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Study of Real-Time Adaptive Closed-Loop Control Algorithm for Reservoir Operation

By
Ross B. Buchanan
and Rafael L. Bras
of Ralph M. Parsons
Laboratory for Water
Resources and Hydrodynamics

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Cambridge, Massachusetts
02139

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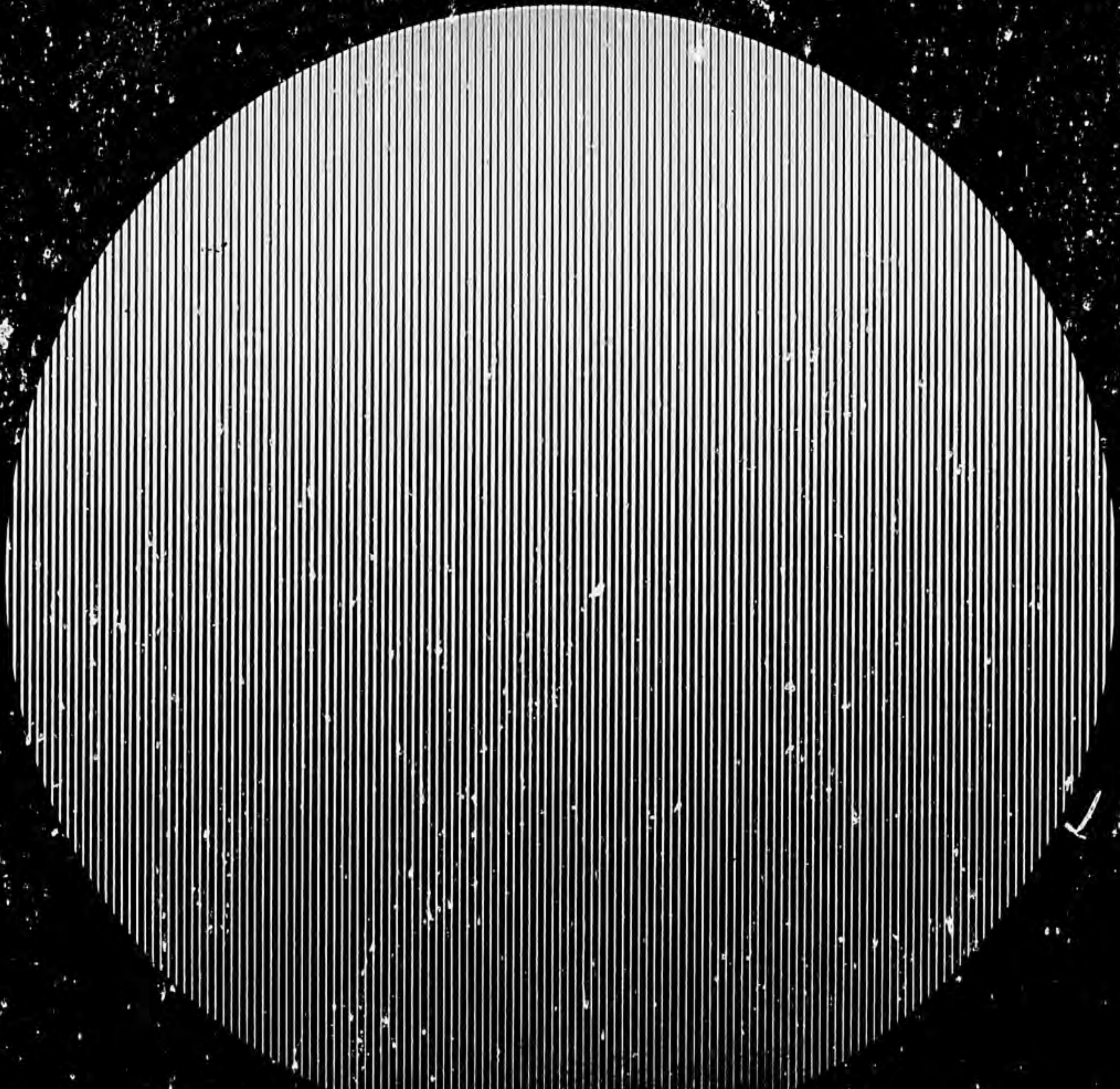

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ABSTRACT

Recent studies on the optimal control of the High Aswan Dam in Egypt have illustrated the usefulness of steady-state stochastic dynamic programming techniques for deriving optimal release policies. This work likewise uses stochastic dynamic programming for the determination of optimal High Dam releases, but a new adaptive reservoir control scheme capable of handling a nonstationary system is investigated. Using results of the stationary control problem as boundary conditions, a finite horizon optimization problem is solved in order to incorporate the multi-lead forecasts of reservoir inflows and any other nonstationarities into the solution procedure.

A comparison is made of a heuristic operating policy for the High Aswan Dam with that resulting from a steady-state stochastic dynamic programming solution and that from the suggested real-time adaptive control formulation. The objective is to minimize losses due to irrigation deficits, power production deficits and damages due to flooding. It can be concluded that performance is better with the steady-state solution, and it is best using the adaptive formulation. Particularly, the use of forecasts and the adaptive formulation significantly reduces flood damages.

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Work was performed at the Ralph M. Parsons Laboratory, Department of Civil Engineering, M. I. T.

PREFACE

This report is one of a series of publications which describe various studies undertaken under the sponsorship of the Technology Adaptation Program at the Massachusetts Institute of Technology.

The United States Department of State, through the Agency for International Development, awarded the Massachusetts Institute of Technology a contract to provide support at M. I. T. for the development, in conjunction with institutions in selected developing countries, of capabilities useful in the adaptation of technologies and problem-solving techniques to the needs of those countries. This particular study describes research conducted in conjunction with Cairo University, Cairo, Egypt.

In the process of making this TAP supported study some insight has been gained into how appropriate technologies can be identified and adapted to the needs of developing countries per se, and it is expected that the recommendations developed will serve as a guide to other developing countries for the solution of similar problems which may be encountered there.

Fred Moavenzadeh

Program Director

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Chapter 1

INTRODUCTION

1.1 Scope of Study

Over the past century, the growth of Egypt has been perpetuated by the effectual utilization of Nile River waters. The country's chief source of income, agriculture, has been substantially increased with the construction of dams, barrages and canals. Further, over the past decade, hydroelectric generating facilities on the Nile have been providing more than one half of Egypt's energy requirements.

Currently, the major regulatory facility on the Nile River, from which Egypt primarily derives its benefits, is the High Aswan Dam. It is the controlled releases from Lake Nasser, created by the High Aswan Dam, that serve to meet irrigation requirements according to the schedule of seasonal demands. High Dam releases also serve the purpose of maintaining manageable reservoir levels for flood control. This is essential both to the maintenance of Nile River banks and to the large-scale development of perennial irrigation. Finally, of the total amount of hydroelectric power generated on the Nile, the High Aswan Dam is responsible for approximately 83 percent.

Determining the optimal release policy for the High Dam has received wide attention since its completion. The problem is complicated due to the multi-objective nature of High Dam releases, particularly since the major objectives are not complementary. Additional complications arise due to the lack of knowledge of future Lake Nasser inflows.

To cope with these complications, recent studies (El Assiouti, et al., 1979, and Alarcon and Marks, 1979) have investigated the performance of reservoir operating policies derived from steady-state stochastic dynamic programming algorithms. In these investigations, Lake Nasser inflows are characterized to be a periodically stationary random process, with the objective space being reduced by the imposition of lower and upper constraints on releases.

This study likewise uses stochastic dynamic programming techniques to derive operating policies for the High Aswan Dam. However, a methodology is investigated capable of handling a nonstationary system, one that allows for the incorporation of multi-lead forecasts of reservoir inflows into the solution procedure. Proposed by Curry and Bras (1980), this methodology is termed a "real-time adaptive closed-loop control" algorithm. The algorithm is 'closed-loop' in the sense that the control (release decision) for each stage of the solution procedure depends upon the state of the system, which is defined by the variables reservoir elevation and inflow. The term 'real-time adaptive' implies that the control is further dependent upon real-time information, and this information might be updated at each time period with the availability of new data.

Though the adaptive control has been discussed prior to this study, it has never been extensively tested, and results based upon utilizing a multi-lead forecasting scheme have never been published. Thus, this study concentrates most of its efforts upon evaluating the performance of the adaptive control approach. This is accomplished with the use of a simulation model of the High Aswan Dam - Lake Nasser system, adopted from the study of Alarcon and Marks (1979).

For measures of comparison, two alternate reservoir operating policies are also simulated. One is a 'heuristic' policy, using a rule curve proposed by Joint Research Project IBM/EXWAP (1979), which tries to draw the reservoir down to level 175.0 m by August 1 of each year. The second alternate policy is derived from a steady-state stochastic dynamic programming algorithm (i.e., without forecasted inflows).

Ultimately, this study addresses the issue of the value of forecasted information. Insight into this issue can be gained by comparing the simulation performances resulting from both the steady-state and the adaptive control schemes.

1.2 Outline of Study

Prior to any analysis, it is first necessary to provide a solid basis of understanding for the problem at hand. Thus, Chapter 2 is provided to familiarize the reader with both the Nile River basin and the High Aswan Dam - Lake Nasser system. Hydrologic information used in the forthcoming analysis, derived from Nile Basin data covering the years 1912 through 1965, is also presented.

In Chapter 3, the steady-state stochastic dynamic programming algorithm employed by this study is presented. Since the algorithm used here is a modified version of that used by Alarcon and Marks (1979), a discussion is provided to explain any significant revisions.

Chapter 4 reviews the adaptive control algorithm described in Curry and Bras (1980). Included is the methodology used to incorporate multi-lead forecasted inflows to Lake Nasser.

Chapter 5 presents examples of operating policies resulting both from the steady-state and the adaptive control algorithms. Discussion focuses upon some specific examples illustrating the similarities and differences of operating policies due to the incorporation of forecasts. Sensitivity analyses are also performed on several system parameters that are not well-defined.

Chapter 6 presents simulation results of each control scheme for three separate system configurations. Eight other system configurations are also simulated using the steady-state control, from which several important observations can be made on the variable system parameters considered in Chapter 5.

Finally, Chapter 7 presents conclusions and recommendations for further research on the subject of adaptive reservoir control.

Chapter 2

THE NILE RIVER BASIN AND THE HIGH ASWAN DAM

2.1 Description of Problem

Throughout history, the Nile River has played a critical role in the development of Egypt, being the only major source of water for the country's livelihood, agriculture. Projects developed for the purpose of controlling Nile River flows, and ultimately for increasing agricultural production, started early in the 18th century. These efforts culminated in the mid-1960's with the construction of the High Aswan Dam.

Today, with the High Aswan Dam in full operation, the Nile River in Egypt is completely regulated, substantially increasing both the quantity and reliability of Egypt's agricultural production. As a further benefit, hydroelectric power generated at the High Dam is currently providing about one half of Egypt's rapidly increasing energy demands.

Until recently though, the national policy of Egypt has considered only conservation storage and flood protection as primary objectives of High Dam releases. Hydroelectric generation has been viewed as a residual benefit, and the hydropower generated has neither been maximal nor in accord with the pattern of Egypt's energy demands. The rate of growth in energy demands occurring in Egypt now necessitates the optimization of hydropower produced at the High Aswan Dam, hence adding a third objective to High Dam releases. With the need for new operating rules to appropriately reflect this additional objective, mathematical techniques can be utilized to provide insight into the problem at hand. However, in view of the fact that future inflows to Lake Nasser are unknown, deriving an 'optimal' release policy relative to these three objectives requires the solution of a multi-objective problem under uncertainty.

For a single stochastic reservoir system, it has been determined that stochastic dynamic programming is the most effectual approach for finding optimal operating policies (Foefs and Guitron, 1975), and this is the approach taken here. Chapter 3 presents a more conventional steady-state stochastic dynamic programming algorithm, while Chapter 4 extends the concepts of Chapter 3 with an adaptive algorithm capable of incorporating forecasted information.

Before presenting these mathematical models though, a broader overview of the problem at hand can be given with the description of the Nile River basin and the High Aswan Dam - Lake Nasser system. The remainder of this chapter, then, is devoted to presenting important physical and behavioral characteristics of the system under study.

2.2 The Nile River Basin

The Nile River is the second longest river in the world (Cairo University, 1977), traveling nearly half the length of Africa to bring its waters to the Nile Delta in Egypt. Over this distance, the Nile basin covers large portions of Uganda, Sudan, Ethiopia and, of course, Egypt. It also reaches the countries of Tanzania, Burundi, Rwanda, Zaire and Kenya (see Figure 2.1).

There are two primary sources of the main Nile River channel, the White Nile and the Blue Nile. Combining with these sources to augment Nile flows are three other major tributaries: Bahr el Ghazal, River Sobat and River Atbara. A complete description of these tributaries and their contributions to the Nile can be found in Abul-Atta (1978). The following paragraphs give a summary of these descriptions, with Figure 2.2 provided to aid the discussion.

2.2.1 The White Nile

Of the White and Blue Nile, the White Nile is the most distant source, emerging from Lake Victoria in the Equatorial Lakes plateau of central Africa. The average annual rainfall received by the Lake Victoria catchment area is 118 milliard m^3[†], but the White Nile begins its journey with an average annual flow of only 23.5 md m^3 due to high evaporation and infiltration losses in the lake.

From Lake Victoria, the river passes through a series of waterfalls and enters a second Equatorial Lake, Lake Kyoga. Rainfall along this stretch adds an average of 11 md m^3 to the 23.5 from Lake Victoria. However, the average annual outflow is only 22.5 md m^3, apparently due to high evaporation losses.

The outflow from Lake Kyoga finds its way to Lake Albert, just west of Lake Kyoga. Fed by the White Nile and by the catchments of Lakes George and Edward, Lake Albert has an average annual inflow of

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[†] 1 milliard = 1×10^9 = 1 md

Figure 2.1

Major Rivers of Africa and Countries of the Nile River Basin .

