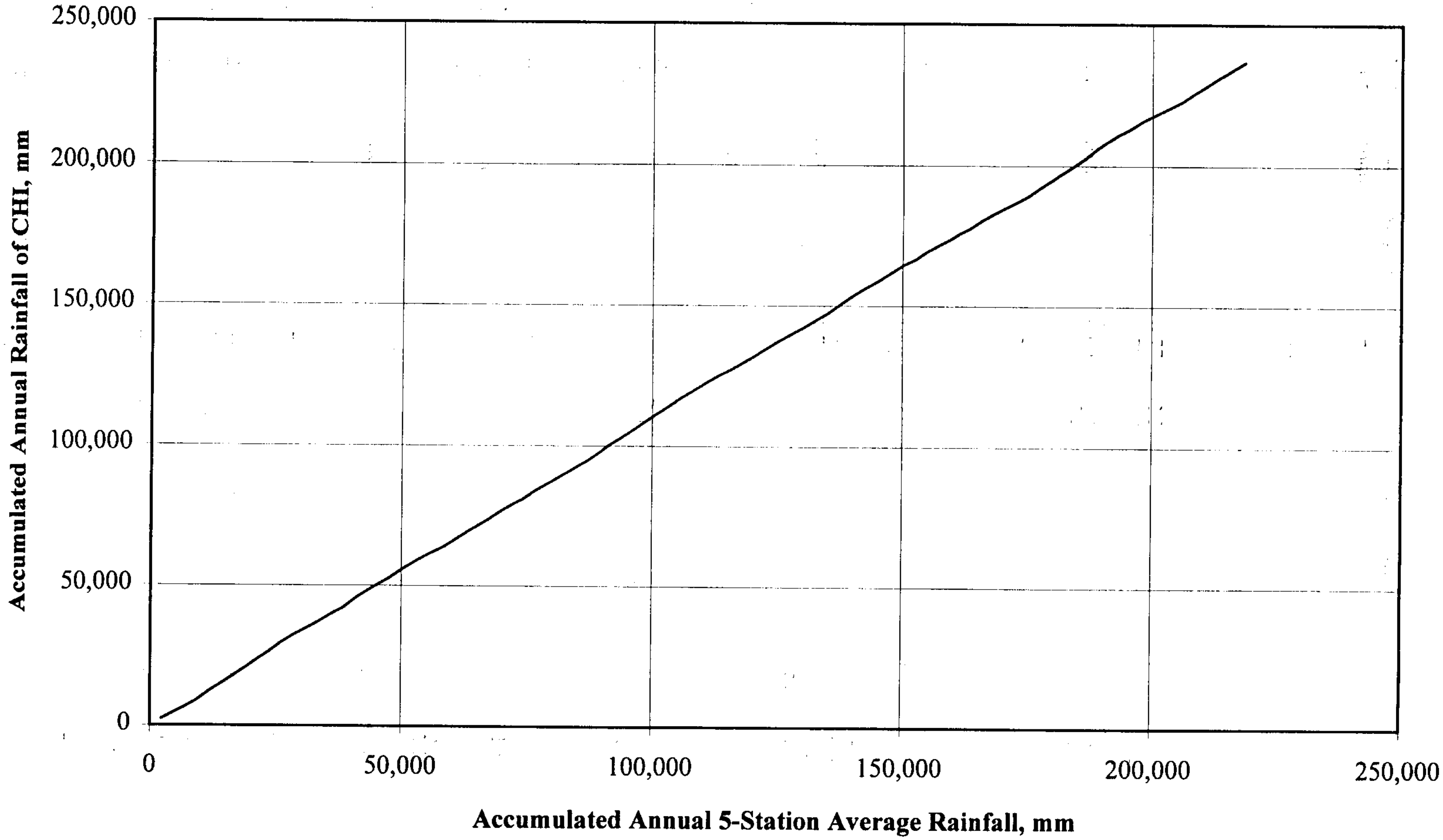
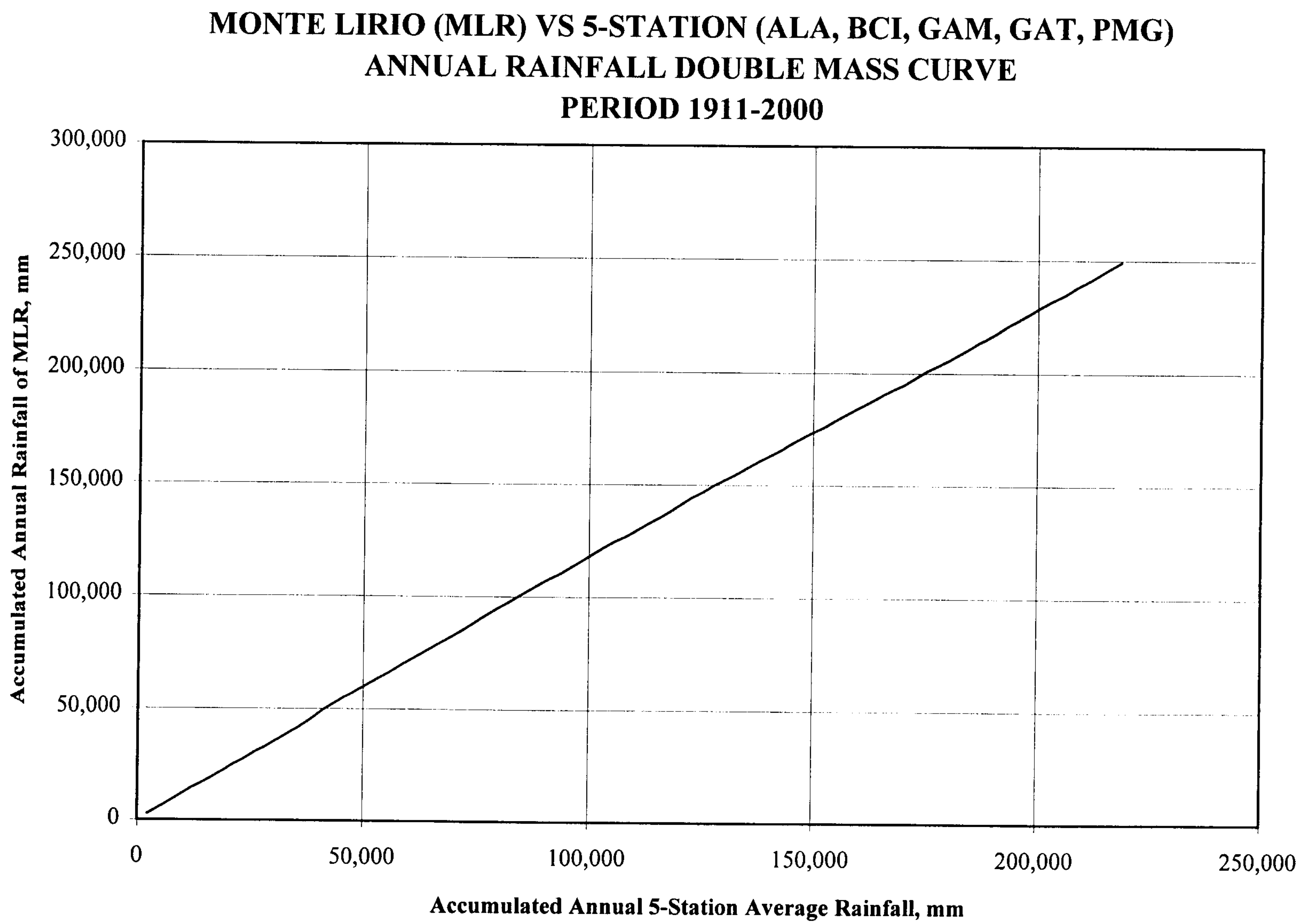


Exhibit 12.6



MONTE LIRIO (MLR) VS 5-STATION (ALA, BCI, GAM, GAT, PMG)
ANNUAL RAINFALL DOUBLE MASS CURVE
PERIOD 1911-2000
300,000
250,000
200,000
150,000
100,000
50,000
0
Accumulated Annual Rainfall of MLR, mm
0
50,000
100,000
150,000
200,000
250,000
Accumulated Annual 5-Station Average Rainfall, mm

Exhibit 12.7

**SAN MIGUEL (SMG) VS 5-STATION (ALA, BCI, GAM, GAT, PMG)
ANNUAL RAINFALL DOUBLE MASS CURVE
PERIOD 1911-2000**

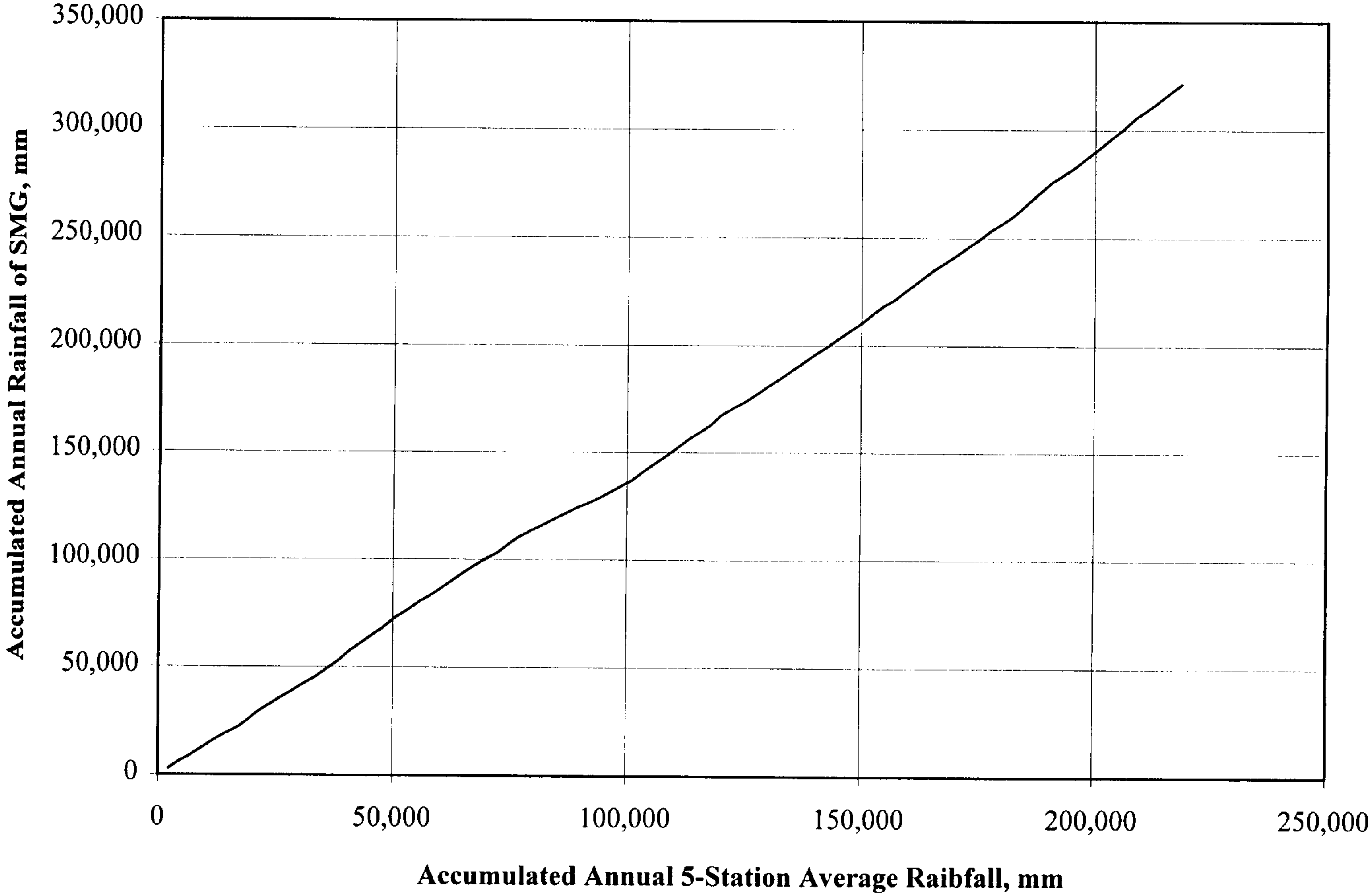


Exhibit 12.8

SALAMANCA (SAL) VS 5-STATION AVERAGE (ALA, BCI, GAM, GAT, PMG)
ANNUAL RAINFALL DOUBLE MASS CURVE
PERIOD 1911-2000

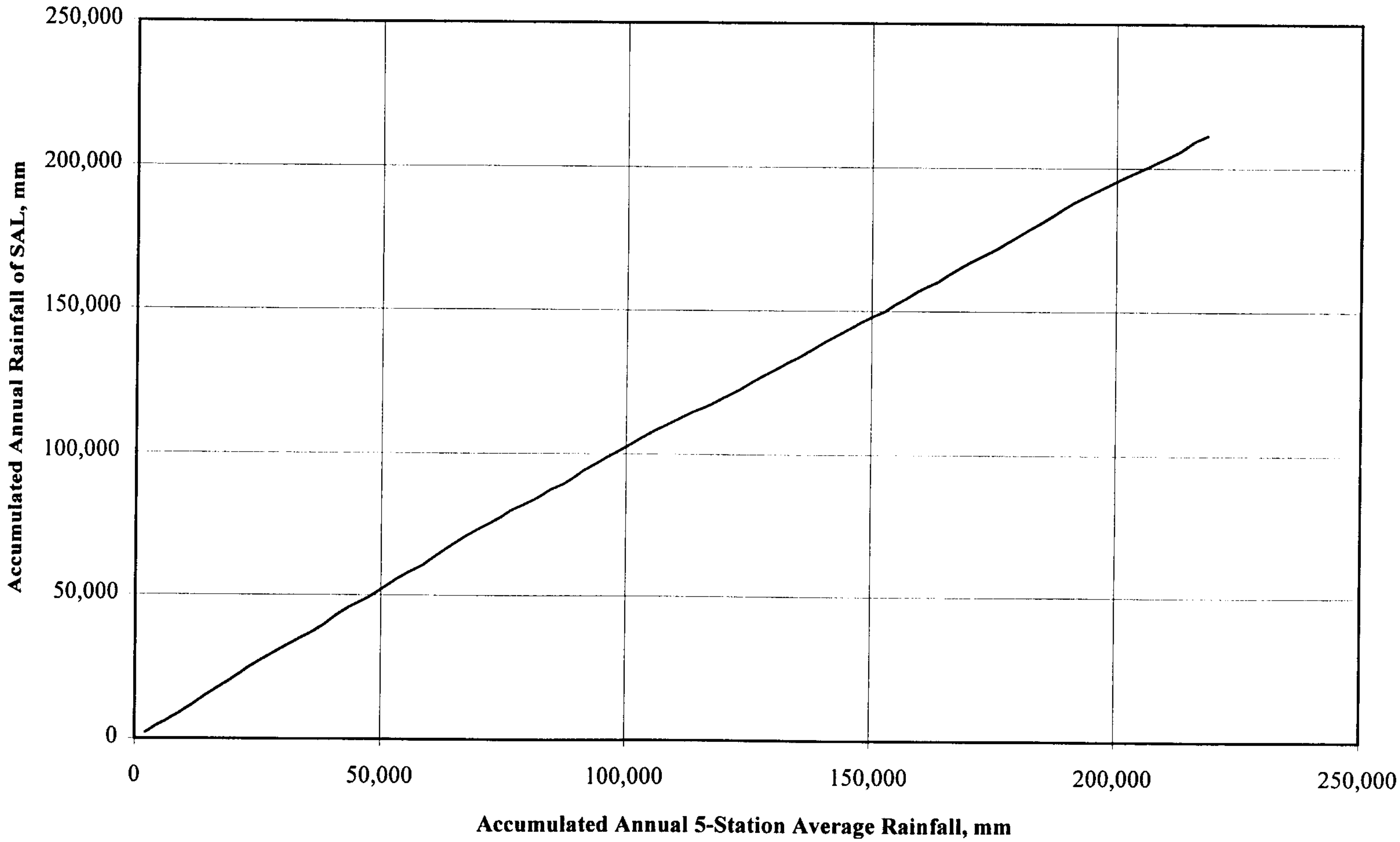


Exhibit 12.9

Exhibit 12.10

ANNUAL RAINFALL SERIES - TREND ANALYSIS
BASED ON CORRELATION COEFFICIENT

Null Hypothesis, Ho Correlation coefficient R is not significantly different from zero at 95 percent confidence level
Y = aX + b
Y = annual rainfall in mm X = year as 1911, 1912, etc., a = slope of line, coeeficient b = intercept

	Rainfall Station		"a"	"b"	R^2	Computed t-value	Critical t-value	Trend
1	**Agua Clara**	ACL	6.0129	-8217.8	0.0609	2.39	1.98	significant
2	**Alhajuela**	ALA	-0.6374	3605.6	0.0027	0.49	1.98	not significant
3	**Balboa Heights**	BHT	2.3403	-2770.7	0.049	2.13	1.98	significant
4	**Borro Colorado**	BCI	-1.9451	6436.4	0.0116	1.02	1.98	not significant
5	Candelaria	CDL	-1.4949	6067.2	0.0055	0.70	1.98	not significant
6	Cano	CNO	-3.5135	9105.4	0.0701	2.58	1.98	significant
7	**Chico**	CHI	-2.3344	7195.8	0.0198	1.33	1.98	not significant
8	Ciento	CNT	-0.9818	5118.6	0.0018	0.40	1.98	not significant
9	**Chorro (or El Chorro)**	CHR	-3.1262	8430.9	0.0397	1.91	1.98	not significant
10	Cascadas (or Las Cascad	CAS	-2.4845	7207.4	0.0248	1.50	1.98	not significant
11	Canones (or Los Canones	CAN	-6.4785	15387	0.0948	3.04	1.98	significant
12	Empire Hills	EMH	-0.2151	2587	0.0003	0.16	1.98	not significant
13	Escandalosa	ESC	0.0941	3118.9	0.00002	0.04	1.98	not significant
14	**Gamboa**	GAM	0.7704	628.76	0.0037	0.57	1.98	not significant
15	**Gatun**	GAT	-3.3522	9542.4	0.0273	1.57	1.98	not significant
16	Guacha	GUA	-3.4119	9105.4	0.0439	2.01	1.98	significant
17	Hodges Hill	HHI	-1.5119	5169.4	0.0179	1.27	1.98	not significant
18	Humedad	HUM	-4.0804	10442	0.0613	2.40	1.98	significant
19	Limon Bay	LMB	-3.7826	10586	0.0379	1.86	1.98	not significant
20	**Monte Lirio**	MLR	-4.0518	10693	0.0508	2.17	1.98	significant
21	Peluca	PEL	-2.5311	7892.7	0.0179	1.27	1.98	not significant
22	**Pedro Miguel**	PMG	1.0312	9.5865	0.0112	1.00	1.98	not significant
23	Racies (or Las Racies)	RAI	-3.6806	9415.5	0.0623	2.42	1.98	significant
24	Rio Piedras	RPD	2.4346	-2447	0.015	1.16	1.98	not significant
25	**Salamanca**	SAL	-5.4504	13007	0.0969	3.07	1.98	significant
26	**San Miguel**	SMG	7.3757	10852	0.075	2.67	1.98	significant
27	Santa Rosa	SRO	-2.463	7302.8	0.0368	1.83	1.98	not significant

NOTE: Stations in bold selected for futher analyses.

Exhibit 12.11

ANNUAL INFLOW SERIES - TREND ANALYSIS
BASED ON CORRELATION COEFFICIENT

Null Hypothesis, Ho   Correlation coefficient R is not significantly different from zero at 95 percent confidence level
Y = aX + b
Y = annual rainfall in mm   X = years, 1941, 1952, etc.   a = slope of line, coeeficient   b = intercept

	Inflow Station	"a"	"b"	R^2	Computed t-value	Critical t-value	Trend
1	Gatun River at Ciento	-0.0048	16.378	0.0015	0.30	2.00	not significant
2	Boqueron River at Peluca	-0.0050	17.373	0.0027	0.40	2.00	not significant
3	Pequeni River at Candelaria	-0.0134	40.303	0.008	0.68	2.00	not significant
4	Chagres River at Chico	0.0238	-16.710	0.0047	0.52	2.00	not significant
5	Trinidad River at Chorro	-0.0183	42.713	0.0307	1.35	2.00	not significant
6	Ciri Grande at Canones	-0.0255	59.600	0.0345	1.44	2.00	not significant
7	Madden Lake	-0.0011	77.254	0.0002	0.01	2.00	not significant
8	Gatun Downstream	-0.1516	408.430	0.0149	0.94	2.00	not significant
9	Gatun Total	-0.1541	488.330	0.0065	0.05	2.00	not significant

13.0 Stochastic Model

13.0 STOCHASTIC MODEL

13.1 Selection of Model

Stochastic models are often used in hydrologic applications to describe a time dependent phenomenon. A hydrologic time series of successive observations is considered as a sample realization from an infinite population of such time series that could have been generated by the stochastic process. Stochastic models can be classified into stationary and non-stationary. If the stochastic process remains in equilibrium about a constant mean, then it is stationary. Non-stationary models do not have natural mean.

Seasonal hydrological time series normally exhibit an autocorrelation structure which depends on the time lag of the year and the season of the year. For example, the correlation between October streamflow and September streamflow may tend to remain the same over the years. Monthly rainfall for April may fluctuate with constant variance and around a long term mean over the years. Periodic autoregressive (PAR) models are commonly used to fit these types of time series where a separate autoregressive (AR) model is used for each season of the year.

Based on the work of Thomas and Fiering (1962), PAR models are ideal for describing monthly hydrological time series such as streamflow and rainfall. Thomas and Fiering used a special case of PAR model where the order of the AR model for each season is held at one.

Hipel and McLeod (1994) conducted an extensive case study of monthly streamflow time series. Thirty monthly time series with average flows varying in a range of 1 to 896 m^3/s and periods of record varying from 37 to 64 years were used in model fitting and forecasting. Ten different models were used to fit the time series by omitting the last three years of data. The forecasts were then made and compared for the last three years (36 monthly flows). Four performance measures including root mean square error (RMSE), mean absolute deviation, mean absolute percentage error (MAPE) and median absolute percentage error were used. The best forecasts were obtained with the family of PAR models. Therefore, the PAR model was used in the current study to fit the three basin average monthly rainfall time series (Madden Lake, Gatun Downstream and Gatun Total) and three inflow series (Madden Lake, Gatun Downstream and Gatun Total).

13.2 Model Description

A stochastic model that is extremely useful in the representation of monthly hydrologic time series is the PAR model as explained above. For each period (or month for monthly time series), the deviation of the current monthly value from its monthly mean is expressed as a sum of the finite, linear aggregate of the deviations of the preceding monthly values from their monthly means of the monthly series and a white noise (also known as shock). Let z_t denotes a periodic time series with period s and seasonal mean μ_m. The PAR model of order ($p_1, p_2, \ldots, p_s$) for z_t may be written

$$(1 - \phi_{m,1} B - \ldots - \phi_{m,P_m} B^{P_m})\ (z_t - \mu_m) = a_{r,m} \qquad m = 1, \ldots\ s$$

where white noise $a_{r,m}$ is a sequence of independent normal random numbers with mean zero and standard deviation, σ_a. B is the back-shift operator on t which shifts back one time unit. For seasonal monthly periodically correlated time series, s=12, m represents the month and r represents the year. Thus, z_t is also denoted by $z_{r.m}$. The white noise is also known as the random component of the model. The linear aggregate part is the stochastic autoregressive component of the model. Monthly mean of the current month is the deterministic component of the PAR model.

The mean parameters, μ_m, are estimated by the means z_m of the data. Autoregressive parameters ($\phi_{m,1}$, ϕ_{m,p_m}) can be solved from a linear systems of equations called the periodic Yule-Walker equations for each season m:

$$\gamma_{m.1} = \phi_{m,1}\ \gamma_{m-1,0} + \phi_{m,2}\ \gamma_{m-2,} + \ldots + \phi_{m,p_m}\ \gamma_{m-pm,p_{m-1}}$$

$$\gamma_{m.2} = \phi_{m,1}\ \gamma_{m-1,1} + \phi_{m,2}\ \gamma_{m-2,} + \ldots + \phi_{m,p_m}\ \gamma_{m-pm,p_{m-2}}$$

$$\ldots = \ldots\ \ldots + \ldots\ \ldots + \ldots + \ldots\ \ldots$$

$$\ldots = \ldots\ \ldots + \ldots\ \ldots + \ldots + \ldots\ \ldots$$

$$\ldots = \ldots\ \ldots + \ldots\ \ldots + \ldots + \ldots\ \ldots$$

$$\gamma_{m.pm} = \phi_{m,1}\ \gamma_{m-1,pm-1} + \phi_{m,2}\ \gamma_{m-2,pm-2} + \ldots + \phi_{m,p_m}\ \gamma_{m-p_{m,0}}$$

where $\gamma_{m,k}$ denotes the periodic autocovariance function for season m at lag k. When k = 0, the periodic autocovariance is simply the variance. Logarithm transformation can be made before the model is fitted to the time series.

A computer PC package MHTS of 2001 version developed by McLeod and Hipel was used in the current study to fit the PAR model. The model order may be chosen by two criteria. They are, Akaike Information Criterion (AIC) and Bayes Information Criterion (BIC). The computation of the AIC and BIC values are given in the User's Manual (page 70-71). The model order ($p_1, p_2, \ldots\ p_m$) which minimizes the value of the criterion is selected. According to McLeod & Hipel, the AIC normally results in more parameters than that of BIC. Therefore, it is recommended to choose the model order by examining the periodic partial autocorrelation function and determine the most parsimonious adequate model. The model order is determined by finding the value of the periodic partial autocorrelation function after which the values are not significantly different from zero.

13.3 Fitting Model

The PAR models were applied to the following monthly time series:

1. Basin average rainfall – Madden Lake basin (1911-2000)

2. Basin average rainfall – Gatun Lake basin excluding Madden Lake basin (1911-2000)

3. Basin average rainfall – Gatun Lake basin including Madden Lake basin (1911-2000)

4. Inflow to Madden Lake (1941-2000)

5. Inflow to Gatun Lake excluding contribution form Madden lake (1941-2000)

6. Inflow to Gatun Lake including contribution from Madden Lake (1941-2000)

MHTS PC Package was used to fit the PAR stochastic model to the above six time series. In the process of model fitting, rainfall and streamflow time series with and without logarithmic transformation were used. Both AIC and BIC criteria were used in the fitting process.

13.3.1 Rainfall Time Series

PAR models were fitted to the three 85-year rainfall time series by omitting the last five years of data. Table 13.1 summarizes the results of model order of PAR estimation. It shows that using the AIC criterion results in more parameters (case 1 vs. 4, 2 vs. 5, 3 vs. 6, 7 vs. 10, 8 vs. 11, and 9 vs. 12). Therefore, parsimonious models using the BIC criterion were adopted in the final model fitting.

A comparison of case No. 4 vs. 10, 5 vs. 11, and 6 vs. 12 shows that about four out of the twelve months result in higher model order when the logarithmic transformation was made to the rainfall time series. Only two months showed lower order with logarithmic transformation (case 5 vs. 11). Therefore, logarithmic transformation of the rainfall time series was not used in the final model fitting.

Based on the principle of parsimony, the PAR estimation of cases 4, 5, and 6 with lower model order and less model parameters are selected for model fitting to the rainfall time series. The estimated model autoregressive parameters are listed in Table 13.2 and used for model verification. Detailed input and output files of these cases are shown in Appendix F-I.

The PAR estimation results (Case No. 4, 5, and 6 of Table 13.1) indicated that about 78% of the time (28 out of 36 months of three rainfall time series fitted) the model order is zero. This means the current monthly rainfall does not have significant correlation with the preceding monthly rainfall. There are 5, 1, and 2 months with order 1, 2, and higher, respectively, for the 36 months of cases 4-6 modeled. There are two Novembers with the model order of four. Model order higher than 2 may not have significant physical meaning. It mainly indicates statistically that the high order model fits better than other orders.

For cases 4-6, the observed data were then compared with the fitted values of the model as shown in Appendix F-II for the period from 1911 to 1995. The fitted value was computed as the difference between the observed and the residual series from the model fitting. In general, the fitted values match very well with the observed values except for some high rainfall months for which the fitted value is less than the observed value. This may be caused by larger standard deviation of high rainfall months as shown in Appendix F-I. Appendix F-III gives the percentage differences between observed and fitted values. In general, the difference is higher for low rainfall months than for high rainfall months. This may be because the higher percentage was obtained by dividing the difference with smaller rainfall.

The adequacy of a fitted model can be checked by examining the properties of the residuals for each season. The residuals should be uncorrelated and normally distributed. Possible inadequacy is suggested if any of the residual autocorrelation is much more than twice its standard deviation. Table 13.3 summarizes the residual correlation and their standard deviations for each model order. None of the residual autocorrelation is more than twice its standard deviation. Therefore, no model inadequacy is suggested based on the residual autocorrelations.

13.3.2 Streamflow Series

PAR models were fitted to three streamflow time series by omitting the last three years of data. Table 13.4 summarizes the results of PAR estimation. Similar to rainfall series, it shows that using the AIC criterion results in more parameters for each month irrespective of logarithmic transformation of the streamflow time series. Based on the principle of parsimony, the BIC criterion was adopted in the final model fitting.

A comparison of case No. 4 vs case No. 10 and case No. 5 vs. case No. 11 shows that only one out the twelve months resulted in a higher model order when the logarithmic transformation was made to the

Table 13.1

MODEL ORDER FOR PAR FITTING
RAINFALL SERIES - DATA PERIOD 1911-1995

Area	Case No	Cri.	Log.	Model Order											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Madden Lake	1	AIC	N	0	0	2	3	2	0	2	1	0	3	0	1
Gatun-D/S	2	AIC	N	3	0	2	2	2	0	5	4	0	0	7	1
Gatun Total	3	AIC	N	3	1	0	2	2	0	1	4	0	0	4	4
Madden Lake	4	BIC	N	0	0	0	0	0	0	0	1	0	0	0	0
Gatun-D/S	5	BIC	N	0	0	0	1	0	0	1	0	0	0	4	1
Gatun Total	6	BIC	N	0	0	0	0	2	0	0	0	0	0	4	1
Madden Lake	7	AIC	Y	0	1	2	2	2	0	2	1	0	0	7	1
Gatun-D/S	8	AIC	Y	1	1	3	1	2	0	5	4	0	0	5	3
Gatun Total	9	AIC	Y	3	5	1	1	2	0	0	4	0	0	7	4
Madden Lake	10	BIC	Y	0	0	2	0	2	0	2	1	0	0	0	1
Gatun-Madden	11	BIC	Y	0	0	1	0	1	0	0	1	0	0	5	1
Gatun Lake	12	BIC	Y	1	0	1	1	2	0	0	1	0	0	4	1

Note: AIC – Akaike information criterion
BIC – Bayes information criterion
N - Rainfall time series without logarithmic transformation
Y - Rainfall time series with logarithmic transformation

Table 13.2

MODEL AUTOREGRESSIVE PARAMETERS
PAR MODEL FITTING TO RAINFALL SERIES - DATA PERIOD 1911-1995

Site	Case No	Month.	Model Autoregressive Parameter			
			Lag 1	Lag 2	Lag 3	Lag 4
Madden Lake	4	Jan	-	-	-	-
		Feb	-	-	-	-
		Mar	-	-	-	-
		Apr	-	-	-	-
		May	-	-	-	-
		Jun	-	-	-	-
		Jul	-	-	-	-
		Aug	.2467	-	-	-
		Sep	-	-	-	-
		Oct	-	-	-	-
		Nov	-	--	-	-
		Dec	-	-	-	-
Gatun Downstream	5	Jan	-	-	-	-
		Feb	-	-	-	-
		Mar	-	-	-	-
		Apr	.6860	-	-	-
		May	-	-	-	-
		Jun	-	-	-	-
		Jul	.2795	-	-	-
		Aug	-	-	-	-
		Sep	-	-	-	-
		Oct	-	-	-	-
		Nov	-.1167	-.0287	.1827	.7594
		Dec	.2895	-	-	-
Gatun Total	6	Jan	-	-	-	-
		Feb	-	`	-	-
		Mar	-		-	-
		Apr	-	-	-	-
		May	.2173	.7777	-	-
		Jun	-	-	-	-
		Jul	-	-	-	-
		Aug	-	-	-	-
		Sep	-	-	-	-
		Oct	-	-	-	-
		Nov	-.1311	.0260	.2828	.6256
		Dec	.2662	-	-	-

streamflow time series. The streamflow model fitting of case 10 results in a much higher (order 7) of the fitted PAR model than that of case 4 (order 4) for month of September. The streamflow model fitting of case 11 results in one order higher (order 2) of the fitted PAR model for month of June than that of case 5 (order 1). There is no difference in model order between case 6 and 12. Therefore, logarithmic transformation of the streamflow time series was not used in the final model fitting.

Based on the principle of parsimony, the PAR estimation of cases 4, 5, and 6 with lower model order and less model parameters are selected for model fitting to the streamflow time series. The estimated model parameters are listed in Table 13.5. and used for model verification. Detailed outputs of these cases are shown in Appendix F-IV.

The PAR estimation results (Case No. 4, 5, and 6 of Table 13.4) indicated that about 81% of the time (29 out of 36 months of three streamflow time series fitted) the model order is one. This means the current monthly flow has high correlation with the preceding monthly flow. There are 2, 2, and 3 months with order 0, 2, and higher, respectively, for the 36 months modeled of the three flow time series. There is one November and one December with the model order of zero for the inflow to Madden Lake time series. This may be because flows in November and December are higher than flows in the other months. These higher flows vary over a wider range. The model fitting results indicate that a model with order zero fits better for these types of flows. A model order higher than 2 may not have a significant physical meaning. It mainly indicates that statistically the high order fits better than other orders.

The observed data were then compared with the fitted value of the model for the period from 1941 to 1997 of cases 4-6 as shown in Appendix F-V. The fitted value includes the deterministic component and the stochastic autoregressive component. Therefore the difference between the observed and the fitted value is the random component. In general, the fitted values match very well with the pattern of the observed values except for some high flow months. This may be caused by larger standard deviation of high flow months as shown in Appendix F-IV. Appendix F-VI shows the percentage differences between observed and fitted values.

The fitted value can be computed as the difference between the observed and the residual series from the model fitting. The deterministic component of the fitted value was given in the PAR output as monthly mean in Appendix F-IV. The stochastic autoregressive component can be computed using the fitted model order and its autoregressive parameters listed in Table 13.5. In general, the percentage difference is higher for low flow month than that of high flow month. This may be because the higher percentage was obtained by dividing by lower flows.

Table 13.3

RESIDUAL AUTOCORRELATION
PAR MODEL FITTING TO RAINFALL SERIES - DATA PERIOD 1911-1995

Site	Case No	Month.	Residual Autocorrelation / Standard Deviation			
			Lag 1	Lag 2	Lag 3	Lag 4
Madden Lake	4	Jan	-	-	-	-
		Feb	-	-	-	-
		Mar	-	-	-	-
		Apr	-	-	-	-
		May	-	-	-	-
		Jun	-	-	-	-
		Jul	-	-	-	-
		Aug	..0000/.1085	-	-	-
		Sep	-	-	-	-
		Oct	-	-	-	-
		Nov	-	--	-	-
		Dec	-	-	-	-
Gatun Downstream	5	Jan	-	-	-	-
		Feb	-	-	-	-
		Mar	-	-	-	-
		Apr	.0000/.1085	-	-	-
		May	-	-	-	-
		Jun	-	-	-	-
		Jul	.0000/.1085	-	-	-
		Aug	-	-	-	-
		Sep	-	-	-	-
		Oct	-	-	-	-
		Nov	.0000/.1085	.0000/.1085	.0000/.1085	.0515/.1085
		Dec	- .0527/.1079	-	-	-
Gatun Total	6	Jan	-	-	-	-
		Feb	-	-	-	-
		Mar	-		-	-
		Apr	-	-	-	-
		May	.0000/.1085	.0000/.1085	-	-
		Jun	-	-	-	-
		Jul	-	-	-	-
		Aug	-	-	-	-
		Sep	-	-	-	-
		Oct	-	-	-	-
		Nov	.0000/.1085	.0000/.1085	.0000/.1085	.0000/.1085
		Dec	- .0964/.1085	-	-	-

Table 13.4

MODEL ORDER FOR PAR MODEL FITTING STREAMFLOW SERIES - DATA PERIOD 1941-1997

Site	Case No	Cri.	Log.	Model Order											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Madden Lake	1	AIC	N	3	2	2	1	2	1	1	1	8	1	0	1
Gatun-D/S	2	AIC	N	5	1	8	10	4	1	3	1	1	2	5	1
Gatun Total	3	AIC	N	3	2	8	1	2	2	1	1	8	1	5	1
Madden Lake	4	BIC	N	1	1	2	1	1	1	1	1	4	1	0	0
Gatun-D/S	5	BIC	N	1	1	1	1	1	1	1	1	1	1	3	1
Gatun Total	6	BIC	N	1	1	2	1	1	1	1	1	1	1	3	1
Madden Lake	7	AIC	Y	3	2	2	1	1	1	1	2	7	1	2	1
Gatun-D/S	8	AIC	Y	5	1	2	10	1	2	3	1	1	2	7	1
Gatun Total	9	AIC	Y	3	2	2	1	1	2	1	1	1	1	5	1
Madden Lake	10	BIC	Y	1	1	1	1	1	1	1	1	7	1	0	1
Gatun-D/S	11	BIC	Y	1	1	1	1	1	2	1	1	1	1	3	1
Gatun Total	12	BIC	Y	1	1	2	1	1	1	1	1	1	1	3	1

Note: AIC – Akaike information criterion
BIC – Bayes information criterion
N - Streamflow time series without logarithmic transformation
Y - Streamflow time series with logarithmic transformation

Similarly, the adequacy of a fitted model can be checked by examining the properties of the residuals for each season. The residuals should be uncorrelated and normally distributed. Possible inadequacy is suggested if any of the residual autocorrelations is much more than twice its standard deviation. Table 13.6 summarizes the residual correlations and their standard deviations for each model order. None of the residual autocorrelation is more than twice its standard deviation. Therefore no model inadequacy is suggested based on the residual autocorrelations.

13.4 Model Verification

Before the fitted model was used for prediction, model verification was performed. Verification values were computed using the observed data and the fitted model. These verification values were then compared with the observed values to check the goodness of PAR model fitting.

13.4.1 Rainfall Series

The model verification was made by applying the fitted model of cases 4-6 to the last five years rainfall data from 1996 to 2000 that were omitted in the model fitting process. The verification values were computed for these last five years using the fitted model based on the 1911-95 data.

A program was written to compute the verification values of the PAR model up to order five for each period. A listing of the program is shown as Appendix F-VII. For each period or month in the current study, the verification value is equal to the sum of three components. They are: monthly mean (deterministic component); sum of the product of model autoregressive parameter and the difference between the observed value and its corresponding mean value of the preceding months (stochastic autoregressive component); and a white noise (random component) which is normally distributed with mean zero and residual standard deviation as shown in the output of the PAR estimation (Appendix F-I). A factor greater than 1 was used to reduce the effect of the random component in the fitted model. If the verification value is greater than the factor times the monthly mean or less than the monthly mean divided by the factor, then a random number is regenerated. This can avoid the problem of a very large or small generated random component. The results from using a factor of 2 are considered reasonable.

The verification values were compared with the observed data as shown in Appendix F-II for basin average rainfall over the drainage area above Madden Lake, Gatun Lake excluding Madden Lake and Gatun Lake including Madden Lake. A comparison of the observed and verification values indicates that the pattern of the observed and fitted monthly rainfall match very well except for some high rainfall months. This deviation may be caused by the wider fluctuation range of higher rainfall.