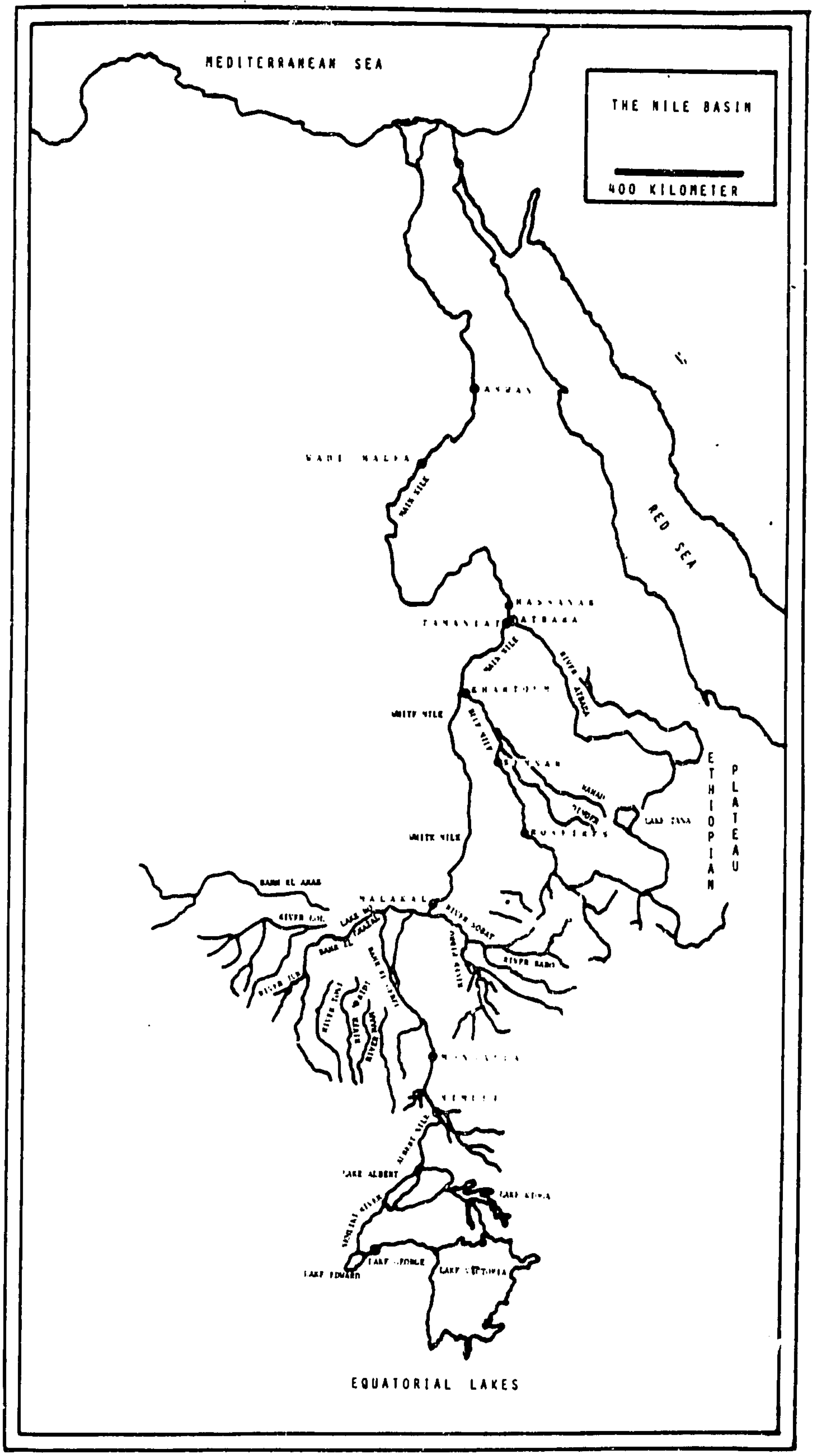


Figure 2.2

Map of Nile Basin (Curry and Bras, 1980)

32.8 md m^3. After losses of 6.3 md m^3, the average annual net outflow via the White Nile is 26.5 md m^3.

From the Equatorial Lakes plateau, the river flows northward to Mongalla and the beginning of the Sudd region, increasing in yield on the average to 30 md m^3. Crossing the Sudd, a swampy area of shallow, meandering channels, the river loses half of its water, mostly to evapotranspiration. Thus, the average outflow from the Sudd is reduced to 15 md m^3 per year.

Before reaching the confluence with the Blue Nile, the White Nile is joined by the Bahr el Ghazal and River Sobat. The Bahr el Ghazal basin adds an average of 0.5 md m^3 per year to the White Nile, while the Sobat adds an average of 13.5 md m^3 per year. Thus, the total amount of water provided by the White Nile at its confluence with the Blue Nile is, on the average, 29 md m^3 per year, distributed relatively uniformly throughout the year. However, this water is to eventually flow through a desert climate before reaching Aswan in Egypt, and only an approximate 24 of these 29 md m^3 arrive at the High Aswan Dam.

2.2.2 Bahr el Ghazal

The Bahr el Ghazal basin is located in the general region of southwestern Sudan. The numerous tributaries in this basin provide the Bahr el Ghazal with an average amount of approximately 18.7 md m^3 of water per year (Chan and Eagleson, 1980). However, the Bahr el Ghazal is a very swampy river, and most of the discharges from the tributaries are lost to evaporation and evapotranspiration. As a result, only 0.5 md m^3 actually reach the White Nile, and this basin currently plays an insignificant role in providing water to the Nile River.

2.2.3 River Sobat

River Sobat, originating in the Ethiopian plateau, is formed by the confluence of two smaller rivers, the Pibor River and the Baro River.

The Baro River is unique in that during periods of high flows, water literally spills over the river banks, destined never to return to the river. Spillage amounting to an annual average of 3.4 md m^3 (El-Hemry and Eagleson, 1980) goes to the Machar Marshes, a large swampy area where the water is lost to seepage and evapotranspiration. Combined with other losses, only 9.2 md m^3 reach the Sobat River.

The Pibor River discharges an average annual amount of 2.8 md m^3. Thus, the total average discharge from these two branches is 12 md m^3 per year. As the Sobat, the yield is eventually increased to 13.5 md m^3 per year before it reaches the White Nile.

2.2.4 The Blue Nile

The other major source of the main Nile is the Blue Nile River. Emerging from Lake Tana in the Ethiopian plateau, the Blue Nile is characterized by its torrential nature, carrying violent floods during the months of August through October. Traveling its course from Lake Tana to Roseires, a distance of 940 km, the Blue Nile increases in yield from 3.8 to about 50 md m^3 per year. From Roseires to Sennar, a distance of 270 km, the yield of the Blue Nile remains fairly constant.

Just below Sennar, however, another 4 md m^3 are added from the tributaries Dinder and Rahad, increasing the yield to 54 md m^3 per year. Of this amount, it is estimated that only 48 md m^3 actually reach Aswan, due to evaporation incurred while flowing through the desert downstream.

2.2.5 River Atbara

The source of River Atbara can be found near Lake Tana in the Ethiopian plateau. Like the Blue Nile, River Atbara is torrential in nature. Its average annual yield is approximately 12 md m^3, though the riverbed is generally dry during the months of January through May.

From the junction of the Nile with River Atbara, the Nile flows through a desert climate as previously mentioned. The actual amount of water arriving at Aswan is reduced to an estimated average of 84 md m^3 per year.

2.2.6 Summary

Within the descriptions of the Nile River tributaries, an attempt has been made to provide certain pieces of information.

First, rainfall in the Nile River basin can provide an average annual yield of approximately 84 md m^3 of water to Egypt.

Second, the major supplier of Nile River flows are the waters originating in the Ethiopian plateau. Via River Sobat, River Atbara and most importantly the Blue Nile, rainfall in Ethiopia is brought down to the Nile River in Sudan, accounting for (averaged over the year) almost 85 percent of Nile flows at Aswan. Of this water, the majority arrives at Egypt during the months of August through October, flooding the Nile River valley upstream of the High Aswan Dam. Supplying the remaining waters are the White Nile and the Bahr el Ghazal.

Finally, it is interesting to note that there are no tributaries to the Nile River in Egypt itself. Since Egypt receives scarce amounts of rainfall, Egyptian agriculture and industry depend almost completely on the regulation provided by the High Aswan Dam.

2.3 The High Aswan Dam - Lake Nasser System

The High Aswan Dam, as previously mentioned, serves Egypt as a multi-purpose project. With the capacity of its reservoir, Lake Nasser, the floods originating in the Ethiopian plateau can be retained, to be released in the winter and spring months when lower flows prevail for irrigation and electricity generation. However, release decisions at the High Dam must take into account the conflicting nature of conservation storage (drought protection), flood protection and the maximization of hydropower. To clarify this problem, information is provided here relating the above objectives to the physical characteristics (limitations) of the dam and its reservoir (see Abul-Atta (1978) for complete information). Concluding this section is a description of the operating policy currently employed by the High Dam Authority to meet the first two objectives.

2.3.1 Physical Description

The High Aswan Dam is located 7 km south of Aswan, just 6 km upstream from the Old Aswan Dam. With a height of 111 meters, it holds back one of the world's largest reservoirs in Lake Nasser. The total length of the High Dam is 3600 meters, of which 520 meters are between the two banks of the Nile River. The dam is of the rockfill type, constructed almost entirely of materials located within a 7 mile radius of the site.

To release the waters of Lake Nasser, a diversion channel on the east bank leads water to six tunnels, each 282 meters in length and approximately 15 meters in diameter. The amount of water released is controlled by steel gates at the inlets of the tunnels. As the tunnels approach a power plant at the base of the dam, each branches into two smaller tunnels to serve the twelve turbine facility. The water can either pass through the turbines, or, if necessary, bypass the turbines altogether. The maximum possible discharge through the diversion channel approaches 11,000 m^3 per second, or approximately 1 md m^3 per day. An emergency spillway exists on the western bank should the storage exceed the capacity of the reservoir.

The storage capacity of Lake Nasser is approximately 168.9 md m^3. Currently, this capacity is divided into six operating zones as illustrated in Figure 2.3, where the live storage includes Zones B, C, D, and E. The live storage volume is approximately 137 md m^3, and it is this portion of the reservoir that this work concerns itself with.

2.3.2 Conservation Storage

The primary objective of the High Aswan Dam is to provide waters to Egypt downstream of Aswan according to the schedule of monthly demands. Currently, these demands vary from month to month, as illustrated in Figure 2.4, with the total annual demands, mainly due to irrigation (henceforth, downstream demands and irrigation demands will be used

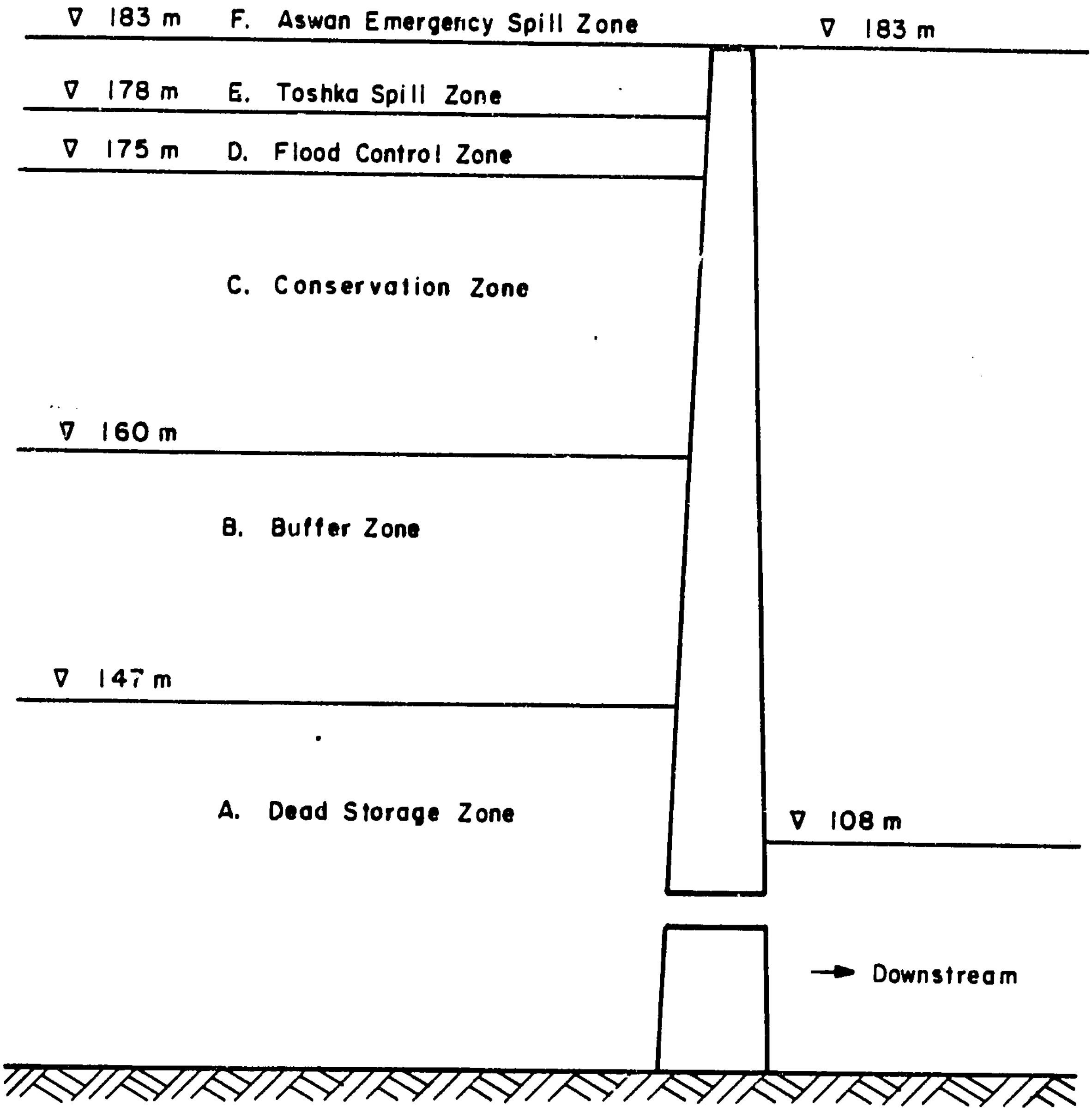


Figure 2.3

Schematic Representation of Different Zones for High Aswan Dam Reservoir

(Adopted From El Assiouti, Et Al. (1979))

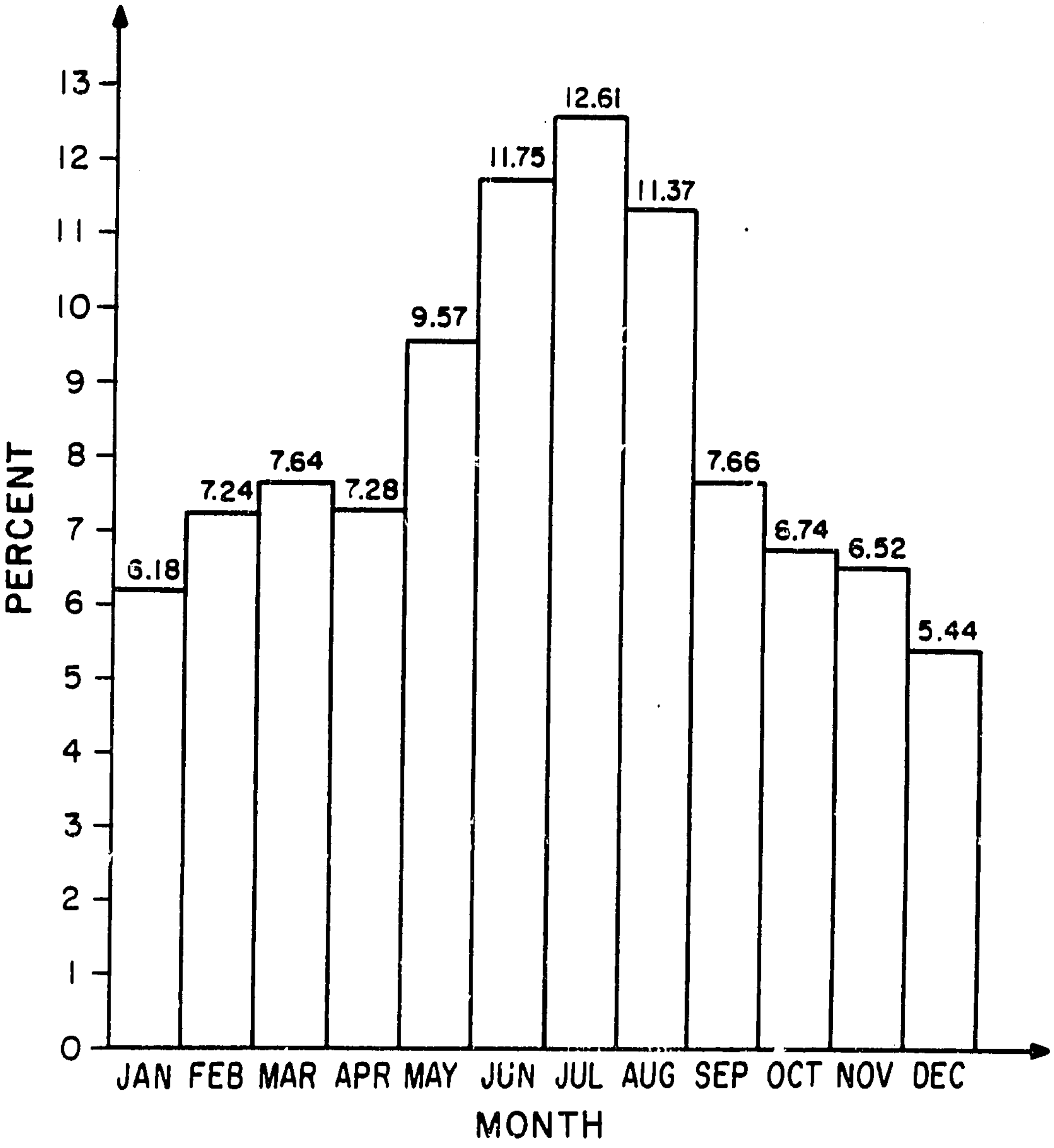


Figure 2.4

Monthly Irrigation Demands Given as Percentage of Total Annual Demands interchangeably), assumed here to be 55.5 md m^3.

The purpose of conservation storage is to retain water in the reservoir in sufficient quantities such that future downstream demands can be met with a high degree of reliability. The stored water is essentially an insurance measure against the event of successive years of low inflows. Considering this objective alone, conservation storage generally allows for future irrigation requirements to be met with the highest possible reliability.

Though it was stated earlier that the Nile River basin yields an annual average of approximately 84 md m^3 to Egypt at Aswan, which is well above the average annual downstream demands of 55.5 md m^3, three sources of water losses much be recognized, resulting in lower quantities of water available to Egypt. The first source of losses is evaporation from Lake Nasser, which is substantial. Evaporation rates range from 105.3 to 324.0 mm per month, as indicated in Figure 2.5. Total annual evaporation amounts to 2.7 meters per year, which corresponds to volumes ranging from approximately 10 to 15 md m^3, depending upon the variable surface area of the reservoir. A second source of water losses is to Toshka spillway, which will be discussed in a later subsection. Finally, from the Nile Water Agreement of 1959, the upstream country of Sudan is allocated 18.5 md m^3 per year in abstractions. These abstractions are assumed to occur on a monthly basis following the distribution given in Figure 2.6. Thus, depending upon the amount of water lost to evaporation and to Toshka, the average quantity of water available annually for downstream releases is very close to the annual demands of 55.5 md m^3.

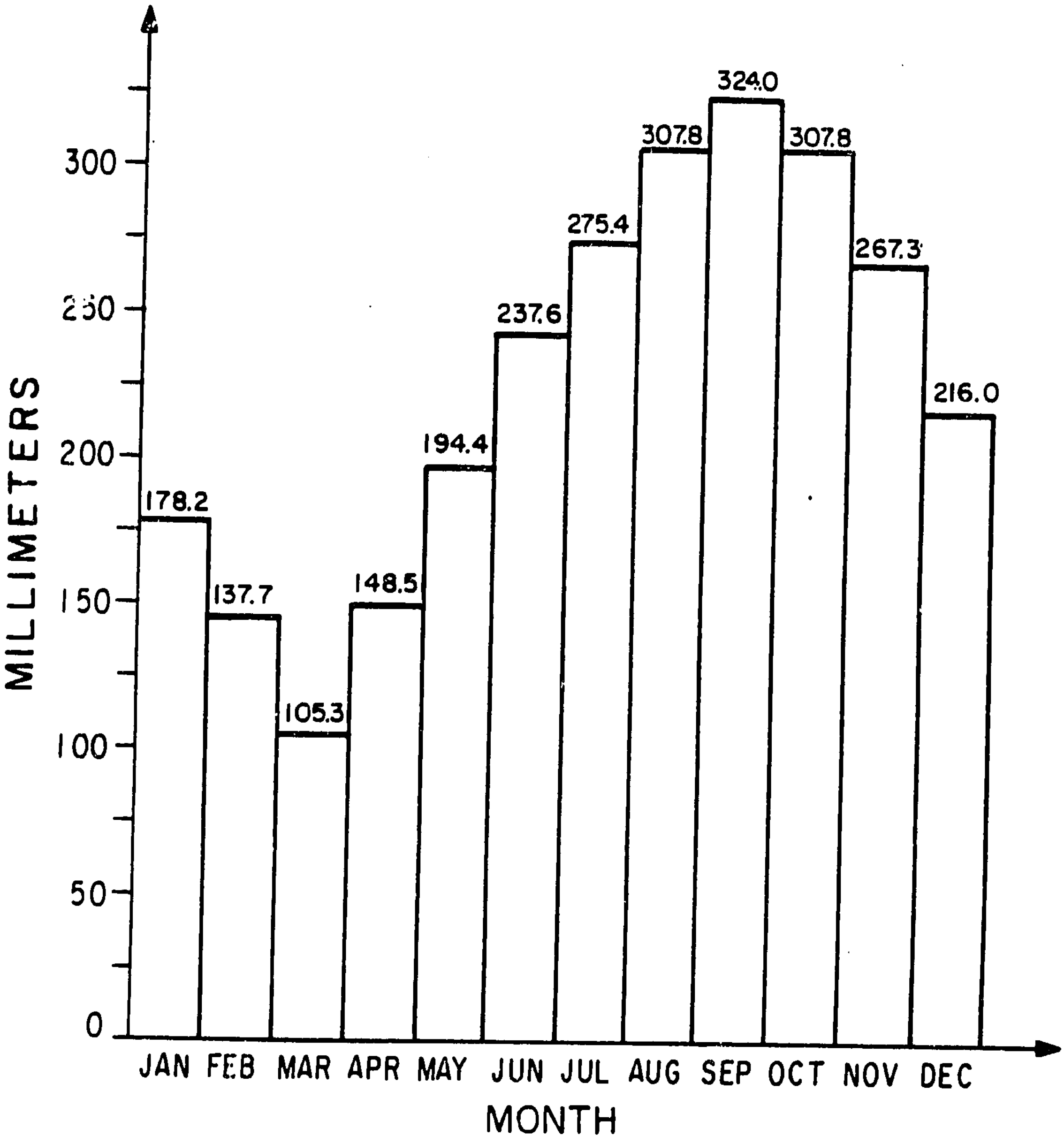


Figure 2.5

Monthly Evaporation Rates for Lake Nasser

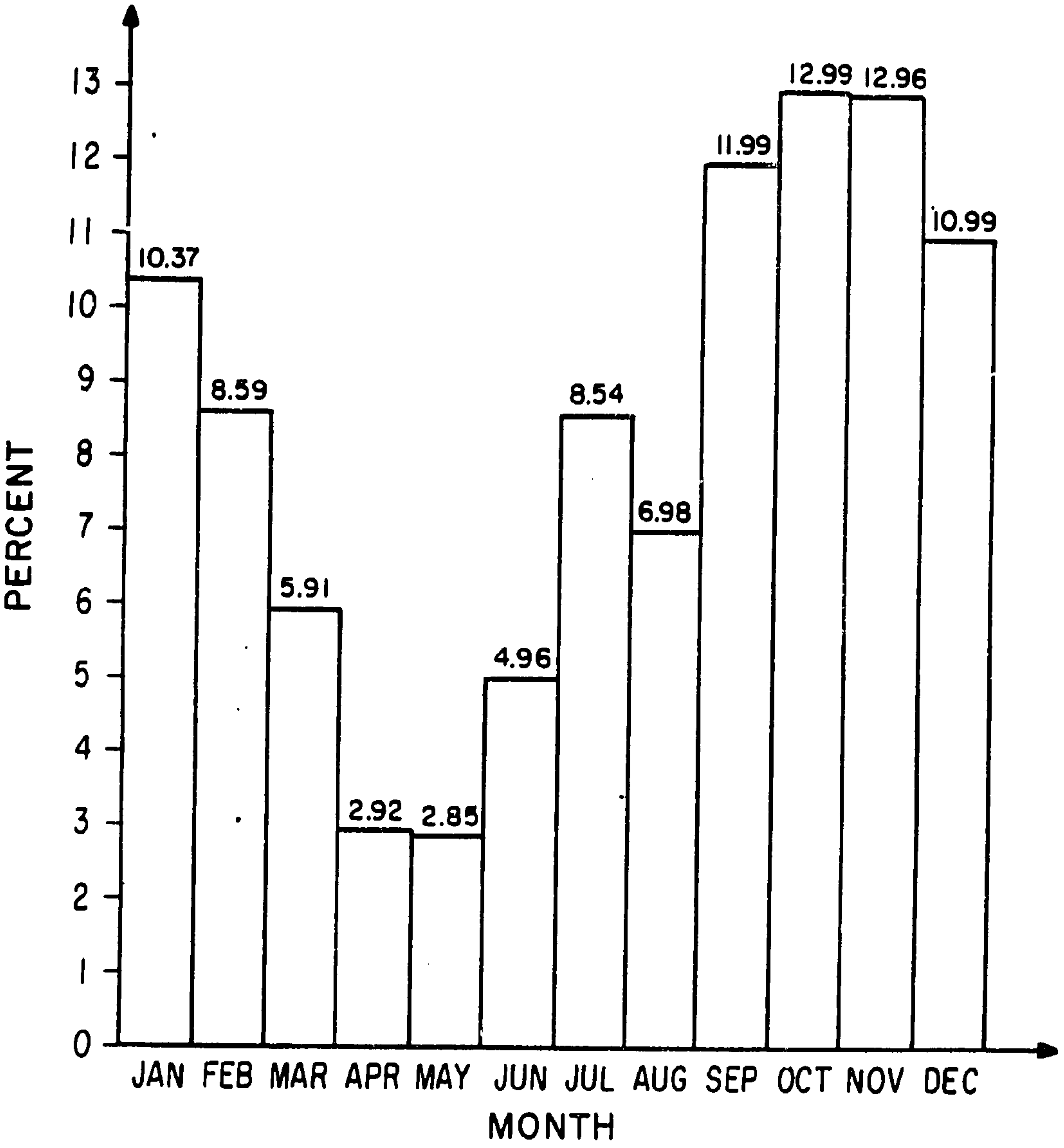


Figure 2.6

Monthly Sudan Abstractions Given as Percentage

of Total Annual Abstractions

2.3.3 Flood Control

A second objective of major importance is the prevention of excessively high releases. This objective is important from two standpoints. First, it is naturally desirable to avoid flooding of the riverbanks, as this is where both the agriculture and the majority of the population exist. Second, with the construction of the High Dam, suspended particles carried by flood waters are now deposited in Lake Nasser. Consequently, there is no replenishment of soil eroded from both the riverbed and the barrages downstream from the dam, and high releases must be avoided to prevent their degradation.

For the High Aswan Dam, the term "flood control" generally pertains to the second of these problems, as downstream degradation will occur before the riverbanks are overtopped. The actual amount of water that can safely be released without incurring significant degradation is not currently known. El Assiouti, et al. (1979) use a figure of 250 million m^3 per day or about 7.6 md m^3 per month as the maximum permissible release. This figure will likewise be used for the current study. Also, to test the sensitivity of High Dam release policies to this figure, 275 million m^3 per day, or about 8.4 milliard m^3 per month, will also be examined.

Considering conservation storage alone, releases above downstream demands would only occur in the extreme case of high reservoir storages combined with high inflows to Lake Nasser. If flood control is considered as the sole objective, releases would frequently be near the maximum permissible release in an effort to keep the reservoir empty. Clearly, this is in conflict with the first objective, and some type of compromise must be made in deciding upon reservoir releases.

2.3.4 Power Generation

A third purpose served by the High Aswan Dam is the generation of electricity. With each of the twelve turbines at the High Dam power plant having a capacity of 175 MW, the total installed capacity is 2100 MW. However, at any given time, two turbines are closed down for maintenance purposes, and the effective installed capacity is 1750 MW, which is still equivalent to more than 15000 GWH per year.

Though the current generation of electricity at the High Dam is substantial, the amount generated for each month is almost entirely dependent upon the monthly irrigation requirements, based upon the current operating policy. As mentioned earlier, this results in suboptimal power generation, and the current study investigates the possibility of circumventing this deficiency.