Table 13.5

MODEL AUTOREGRESSIVE PARAMETERS
PAR MODEL FITTING TO STREAMFLOW SERIES - DATA PERIOD 1941-1997

Site	Case No	Month.	Model Autoregressive Parameter			
			Lag 1	Lag 2	Lag 3	Lag 4
Madden Lake	4	Jan	.2231	-	-	-
		Feb	.1655	-	-	-
		Mar	.4613	.0552	-	-
		Apr	1.2370	-	-	-
		May	.4501	-	-	-
		Jun	.2448	-	-	-
		Jul	.5528	-	-	-
		Aug	.6251	-	-	-
		Sep	.2589	-.1144	.1148	.1804
		Oct	.5822	-	-	-
		Nov	-	-	-	-
		Dec	-	-	-	-
Gatun Downstream	5	Jan	.1358	-	-	-
		Feb	.2060	-	-	-
		Mar	.6122	-	-	-
		Apr	1.0962	-	-	-
		May	.7556	-	-	-
		Jun	.6029	-	-	-
		Jul	.7932	-	-	-
		Aug	.7133	-	-	-
		Sep	.4807	-	-	-
		Oct	.5385	-	-	-
		Nov	.3837	-.3733	.8696	-
		Dec	.3480	-	-	-
Gatun Total	6	Jan	.1784	-	-	-
		Feb	.1958	-	-	-
		Mar	.4528	.0702	-	-
		Apr	1.3182	-	-	-
		May	.6132	-	-	-
		Jun	.4346	-	-	-
		Jul	.7694	-	-	-
		Aug	.6971	-	-	-
		Sep	.3972	-	-	-
		Oct	.6248	-	-	-
		Nov	.2787	-.1551	.5989	-
		Dec	.3700	-	-	-

13.4.2 Streamflow Series

The model verification was made by applying the fitted model of cases 4-6 to the last three years data from 1998 to 2000 that were omitted in the model fitting process. Verification of streamflow was made using the fitted model based on the 1941-97 data and model autoregressive parameters listed in Table 13.5. The computation was made using the program listed in Appendix F-VII.

The verification values were compared with the observed data as shown in Appendix F-V for inflow to Madden Lake, Gatun Lake Downstream and Gatun Lake Total. A comparison of the observed and verification values indicates that the pattern of the observed and verification monthly flows match very well except for some high flow months. Similarly, this deviation may have been caused by the wider fluctuation range of higher flows.

13.5 Evaluation of Model Verification

The performance of the model verification is assessed using the MAPE criteria. The MAPE is the average of the absolute value of the percentage of the difference between the computed and observed values divided by the observed value.

The computed MAPE for 1996-2000 rainfall time series are 57%, 75% and 54% for basin average rainfall over Madden Lake, Gatun Downstream and Gatun Total, respectively. There are a few months with very high percentage difference values. They mostly occur in the months of January, February, March and December when the observed rainfalls are relatively low. For example, the observed Madden rainfall on December 1997 is 31 mm and the computed average December rainfall for the period of 1911-95 is about 216 mm. The computed verification value is 340 mm. The percentage difference for this month is 996%. This significantly increases the MAPE value.

The computed MAPE for 1998-2000 streamflow time series are 34%, 46% and 36% for basin average inflow over Madden Lake, Gatun Downstream and Gatun Total, respectively. Similarly, there are a few months with very high percentage difference values. They mostly occur in the months of January, February, March, November, and December when the observed streamflows are relatively low. For example, the observed Madden inflow on February 1998 is 16.8 cms and the computed average February inflow for the period 1941-97 is 33.6 cms. The computed verification value is 47.5 cms. The percentage difference for this month is 183%. This significantly increases the MAPE value.

Table 13.6

RESIDUAL AUTOCORRELATION PAR MODEL FITTING TO STREAMFLOW SERIES - DATA PERIOD 1941-1997

Site	Case No	Month.	**Residual Autocorrelation /** Standard Deviation			
			Lag 1	Lag 2	Lag 3	Lag 4
Madden Lake	4	Jan	.0111/.1173	-	-	-
		Feb	-.0458/.1379	-	-	-
		Mar	.0000/.0959	.0695/.1615	-	-
		Apr	.1238/.1323	-	-	-
		May	-.0775/.1326	-	-	-
		Jun	-.0370/.1339	-	-	-
		Jul	-.0159/.1330	-	-	-
		Aug	.0657/.1240	-	-	-
		Sep	.0000/.0000	.0000/.0000	.0000/.0000	.0893/.0669
		Oct	.0016/.0757	-	-	-
		Nov	-	-	-	-
		Dec	-	-	-	-
Gatun Downstream	5	Jan	-.0044/.1101	-	-	-
		Feb	-.0275/.1497	-	-	-
		Mar	-.1307/.1233	-	-	-
		Apr	.0821/.1325	-	-	-
		May	-.0812/.1338	-	-	-
		Jun	-.1165/.1287	-	-	-
		Jul	-.1155/.0729	-	-	-
		Aug	-.0384/.0881	-	-	-
		Sep	-.1095/.0935	-	-	-
		Oct	-.1174/.0759	-	-	-
		Nov	.0000/.0000	.0000/.0000	-.1678/.0922	-
		Dec	.0450/.0788	-	-	-
Gatun Total	6	Jan	-.0011/.1139	-	-	-
		Feb	-.0504/.1408	-	-	-
		Mar	.0000/.1134	.0205/.1621	-	-
		Apr	.1262/.1322	-	-	-
		May	-.0922/.0527	-	-	-
		Jun	-.1348/.0878	-	-	-
		Jul	-.0535/.0640	-	-	-
		Aug	.0164/.0838	-	-	-
		Sep	-.0130/.0916	-	-	-
		Oct	-.0650/.0736	-	-	-
		Nov	.0000/.0000	.0000/.0000	-.1479/.0911	-
		Dec	.0006/.0642	-	-	-

13.6 Model Prediction

After the model verification was performed, the model prediction of three months ahead was also made. The model prediction was made by applying the fitted model of cases 4-6 to the rainfall and streamflow of the last years. In actual practice, the model prediction would be made using the model parameters computed from all available data.

A program was written to compute the prediction values of PAR model up to order five for each period. A listing of the program is shown as Appendix F-VII. Similar to the verification program, for each period or month in the current study, the prediction value is equal to the sum of three components. They are: monthly mean (deterministic component); sum of the product of model autoregressive parameter and the difference between the observed value and its corresponding mean value of the preceding months (stochastic autoregressive component); and a white noise (random component) which is normally distributed with mean zero and residual standard deviation as shown in the output of PAR estimation. A factor greater than 1 was used to reduce the effect of random component in the fitted model. If the computed value is greater than the factor times the monthly mean or less than the monthly mean divided by the factor, then a random number is regenerated. This can avoid the problem of a very large or small generated random component. The results from using a factor of 2 are considered reasonable.

In the prediction model, the predicted values are used for the prediction of the subsequent months if they are required. When the observed values of the predicted months become available, they should be used in the prediction. The predicted rainfall and streamflow values are listed in Table 13.7. These prediction values were made using the results from model fitting. The model parameters need to be updated by including the period used for verification.

TABLE 13.7

MODEL PREDICTION

Site	Rainfall, mm			Streamflow, cms		
	Jan. 2001	Feb. 2001	Mar. 2001	Jan. 2001	Feb. 2001	Mar. 2001
Madden Lake	94	45	17	96	60	36
Gatun Downstream	99	23	42	91	53	32
Gatun Total	136	26	45	183	109	66

Model fitting and verification should be updated when an additional two years of data become available.

14.0 Synthetic Time Series

14.0 SYNTHETIC TIME SERIES

The objective of streamflow generation is to generate a set of streamflow sequences that are as equally likely to occur as the observed sequence. Statistically, this amounts to generating a set of samples from the population underlying the streamflow process. However, the characteristics of this population are not known, but can only be inferred on the basis of the information contained in the observed sequence. Thus, the data generated through application of a stochastic model would best represent the streamflow process within the limit of the observed sequence.

The HEC-4 computer program was used to generate synthetic time series. Ten synthetic series each of 100-year period were generated for each of the following series:

1. Inflow to Madden Lake
2. Inflow to Gatun Lake excluding Madden Lake (Gatun Downstream)
3. Inflow to Gatun Lake including Madden Lake (Gatun Total)
4. Basin average rainfall – Madden Lake basin
5. Basin average rainfall – Gatun Lake basin excluding Madden Lake basin (Gatun Downstream)
6. Basin average rainfall – Gatun Lake basin including Madden Lake basin (Gatun Total)

14.1 Model Description

The HEC-4 Monthly Streamflow Simulation program was developed by the Hydrologic Engineering Center, Corps of Engineers in 1971. The program can analyze monthly streamflow of a multi-site data set to determine the statistical characteristics and generate a sequence of synthetic streamflow. It can reconstitute missing data based on concurrent flows and compute the maximum and minimum values of each month for the specified duration. There are additional options not related to the current study.

The computation procedures of HEC-4 are summarized into the following steps:

1. Compare the statistical parameters of mean, standard deviation and skew coefficient for each month.
2. Adjust the mean and standard deviation to increase the reliability of these statistics computed from the incomplete data.

3. Convert each streamflow to a normalized standard variate based on the Pearson Type III distribution.

4. Compute lag-one correlation coefficients of the transformed flows.

5. Estimate correlation coefficients for data set without sufficient data for computing the required coefficients.

6. Estimate monthly flows for each missing month.

7. Check consistency of the correlation coefficients and recompute if required.

8. Convert the normal standard variate to streamflow.

9. Check consistency of the correlation coefficients of the complete set of flows. Make adjustments until consistency is reached.

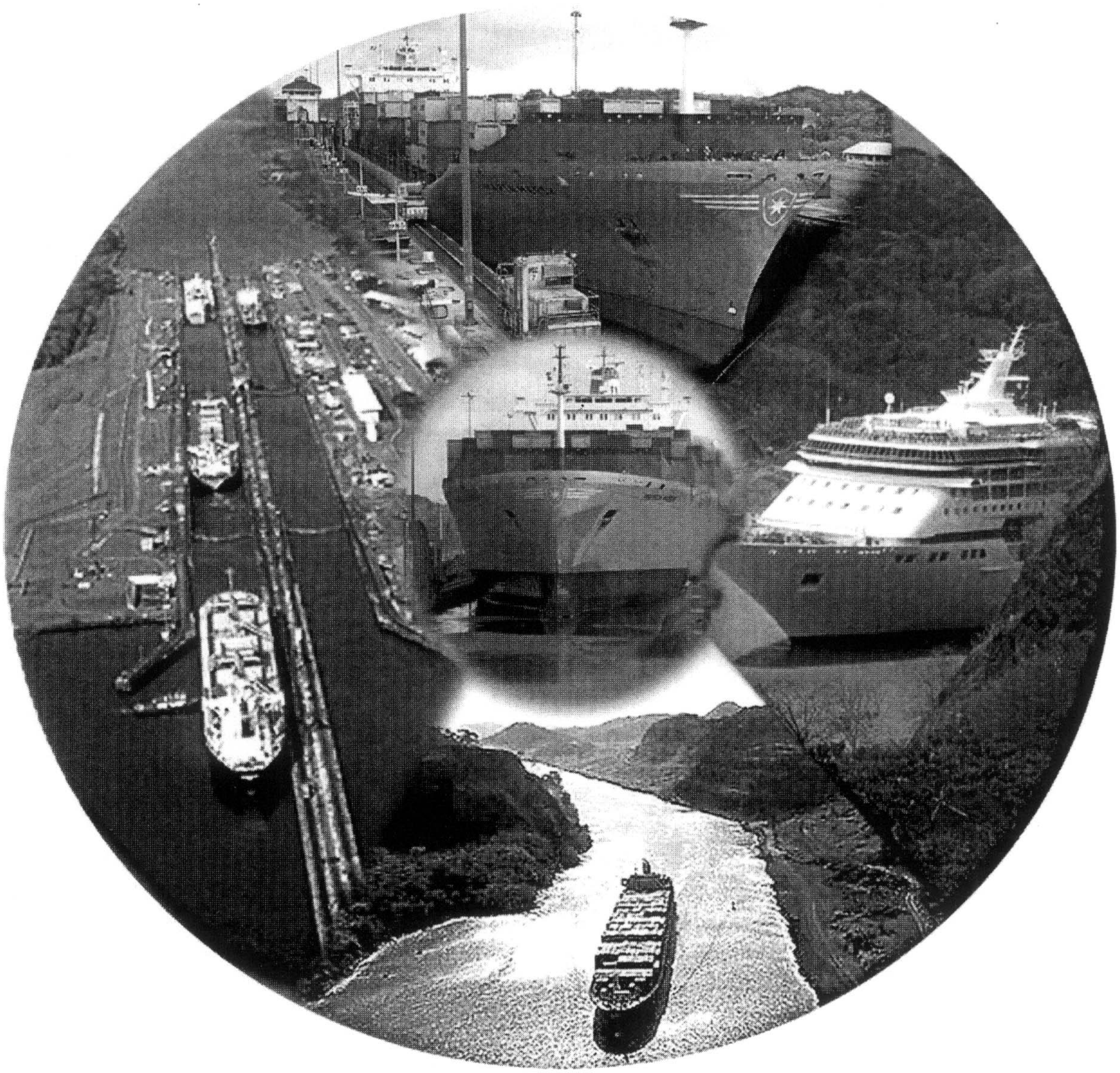
10. Generate synthetic flows.

11. Compute maximum, minimum, and average flows for the entire and specified period of filled-in data set.

14.2 Generation of 100-Year Time Series

The HEC-4 model was used to generate 10 sets each of 100-year period based on the 90 years (1911 to 2000) of monthly rainfall data for the three rainfall series and 60 years (1941 to 2000) of monthly flow data for the three flow series discussed above. HEC-4 input and output files are given in Appendix G. The appendix also includes the copy of synthetic flows.

15.0 Analysis of El Nino Effect on Time Series



15.0 ANALYSIS OF EL NINO EFFECT ON TIME SERIES

15.1 General

A large-scale coupled ocean-atmosphere oscillation in the Pacific Ocean, known as the El Nino-Southern Oscillation (ENSO), is generally related to inter-annual variation in precipitation and streamflow in several regions of the world. ENSO events are warming episodes of the eastern equatorial Pacific Ocean that influence the global climate on a time scale of years to decades. It is also recognized that the ENSO temperature signal pervades the entire tropical belt. Recent studies indicate that ENSO events can be predicted with reasonable accuracy one to two years in advance using a physical model of the coupled ocean-atmosphere system. Therefore, the ability to predict flow patterns in rivers can be enhanced if a strong relationship exists between river flows and ENSO index (extract from Amarasekera, et al., 1997).

The indices observed to quantify ENSO include sea surface temperature (SST) anomalies, southern oscillation index (SOI), wind indices at 850-hPa and 200hPa and outgoing long-wave solar radiation (OLR). Two indices – SST and SOI are more commonly used. The SST anomaly is the sea surface temperature departure from the long-term mean, averaged over a well-defined area of the eastern and central equatorial Pacific Ocean. The SOI is the difference in the standardized sea level pressure between Tahiti and Darwin, also in the equatorial Pacific. El Nino events, which occur every 2-7 years, are associated with high SST anomalies and a corresponding low SOI. The warm El Nino phase is characterized by elevated temperatures throughout the tropics. Conversely, La Nina events are episodes of low SST anomalies and high SOI. This phase is characterized by suppressed temperatures throughout the tropics.

15.2 Major El Nino Episodes

El Nino episodes have been observed as far back as 1525. A list of warm phase years of El Nino is provided in Table 15.1. The information was derived from previous reports (Amarasekera, et al., 1997; and C.V.G., Julio 1997). The most recent episodes are of 1976/77, 1982/83, 1991/92, 1993/94 and 1997/98. The data on SST, SOI and other climatic indices are published in the monthly "Climate Diagnostics Bulletin" by the Climate Prediction Center (CPC) on a monthly basis. The bulletin includes the following data.

- Sea level pressure (SLP) at Tahiti and Darwin
- Tahiti minus Darwin southern oscillation index (SOI), standardized by the mean annual standard deviation

- 850-hPa zonal wind standardized by the mean annual standard deviation, averaged over 5N – 5S, 135E – 180W; 5N – 5S, 175W – 140W; and 5N – 5S, 135W – 110W

- 200-hPa wind index standardized by the mean annual standard deviation, averaged over 5N – 5S, 165W – 110W

- Outgoing long-wave radiation (OLR) index, standardized by the mean annual standard deviation, averaged over 5N – 5S, 160E – 160W

- Pacific SST observed as Nino 1+2 (0-10S and 90W-80W), Nino 3 (5N-5S and 150W-90W), Nino 3.4 (5N-5S and 170W-120W) and Nino 4 (5N-5N and 160E-150W)

- Atlantic SST observed as North Atlantic (5N-20N and 60W-30W) and South Atlantic (0-20S and 30W-10E)

- Global SST reported for region 10N-10S and 0W-360W.

The data can be obtain through the following web site:

http://www.cpc.ncep.noaa.gov/data/indices/index.html

The data for the period 1951 to date are available from the above source. The data for Pacific SST and SOI were retrieved. Pacific monthly SST anomalies and SOI are shown on Exhibits 15.1 and 15.2, respectively. The study area is relatively close to El Nino 3 and the North Atlantic (see Exhibit 15.3). SST anomalies in the North Atlantic (see Exhibit 15.4) were compared with the basin average rainfall and inflows data. There was no apparent correlation between the two. The data for OLR was available from 1972 but was missing for some years. This also could not be used. Therefore, further analysis was continued with the Pacific SST Nino 3 region monthly data and monthly SOI (see Exhibit 15.5).

15.3 Review of Previous Investigations

CVG (July 1997) compared the annual flows of the Caroni River at Guri with the years in which the El Nino episode occurred. This showed that for most of the El Nino years the annual flow was less than normal. Graphs were also presented for the months of July through December indicating that during the El Nino episodes the flows were either above or below normal, without any regular pattern. There was correlation developed between the El Nino climatic indices and rainfall or runoff in Venezuela.

TABLE 15.1

EL NINO EPISODES REPORTED IN VARIOUS REPORTS

Year	Year	Year	Year	Year
1525	1634	1747	1899	1946
1531	1652	1761	1902	1951
1539	1660	1775	1905	1953
1552	1671	1785	1911	1957/58
1567	1681	1791	1914	1965
1574	1687	1803	1917/18	1969
1578	1696	1814	1923	1972/73
1591	1701	1828	1925	1976/77
1607	1707	1844	1930	1982/83
1614	1714	1887	1832	1986/87
1618	1720	1891	1939	1991/92
1624	1728	1896	1941	1993

Amarasekera and others (1997) attempted correlation between the annual discharge of several major rivers and SST index of El Nino. The total discharge of each river over the 12-month seasonal cycle was assumed to capture the long-term variability due to ENSO. The seasonal cycle of each river was defined as a 12-month period starting from the month of lowest average discharge for each year. The annual discharges were plotted against eight quarterly averages of the SST anomaly. These quarterly averages of mean monthly SST anomalies were used as the SST index of ENSO. The selected quarters were: Sep-Oct-Nov, Dec-Jan-Feb, Mar-Apr-May, Jun-Jul-Aug, Sep-Oct-Nov, Dec-Jan-Feb, Mar-Apr-May and Jun-Jul-Aug. The quarter giving maximum correlation was judged to be the best representative for the annual flows at that particular location.

Estoque and others (1985) studied the effect of El Nino on the rainfall in Panama. Thirteen episodes of El Nino during the period, 1920 to 1983 were analyzed. The rainfall stations selected were in the Panama Canal watershed and other parts of Panama. The stations in the Panama Canal included Cristobal (Atlantic side), Alhajuela and Gamboa (Central section), and Balboa Heights (Pacific side). The results indicated that El Nino produced below normal rainfall. The average annual deviation for the Panama Canal area was 8 percent below normal for an El Nino of average intensity. In the case of strong episodes of 1976 and 1982, the corresponding values were 28 percent and 24 percent below normal, respectively. The driest month of the year December 1982 had a rainfall of about 60 percent below normal. The results of these studies also showed that there was considerable geographical variation of the effects of the El Nino. In the case of 1976 El Nino, the largest magnitudes of negative deviations were located generally in the southwestern part of Panama, just south of the central cordillera. On the other hand, the

1976 El Nino had the opposite effect, or positive rainfall anomalies, north of the cordillera in the Atlantic coastal region. The occurrence of negative anomalies during El Nino years in Panama appears to be consistent with the idea that the intertropical convergence zone (ITCZ) shifts its position southward during those years. Most of the rainfall in Panama is due to the ITCZ. A southward displacement of the ITCZ, away from Panama, produces low rainfall, resulting in negative rainfall deviations. This southward shift of ITCZ produces positive rainfall anomalies over Peru. The authors also attempted to correlate the rainfall anomalies with the temperature anomalies using a multivariate regression equation. A reasonable negative correlation was developed between the rainfall anomalies and the sea surface temperature anomalies during the preceding months.

Giannini and others (January 2000) examined the large-scale ocean-atmosphere patterns that influence the interannual variability of Caribbean (Central American) rainfall. It was inferred that the atmospheric circulation over the study region is affected by the North Atlantic subtropical high sea level pressure system and the eastern Pacific ITCZ. Correlation analyses were made between the rainfall over the Caribbean region (5N-25N and 90W-60W), and SLP and SST over the eastern Pacific and Atlantic Oceans (35S-45N and 150W-15E). The analysis indicated that Nino-3 and the strength of the North Atlantic High are the climatic indices relevant to Caribbean rainfall variability. Most of the discussion presented in the paper provided qualitative inferences. No regression equations were presented between the rainfall and climatic indices.

German and others studied the seasonality in ENSO-related precipitation, river discharges, soil moisture and vegetation index in Columbia. The conclusions reached were that El Nino produces drier than normal and more prolonged seasonal dry periods in Columbia and that La Nina amplifies the wetness of the wet season. Rainfall and runoff data at stations in the western and central region of the country were found to correlate with SOI during the months of December-January-February.

15.4 Relationship between Rainfall and SST/SOI

Long-term annual basin average rainfalls were estimated to be 2,837 mm, 2,576 mm and 2,663 mm for Madden Lake, Gatun Downstream and Gatun Total, respectively. These were compared with the basin average rainfall in the El Nino years (Exhibit 15.6). The most severe episodes were of 1976-77, 1982 and 1997. The annual rainfalls were about 25 to 35 percent less than the normal. On a monthly basis (Exhibit 15.7), the worst affected months were normally November through March. The rainfall during these months could be as low as 70 to 90 percent of the normal.

15.5 Relationship between Streamflow and SST/SOI

Comparisons of long-term annual and monthly flows (Madden Lake and Gatun Downstream) are given on Exhibits 15.8 and 15.9. The years of 1976-77, 1982 and 1997 were the most severe episodes. The flows were about 20 to 30 percent less than normal on annual basis. On monthly basis, the flows were up to about 70 percent less than normal during the months of November to March. Generally, the most effected month was December.

15.6 General Observations

The following observations were made from a review of the percentage reductions in rainfall/runoff:

- Dry months may start one or two months ahead of the warming episode.
- During an episode, there could be higher than normal rainfall/runoff. This implies that although El Nino is the primary index to shift ITCZ, there could be other important factors affecting ITCZ during an episode.
- After the ending of an episode, the rainfall/runoff may be below normal due to some other factors.
- There is no clear indication of a relationship between the magnitudes of anomalies or SOI and the reduction in rainfall/runoff. Extensive analyses are required to look for a relationship. Even then, a meaningful relationship may not exist.
- North Atlantic and El Nino 3 region anomalies did not have any correspondence. The North Atlantic anomalies occurred much earlier than the dry conditions in the Gatun watershed. El Nino 3 region anomalies did show some relationship.

PACIFIC MONTHLY SEA SURFACE TEMPERATURE (SST) ANOMALIES

		NINO 1+2	NINO 3	NINO 3.4	NINO 4		NINO 1+2	NINO 3	NINO 3.4	NINO 4		NINO 1+2	NINO 3	NINO 3.4	NINO 4
	Latitude	0-10S	5N-5S	5N-5S	5N-5S		0 - 10 S	5 N - 5 S	5 N - 5 S	5 N - 5 S		0 - 10 S	5 N - 5 S	5 N - 5 S	5 N - 5 S
	Longitude	80-90W	90-150W	120-170W	160W-160E		80-90W	90-150W	120-170W	160W-160E		80-90W	90-150W	120-170W	160W-160E
1950	1	-1.00	-1.64	-1.50	-0.73	1967	-0.72	-0.49	-0.36	-0.40	1984	-0.23	-0.82	-0.91	-0.50
	2	-1.49	-1.85	-1.77	-1.24		-0.40	-0.14	-0.27	-0.45		-0.71	-0.15	-0.32	-0.76
	3	-0.89	-0.43	-0.73	-1.09		-0.73	-0.67	-0.57	-0.20		-0.34	0.05	-0.26	-0.88
	4	-1.62	-0.76	-0.94	-1.28		-0.24	-0.88	-0.82	-0.06		-0.17	-0.06	-0.29	-0.70
	5	-0.93	-1.14	-1.47	-0.92		-0.45	-0.30	-0.26	-0.01		-1.01	-0.60	-0.37	-0.68
	6	-1.32	-0.74	-0.70	-0.79		-0.84	0.17	0.24	-0.09		-1.03	-1.00	-0.64	-0.52
	7	-1.11	-0.41	-0.48	-0.73		-0.86	-0.45	-0.15	-0.07		-0.56	-0.62	-0.32	-0.21
	8	-0.30	-0.44	-0.59	-0.91		-1.09	-0.72	-0.22	-0.10		-0.60	-0.45	-0.36	-0.28
	9	-0.65	-0.71	-1.09	-1.37		-1.28	-1.17	-0.61	-0.16		-0.07	-0.49	-0.22	0.12
	10	-0.72	-0.57	-0.57	-0.77		-1.50	-1.09	-0.51	0.01		-0.36	-0.94	-0.67	-0.13
	11	-1.22	-1.15	-1.09	-1.23		-1.47	-0.97	-0.33	0.01		-0.16	-0.93	-1.11	-0.38
	12	-0.92	-0.64	-0.93	-1.01		-1.54	-0.87	-0.37	0.08		-0.23	-1.38	-1.47	-0.85
1951	1	0.65	-0.51	-1.04	-0.79	1968	-1.31	-1.12	-0.63	-0.11	1985	-0.83	-1.10	-1.07	-0.43
	2	-0.60	0.20	-0.07	-1.09		-1.26	-1.45	-0.92	0.14		-1.09	-1.15	-1.00	-0.44
	3	-0.58	-0.50	-0.70	-0.80		-1.31	-1.15	-0.60	-0.08		-0.63	-0.98	-0.91	-0.70
	4	-0.18	0.27	0.05	-0.47		-1.38	-0.70	-0.41	-0.04		-1.12	-0.88	-0.89	-0.68
	5	0.57	-0.02	-0.22	-0.33		-1.80	-0.93	-0.57	-0.32		-1.97	-0.95	-0.65	-0.59
	6	1.54	0.09	0.04	0.66		-1.42	-0.22	0.10	0.21		-1.22	-0.77	-0.63	-0.58
	7	2.19	0.96	0.41	-0.09		-0.72	0.32	0.40	-0.06		-1.37	-0.84	-0.39	-0.29
	8	1.61	1.01	0.74	0.23		-0.09	0.31	0.44	0.26		-1.50	-0.57	-0.22	-0.15
	9	1.05	0.62	0.38	-0.06		0.39	0.12	0.05	0.03		-1.02	-0.67	-0.40	-0.16
	10	1.29	0.99	0.80	0.10		0.25	0.23	0.32	0.42		-1.00	-0.72	-0.41	-0.14
	11	1.22	1.01	0.80	0.51		-0.33	0.37	0.85	0.82		-0.95	-0.67	-0.32	0.16
	12	0.18	0.91	0.72	0.08		0.16	0.64	0.80	0.73		-0.40	-0.79	-0.36	0.24
1952	1	-0.01	0.29	0.37	0.29	1969	0.27	0.76	1.18	1.20	1986	0.19	-0.87	-0.70	-0.02
	2	0.38	0.34	0.34	0.13		-0.50	0.39	1.12	1.33		0.10	-0.54	-0.75	-0.08
	3	0.03	-0.14	-0.26	-0.11		0.40	0.61	0.84	0.77		-0.45	-0.23	-0.49	-0.14
	4	-0.92	0.16	0.43	0.25		0.96	0.49	0.49	0.65		-0.73	-0.23	-0.24	-0.20
	5	-0.64	-0.42	-0.18	0.01		1.63	0.96	0.81	0.71		-0.84	-0.38	-0.27	-0.06
	6	-0.67	-0.62	-0.43	-0.06		1.28	0.72	0.60	0.34		-0.98	-0.07	0.19	0.21
	7	-1.11	-0.46	-0.26	-0.40		0.39	0.22	0.20	0.18		-0.67	0.13	0.30	0.33
	8	-0.87	-0.10	0.13	0.11		0.19	0.55	0.63	0.41		0.19	0.08	0.45	0.58
	9	-0.35	-0.24	-0.15	-0.10		0.21	0.61	0.63	0.56		0.00	0.43	0.70	0.70
	10	-0.46	-0.27	0.10	0.09		0.88	0.77	0.85	0.78		0.19	0.73	0.96	0.93
	11	-0.96	-0.42	-0.15	-0.23		0.65	0.78	0.73	0.53		0.40	0.97	1.22	1.03
	12	-0.30	-0.63	-0.48	-0.12		0.61	1.18	1.15	0.52		0.20	0.77	1.22	0.90
1953	1	-0.30	0.30	0.51	0.43	1970	0.44	0.92	0.88	0.55	1987	0.88	1.07	1.39	0.88
	2	0.29	0.45	0.39	0.16		-0.42	0.21	0.41	0.54		1.17	1.06	1.34	0.93
	3	0.73	0.32	0.27	-0.03		-0.91	-0.15	0.28	0.21		1.65	1.13	1.35	0.95
	4	1.38	0.82	0.71	0.17		-0.98	0.06	0.45	0.22		1.82	1.09	1.11	0.80
	5	0.90	0.38	0.14	-0.16		-1.21	-0.69	-0.07	0.21		1.29	1.15	0.99	0.61
	6	0.72	0.53	0.38	0.00		-1.69	-1.00	-0.40	-0.07		1.07	1.33	1.54	0.90
	7	0.60	0.46	0.58	0.32		-2.15	-1.71	-0.86	-0.07		0.96	1.49	1.72	0.90
	8	0.86	0.17	0.12	0.16		-1.52	-1.40	-0.88	-0.56		0.94	1.57	1.88	0.96
	9	1.03	0.86	0.81	0.26		-0.98	-1.26	-1.06	-0.77		1.01	1.75	1.75	1.03
	10	0.17	0.24	0.31	-0.05		-0.62	-1.21	-1.19	-0.86		1.54	1.31	1.47	1.20
	11	0.39	0.32	0.43	0.23		-1.36	-1.54	-1.44	-0.96		1.06	1.17	1.47	1.44
	12	-0.37	0.27	-0.05	-0.64		-1.05	-1.68	-1.84	-1.42		0.71	1.11	1.13	1.16
1954	1	-1.43	0.15	0.57	0.41	1971	-1.17	-1.26	-1.50	-1.33	1988	0.20	0.51	0.81	0.99
	2	-0.82	0.04	0.26	0.03		-1.38	-1.41	-1.42	-1.07		-0.23	0.18	0.53	0.69
	3	-0.65	-0.03	0.21	0.00		-1.57	-0.92	-1.03	-0.95		-0.58	0.05	0.17	0.11

PACIFIC MONTHLY SEA SURFACE TEMPERATURE (SST) ANOMALIES

		NINO 1+2	NINO 3	NINO 3.4	NINO 4		NINO 1+2	NINO 3	NINO 3.4	NINO 4		NINO 1+2	NINO 3	NINO 3.4	NINO 4
Latitude		0-10S	5N-5S	5N-5S	5N-5S		0 - 10 S	5 N - 5 S	5 N - 5 S	5 N - 5 S		0 - 10 S	5 N - 5 S	5 N - 5 S	5 N - 5 S
Longitude		80-90W	90-150W	120-170W	160W-160E		80-90W	90-150W	120-170W	160W-160E		80-90W	90-150W	120-170W	160W-160E
	4	-2.41	-1.15	-0.30	-0.07		-0.36	-0.71	-1.05	-0.83		-0.79	-0.67	-0.35	-0.25
	5	-2.54	-1.04	-0.30	-0.07		-1.37	-0.68	-0.60	-0.66		-0.62	-1.84	-1.28	-0.28
	6	-2.00	-1.04	-0.43	-0.34		-1.16	-0.66	-0.56	-0.52		-1.68	-1.90	-1.37	-0.51
	7	-1.96	-1.12	-0.76	-0.58		-0.59	-0.47	-0.44	-0.66		-1.53	-1.86	-1.50	-0.69
	8	-1.04	-1.22	-1.06	-0.43		-0.96	-0.81	-0.46	-0.59		-1.67	-1.58	-1.46	-0.77
	9	-1.24	-1.08	-1.09	-0.84		-0.68	-0.89	-0.76	-0.84		-1.27	-1.22	-1.21	-0.86
	10	-1.71	-1.07	-0.80	-0.52		-0.84	-0.98	-0.67	-0.60		-1.40	-1.72	-1.98	-1.35
	11	-1.22	-0.89	-0.87	-1.05		-0.56	-1.05	-0.94	-0.74		-1.09	-1.95	-2.27	-1.59
	12	-1.59	-0.95	-0.95	-1.14		-0.87	-1.14	-0.86	-0.54		-0.99	-2.02	-2.14	-1.52
1955	1	-0.78	-1.03	-1.39	-1.24	1972	0.14	-0.49	-0.67	-0.51	1989	-0.31	-1.43	-1.96	-1.60
	2	-1.41	-0.10	-0.42	-1.13		0.77	-0.16	-0.20	0.13		0.29	-0.75	-1.36	-1.46
	3	-0.97	-0.81	-0.83	-0.76		0.83	-0.11	-0.06	0.07		0.30	-1.07	-1.24	-1.09
	4	-1.12	-0.51	-0.67	-0.99		0.89	0.51	0.40	0.53		0.29	-0.74	-1.00	-0.86
	5	-1.81	-1.48	-1.11	-0.90		1.17	0.60	0.60	0.75		-1.07	-0.69	-0.68	-0.51
	6	-1.90	-1.06	-0.78	-0.56		1.84	1.04	0.85	0.58		-0.92	-0.29	-0.51	-0.70
	7	-1.29	-0.66	-0.69	-0.75		2.22	1.45	1.09	0.71		-0.67	-0.31	-0.34	-0.38
	8	-1.06	-0.76	-0.78	-0.91		2.45	1.92	1.43	0.49		-0.47	-0.40	-0.39	-0.32
	9	-1.00	-1.73	-1.63	-0.78		1.65	1.52	1.22	0.47		-0.58	-0.38	-0.38	-0.23
	10	-1.56	-1.67	-1.77	-1.78		1.65	1.91	1.78	0.92		-0.56	-0.40	-0.34	-0.02
	11	-1.69	-2.25	-2.18	-1.50		1.72	2.16	2.11	1.06		-0.38	-0.40	-0.28	-0.13
	12	-1.74	-1.48	-1.43	-1.17		1.85	2.42	2.14	0.91		-0.61	-0.37	-0.09	0.24
1956	1	-0.82	-1.33	-1.19	-0.88	1973	1.85	1.76	1.74	0.98	1990	-0.43	-0.27	0.04	0.43
	2	-1.26	-0.41	-0.51	-0.73		0.45	1.03	1.29	0.79		-0.14	0.01	0.26	0.62
	3	-0.72	-0.60	-0.78	-0.96		-0.33	0.28	0.68	0.44		-0.23	-0.06	0.32	0.68
	4	-0.40	-0.51	-0.77	-0.83		-0.94	-0.52	-0.15	-0.04		-0.11	0.26	0.33	0.51
	5	-1.04	-0.41	-0.13	-0.40		-0.86	-0.94	-0.50	0.05		-0.19	0.30	0.30	0.31
	6	-0.73	-0.34	-0.34	-0.58		-1.51	-1.04	-0.80	-0.44		-0.29	0.08	0.09	0.30
	7	-0.23	-0.65	-0.76	-1.04		-1.10	-1.20	-1.04	-0.45		-0.82	-0.13	0.18	0.41
	8	-0.16	-0.73	-0.72	-0.73		-1.34	-1.30	-1.05	-0.62		-0.54	0.11	0.35	0.72
	9	-0.48	-0.95	-0.86	-1.06		-1.22	-1.23	-1.20	-0.93		-0.31	0.02	0.10	0.55
	10	-1.08	-0.46	-0.30	-0.66		-1.23	-1.32	-1.35	-1.16		-0.62	0.01	0.38	0.82
	11	-0.82	-1.06	-0.88	-0.44		-0.97	-1.48	-1.75	-1.30		-0.81	-0.13	0.21	0.71
	12	-1.23	-0.71	-0.28	-0.22		-1.22	-1.54	-1.90	-1.62		-0.34	0.00	0.43	0.84
1957	1	-1.24	-0.81	-0.35	0.02	1974	-1.17	-1.64	-1.93	-1.53	1991	-0.58	0.04	0.51	0.86
	2	0.28	0.05	0.19	0.42		-1.12	-1.20	-1.49	-1.27		-0.01	-0.10	0.24	0.73
	3	0.99	0.26	0.23	0.04		-0.44	-0.70	-1.10	-0.98		0.18	-0.09	0.11	0.54
	4	1.40	0.53	0.48	0.52		-0.17	-0.58	-0.79	-0.89		-0.35	-0.09	0.30	0.72
	5	1.95	0.49	0.37	0.56		0.08	-0.57	-0.94	-0.86		0.18	0.52	0.59	0.79
	6	1.89	0.85	0.41	0.03		-0.34	-0.22	-0.31	-0.68		0.13	0.97	0.87	0.72
	7	1.97	1.00	0.75	0.33		-0.25	-0.08	-0.36	-0.77		0.24	0.99	0.84	0.69
	8	1.51	1.39	1.27	0.57		-0.35	-0.18	-0.40	-0.47		0.29	0.52	0.73	0.80
	9	1.42	0.48	0.36	0.47		-0.55	-0.47	-0.45	-0.76		0.31	0.19	0.41	0.69
	10	0.85	0.71	0.79	0.28		-0.89	-0.74	-0.73	-0.82		0.24	0.73	1.04	1.03
	11	0.72	1.24	1.42	0.81		-0.73	-0.90	-0.93	-0.86		0.52	1.03	1.34	1.09
	12	0.91	1.60	1.61	0.60		-1.42	-0.85	-0.69	-0.65		0.64	1.43	1.89	1.14
1958	1	0.47	1.48	1.91	1.01	1975	-0.81	-0.44	-0.43	-0.68	1992	0.40	1.39	1.90	0.92
	2	0.70	1.01	1.55	1.37		-1.15	-0.63	-0.36	-0.18		0.71	1.31	1.94	1.02
	3	0.59	0.69	1.22	1.11		-0.31	-0.52	-0.55	-0.56		1.40	1.24	1.69	0.99
	4	0.99	0.33	0.53	0.61		-0.02	-0.29	-0.54	-0.66		2.34	1.31	1.46	1.01
	5	0.74	-0.03	0.35	0.58		-0.98	-1.06	-0.89	-0.88		2.06	1.37	1.23	0.82