The amount of electricity generated increases with increasing amounts of water passing through the turbines and increasing heads. Several attempts have been made to relate monthly electricity generation to the variables of release and reservoir water elevation. Based upon the research of Hydroproject, USSR (1976), El Assiouti, et al. (1979) and Alarcon and Marks (1979) use the relation

$$GN = (93 + 2.39 \cdot (H - 150)) \cdot V \qquad (2.1)$$

where

GN = power generation (GWH/month)

H = average elevation for the month (meters)

V = volume of water released (md m^3/month)

A relationship suggested in Ministry of Irrigation (1980, Technical Report 14) takes the form:

$$GN = 0.6792 \cdot V^{1.194} \cdot H^{1.208} \tag{2.2}$$

where GN, H and V take on the same definitions as in Equation (2.1). This relationship is based upon the theoretical equation

$$GN = \delta_1 \cdot V^{\delta_2} \cdot H^{\delta_3}$$

with the coefficients δ_1, δ_2 and δ_3 derived from a non-linear regression analysis. A third alternative, and the one incorporated in this work, is to determine the electricity generated per turbine using the characteristic curves of Figure 2.7. As the family of curves is fairly linear, a linear approximation is used for each individual curve, and a linear interpolation scheme can be used for points not falling directly on a curve. The use of Figure 2.7 instead of Equations (2.1) or (2.2) guarantees that hydropower generation will not exceed 1280 GWH per month, which corresponds to the capacity figure of 1750 MW.

With the maximization of hydropower as a third objective, further conflicts in release decisions arise. Higher water surface elevations are desirable for higher power production, and thus high releases are discouraged in an effort to maintain these high elevations. Conversely, high releases will provide high power generation, but this will result in the depletion of reservoir storage. Clearly then, the

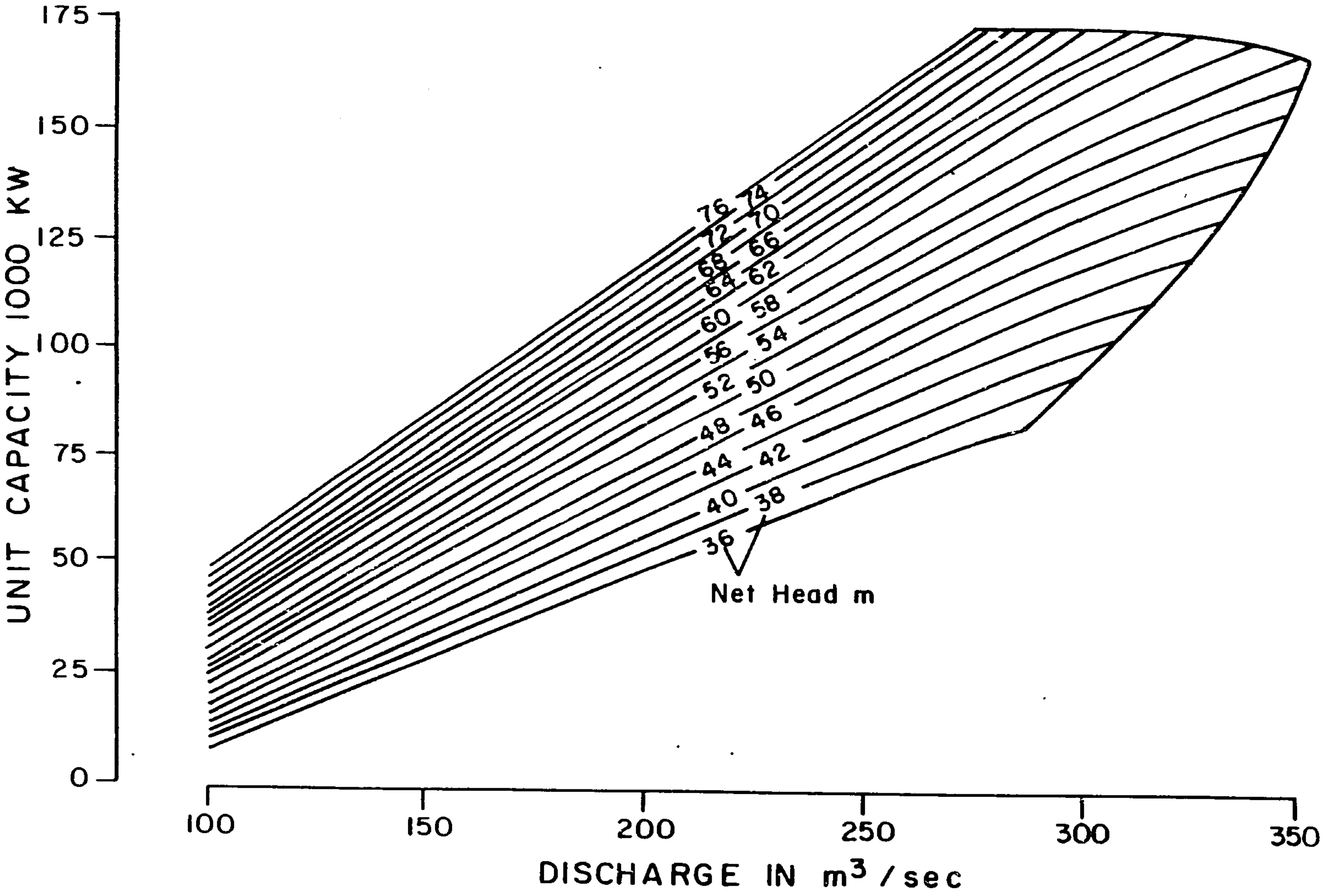


Figure 2.7
High Aswan Dam Power House Capacity Head and Discharge Relationship of the Turbines
(Ministry of Irrigation [1979])

simultaneous consideration of conservation storage, flood protection and hydropower maximization renders a complex management problem, requiring tradeoffs between the different system objectives in an effort to reach an optimal release policy.

2.3.5 Current Operating Policy

The operating policy currently used for the High Aswan Dam is intuitive in nature, making no allowance for the optimization of the given objectives or for the variability of future reservoir inflows (Attia, 1980). The scheduling of releases is made by the Ministry of Irrigation in Egypt, taking into account the monthly irrigation requirements and the particular zone in which the reservoir water surface elevation is located. These zones, illustrated in Figure 2.3, have associated operating rule curves which are summarized in the following paragraphs, based upon descriptions given by Attia (1980).

Zone A is considered to be dead storage, from which water cannot be released. The rule curve for this zone is thus zero release, regardless of the irrigation requirements. In practice, this zone is allocated to receive the sediment trapped by the reservoir.

Zone B is a buffer zone, with releases from this zone being some fraction of the actual monthly irrigation requirement. The particular fraction is determined by a 'sliding scale', which currently has not been explicitly defined. This sliding scale constitutes the so-called 'lower rule' curve.

Zone C is called a conservation zone. When reservoir elevations are in this zone, the rule curve calls for the release of irrigation requirements only.

Zone D is a flood control zone, allocated for the storage of flood waters to avoid downstream damage or degradation. When reservoir levels are in this zone, an 'upper rule'curve is invoked, calling for releases in excess of irrigation requirements.

Zone E starts at an elevation where the Toshka spillway, a flood control measure just recently completed, begins to operate. This spillway has a width of 125 meters, with no control facility for regulating spills. Prior to the completion of this spillway, releases in excess of irrigation requirements would have occurred had the reservoir reached such elevations, constituting the remainder of the upper rule curve.

Finally, an emergency spillway exists such that the reservoir level does not exceed the maximum allowable elevation of 183 meters. This emergency spillway is equipped with radial type gated underflow sluices with a sill level of 178.0 meters. For this study, it is assumed that the emergency spillway begins to operate at the elevation of 183 meters.

In practice, the High Dam Authority implements the above policy with guidance provided by reservoir routing computations for five different historic inflow conditions as given below:

Inflow Condition	Typical Year	Total Inflow
Very low flood	1913	53 milliard m^3
Low flood	1954	70 milliard m^3
Average flood	1959	92 milliard m^3
High flood	1964	115 milliard m^3
Very high flood	1878	138 milliard m^3

Once the flood status of a year is known, the curves are used with estimated downstream irrigation requirements to prepare a release schedule that will ensure the evacuation of the flood control zone (Zones D and E) prior to August 1 of the following year. The derived schedule must comply with the constraint that releases must not exceed a maximum allowable release, previously mentioned to be 250 million m^3 per day.

2.4 Hydrologic Information

The discussion of Section 2.2 is provided to familiarize the reader with the Nile River basin. However, the hydrologic information actually required for this study is of a different nature. Specifically, what is required is a set of probability distributions of inflows to Lake Nasser for each month. This section presents two approaches for deriving these distributions using historical streamflow observations of the Nile basin.

2.4.1 Monthly Inflow Distributions Assuming Stationarity

The first approach assumes that inflows to Lake Nasser for the infinite future can be characterized by a periodically stationary Markov process. On a monthly basis, this simply implies that each year is composed of twelve different monthly distributions of inflow, and this set of distributions remains fixed for all future years. With the further assumption that future inflows will be similar (in a statistical sense) to past streamflows at the High Dam site, statistics derived from historical monthly streamflow observations at some station near

Aswan can be used to generate the required monthly distributions.

The statistics required are the monthly means, variances and lag-one correlation coefficients. Upon fitting each month to a normal or lognormal distribution (obtained using, e.g., a Chi-Square Goodness of Fit Test), the monthly marginal probability distributions are completely described by their respective means and variances. The lag-one correlation coefficients are used to derive monthly conditional probability distributions. For this study, historical streamflow data for the years 1912 to 1965 recorded at Wadi Halfa is used. Statistics extracted from this data are presented in Table 2.1.

2.4.2 Monthly Inflow Distributions with Forecasting

The second approach uses forecasted information as well as sample statistics to describe future monthly inflow distributions. The forecasting procedure used is adopted from the work of Curry and Bras (1980), where Nile basin data is used to examine the performance of both univariate and multivariate models. Presented in this subsection are selected portions of their study essential to the understanding of the adaptive control algorithm presented in Chapter 4.

The different forecasting models analyzed lie somewhere between conceptual and black-box approaches. The structural form of the models rely upon physical principles, while the estimation of the model's coefficients are derived from purely statistical procedures. The particular model giving the best overall performance, and the one used in this study, is a multivariate autoregressive model with the following form:

Month	Mean[1]	STDV	Lag-1	XMAX[1,2]	XMIN[1,3]	NOR/LOG-NOR
1	3.51	0.74	0.486	5.75	2.04	Log-Normal
2	2.45	0.69	0.276	5.08	1.42	Log-Normal
3	2.28	0.67	0.555	4.81	1.26	Log-Normal
4	2.04	0.69	0.640	4.54	1.05	Normal
5	1.92	0.76	0.471	4.34	0.88	Log-Normal
6	2.07	0.78	0.270	4.52	1.00	Log-Normal
7	5.17	1.53	0.607	10.00	2.23	Normal
8	19.45	3.86	0.805	27.10	7.68	Normal
9	21.99	3.78	0.896	31.70	13.40	Normal
10	14.61	3.15	0.887	24.20	7.86	Normal
11	7.17	1.77	0.929	12.20	4.14	Normal
12	4.54	0.87	0.874	7.06	2.99	Normal

[1] md

[2] maximum recorded observation

[3] minimum recorded observation

Table 2.1

Statistics of Historical Streamflow at Wadi Halfa (1912-1965)

$$\underline{Y}(k, i) = \underline{\underline{\Pi}}_i \begin{vmatrix} \underline{Y}(k, i-1) \\ \underline{Y}(k, i-2) \\ \vdots \\ \underline{Y}(k, i-n_1(i)) \end{vmatrix} + \underline{U}'(i) + \underline{V}'(k, i) \qquad (2.3)$$

where

$$\underline{Y}(k, i) = \begin{vmatrix} Y_1(k, i) \\ Y_2(k, i) \\ \vdots \\ Y_{n_o}(k, i) \end{vmatrix}$$

$Y_j(k, i)$ = discharge at station j, year k and month i

$$\underline{U}'(i) = \begin{vmatrix} U_1(i) \\ U_2(i) \\ \\ U_{n_o}(i) \end{vmatrix}$$

$$\underline{V}'(k, i) = \begin{vmatrix} V_1(k, i) \\ V_2(k, i) \\ \\ V_{n_o}(k, i) \end{vmatrix}$$

$$V_j(k, i) = \sum_{m=1}^{n_o} C_i(j, m)\ W_m(k, i)$$

In the above, n_o is the number of streamflow measuring stations considered in the basin. The vector $\underline{U}'(i)$ represents a periodic (period 12) mean streamflow and the vector $\underline{V}'(k, i)$ is a white, uncorrelated noise of zero mean and unit variance. Notice that the elements of $V'(k, i)$ are not necessarily uncorrelated and their variance is a function of time. These effects are introduced by the use of parameters $C_i(j, m)$ in the expression for $V_j(k, i)$. Calibration of this model requires 1) defining an autoregressive lag, given by the term $n_1(i)$, for each month i and 2) estimating a coefficient matrix $\underline{\Pi}_i$, the mean vector $\underline{U}'(i)$ and the corresponding residuals $\underline{V}'(k, i)$ for each month i. The procedure involves iterative use of generalized least squares (GLS) techniques.

For the multivariate autoregressive model, eight Nile basin stations ($n_o = 8$) are used, and their locations are schematically illustrated in Figure 2.8. The period for which monthly streamflow data is available at all eight stations covers the years from 1912 to 1965 inclusive (see Appendix A). The resulting non-zero coefficients of the GLS estimation for lead-one forecasts of each month and each station can be found in Tables 2.2a-h.

Upon estimating the Π matrices and the U(i) vectors, the equation used to generate a one month ahead (lead-one) forecast is:

$$\hat{\underline{Y}}(k, i) = \hat{\underline{\Pi}}_i \left| \begin{array}{l} Y(k, i-1) \\ Y(k, i-2) \\ \\ Y(k, i-n_1(i)) \end{array} \right| + \hat{\underline{U}}'(i) \qquad (2.4)$$

where the symbol '^' designates estimator.

The coefficients of Tables 2.2a-h, when applied to the 54 years of data from which they are derived, generate forecasts using Equation (2.4) with the following important properties:

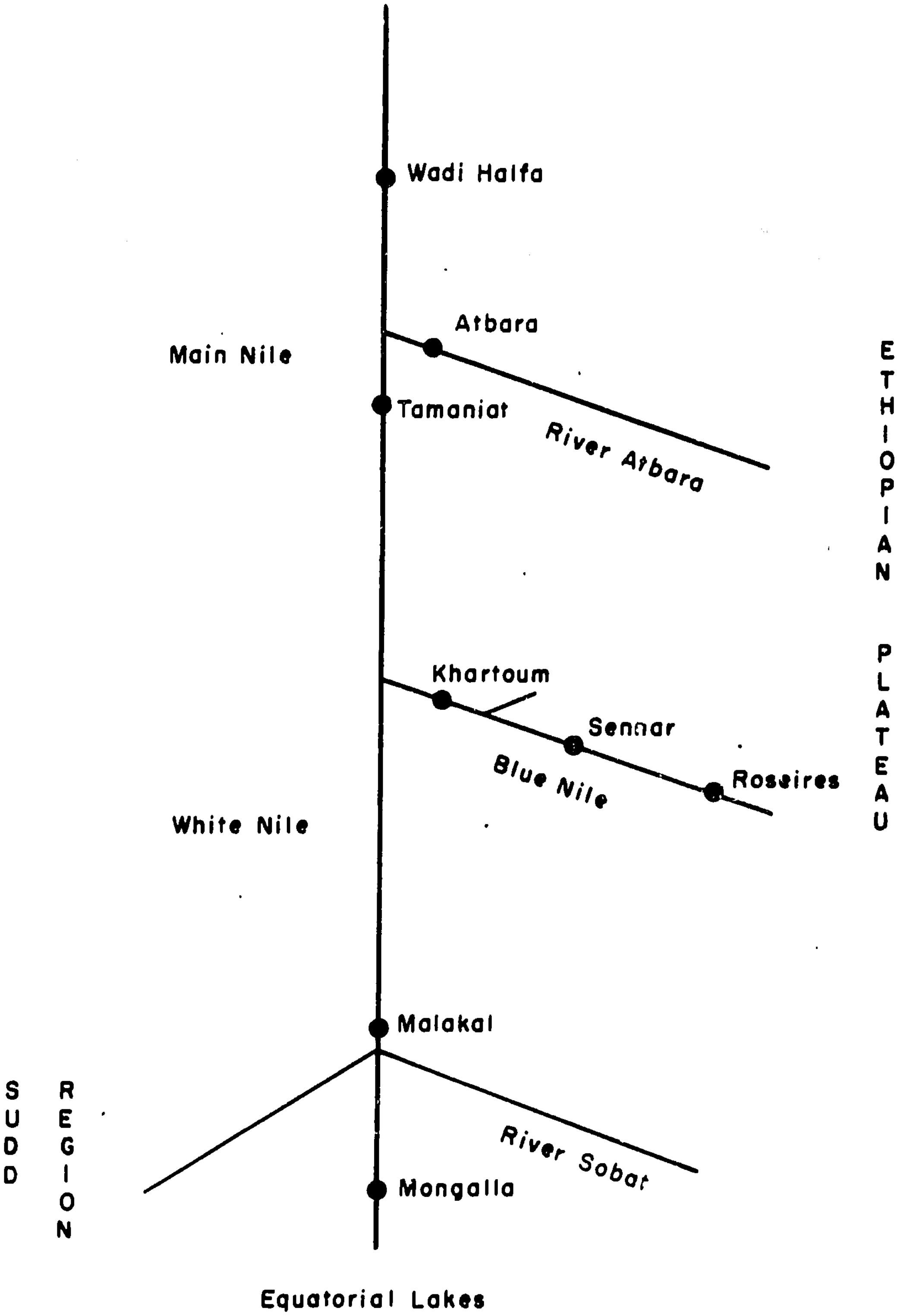


Figure 2.8

Schematic Diagram of Eight Nile Basin Station Locations

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
January	Wadi Halfa	Dec	1	0.457	0.064	51.549	47	100.0	0.468	0.055
	Tamaniat	Dec	1	0.273	0.071	14.949	47	100.0	0.0268	0.062
	Malakal	Dec	1	0.393	0.039	103.792	47	100.0	0.390	0.034
	Sennar	Nov	2	-0.180	0.025	49.853	47	100.0	-0.189	0.023
	Roseires	Jun	7	0.083	0.024	11.894	47	99.9	0.078	0.021
	Tamaniat	Mar	10	-0.141	0.025	31.896	47	100.0	-0.145	0.022
	Khartoum	Mar	10	0.257	0.107	5.753	47	98.0	0.269	0.095
	Constant			-372.251	108.342	11.805	47	99.9	-357.115	96.522
February	Wadi Halfa	Jan	1	0.419	0.043	92.821	52	100.0	0.405	0.036
	Malakal	Jan	1	0.420	0.034	152.367	52	100.0	0.435	0.030
	Constant			-9.647	103.870	0.009	52	7.4	4.554	89.308
March	Atbara	Feb	1	-3.611	1.548	5.441	46	97.6	-3.562	1.185
	Tamaniat	Feb	1	0.922	0.092	101.589	46	100.0	0.960	0.071
	Malakal	Feb	1	0.507	0.113	20.045	46	100.0	0.456	0.092
	Tamaniat	Jan	2	-0.437	0.058	57.020	46	100.0	-0.417	0.046
	Mongalla	Nov	4	-0.503	0.077	43.232	46	100.0	-0.389	0.058
	Roseires	Nov	4	0.225	0.057	15.583	46	100.0	0.164	0.044
	Atbara	Oct	5	-0.218	0.097	5.010	46	97.0	-0.132	0.074
	Mongalla	Oct	5	0.316	0.077	16.910	46	100.0	0.237	0.061
	Constant			625.061	133.407	21.953	46	100.0	588.348	111.500
April	Tamaniat	Mar	1	0.860	0.047	334.866	46	100.0	0.868	0.041

Table 2.2a

Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Wadi Halfa

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
April (contd)	Malakal	Mar	1	0.160	0.046	12.289	46	99.9	0.147	0.040
	Khartoum	Mar	1	-1.714	0.202	72.104	46	100.0	-1.518	0.176
	Roseires	Mar	1	2.113	0.198	113.347	46	100.0	1.896	0.174
	Atbara	Feb	2	-7.616	1.323	33.149	46	100.00	-6.370	1.121
	Roseires	May	10	-0.422	0.174	11.628	46	99.9	0.389	0.171
	Khartoum	May	10	0.441	0.203	4.714	46	96.5	-0.349	0.104
	Khartoum	Apr	12	0.480	0.154	9.772	46	99.7	0.389	0.130
	Constant			-400.029	111.060	12.974	46	99.9	-390.171	96.824
May	Tamaniat	Apr	1	0.593	0.035	287.089	45	100.0	0.618	0.029
	Malakal	Apr	1	0.764	0.118	41.885	45	100.0	0.806	0.094
	Khartoum	Apr	1	0.385	0.172	5.014	45	97.0	0.447	0.138
	Khartoum	Mar	2	-1.729	0.347	24.813	45	100.0	-1.280	0.272
	Sennar	Mar	2	0.919	0.272	11.399	45	99.8	0.613	0.213
	Tamaniat	Feb	3	-0.308	0.063	24.092	45	100.0	-0.272	0.049
	Roseires	Feb	3	0.685	0.208	10.881	45	99.8	0.453	0.162
	Malakal	Jan	4	0.347	0.052	44.175	45	100.0	0.279	0.041
	Mongalla	Oct	7	-0.123	0.037	11.274	45	99.8	-0.107	0.029
	Constant			-302.098	97.250	9.650	45	99.7	-354.327	80.777
June	Tamaniat	May	1	0.703	0.046	236.361	50	100.0	0.768	0.038
	Roseires	May	1	0.655	0.093	49.095	50	100.0	0.547	0.080
	Atbara	Feb	4	11.982	2.963	16.352	50	100.0	9.218	2.201

Table 2.2a (cont'd)

Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Wadi Halfa

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
June (Contd)	Atbara	Jan	5	-4.743	1.847	6.596	50	98.7	-4.583	1.386
	Constant			164.115	96.321	2.903	50	90.5	104.608	84.533
July	Atbara	Jun	1	7.344	1.137	41.715	44	100.0	5.537	0.841
	Sennar	Jun	1	-1.230	0.378	10.571	44	99.8	-0.909	0.280
	Roseires	Jun	1	2.103	0.412	26.009	44	100.0	1.854	0.309
	Atbara	May	2	-9.597	4.618	4.319	44	95.6	-6.662	3.415
	Mongalla	May	2	0.374	0.103	13.046	44	99.9	0.370	0.077
	Khartoum	May	2	1.561	0.469	11.097	44	99.8	1.243	0.347
	Atbara	Apr	3	-23.426	7.361	10.127	44	99.7	-16.482	5.444
	Roseires	Dec	7	1.952	0.355	30.303	44	100.0	1.542	0.262
	Khartoum	Nov	8	-0.501	0.126	15.953	44	100.0	-0.364	0.093
	Atbara	Jul	12	-0.497	0.124	16.005	44	100.0	-0.401	0.092
	Constant			715.067	446.619	2.563	44	88.3	995.165	341.805
August	Atbara	Jul	1	1.410	0.383	13.534	50	99.9	1.282	0.249
	Sennar	Jul	1	1.762	0.211	69.519	50	100.0	1.411	0.151
	Sennar	Jun	2	-1.305	0.545	5.739	50	98.0	-0.302	0.346
	Sennar	Feb	6	-4.799	1.829	6.888	50	98.9	-2.738	1.213
	Constant			10102.008	1175.671	73.832	50	100.0	10150.064	902.921
September	Atbara	Aug	1	0.949	0.211	20.286	50	100.0	0.771	0.111
	Sennar	Aug	1	0.591	0.145	16.538	50	100.0	0.571	0.085
	Khartoum	Feb	7	12.715	3.380	14.152	50	100.0	4.596	1.834

Table 2.2a (cont'd)
Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Wadi Halfa

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
September (contd)	Khartoum	Nov	10	-1.004	0.448	5.019	50	97.0	-0.310	0.247
	Constant			4584.462	1737.609	6.961	50	98.9	7657.633	1172.785
October	Sennar	Sep	1	1.073	0.086	156.919	51	100.0	1.040	0.071
	Atbara	Apr	6	-34.304	10.616	10.442	51	99.8	-18.518	5.760
	Sennar	Apr	6	-2.864	1.193	5.758	51	98.0	-1.536	0.730
	Constant			1891.081	1210.145	2.442	51	87.6	1760.970	968.057
November	Sennar	Oct	1	0.677	0.033	422.734	50	100.0	0.622	0.025
	Wadi Halfa	Dec	11	0.612	0.142	18.451	50	100.0	0.609	0.083
	Atbara	Dec	11	-5.709	2.186	6.820	50	98.8	-4.255	1.277
	Roseires	Nov	12	-0.460	0.183	6.291	50	98.5	-0.485	0.106
	Constant			1326.222	506.258	6.863	50	98.8	1687.365	310.970
December	Tamaniat	Nov	1	0.480	0.032	229.332	48	100.0	0.502	0.028
	Malakal	Oct	2	0.203	0.067	9.223	48	99.6	0.160	0.059
	Tamaniat	Sep	3	0.121	0.035	12.099	48	99.9	0.134	0.029
	Khartoum	Sep	3	-0.086	0.034	6.362	48	98.5	-0.100	0.029
	Atbara	May	7	2.526	1.042	5.878	48	98.1	2.240	0.877
	Atbara	Mar	9	-18.341	7.871	5.429	48	97.6	-17.660	6.623
	Constant			426.739	234.214	3.320	48	92.5	427.699	208.979

Table 2.2a (cont'd)

Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Wadi Halfa

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
January	Atbara	Dec	1	0.283	0.073	14.935	62	100.0	0.259	0.081
	Atbara	Jan	12	0.265	0.109	5.964	62	98.3	0.248	0.115
	Constant			-2.546	6.006	0.180	62	32.7	0.163	6.587
February	Atbara	Jan	1	0.588	0.040	214.754	60	100.0	0.583	0.036
	Atbara	Dec	2	-0.177	0.036	23.713	60	100.0	-0.199	0.034
	Atbara	Oct	4	0.010	0.004	7.313	60	99.1	0.016	0.004
	Atbara	Mar	11	0.725	0.280	6.683	60	98.8	0.738	0.204
	Constant			-3.283	2.470	1.767	60	81.1	-6.859	2.532
March	Atbara	Jan	2	0.040	0.015	7.344	61	99.1	0.042	0.014
	Atbara	Nov	4	0.021	0.005	16.239	61	100.0	0.016	0.005
	Atbara	Sep	6	-0.001	0.000	12.677	61	99.9	-0.001	0.000
	Constant			0.999	1.150	0.754	61	61.1	0.220	1.304
April	Atbara	Apr	12	0.581	0.127	21.070	63	100.0	0.505	0.125
	Constant			2.148	2.025	1.126	63	70.7	2.715	2.372
May	Atbara	Apr	1	1.119	0.140	64.093	62	100.0	1.203	0.136
	Atbara	May	12	0.372	0.123	9.097	62	99.6	0.287	0.119
	Constant			1.989	2.424	0.673	62	58.5	2.332	2.803
June	Atbara	Jun	12	0.299	0.199	6.300	63	98.5	0.158	0.121
	Constant			68.843	21.698	10.066	63	99.8	67.490	16.992
July	Constant			1627.323	*	278.235	64	100.0	1656.237	109.672
August	Atbara	Jul	1	1.701	0.234	52.663	63	100.0	1.388	0.187
	Constant			2842.716	422.919	45.181	63	100.0	3345.475	359.204

Table 2.2b
Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Atbara

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
September	Atbara	Aug	1	0.466	0.062	56.604	62	100.0	0.373	0.047
	Atbara	Dec	9	7.421	2.679	7.671	62	99.3	4.826	1.716
	Constant			619.304	395.224	2.455	62	87.8	1293.848	321.783
October	Atbara	Sep	1	0.221	0.025	78.717	63	100.0	0.182	0.022
	Constant			41.038	99.004	0.172	63	32.0	204.453	90.107
November	Atbara	Oct	1	0.215	0.018	140.788	63	100.0	0.221	0.017
	Constant			10.144	17.380	0.341	63	43.8	-1.077	16.996
December	Atbara	Nov	1	0.312	0.030	109.200	60	100.0	0.329	0.030
	Atbara	Jul	5	0.009	0.004	5.375	60	97.6	0.011	0.003
	Atbara	Jan	11	0.214	0.106	4.072	60	95.2	0.221	0.092
	Atbara	Dec	12	0.187	0.074	6.435	60	98.6	0.227	0.068
	Constant			-28.504	8.310	11.765	60	99.9	-37.203	7.971

Table 2.2b (cont'd)
Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Atbara

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
January	Malakal	Dec	1	1.372	0.118	134.026	49	100.0	1.234	0.115
	Sennar	Dec	1	0.657	0.089	55.045	49	100.0	0.663	0.090
	Malakal	Nov	2	-0.760	0.209	13.280	49	99.9	-0.573	0.189
	Roseires	Nov	2	-0.171	0.059	8.515	49	99.5	-0.132	0.054
	Malakal	Sep	4	0.463	0.156	8.810	49	99.5	0.447	0.134
	Tamaniat	Aug	5	0.080	0.013	37.250	49	100.0	0.054	0.019
	Roseires	Aug	5	-0.075	0.011	50.025	49	100.0	-0.060	0.018
	Mongalla	Jul	6	-0.310	0.056	30.543	49	100.0	-0.260	0.052
	Tamaniat	Mar	10	-0.207	0.045	21.302	49	100.0	-0.200	0.046
	Khartoum	Mar	10	0.490	0.179	7.479	49	99.1	0.300	0.175
	Mongalla	Feb	11	0.290	0.060	23.377	49	100.0	0.210	0.066
	Constant			27.844	254.029	0.012	49	8.7	67.381	220.849
February	Malakal	Jan	1	0.614	0.038	262.424	59	100.0	0.671	0.038
	Constant			878.665	99.824	77.477	59	100.0	877.850	97.892
March	Tamaniat	Feb	1	0.673	0.058	134.899	56	100.0	0.645	0.065
	Roseires	Feb	1	0.330	0.155	4.566	56	96.3	0.397	0.331
	Tamaniat	Mar	12	0.670	0.067	99.728	56	100.0	0.639	0.062
	Malakal	Mar	12	-0.470	0.070	44.716	56	100.0	-0.434	0.064
	Constant			-221.884	150.965	2.160	56	85.3	-168.365	157.237
April	Tamaniat	Mar	1	0.814	0.079	105.464	52	100.0	0.842	0.062
	Roseires	Mar	1	0.588	0.197	8.852	52	996	0.519	0.235
	Tamaniat	Feb	2	-0.622	0.130	22.930	52	100.0	-0.535	0.103