PACIFIC MONTHLY SEA SURFACE TEMPERATURE (SST) ANOMALIES

		NINO 1+2	NINO 3	NINO 3.4	NINO 4		NINO 1+2	NINO 3	NINO 3.4	NINO 4		NINO 1+2	NINO 3	NINO 3.4	NINO 4
	Latitude	0-10S	5N-5S	5N-5S	5N-5S		0 - 10 S	5 N - 5 S	5 N - 5 S	5 N - 5 S		0 - 10 S	5 N - 5 S	5 N - 5 S	5 N - 5 S
	Longitude	80-90W	90-150W	120-170W	160W-160E		80-90W	90-150W	120-170W	160W-160E		80-90W	90-150W	120-170W	160W-160E
	6	0.02	0.22	0.61	0.55		-1.31	-1.13	-1.09	-1.11		0.87	0.29	0.53	0.66
	7	0.53	0.15	0.26	0.37		-0.87	-0.81	-0.94	-1.05		0.14	-0.05	0.45	0.78
	8	-0.26	0.14	0.52	0.44		-0.77	-0.81	-1.15	-1.31		-0.23	-0.25	-0.07	0.45
	9	0.25	-0.62	-0.51	0.03		-1.66	-1.14	-1.33	-1.45		-0.38	-0.31	-0.16	0.31
	10	0.05	-0.30	0.11	0.50		-1.78	-1.49	-1.53	-1.57		-0.06	-0.27	-0.27	0.28
	11	-0.04	-0.17	0.20	0.45		-2.07	-1.23	-1.28	-1.47		-0.14	-0.17	-0.01	0.34
	12	-0.36	0.05	0.54	0.66		-1.91	-1.71	-1.66	-1.66		-0.32	-0.08	0.25	0.47
1959	1	-0.40	-0.11	0.55	0.82	1976	-0.75	-1.78	-1.85	-1.24	1993	0.01	-0.05	0.18	0.47
	2	-0.37	0.07	0.61	0.50		-0.42	-0.97	-1.08	-0.84		0.53	0.25	0.28	0.40
	3	0.59	-0.29	0.10	0.35		-0.27	-0.59	-0.66	-0.56		0.81	0.45	0.52	0.50
	4	0.42	0.17	0.28	0.25		0.32	-0.50	-0.69	-0.34		1.11	1.04	0.89	0.52
	5	-0.07	0.12	0.16	0.40		0.99	-0.17	-0.54	-0.50		0.91	1.10	1.06	0.49
	6	-0.39	-0.34	-0.13	-0.25		1.37	0.51	-0.10	-0.41		0.81	0.74	0.79	0.53
	7	-0.40	-0.63	-0.46	-0.28		1.61	0.65	0.13	-0.38		0.27	0.19	0.48	0.62
	8	-0.48	-0.63	-0.38	-0.16		1.37	0.84	0.37	-0.22		0.27	-0.02	0.13	0.48
	9	-0.06	-0.57	-0.60	-0.21		1.21	0.95	0.56	-0.13		0.40	0.14	0.27	0.58
	10	0.00	-0.16	-0.07	0.09		0.61	0.95	0.98	0.45		0.10	0.33	0.34	0.49
	11	0.30	-0.19	-0.11	-0.17		0.32	0.85	0.96	0.56		-0.02	0.22	0.40	0.61
	12	-0.14	-0.18	-0.08	-0.23		0.86	0.77	0.73	0.07		-0.05	0.24	0.30	0.62
1960	1	0.08	-0.08	-0.03	-0.43	1977	0.82	0.86	0.87	0.18	1994	-0.10	0.09	0.08	0.33
	2	-0.33	-0.44	-0.35	-0.32		-0.07	0.46	0.33	-0.12		-0.17	-0.28	-0.10	0.06
	3	-0.33	-0.13	0.02	-0.08		-0.13	0.33	0.40	-0.06		-0.90	-0.20	0.13	0.16
	4	-0.74	-0.09	0.15	-0.05		-0.21	-0.40	-0.11	-0.08		-1.02	-0.34	0.22	0.22
	5	-0.58	-0.43	-0.12	-0.26		-0.39	-0.11	0.27	0.17		-1.03	-0.07	0.28	0.36
	6	-0.87	-0.41	-0.14	-0.30		-0.20	0.08	0.36	0.15		-0.52	0.13	0.49	0.54
	7	-0.84	-0.22	0.00	-0.13		-0.10	-0.09	0.30	0.41		-0.60	-0.39	0.28	0.82
	8	-0.45	-0.06	0.19	-0.27		-0.54	-0.38	0.14	0.28		-1.08	-0.24	0.65	1.01
	9	0.07	-0.01	-0.01	-0.09		-0.61	-0.13	0.32	0.47		-0.28	-0.02	0.35	0.75
	10	-0.69	-0.64	-0.32	-0.05		0.07	0.37	0.71	0.47		0.65	0.65	0.90	1.04
	11	-0.77	-0.83	-0.40	0.01		-0.03	0.40	0.77	0.75		0.77	0.92	1.36	1.27
	12	-0.10	-0.43	-0.17	0.38		-0.35	0.25	0.69	0.65		0.81	0.98	1.40	1.21
1961	1	-0.04	-0.51	-0.29	-0.11	1978	-0.15	0.37	0.83	0.65	1995	0.91	0.73	1.04	1.06
	2	0.51	0.06	-0.08	-0.03		-0.06	-0.10	0.24	0.46		0.47	0.51	0.76	1.01
	3	-0.57	-0.21	-0.11	-0.32		-0.94	-0.14	0.22	0.18		-0.25	-0.01	0.48	0.86
	4	-0.49	0.14	0.08	-0.25		-0.44	-0.73	-0.46	-0.16		-0.87	-0.30	0.25	0.49
	5	-0.63	-0.14	0.08	-0.15		-0.87	-0.83	-0.37	0.21		-1.14	-0.67	-0.04	0.50
	6	-0.64	0.25	0.55	-0.04		-0.93	-0.76	-0.38	-0.07		-0.52	-0.18	0.10	0.37
	7	-1.30	-0.76	-0.18	-0.13		-0.74	-0.65	-0.40	-0.14		-0.58	-0.16	-0.07	0.21
	8	-0.86	-0.69	-0.26	-0.21		-0.79	-0.60	-0.58	-0.30		-0.78	-0.62	-0.37	-0.02
	9	-0.72	-1.22	-0.72	-0.21		-0.61	-0.57	-0.44	-0.01		-0.27	-0.81	-0.68	-0.24
	10	-0.92	-0.92	-0.57	-0.40		-0.56	-0.31	-0.18	-0.17		-0.74	-0.88	-0.94	-0.34
	11	-0.61	-0.60	-0.35	-0.12		0.31	-0.15	-0.11	-0.01		-0.42	-0.93	-0.86	-0.39
	12	-0.77	-0.22	-0.19	-0.26		0.46	0.27	0.06	-0.01		-0.78	-0.89	-0.91	-0.21
1962	1	-0.38	-0.27	-0.34	-0.50	1979	0.28	-0.21	-0.01	0.37	1996	-0.59	-0.65	-0.77	-0.22
	2	-0.49	-0.25	-0.33	-0.37		-0.34	-0.09	0.00	0.13		-0.26	-0.64	-0.84	-0.43
	3	-1.85	-0.57	-0.27	-0.31		-0.23	0.19	0.46	0.36		-0.28	-0.38	-0.52	-0.38
	4	-1.89	-0.80	-0.40	-0.13		-0.07	0.22	0.20	0.10		-1.49	-0.68	-0.32	-0.33
	5	-0.86	-0.81	-0.52	-0.38		-0.21	0.11	0.05	0.11		-1.35	-0.72	-0.35	-0.19
	6	-1.17	-0.41	-0.09	-0.26		0.27	0.38	0.27	0.13		-1.40	-0.48	-0.16	-0.09
	7	-1.28	-0.28	-0.03	-0.19		0.33	-0.12	-0.24	0.01		-1.76	-0.23	0.01	-0.08
	8	-0.45	-0.02	0.10	-0.22		0.39	0.07	-0.02	-0.06		-1.25	-0.34	-0.13	0.09

Exhibit 15.1
Sheet 4 of 4

PACIFIC MONTHLY SEA SURFACE TEMPERATURE (SST) ANOMALIES

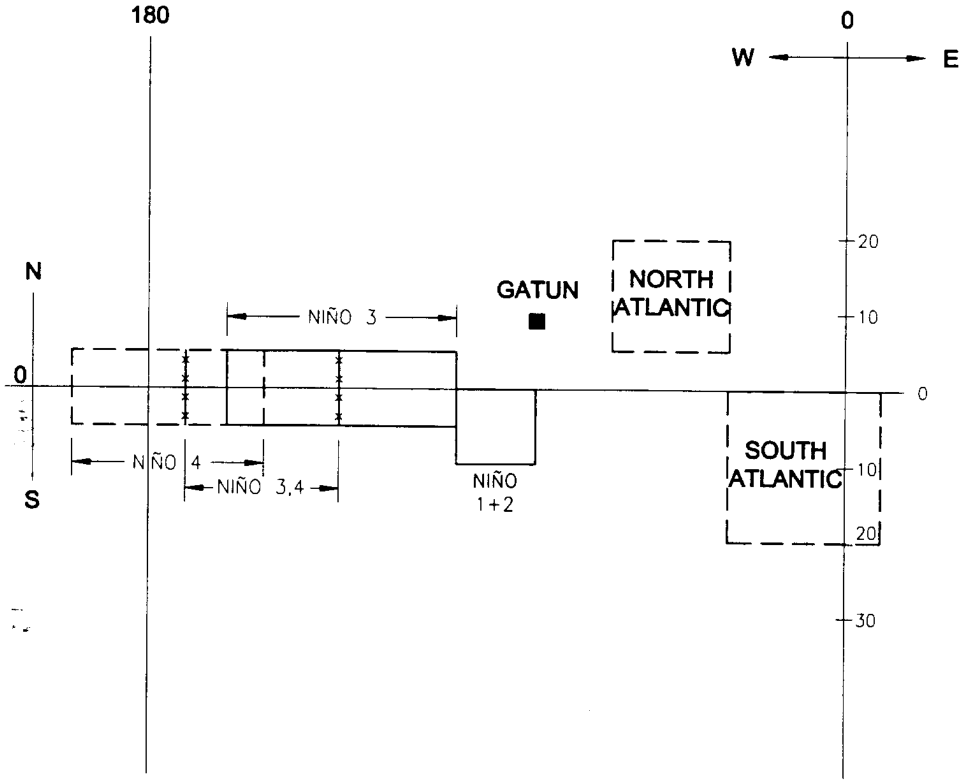
		NINO 1+2	NINO 3	NINO 3.4	NINO 4		NINO 1+2	NINO 3	NINO 3.4	NINO 4		NINO 1+2	NINO 3	NINO 3.4	NINO 4
	Latitude	0-10S	5N-5S	5N-5S	5N-5S		0 - 10 S	5 N - 5 S	5 N - 5 S	5 N - 5 S		0 - 10 S	5 N - 5 S	5 N - 5 S	5 N - 5 S
	Longitude	80-90W	90-150W	120-170W	160W-160E		80-90W	90-150W	120-170W	160W-160E		80-90W	90-150W	120-170W	160W-160E
	9	-0.31	-0.62	-0.54	-0.34		0.83	1.00	0.86	0.22		-1.20	-0.46	-0.30	-0.06
	10	-0.99	-0.62	-0.43	-0.47		0.69	0.37	0.27	0.17		-0.93	-0.52	-0.36	0.02
	11	-0.80	-0.85	-0.55	-0.22		0.52	0.30	0.37	0.43		-1.37	-0.57	-0.32	-0.03
	12	-1.01	-0.93	-0.65	-0.44		0.41	0.40	0.56	0.53		-1.18	-0.88	-0.45	0.16
1963	1	-0.38	-0.56	-0.64	-0.75	1980	0.29	0.45	0.62	0.66	1997	-0.76	-0.91	-0.55	0.27
	2	-0.68	-0.55	-0.50	-0.27		-0.27	0.18	0.49	0.75		-0.23	-0.61	-0.32	0.33
	3	-0.60	-0.14	0.00	-0.19		0.13	-0.17	0.13	0.56		0.59	-0.10	-0.12	0.42
	4	-0.92	0.18	0.14	-0.24		0.34	-0.03	0.17	0.42		1.30	0.19	0.34	0.91
	5	-0.17	-0.10	-0.21	-0.28		0.21	0.07	0.20	0.40		2.47	1.00	0.85	0.82
	6	-0.42	0.30	0.11	-0.35		0.25	0.50	0.62	0.35		3.33	1.76	1.44	0.76
	7	0.16	0.85	0.93	0.44		-0.33	0.00	0.25	0.25		3.81	2.43	1.84	0.93
	8	0.64	0.90	0.92	0.36		-0.05	-0.26	-0.11	-0.04		4.00	2.89	2.13	0.81
	9	0.69	0.61	0.78	0.34		0.19	0.12	-0.05	0.05		3.93	3.00	2.29	0.84
	10	0.09	0.67	0.99	0.65		-0.55	-0.23	-0.09	0.15		3.69	3.27	2.62	0.91
	11	0.24	0.80	0.94	0.34		-0.12	0.16	0.09	0.25		4.05	3.62	2.82	1.13
	12	-0.01	0.97	1.11	0.20		-0.30	0.48	0.43	0.17		4.04	3.67	2.78	1.04
1964	1	-0.32	0.40	0.91	0.53	1981	-1.01	-0.56	-0.40	-0.09	1998	3.79	3.32	2.59	0.87
	2	-1.06	-0.02	0.45	0.20		-0.84	-0.76	-0.53	-0.10		3.01	2.57	2.17	0.86
	3	-1.44	-0.43	-0.18	-0.40		-0.17	-0.29	-0.23	0.08		2.79	2.05	1.52	0.56
	4	-0.94	-0.98	-0.62	-0.16		-0.43	-0.46	-0.40	-0.30		3.28	1.68	0.87	0.13
	5	-2.38	-1.66	-0.94	-0.33		-0.28	-0.32	-0.30	-0.21		3.45	1.11	0.71	0.06
	6	-1.75	-1.33	-0.91	-0.48		-0.28	-0.14	-0.08	-0.18		2.23	-0.37	-0.78	-0.03
	7	-1.42	-0.70	-0.55	-0.40		-0.47	-0.50	-0.43	-0.37		1.64	-0.35	-1.13	-0.50
	8	-1.62	-1.14	-0.71	-0.66		-0.30	-0.93	-0.70	-0.39		0.98	-0.33	-1.22	-0.68
	9	-0.96	-0.89	-1.12	-1.36		-0.54	-0.16	-0.08	-0.09		0.43	-0.64	-1.04	-0.60
	10	-0.95	-0.76	-0.76	-0.83		-0.36	0.04	0.20	0.04		0.28	-0.83	-1.26	-1.07
	11	-0.76	-1.07	-1.19	-0.99		-0.27	-0.17	-1.00	0.10		-0.22	-0.85	-1.33	-1.13
	12	-0.99	-1.39	-1.09	-1.05		0.16	0.36	0.10	0.14		-0.24	-1.22	-1.69	-1.17
1965	1	-0.30	-0.82	-0.69	-0.62	1982	-0.13	0.26	0.22	0.16	1999	-0.69	-1.21	-1.61	-1.55
	2	-0.10	-0.27	-0.28	-0.29		-0.48	-0.01	-0.03	0.17		-0.33	-0.79	-1.28	-1.49
	3	0.20	-0.12	0.01	-0.27		-1.18	-0.12	0.03	0.28		0.26	-0.41	-0.89	-1.19
	4	1.63	0.27	0.07	-0.37		-0.84	0.27	0.33	0.50		-1.03	-0.74	-0.84	-1.06
	5	1.70	0.55	0.33	-0.05		-0.28	0.72	0.77	0.84		-0.78	-0.62	-0.79	-0.78
	6	1.54	0.82	0.78	0.33		-0.04	1.10	1.26	1.13		-1.12	-0.78	-0.90	-0.63
	7	1.49	1.16	1.15	0.49		0.67	0.86	1.01	0.81		-1.36	-0.73	-0.73	-0.65
	8	1.20	1.25	1.34	0.58		0.94	1.21	1.23	0.60		-1.04	-0.93	-1.12	-0.72
	9	0.92	1.20	1.29	0.44		1.36	1.69	1.46	0.68		-1.21	-1.10	-0.94	-0.66
	10	0.76	1.29	1.56	0.85		2.04	2.21	2.03	0.96		-0.84	-1.14	-0.96	-0.56
	11	0.62	1.43	1.62	0.80		2.94	2.64	2.28	0.84		-1.13	-1.50	-1.39	-0.80
	12	0.61	1.55	1.84	0.82		3.29	3.30	2.73	0.83		-1.07	-1.54	-1.56	-1.04
1966	1	0.79	1.17	1.31	0.78	1983	3.01	3.29	2.84	0.85	2000	-0.64	-1.73	-1.85	-1.18
	2	-0.13	0.53	0.98	0.73		2.13	2.54	2.42	0.78		-0.36	-1.05	-1.50	-1.35
	3	-1.07	0.03	0.89	1.07		2.34	2.00	1.88	0.69		-0.35	-0.48	-1.06	-1.33
	4	-1.28	0.13	0.70	0.53		3.22	1.71	1.22	0.44		0.30	0.06	-0.67	-1.04
	5	-1.27	-0.84	-0.10	0.45		3.90	1.91	1.14	0.45		-0.29	-0.26	-0.64	-0.83
	6	-1.18	-0.17	0.53	0.33		4.36	1.77	0.75	0.25		-0.80	-0.53	-0.47	-0.54
	7	-1.03	-0.09	0.37	0.42		4.12	1.03	-0.02	0.08		-1.25	-0.45	-0.36	-0.37
	8	-0.55	-0.30	0.08	0.28		3.00	0.93	-0.18	-0.07		-0.71	-0.48	-0.25	-0.13
	9	-0.84	-0.66	-0.13	0.32		1.82	0.40	-0.21	-0.26		-0.50	-0.47	-0.44	-0.05
	10	-0.27	-0.39	-0.09	0.31		0.97	-0.29	-0.74	-0.65		-0.47	-0.48	-0.64	-0.23
	11	-0.61	-0.71	-0.22	0.25		0.27	-0.79	-0.94	-0.59		-1.08	-0.79	-0.73	-0.26
	12	-0.52	-0.79	-0.30	0.21		0.22	-0.65	-0.89	-0.46		-0.59	-0.66	-0.89	-0.68

EL-NINO SOUTHERN OSCILLATION INDEX (SOI)
STAND TAHITI MINUS STAND DARWIN SEA LEVEL PRESSURES
ANOMALY

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1951	2.7	1.0	-1.3	-1.1	-1.7	-0.5	-2.3	-1.2	-2.1	-2.3	-1.6	-1.6
1952	-2.0	-1.8	0.0	-0.9	1.0	0.8	0.7	-0.7	-0.4	0.3	-0.3	-2.6
1953	0.4	-1.6	-1.4	-0.1	-3.6	-0.5	-0.2	-3.1	-2.4	-0.3	-0.7	-1.1
1954	1.0	-1.2	-0.5	0.6	0.4	-0.5	0.4	1.3	0.3	0.1	0.2	2.4
1955	-1.1	2.9	0.1	-0.8	1.4	1.7	2.7	2.0	2.5	2.5	2.2	1.7
1956	2.3	2.4	1.5	1.2	2.2	1.3	1.7	1.5	0.0	3.0	0.1	1.7
1957	1.0	-0.8	-0.6	0.0	-1.7	-0.4	0.1	-1.7	-1.8	-0.3	-2.0	-0.9
1958	-3.8	-1.6	-0.5	0.2	-1.5	-0.2	0.4	1.0	-0.7	-0.4	-1.0	-1.4
1959	-2.0	-3.2	1.4	0.3	0.4	-0.9	-0.8	-0.9	0.0	0.5	1.6	1.4
1960	0.0	-0.4	0.9	1.0	0.5	-0.5	0.6	0.8	-1.1	-0.2	0.9	1.3
1961	-0.7	1.1	-4.5	1.1	0.2	-0.5	0.2	-0.4	0.1	-1.1	0.9	2.6
1962	3.6	-1.1	-0.7	-0.1	1.6	0.6	-0.2	0.6	0.8	1.4	0.4	0.1
1963	1.8	0.6	1.1	1.0	0.2	-1.6	-0.5	-0.8	-1.1	-2.7	-1.7	-2.6
1964	-0.9	-0.5	1.1	1.7	-0.1	0.7	0.7	2.2	2.3	2.0	0.1	-0.9
1965	-1.1	0.1	0.4	-1.4	-0.2	-1.7	-3.6	-2.0	-2.5	-2.0	-2.9	0.0
1966	-2.8	-1.1	-2.8	-0.8	-1.1	0.0	-0.2	0.5	-0.4	-0.6	-0.2	-1.0
1967	3.0	2.6	1.3	-0.4	-0.5	0.6	0.0	0.7	1.0	-0.3	-1.0	-1.4
1968	0.6	1.8	-0.8	-0.4	1.9	1.4	1.0	-0.2	-0.5	-0.5	-0.7	0.1
1969	-3.2	-1.8	-0.2	-1.1	-0.9	-0.3	-1.2	-0.9	-2.0	-2.2	-0.3	0.5
1970	-2.3	-2.7	0.1	-0.6	0.2	1.2	-1.0	0.4	2.1	1.5	2.8	3.3
1971	0.4	3.1	3.4	2.8	1.2	0.2	0.1	2.2	2.7	2.8	0.9	0.1
1972	0.6	1.4	0.1	-0.6	-3.4	-1.8	-3.1	-1.6	-2.6	-2.0	-0.7	-2.6
1973	-0.8	-3.2	0.3	-0.3	0.4	1.3	0.9	1.7	2.3	1.0	4.7	3.2
1974	4.3	3.2	3.6	1.4	1.4	0.1	1.9	0.8	2.0	1.3	-0.5	0.0
1975	-1.3	1.0	1.9	1.7	0.8	1.8	3.4	3.1	3.9	2.8	2.1	3.7
1976	2.4	2.6	2.2	0.2	0.3	-0.2	-1.9	-2.2	-2.2	0.4	1.1	-1.0
1977	-1.1	1.7	-2.1	-1.3	-1.4	-2.5	-2.5	-2.2	-1.6	-2.3	-2.5	-2.3
1978	-0.7	-5.7	-1.3	-1.0	2.1	0.5	0.7	0.0	0.1	-1.2	-0.2	-0.4
1979	-1.1	1.3	-0.8	-0.7	0.5	0.6	2.2	-1.0	0.2	-0.6	-1.0	-1.6
1980	0.5	0.0	-2.0	-1.7	-0.5	-0.7	-0.4	0.0	-0.9	-0.4	-0.8	-0.5
1981	0.4	-1.0	-3.4	-0.7	1.1	1.7	1.2	0.6	0.6	-1.2	0.1	0.7
1982	2.2	-0.1	0.1	-0.3	-1.1	-2.6	-3.2	-4.0	-3.3	-3.6	-5.1	-4.6
1983	-6.9	-7.6	-5.6	-2.2	0.7	-0.5	-1.3	-0.3	1.7	0.4	-0.3	-0.2
1984	0.2	0.9	-1.5	0.3	-0.1	-1.3	0.1	0.1	0.2	-1.0	0.4	-0.7
1985	-0.7	1.7	0.3	1.7	0.3	-1.5	-0.4	1.1	-0.1	-1.2	-0.5	0.2
1986	1.5	-2.7	-0.1	0.1	-0.9	1.1	0.2	-1.6	-1.0	0.9	-2.5	-3.0
1987	-1.5	-3.1	-3.3	-3.0	-2.8	-2.8	-2.8	-2.5	-1.9	-1.1	-0.2	-1.2
1988	-0.3	-1.4	0.1	-0.1	1.3	-0.4	1.7	2.2	3.4	2.2	3.0	2.1
1989	2.7	1.8	1.0	2.6	1.9	0.8	1.4	-1.3	0.9	1.0	-0.6	-1.2
1990	-0.4	-3.9	-1.9	-0.1	1.8	-0.1	0.8	-1.0	-1.3	0.1	-1.1	-0.7
1991	1.0	-0.1	-2.2	-1.7	-2.4	-0.9	-0.2	-1.4	-2.9	-2.4	-1.4	-3.7
1992	-5.6	-2.3	-4.8	-2.3	0.1	-1.9	-1.3	0.0	0.0	-3.2	-1.4	-1.4
1993	-2.0	-2.1	-1.8	-2.6	-1.0	-2.2	-1.8	-2.4	-1.3	-2.5	-0.3	0.1
1994	-0.5	-0.1	-2.2	-2.9	-1.7	-1.5	-2.9	-3.0	-3.0	-2.6	-1.2	-2.6
1995	-1.0	-0.8	0.4	-1.8	-1.2	-0.4	0.6	-0.1	0.5	-0.5	-0.1	-1.3
1996	1.7	-0.2	1.2	1.1	0.2	1.6	1.0	0.7	1.0	0.7	-0.3	1.3
1997	0.8	2.6	-1.9	-1.4	-3.0	-3.2	-1.7	-3.4	-2.6	-3.1	-2.3	-2.1
1998	-5.4	-4.4	-5.7	-3.2	0.1	1.2	2.0	1.6	2.0	1.6	1.7	2.3
1999	3.2	1.2	1.4	2.2	0.1	-0.1	0.8	0.1	-0.1	1.5	1.8	2.5
2000	1.1	2.6	1.6	1.9	0.3	-1.0	-0.7	0.6	1.7	1.6	3.3	1.1
2001	1.8	2.4	0.8	-0.1	-1.4	-0.1	-0.7	-1.6				

EL-NINO SOUTHERN OSCILLATION INDEX (SOI)
STAND TAHITI MINUS STAND DARWIN SEA LEVEL PRESSURES
STANDARDIZED BY MEAN ANNUAL STANDARD DEVIATION

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1951	1.7	0.6	-0.8	-0.6	-1.0	-0.3	-1.4	-0.7	-1.3	-1.4	-1.0	-1.0
1952	-1.2	-1.1	0.0	-0.5	0.6	0.5	0.4	-0.4	-0.3	0.2	-0.2	-1.6
1953	0.2	-1.0	-0.8	-0.1	-2.2	-0.3	-0.1	-1.9	-1.5	-0.2	-0.4	-0.7
1954	0.6	-0.7	-0.3	0.4	0.3	-0.3	0.3	0.8	0.2	0.1	0.1	1.5
1955	-0.7	1.8	0.1	-0.5	0.9	1.1	1.7	1.2	1.5	1.5	1.3	1.0
1956	1.4	1.5	0.9	0.7	1.3	0.8	1.1	0.9	0.0	1.9	0.1	1.0
1957	0.6	-0.5	-0.4	0.0	-1.0	-0.2	0.1	-1.0	-1.1	-0.2	-1.2	-0.5
1958	-2.3	-1.0	-0.3	0.1	-0.9	-0.2	0.3	0.6	-0.4	-0.2	-0.6	-0.9
1959	-1.2	-2.0	0.9	0.2	0.3	-0.6	-0.5	-0.6	0.0	0.3	1.0	0.8
1960	0.0	-0.3	0.6	0.6	0.3	-0.3	0.4	0.5	0.7	-0.1	0.5	0.8
1961	-0.4	0.7	-2.7	0.7	0.1	-0.3	0.1	-0.2	0.1	-0.7	0.6	1.6
1962	2.2	-0.7	-0.4	0.0	1.0	0.4	-0.1	0.3	0.5	0.9	0.3	0.0
1963	1.1	0.4	0.7	0.6	0.1	-1.0	-0.3	-0.5	-0.7	-1.6	-1.0	-1.6
1964	-0.5	-0.3	0.7	1.0	-0.1	0.4	0.4	1.3	1.4	1.3	0.0	-0.5
1965	-0.6	0.1	0.2	-0.8	-0.1	-1.0	-2.2	-1.2	-1.5	-1.2	-1.8	0.0
1966	-1.7	-0.7	-1.7	-0.5	-0.7	0.0	-0.1	0.3	-0.3	-0.4	-0.1	-0.6
1967	1.9	1.6	0.8	-0.3	-0.3	0.3	0.0	0.5	0.6	-0.2	-0.6	-0.8
1968	0.4	1.1	-0.5	-0.2	1.1	0.9	0.6	-0.1	-0.3	-0.3	-0.5	0.0
1969	-2.0	-1.1	-0.1	-0.6	-0.6	-0.2	-0.7	-0.6	-1.2	-1.3	-0.2	0.3
1970	-1.4	-1.6	0.0	-0.4	0.1	0.7	-0.6	0.2	1.3	0.9	1.7	2.1
1971	0.3	1.9	2.1	1.7	0.7	0.1	0.1	1.3	1.6	1.7	0.5	0.0
1972	0.4	0.8	0.1	-0.4	-2.1	-1.1	-1.9	-1.0	-1.6	-1.2	-0.5	-1.6
1973	-0.5	-2.0	0.2	-0.2	0.2	0.8	0.5	1.1	1.4	0.6	2.9	2.0
1974	2.7	2.0	2.2	0.8	0.9	0.1	1.2	0.5	1.3	0.8	-0.3	0.0
1975	-0.8	0.6	1.2	1.1	0.5	1.1	2.1	1.9	2.4	1.7	1.3	2.3
1976	1.5	1.6	1.3	0.1	0.2	-0.1	-1.2	-1.3	-1.4	0.2	0.7	-0.6
1977	-0.7	1.1	-1.3	-0.8	-0.9	-1.5	-1.5	-1.3	-1.0	-1.4	-1.6	-1.4
1978	-0.4	-3.5	-0.8	-0.6	1.3	0.3	0.4	0.0	0.0	-0.7	-0.1	-0.3
1979	-0.7	0.8	-0.5	-0.4	0.3	0.4	1.3	-0.6	0.1	-0.4	-0.6	-1.0
1980	0.3	0.0	-1.2	-1.0	-0.3	-0.4	-0.2	0.0	-0.6	-0.3	-0.5	-0.3
1981	0.2	-0.6	-2.1	-0.4	0.7	1.0	0.8	0.4	0.4	-0.7	-0.1	0.5
1982	1.3	-0.1	0.1	-0.2	-0.7	-1.6	-1.9	-2.5	-2.0	-2.2	-3.2	-2.8
1983	-4.2	-4.6	-3.4	-1.3	0.5	-0.3	-0.8	-0.2	1.0	0.3	-0.2	-0.1
1984	0.1	0.6	-0.9	0.2	0.0	-0.8	0.0	0.0	0.1	-0.6	0.2	-0.4
1985	-0.5	1.0	0.2	1.0	0.2	-0.9	-0.3	0.7	0.0	-0.7	-0.3	0.1
1986	0.9	-1.6	0.0	0.1	-0.5	0.7	0.1	-1.0	-0.6	0.5	-1.5	-1.8
1987	-0.9	-1.9	-2.0	-1.9	-1.7	-1.7	-1.7	-1.5	-1.2	-0.7	-0.1	-0.7
1988	-0.2	-0.9	0.1	-0.1	0.8	-0.2	1.1	1.4	2.1	1.4	1.9	1.3
1989	1.7	1.1	0.6	1.6	1.2	0.5	0.8	-0.8	0.6	0.6	-0.4	-0.7
1990	-0.2	-2.4	-1.2	0.0	1.1	0.0	0.5	-0.6	-0.8	0.1	-0.7	-0.5
1991	0.6	-0.1	-1.4	-1.0	-1.5	-0.5	-0.2	-0.9	-1.8	-1.5	-0.8	-2.3
1992	-3.4	-1.4	-3.0	-1.4	0.0	-1.2	-0.8	0.0	0.0	-1.9	-0.9	-0.9
1993	-1.2	-1.3	-1.1	-1.6	-0.6	-1.4	-1.1	-1.5	-0.8	-1.5	-0.2	0.0
1994	-0.3	-0.1	-1.4	-1.8	-1.0	-0.9	-1.8	-1.8	-1.8	-1.6	-0.7	-1.6
1995	-0.6	-0.5	0.2	-1.1	-0.7	-0.2	0.3	-0.1	0.3	-0.3	0.0	-0.8
1996	1.0	-0.1	0.7	0.6	0.1	1.0	0.6	0.4	0.6	0.4	-0.2	0.8
1997	0.5	1.6	-1.1	-0.9	-1.8	-2.0	-1.0	-2.1	-1.6	-1.9	-1.4	-1.3
1998	-3.3	-2.7	-3.5	-1.9	0.1	0.7	1.3	1.0	1.2	1.0	1.1	1.4
1999	2.0	0.8	0.9	1.4	0.1	-0.1	0.5	0.1	-0.1	0.9	1.1	1.5
2000	0.7	1.6	1.0	1.2	0.2	-0.6	-0.4	0.4	1.0	1.0	2.0	0.7
2001	1.1	1.5	0.5	-0.1	-0.8	-0.1	-0.4	-1.0				



NOTE:

GATUN WATERSHED IS LOCATED APPROXIMATELY BETWEEN LATITUDES FROM 8°41' W TO 9°40' W AND LONGITUDES BETWEEN 79°10' N AND 80°10' N. THIS LOCATION IS CLOSE TO THE REGIONS OF NIÑO 3 AND NORTH ATLANTIC.

AUTORIDAD DEL CANAL DE PANAMA
Oficina de Proyectos de Capacidad del Canal

CONTRACT NO. CC-3-536
STUDY OF HYDROLOGIC SERIES IN GATUN LAKE WATERSHED

Location of El Niño Climatic Indices Regions

MWH MONTGOMERY WATSON HARZA

FECHA: DECEMBER, 2001

EXHIBIT: 15.3

Exhibit 15.4

SST ANOMALIES FOR NORTH ATLANTIC REGION

Year	Mon	North Atlantiic Anomaly°C
1951	3	0.19
	4	0.43
	5	0.29
	6	0.19
	7	0.23
	8	0.27
	9	0.09
1952	3	0.12
	4	0.06
	5	0.28
	6	0.22
	7	0.16
	8	0.13
	9	0.32
	10	0.08
	11	0
	12	0.45
1953	1	0.45
	2	0.55
	3	0.2
	4	0.33
	5	0.14
	6	0.22
	7	0.26
	8	0.16
	9	0.05
	10	0.06
	11	0.27
	12	0.17
1954	1	0.13
	2	0.07
1955	7	0.11
	8	0.12
	9	0.2
	10	0.27
	11	0.48
	12	0.32
1956	1	0.51
	2	0.34
	3	0.42
1957	8	0.17
	9	0.17
	10	0.29
	11	0.26
	12	0.35
1958	1	0.55
	2	0.81
	3	1.15
	4	1.02
	5	0.78
	6	1.02
	7	0.58
	8	0.51
	9	0.23
	10	0.09
	11	0.2
	12	0.22
1959	1	0.39
	2	0.27

Year	Mon	North Atlantiic Anomaly°C
1961	12	0.06
1962	1	0.21
	2	0.07
	3	0.45
	4	0.33
	5	0.43
	6	0.35
	7	0.32
	8	0.17
	9	0.06
	10	0.02
	11	0.39
	12	0.71
1963	1	0.69
	2	0.55
	3	0.27
	4	0.44
	5	0.23
	6	0.08
1963	7	0.06
	8	0.02
	9	0.06
	10	0.19
	11	0.18
	12	0.17
1964	1	0.06
	2	0.19
	3	0.13
1966	2	0.26
	3	0.29
	4	0.47
	5	0.2
	6	0.29
	7	0.3
	8	0.02
	9	0.14
	10	0.14
	11	0.36
	12	0.45
1967	1	0.14
1968	12	0.22
1969	1	0.32
	2	0.66
	3	1.08
	4	0.91
	5	0.78
	6	0.39
	7	0.52
	8	0.3
	9	0.33
	10	0.23
	11	0.41
	12	0.46
1970	1	0.57
	2	0.52
	3	0.8
	4	0.39
	5	0.47
	6	0.23
1972	NO	

Year	Mon	North Atlantiic Anomaly°C
1976		NO
1979	1	0.13
	2	0.28
	3	0.24
	4	0.4
	5	0.46
	6	0.46
	7	0.23
	8	0.15
	9	0.14
	10	0.16
	11	0.18
	12	0.2
1980	1	0.45
	2	0.37
	3	0.28
	4	0.42
	5	0.73
	6	0.55
	7	0.22
	8	0.32
	9	0.31
	10	0.13
	11	0.06
	12	0.15
1981	1	0.49
	2	0.27
	3	0.79
	4	0.48
	5	0.56
	6	0.17
	7	0.26
	8	0.09
	9	0.02
1983	2	0.07
	3	0.56
	4	0.74
	5	0.54
	6	0.53
	7	0.17
	8	0.02
1987	3	0.22
	4	0.38
	5	0.35
	6	0.69
	7	0.37
	8	0.55
	9	0.41
	10	0.52
	11	0.53
	12	0.66
1988	1	0.39
	2	0.16
	3	0.34
	4	0.32
	5	0.15
	6	0.45
	7	0.43
	8	0.19
	9	0.17

Year	Mon	North Atlantiic Anomaly°C
1990	4	0.19
	5	0.35
	6	0.06
	7	0.23
	8	0.18
	9	0.33
	10	0.34
	11	0.16
	12	0.18
1992-93		NO
1995	1	0.06
	2	0.01
	3	0.16
	4	0.41
	5	0.56
	6	0.41
	7	0.48
	8	0.52
	9	0.47
	10	0.63
	11	0.64
	12	0.72
1996	1	0.85
	2	0.7
	3	0.5
	4	0.46
	5	0.36
	6	0.2
	7	0.09
	8	0.2
	9	0.28
	10	0.15
1997	4	0.2
	5	0.22
	6	0.27
	7	0.33
	8	0.27
	9	0.29
	10	0.63
	11	0.59
	12	0.38
1998	1	0.39
	2	0.64
	3	0.68
	4	0.69
	5	0.92
	6	0.77
	7	0.84
	8	0.82
	9	0.71
	10	0.61
	11	0.48
	12	0.41

Exhibit 15.5

MONTHLY SST NINO 3 ANOMALIES AND SOI FOR SIGNIFICANT EL NINO EPISODES

Year	Mon	Nino 3 Anomaly°C	SOI
1951	6	0.09	-0.5
	7	0.96	-2.3
	8	1.01	-1.2
	9	0.62	-2.1
	10	0.99	-2.3
	11	1.01	-1.6
	12	0.91	-1.6
1952	1	0.29	-2
	2	0.34	-1.8
1953	1	0.3	0.4
	2	0.45	-1.6
	3	0.32	-1.4
	4	0.82	-0.1
	5	0.38	-3.6
	6	0.53	-0.5
	7	0.46	-0.2
	8	0.17	-3.1
	9	0.86	-2.4
	10	0.24	-0.3
	11	0.32	-0.7
	12	0.27	-1.1
1954	1	0.15	1
	2	0.04	-1.2
1957	2	0.05	-0.8
	3	0.26	-0.6
	4	0.53	0
	5	0.49	-1.7
	6	0.85	-0.4
	7	1	0.1
	8	1.39	-1.7
	9	0.48	-1.8
	10	0.71	-0.3
	11	1.24	-2
	12	1.6	-0.9
1958	1	1.48	-3.8
	2	1.01	-1.6
	3	0.69	-0.5
	4	0.33	0.2
1965	4	0.27	-1.4
	5	0.55	-0.2
	6	0.82	-1.7
	7	1.16	-3.6
	8	1.25	-2
	9	1.2	-2.5
	10	1.29	-2
	11	1.43	-2.9
	12	1.55	0
1966	1	1.17	-2.8
	2	0.53	-1.1
	3	0.03	-2.8
1968	7	0.32	1
	8	0.31	-0.2
	9	0.12	-0.5
	10	0.23	-0.5
	11	0.37	-0.7
	12	0.64	0.1

Year	Mon	Nino 3 Anomaly°C	SOI
1969	1	0.76	-3.2
	2	0.39	-1.8
	3	0.61	-0.2
	4	0.49	-1.1
	5	0.96	-0.9
	6	0.72	-0.3
	7	0.22	-1.2
	8	0.55	-0.9
	9	0.61	-2
	10	0.77	-2.2
	11	0.78	-0.3
	12	1.18	0.5
1970	1	0.92	-2.3
	2	0.21	-2.7
1972	4	0.51	-0.6
	5	0.6	-3.4
	6	1.04	-1.8
	7	1.45	-3.1
	8	1.92	-1.6
	9	1.52	-2.6
	10	1.91	-2
	11	2.16	-0.7
	12	2.42	-2.6
1973	1	1.76	-0.8
	2	1.03	-3.2
	3	0.28	3.6
1976	6	0.51	-0.2
	7	0.65	-1.9
	8	0.84	-2.2
	9	0.95	-2.2
	10	0.95	0.4
	11	0.85	1.1
	12	0.77	-1
1977	1	0.86	-1.1
	2	0.46	1.7
	3	0.33	-2.1
1979	8	0.07	-1
	9	1	0.2
	10	0.37	-0.6
	11	0.3	-1
	12	0.4	-1.6
1980	1	0.45	0.5
	2	0.18	0
1982	4	0.27	-0.3
	5	0.72	-1.1
	6	1.1	-2.6
	7	0.86	-3.2
	8	1.21	-4
	9	1.69	-3.3
	10	2.21	-3.6
	11	2.64	-5.1
	12	3.3	-4.6
1983	1	3.29	-6.9
	2	2.54	-7.6
	3	2	-5.6
	4	1.71	-2.2
	5	1.91	0.7
	6	1.77	-0.5
	7	1.03	-1.3
	8	0.93	-0.3

Year	Mon	Nino 3 Anomaly°C	SOI
1986	7	0.13	0.2
	8	0.08	-1.6
	9	0.43	-1
	10	0.73	0.9
	11	0.97	-2.5
	12	0.77	-3
1987	1	1.07	-1.5
	2	1.06	-3.1
	3	1.13	-3.3
	4	1.09	-3
	5	1.15	-2.8
	6	1.33	-2.8
	7	1.49	-2.8
	8	1.57	-2.5
	9	1.75	-1.9
	10	1.31	-1.1
	11	1.17	-0.2
	12	1.11	-1.2
1988	1	0.51	-0.3
	2	0.18	-1.4
	3	0.05	0.1
1991	5	0.52	-2.4
	6	0.97	-0.9
	7	0.99	-0.2
	8	0.52	-1.4
	9	0.19	-2.9
	10	0.73	-2.4
	11	1.03	-1.4
	12	1.43	-3.7
1992	1	1.39	-5.6
	2	1.31	-2.3
	3	1.24	-4.8
	4	1.31	-2.3
	5	1.37	0.1
	6	0.29	-1.9
1993	2	0.25	-2.1
	3	0.45	-1.8
	4	1.04	-2.6
	5	1.1	-1
	6	0.74	-2.2
	7	0.19	-1.8
1994	10	0.65	-2.6
	11	0.92	-1.2
	12	0.98	-2.6
1995	1	0.73	-1
	2	0.51	-0.8
1997	4	0.19	-1.4
	5	1	-3
	6	1.76	-3.2
	7	2.43	-1.7
	8	2.89	-3.4
	9	3	-2.6
	10	3.27	-3.1
	11	3.62	-2.3
	12	3.67	-2.1
1998	1	3.32	-5.4
	2	2.57	-4.4
	3	2.05	-5.7
	4	1.68	-3.2
	5	1.11	0.1

Exhibit 15.6

DEPARTURES OF ANNUAL RAINFALLS FROM LONG-TERM MEAN
DURING THE YEARS OF EL NINO EPISODES

1911-2000 Mean Annual Rainfall								
Madden Lake		2837 mm	Gatun Downstream		2576 mm	Gatun Total		2663 mm
Year	Rainfall (mm)	% Depar.	Year	Rainfall (mm)	% Depar.	Year	Rainfall (mm)	% Depar.
1911	2527	-10.9	1911	2360	-8.4	1911	2415	-9.3
1914	2493	-12.1	1914	2592	0.6	1914	2567	-3.6
1917	2793	-1.6	1917	3004	16.6	1917	2945	10.6
1918	2669	-5.9	1918	2303	-10.6	1918	2419	-9.2
1923	2597	-8.5	1923	2578	0.1	1923	2589	-2.8
1925	2742	-3.3	1925	2432	-5.6	1925	2531	-5.0
1930	2204	-22.3	1930	2049	-20.5	1930	2100	-21.1
1939	2466	-13.1	1939	2388	-7.3	1939	2417	-9.2
1941	2904	2.4	1941	2616	1.6	1941	2708	1.7
1946	2499	-11.9	1946	2274	-11.7	1946	2347	-11.9
1951	2698	-4.9	1951	2507	-2.7	1951	2570	-3.5
1953	2691	-5.1	1953	2505	-2.8	1953	2566	-3.6
1957	2019	-28.8	1957	2200	-14.6	1957	2149	-19.3
1965	2598	-8.4	1965	2592	0.6	1965	2426	-8.9
1969	2601	-8.3	1969	2577	0.0	1969	2590	-2.7
1972	2637	-7.0	1972	2274	-11.7	1972	2388	-10.3
1976	1765	-37.8	1976	1865	-27.6	1976	1839	-30.9
1977	2306	-18.7	1977	2189	-15.0	1977	2228	-16.3
1982	2061	-27.4	1982	1949	-24.3	1982	1986	-25.4
1983	2906	2.4	1983	2233	-13.3	1983	2442	-8.3
1985	2454	-13.5	1985	2199	-14.6	1985	2281	-14.3
1986	2569	-9.4	1986	2021	-21.5	1986	2191	-17.7
1991	2648	-6.7	1991	2302	-10.6	1991	2441	-8.3
1997	1889	-33.4	1997	1592	-38.2	1997	1685	-36.7

MONTHLY RAINFALL DEPARTURES FROM THE LONG-TERM MEAN DURING THE YEARS OF EL NINO EPISODES
MADDEN LAKE

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Nino 3 Anomaly °C							0.1	1.0	1.0	0.6	1.0	1.0	0.9	0.3	0.3													
MAP (mm)							324	318	317	318	364	360	228	73	45	41												
Episode 6/51-2/52							219	258	383	361	361	259	158	40	8	2												
Percent Diff.							-32	-19	21	14	-1	-28	-31	-45	-82	-95												
Nino 3 Anomaly °C		0.3	0.5	0.3	0.8	0.4	0.5	0.5	0.2	0.9	0.2	0.3	0.3	0.2	0.0													
MAP (mm)		73	45	41	132	317	324	318	317	318	364	360	228	73	45													
Episode 1/53-2/54		238	42	59	108	413	161	297	238	197	375	359	204	32	70													
Percent Diff.		226	-7	44	-18	30	-50	-7	-25	-38	3	0	-11	-56	56													
Nino 3 Anomaly °C			0.1	0.3	0.5	0.5	0.9	1.0	1.4	0.5	0.7	1.2	1.6	1.5	1.0	0.7	0.3											
MAP (mm)			45	41	132	317	324	318	317	318	364	360	228	73	45	41	132	317										
Episode 2/57-4/58			34	7	25	233	191	166	191	193	387	415	155	123	56	63	37	288										
Percent Diff.			-24	-83	-81	-26	-41	-48	-40	-39	6	15	-32	68	24	54	-72	-9										
Nino 3 Anomaly °C					0.3	0.6	0.8	1.2	1.3	1.2	1.3	1.4	1.6	1.2	0.5	0.0												
MAP (mm)	228	73	45	41	132	317	324	318	317	318	364	360	228	73	45	41	132											
Episode 4/65-3/66	104	43	11	8	29	293	252	231	280	347	388	469	248	88	21	36	286											
Percent Diff.	-54	-41	-76	-80	-78	-8	-22	-27	-12	9	7	30	9	21	-53	-12	117											
Nino 3 Anomaly °C								0.3	0.3	0.1	0.2	0.4	0.6	0.8	0.4	0.6	0.5	1.0	0.7	0.2	0.6	0.6	0.8	0.8	1.2	0.9	0.2	
MAP (mm)		73	45	41	132	317	324	318	317	318	364	360	228	73	45	41	132	317	324	318	317	318	364	360	228	73	45	
Episode 7/68-2/70		9	66	75	46	348	308	285	306	233	453	323	133	65	22	70	132	309	157	270	360	365	189	294	367	384	89	
Percent Diff.		-88	47	83	-65	10	-5	-10	-3	-27	24	-10	-42	-11	-51	71	0	-3	-52	-15	13.6	14.8	-48.1	-18.3	61.0	426.0	97.8	
Nino 3 Anomaly °C					0.5	0.6	1.0	1.5	1.9	1.5	1.9	2.2	2.4	1.8	1.0	0.3												
MAP (mm)		73	45	41	132	317	324	318	317	318	364	360	228	73	45	41	132	317										
Episode 4/72-3/73		296	40	21	232	306	370	159	204	293	357	240	120	43	27	8	21	294										
Percent Diff.		305	-11	-49	76	-3	14	-50	-36	-8	-2	-33	-47	-41	-40	-80	-84	-7										
Nino 3 Anomaly °C							0.5	0.7	0.8	1.0	1.0	0.9	0.8	0.9	0.5	0.3												
MAP (mm)		73	45	41	132	317	324	318	317	318	364	360	228	73	45	41	132	317										
Episode 6/76-3/77		42	29	38	123	203	199	72	233	323	257	214	32	81	11	22	40	235										
Percent Diff.		-42	-36	-7	-7	-36	-39	-77	-26	2	-29	-41	-86	11	-76	-46	-70	-26										
Nino 3 Anomaly °C									0.1	1.0	0.4	0.3	0.4	0.5	0.2													
MAP (mm)									317	318	364	360	228	73	45	41	132	317										
Episode 8/79-2/80									252	192	308	405	331	118	95	24	55	254										
Percent Diff.									-21	-40	-15	13	45	62	111	-41	-58	-20										
Nino 3 Anomaly °C					0.3	0.7	1.1	0.9	1.2	1.7	2.2	2.6	3.3	3.3	2.5	2.0	1.7	1.9	1.8	1.0	0.9							
MAP (mm)		73	45	41	132	317	324	318	317	318	364	360	228	73	45	41	132	317	324	318	317	318						
Episode 4/82-8/83		81	19	12	100	196	268	320	186	256	428	137	57	30	24	29	163	310	236	173	226	409						
Percent Diff.		11	-58	-71	-24	-38	-17	1	-41	-19	18	-62	-75	-59	-47	-29	23	-2	-27	-46	-29	29						
Nino 3 Anomaly °C								0.1	0.1	0.4	0.7	1.0	0.8	1.1	1.1	1.1	1.1	1.2	1.3	1.5	1.6	1.8	1.3	1.2	1.1	0.5	0.2	0:1
MAP (mm)								318	317	318	364	360	228	73	45	41	132	317	324	318	317	318	364	360	228	73	45	41
Episode 7/86-3/88								146	224	339	492	295	72	43	57	12	416	514	309	423	359	411	442	497	179	20	117	44
Percent Diff.								-54	-29	7	35	-18	-68	-41	27	-71	215	62	-5	33	13	29	21	38	-21	-73	160	7
Nino 3 Anomaly °C						0.5	1.0	1.0	0.5	0.2	0.7	1.0	1.4	1.4	1.3	1.2	1.3	1.4	0.3									
MAP (mm)						317	324	318	317	318	364	360	228	73	45	41	132	317	324									
Episode 5/91-6/92						362	259	285	246	393	304	437	95	35	20	25	173	523	405									
Percent Diff.						14	-20	-10	-22	24	-16	21	-58	-52	-56	-39	31	65	25									
Nino 3 Anomaly °C			0.25	0.45	1.04	1.1	0.74	0.19																				
MAP (mm)		73	45	41	132	317	324	318																				
Episode 2/93-7/93		14	180	267	313	561	220	197																				
Percent Diff.		-81	300	551	137	77	-32	-38																				
Nino 3 Anomaly °C											0.7	0.9	1.0	0.7	0.5													
MAP (mm)											364	360	228	73	45	41												
Episode 10/94-2/95											363	511	91	95	11	49												
Percent Diff.											0	42	-60	30	-76	20												
Nino 3 Anomaly °C					0.2	1.0	1.8	2.4	2.9	3.0	3.3	3.6	3.7	3.3	2.6	2.1	1.7	1.1										
MAP (mm)		73	45	41	132	317	324	318	317	318	364	360	228	73	45	41	132	317										
Episode 4/97-2/98		32	57	17	86	300	271	153	144	267	262	271	31	33	25	32	150	407										
Percent Diff.		-56	27	-59	-35	-5	-16	-52	-55	-16	-28	-25	-86	-55	-44	-22	14	28										

MONTHLY RAINFALL DEPARTURES FROM THE LONG-TERM MEAN DURING THE YEARS OF EL NINO EPISODES
GATUN DOWNSTREAM

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Nino 3 Anomaly °C							0.1	1.0	1.0	0.6	1.0	1.0	0.9	0.3	0.3														
MAP (mm)							275	258	285	298	362	368	206	70	34	32													
6/51-2/52							176	234	242	287	355	333	237	66	22	5													
Percent Diff.							-36	-9	-15	-4	-2	-10	15	-6	-35	-84													
Nino 3 Anomaly °C		0.3	0.5	0.3	0.8	0.4	0.5	0.5	0.2	0.9	0.2	0.3	0.3	0.2	0.0														
MAP (mm)		70	34	32	104	284	275	258	285	298	362	368	206	70	34	32													
1/53-2/54		164	20	27	88	297	170	270	256	244	411	416	141	164	20	27													
Percent Diff.		134	-41	-16	-15	5	-38	5	-10	-18	14	13	-32	134	-41	-16													
Nino 3 Anomaly °C			0.1	0.3	0.5	0.5	0.9	1.0	1.4	0.5	0.7	1.2	1.6	1.5	1.0	0.7	0.3												
MAP (mm)	206	70	34	32	104	284	275	258	285	298	362	368	206	70	34	32	104												
2/57-4/58	125	22	18	7	14	259	211	212	267	252	391	345	151	115	75	72	67												
Percent Diff.	-39	-69	-47	-78	-87	-9	-23	-18	-6	-15	8	-6	-27	64	121	125	-36												
Nino 3 Anomaly °C					0.3	0.6	0.8	1.2	1.3	1.2	1.3	1.4	1.6	1.2	0.5	0.0													
MAP (mm)			34	32	104	284	275	258	285	298	362	368	206	70	34	32													
4/65-3/66			16	17	39	272	203	186	278	288	471	574	134	66	26	28													
Percent Diff.			-53	-47	-63	-4	-26	-28	-2	-3	30	56	-35	-6	-24	-13													
Nino 3 Anomaly °C								0.3	0.3	0.1	0.2	0.4	0.6	0.8	0.4	0.6	0.5	1.0	0.7	0.2	0.6	0.6	0.8	0.8	1.2	0.9	0.2		
MAP (mm)								258	285	298	362	368	206	70	34	32	104	284	275	258	285	298	362	368	206	70	34		
7/68-2/70								197	340	259	394	314	56	56	19	22	106	270	184	277	340	356	342	349	256	227	58		
Percent Diff.								-24	19	-13	9	-15	-73	-20	-44	-31	2	-5	-33	7	19	19	-6	-5	24	224	71		
Nino 3 Anomaly °C					0.5	0.6	1.0	1.5	1.9	1.5	1.9	2.2	2.4	1.8	1.0	0.3													
MAP (mm)					104	284	275	258	285	298	362	368	206	70	34	32	104	284											
4/72-3/73					220	215	282	139	198	320	338	211	113	59	15	4	35	238											
Percent Diff.					112	-24	3	-46	-31	7	-7	-43	-45	-16	-56	-88	-66	-16											
Nino 3 Anomaly °C							0.5	0.7	0.8	1.0	1.0	0.9	0.8	0.9	0.5	0.3													
MAP (mm)						284	275	258	285	298	362	368	206	70	34	32	104	284	275	258	285								
6/76-3/77						220	222	88	201	360	337	196	69	38	12	7	28	258	191	176	378								
Percent Diff.						-23	-19	-66	-29	21	-7	-47	-67	-46	-65	-78	-73	-9	-31	-32	33								
Nino 3 Anomaly °C									0.1	1.0	0.4	0.3	0.4	0.5	0.2														
MAP (mm)									285	298	362	368	206	70	34														
8/79-2/80									287	228	283	280	151	126	55														
Percent Diff.									1	-23	-22	-24	-27	80	62														
Nino 3 Anomaly °C					0.3	0.7	1.1	0.9	1.2	1.7	2.2	2.6	3.3	3.3	2.5	2.0	1.7	1.9	1.8	1.0	0.9								
MAP (mm)			34	32	104	284	275	258	285	298	362	368	206	70	34	32	104	284	275	258	285	298							
4/82-8/83			18	14	112	234	204	194	201	254	390	153	30	22	4	8	74	257	241	204	222	323							
Percent Diff.			-47	-56	8	-18	-26	-25	-29	-15	8	-58	-85	-69	-88	-75	-29	-10	-12	-21	-22	8							
Nino 3 Anomaly °C								0.1	0.1	0.4	0.7	1.0	0.8	1.1	1.1	1.1	1.1	1.2	1.3	1.5	1.6	1.8	1.3	1.2	1.1	0.5	0.2	0.1	
MAP (mm)						284	275	258	285	298	362	368	206	70	34	32	104	284	275	258	285	298	362	368	206	70	34	32	104
7/86-3/88						171	252	160	212	266	447	204	61	21	36	5	224	354	232	270	298	444	475	295	192	8	32	8	39
Percent Diff.						-40	-8	-38	-26	-11	23	-45	-70	-70	6	-84	115	25	-16	5	5	49	31	-20	-7	-89	-6	-75	-63
Nino 3 Anomaly °C						0.5	1.0	1.0	0.5	0.2	0.7	1.0	1.4	1.4	1.3	1.2	1.3	1.4	0.3										
MAP (mm)						284	275	258	285	298	362	368	206	70	34	32	104	284	275	258									
5/91-6/92						364	311	245	298	342	280	274	132	90	19	83	170	239	322	224									
Percent Diff.						28	13	-5	5	15	-23	-26	-36	29	-44	159	63	-16	17	-13									
Nino 3 Anomaly °C			0.3	0.5	1.0	1.1	0.7	0.2																					
MAP (mm)			34	32	104	284	275	258																					
2/93-7/93			19	83	170	239	322	224																					
Percent Diff.			-44	159	63	-16	17	-13																					
Nino 3 Anomaly °C											0.7	0.9	1.0	0.7	0.5														
MAP (mm)											362	368	206	70	34	32	104												
10/94-2/95											333	404	46	115	17	20	131												
Percent Diff.											-8	10	-78	64	-50	-38	26												
Nino 3 Anomaly °C					0.2	1.0	1.8	2.4	2.9	3.0	3.3	3.6	3.7	3.3	2.6	2.1	1.7	1.1											
MAP (mm)	206	70	34	32	104	284	275	258	285	298	362	368	206	70	34	32	104	284											
4/97-2/98	127	24	22	3	28	237	225	178	164	242	210	223	35	12	19	28													
Percent Diff.	-38	-66	-35	-91	-73	-17	-18	-31	-42	-19	-42	-39	-83	-83	-44	-13													

MONTHLY RAINFALL DEPARTURES FROM THE LONG-TERM MEAN DURING THE YEARS OF EL NINO EPISODES
GATUN TOTAL

		Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Nino 3 Anomaly	°C							0.1	1.0	1.0	0.6	1.0	1.0	0.9	0.3	0.3														
MAP	(mm)	219	84	38	35	109	287	290	278	292	304	362	364	219	84	38	35	109	287	290	278	292	304	362	364	219	84	38	35	109
6/51-2/52								189	242	285	310	358	311	213	58	18	4													
Percent Diff.								-35	-13	-2	2	-1	-15	-3	-31	-53	-89													
Nino 3 Anomaly	°C		0.3	0.5	0.3	0.8	0.4	0.5	0.5	0.2	0.9	0.2	0.3	0.3	0.2	0.0														
MAP	(mm)		84	38	35	109	287	290	278	292	304	362	364	219	84	38	35													
1/53-2/54			187	27	37	94	333	168	279	251	230	401	400	161	33	43	24													
Percent Diff.			123	-29	6	-14	16	-42	0	-14	-24	11	10	-26	-61	13	-31													
Nino 3 Anomaly	°C			0.1	0.3	0.5	0.5	0.9	1.0	1.4	0.5	0.7	1.2	1.6	1.5	1.0	0.7	0.3												
MAP	(mm)	219	84	38	35	109	287	290	278	292	304	362	364	219	84	38	35	109												
2/57-4/58		125	22	18	7	14	259	211	212	267	252	391	345	151	115	75	72	67												
Percent Diff.		-43	-74	-53	-80	-87	-10	-27	-24	-9	-17	8	-5	-31	37	97	106	-39												
Nino 3 Anomaly	°C					0.3	0.6	0.8	1.2	1.3	1.2	1.3	1.4	1.6	1.2	0.5	0.0													
MAP	(mm)				35	109	287	290	278	292	304	362	364	219	84	38	35													
4/65-3/66					21	21	87	338	227	275	302	291	303	323	282	25	31													
Percent Diff.					-40	-81	-70	17	-18	-6	-1	-20	-17	47	236	-34	-11													
Nino 3 Anomaly	°C								0.3	0.3	0.1	0.2	0.4	0.6	0.8	0.4	0.6	0.5	1.0	0.7	0.2	0.6	0.6	0.8	0.8	1.2	0.9	0.2		
MAP	(mm)								278	292	304	362	364	219	84	38	35	109	287	290	278	292	304	362	364	219	84	38		
7/68-2/70									224	331	252	413	317	79	59	20	37	114	283	176	275	347	360	296	333	291	275	67		
Percent Diff.									-19	13	-17	14	-13	-64	-30	-47	6	5	-1	-39	-1	19	18	-18	-9	33	227	76		
Nino 3 Anomaly	°C					0.5	0.6	1.0	1.5	1.9	1.5	1.9	2.2	2.4	1.8	1.0	0.3													
MAP	(mm)				35	109	287	290	278	292	304	362	364	219	84	38	35	109												
4/72-3/73					28	224	243	309	145	200	312	344	220	115	55	19	5	31												
Percent Diff.					-20	106	-15	7	-48	-32	3	-5	-40	-47	-35	-50	-86	-72												
Nino 3 Anomaly	°C							0.5	0.7	0.8	1.0	1.0	0.9	0.8	0.9	0.5	0.3													
MAP	(mm)						287	290	278	292	304	362	364	219	84	38	35	109												
6/76-3/77							215	215	84	211	349	313	202	58	51	12	12	32												
Percent Diff.							-25	-26	-70	-28	15	-14	-45	-74	-39	-68	-66	-71												
Nino 3 Anomaly	°C									0.1	1.0	0.4	0.3	0.4	0.5	0.2														
MAP	(mm)									292	304	362	364	219	84	38	35	109												
8/79-2/80										277	218	291	318	206	124	67	12	44												
Percent Diff.										-5	-28	-20	-13	-6	48	76	-66	-60												
Nino 3 Anomaly	°C					0.3	0.7	1.1	0.9	1.2	1.7	2.2	2.6	3.3	3.3	2.5	2.0	1.7	1.9	1.8	1.0	0.9								
MAP	(mm)			38	35	109	287	290	278	292	304	362	364	219	84	38	35	109	287	290	278	292								
4/82-8/83				18	13	109	223	224	233	197	255	402	148	38	24	10	14	101	273	240	195	224								
Percent Diff.				-53	-63	0	-22	-23	-16	-33	-16	11	-59	-83	-71	-74	-60	-7	-5	-17	-30	-23								
Nino 3 Anomaly	°C								0.1	0.1	0.4	0.7	1.0	0.8	1.1	1.1	1.1	1.1	1.2	1.3	1.5	1.6	1.8	1.3	1.2	1.1	0.5	0.2	0.1	
MAP	(mm)								278	292	304	362	364	219	84	38	35	109	287	290	278	292	304	362	364	219	84	38	35	109
7/86-3/88									156	216	289	461	232	64	28	42	7	283	403	256	317	317	435	466	357	189	12	58	19	45
Percent Diff.									-44	-26	-5	27	-36	-71	-67	11	-80	160	40	-12	14	9	43	29	-2	-14	-86	53	-46	-59
Nino 3 Anomaly	°C						0.5	1.0	1.0	0.5	0.2	0.7	1.0	1.4	1.4	1.3	1.2	1.3	1.4	0.3										
MAP	(mm)						287	290	278	292	304	362	364	219	84	38	35	109	287	290										
5/91-6/92							357	246	259	216	362	278	380	94	28	14	14	169	413	340										
Percent Diff.							24	-15	-7	-26	19	-23	4	-57	-67	-63	-60	55	44	17										
Nino 3 Anomaly	°C			0.3	0.5	1.0	1.1	0.7	0.2																					
MAP	(mm)			38	35	109	287	290	278																					
2/93-7/93				18	112	200	262	395	223	208																				
Percent Diff.				-53	220	83	-9	36	-20																					
Nino 3 Anomaly	°C											0.7	0.9	1.0	0.7	0.5														
MAP	(mm)											362	364	219	84	38	35													
10/94-2/95												343	437	60	109	16	29													
Percent Diff.												-5	20	-73	30	-58	-17													
Nino 3 Anomaly	°C					0.2	1.0	1.8	2.4	2.9	3.0	3.3	3.6	3.7	3.3	2.6	2.1	1.7	1.1											
MAP	(mm)				35	109	287	290	278	292	304	362	364	219	84	38	35	109	287											
4/97-2/98					7	45	257	240	170	158	250	226	238	34	18	21	29	176	312											
Percent Diff.					-80	-59	-10	-17	-39	-46	-18	-38	-35	-84	-79	-45	-17	61	9											

Exhibit 15.8

DEPARTURES OF ANNUAL RUNOFFS FROM LONG-TERM MEAN DURING THE YEARS OF EL NINO EPISODES

1941-2000 Mean Annual Runoff

Madden Lake	75.1 cms		Gatun Downstream	109.7 cms	
Year	Runoff (cms)	% Depar.	Year	Runoff (cms)	% Depar.
1941	87	15.8	1941	120.6	9.9
1946	71.3	-5.1	1946	89.6	-18.3
1951	71.1	-5.3	1951	103.3	-5.8
1953	73.7	-1.9	1953	111.1	1.3
1957	49.7	-33.8	1957	68.7	-37.4
1965	73	-2.8	1965	129.9	18.4
1969	69.9	-6.9	1969	101.6	-7.4
1972	69.7	-7.2	1972	91.1	-17.0
1976	51.9	-30.9	1976	75.1	-31.5
1977	59.6	-20.6	1977	81.6	-25.6
1982	61.5	-18.1	1982	83.9	-23.5
1983	71.9	-4.3	1983	86.7	-21.0
1985	63.9	-14.9	1985	94.7	-13.7
1986	76.7	2.1	1986	90.3	-17.7
1991	68	-9.5	1991	92.1	-16.0
1997	47.5	-36.8	1997	55.6	-49.3
1998	66	-12.1	1998	88.5	-19.3

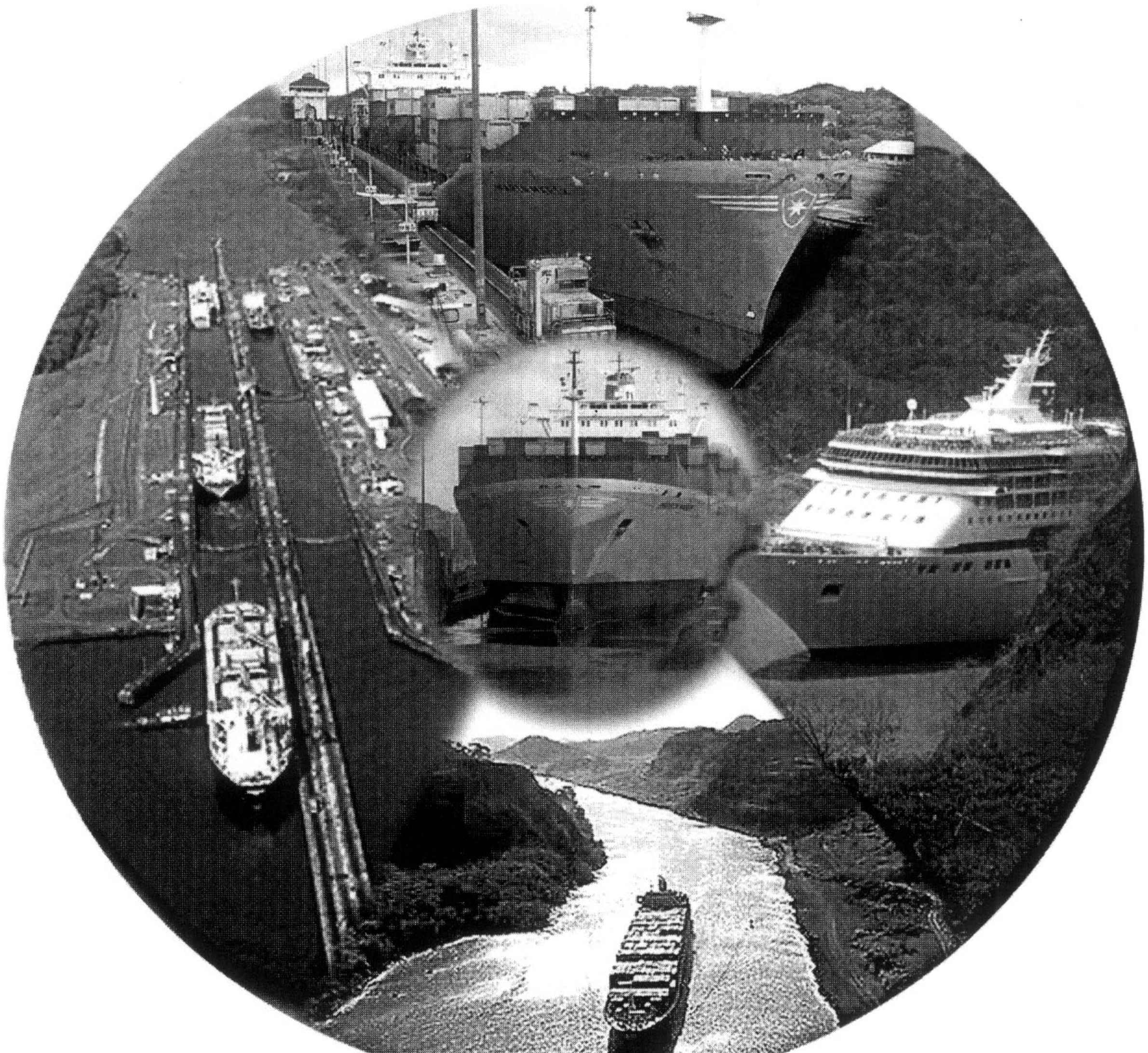
MONTHLY FLOW DEPARTURES FROM THE LONG-TERM MEAN DURING THE YEARS OF EL NINO EPISODES
MADDEN LAKE

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Nino 3 Anomaly °C							0.1	1.0	1.0	0.6	1.0	1.0	0.9	0.3	0.3														
Mean Annual (cms)						75.3	80.3	87.5	91.4	84.0	94.4	115.2	116.3	59.1	33.9	24.6	39.0	75.3	80.3										
6/51-2/52						78.4	76.6	71.5	76.1	70.6	73.4	78.4	71.1	42.5	27.1	18.3	24.8	61.8	62.9										
Percent Diff.						4	-5	-18	-17	-16	-22	-32	-39	-28	-20	-26	-36	-18	-22										
Nino 3 Anomaly °C		0.3	0.5	0.3	0.8	0.4	0.5	0.5	0.2	0.9	0.2	0.3	0.3	0.2	0.0														
Mean Annual (cms)		59.1	33.9	24.6	39.0	75.3	80.3	87.5	91.4	84.0	94.4	115.2	116.3	59.1	33.9														
1/53-2/54		99.9	65.9	29.3	29.5	96.2	67.8	82.6	76.4	68.9	79.2	105.5	83.6	39.8	29.6														
Percent Diff.		69	94	19	-24	28	-16	-6	-16	-18	-16	-8	-28	-33	-13														
Nino 3 Anomaly °C			0.1	0.3	0.5	0.5	0.9	1.0	1.4	0.5	0.7	1.2	1.6	1.5	1.0	0.7	0.3												
Mean Annual (cms)		59.1	33.9	24.6	39.0	75.3	80.3	87.5	91.4	84.0	94.4	115.2	116.3	59.1	33.9	24.6	39.0	75.3	80.3	87.5	91.4								
2/57-4/58		37.2	24.7	18.0	15.2	36.7	37.4	33.7	42.0	47.8	77.9	136.0	89.8	86.1	36.0	27.7	19.0	48.4	53.2	73.0	70.9								
Percent Diff.		-37	-27	-27	-61	-51	-53	-61	-54	-43	-17	18	-23	46	6	13	-51	-36	-34	-17	-22								
Nino 3 Anomaly °C					0.3	0.6	0.8	1.2	1.3	1.2	1.3	1.4	1.6	1.2	0.5	0.0													
Mean Annual (cms)					39.0	75.3	80.3	87.5	91.4	84.0	94.4	115.2	116.3	59.1	33.9	24.6													
4/65-3/66					21.2	58.7	96.2	70.6	68.4	95.4	114.9	131.4	125.0	59.7	35.6	27.2													
Percent Diff.					-46	-22	20	-19	-25	14	22	14	7	1	5	11													
Nino 3 Anomaly °C								0.3	0.3	0.1	0.2	0.4	0.6	0.8	0.4	0.6	0.5	1.0	0.7	0.2	0.6	0.6	0.8	0.8	1.2	0.9	0.2		
Mean Annual (cms)		59.1	33.9	24.6	39.0	75.3	80.3	87.5	91.4	84.0	94.4	115.2	116.3	59.1	33.9	24.6	39.0	75.3	80.3	87.5	91.4	84.0	94.4	115.2	116.3	59.1	33.9		
7/68-2/70		30.5	28.5	21.5	23.8	58.6	57.6	74.9	91.5	95.3	85.7	83.0	50.1	30.0	29.4	24.0	43.6	70.7	49.4	61.3	85.0	78.9	67.0	87.1	213.0	147.1	35.4		
Percent Diff.		-48	-16	-13	-39	-22	-28	-14	0	13	-9	-28	-57	-49	-13	-2	12	-6	-38	-30	-7	-6	-29	-24	83	149	4		
Nino 3 Anomaly °C					0.5	0.6	1.0	1.5	1.9	1.5	1.9	2.2	2.4	1.8	1.0	0.3													
Mean Annual (cms)					39.0	75.3	80.3	87.5	91.4	84.0	94.4	115.2	116.3	59.1	33.9	24.6	39.0	75.3	80.3										
4/72-3/73					55.6	66.6	67.0	48.1	61.6	73.5	84.8	83.8	57.6	29.0	19.0	11.1	10.2	48.3	68.8										
Percent Diff.					43	-12	-17	-45	-33	-13	-10	-27	-50	-51	-44	-55	-74	-36	-14										
Nino 3 Anomaly °C							0.5	0.7	0.8	1.0	1.0	0.9	0.8	0.9	0.5	0.3													
Mean Annual (cms)						75.3	80.3	87.5	91.4	84.0	94.4	115.2	116.3	59.1	33.9	24.6	39.0	75.3	80.3	87.5	91.4	84.0							
6/76-3/77						51.5	53.4	35.8	41.0	59.5	90.4	109.8	37.9	34.5	23.1	17.0	17.7	35.6	41.4	56.6	81.1	73.1							
Percent Diff.						-32	-33	-59	-55	-29	-4	-5	-67	-42	-32	-31	-55	-53	-48	-35	-11	-13							
Nino 3 Anomaly °C									0.1	1.0	0.4	0.3	0.4	0.5	0.2														
Mean Annual (cms)						75.3	80.3	87.5	91.4	84.0	94.4	115.2	116.3	59.1	33.9														
8/79-2/80						47.3	67.3	67.0	83.0	67.0	71.8	102.0	121.7	73.3	42.9														
Percent Diff.						-37	-16	-23	-9	-20	-24	-11	5	24	27														
Nino 3 Anomaly °C					0.3	0.7	1.1	0.9	1.2	1.7	2.2	2.6	3.3	3.3	2.5	2.0	1.7	1.9	1.8	1.0	0.9								
Mean Annual (cms)				24.6	39.0	75.3	80.3	87.5	91.4	84.0	94.4	115.2	116.3	59.1	33.9	24.6	39.0	75.3	80.3	87.5	91.4								
4/82-8/83				20.5	30.0	49.5	47.6	86.0	85.4	73.7	118.2	74.9	45.9	34.8	19.2	14.2	21.8	91.5	65.9	61.2	62.7								
Percent Diff.				-17	-23	-34	-41	-2	-7	-12	25	-35	-61	-41	-43	-42	-44	22	-18	-30	-31								
Nino 3 Anomaly °C								0.1	0.1	0.4	0.7	1.0	0.8	1.1	1.1	1.1	1.1	1.2	1.3	1.5	1.6	1.8	1.3	1.2	1.1	0.5	0.2	0.1	
Mean Annual (cms)								87.5	91.4	84.0	94.4	115.2	116.3	59.1	33.9	24.6	39.0	75.3	80.3	87.5	91.4	84.0	94.4	115.2	116.3	59.1	33.9	24.6	39.0
7/86-3/88								73.2	65.8	102.2	120.7	138.1	58.0	26.5	25.9	16.1	83.8	162.1	96.3	91.2	109.0	125.5	98.6	148.0	68.2	28.8	31.7	19.6	16.0
Percent Diff.								-16	-28	22	28	20	-50	-55	-24	-35	115	115	20	4	19	49	4	28	-41	-51	-6	-20	-59
Nino 3 Anomaly °C						0.5	1.0	1.0	0.5	0.2	0.7	1.0	1.4	1.4	1.3	1.2	1.3	1.4	0.3										
Mean Annual (cms)					39.0	75.3	80.3	87.5	91.4	84.0	94.4	115.2	116.3	59.1	33.9	24.6	39.0	75.3	80.3	87.5									
5/91-6/92					25.4	97.3	58.0	55.7	63.5	108.6	77.4	157.7	74.7	34.8	21.6	18.0	39.7	143.5	104.5	88.7									
Percent Diff.					-35	29	-28	-36	-31	29	-18	37	-36	-41	-36	-27	2	91	30	1									
Nino 3 Anomaly °C			0.3	0.5	1.0	1.1	0.7	0.2																					
Mean Annual (cms)			28.5	21.5	23.8	58.6	57.6	74.9	91.4	84.0																			
2/93-7/93			28.9	39.8	77.1	85.4	112.4	84.4	63.9	98.4																			
Percent Diff.			1	85	224	46	95	13	-30	17																			
Nino 3 Anomaly °C											0.7	0.9	1.0	0.7	0.5	24.6													
Mean Annual (cms)											94.4	115.2	116.3	59.1	33.9	24.6	39.0	75.3											
10/94-2/95											83.7	151.4	63.2	35.8	19.0	12.0	19.4	54.3											
Percent Diff.											-11	31	-46	-39	-44	-51	-50	-28											
Nino 3 Anomaly °C					0.2	1.0	1.8	2.4	2.9	3.0	3.3	3.6	3.7	3.3	2.6	2.1	1.7	1.1											
Mean Annual (cms)				24.6	39.0	75.3	80.3	87.5	91.4	84.0	94.4	115.2	116.3	59.1	33.9	24.6	39.0	75.3	80.3										
4/97-2/98				20.9	17.7	78.7	74.4	44.5	41.0	49.6	60.3	51.0	38.3	23.2	16.8	9.7	37.8	84.6	60.7										
Percent Diff.				-15	-55	5	-7	-49	-55	-41	-36	-56	-67	-61	-50	-61	-3	12	-24										