Table 2.2c

Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Tamaniat

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
April (Contd)	Malakal	Jan	3	0.438	0.090	23.743	52	100.0	0.356	0.069
	Roseires	Jan	3	0.868	0.199	18.967	52	100.0	0.836	0.183
	Mongalla	Dec	4	0.125	0.050	6.128	52	98.3	0.127	0.040
	Tamaniat	Nov	5	-0.118	0.033	12.545	52	99.9	-0.128	0.026
	Tamaniat	Sep	6	-0.031	0.014	5.000	52	97.0	-0.016	0.011
	Constant			623.700	230.965	7.292	52	99.1	402.007	186.272
May	Tamaniat	Apr	1	0.584	0.102	32.974	55	100.0	0.603	0.079
	Malakal	Apr	1	1.235	0.144	73.511	55	100.0	1.164	0.105
	Roseires	Apr	1	1.446	0.313	21.413	55	100.0	0.946	0.255
	Tamaniat	Mar	2	-0.271	0.104	6.834	55	98.8	-0.208	0.079
	Roseires	Mar	2	-1.051	0.294	12.807	55	99.9	-0.649	0.312
	Constant			-293.890	176.268	2.780	55	89.9	-366.595	140.418
June	Tamaniat	May	1	-0.514	0.111	21.281	56	100.0	0.894	0.072
	Khartoum	May	1	-1.424	0.475	8.965	56	99.6	-1.283	0.309
	Sennar	May	1	1.446	0.306	22.384	56	100.0	1.231	0.230
	Tamaniat	Apr	2	-0.514	0.111	21.281	56	100.0	-0.316	0.073
	Constant			1699.484	178.462	90.687	56	100.0	1511.771	133.805
July	Roseires	Jun	1	1.883	0.290	42.144	58	100.0	1.263	0.197
	Sennar	Sep	10	0.114	0.054	4.505	58	96.2	0.028	0.029
	Constant			2156.098	818.511	6.939	58	98.9	4335.810	510.691
August	Sennar	Jul	1	1.274	0.168	57.735	58	100.0	1.121	0.113

Table 2.2c (cont'd)

Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Tamaniat

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
August (contd)	Sennar	Feb	6	-5.014	1.818	7.605	58	99.2	-1.841	0.999
	Constant			11147.903	1238.987	80.957	58	100.0	10898.557	796.936
September	Tamaniat	Aug	1	0.784	0.076	105.041	57	100.0	0.664	0.064
	Sennar	Dec	9	4.205	0.861	23.825	57	100.0	2.193	0.515
	Roseires	Nov	10	-1.477	0.530	7.763	57	99.3	-0.732	0.269
	Constant			2376.590	1619.305	2.154	57	85.2	4916.657	1282.797
October	Sennar	Sep	1	0.800	0.088	82.542	58	100.0	0.893	0.079
	Khartoum	Apr	6	-2.983	1.442	4.276	58	95.7	-1.213	0.592
	Constant			2184.817	1325.638	2.716	58	89.5	274.927	1053.779
November	Sennar	Oct	1	0.734	0.075	96.749	55	100.0	0.625	0.054
	Roseires	Oct	1	-0.329	0.078	17.700	55	100.0	-0.258	0.058
	Malakal	Sep	2	1.060	0.157	45.679	55	100.0	1.001	0.077
	Tamaniat	Mar	8	-0.430	0.123	12.190	55	99.9	-0.368	0.062
	Roseires	Feb	9	0.805	0.355	5.142	55	97.3	0.412	0.321
	Constant			248.905	468.889	0.282	55	40.2	707.979	291.801
December	Tamaniat	Nov	1	0.290	0.087	11.069	50	99.8	0.405	0.066
	Malakal	Nov	1	0.637	0.082	60.441	50	100.0	0.501	0.066
	Khartoum	Nov	1	-0.765	0.160	22.869	50	100.0	-0.875	0.120
	Sennar	Nov	1	0.435	0.135	10.399	50	99.8	0.512	0.100
	Roseires	Nov	1	0.634	0.118	29.037	50	100.0	0.555	0.087
	Malakal	May	7	-0.311	0.132	5.577	50	97.8	-0.140	0.107

Table 2.2c (cont'd)

Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Tamaniat

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
December (contd)	Tamaniat	Feb	10	-0.281	0.067	17.658	50	100.0	-0.303	0.052
	Roseires	Feb	10	-0.318	0.132	5.764	50	98.0	-0.361	0.316
	Tamaniat	Dec	12	0.581	0.072	64.827	50	100.0	0.474	0.056
	Roseires	Dec	12	-0.463	0.129	12.842	50	99.9	-0.271	0.115
	Constant			-721.990	201.806	12.800	50	99.9	-633.540	153.777

Table 2.2c (cont'd)
Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Tamaniat

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
January	Malakal	Dec	1	0.815	0.085	91.170	57	100.0	0.810	0.089
	Mongalla	Oct	3	0.059	0.017	11.897	57	99.9	0.180	0.054
	Roseires	Oct	3	0.168	0.048	12.482	57	99.9	0.049	0.018
	Constant			-1031.643	167.999	37.709	57	100.0	-977.268	173.341
February	Malakal	Jan	1	0.465	0.053	77.440	58	100.0	0.439	0.052
	Mongalla	Oct	4	0.219	0.037	34.839	58	100.0	0.255	0.040
	Constant			-77.772	77.257	1.013	58	68.2	-103.792	74.549
March	Malakal	Feb	1	0.979	0.097	102.142	57	100.0	0.984	0.099
	Malakal	Jan	2	-0.258	0.060	18.796	57	100.0	-0.261	0.057
	Mongalla	Oct	5	0.094	0.035	7.460	57	99.2	0.104	0.042
	Constant			284.682	57.476	24.533	57	100.0	259.626	58.720
April	Malakal	Mar	1	0.396	0.037	114.672	57	100.0	0.372	0.031
	Mongalla	Feb	2	0.069	0.025	7.915	57	99.3	0.104	0.026
	Malakal	Oct	6	0.168	0.037	21.007	57	100.0	0.127	0.029
	Constant			122.791	88.591	1.921	57	82.9	235.215	70.571
May	Malakal	Apr	1	0.575	0.074	59.927	58	100.0	0.629	0.049
	Mongalla	May	12	0.093	0.028	11.135	58	99.9	0.064	0.019
	Constant			558.534	69.215	65.118	58	100.0	550.129	48.598
June	Malakal	May	1	0.481	0.077	38.607	53	100.0	0.402	0.067
	Roseires	May	1	0.183	0.040	21.038	53	100.0	0.185	0.034
	Malakal	Feb	2	0.093	0.034	7.456	53	99.1	0.107	0.026

Table 2.2d
Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Malakal

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
June (contd)	Roseires	Oct	8	0.018	0.006	8.899	53	99.6	0.022	0.005
	Malakal	Sep	9	-0.128	0.051	6.407	53	98.6	-0.097	0.040
	Malakal	Jul	11	0.409	0.071	33.595	53	100.0	0.389	0.056
	Roseires	Jun	12	-0.087	0.024	12.786	53	99.9	-0.101	0.018
	Constant			344.228	122.932	7.841	53	99.3	395.520	93.498
July	Malakal	Jun	1	0.854	0.042	422.147	56	100.0	0.832	0.037
	Roseires	May	2	-0.059	0.025	5.477	56	97.7	-0.063	0.022
	Malakal	Oct	9	0.113	0.021	29.892	56	100.0	0.113	0.018
	Roseires	Jul	12	-0.012	0.004	8.199	56	99.4	-0.011	0.004
	Constant			510.338	51.984	96.379	56	100.0	546.762	45.428
August	Malakal	Jul	1	1.150	0.213	29.244	54	100.0	0.989	0.219
	Mongalla	Jul	1	0.112	0.031	12.721	54	99.9	0.100	0.031
	Malakal	Jun	2	-0.464	0.172	7.280	54	99.1	-0.279	0.173
	Malakal	Apr	4	0.360	0.089	16.358	54	100.0	0.373	0.093
	Roseires	Mar	5	-0.174	0.065	7.100	54	99.0	-0.087	0.046
	Mongalla	Mar	5	-0.096	0.047	4.182	54	95.4	-0.288	0.102
	Constant			362.770	205.575	3.114	54	91.7	427.931	210.971
September	Malakal	Aug	1	1.761	0.089	392.427	56	100.0	1.677	0.075
	Mongalla	Aug	1	0.095	0.019	26.168	56	100.0	0.101	0.017
	Malakal	Jul	2	-0.708	0.114	38.302	56	100.0	-0.692	0.095
	Mongalla	Mar	6	-0.095	0.029	10.938	56	99.8	-0.074	0.024

Table 2.2d (cont'd)
Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Malakal

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
September	Constant			-296.655	142.939	4.307	56	95.7	-154.923	117.537
October	Malakal	Sep	1	1.640	0.155	112.454	56	100.0	1.551	0.111
	Malakal	Aug	2	-0.807	0.185	19.044	56	100.0	-0.739	0.134
	Mongalla	Aug	2	0.089	0.027	10.734	56	99.8	0.085	0.022
	Roseires	Aug	2	-0.016	0.006	8.870	56	99.6	-0.003	0.005
	Constant			650.723	206.444	9.935	56	99.7	539.796	156.355
November	Malakal	Oct	1	0.499	0.091	30.083	55	100.0	0.824	0.143
	Malakal	Sep	2	0.578	0.126	21.049	55	100.0	0.168	0.180
	Roseires	Sep	2	0.039	0.006	44.365	55	100.0	0.026	0.006
	Mongalla	Apr	7	0.169	0.032	27.846	55	100.0	0.162	0.033
	Malakal	Mar	8	-0.213	0.047	20.624	55	100.0	-0.187	0.047
	Constant			-681.872	126.657	28.983	55	100.0	-380.022	127.697
December	Malakal	Nov	1	0.957	0.073	171.580	56	100.0	0.984	0.071
	Roseires	Nov	1	0.165	0.040	17.133	56	100.0	0.168	0.039
	Roseires	Sep	3	0.037	0.010	14.229	56	100.0	0.041	0.011
	Mongalla	Aug	4	0.088	0.038	5.419	56	97.6	0.047	0.041
	Constant			-1196.090	152.166	61.786	56	100.0	-1227.089	159.324

Table 2.2d (cont'd)

Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Malakal

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
January	Mongalla	Dec	1	0.589	0.045	170.320	66	100.0	0.685	0.049
	Mongalla	Oct	3	0.158	0.035	20.664	66	100.0	0.125	0.033
	Mongalla	Jul	6	0.185	0.045	16.741	66	100.0	0.130	0.040
	Constant			-165.771	49.181	11.361	66	99.9	-147.707	43.865
February	Mongalla	Jan	1	0.917	0.013	4753.672	68	100.0	0.881	0.010
	Constant			-101.910	34.421	8.766	68	99.6	-45.533	23.635
March	Mongalla	Feb	1	0.302	0.132	5.219	66	97.4	1.476	0.247
	Mongalla	Jan	2	0.784	0.137	32.979	66	100.0	-0.255	0.230
	Mongalla	Jul	8	-0.136	0.045	9.291	66	99.7	-0.097	0.040
	Constant			65.955	45.078	2.141	66	85.2	45.164	38.441
April	Mongalla	Mar	1	1.082	0.054	409.038	67	100.0	1.192	0.059
	Mongalla	Oct	6	-0.102	0.041	6.257	67	98.5	-0.159	0.042
	Constant			182.384	50.227	13.186	67	99.9	143.203	50.503
May	Mongalla	Apr	1	1.515	0.155	95.760	67	100.0	1.505	0.149
	Mongalla	Jan	4	-0.436	0.142	9.419	67	99.7	-0.422	0.140
	Constant			311.125	84.318	13.615	67	100.0	320.282	83.589
June	Mongalla	May	1	0.786	0.068	135.686	67	100.0	0.793	0.079
	Mongalla	Dec	6	0.157	0.063	6.275	67	98.5	0.148	0.080
	Constant			55.237	83.011	0.443	67	49.2	58.562	94.063
July	Mongalla	Jun	1	0.831	0.075	124.100	66	100.0	0.771	0.080
	Mongalla	Feb	5	-0.409	0.176	5.435	66	97.7	-0.386	0.287

Table 2.2e
Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Mongalla

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
July (contd)	Mongalla	Dec	7	0.500	0.148	11.445	66	99.9	0.540	0.230
	Constant			217.124	89.410	5.897	66	98.2	225.946	96.962
August	Mongalla	Jul	1	1.327	0.123	115.790	67	100.0	1.313	0.109
	Mongalla	May	3	-0.317	0.122	6.767	67	98.9	-0.341	0.106
	Constant			342.159	122.010	7.864	67	99.3	422.340	109.841
September	Mongalla	Aug	1	1.059	0.046	541.912	68	100.0	1.027	0.043
	Constant			-201.713	154.357	1.708	68	80.4	-130.044	139.379
October	Mongalla	Sep	1	0.929	0.045	435.776	67	100.0	0.977	0.045
	Mongalla	Oct	12	0.105	0.043	5.907	67	98.2	0.061	0.042
	Constant			-168.208	117.639	2.045	67	84.3	-122.296	116.513
November	Mongalla	Oct	1	0.649	0.053	148.115	67	100.0	0.667	0.044
	Mongalla	Mar	8	0.312	0.071	19.247	67	100.0	0.278	0.060
	Constant			119.834	113.764	1.110	67	70.4	93.860	99.404
December	Mongalla	Nov	1	0.758	0.044	295.871	67	100.0	0.773	0.030
	Mongalla	Jun	6	0.254	0.050	25.301	67	100.0	0.205	0.034
	Constant			-170.645	70.027	5.938	67	98.3	-109.021	49.561