MONTHLY FLOW DEPARTURES FROM THE LONG-TERM MEAN DURING THE YEARS OF EL NINO EPISODES
GATUN DOWNSTREAM

		Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb		
Nino 3	Anomaly °C							0.1	1.0	1.0	0.6	1.0	1.0	0.9	0.3	0.3														
Mean	Annual (cms)							112.5	116.4	136.1	147.4	197.0	213.4	148.6	63.9	32.2	22.9	36.0	90.0											
	6/51-2/52							85.9	103.6	132.0	142.6	169.3	188.5	127.2	47.9	26.9	16.5	28.5	70.1											
	Percent Diff.							-24	-11	-3	-3	-14	-12	-14	-25	-16	-28	-21	-22											
Nino 3	Anomaly °C		0.3	0.5	0.3	0.8	0.4	0.5	0.5	0.2	0.9	0.2	0.3	0.3	0.2	0.0														
Mean	Annual (cms)		63.9	32.2	22.9	36.0	90.0	112.5	116.4	136.1	147.4	197.0	213.4	148.6	63.9	32.2	22.9													
	1/53-2/54		105.5	48.5	28.0	33.8	109.0	80.3	126.8	111.4	114.0	229.5	236.3	110.3	46.3	30.4	16.6													
	Percent Diff.		65	51	22	-6	21	-29	9	-18	-23	16	11	-26	-28	-6	-28													
Nino 3	Anomaly °C			0.1	0.3	0.5	0.5	0.9	1.0	1.4	0.5	0.7	1.2	1.6	1.5	1.0	0.7	0.3												
Mean	Annual (cms)	148.6	63.9	32.2	22.9	36.0	90.0	112.5	116.4	136.1	147.4	197.0	213.4	148.6	63.9	32.2	22.9	36.0	90.0	112.5										
	2/57-4/58	86.1	23.7	13.8	8.3	6.1	59.9	53.6	54.2	90.3	87.1	172.9	172.8	81.1	60.3	53.1	32.0	30.0	82.7	84.9										
	Percent Diff.	-42	-63	-57	-64	-83	-33	-52	-53	-34	-41	-12	-19	-45	-6	65	40	-17	-8	-25										
Nino 3	Anomaly °C					0.3	0.6	0.8	1.2	1.3	1.2	1.3	1.4	1.6	1.2	0.5	0.0													
Mean	Annual (cms)				22.9	36.0	90.0	112.5	116.4	136.1	147.4	197.0	213.4	148.6	63.9	32.2	22.9													
	4/65-3/66				18.5	13.1	78.6	91.8	82.7	124.4	121.3	288.6	428.6	216.1	73.0	26.7	17.1													
	Percent Diff.				-19	-64	-13	-18	-29	-9	-18	46	101	45	14	-17	-25													
Nino 3	Anomaly °C								0.3	0.3	0.1	0.2	0.4	0.6	0.8	0.4	0.6	0.5	1.0	0.7	0.2	0.6	0.6	0.8	0.8	1.2	0.9	0.2		
Mean	Annual (cms)								116.4	136.1	147.4	197.0	213.4	148.6	63.9	32.2	22.9	36.0	90.0	112.5	116.4	136.1	147.4	197.0	213.4	148.6	63.9	32.2		
	7/68-2/70								83.0	132.5	128.3	182.2	171.5	71.9	49.7	23.7	16.6	29.8	66.2	67.2	96.0	136.4	173.8	175.1	203.2	181.5	122.4	40.0		
	Percent Diff.								-29	-3	-13	-8	-20	-52	-22	-26	-28	-17	-26	-40	-18	0	18	-11	-5	22	92	24		
Nino 3	Anomaly °C					0.5	0.6	1.0	1.5	1.9	1.5	1.9	2.2	2.4	1.8	1.0	0.3													
Mean	Annual (cms)					36.0	90.0	112.5	116.4	136.1	147.4	197.0	213.4	148.6	63.9	32.2	22.9	36.0	90.0											
	4/72-3/73					72.8	71.6	123.9	67.0	72.5	140.0	157.8	127.2	99.7	44.9	30.6	9.9	15.3	70.7											
	Percent Diff.					102	-20	10	-42	-47	-5	-20	-40	-33	-30	-5	-57	-58	-21											
Nino 3	Anomaly °C							0.5	0.7	0.8	1.0	1.0	0.9	0.8	0.9	0.5	0.3													
Mean	Annual (cms)				22.9	36.0	90.0	112.5	116.4	136.1	147.4	197.0	213.4	148.6	63.9	32.2	22.9	36.0	90.0	112.5	116.4									
	6/76-3/77				18.4	33.0	64.0	75.3	31.2	52.1	125.9	189.9	160.0	57.5	30.7	17.7	10.2	10.4	54.2	59.1	63.2									
	Percent Diff.				-20	-8	-29	-33	-73	-62	-15	-4	-25	-61	-52	-45	-55	-71	-40	-47	-46									
Nino 3	Anomaly °C									0.1	1.0	0.4	0.3	0.4	0.5	0.2														
Mean	Annual (cms)									136.1	147.4	197.0	213.4	148.6	63.9	32.2	22.9	36.0												
	8/79-2/80									148.1	145.5	198.7	166.1	94.7	96.5	43.9	20.8	20.6												
	Percent Diff.									9	-1	1	-22	-36	51	36	-9	-43												
Nino 3	Anomaly °C					0.3	0.7	1.1	0.9	1.2	1.7	2.2	2.6	3.3	3.3	2.5	2.0	1.7	1.9	1.8	1.0	0.9								
Mean	Annual (cms)					36.0	90.0	112.5	116.4	136.1	147.4	197.0	213.4	148.6	63.9	32.2	22.9	36.0	90.0	112.5	116.4	136.1								
	4/82-8/83					44.4	71.2	83.7	80.4	72.6	105.5	189.9	123.6	41.1	26.0	15.3	10.5	22.3	72.4	81.5	63.9	89.1								
	Percent Diff.					23	-21	-26	-31	-47	-28	-4	-42	-72	-59	-52	-54	-38	-20	-28	-45	-35								
Nino 3	Anomaly °C								0.1	0.1	0.4	0.7	1.0	0.8	1.1	1.1	1.1	1.1	1.2	1.3	1.5	1.6	1.8	1.3	1.2	1.1	0.5	0.2	0.1	
Mean	Annual (cms)								116.4	136.1	147.4	197.0	213.4	148.6	63.9	32.2	22.9	36.0	90.0	112.5	116.4	136.1	147.4	197.0	213.4	148.6	63.9	32.2	22.9	36.0
	7/86-3/88								77.1	88.8	108.9	256.3	171.3	67.0	30.5	26.7	13.1	84.7	131.1	95.5	119.7	143.3	174.4	263.4	202.9	107.6	32.2	22.4	11.3	15.1
	Percent Diff.								-34	-35	-26	30	-20	-55	-52	-17	-43	135	46	-15	3	5	18	34	-5	-28	-50	-30	-51	-58
Nino 3	Anomaly °C						0.5	1.0	1.0	0.5	0.2	0.7	1.0	1.4	1.4	1.3	1.2	1.3	1.4	0.3										
Mean	Annual (cms)					36.0	90.0	112.5	116.4	136.1	147.4	197.0	213.4	148.6	63.9	32.2	22.9	36.0	90.0	112.5										
	5/91-6/92					28.9	114.9	85.1	92.2	86.9	146.6	152.4	190.2	90.9	57.9	24.0	13.2													
	Percent Diff.					-20	28	-24	-21	-36	-1	-23	-11	-39	-9	-25	-42													
Nino 3	Anomaly °C			0.3	0.5	1.0	1.1	0.7	0.2																					
Mean	Annual (cms)			32.2	22.9	36.0	90.0	112.5	116.4	136.1	147.4	197.0																		
	2/93-7/93			38.7	44.9	67.0	72.2	119.5	121.3	94.4	191.8	187.7																		
	Percent Diff.			20	96	86	-20	6	4	-31	30	-5																		
Nino 3	Anomaly °C											0.7	0.9	1.0	0.7	0.5														
Mean	Annual (cms)								116.4	136.1	147.4	197.0	213.4	148.6	63.9	32.2	22.9	36.0												
	10/94-2/95								77.3	95.1	114.6	163.6	211.6	65.0	55.5	20.1	15.2	31.1												
	Percent Diff.								-34	-30	-22	-17	-1	-56	-13	-38	-34	-14												
Nino 3	Anomaly °C					0.2	1.0	1.8	2.4	2.9	3.0	3.3	3.6	3.7	3.3	2.6	2.1	1.7	1.1											
Mean	Annual (cms)		63.9	32.2	22.9	36.0	90.0	112.5	116.4	136.1	147.4	197.0	213.4	148.6	63.9	32.2	22.9	36.0	90.0	112.5	116.4	136.1	147.4	197.0	213.4					
	4/97-2/98		45.6	29.8	15.1	5.1	65.3	68.4	53.9	46.9	72.9	101.0	115.1	37.8	18.5	12.5	9.6	48.0	69.8	80.3	103.1	120.0	119.3	167.1	121.4					
	Percent Diff.		-29	-7	-34	-86	-27	-39	-54	-66	-51	-49	-46	-75	-71	-61	-58	33	-22	-29	-11	-12	-19	-15	-43					

16.0 Analysis of Effect of Sunspots Cycle on Time Series



16.0 ANALYSIS OF EFFECT OF SUNSPOT CYCLE ON TIME SERIES

16.1 Definitions

A sunspot is a relatively dark, sharply defined region on the solar disk, marked by an umbra some 2000 K cooler than the effective photospheric temperature, surrounded by a less dark but also sharply bounded penumbra. The average spot diameter is about 37,000 km, and exceptionally large spots can be up to 245,000 km across (Herman and Goldberg, 1978, page 12). Sunspot number, devised by the astronomical observatory in Zurich, Switzerland, is defined as:

$$R = k\,(10\,g + f)$$

where 'f' is total number of spots regardless of size, 'g' is the number of spot groups and 'k' normalizes the counts from different observatories. The daily sunspot number can range from 0 to 355 or more. The annual mean number varies from 0 to 10 in years of minimum and from 50 to 190 for years of maximum. A cycle is measured from minimum to minimum. It has become a common practice to refer to a 11-year sunspots cycle (see Exhibit 16.1). However, Hale sunspot cycle refers to 22 years, where 11-year maxima are plotted as positive or negative peaks. The 22-year cycle is the period in which the magnetic polarity of bipolar sunspots completes a cycle. The polarity reversal takes place at a minimum in the 11-year cycle. Thus, the 22-year cycle includes two successive 11-year cycles, one positive (or negative) and other negative (or positive).

The first cycle was assigned to 1755-66. The beginning of each cycle is marked by the appearance of new sunspots and group of sunspots at high solar latitudes. As the cycle progresses sunspots appear at successively lower latitudes until most appear within 5° of the solar equator near the end of an 11-year period. The beginning of the new cycle usually overlaps the end of the cycle, sometimes by a year or more.

Herman and Goldberg (1978) described, with reference to other publications, that two prolonged minima and one major prolonged maxima in sunspots activities must have occurred. In these three apparently non-periodic events, no 11-year variation in sunspots activities was discernable. The 12th century grand maxima in sunspot activities spanned the years 1100 to 1250. A general decline then occurred until the year 1520, interrupted only by a relatively brief minor maximum, centered at about the year 1400. The first deep prolonged minimum, centered at the year 1520 (covering the years 1460 to 1550), is called "Sporer Minimum." The second minimum, named "Maunder Minimum," occurred during the years 1645 to 1715. The coldest part of the climatic temperature minimum known as the "Little Ice Age," coincided with the Maunder Minimum.

16.2 Previous Study by MWH

In early 1980's Harza made a detailed search of literature to identify studies and research that developed or attempted relationships between sunspots and air surface temperatures, annual rainfall or annual river flows. The purpose of this search was to assess the feasibility of correlating sunspots and annual inflows of Guri Reservoir in Venezuela, and providing some model for predicting long-term water supply for Guri.

Through personal contacts and review of literature on sunspots activities and related effect on weather (Wilson, Vaughan and Mihalas, 1978; Willett, 1976; Stockton, Mitchel and Meko, 1978; Mitchel, Stockton and Meko, 1981; Pittock, 1978; and Herman and Goldberg, 1978), Harza made the following conclusions.

- The studies strongly support a 22-year drought rhythm or cycle in the western United States and suggest that the droughts cycle is in some manner controlled by solar variability directly or indirectly related to solar magnetic effects.
- Current drought-solar behavior is hardly to be considered as a basis for operational climate forecast. However, risk of large scale drought increasing follows the sunspot minimum.
- Many and varied claims have been made over many years for a relationship between weather or climate and sunspot cycles (single of 11 years or double of 22 years). However, little convincing evidence has yet been produced for real correlation between sunspots cycles and weather or climate in 11- and 22-year time scale.
- Weather and climate are highly variable on all time scale and only a fraction of that variability can reasonably ascribed to sunspots cycles (Pittock, 1978).
- No matter how strong the relationship between drought and sunspots, drought prediction is made uncertain by the unpredictability of the Hale series itself. The period of 11-year sunspot series has in the past ranged from 8.5 years to 16 years, implying that one could be in error at least by five or more years in predicting the time of the next Hale minimum.

16.3 Current Analysis

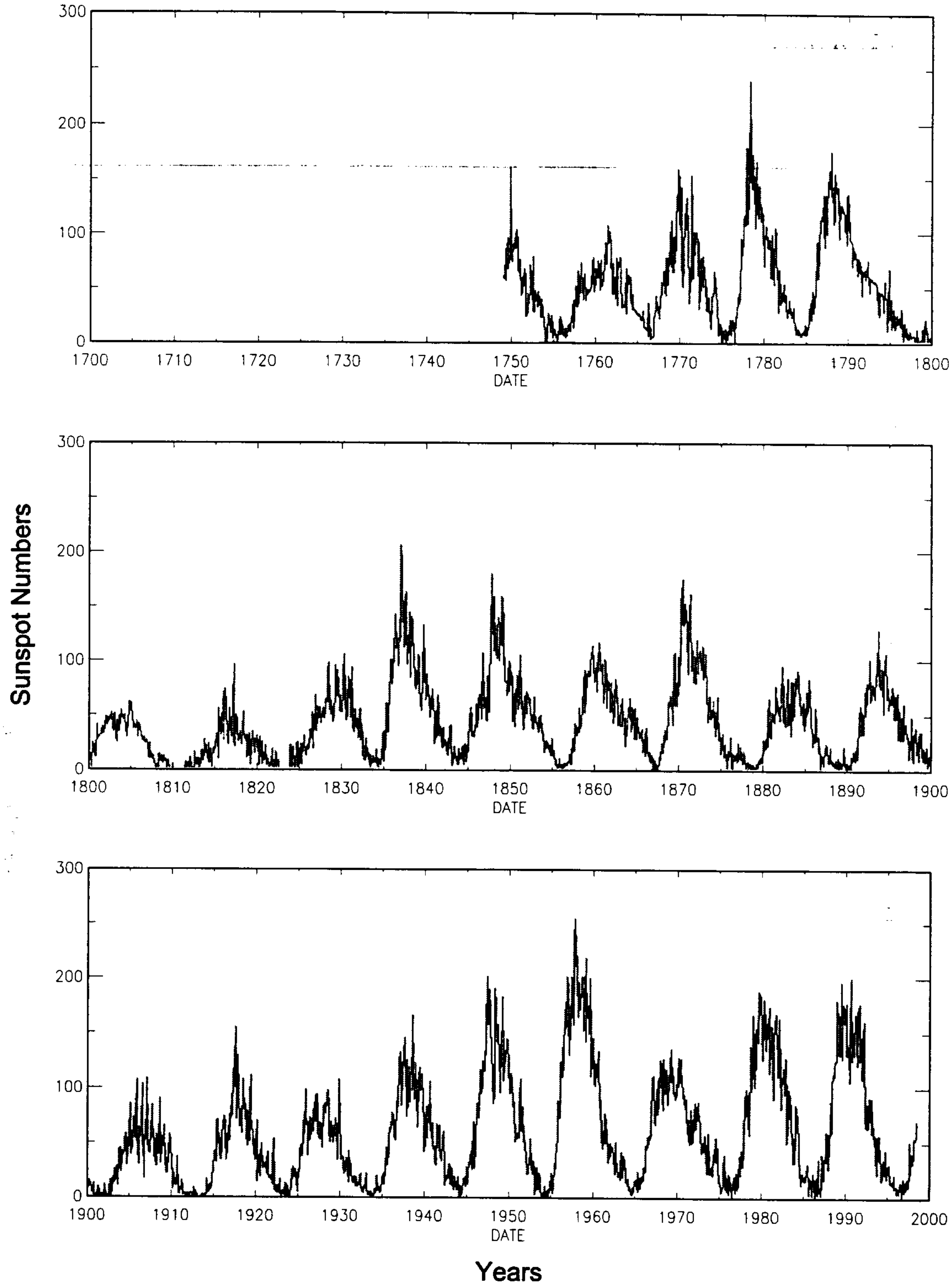
The sunspot data were derived from Exhibit 16.1 as average for a year and are shown on Exhibit 16.2. These smoothed data were plotted as time series against basin average rainfall and inflows as shown on Exhibits 16.3 and 16.4. The exhibits do no show any short-term effect on the flow or rainfall.

The smoothed sunspot numbers were plotted beginning with 1750 and are shown on Exhibit 16.5. A close review of the cycles indicated a long-term cyclic trend. Herman and Goldberg (p100, 1978) have reported a cycle of about 90 years. Next Exhibits 16.6 and 16.7 were prepared with 11-year and 22-year moving average series. Since 1900 there is a rising trend in the sunspot cycles. From about mid 1960's, there appears to be a slight decreasing trend (Exhibit 16.7).

Herman and Goldberg (p269, 1978) have reported that "On a long-term basis, a number of statistically significant correlations that may be regarded as circumstantial evidence have been found between sunspots number and meteorological parameters. Although it is recognized that sunspot number variations offer only the most general indications of solar activity, the fact that correlations are found is an encouragement to have a closer look. Sunspots are either a barometer for changes in solar constant or reflect direct processes related to solar activity which interact with the Earth's atmosphere to affect weather and climate."

Herman and Goldberg (p269, 1978) also concluded that "The amount of annual rainfall, for example, exhibits a dependence on the 11-year sunspot cycle in many land areas of the world. There is a pronounced trend for greater than average rainfall during solar maximum years in equatorial latitudes (between 20° north and 20° south) and less than average rainfall in middle latitude regions from 20° to 40° (north and south). However, there are a number of locations in the world where orographic and other meteorological factors override any solar cycle influence."

A general conclusion from the literature on effects of sunspots is that increase in sunspots may decrease or increase air temperatures and decrease or increase rainfall depending upon the locations. As discussed earlier, there is a slight decrease in number of sunspots since mid 1960's. It is likely that a slight decreasing trend in rainfall in Gatun watershed may be associated with sunspots. However, this should be confirmed from rainfall data at other stations in the equatorical belt.



AUTORIDAD DEL CANAL DE PANAMA
Oficina de Proyectos de Capacidad del Canal

ACP

CONTRACT NO. CC-3-536

STUDY OF HYDROLOGIC SERIES IN GATUN LAKE WATERSHED

Historical Sunspot Cycles

MWH MONTGOMERY WATSON HARZA

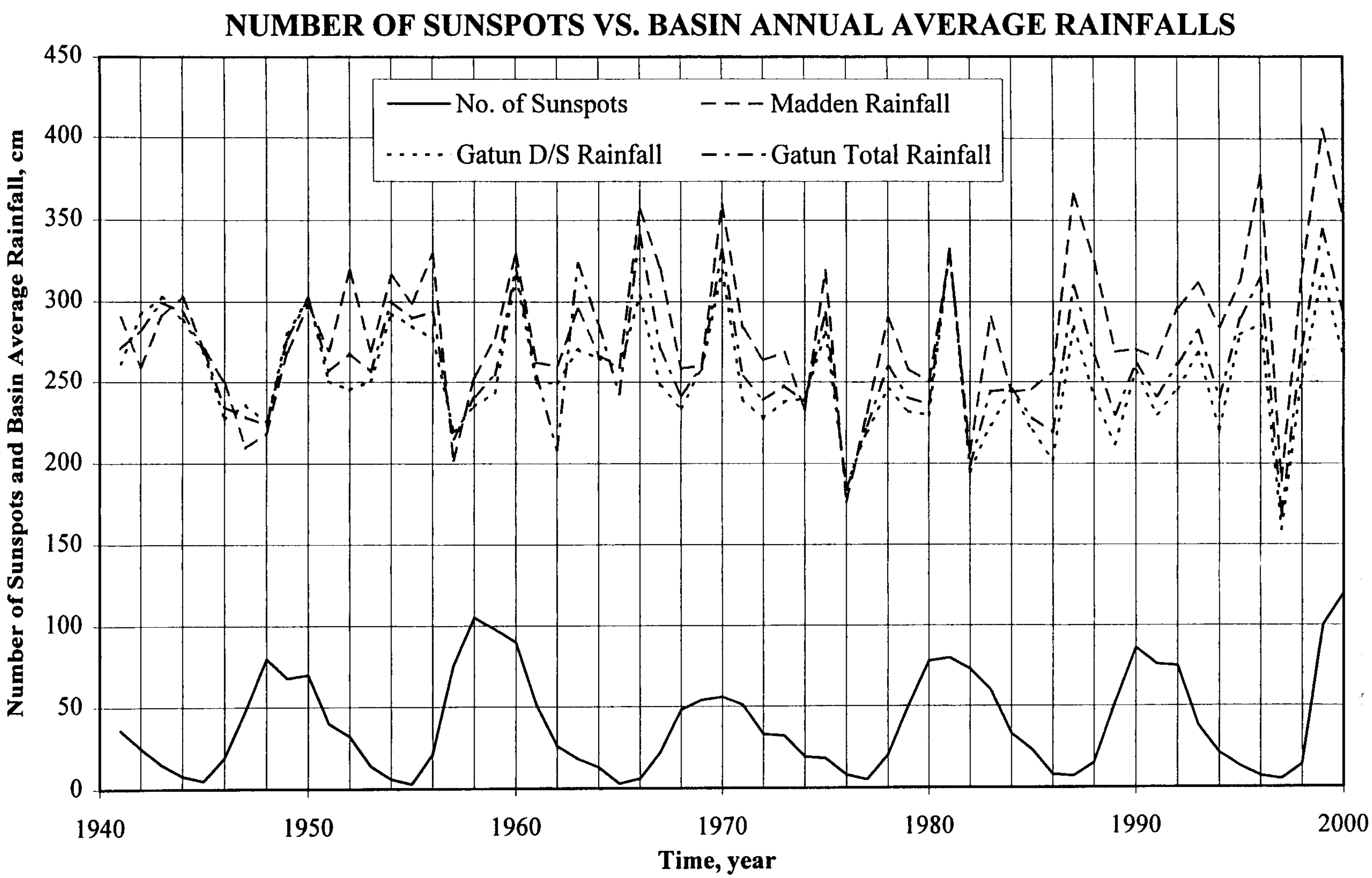
FECHA: DECEMBER, 2001

EXHIBIT: 16.1

Exhibit 16.2

NUMBER OF SUNSPOTS

Year	No. of Sunspots	Year	No. of Sunspots	Year	No. of Sunspots	Year	No. of Sunspots	Year	No. of Sunspots
1750	43								
1751	48	1801	8	1851	35	1901	4	1951	40
1752	30	1802	47	1852	32	1902	2	1952	32
1753	50	1803	24	1853	27	1903	2	1953	14
1754	15	1804	22	1854	22	1904	12	1954	6
1755	7	1805	26	1855	11	1905	26	1955	3
1756	5	1806	23	1856	4	1906	34	1956	21
1757	5	1807	15	1857	2	1907	30	1957	76
1758	19	1808	5	1858	15	1908	26	1958	105
1759	26	1809	4	1859	30	1909	25	1959	98
1760	28	1810	1	1860	49	1910	20	1960	90
1761	33	1811	0	1861	50	1911	8	1961	51
1762	44	1812	2	1862	41	1912	3	1962	26
1763	31	1813	4	1863	34	1913	2	1963	18
1764	24	1814	8	1864	24	1914	1	1964	13
1765	18	1815	6	1865	22	1915	5	1965	3
1766	10	1816	20	1866	15	1916	24	1966	6
1767	6	1817	23	1867	9	1917	30	1967	22
1768	18	1818	19	1868	4	1918	51	1968	48
1769	34	1819	13	1869	18	1919	40	1969	54
1770	52	1820	11	1870	40	1920	32	1970	56
1771	48	1821	8	1871	72	1921	20	1971	51
1772	45	1822	3	1872	57	1922	13	1972	33
1773	30	1823	2	1873	53	1923	7	1973	32
1774	18	1824	1	1874	30	1924	3	1974	19
1775	13	1825	5	1875	25	1925	8	1975	18
1776	4	1826	8	1876	9	1926	25	1976	8
1777	10	1827	19	1877	6	1927	34	1977	5
1778	55	1828	24	1878	5	1928	38	1978	20
1779	86	1829	33	1879	1	1929	37	1979	50
1780	66	1830	36	1880	3	1930	30	1980	78
1781	46	1831	38	1881	20	1931	16	1981	80
1782	36	1832	23	1882	30	1932	10	1982	73
1783	20	1833	12	1883	32	1933	5	1983	60
1784	11	1834	4	1884	35	1934	3	1984	33
1785	5	1835	7	1885	35	1935	4	1985	23
1786	14	1836	28	1886	26	1936	21	1986	8
1787	38	1837	64	1887	11	1937	42	1987	7
1788	65	1838	68	1888	7	1938	59	1988	15
1789	70	1839	50	1889	3	1939	60	1989	52
1790	60	1840	46	1890	3	1940	50	1990	86
1791	47	1841	30	1891	2	1941	36	1991	76
1792	34	1842	18	1892	20	1942	25	1992	75
1793	33	1843	13	1893	36	1943	15	1993	38
1794	26	1844	5	1894	43	1944	8	1994	21
1795	22	1845	7	1895	40	1945	5	1995	13
1796	12	1846	21	1896	32	1946	19	1996	7
1797	7	1847	35	1897	20	1947	48	1997	5
1798	3	1848	56	1898	12	1948	80	1998	14
1799	2	1849	63	1899	11	1949	68	1999	100
1800	3	1850	45	1900	6	1950	70	2000	120



NUMBER OF SUNSPOTS VS. BASIN ANNUAL AVERAGE RAINFALLS
No. of Sunspots
Madden Rainfall
Gatun D/S Rainfall
Gatun Total Rainfall
Number of Sunspots and Basin Average Rainfall, cm
0
50
100
150
200
250
300
350
400
450
1940
1950
1960
1970
1980
1990
2000
Time, year

Exhibit 16.3

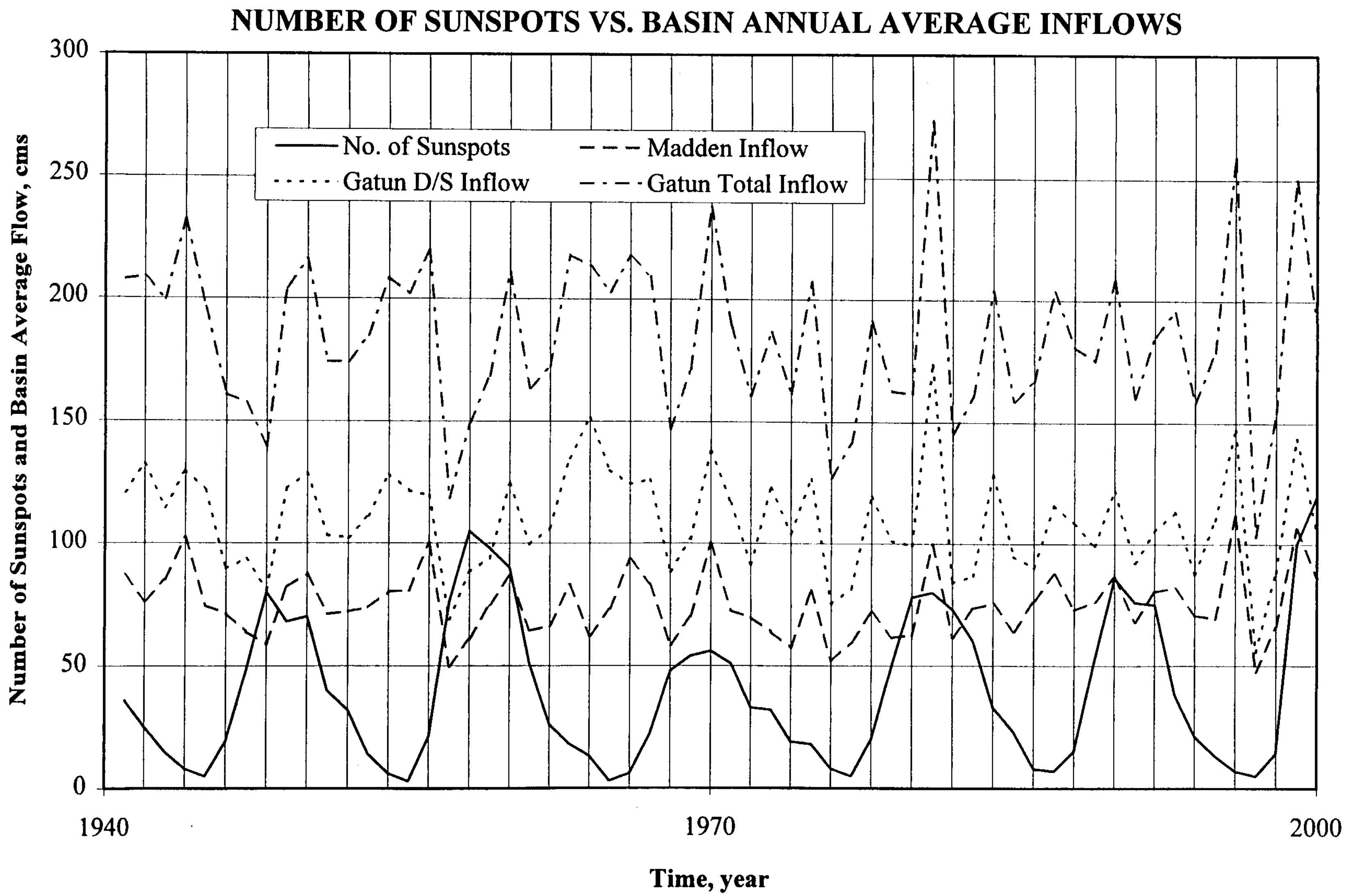

NUMBER OF SUNSPOTS VS. BASIN ANNUAL AVERAGE INFLOWS
No. of Sunspots
Madden Inflow
Gatun D/S Inflow
Gatun Total Inflow
Number of Sunspots and Basin Average Flow, cms
300
250
200
150
100
50
0
1940
1970
2000
Time, year

Exhibit 16.4

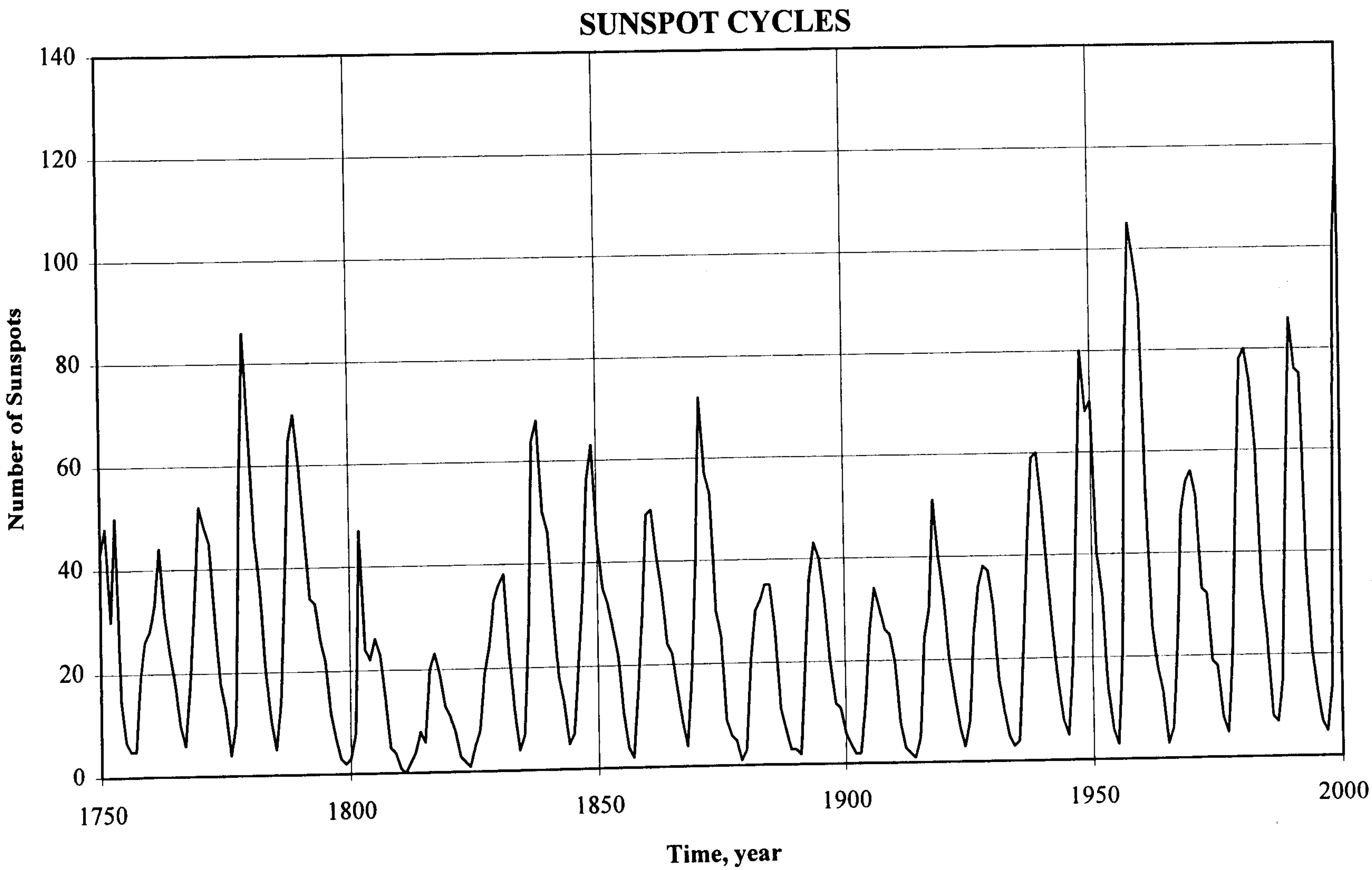

SUNSPOT CYCLES
140
120
100
80
60
40
20
0
Number of Sunspots
1750
1800
1850
1900
1950
2000
Time, year

Exhibit 16.5

SUNSPOT CYCLES WITH 11-YEAR MOVING AVERAGE

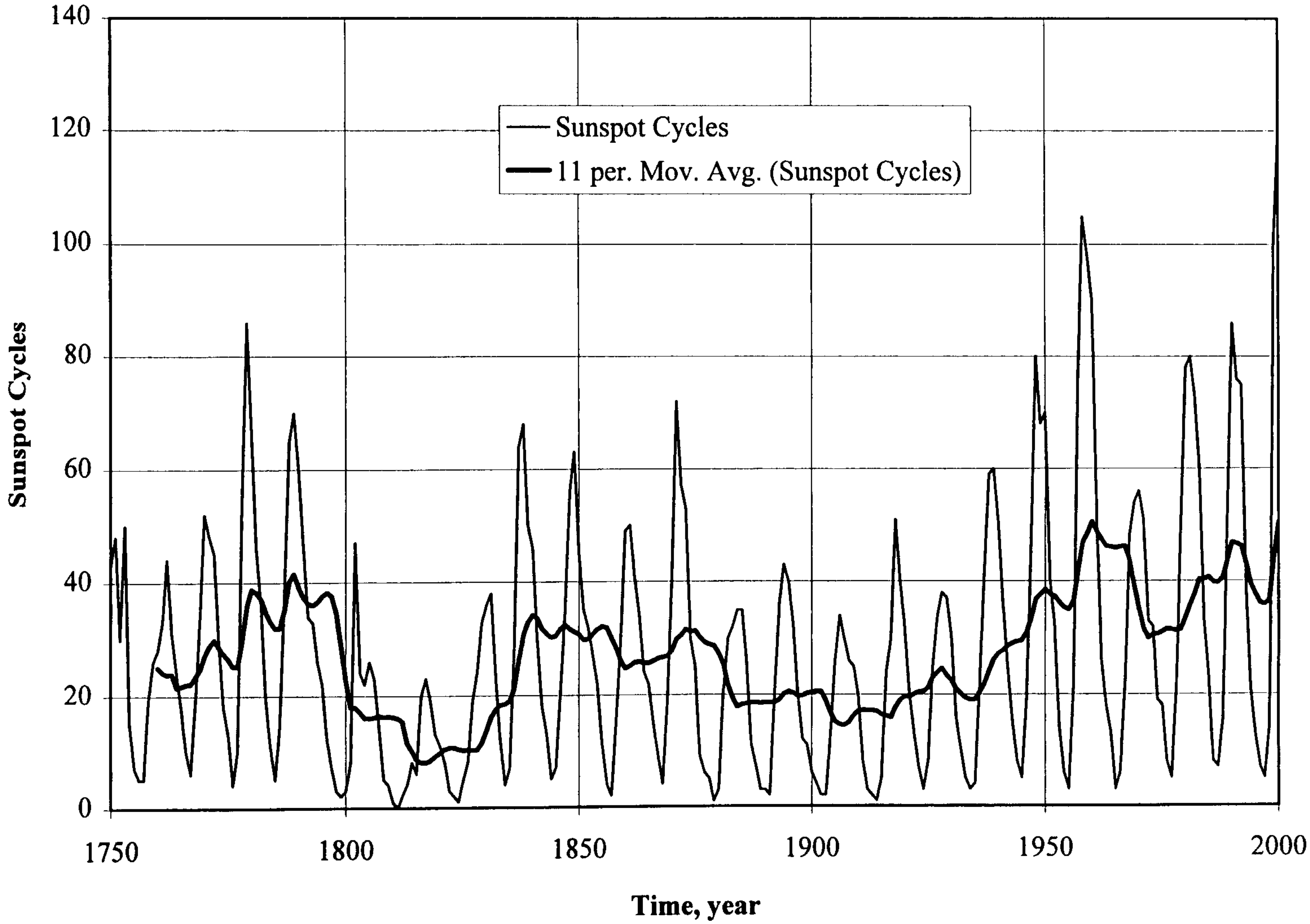
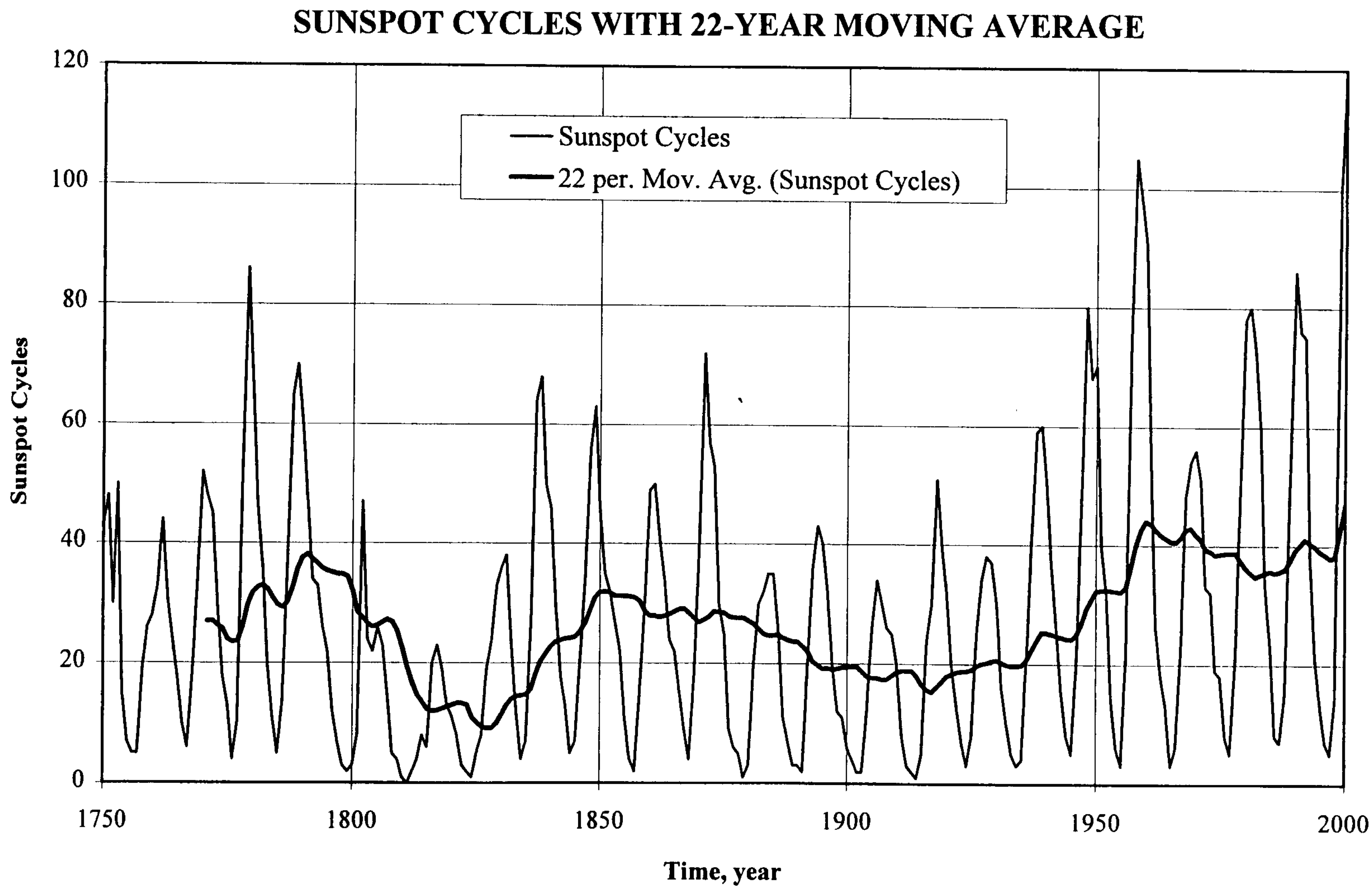