Table 2.2e (cont'd)
Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Mongalla

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
January	Khartoum	Dec	1	0.518	0.040	165.737	55	100.0	0.484	0.029
	Roseires	Oct	3	-0.017	0.008	5.199	55	97.4	-0.004	0.005
	Sennar	Aug	5	0.018	0.006	9.909	55	99.7	0.010	0.004
	Sennar	Apr	9	-0.246	0.082	8.877	55	99.6	-0.103	0.055
	Roseires	Feb	11	0.258	0.064	16.405	55	100.0	0.034	0.103
	Constant			-132.643	87.061	2.321	55	86.7	1.494	73.606
February	Sennar	Jan	1	0.441	0.076	33.362	54	100.0	0.300	0.067
	Khartoum	Dec	2	0.279	0.080	12.097	54	99.9	0.214	0.056
	Sennar	Dec	2	-0.323	0.086	14.049	54	100.0	-0.157	0.066
	Roseires	Oct	4	0.011	0.005	4.827	54	96.8	0.004	0.003
	Sennar	Aug	6	0.025	0.005	27.456	54	100.0	0.021	0.007
	Roseires	Aug	6	-0.014	0.003	17.721	54	100.0	-0.011	0.006
	Constant			-57.130	52.175	1.199	54	72.2	-26.478	39.016
March	Khartoum	Feb	1	0.959	0.127	57.475	55	100.0	0.856	0.164
	Khartoum	Jan	2	-0.238	0.082	8.314	55	99.4	-0.159	0.077
	Khartoum	Oct	5	0.021	0.006	10.857	55	99.8	0.011	0.006
	Sennar	Sept	6	-0.020	0.007	8.574	55	99.5	-0.003	0.006
	Sennar	Jul	8	0.018	0.008	4.814	55	96.8	0.004	0.006
	Constant			120.506	56.067	4.620	55	96.4	67.116	55.059
April	Khartoum	Mar	1	0.753	0.144	27.207	56	100.0	0.895	0.105
	Roseires	Mar	1	0.234	0.094	6.257	56	98.5	0.164	0.094

Table 2.2f
Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Khartoum

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
April (contd)	Sennar	Feb	2	-0.461	0.139	10.977	56	99.8	-0.442	0.095
	Roseires	Jan	3	0.225	0.084	7.154	56	99.0	0.119	0.058
	Constant			-23.559	53.296	0.195	56	34.0	25.682	38.140
May	Sennar	Apr	1	0.855	0.157	29.777	58	100.0	0.597	0.089
	Roseires	Mar	2	-0.272	0.112	5.907	58	98.2	-0.171	0.096
	Constant			288.311	56.640	25.911	58	100.0	340.202	40.852
June	Sennar	May	1	1.055	0.153	47.284	59	100.0	0.783	0.134
	Constant			553.047	98.782	31.345	59	100.0	721.025	95.158
July	Khartoum	Jun	1	2.122	0.363	34.191	59	100.0	1.269	0.227
	Constant			2923.787	453.201	41.621	59	100.0	3998.384	328.107
August	Sennar	Jul	1	1.533	0.154	99.150	57	100.0	1.278	0.122
	Sennar	Jun	1	-1.421	0.451	9.940	57	99.7	-0.832	0.252
	Roseires	Aug	12	-0.183	0.060	9.329	57	99.7	-0.085	0.047
	Constant			11292.589	1107.451	103.977	57	100.0	10622.106	1013.346
September	Khartoum	Aug	1	0.571	0.121	22.168	56	100.0	0.419	0.101
	Roseires	Aug	1	0.253	0.094	7.186	56	99.0	0.189	0.104
	Roseires	Apr	5	-4.496	1.327	11.490	56	99.9	-1.405	0.674
	Khartoum	Dec	9	2.237	0.519	18.563	56	100.0	0.779	0.327
	Constant			87.506	1582.551	0.003	56	4.4	4442.117	1117.669
October	Sennar	Sep	1	0.753	0.086	76.189	59	100.0	0.786	0.070
	Constant			-1623.928	1098.143	2.187	59	85.5	-2042.153	935.131

Table 2.2f (cont'd)

Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Khartoum

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
November	Sennar	Oct	1	0.516	0.060	73.576	58	100.0	0.449	0.039
	Roseires	Oct	1	-0.186	0.066	7.858	58	99.3	-0.137	0.044
	Constant			426.780	192.618	4.909	58	96.9	513.356	172.258
December	Sennar	Nov	1	0.364	0.030	146.432	57	100.0	0.423	0.024
	Sennar	Sep	2	0.027	0.011	6.180	57	98.4	0.011	0.008
	Khartoum	Dec	12	0.121	0.053	5.153	57	97.3	0.082	0.034
	Constant			-24.759	112.731	0.048	57	17.3	92.656	102.461

Table 2.2f (cont'd)

Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Khartoum

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
January	Sennar	Dec	1	0.551	0.030	328.874	58	100.0	0.529	0.024
	Roseires	Feb	11	0.350	0.059	34.973	58	100.0	0.098	0.110
	Constant			-175.645	58.576	8.992	58	99.6	-29.981	63.854
February	Sennar	Jan	1	0.411	0.048	72.928	56	100.0	0.383	0.032
	Sennar	Aug	6	0.028	0.006	21.705	56	100.0	0.020	0.008
	Roseires	Aug	6	-0.013	0.004	8.419	56	99.5	-0.005	0.007
	Roseires	Feb	12	0.116	0.053	4.872	56	96.9	0.007	0.062
	Constant			-129.969	69.278	3.520	56	93.4	-66.228	54.444
March	Sennar	Feb	1	1.268	0.178	50.645	55	100.0	0.903	0.139
	Roseires	Feb	1	-0.437	0.119	13.563	55	99.9	-0.417	0.148
	Sennar	Oct	5	-0.073	0.022	11.262	55	99.9	-0.031	0.016
	Roseires	Oct	5	0.096	0.020	23.039	55	100.0	0.050	0.016
	Sennar	Sep	6	-0.022	0.007	9.968	55	99.7	-0.002	0.007
	Constant			166.240	70.846	5.506	55	97.7	91.951	63.111
April	Sennar	Mar	1	0.637	0.095	45.000	58	100.0	0.630	0.073
	Roseires	Jul	9	0.025	0.010	6.510	58	98.7	0.012	0.006
	Constant			-43.467	63.456	0.469	58	50.4	47.988	42.426
May	Sennar	Apr	1	1.665	0.343	23.517	58	100.0	0.823	0.177
	Roseires	Apr	1	-0.979	0.306	10.255	58	99.8	-0.425	0.167
	Constant			306.574	80.066	14.661	58	100.0	437.833	53.364
June	Sennar	May	1	1.262	0.178	50.014	59	100.0	0.877	0.160

Table 2.2g

Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Sennar

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
June	Constant			683.296	114.882	35.376	59	100.0	917.629	113.564
July	Roseires	Jun	1	1.896	0.336	31.794	59	100.0	1.137	0.221
	Constant			2895.110	578.267	25.065	59	100.0	4247.254	407.480
August	Sennar	Jul	1	1.461	0.163	80.402	57	100.0	1.152	0.118
	Roseires	Jun	2	-1.461	0.515	8.041	57	99.4	-0.600	0.285
	Roseires	Aug	12	-0.215	0.060	13.023	57	99.9	-0.040	0.046
	Constant			12096.317	1140.771	112.437	57	100.0	9867.280	959.867
September	Roseires	Aug	1	0.351	0.075	22.021	56	100.0	0.322	0.064
	Sennar	Jul	2	0.585	0.169	11.955	56	99.9	0.301	0.081
	Sennar	Apr	5	-3.519	1.457	5.830	56	98.1	-1.308	0.613
	Sennar	Dec	9	2.023	0.547	13.707	56	100.0	0.840	0.273
	Constant			2508.847	1243.511	4.071	56	95.2	5455.730	947.347
October	Sennar	Sep	1	0.651	0.080	65.858	59	100.0	0.648	0.066
	Constant			-1586.124	1020.887	2.414	59	97.4	-1505.889	888.085
November	Sennar	Oct	1	0.592	0.056	104.486	58	100.0	0.526	0.034
	Roseires	Oct	1	-0.277	0.062	20.119	58	100.0	-0.245	0.039
	Constant			402.900	179.209	5.054	58	97.2	464.171	158.574
December	Sennar	Nov	1	0.370	0.025	217.420	57	100.0	0.405	0.019
	Roseires	Sep	3	0.034	0.009	13.916	57	100.0	0.021	0.006
	Roseires	May	7	0.131	0.065	4.020	57	95.0	0.055	0.037
	Constant			-145.668	101.698	2.052	57	84.2	3.229	83.675

Table 2.2g (cont'd)
Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Sennar

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
January	Roseires	Dec	1	0.503	0.031	255.203	58	100.0	0.477	0.026
	Roseires	Feb	11	0.620	0.530	136.319	58	100.0	0.202	0.107
	Constant			-188.823	54.858	11.848	58	99.9	38.232	62.173
February	Roseires	Jan	1	0.453	0.066	46.752	55	100.0	0.369	0.054
	Roseires	Oct	4	0.019	0.006	8.402	55	99.5	0.009	0.005
	Roseires	Aug	6	-0.008	0.004	4.294	55	95.7	0.006	0.004
	Roseires	Mar	11	0.249	0.087	8.238	55	99.4	-0.039	0.079
	Roseires	Feb	12	0.243	0.093	6.830	55	98.8	0.177	0.104
	Constant			-109.608	74.897	2.142	55	85.1	-52.558	68.753
March	Roseires	Feb	1	0.836	0.081	105.469	59	100.0	0.771	0.123
	Constant			-8.467	48.069	0.031	59	13.9	19.045	60.873
April	Roseires	Mar	1	0.571	0.065	76.694	58	100.0	0.550	0.074
	Roseires	Oct	6	0.019	0.007	7.881	58	99.5	0.009	0.004
	Constant			-11.563	49.710	0.054	58	18.3	67.056	35.176
May	Constant			606.938	*	193.114	60	100.0	620.800	47.570
June	Roseires	May	1	0.897	0.168	28.375	59	100.0	0.529	0.141
	Constant			1090.548	116.973	86.919	59	100.0	1315.851	107.096
July	Roseires	Jun	1	1.908	0.329	33.543	59	100.0	1.180	0.215
	Constant			3438.942	566.341	36.872	59	100.0	4682.497	399.717
August	Roseires	Jul	1	1.053	0.219	23.133	58	100.0	0.971	0.142
	Roseires	Mar	5	-6.998	1.499	21.788	58	100.0	-0.248	1.192

Table 2.2h

Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Roseires

Model of	Variable		Lag	OLS Estimated Coefficient	OLS Standard Error	Partial F Statistic	Degree of Freedom	Significance Level	GLS Estimated Coefficient	GLS Standard Error
August	Constant			11265.273	1644.560	46.923	58	100.0	9277.227	1084.062
September	Roseires	Aug	1	0.404	0.078	26.802	58	100.0	0.419	0.076
	Roseires	Jul	2	0.489	0.175	7.852	58	99.3	0.200	0.109
	Constant			3278.444	1204.629	7.407	58	99.1	5105.776	979.033
October	Roseires	Sep	1	0.492	0.086	32.467	59	100.0	0.535	0.064
	Constant			682.742	1112.915	0.376	59	45.8	107.520	870.687
November	Roseires	Oct	1	0.265	0.022	148.238	59	100.0	0.252	0.019
	Constant			868.305	158.045	30.185	59	100.0	959.844	144.540
December	Roseires	Nov	1	0.405	0.042	91.300	57	100.0	0.462	0.035
	Roseires	May	7	0.204	0.092	4.850	57	96.8	0.127	0.060
	Roseires	Dec	12	0.244	0.079	9.665	57	99.7	0.181	0.051
	Constant			-102.854	181.919	0.320	57	42.6	-133.121	126.329

Table 2.2h (cont'd)

Estimation Statistical Information and GLS Estimated Coefficients for Lead-1 Forecasts for Roseires

$$\frac{1}{53}\sum_{k=2}^{54}\hat{Y}_j(k,\ i) = \frac{1}{53}\sum_{k=2}^{54} Y_j(k,\ i) = \overline{Y}_j(i) \qquad i = 1,\ 2,\ \ldots,\ 12$$

$$j = 1,\ 2,\ \ldots,\ 8 \qquad (2.5)$$

and

$$0 \leq \frac{\frac{1}{52}\sum_{k=2}^{54}(Y_j(k,\ i) - \hat{Y}_j(k,\ i))^2}{\frac{1}{52}\sum_{k=2}^{54}(Y_j(k,\ i) - \overline{Y}_j(i))^2} = 1 - R_j^2(i) \leq 1 \qquad i = 1,\ 2,\ \ldots,\ 12$$

$$j = 1,\ 2,\ \ldots,\ 8 \qquad (2.6)$$

where

$\hat{Y}_j(k,\ i)$ = forecast for station j, year k, month i

$Y_j(k,\ i)$ = true observation for station j, year k, month i

$\overline{Y}_j(i)$ = sample mean for station j, month i

$R_j^2(i)$ = variance reduction factor for station j, month i, known also as the R-square statistic of a regression

In words, Equation (2.5) says that the mean forecast for a given month i and station j is equal to the mean historical observation over the years 1913-1965. The year 1912 cannot be forecasted without data from 1911, so the first forecast is for January of 1913, using observations of 1912. Equation (2.5) is a direct result of the zero-mean assumption placed on the residuals in Equation (2.3), and holds for all twelve months at all eight stations.

Equation (2.6) yields R square statistics, which represent the reduction of variance (relative to the historical variance) achieved by the forecasting equation. R^2 is always less than unity and non-negative, implying that the Mean Square Error (MSE) of a forecast is less than the historical sample variance. If the GLS estimation does not detect any information useful for predicting the flow of station j and month i, the elements of the Π-matrix for month i corresponding to the prediction of station j will all be zero. The deterministic term U(i) in the U-vector will simultaneously take on a value equal to the monthly mean. In this case, the forecast will always be the monthly mean, and MSE(i, j), where i indicates the month and j indicates the station, will simply be the historical variance. This is the worst that the GLS estimation will do. In general, one or more elements of the Π-matrix take on non-zero values, and the resulting mean square error of the true observation about the forecast will be less than the sample variance about the sample mean.

Our ultimate forecasting goal is to generate multi-lead forecasts, and these are easily obtainable from the recursive application of Equation (2.4). For example, a lead two forecast for month i (from the end of month i-2) utilizes the lead-one forecasting equation for month i, replacing lag-one explanatory variables (which have not been observed at the time of the lead-two forecast) with the lead-one predictions generated from the end of month i-2. Using both the lead-one and lead-two predictions, as well as all observations prior to and including month i-2, lead-three forecasts can be generated and so forth. Further details of this procedure can be found in Curry and Bras (1980).