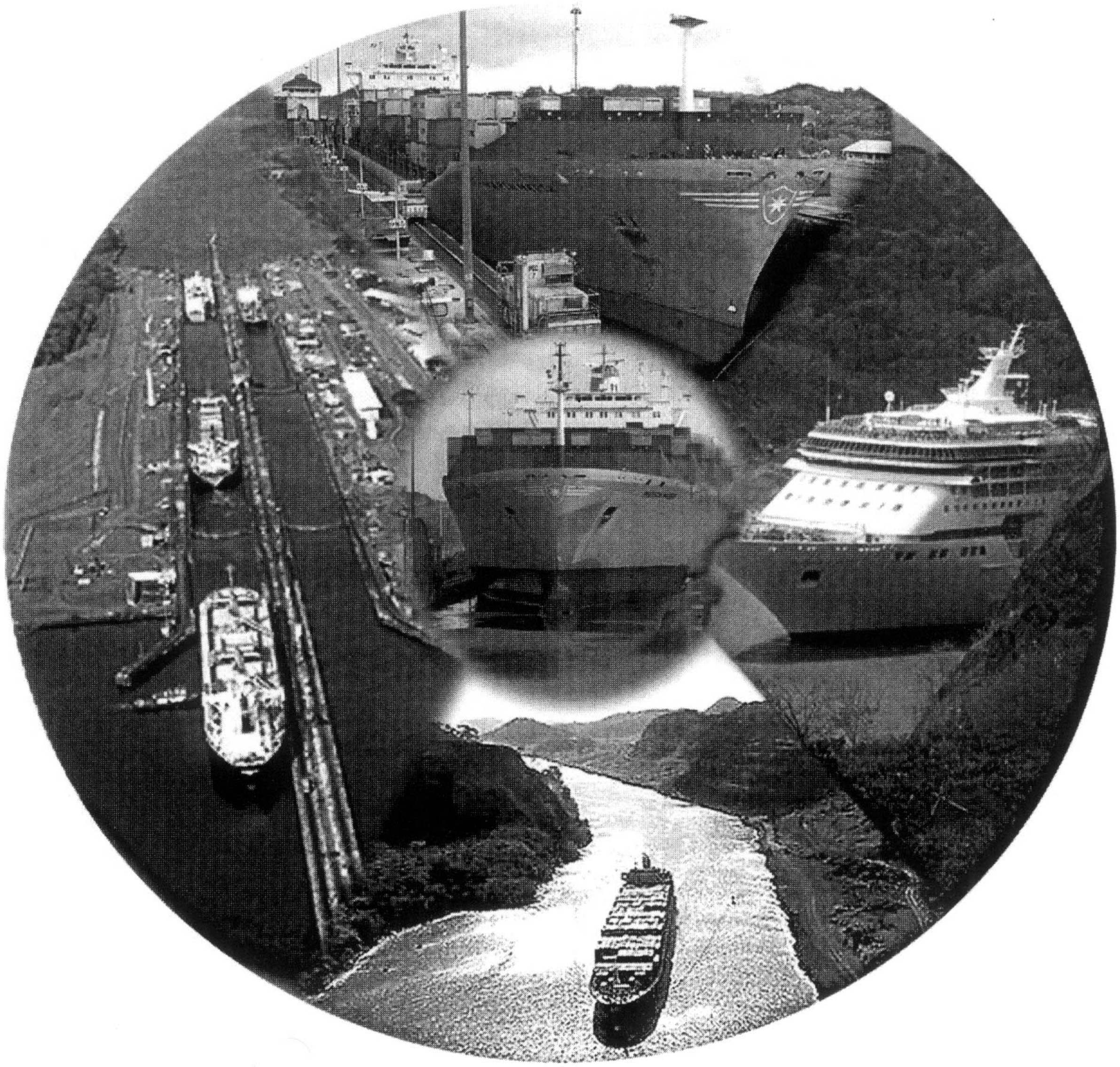
Exhibit 16.6



SUNSPOT CYCLES WITH 22-YEAR MOVING AVERAGE
Sunspot Cycles
22 per. Mov. Avg. (Sunspot Cycles)
120
100
80
60
40
20
0
1750
1800
1850
1900
1950
2000
Sunspot Cycles
Time, year

Exhibit 16.7

17.0 Analysis of Droughts



17.0 ANALYSIS OF DROUGHTS

17.1 Duration and Frequency

Monthly runoff series (inflows to Gatun Lake including Madden Lake (Gatun total), Gatun Lake excluding Madden Lake (Gatun downstream) and Maddan Lake) were analyzed for magnitude, duration and frequency of occurrence of droughts. Durations of 3, 6, 12, 18, 24, 30 and 36 months were selected. The runoff volumes were estimated corresponding to return periods of frequency of 10, 25, 50 and 75 years. The driest and the wettest inflow volumes were also identified for the selected durations.

17.2 Development of Drought Magnitude-Duration-Frequency Relationship

The method of analyzing drought frequencies and duration is based on the assumption that meteorological conditions recorded in the past would be repeated. In most cases, absence of long record, potential long-term variation in rainfall and runoff, and topographic changes brought by man, make it rather difficult to make precise forecasts.

For drought analysis, data is selected by one of two methods; either one extreme value is chosen for each time unit, such as the lowest monthly flow in a year, or the lowest monthly flows for selected duration in the period of record are chosen regardless of when they occurred. With the latter method, the number of values chosen need not equal the number of years of record.

The first method is not very useful since this deals with a discrete value of flow and reveals nothing about the sequence of low flows. The second method is more useful. In this case, the analysis is made by determining the flows over a given period of consecutive days, months or years. A difficulty encountered in frequency analysis of sequential events is overlapping of data and repeated appearance of extreme values. Thus, in the analysis of droughts, say lasting for 24 months, certain low flow months might appear twice. This can be treated using the procedure by Chow (Chow, 1964). The procedure is illustrated by the following example of monthly inflows of Madden Lake.

Monthly flows of Madden Lake for the period from 1941 to 2000 were arrayed in one column. Running totals of 3-, 6-, 12-, 18-, 24-, 30- and 36-month periods were computed. For the flows in each period, the following procedure, illustrated for the 12-month period, was used.

1. Select the lowest 12-month value.

2. To avoid over-lapping, exclude the 11 totals prior and subsequent to the selected lowest value.

3. After excluding the values, select the next lowest value and again exclude the 11 totals prior and subsequent to the selected value.

4. Continue until all totals have been used either by selecting or excluding.

5. Array the selected values from lowest to highest and assign 1 to the lowest value, 2 to the next value and so on.

6. Compute the return period of the lowest value as "number of years of record plus 1 divided by the order of the value," that is, 61 (Stall, 1964, used Weibull's position). The return period for the second lowest value will be (61/2 = 30.5).

In case of 3- and 6-month periods, the values were than the number of years of record. In these cases only the lowest values equal to the number of years of record were used. The lowest values for the selected durations with corresponding return periods are given in Exhibit 17.1. Exhibit 17.2 shows the frequency curves.

The flows of selected durations and their assigned recurrence intervals furnish estimates of average length of time in years which can be expected to elapse between the beginning of various events. For example, the third ranking event in the 12-month series has a recurrence interval of 61/3 = about 20 years. Thus, it can be said that in any year the probability is 1 in 20 for the start of a 12-month period during which the total flow would be as low as 1,540 mcm.

The frequency curves were used to derive the volumes for 3, 6, 12, 18, 24, 30 and 36 months corresponding to return periods of 10, 25, 50 and 75 years. The driest and wettest volumes for the above durations were also computed. The data are given in Table 17.1.

The above analysis was also made for the monthly flow series of Gatun downstream and Gatun total. The results are given on Exhibits 17.3 to 17.6. Table 17.1 gives the volumes for various durations.

17.3 Risk of Occurrence of Selected Runoff Volumes

Exhibits 17.1 to 17.6 were used to determine the return periods of the driest years of record for Madden Lake, Gatun Downstream and Gatun Total. The return period of other flows are given in Table 17.1.

The risk of occurrence for each flow listed in Table 17.2 was determined using the following equation:

$$P = (1 - ((1 - 1/Tr)^{N}))\ 100$$

P = percent risk of occurrence in a period of N years.

Tr = return period.

Table 17.2 shows the results.

Table 17.1

RUNOFF VOLUMES (MCM) FOR SELECTED DURATIONS AND RETURN PERIODS

Return Period (yr)	Duration in Months						
Madden Lake	3	6	12	18	24	30	36
Driest	100	430	1309	2054	3387	3952	5340
Wettest	1432	2281	3478	5015	5990	7438	8266
10	135	500	1630	2450	3730	4790	6400
25	114	445	1480	2160	3500	4300	5500
50	110	425	1350	2060	3400	4000	5300
75	100	410	1250	2000	3300	3800	5100
Gatun D/S							
Driest	73	429	1599	2347	4375	5412	7255
Wettest	2419	3916	5447	7865	8971	11797	12942
10	127	533	2616	3404	5655	6745	9182
25	100	477	2104	2917	4839	5800	8223
50	80	440	1800	2500	4400	5600	7600
75	73	410	1700	2300	4100	5300	7100
Gatun Total							
Driest	223	868	2908	4426	8476	9364	12708
Wettest	3399	5629	8582	12057	16071	18115	20225
10	249	1061	4020	5860	10250	11800	15350
25	234	970	3580	5070	8500	10250	14050
50	230	900	3100	4700	8200	9400	13000
75	225	860	2800	4300	7900	8900	12000

Table 17.2

RISK OF OCCURRENCE OF SELECTED RUNOFF VOLUMES

Volume (mcm)	Return Period (years)	Selected Periods (Years)					Remarks
		5	10	25	50	100	
		Risk of Occurrence of Flow Lower than the Indicated (Percent)					
3-Month Duration							
Madden Lake							
135	10	41.0	65.1	92.8	99.5	100.0	
114	25	18.5	33.5	64.0	87.0	98.3	
110	50	9.6	18.3	39.7	63.6	86.7	
100	75	6.5	12.6	28.5	48.9	73.9	
100	75	6.5	12.6	28.5	48.9	73.9	driest period
Gatun D/S							
127	10	41.0	65.1	92.8	99.5	100.0	
100	25	18.5	33.5	64.0	87.00	98.3	
80	50	9.6	18.3	39.7	63.6	86.7	
73	75	6.5	12.6	28.5	48.9	73.9	
73	75	6.5	12.6	28.5	48.9	73.9	driest period
Gatun Total							
249	10	41.0	65.1	92.8	99.5	100.0	
234	25	18.5	33.5	64.0	87.0	98.3	
230	50	9.6	18.3	39.7	63.6	86.7	
225	75	6.5	12.6	28.5	48.9	73.9	
223	75	6.5	12.6	28.5	48.9	73.9	driest period
6-Month Duration							
Madden Lake							
500	10	41.0	65.1	92.8	99.5	100.0	
445	25	18.5	33.5	64.0	87.0	98.3	
425	50	9.6	18.3	39.7	63.6	86.7	
410	75	6.5	12.6	28.5	48.9	73.9	
430	61	7.9	15.2	33.8	56.2	80.9	driest period
Gatun D/S							
533	10	41.0	65.1	92.8	99.5	100.0	
477	25	18.5	33.5	64.0	87.0	98.3	
440	50	9.6	18.3	39.7	63.6	86.7	
410	75	6.5	12.6	28.5	48.9	73.9	
429	61	7.9	15.2	33.8	56.2	80.9	driest period
Gatun Total							
1061	10	41.0	65.1	92.8	99.5	100.0	
970	25	18.5	33.5	64.0	87.0	98.3	
900	50	9.6	18.3	39.7	63.6	86.7	
860	75	6.5	12.6	28.5	48.9	73.9	
868	61	7.9	15.2	33.8	56.2	80.9	driest period
12-Month Duration							
Madden Lake							
1630	10	41.0	65.1	92.8	99.5	100.0	
1480	25	18.5	33.5	64.0	87.0	98.3	
1350	50	9.6	18.3	39.7	63.6	86.7	
1250	75	6.5	12.6	28.5	48.9	73.9	
1309	61	7.9	15.2	33.8	56.2	80.9	driest period
Gatun D/S							
2616	10	41.0	65.1	92.8	99.5	100.0	
2104	25	18.5	33.5	64.0	87.0	98.3	
1800	50	9.6	18.3	39.7	63.6	86.7	
1700	75	6.5	12.6	28.5	48.9	73.9	

Volume (mcm)	Return Period (years)	Selected Periods (Years) 5	10	25	50	100	Remarks
		Risk of Occurrence of Flow Lower than the Indicated (Percent)					
1599	90	5.4	10.6	24.4	42.8	67.3	driest period
Gatun Total							
4020	10	41.0	65.1	92.8	99.5	100.0	
3580	25	18.5	33.5	64.0	87.0	98.3	
3100	50	9.6	18.3	39.7	63.6	86.7	
2800	75	6.5	12.6	28.5	48.9	73.9	
2908	61	7.9	15.2	33.8	56.2	80.9	driest period
18-Month Duration							
Madden Lake							
2450	10	41.0	65.1	92.8	99.5	100.0	
2160	25	18.5	33.5	64.0	87.0	98.3	
2060	50	9.6	18.3	39.7	63.6	86.7	
2000	75	6.5	12.6	28.5	48.9	73.9	
2054	61	7.9	15.2	33.8	56.2	80.9	driest period
Gatun D/S							
3404	10	41.0	65.1	92.8	99.5	100.0	
2917	25	18.5	33.5	64.0	87.0	98.3	
2500	50	9.6	18.3	39.7	63.6	86.7	
2300	75	6.5	12.6	28.5	48.9	73.9	
2347	61	7.9	15.2	33.8	56.2	80.9	driest period
Gatun Total							
5860	10	41.0	65.1	92.8	99.5	100.0	
5070	25	18.5	33.5	64.0	87.0	98.3	
4700	50	9.6	18.3	39.7	63.6	86.7	
4300	75	6.5	12.6	28.5	48.9	73.9	
4426	61	7.9	15.2	33.8	56.2	80.9	driest period
24-Month Duration							
Madden Lake							
3730	10	41.0	65.1	92.8	99.5	100.0	
3500	25	18.5	33.5	64.0	87.0	98.3	
3400	50	9.6	18.3	39.7	63.6	86.7	
3300	75	6.5	12.6	28.5	48.9	73.9	
3387	61	7.9	15.2	33.8	56.2	80.9	driest period
Gatun D/S							
5655	10	41.0	65.1	92.8	99.5	100.0	
4839	25	18.5	33.5	64.0	87.0	98.3	
4400	50	9.6	18.3	39.7	63.6	86.7	
4100	75	6.5	12.6	28.5	48.9	73.9	
4375	61	7.9	15.2	33.8	56.2	80.9	driest period
Gatun Total							
10250	10	41.0	65.1	92.8	99.5	100.0	
8500	25	18.5	33.5	64.0	87.0	98.3	
8200	50	9.6	18.3	39.7	63.6	86.7	
7900	75	6.5	12.6	28.5	48.9	73.9	
8476	40	11.9	22.4	46.9	71.8	92.0	driest period
30-Month Duration							
Madden Lake							
4790	10	41.0	65.1	92.8	99.5	100.0	
4300	25	18.5	33.5	64.0	87.0	98.3	
4000	50	9.6	18.3	39.7	63.6	86.7	
3800	75	6.5	12.6	28.5	48.9	73.9	
3952	61	7.9	15.2	33.8	56.2	80.9	driest period
Gatun D/S							
6745	10	41.0	65.1	92.8	99.5	100.0	
5800	25	18.5	33.5	64.0	87.0	98.3	
5600	50	9.6	18.3	39.7	63.6	86.7	

Volume (mcm)	Return Period (years)	Selected Periods (Years)					Remarks
		5	10	25	50	100	
		Risk of Occurrence of Flow Lower than the Indicated (Percent)					
5300	75	6.5	12.6	28.5	48.9	73.9	
5412	61	7.9	15.2	33.8	56.2	80.9	driest period
Gatun Total							
11800	10	41.0	65.1	92.8	99.5	100.0	
10250	25	18.5	33.5	64.0	87.0	98.3	
9400	50	9.6	18.3	39.7	63.6	86.7	
8900	75	6.5	12.6	28.5	48.9	73.9	
9364	60	8.1	15.5	34.3	56.8	81.4	driest period
36-Month Duration							
Madden Lake							
6400	10	41.0	65.1	92.8	99.5	100.0	
5500	25	18.5	33.5	64.0	87.0	98.3	
5300	50	9.6	18.3	39.7	63.6	86.7	
5100	75	6.5	12.6	28.5	48.9	73.9	
5340	61	7.9	15.2	33.8	56.2	80.9	driest period
Gatun D/S							
9182	10	41.0	65.1	92.8	99.5	100.0	
8223	25	18.5	33.5	64.0	87.0	98.3	
7600	50	9.6	18.3	39.7	63.6	86.7	
7100	75	6.5	12.6	28.5	48.9	73.9	
7255	61	7.9	15.2	33.8	56.2	80.9	driest period
Gatun Total							
15350	10	41.0	65.1	92.8	99.5	100.0	
14050	25	18.5	33.5	64.0	87.0	98.3	
13000	50	9.6	18.3	39.7	63.6	86.7	
12000	75	6.5	12.6	28.5	48.9	73.9	
12708	61	7.9	15.2	33.8	56.2	80.9	driest period

MADDEN MONTHLY INFLOWS (MCM)
DROUGHT-DURATION-FREQUENCY ANALYSIS

Rank of Event	Return Period (years)	3-Month Flows (mcm)	Rank of Event	Return Period (years)	6-Month Flows (mcm)	Rank of Event	Return Period (years)	12-Month Flows (mcm)
1	61.0	100	1	61.0	430	1	61.0	1309
2	30.5	104	2	30.5	430	2	30.5	1409
3	20.3	123	3	20.3	454	3	20.3	1540
4	15.3	129	4	15.3	458	4	15.3	1594
5	12.2	131	5	12.2	477	5	12.2	1633
6	10.2	136	6	10.2	500	6	10.2	1633
7	8.7	139	7	8.7	513	7	8.7	1718
8	7.6	143	8	7.6	528	8	7.6	1729
9	6.8	150	9	6.8	531	9	6.8	1743
10	6.1	150	10	6.1	544	10	6.1	1773
11	5.5	153	11	5.5	546	11	5.5	1812
12	5.1	155	12	5.1	549	12	5.1	1813
13	4.7	166	13	4.7	550	13	4.7	1861
14	4.4	167	14	4.4	572	14	4.4	1890
15	4.1	174	15	4.1	582	15	4.1	1902
16	3.8	175	16	3.8	594	16	3.8	1903
17	3.6	178	17	3.6	596	17	3.6	1959
18	3.4	180	18	3.4	600	18	3.4	1968
19	3.2	182	19	3.2	604	19	3.2	2055
20	3.1	185	20	3.1	615	20	3.1	2077
21	2.9	187	21	2.9	626	21	2.9	2112
22	2.8	189	22	2.8	636	22	2.8	2139
23	2.7	191	23	2.7	639	23	2.7	2162
24	2.5	191	24	2.5	640	24	2.5	2192
25	2.4	192	25	2.4	657	25	2.4	2197
26	2.3	193	26	2.3	658	26	2.3	2213
27	2.3	202	27	2.3	663	27	2.3	2247
28	2.2	202	28	2.2	667	28	2.2	2253
29	2.1	214	29	2.1	674	29	2.1	2294
30	2.0	214	30	2.0	702	30	2.0	2303
31	2.0	215	31	2.0	714	31	2.0	2334
32	1.9	216	32	1.9	721	32	1.9	2354
33	1.8	216	33	1.8	722	33	1.8	2357
34	1.8	224	34	1.8	756	34	1.8	2391
35	1.7	228	35	1.7	759	35	1.7	2486
36	1.7	229	36	1.7	777	36	1.7	2553
37	1.6	230	37	1.6	841	37	1.6	2553
38	1.6	231	38	1.6	847	38	1.6	2560
39	1.6	231	39	1.6	861	39	1.6	2573
40	1.5	239	40	1.5	863	40	1.5	2595
41	1.5	240	41	1.5	881	41	1.5	2649
42	1.5	276	42	1.5	895	42	1.5	2655
43	1.4	280	43	1.4	903	43	1.4	2676
44	1.4	290	44	1.4	910	44	1.4	2894
45	1.4	294	45	1.4	923	45	1.4	3031
46	1.3	304	46	1.3	925	46	1.3	3116
47	1.3	306	47	1.3	925	47	1.3	3217
48	1.3	307	48	1.3	939			
49	1.2	307	49	1.2	959			
50	1.2	315	50	1.2	962			
51	1.2	316	51	1.2	997			
52	1.2	318	52	1.2	998			
53	1.2	323	53	1.2	1000			
54	1.1	333	54	1.1	1033			
55	1.1	337	55	1.1	1046			
56	1.1	346	56	1.1	1050			
57	1.1	347	57	1.1	1058			
58	1.1	350	58	1.1	1124			
59	1.0	364	59	1.0	1139			
60	1.0	375	60	1.0	1159			

MADDEN MONTHLY INFLOWS (MCM)
DROUGHT-DURATION-FREQUENCY ANALYSIS

Rank of Event	Return Period (years)	18-Month Flows (mcm)	Rank of Event	Return Period (years)	24-Month Flows (mcm)	Rank of Event	Return Period (years)	30-Month Flows (mcm)	Rank of Event	Return Period (years)	36-Month Flows (mcm)
1	61.0	2054	1	61.0	3387	1	61.0	3952	1	61.0	5340
2	30.5	2080	2	30.5	3404	2	30.5	4254	2	30.5	5454
3	20.3	2247	3	20.3	3527	3	20.3	4357	3	20.3	5577
4	15.3	2349	4	15.3	3591	4	15.3	4478	4	15.3	5956
5	12.2	2408	5	12.2	3693	5	12.2	4560	5	12.2	6329
6	10.2	2458	6	10.2	3730	6	10.2	4788	6	10.2	6400
7	8.7	2461	7	8.7	3742	7	8.7	4805	7	8.7	6459
8	7.6	2521	8	7.6	3849	8	7.6	5024	8	7.6	6504
9	6.8	2522	9	6.8	3934	9	6.8	5129	9	6.8	6568
10	6.1	2592	10	6.1	4052	10	6.1	5146	10	6.1	6657
11	5.5	2635	11	5.5	4208	11	5.5	5242	11	5.5	6751
12	5.1	2777	12	5.1	4276	12	5.1	5294	12	5.1	6960
13	4.7	2818	13	4.7	4373	13	4.7	5320	13	4.7	7031
14	4.4	2825	14	4.4	4455	14	4.4	5686	14	4.4	7713
15	4.1	2900	15	4.1	4504	15	4.1	5939			
16	3.8	2910	16	3.8	4573	16	3.8	6219			
17	3.6	3027	17	3.6	4624	17	3.6	6803			
18	3.4	3046	18	3.4	4770	18	3.4	7329			
19	3.2	3324	19	3.2	5202						
20	3.1	3348	20	3.1	5570						
21	2.9	3788	21	2.9	5716						
22	2.8	3950	22	2.8	5990						
23	2.7	3973									
24	2.5	4047									
25	2.4	4054									
26	2.3	4171									
27	2.3	4225									
28	2.2	4322									
29	2.1	4483									
30	2.0	4720									

MADDEN MONTHLY INFLOWS
DROUGHT-DURATION-FREQUENCY ANALYSIS

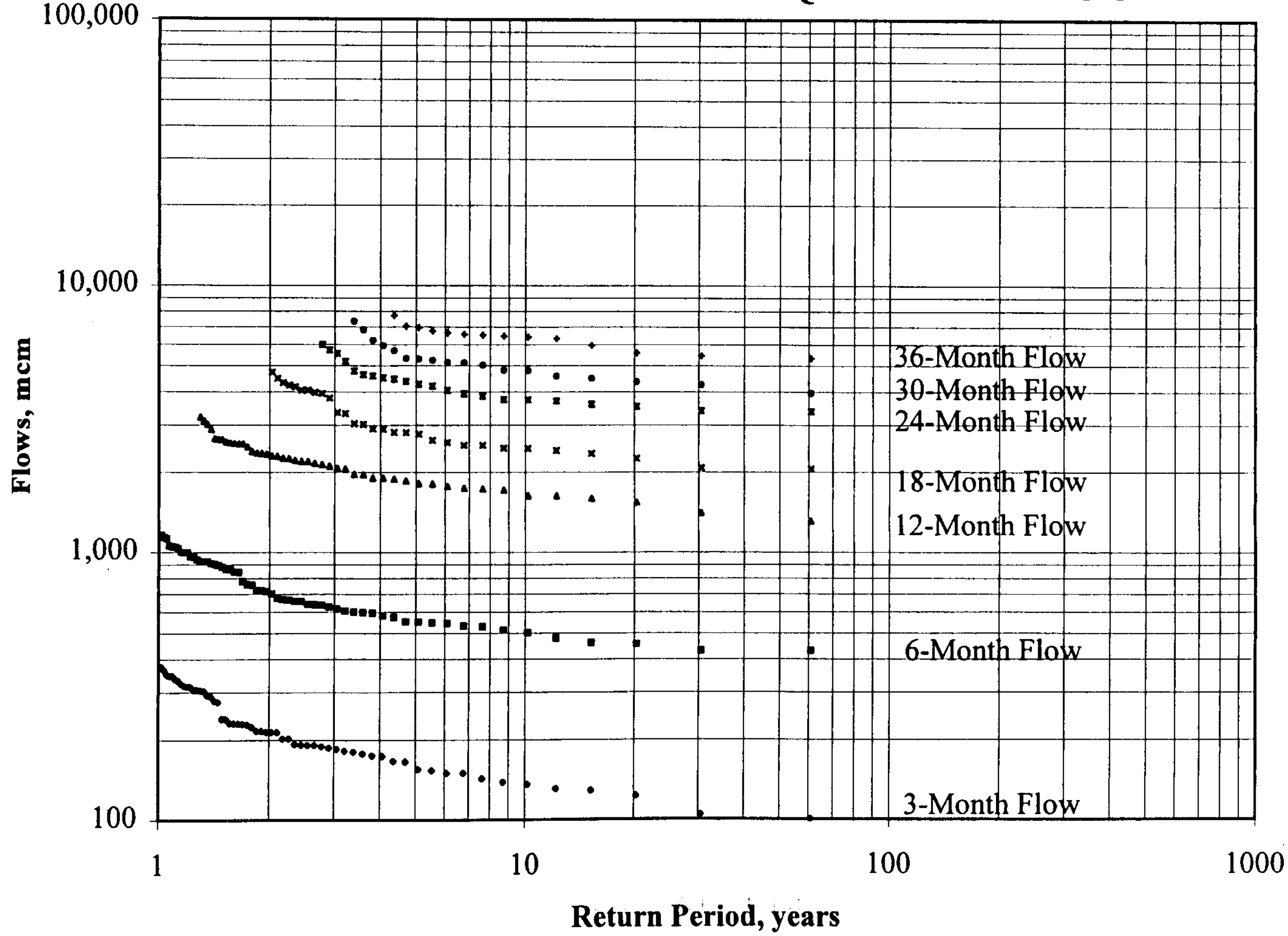


Exhibit 17.2

GATUN DOWNSTREAM MONTHLY INFLOWS (MCM)
DROUGHT-DURATION-FREQUENCY ANALYSIS

Rank of Event	Return Period (years)	3-Month Flows (mcm)	Rank of Event	Return Period (years)	6-Month Flows (mcm)	Rank of Event	Return Period (years)	12-Month Flows (mcm)
1	61.0	73	1	61.0	429	1	61.0	1599
2	30.5	99	2	30.5	468	2	30.5	2071
3	20.3	101	3	20.3	486	3	20.3	2136
4	15.3	105	4	15.3	508	4	15.3	2137
5	12.2	125	5	12.2	511	5	12.2	2143
6	10.2	127	6	10.2	533	6	10.2	2416
7	8.7	127	7	8.7	585	7	8.7	2487
8	7.6	135	8	7.6	603	8	7.6	2651
9	6.8	136	9	6.8	619	9	6.8	2695
10	6.1	145	10	6.1	620	10	6.1	2724
11	5.5	146	11	5.5	657	11	5.5	2750
12	5.1	156	12	5.1	657	12	5.1	2780
13	4.7	161	13	4.7	666	13	4.7	2807
14	4.4	167	14	4.4	674	14	4.4	2849
15	4.1	172	15	4.1	703	15	4.1	2891
16	3.8	172	16	3.8	708	16	3.8	2898
17	3.6	181	17	3.6	740	17	3.6	2948
18	3.4	181	18	3.4	753	18	3.4	2971
19	3.2	182	19	3.2	753	19	3.2	3083
20	3.1	182	20	3.1	760	20	3.1	3130
21	2.9	187	21	2.9	762	21	2.9	3171
22	2.8	192	22	2.8	770	22	2.8	3191
23	2.7	193	23	2.7	781	23	2.7	3221
24	2.5	196	24	2.5	783	24	2.5	3241
25	2.4	196	25	2.4	815	25	2.4	3244
26	2.3	199	26	2.3	826	26	2.3	3258
27	2.3	202	27	2.3	836	27	2.3	3291
28	2.2	204	28	2.2	857	28	2.2	3433
29	2.1	204	29	2.1	879	29	2.1	3450
30	2.0	206	30	2.0	898	30	2.0	3455
31	2.0	206	31	2.0	903	31	2.0	3480
32	1.9	213	32	1.9	915	32	1.9	3547
33	1.8	216	33	1.8	915	33	1.8	3592
34	1.8	221	34	1.8	922	34	1.8	3640
35	1.7	222	35	1.7	937	35	1.7	3708
36	1.7	223	36	1.7	941	36	1.7	3711
37	1.6	236	37	1.6	943	37	1.6	3734
38	1.6	236	38	1.6	943	38	1.6	3784
39	1.6	238	39	1.6	955	39	1.6	3792
40	1.5	241	40	1.5	962	40	1.5	3794
41	1.5	250	41	1.5	963	41	1.5	3908
42	1.5	257	42	1.5	969	42	1.5	3949
43	1.4	262	43	1.4	972	43	1.4	4020
44	1.4	266	44	1.4	975	44	1.4	4066
45	1.4	270	45	1.4	1011	45	1.4	4091
46	1.3	275	46	1.3	1012	46	1.3	4174
47	1.3	281	47	1.3	1014			
48	1.3	286	48	1.3	1050			
49	1.2	298	49	1.2	1065			
50	1.2	304	50	1.2	1100			
51	1.2	320	51	1.2	1106			
52	1.2	333	52	1.2	1118			
53	1.2	334	53	1.2	1123			
54	1.1	340	54	1.1	1124			
55	1.1	340	55	1.1	1174			
56	1.1	340	56	1.1	1217			
57	1.1	341	57	1.1	1232			
58	1.1	377	58	1.1	1265			
59	1.0	384	59	1.0	1501			
60	1.0	411	60	1.0	1716			

GATUN DOWNSTREAM MONTHLY INFLOWS (MCM)
DROUGHT-DURATION-FREQUENCY ANALYSIS

Rank of Event	Return Period (years)	18-Month Flows (mcm)	Rank of Event	Return Period (years)	24-Month Flows (mcm)	Rank of Event	Return Period (years)	30-Month Flows (mcm)	Rank of Event	Return Period (years)	36-Month Flows (mcm)
1	61.0	2347	1	61.0	4375	1	61.0	5412	1	61.0	7255
2	30.5	2809	2	30.5	4799	2	30.5	5551	2	30.5	8076
3	20.3	3025	3	20.3	4879	3	20.3	6000	3	20.3	8370
4	15.3	3080	4	15.3	5084	4	15.3	6185	4	15.3	8514
5	12.2	3129	5	12.2	5265	5	12.2	6224	5	12.2	9017
6	10.2	3404	6	10.2	5655	6	10.2	6745	6	10.2	9182
7	8.7	3424	7	8.7	5770	7	8.7	7100	7	8.7	9377
8	7.6	3568	8	7.6	5988	8	7.6	7196	8	7.6	9382
9	6.8	3623	9	6.8	6005	9	6.8	7266	9	6.8	9683
10	6.1	3729	10	6.1	6137	10	6.1	7411	10	6.1	9701
11	5.5	3842	11	5.5	6164	11	5.5	7443	11	5.5	9790
12	5.1	3934	12	5.1	6270	12	5.1	7541	12	5.1	10188
13	4.7	3960	13	4.7	6393	13	4.7	8034	13	4.7	10865
14	4.4	3975	14	4.4	6396	14	4.4	8418	14	4.4	11875
15	4.1	3993	15	4.1	6526	15	4.1	8827	15	4.1	11994
16	3.8	4032	16	3.8	6712	16	3.8	8962			
17	3.6	4123	17	3.6	6787						
18	3.4	4382	18	3.4	7285						
19	3.2	4685	19	3.2	7357						
20	3.1	4744	20	3.1	7466						
21	2.9	4794	21	2.9	7683						
22	2.8	4983	22	2.8	7710						
23	2.7	4993									
24	2.5	5055									
25	2.4	5521									
26	2.3	5541									
27	2.3	5606									
28	2.2	6210									
29	2.1	6691									
30	2.0	6739									
31	2.0	7022									
32	1.9	7083									
33	1.8	7665									

GATUN DOWNSTREAM MONTHLY INFLOWS
DROUGHT-DURATION-FREQUENCY ANALYSIS

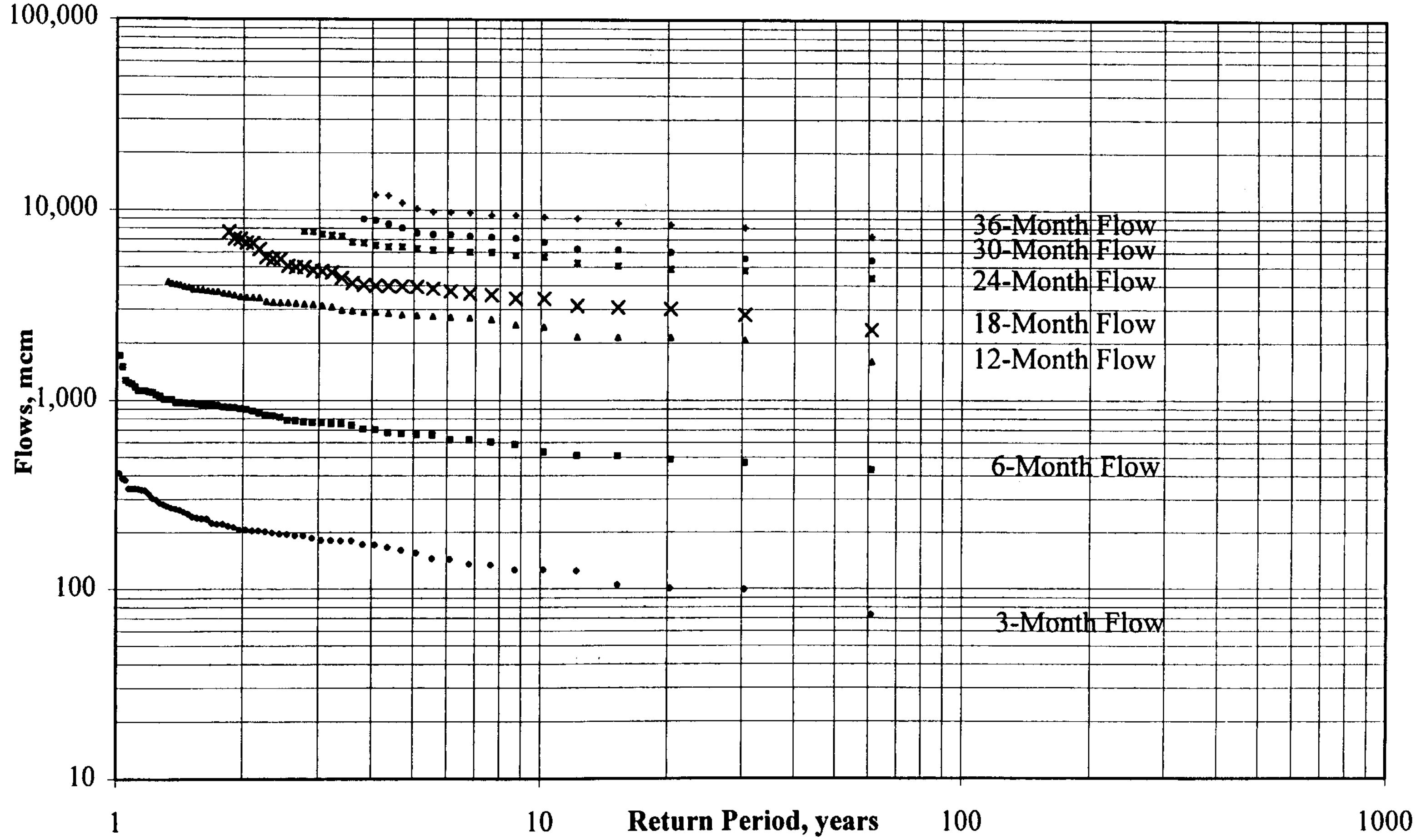


Exhibit 17.4

Exhibit 17.5
Sheet 1of 2

GATUN TOTAL MONTHLY INFLOWS (MCM)
DROUGHT-DURATION-FREQUENCY ANALYSIS

Rank of Event	Return Period (years)	3-Month Flows (mcm)	Rank of Event	Return Period (years)	6-Month Flows (mcm)	Rank of Event	Return Period (years)	12-Month Flows (mcm)
1	61.0	223	1	61.0	868	1	61.0	2908
2	30.5	234	2	30.5	898	2	30.5	3480
3	20.3	235	3	20.3	1046	3	20.3	3682
4	15.3	237	4	15.3	1054	4	15.3	3807
5	12.2	249	5	12.2	1061	5	12.2	3922
6	10.2	249	6	10.2	1062	6	10.2	4027
7	8.7	259	7	8.7	1075	7	8.7	4235
8	7.6	267	8	7.6	1147	8	7.6	4528
9	6.8	280	9	6.8	1151	9	6.8	4585
10	6.1	301	10	6.1	1251	10	6.1	4755
11	5.5	303	11	5.5	1252	11	5.5	4766
12	5.1	330	12	5.1	1281	12	5.1	4821
13	4.7	334	13	4.7	1297	13	4.7	4862
14	4.4	350	14	4.4	1325	14	4.4	4884
15	4.1	353	15	4.1	1330	15	4.1	4904
16	3.8	358	16	3.8	1345	16	3.8	4994
17	3.6	359	17	3.6	1353	17	3.6	5005
18	3.4	360	18	3.4	1356	18	3.4	5040
19	3.2	361	19	3.2	1377	19	3.2	5085
20	3.1	362	20	3.1	1381	20	3.1	5111
21	2.9	369	21	2.9	1382	21	2.9	5133
22	2.8	372	22	2.8	1406	22	2.8	5218
23	2.7	374	23	2.7	1419	23	2.7	5221
24	2.5	377	24	2.5	1462	24	2.5	5316
25	2.4	378	25	2.4	1494	25	2.4	5328
26	2.3	396	26	2.3	1499	26	2.3	5433
27	2.3	410	27	2.3	1554	27	2.3	5495
28	2.2	412	28	2.2	1585	28	2.2	5520
29	2.1	432	29	2.1	1590	29	2.1	5616
30	2.0	433	30	2.0	1619	30	2.0	5827
31	2.0	435	31	2.0	1633	31	2.0	5920
32	1.9	438	32	1.9	1637	32	1.9	5939
33	1.8	445	33	1.8	1645	33	1.8	6017
34	1.8	447	34	1.8	1753	34	1.8	6100
35	1.7	452	35	1.7	1779	35	1.7	6148
36	1.7	453	36	1.7	1798	36	1.7	6169
37	1.6	469	37	1.6	1802	37	1.6	6228
38	1.6	481	38	1.6	1810	38	1.6	6271
39	1.6	490	39	1.6	1823	39	1.6	6411
40	1.5	513	40	1.5	1826	40	1.5	6434
41	1.5	521	41	1.5	1875	41	1.5	6661
42	1.5	549	42	1.5	1880	42	1.5	6693
43	1.4	551	43	1.4	1921	43	1.4	6793
44	1.4	560	44	1.4	1973	44	1.4	6815
45	1.4	563	45	1.4	2010	45	1.4	7068
46	1.3	609	46	1.3	2027	46	1.3	7590
47	1.3	611	47	1.3	2044			
48	1.3	620	48	1.3	2047			
49	1.2	626	49	1.2	2057			
50	1.2	636	50	1.2	2066			
51	1.2	646	51	1.2	2128			
52	1.2	647	52	1.2	2129			
53	1.2	650	53	1.2	2151			
54	1.1	655	54	1.1	2208			
55	1.1	678	55	1.1	2262			
56	1.1	714	56	1.1	2390			
57	1.1	716	57	1.1	2506			
58	1.1	733	58	1.1	2773			
59	1.0	749	59	1.0	2778			
60	1.0	800	60	1.0	2814			

Exhibit 17.5
Sheet 2of 2

GATUN TOTAL MONTHLY INFLOWS (MCM)
DROUGHT-DURATION-FREQUENCY ANALYSIS

Rank of Event	Return Period (years)	18-Month Flows (mcm)	Rank of Event	Return Period (years)	24-Month Flows (mcm)	Rank of Event	Return Period (years)	30-Month Flows (mcm)	Rank of Event	Return Period (years)	36-Month Flows (mcm)
1	61.0	4426	1	61.0	8476	1	61.0	9367	1	61.0	12708
2	30.5	4862	2	30.5	8486	2	30.5	10162	2	30.5	14033
3	20.3	5272	3	20.3	8509	3	20.3	10361	3	20.3	14092
4	15.3	5589	4	15.3	9227	4	15.3	10719	4	15.3	14778
5	12.2	5602	5	12.2	9471	5	12.2	11017	5	12.2	15009
6	10.2	5862	6	10.2	10257	6	10.2	11812	6	10.2	15398
7	8.7	6024	7	8.7	10528	7	8.7	12145	7	8.7	16101
8	7.6	6190	8	7.6	10724	8	7.6	12373	8	7.6	16142
9	6.8	6386	9	6.8	10784	9	6.8	12425	9	6.8	16173
10	6.1	6400	10	6.1	10892	10	6.1	12692	10	6.1	16344
11	5.5	6586	11	5.5	10984	11	5.5	12839	11	5.5	16780
12	5.1	6630	12	5.1	11040	12	5.1	12870	12	5.1	16884
13	4.7	6757	13	4.7	11246	13	4.7	13102	13	4.7	18859
14	4.4	6800	14	4.4	11249	14	4.4	14658	14	4.4	18883
15	4.1	6985	15	4.1	11289	15	4.1	14831	15	4.1	18959
16	3.8	6987	16	3.8	11661	16	3.8	14970			
17	3.6	7317	17	3.6	12096	17	3.6	15005			
18	3.4	7415	18	3.4	12596	18	3.4	17084			
19	3.2	7977	19	3.2	12942	19	3.2	17333			
20	3.1	8346	20	3.1	13373	20	3.1	17937			
21	2.9	8788	21	2.9	13404						
22	2.8	9030	22	2.8	13656						
23	2.7	9525	23	2.7	13974						
24	2.5	9714									
25	2.4	9776									
26	2.3	9863									
27	2.3	10587									
28	2.2	11138									
29	2.1	11222									
30	2.0	11275									
31	2.0	11742									

GATUN TOTAL MONTHLY INFLOWS
DROUGHT-DURATION-FREQUENCY ANALYSIS

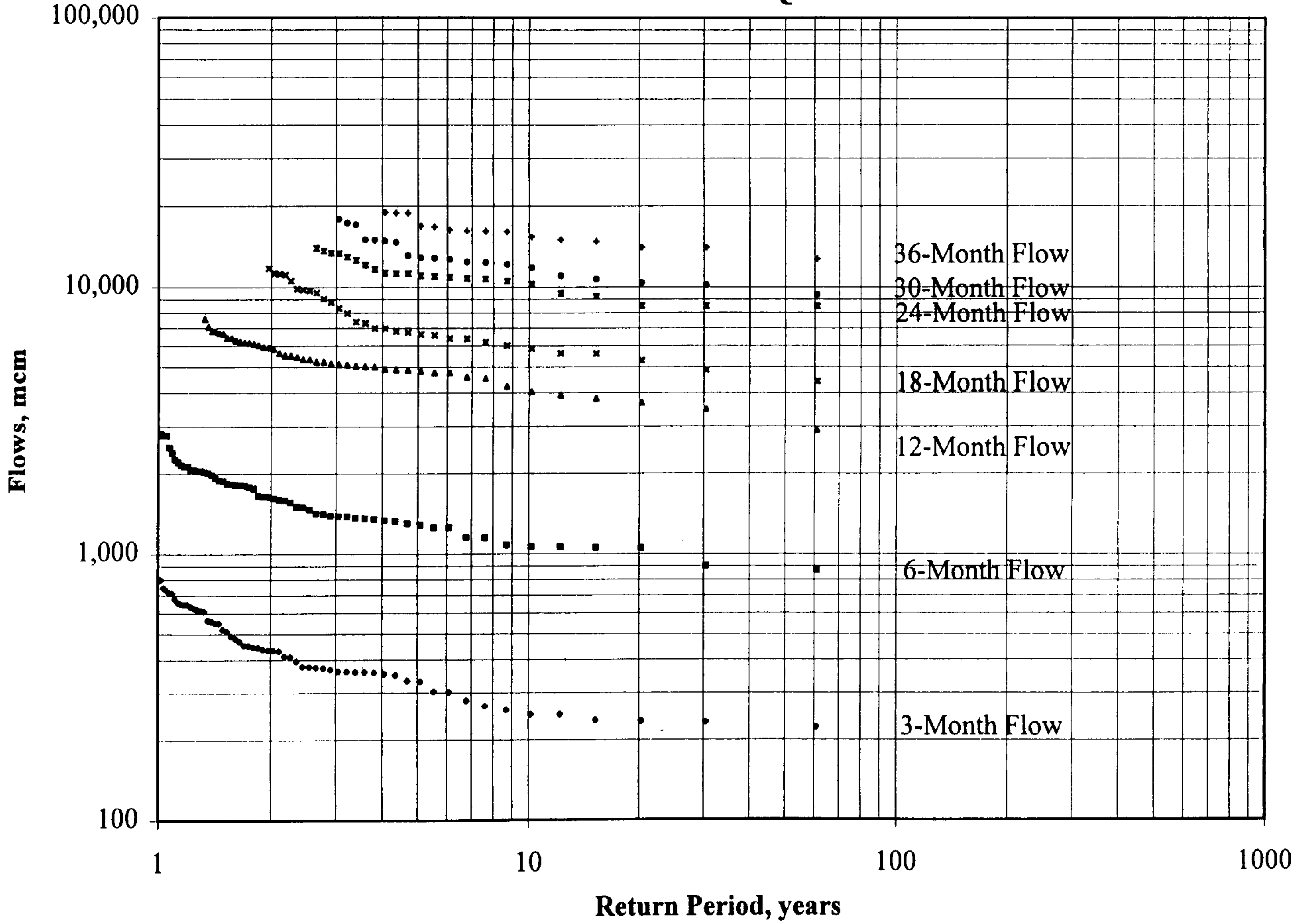
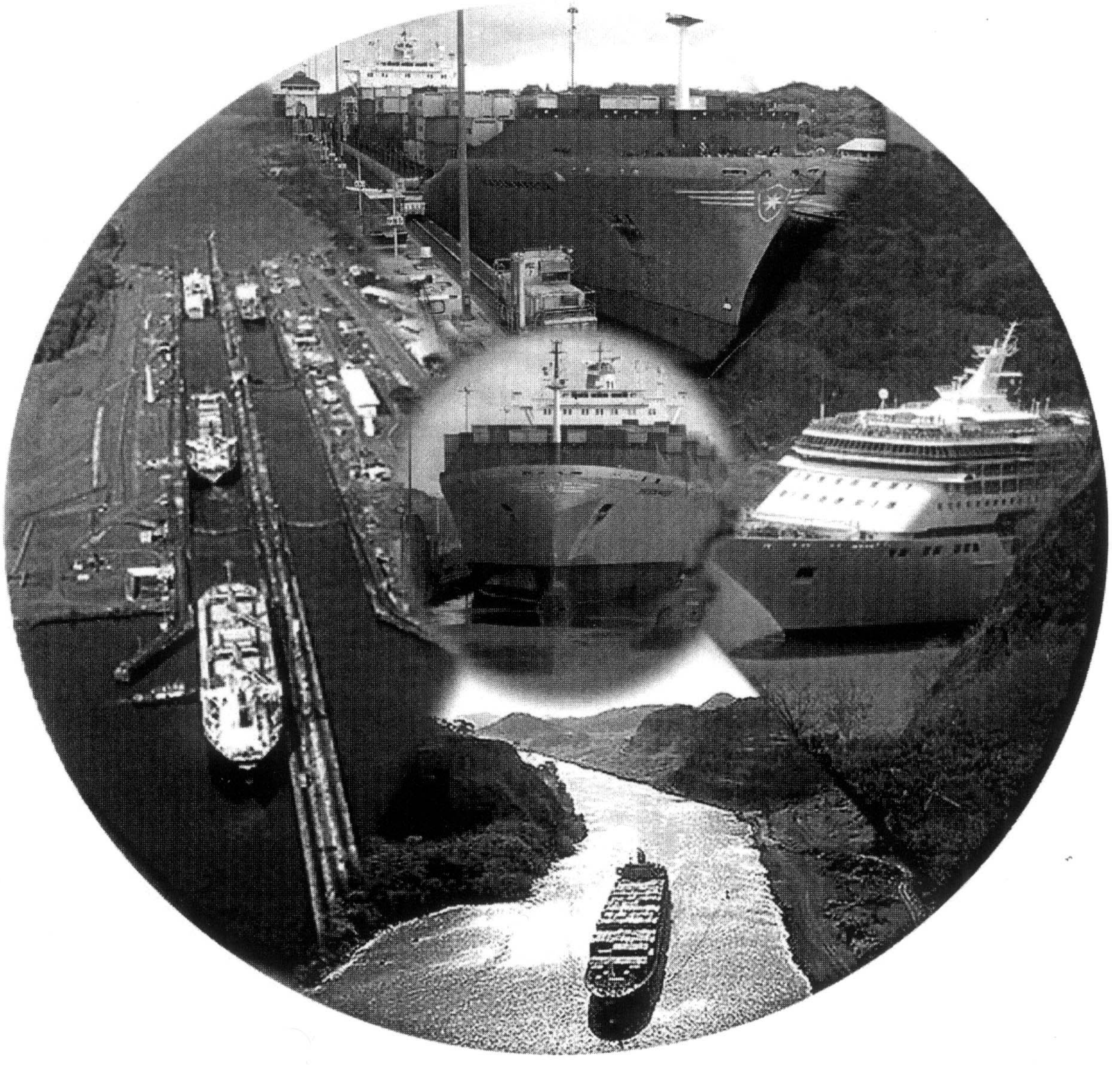


Exhibit 17.6

18.0 Global Warming



18.0 GLOBAL WARMING

18.1 Literature Review

As part of this study, investigations were conducted to understand the phenomenon of global warming and changes in climate. MWH has done some preliminary research to identify the factors causing an overall global warming and its associated effect on potential change in climate. The literature is full of research efforts that have been intensified recently. Through the use of computer models, a number of probable conclusions have been derived. Although the models have successfully simulated the historic trends in climate, the prediction of future conditions still requires substantial work. Through research of literature on climate changes, the following general inferences can be drawn:

- Infrared (IR) active gases (water vapor, carbon dioxide and ozone, naturally present in the Earth's atmosphere) absorb thermal IR radiation emitted by the Earth's surface and atmosphere. The atmosphere is warmed by this mechanism and, in turn, emits IR radiation, with a significant portion of this energy acting to warm the surface and the lower atmosphere. As a consequence the average surface air temperature of the Earth is about 300°C higher than it would be without atmospheric absorption and re-radiation of IR energy.

- Due to man-made activities, an increase in the concentration of greenhouse gages (carbon dioxide, methane, nitrous oxides and chlorofluorocarbons) has occurred over the industrial period.

- Because of their IR absorption, the increased concentrations of greenhouse gases exert a global warming influence. The magnitude and timing of the resulting warming is less certain.

- The reduction of augmented carbon dioxide concentration to its pre-industrial level would take centuries, even if emissions were substantially reduced in the near future. Further, because a substantial reduction in global carbon dioxide emission below current levels is unlikely in the next few decades, the atmospheric carbon dioxide concentration is expected to continue to increase.

- Sulfate aerosols, both from volcanic injections and from fossil fuel combustion, exert a cooling influence on the climate.

- Globally, average surface air temperatures are about 0.50°C (about 10°F) higher than average temperatures in the 19th century.

- Globally, the rate of warming of the mean surface temperature will increase by the mid-21st century. These surface temperatures will increase by about 0.50 – 2.00°C from 1990 to 2050 due to increases in the concentrations of greenhouse gases alone, assuming no significant actions are taken to reduce these gages.

- Globally, mean precipitation will increase.

- Northern Hemisphere sea-ice will be reduced.

- Artic land areas will experience wintertime warming.

- Globally, sea level will rise at an increasing rate, although the rate of rise may not be significantly greater than at present.

- Solar variability over the next 50 years will not induce a prolonged forcing (temperature increase) significant in comparison with the effects of the increasing concentration of carbon dioxide and other greenhouse gases.

18.2 Climatic Parameters Affecting Regional and Local Climate

The major climatic parameter affecting regional or local climate is expected to be air temperatures as confirmed in many research articles on global warming. Trend in air temperature is considered to be a major index of long-term climatic changes in the region. Many studies have been made to understand the effect of increasing temperature on the water resources.

Extracts from two articles, pertinent to this study are summarized below

·McCabe, Gergory J., and Ayers, Mark A., "Hydrologic Effects of Climate Change in Delaware River Basin," Water Resources Bulletin 25, pp.1231-1241, 1989.

"The study indicated that increased temperature could cause either increase or decrease in precipitation at different locations."

·EOS January 1999, "Potomac Perspective on the Growing Global Greenhouse by Bruce R. Doe."

This is a research type study and no conclusion was made except that at the five selected stations, the trends in annual average temperatures were not consistent . The trends in the annual rainfall were relatively consistent. The period of record was from 1957 to 1998. A comparison of the temperature and rainfall plots showed there could be either decrease or increase in precipitation due to increase in temperatures.

18.3 Potential Effects in Gatun Watershed

To understand temperature trends in Gatun watershed, monthly air temperature data at four long-term stations Tocumen (1971 to 2000), David (1972 to 2000), Balboa Heights (1906 to 1972) and Balboa FAA (1973 to 1999) were collected. The station at Balboa Heights was replaced by the station at Balboa FAA. Monthly data are given on Exhibit 18.1 to 18.4. Exhibits 18.5 to 18.8 shows the annual time series plots. A rising temperature trend is seen at all four stations.

Combined annual rainfall and temperature data at Balboa Heights and Balboa FAA are shown on Exhibit 18.9 and plotted on Exhibit 18.10. There is a strong indication of an increasing rainfall trend with the increasing temperature data. Therefore, it may be possible that in the Gatun watershed, increase in temperature would increase rainfall on a long-term basis.

Exhibit 18.1

MEAN MONTHLY TEMPERATURES AT TOCUMEN (°C)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1971	25.2	25.4	26.1	26.4	25.9	26.1	25.9	25.0	25.7	25.5	25.5	25.6
1972	25.5	26.2	26.3	26.9	27.0	26.7	27.6	26.7	26.3	26.2	26.4	26.4
1973	26.8	26.8	27.5	27.9	27.4	26.1	26.6	26.1	26.0	25.7	25.9	25.8
1974	25.9	26.4	26.8	27.6	26.9	26.7	26.4	26.9	25.6	25.7	26.2	26.2
1975	26.5	26.2	27.5	27.9	27.1	26.0	25.4	26.1	25.9	26.0	25.9	25.6
1976	25.9	26.0	26.9	27.0	27.4	26.7	27.5	27.2	27.0	26.5	26.7	26.6
1977	26.7	27.3	28.0	28.3	27.0	26.6	27.4	26.8	26.6	26.5	26.2	26.7
1978	26.5	27.4	27.5	26.9	27.2	26.7	26.5	26.6	26.1	26.3	26.5	26.2
1979	26.3	27.2	27.5	27.7	27.3	26.9	27.1	26.8	26.6	26.5	26.5	26.7
1980	26.7	26.7	28.0	27.6	27.1	27.7	27.6	27.0	27.0	26.8	26.7	26.8
1981	26.2		27.4	27.8	26.9	26.6	26.9	26.8	26.7	26.2		26.6
1982					26.9	27.2	27.1	27.7	26.6	26.2	26.9	26.7
1983	27.3	27.6	28.5	28.4	28.4	27.7	27.7	27.4	26.6	26.1	26.7	26.6
1984	26.0	26.6	26.5	26.9	27.0	25.9	25.8	26.4	25.8	25.9	26.0	26.3
1985	25.7	26.4	26.6	27.1	27.2	26.8	26.2	26.4	26.4	26.2	26.4	26.0
1986	26.6	25.8	26.9	27.8	27.1	27.3	27.2	27.1	26.8	26.1	26.4	26.5
1987	26.7	27.7	27.6	28.4	27.6	27.5	27.4	27.6	27.2	26.7	27.2	27.1
1988	26.9	27.8	27.7	28.0	27.4	26.5	26.6	26.4	26.2	26.2	26.2	26.1
1989	26.1	26.3	26.4	27.9	27.3	26.6	26.6	26.2	26.3	25.9	26.4	26.1
1990	26.6	26.3	27.5	27.9	27.5	27.5	27.0	27.1	26.9	26.0	27.0	26.3
1991	26.6	27.2	27.7	28.2	27.2	27.4	27.5	27.3	26.8	26.2	26.5	26.1
1992	26.7	27.3	28.6	28.6	28.0	27.3	26.8	27.1	26.5	26.7	26.3	26.4
1993	26.5	26.4	27.3	27.4	26.9	27.9	27.2	27.2	26.2	26.6	26.5	26.6
1994	26.4	26.7	27.2	27.8	27.7	26.9	27.5	26.9	27.3	26.3	26.9	26.9
1995	27.2	27.1	27.5	27.7	27.3	27.0	26.6	26.7	27.1	26.5	26.5	26.6
1996	26.1	26.8	27.1	27.7	26.9	26.7	26.7	26.8	26.2	26.0	26.2	26.1
1997	25.7	27.2	27.3	28.3	29.0	27.7	28.5	28.6	27.4	27.5	26.8	27.5
1998	28.0	28.1	29.0	29.0	28.4	27.9	27.3	27.2	27.1	26.5	26.4	26.5
1999	26.7	26.8	27.0	27.6	27.0	26.6	26.6	26.2	26.1	25.8	26.3	26.1
2000	25.9	26.4	26.8	27.5	26.7	26.7	27.0	27.4	26.7	27.2	26.9	27.3
2001	27.4	26.8	27.1	28.4	27.8	27.6						

Exhibit 18.2

MEAN MONTHLY TEMPERATURES AT DAVID (°C)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1971						26.3	26.3	25.9	25.6	25.5		
1972	26.0		28.0	28.4	27.2			26.2	26.8	26.6	26.8	27.2
1973	27.9	28.7	28.0	28.3	27.2	26.6	26.5	26.0	25.9	25.8	25.9	25.3
1974	25.8	26.3	27.2	28.0	26.5	26.3	26.0	26.4	25.6	25.5	25.7	25.8
1975	26.5	26.6	28.3	28.9	27.1	26.4	25.8	25.6	25.6	25.4	25.1	24.9
1976	25.9	26.6	28.0	27.7	27.5	26.7	27.1	26.6	26.7	26.3	26.4	26.6
1977	27.2	28.1	29.0	28.5	27.3	26.7	27.0	26.4	26.4	26.2	26.0	26.5
1978	27.1	28.0	27.7	27.5	27.0	26.4	26.4	26.6	26.2	25.9	26.4	26.4
1979	26.7	28.3	28.5	27.6	27.1	26.7	26.9	26.7	26.3	26.2	26.4	26.3
1980	27.1	27.5	28.0	28.3	27.5	27.1	26.9	26.7	26.3	26.4	25.8	26.2
1981	26.6	27.6	27.7	28.2	26.9	26.4	26.6	26.5	26.4	26.1	26.1	26.3
1982	26.2	27.4	27.7	27.8	27.0	27.3	27.0	27.2	26.7	26.3	26.9	27.6
1983	28.7	29.1	29.8	29.2	28.7	28.2	27.7	27.2	26.7	26.3	26.5	26.0
1984	26.2	26.9	27.9	27.8	26.9	26.2	26.1	26.1	25.7	25.7	25.7	26.4
1985	25.9	27.6	28.7	28.0	26.8	26.7	26.1	25.9	26.0	26.0	25.7	26.1
1986	26.5	26.8	28.2	28.0	27.6	26.8	26.8	26.9	26.5	25.8	26.2	26.7
1987	27.2	28.4	28.2	28.5	27.6	27.6	27.1	26.9	26.9	26.3		27.6
1988	27.5	28.5	28.7	27.9	27.3	26.6	26.2	26.0	26.0	25.7	26.1	25.7
1989	26.7	27.7	27.4	28.2	27.0	26.5	26.4	26.4	26.2	26.2	26.3	26.2
1990	27.2	27.7	28.9	28.6	27.4	27.3	26.7	26.8	26.7	26.2	26.1	26.0
1991	26.6	28.2	28.2	27.8	27.2	27.1	27.0	26.7	26.6	26.3	26.2	26.8
1992	27.4	28.0	29.8	29.1	27.9	27.7	26.6	26.7	26.2	26.5	26.4	26.4
1993	26.7	27.1	27.9	28.3	27.2	27.3	27.0	26.8	26.2	26.6	26.4	26.5
1994	26.5	27.6	28.1	28.3	27.2	26.8	27.0	26.6	26.8	26.5	26.2	26.7
1995	27.4	27.9	28.3	27.9	27.2	26.9	26.7	26.5	26.9	26.4	26.4	26.4
1996	26.5	27.2	28.1	27.6	26.9	26.7	26.6	26.4	26.7	26.0	25.9	26.2
1997	26.1	27.6	29.0	28.7	28.4	27.4	28.2	28.1	27.4	27.4	26.8	27.5
1998	28.0	29.0	30.0	30.2	29.0	27.9	27.0	27.0	27.0	26.3	26.4	26.0
1999	26.0	27.3	27.9	27.6	26.6	26.5	26.5	26.3	26.1	26.1	25.7	25.8
2000	26.0	27.3	27.5	28.4	27.3	26.7	26.5	26.9	26.4	26.7	26.1	26.2

MEAN MONTHLY TEMPERATURES AT BALBOA HEIGHTS (°C)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1906	27.3	27.6	27.9	28.3	27.7	26.8	26.8	26.8	27.2	26.4	26.4	26.4
1907	26.8	26.0	27.4	27.3	27.8	26.6	27.0	27.2	27.0	26.4	26.6	27.3
1908	27.4	24.9	28.1	28.2	26.8	26.6	26.6	26.8	26.5	26.1	26.0	26.4
1909	26.3	26.8	27.4	27.4	26.4	26.0	26.0	25.9	26.1	25.9	25.0	25.5
1910	26.0	26.5	26.3	26.9	26.2	26.3	25.7	26.3	25.9	25.8	26.1	26.2
1911	26.6	26.5	26.6	27.3	26.2	26.7	27.9	27.0	27.1	26.7	26.3	27.3
1912	27.0	27.4	28.4	27.8	27.8	27.1	27.0	26.8	26.3	26.1	26.1	27.1
1913	27.1	26.6	27.8	27.6	26.8	26.8	27.3	26.8	26.5	26.4	26.1	26.7
1914	26.9	27.6	28.3	28.1	27.7	27.2	28.0	27.6	26.8	26.5	26.7	27.4
1915	27.5	27.4	28.3	26.9	27.4	27.3	26.6	26.9	26.8	26.2	26.0	26.7
1916	26.8	26.1	26.9	27.3	26.6	26.2	25.8	25.6	26.3	25.6	25.6	26.2
1917	25.7	25.6	26.6	26.8	26.3	26.1	26.2	26.4	26.1	25.7	25.5	25.8
1918	25.8	26.5	26.3	26.9	27.0	26.8	27.5	27.1	27.1	26.6	26.8	27.3
1919	26.6	27.5	27.1	27.6	27.3	27.0	27.0	27.4	26.3	26.5	26.2	26.6
1920	26.9	26.8	27.4	28.0	27.3	27.0	27.1	26.8	26.7	26.5	26.4	26.9
1921	26.6	26.5	27.1	27.3	26.8	26.6	26.9	27.0	26.4	26.2	26.7	26.6
1922	26.4	27.3	27.4	28.4	27.0	26.6	27.5	26.9	26.4	26.1	25.9	26.4
1923	26.1	26.6	27.1	27.3	27.0	26.8	27.1	26.8	27.0	26.1	26.8	26.7
1924	26.7	26.6	27.5	27.7	27.0	26.2	26.2	26.0	25.9	26.0	25.5	26.1
1925	25.7	25.9	26.4	27.2	27.4	26.9	26.8	27.0	26.5	26.9	26.7	27.4
1926	27.1	27.5	27.8	28.3	27.9	27.2	26.8	26.7	26.5	26.4	26.4	26.3
1927	26.7	26.1	27.7	27.4	26.8	26.3	27.0	26.8	25.9	26.2	26.8	26.8
1928	26.7	27.4	27.6	27.7	27.1	26.3	27.2	26.5	26.5	26.7	25.8	26.6
1929	26.3	26.8	27.2	27.5	27.3	26.4	27.2	26.4	26.3	26.0	26.5	26.5
1930	26.5	26.5	27.8	27.4	27.0	26.9	27.6	27.2	27.1	26.1	27.1	27.3
1931	27.0	27.4	28.2	28.7	27.2	26.9	26.3	27.3	26.4	26.9	25.5	26.7
1932	26.6	26.7	27.2	28.0	26.9	26.6	27.0	26.6	26.6	26.3	25.9	26.3
1933	26.2	26.5	27.0	27.6	26.9	26.4	26.4	26.5	26.3	26.3	25.5	26.0
1934	25.9	25.9	26.8	27.8	26.9	26.8	27.1	27.0	26.9	25.8	25.9	26.8
1935	26.2	26.4	27.7	27.5	27.0	26.7	26.7	26.1	26.9	26.3	25.8	26.5
1936	26.8	26.7	27.6	28.0	27.2	26.7	27.0	26.9	26.3	26.2	26.8	26.5
1937	26.6	26.8	27.4	27.8	27.0	26.8	27.1	27.1	26.6	26.5	26.2	25.9
1938	26.5	26.7	27.0	27.3	26.8	26.0	26.7	26.3	26.3	26.1	26.1	26.1
1939	26.3	25.8	26.9	27.9	28.0	27.1	27.4	27.6	26.6	26.5	26.3	27.0
1940	26.6	27.6	28.0	28.5	28.2	27.7	27.8	27.4	26.9	26.8	26.7	27.5
1941	26.9	28.1	28.1	28.7	28.1	27.9	27.2	27.1	26.8	27.0	26.8	27.0
1942	27.6	27.9	28.3	28.2	27.3	27.2	27.2	26.7	26.7	26.3	26.3	26.3
1943	26.8	26.8	27.2	27.8	27.1	26.6	27.0	26.8	27.0	26.1	26.4	26.3
1944	26.5	26.9	27.6	28.2	26.9	26.5	27.2	26.7	26.4	26.0	26.5	26.9
1945	26.4	27.4	28.3	28.6	27.2	27.7	27.4	27.1	27.3	26.3	26.7	26.3
1946	26.8	27.2	27.8	28.6	27.9	27.8	27.7	27.1	26.8	26.4	26.3	26.6
1947	27.0	27.0	28.1	28.7	27.8	26.6	26.7	27.1	26.5	26.1	26.4	26.3
1948	26.9	27.2	27.9	28.2	27.8	27.1	26.9	27.2	26.5	26.1	26.2	26.7
1949	26.3	27.1	27.6	28.2	27.3	26.4	26.8	26.8	26.4	25.8	25.6	25.9
1950	26.4	27.1	27.6	27.6	26.5	25.9	26.4	26.3	26.8	26.0	25.9	26.1
1951	26.3	26.3	26.9	27.7	27.1	27.4	27.1	27.2	26.9	26.7	26.8	27.3
1952	27.2	27.5	28.3	28.7	27.3	26.6	26.8	27.0	26.7	26.4	26.4	26.3
1953	26.6	27.0	27.4	28.4	27.1	27.1	27.0	27.7	26.8	26.3	26.6	26.7
1954	27.1	27.0	28.2	28.3	27.0	26.2	26.1	26.4	26.1	25.3	25.6	25.9
1955	26.0	26.9	27.4	27.5	27.3	26.3	25.7	25.8	25.6	25.5	25.4	25.6
1956	25.2	26.7	27.3	27.9	26.4	25.9	26.2	26.6	26.0	25.4	25.3	25.9
1957	26.4	26.8	27.3	28.3	27.4	27.3	27.4	26.9	26.6	26.0	26.8	27.2
1958	27.1	27.6	28.6	29.0	27.4	27.6	27.2	26.8	26.9	26.8	26.9	27.1
1959	27.5	27.7	28.6	29.3	27.9	26.6	27.4	26.9	26.8	26.2	26.8	27.3
1960	27.3	27.6	27.9	28.2	26.8	26.9	26.9	26.9	26.5	26.6	26.7	26.4
1961	27.5	27.4	27.9	28.3	28.1	26.8	26.5	27.1	26.5	26.1	25.6	26.9
1962	27.2	27.6	27.8	28.3	27.2	26.5	26.8	26.5	26.8	26.5	26.3	26.9
1963	26.9	26.7	28.0	27.2	27.2	27.1	26.6	27.3	26.7	26.6	26.3	27.6
1964	27.7	27.9	28.6	27.9	27.2	26.1	26.3	26.3	26.4	25.8	26.4	26.3
1965	26.4	27.3	27.8	28.1	27.6	27.1	27.6	26.5	26.6	26.2	26.0	26.8
1966	27.4	27.8	27.8	28.0	26.9	26.6	26.9	26.7	26.6	26.2	26.1	26.2
1967	27.3	27.5	27.1	27.4	27.4	26.3	26.4	26.4	26.3	26.1	26.0	26.8
1968	27.1	26.6	27.4	27.4	26.9	26.2	26.9	26.8	26.7	26.7	26.9	27.4
1969	27.5	27.3	28.7	28.3	28.0	27.3	27.7	26.6	26.9	26.8	26.6	27.0
1970	26.9	27.8	28.0	28.6	27.4	27.3	26.8	26.4	26.3	26.2	25.8	25.9
1971	26.1	26.8	27.1	27.4	26.6	26.3	26.5	26.2	26.5	26.1	26.3	26.9
1972	26.4	27.2	27.4	27.5	27.5	27.1	28.2	27.2	27.3	27.0	27.4	27.5

Exhibit 18.4

MEAN MONTHLY TEMPERATURES AT BALBOA FAA (°C)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1973	28.2	28.3	29.0	29.1	27.8	26.6	27.1	26.7	26.5	26.4	26.3	26.2
1974	26.5	26.9	27.3	28.5	27.4	27.0	26.5	27.0	26.2	26.0	26.2	26.7
1975	27.1	26.8	27.9	28.0	27.0	26.6	24.8	25.6	26.2	26.0	25.8	25.6
1976	26.4	26.5	27.4	27.2	27.6	27.0	27.9	27.6	27.1	26.4	26.4	26.6
1977	26.2	26.9	27.4	27.7	26.8	26.2	26.9	26.5	27.5	27.6	27.6	27.9
1978	27.5	28.4	28.5	28.1	27.7	27.1	27.3	27.6	26.8	26.8	27.1	26.9
1979	27.0	28.1	27.9	27.9	27.5	27.3	27.7	27.4	26.5	26.6	26.7	27.8
1980	28.3	28.0	29.1	29.2	28.8	28.8	28.7	28.3	27.7	27.1	26.9	27.0
1981	27.4	29.1	29.0	28.7	28.2	27.6	27.9	27.4	27.9	27.4	27.8	28.0
1982	27.7	28.8	29.1	28.9	28.3	28.1	28.5	29.9	28.5	27.4	27.6	27.8
1983	28.4	28.5	29.4	29.7	28.4	27.8	27.7	26.6	26.0	26.0	27.7	27.5
1984	27.2				27.3	27.0	27.1	27.0	26.5	26.7	26.1	25.7
1985	26.6	27.6	30.8	28.1	27.9	27.5	27.2	27.1	27.2	26.7	27.0	26.7
1986	27.0	26.9	27.6	27.9	27.6	27.6	27.6	27.4	27.1	26.1	27.3	27.3
1987	26.2	28.9	29.1	30.5	29.4	29.8	29.4	29.5	29.0	28.3	29.3	29.7
1988	30.1	30.7	30.2	30.5	28.9	27.5	27.8	27.3	27.5	27.4	27.8	27.6
1989	28.1	28.6	28.1	29.1	27.9	27.2	27.2	26.7	26.8	26.6	26.7	26.9
1990	27.9	28.1	29.0	29.6	28.2	28.3	28.0	28.1	27.8	26.8	27.6	27.6
1991	28.1	28.6	29.1	29.5	28.2	27.9	27.9	27.4	27.3	26.8	27.1	27.3
1992	28.4	28.8	28.5	28.8	27.8	27.0	28.7	26.2	27.3	27.5	27.1	27.8
1993	27.6	28.4	29.1	28.7	28.2	28.4	28.0	27.9	26.9	27.6	27.1	28.0
1994	28.1	28.4	28.8	29.4	27.9	27.7	28.3	27.6	28.1	27.4	27.3	28.1
1995	28.5	28.8	28.6	28.4	27.9	28.0	26.8	27.0	27.0	26.5	26.8	26.8
1996	26.5	27.2	27.4	28.1	27.1	27.2	26.7	26.8	26.7	26.7	26.5	26.7
1997	26.8	28.1	28.0	28.8	29.1	27.5	28.3	28.5	27.5	27.7	27.2	28.3
1998	29.1	29.1	29.9	29.5	28.6	28.0	27.8	27.3	27.2	27.4	27.0	26.8
1999	27.1	27.6	28.2	28.0	27.3	26.9	27.2	26.7	26.5	26.4	26.6	26.1

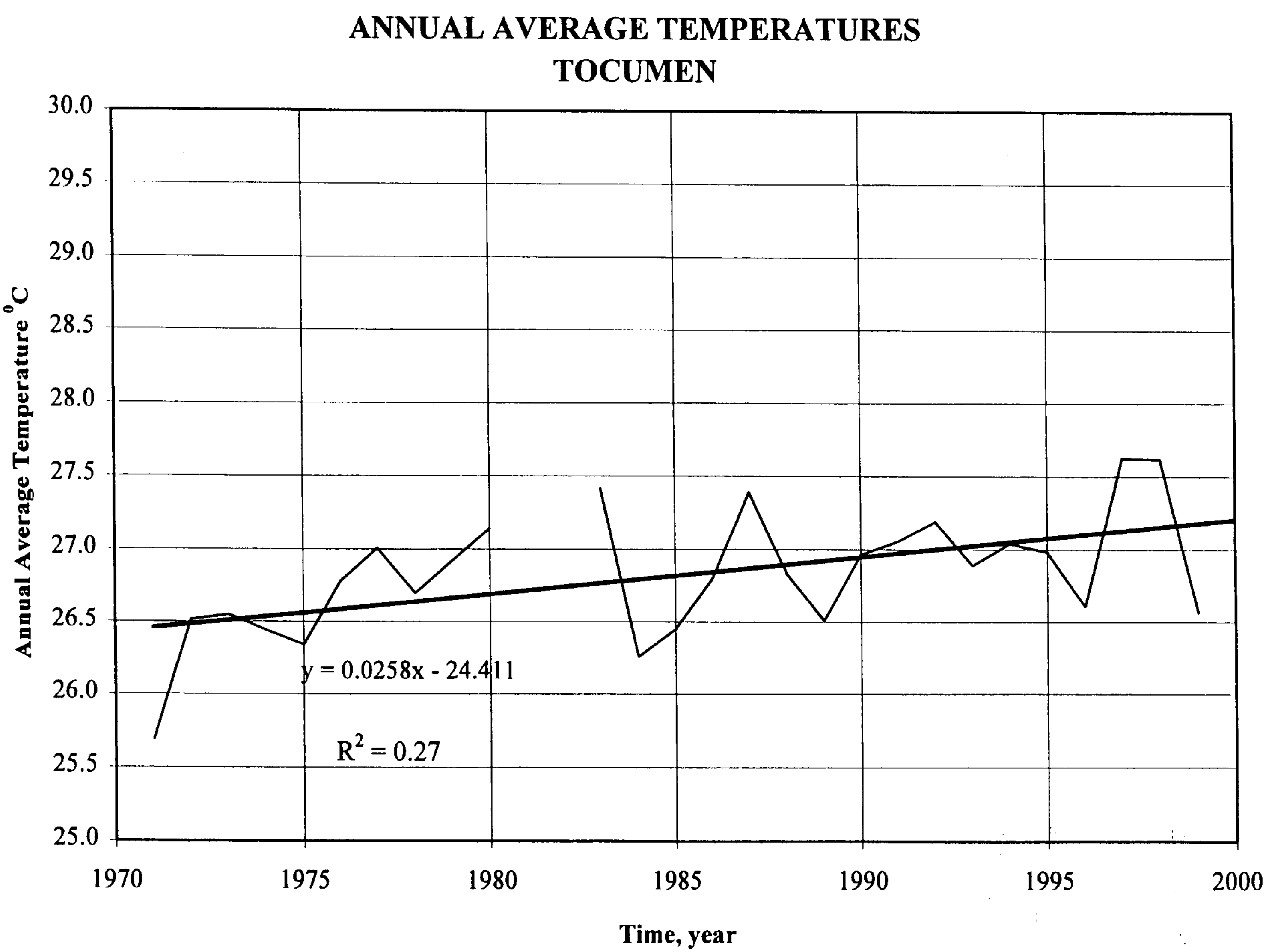

ANNUAL AVERAGE TEMPERATURES
TOCUMEN
Annual Average Temperature °C
30.0
29.5
29.0
28.5
28.0
27.5
27.0
26.5
26.0
25.5
25.0
y = 0.0258x - 24.411
R² = 0.27
1970
1975
1980
1985
1990
1995
2000
Time, year

Exhibit 18.5

ANNUAL AVERAGE TEMPERATURES
DAVID

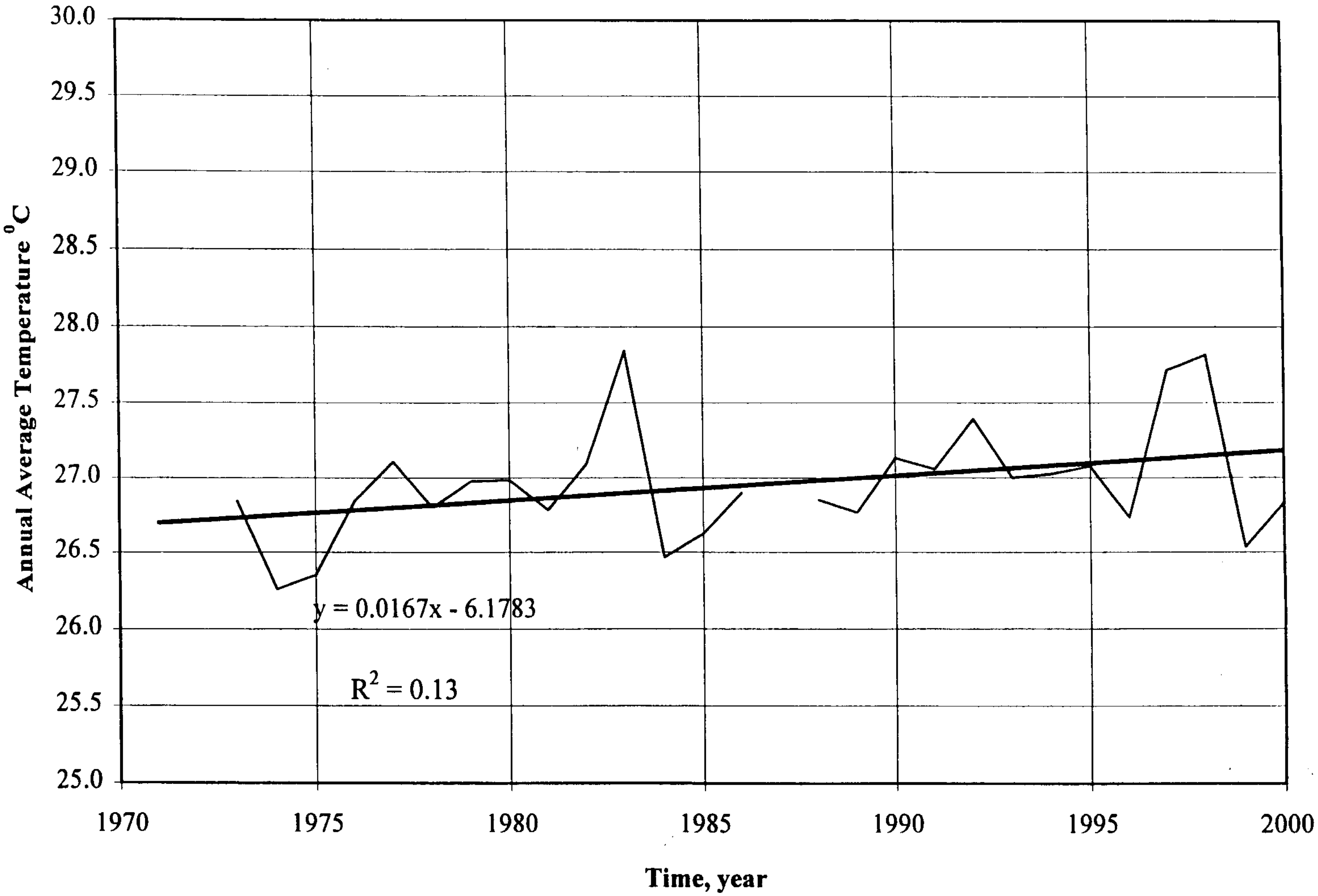


Exhibit 18.6

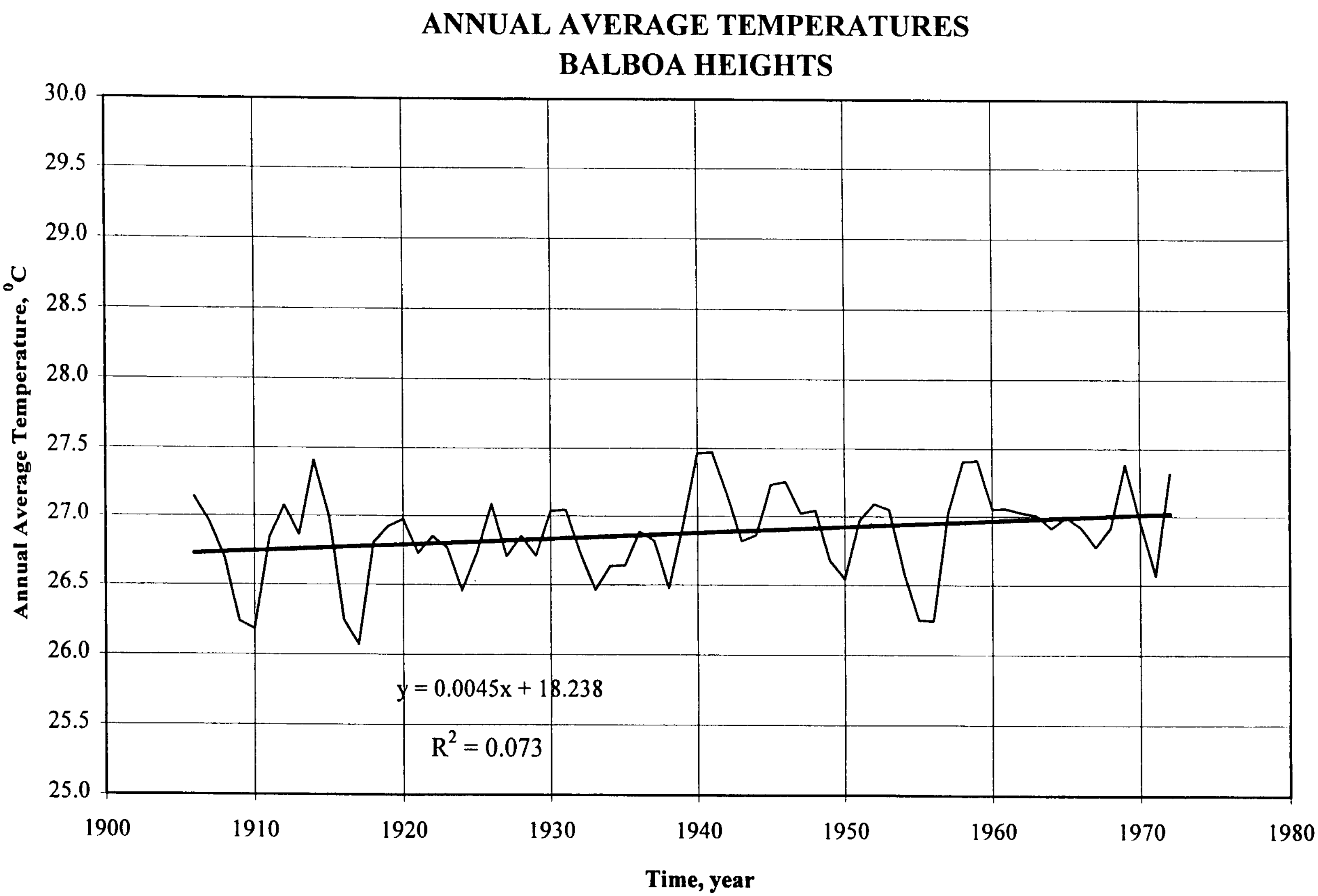
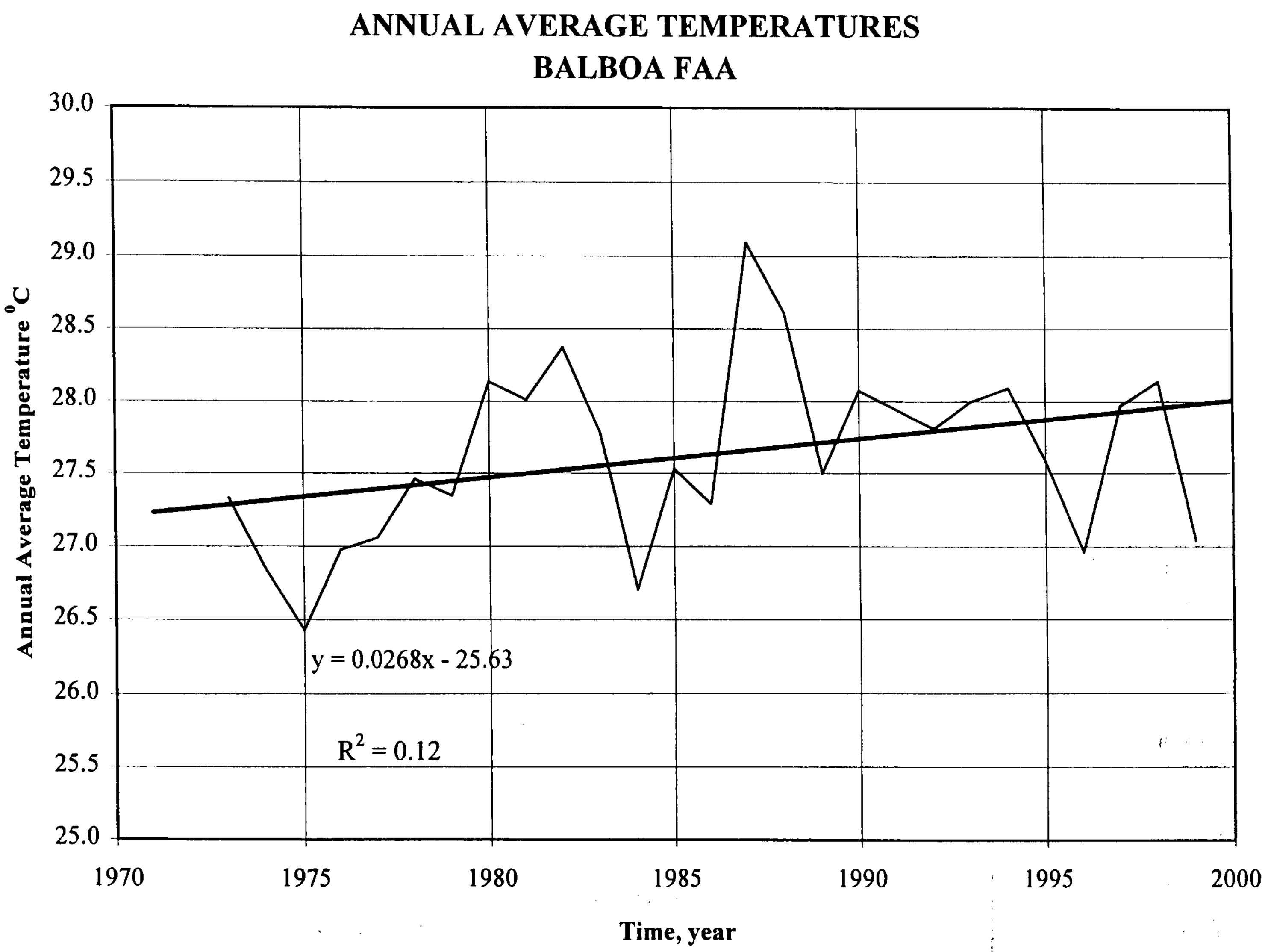

ANNUAL AVERAGE TEMPERATURES
BALBOA HEIGHTS
Annual Average Temperature, °C
30.0
29.5
29.0
28.5
28.0
27.5
27.0
26.5
26.0
25.5
25.0
y = 0.0045x + 18.238
R2 = 0.073
1900
1910
1920
1930
1940
1950
1960
1970
1980
Time, year

Exhibit 18.7



ANNUAL AVERAGE TEMPERATURES
BALBOA FAA
30.0
29.5
29.0
28.5
28.0
27.5
27.0
26.5
26.0
25.5
25.0
Annual Average Temperature °C
y = 0.0268x - 25.63
R² = 0.12
1970
1975
1980
1985
1990
1995
2000
Time, year

Exhibit 18.8

Exhibit 18.9

BALBOA HEIGHTS AND BALBOA FAA

	Avg of Monthly Temp. (°C)			Annual		Avg of Monthly Temp. (°C)			Annual
Year	Max	Min	Avg	Rainfall (in)	Year	Max	Min	Avg	Rainfall (in)
1906	31.5	22.8	27.1	69.8	1953	30.8	23.3	27.1	67.7
1907	31.5	22.4	27.0	63.5	1954	30.4	22.8	26.6	83.9
1908	30.9	22.5	26.7	60.0	1955	29.8	22.7	26.3	84.2
1909	30.2	22.2	26.2	83.9	1956	29.9	22.6	26.2	83.2
1910	30.5	21.9	26.2	75.8	1957	31.1	23.0	27.0	62.6
1911	31.5	22.2	26.8	64.1	1958	31.3	23.5	27.4	75.0
1912	31.8	22.3	27.1	71.8	1959	31.7	23.2	27.4	70.3
1913	31.5	22.2	26.9	66.0	1960	31.0	23.1	27.1	74.1
1914	31.9	22.9	27.4	64.5	1961	31.1	23.0	27.1	64.8
1915	30.5	23.5	27.0	66.7	1962	31.1	23.0	27.0	69.6
1916	29.9	22.6	26.2	77.1	1963	31.0	23.0	27.0	63.6
1917	29.8	22.3	26.1	68.8	1964	30.9	22.9	26.9	67.4
1918	30.7	22.9	26.8	54.8	1965	31.1	22.9	27.0	73.5
1919	30.7	23.2	26.9	61.2	1966	31.0	22.9	26.9	96.4
1920	30.9	23.1	27.0	66.4	1967	30.9	22.7	26.8	80.9
1921	30.5	22.9	26.7	70.9	1968	30.8	23.0	26.9	60.9
1922	30.6	23.1	26.8	58.8	1969	31.2	23.6	27.4	73.0
1923	30.6	23.0	26.8	54.0	1970	30.5	23.4	27.0	70.8
1924	30.1	22.8	26.5	82.1	1971	30.2	23.0	26.6	74.0
1925	30.8	22.7	26.7	65.7	1972	31.1	23.5	27.3	86.1
1926	30.9	23.3	27.1	73.4	1973	31.0	23.7	27.3	82.7
1927	30.4	23.0	26.7	66.4	1974	30.7	22.9	26.8	60.2
1928	30.5	23.2	26.8	84.2	1975	30.2	22.7	26.4	101.6
1929	30.6	22.8	26.7	67.3	1976	31.0	23.0	27.0	51.5
1930	31.0	23.1	27.0	51.7	1977	30.9	23.2	27.1	51.8
1931	30.7	23.4	27.0	75.8	1978	31.3	23.7	27.5	79.9
1932	30.4	23.0	26.7	72.7	1979	31.1	23.6	27.3	53.7
1933	30.1	22.8	26.5	72.4	1980	32.0	24.3	28.1	50.7
1934	30.5	22.8	26.6	78.5	1981	31.7	24.4	28.0	99.4
1935	30.4	22.9	26.6	83.3	1982	32.5	24.3	28.4	62.7
1936	30.7	23.0	26.9	58.6	1983	31.6	24.0	27.8	73.2
1937	30.5	23.1	26.8	85.2	1984	29.8	23.6	26.7	61.3
1938	30.3	22.6	26.5	85.3	1985	31.9	23.2	27.5	63.4
1939	30.9	23.0	26.9	62.6	1986	31.5	23.1	27.3	67.6
1940	31.4	23.5	27.5	55.1	1987	34.2	24.0	29.1	73.3
1941	31.5	23.4	27.5	72.7	1988	33.8	23.4	28.6	82.1
1942	31.1	23.2	27.2	70.0	1989	32.4	22.6	27.5	64.4
1943	30.9	22.7	26.8	71.9	1990	32.6	23.6	28.1	70.3
1944	31.0	22.7	26.9	76.7	1991	32.5	23.4	27.9	76.5
1945	31.1	23.4	27.2	63.9	1992	32.4	23.2	27.8	75.7
1946	31.2	23.3	27.3	53.8	1993	32.3	23.7	28.0	81.1
1947	31.0	23.0	27.0	58.5	1994	32.5	23.6	28.1	74.0
1948	31.0	23.0	27.0	58.7	1995	31.8	23.4	27.6	95.5
1949	30.6	22.8	26.7	68.5	1996	31.0	22.9	27.0	82.3
1950	30.6	22.5	26.5	72.4	1997	32.5	23.5	28.0	75.2
1951	31.0	23.0	27.0	63.9	1998	32.5	23.8	28.1	71.4
1952	31.0	23.2	27.1	84.0	1999	31.1	23.0	27.0	80.0

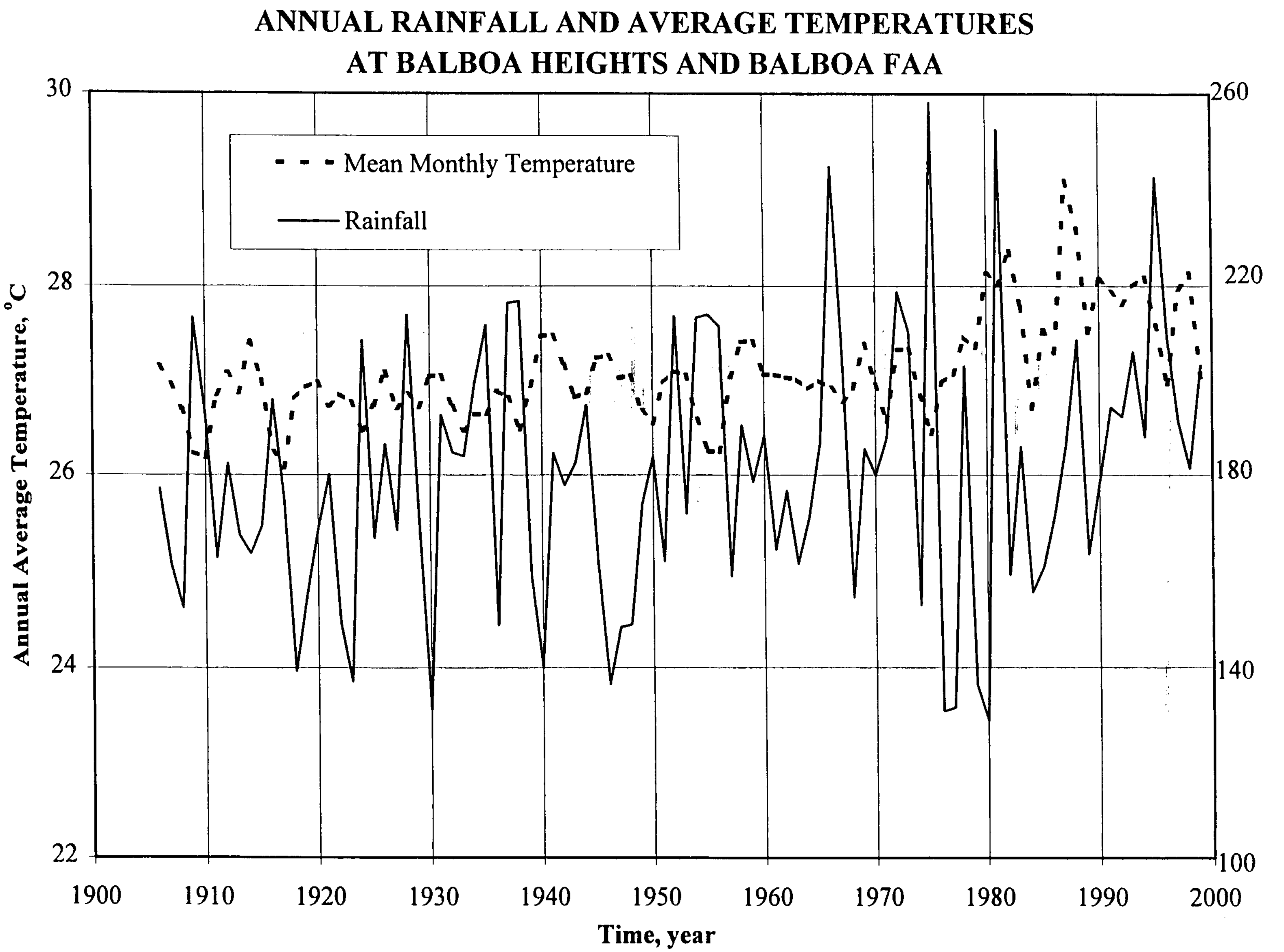
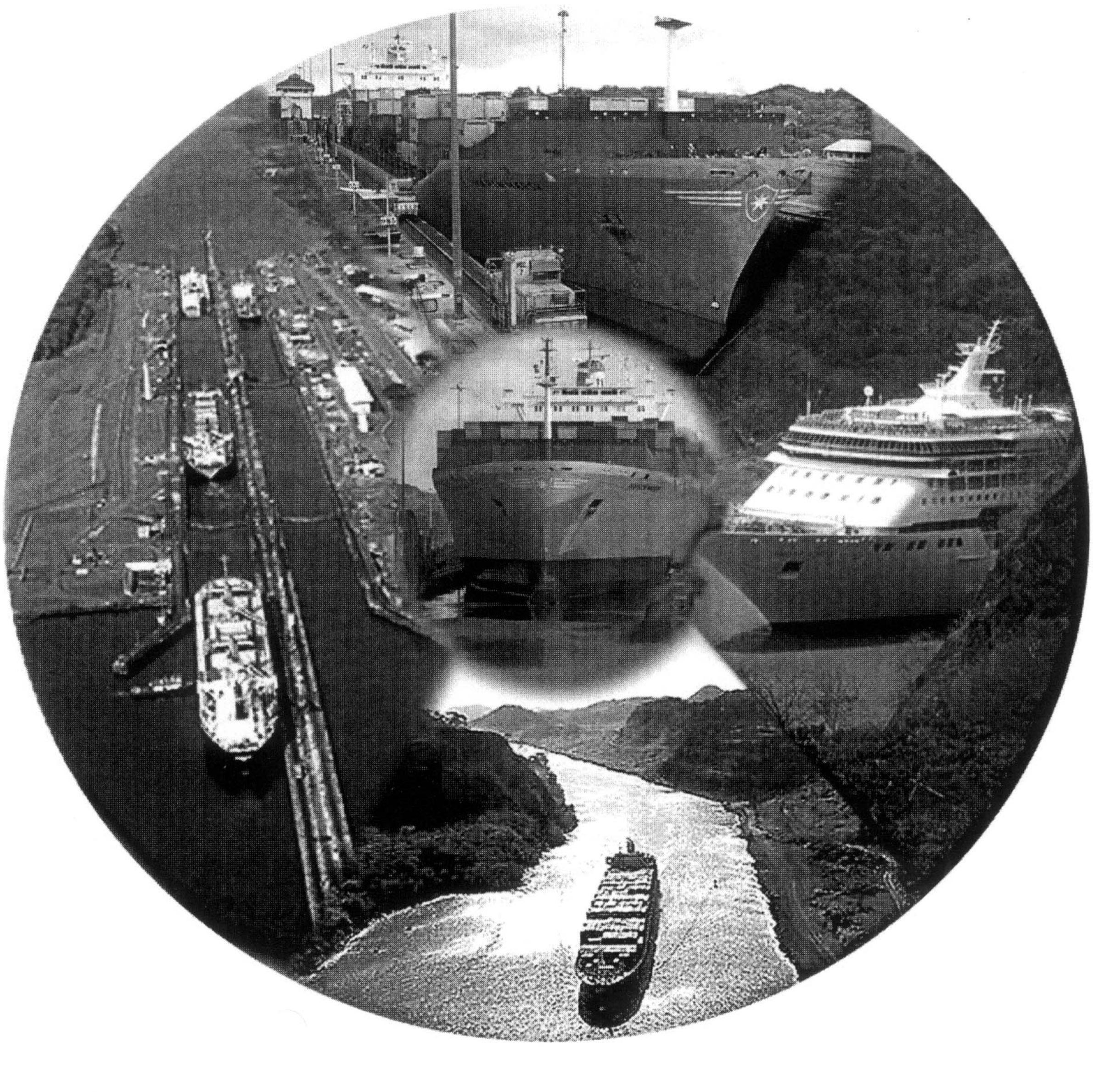


Exhibit 18.10

19.0 Conclusions and Recommendations



19.0 CONCLUSIONS AND RECOMMENDATIONS

As a result of this study, the following conclusions were made. Recommendations for additional analyses are also given where needed.

1. Hydrometeorological data collection and transmission system of ACP are well maintained.

2. Use of storage rainfall gauges may be discontinued. Instead a non-recording rain gauge may be installed at each meteorological station to provide a check on the tipping bucket gauge.

3. Stream gauging procedures should be improved. The wading discharge measuring method should be introduced for low flow measurements at stations where feasible. The number of observation points for depth and velocities should be increased. The observations should be made at 20 to 25 verticals across the river. The minimum distance between the verticals should be 0.5 meter for wading and 1.0 meter for measurements from an overhead cableway.

4. Air line corrections should be avoided as discussed in the report.

5. Time series analysis indicated that all rainfall and runoff series are consistent and homogeneous. The decreasing trends shown are insignificant at 95 percent confidence level.

6. Long-term rainfall and runoff data at various locations in the watershed can be used for further analysis of canal lockages. There is no need to treat the data to correct for decreasing trend.

7. El Nino has a negative effect on the rainfall and runoff series. Depending upon the severity of an episode, the rainfall or runoff could be as low as 10 to 20 percent of normal values on monthly basis. Worst affected months are November through February / march.

8. A decreasing trend since 1971 (indicated by mass curves at some stations) could be due to most severe El Nino episodes of 1976-77, 1982-83 and 1997-98. Those affected the mean and standard deviation of the annual series from 1971 to 2000.

9. There is no reason to believe that slightly decreasing trend from early 1970's was due to any change in instrumentation, environment or observation techniques.

10. An increasing trend in number of sunspots from mid 1960's and decreasing trend since mid 1980's, may also be responsible for a slight decreasing trend since early 1970's.

11. There is an increasing trend in temperatures at the four selected stations. This could produce an increasing trend in the rainfall. Rainfall data at Balboa Heights confirms that but it must be confirmed by analyzing other stations.

12. A more detailed study may be initiated to analyze El Nino effect on hydrologic series and relation between El Nino, intertropical convergence zone and sunspots.

20.0 Review Comments

20.0 REVIEW COMMENTS

20.1 Inhouse Review

Inhouse review was performed by Dr. James E. Lindell, Senior Vice President and Quality Assurance Manager, MWH. Dr. Lindell reviewed all the sections of the report and appendices with time series plots and stochastic modeling results. The comments were directly marked on the report. All comments by Dr. Lindell have been incorporated.

20.2 Comments by ACP

Comments received from ACP are attached at the end of this section. These comments have been incorporated where applicable. In response to comments by Mr. J. Gribar, Section 17 of the report was revised.

COMMENTS

Subject: RE: Seminar and Training
Date: Mon, 12 Nov 2001 09:17:31 -0500
From: JdelaGuardia <IPC@pancanal.com>
To: "khalid.jawed@ei.mwhglobal.com" <khalid.jawed@ei.mwhglobal.com>

Khalid:
Hope your spanish is still good. Below are our field people comments (Massott & Daly Espinoza), I am still waiting for C.Vargas.

Comentarios sobre el "Estudio de Variación y Tendencia de la información históricas de lluvia y escurrimiento en la cuenca del Lago Gatún"(MWH-Montgomery Watson HARZA).

Punto E.2.2. Estaciones de Aforo
En el primer párrafo El Consultor señala que "corrientemente, todos las medidas son hechas desde cablevía, y que es altamente deseable que los flujos bajos se hagan por vadeo".

Por seguridad, solamente en la estación Chico todos los aforos son realizados desde el cablevía, ya que las profundidades en la sección de aforo no bajan de 4 pies, tanto en el periodo seco como en el lluvioso. En las demás estaciones, se hace por vadeo si las condiciones del río lo permiten.

Con respecto al segundo párrafo, relacionado con el número de verticales en un aforo, estamos de acuerdo con El Consultor, por lo que, actualmente la salida del cálculo de aforo presenta el porcentaje del caudal total máximo de todas las verticales. De acuerdo al procedimiento para hacer aforos, el número de verticales debe ser tal que ninguna de ellas exceda el 10% del caudal total, por lo tanto, el aforo debe tener como mínimo 10 verticales. El número máximo de verticales depende del ancho del río y la distancia entre verticales depende de la distribución de la velocidad en la sección.

Con relación al ángulo de arrastre en los aforos de crecida, tercer párrafo, no solamente se le ha dado las instrucciones a los Técnicos Hidrólogos de la importancia de usar el peso adecuado al momento de hacer un aforo sino también, que debe tomar la lectura de los ángulos en los casos en que se den. Para control, esto se ha considerado en el algoritmo de cálculo de aforo (al introducir el ángulo de arrastre, el programa corregirá automáticamente las profundidades).

Para el cálculo de los caudales diarios, (cuarto párrafo) se va a llevar un mejor control de los aforos y las curvas de descarga, una vez éstas se definan. Sería bueno disponer de la referencia sobre el "shift adjustment" el cual es un procedimiento de ajuste usado por USGS.

Respecto a las Conclusiones y Recomendaciones

El punto 2, relacionado con la recomendación de eliminar los Handar de las estaciones de lluvia e instalar pluviómetros (no-recording) para control del "tpping bucket", considero que debe analizarse mas profundamente. El Consultor Phillip Brown (Base de Datos), observó diferencias significativas entre ambos métodos de recolección, él recomienda, y en eso estamos de acuerdo, que ESMW-OP y EIEH evaluemos los datos en términos de precisión y validez a fin de determinar qué datos o cuál equipo es el apropiado. (Ver página 9 del informe de Phillip).

Estamos de acuerdo con la recomendación 3, relacionada con el número de verticales en un aforo. En los aforos que se han realizado durante los últimos dos años, por lo general, se toma en cuenta esta observación.

-----Mensaje original-----
De: Khalid Jawed [mailto:khalid.jawed@ei.mwhglobal.com]
Enviado el: Tuesday, October 09, 2001 3:46 PM
Para: jdelaguardia@pancanal.com
Asunto: Seminar and Training

Jorge:

Attached is a tentative program for seminar and training. Please make any change and let me know.

I will appreciate if someone can collect the following information for Charges project:

1. annual maximum daily rainfall at Alhajuela, Chico, Piedras, Salamanca and Candelaria for the period of record.

2. annual maximum instantneous flood peaks at Chagres River at Chico for the period of record.

3. hourly rainfall data for Chico and Piedras for the period of record.

4. any study made by ACP for rainfall depth-area-duration curves in Gatun watershed or any study made for rainfall depth-duration-frequency data.

Khalid <<Archivo: 19844-j.doc>>

Subject: **RV: Comentarios a Infol khalid**
Date: Mon, 3 Dec 2001 11:48:04 -0500
From: CVargas <EIEH@pancanal.com>
To: "Khalid Jawed (E-mail)" <khalid.jawed@ei.mwhglobal.com>
CC: JdelaGuardia <IPC@pancanal.com>

Khalid,

Enclosed are comments related to your study on TRENDS.

Carlos

> -----Mensaje original-----
> De: EIEH-JE
> Enviado el: Monday, December 03, 2001 11:37 AM
> Para: CVargas
> Asunto: Comentarios a Infol khalid
>
> <<ComInfHarzaDec01.doc>>
>
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Comentarios del Informe "Study of Variations and Trends in the Historical Rainfall and Runoff Data in the Gatun Lake Watershed", December 2001 de la Cia. Montgomery Watson Harza.

Por Jorge A. Espinosa

En la página ES-2, Se recomienda tener un pluviómetro totalizador con capacidad para almacenar la precipitación por dos semanas como sistema alterno a los pluviógrafos de cubeta basculante "tipping buckets".

1. La ACP ya cuenta con un sistema, instalado y probado para respaldo de los pluviógrafos de cubeta basculante, el cual consiste en tanques con flota que registran la precipitación cada 15 minutos electrónicamente. Estos tanques tienen capacidad para almacenar la precipitación por más de un (1) mes en las estaciones donde más llueve.
2. No creo que sea conveniente abandonar el sistema de tanques existentes, los cuales funcionan muy bien, para invertir en la adquisición de nuevos y desconocidos equipos, que solo tienen capacidad de almacenar la precipitación por dos (2) semanas.
3. Un equipo que solo almacene la lluvia por dos semanas incrementaría los costos ya que las estaciones se tendrían que visitar dos veces al mes en lugar de una sola vez como actualmente se hace.
4. Las medidas de la precipitación en los pluviómetros totalizadores recomendados tenderían a subestimarse debido a la evaporación que sufriría el agua almacenada en los mismos durante 15 días. El sistema existente hace una medición del nivel de agua en el tanque cada quince (15) minutos reduciendo la posibilidad de que el agua almacenada se evapore.
5. No creo conveniente cambiar el sistema existente de tanques por el recomendado en el informe.

En la Sección 4, página 4-1 se dice "When the ITCZ is well north of Panamá, occasionally, the strength of the rainny season subsides and ..." No considero que la ITCZ se ubique al norte de Panamá con una frecuencia tan alta. Es conveniente que se muestre evidencia de esta afirmación (ITCZ al norte de Panamá). En mi artículo de Junio de 1998, "Veranillo de San Juan within the Panama Canal Watershed" muestro evidencia que indica que los períodos de sequía que ocurren entre junio y agosto se debe a un reforzamiento del sistema de alta presión del atlántico que afecta a toda la región del caribe y no a un desplazamiento de la ITCZ al norte de Panamá. La ITCZ no afecta directamente a los países del Caribe y aún en estos se experimenta una pequeña sequía entre junio y agosto, lo que indica que el veranillo se debe a otra causa distinta a la ubicación de la ITCZ. Por otro lado, la dirección de los vientos al nivel de 850 hectopascales no evidencian una ITCZ al norte de Panamá durante esta época del año.

La Figura que se muestra en la sección 4.0 (Exhibit 4.1, Ref. Riehl, H., 1979) representa la ubicación promedio de la ITCZ durante el año, esta localización de la ITCZ tiene grandes variaciones de este promedio dependiendo de la zona geográfica que se analice.

La figura 1.10 de la misma referencia (Riehl, H., 1979) muestra las desviaciones del promedio que sufre la ITCZ según la zona geográfica (longitud).

En la Sección 6.0, punto 6.1 dice que las estaciones de aforo de ríos están unidas por microondas a la computadora central en Balboa Heights vía microondas, esto no es correcto, la unión es vía radio VHF.

La red telemétrica de observación meteorológica es fabricada por la Compañía VAISALA/HANDAR business unit, no HANDER.

NO se encuentra el Exhibit 5.1.

Jorge A. Espinosa

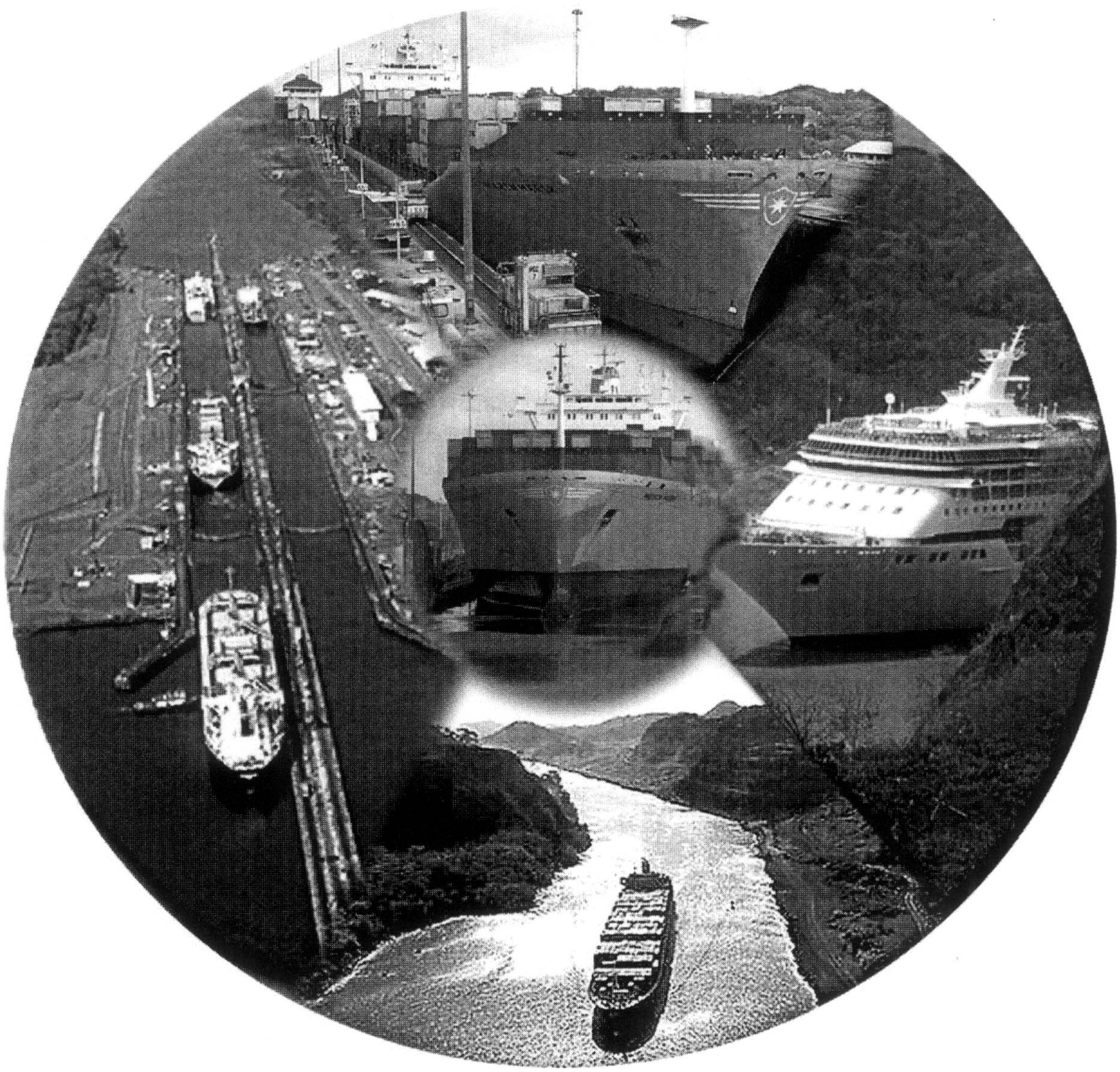
Subject: **Comments J. Gribar**
Date: Tue, 11 Dec 2001 10:58:27 -0500
From: JdelaGuardia <IPC@pancanal.com>
To: "'khalid.jawed@ei.mwhglobal.com'" <khalid.jawed@ei.mwhglobal.com>

Khalid:
Jhon Gribar just pointed out to me that there are a couple of items missing from the trend report, these are:
In the description of work to be performed 1st paragraph mentions "It shall also establish levels of reliability and define the probabilities of occurence to the range of low, medium and high flow records"
And in the 6th paragraph "The data shall be segregated to show significance of..........
and furhte down "The data shall be further sorted to show level of occurence.............

Those three items are not in the report.
Thanks

Jorge

Appendix A
References



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