As with lead-one forecasts, R^2 statistics can be calculated for higher lead forecasts using a ratio similar to that found in Equation (2.6). Equation (2.6) is thus revised to

$$0 \leq R_j^2(\ell, i) \leq 1 \qquad (2.7)$$

where ℓ is the lead of the forecast ($\ell = 1, 2, \ldots, 12$), and i denotes the particular month being forecasted.

It is important to emphasize that the nature of the forecasting model is such that essentially there will be a different equation (different coefficients) for each month's forecast of Wadi Halfa (as well as all other stations). As an example, a substantial variation can be seen in the explanatory variables used for one month lead forecasts for the months of January, August and December (Table 2.2a). Considerable variation can also be seen in the accuracy of forecasts for any given lead, as indicated by the R^2 statistics of Table 2.3. For example, the dry month of April at Wadi Halfa can be forecasted in March (lead 1) with a variance reduction of 96%, while the twelve month lead forecast at Wadi Halfa has a variance reduction of 58%. On the other hand, the flood month of August at Wadi Halfa is forecasted with a 75% variance reduction at lead 1, but only a 1% variance reduction with a six-month lead and 17% with a twelve month lead.

The data given in Tables 2.2a-h and Table 2.3 will be used later in this study.

2.5 Upper Nile Development Projects

At the present time, the water available from the Nile in excess of the irrigation demands of Egypt is minimal. With the population on the rise, the need for more water is inevitable, hence Egyptian authorities have been researching possibilities for increasing the yield

Lead	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.9864	0.9569	0.9281	0.9589	0.9822	0.9255	0.8358	0.7502	0.7180	0.7724	0.8918	0.9282
2	0.9507	0.9089	0.7298	0.8299	0.9238	0.6928	0.4002	0.1037	0.4571	0.4262	0.4285	0.8707
3	0.8992	0.8891	0.6603	0.8166	0.9013	0.5959	0.2291	0.0279	0.0533	0.3944	0.2111	0.6297
4	0.8174	0.8637	0.6679	0.8289	0.8649	0.6018	0.2045	0.0132	0.0451	0.1818	0.1881	0.4598
5	0.6503	0.7822	0.6191	0.8162	0.8284	0.5423	0.2132	0.0140	0.0466	0.1345	0.0826	0.3796
6	0.5565	0.6277	0.6113	0.7985	0.7989	0.5154	0.2202	0.0146	0.0466	0.1343	0.0426	0.2725
7	0.4489	0.5273	0.4940	0.7609	0.7962	0.4942	0.1986	0.0214	0.0466	0.0541	0.0465	0.2191
8	0.3617	0.4194	0.4218	0.6992	0.7261	0.4791	0.1872	0.0107	0.0326	0.0475	0.0353	0.2049
9	0.3355	0.3379	0.3595	0.7034	0.6512	0.4440	0.1678	0.1827	0.0080	0.0471	0.0298	0.2139
10	0.3118	0.3137	0.2344	0.6788	0.6207	0.4066	0.1822	0.1759	0.0916	0.0349	0.0301	0.1997
11	0.3035	0.2628	0.1861	0.6281	0.5835	0.3774	0.1734	0.1677	0.0897	0.1027	0.0130	0.1913
12	0.2779	0.2684	0.1481	0.5849	0.5394	0.3631	0.1792	0.1651	0.0875	0.0989	0.0915	0.1700

Table 2.3

R^2 Statistics for Multi-Lead Forecasts at Wadi Halfa of the Nile. From these studies, three projects in particular have been scheduled to be implemented in the near future. These projects deserve some attention, as future studies on High Aswan Dam operation will necessarily include them.

2.5.1 Jonglei Canal

The Sudd region on the White Nile branch is one of the largest sources of water losses in the Nile basin. In this region, the river is known as the Bahr el Gebel. As the Bahr el Gebel, the river exits the Sudd with only half of the water that once entered, due to evaporation and evapotranspiration.

Currently proposed for the Sudd is a two-phase development project. The first phase calls for the construction of a canal from Jonglei, near the entrance of the Sudd, to the mouth of River Sobat. Known as the Jonglei Canal, this project will divert water around the Sudd, and waters previously retained and lost in the swamps will bypass the area. The second phase involves the widening of the canal and the construction of Lake Albert reservoir for storage.

The implementation of these two phases is expected to increase the flow of the Nile at Aswan by approximately 7 md m^3 per year.

2.5.2 Bahr el Ghazal Development

A second source of large water losses in the Nile basin is the Bahr el Ghazal region. Like the Sudd, this region loses excessive amounts of water to evaporation and evapotranspiration in swamps.

The tributaries in the Bahr el Ghazal basin drain either into the swamps of the Bahr el Ghazal or into the swamps of the Bahr el Gebel.

Proposed for this basin is the construction of two canals. One canal will divert the tributarial waters draining into the Bahr el Ghazal around the swamps and directly to the White Nile. The second canal will divert the tributarial waters draining into the Bahr el Gebel around its swamps to a point in the Bahr el Gebel farther downstream.

The two canals, combined, are expected to increase the flow of the Nile at Aswan by an average amount of 7 md m^3 per year.

2.5.3 River Sobat and the Machar Marshes

A third source of major water losses is the Sobat basin. Within this basin the ultimate source of the water losses are the Machar Marshes. As previously mentioned, when flows in River Baro are particularly high, water literally spills over the riverbanks and through various khors to the Machar Marshes. Once in this swampy region, water is evaporated and evapotranspirated at a high rate.

To minimize these losses, spillage to the Machar Marshes must be circumvented. Proposed for this basin are three developments. The first involves the closing of the intakes of the khors leading to the swamps, making all the necessary embankments to stop spillage. To aid this effort, a second development is the construction of a storage reservoir upstream in the vicinity of Gambeila. The purpose of this reservoir will be to retain the floods of the Baro, and then release these waters in drier months. Finally, a canal is proposed to cut through the Machar Marshes, diverting waters to Khor Adar, which eventually leads to the White Nile.

With the completion of this entire proposal, it is expected that Nile flows at Aswan will be increased by an average amount of 4 md m^3 per year.

2.6 Previous Studies on High Aswan Dam Operation

Previous studies have been performed on the High Aswan Dam attempting to develop operating rules for the multi-purpose project. Several of these studies are mentioned here, as they essentially illustrate the evolution of approaches used to cope with this problem.

In 1966, Thomas and Revelle presented a linear programming approach for examining the "complementarity" of agriculture and energy production with respect to releases at the High Aswan Dam. Their efforts were directed toward identifying a monthly pattern of releases that would maximize the net benefits from irrigation and firm power for a given total annual water availability. This approach is similar to the classic inventory problem in operations research literature, with the costs due to holding water from period 'i' to period 'i+1' being water losses from evaporation and seepage, and all other costs are considered insignificant.

An updated version of Thomas and Revelle's work was presented by Guariso, et al. (1979). Data unavailable to Thomas and Revelle was utilized, including information on irrigation demands, water supply and the value of water in Egyptian agriculture. A further revision placed a constraint on reservoir releases as a measure for avoiding downstream degradation. However, neither work accounts for the stochasticity of Lake Nasser inflows, nor do they attempt to provide information on how to operate the reservoir in cases of surplus or deficit storage.

El Assiouti, et al. (1979) and Alarcon and Marks (1979) performed separate studies in conjunction with Cairo University using stochastic dynamic programing techniques. In both works, inflows are treated as a random variable, characterized by a periodically stationary process. Reservoir release policies were then developed based upon two state variables; the current storage and the inflow of the month to come. The major difference between the two studies are the reservoir zones subjected to analysis. El Assiouti, et al., consider the entire live storage volume, whereas Alarcon and Marks only consider Zones D and E (see Figure 2.3).

The promising results generated from these stochastic methods motivated the work of Curry and Bras (1980), where a methodology was introduced capable of handling a non-stationary system. A major implication of this work is the ability of incorporating forecasted information into the solution procedure. Their development of monthly forecasting equations for the Nile basin and corresponding methodology for the solution of the operation problem in a non-stationary environment form the basis of this study.

Chapter 3

TWO STEADY-STATE STOCHASTIC DYNAMIC PROGRAMMING ALGORITHMS

3.1 Introduction

The ultimate aim of this study is to evaluate different reservoir release policies for the High Aswan Dam - Lake Nasser system. Though release policies can be based upon a wide variety of approaches, this study specifically investigates the performance of control policies derived from mathematical optimization techniques.

In this chapter, two stochastic dynamic programming algorithms are presented, both providing 'optimal' steady-state reservoir release policies given a stationary system. In accordance with the nature of dynamic programs, the decision variable (release) will depend upon the 'state' of the system, which is defined by two variables: the reservoir storage at the beginning of the time period and the reservoir inflow of either the previous or the current month (chosen by the user).

Providing the foundation of the solution procedure for both algorithms is the stochastic characterization of reservoir inflows as a periodically stationary, first order Markov chain, where the periodicity is due to the annual streamflow cycle. Discretizing time into monthly time steps, transition probabilities are calculated for 'representative' discrete inflow values of consecutive months. Storage, the other state variable, is also discretized into 'representative' values.

The overall objective of High Dam releases, as defined by this study, is to minimize expected present and future costs resulting from insufficient and excessive releases and from monthly power generation deficits. Upon quantifying these objectives with an objective function (see Section 3.5), the optimal release policy will be that which minimizes the expected total costs of operating the system over an infinite time horizon, with or without discounting future costs.

As a final introductory remark, it will be noticed that the distinguishing feature between the two algorithms to be presented lies in the definition of the state variable 'inflow.' Algorithm 1 considers the previous month's inflow as a state variable, while Algorithm 2 defines the current month's inflow to be a state variable. The implications of each definition will be discussed after the presentation of both algorithms.

3.2 Algorithm 1

Using notation similar to Alarcon and Marks (1979), consider the following time index definitions:

T = number of time periods per cycle

t = number of time periods remaining in a cycle ($t = 1, 2, \ldots, T$)

m = integer number of full cycles remaining until the end of the planning horizon

n = number of time periods remaining until the end of the planning horizon

The relationship between these indices is illustrated in Figure 3.1. For this study, one cycle pertains to a year, and each time period

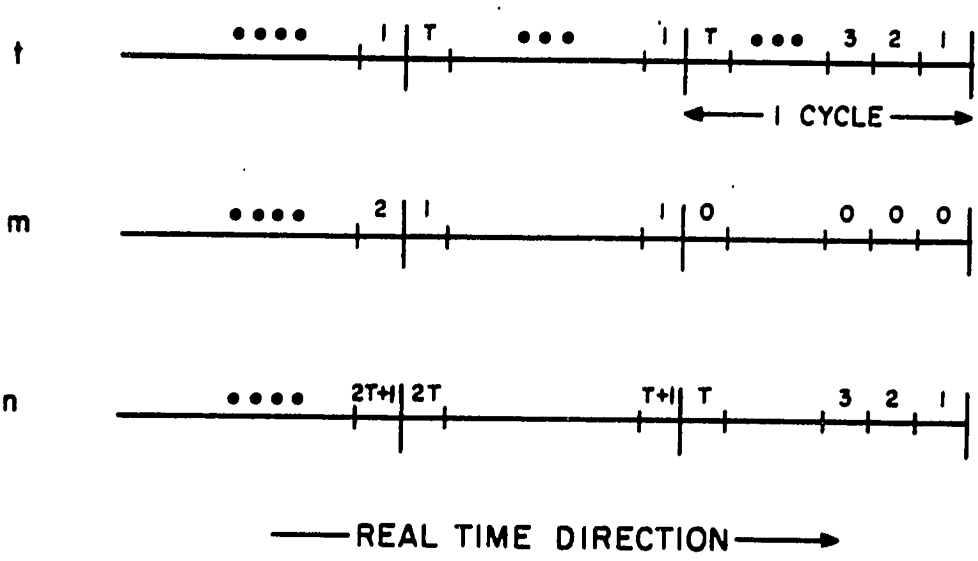


Figure 3.1

Relationship Between Time Indices

corresponds to one month (i.e., T = 12; t = 1 for December, t = 12 for January). It can be noticed from Figure 3.1 that the relationship n = mT + t holds. This implies that for a given value of T, the value of n uniquely determines the value of t (for example, with T = 12, then for m = 0, 1, 2, ..., t = 1 when n = 1, 13, 25, ..., t = 2 when n = 2, 14, 26, ..., etc.)

Implementing this relationship, the <u>state variables</u> of Algorithm 1 for month t are defined as:

S_i^t = storage at the beginning of month t, equal to the i^{th} discrete value

Q_j^{n+1} = inflow during time period n + 1, equal to the j^{th} discrete value

with inflow transition probabilities defined to be

P_{jk}^n = probability of occurrence of inflow k during time period n given that in period n+1 inflow j was realized

The definition of $Q_j^.$ and $P_{jk}^.$ as a function of the cycle m (n = mT + t) implies that the stochastic description of the inflow process for each month can vary from year to year. However, the algorithms presented in this chapter are designed to handle periodic stationary systems only. Thus, the following conditions are assumed to hold:

$$E[Q_j^{mT+t}] = E[Q_j^t] \qquad \forall j, \text{ m and t} \tag{3.1}$$

$$P_{jk}^{mT+t} = P_{jk}^t \qquad \forall j, \text{ k, m and t} \tag{3.2}$$

These two conditions indicate that the stochastic description of inflow is reduced to be only a function of the month t, and not on the particular cycle m, giving a periodically stationary random process as required.

Using Conditions (3.1) and (3.2), the remaining definitions are given as:

$R^n(S_i^t, Q_j^{t+1})$ = optimal release decision for month t, when the storage state is S_i^t, the inflow state is Q_j^{t+1} and n (=mT + t) periods remain until the end of the planning horizon

$L_t(S_i^t, Q_k^t, R)$ = losses from reservoir (evaporation, spills to Toshka) during month t, when the initial storage is S_i^t, the inflow during the month is Q_k^t and the release is R

$g_n(S_i^t, Q_k^t, R)$ = costs incurred during time period n (=mT + t), when the initial storage is S_i^t, the inflow during the month is Q_k^t and the release is R (described further in Section 3.5)

r = monthly rate of discount (r = 0 for the undiscounted case)

$\beta = \frac{1}{1+r}$

S_{max} = maximum reservoir storage

S_{min} = minimum reservoir storage

$f^n(S_i^t, Q_j^{t+1})$ = minimum expected cost from the present period to the end of the planning horizon (mT + t periods to go), provided that in month t the system is in states (S_i^t, Q_j^{t+1})

Figure 3.2 illustrates the relationship between the variables $S_\cdot^\cdot$, $Q_\cdot^\cdot$, $P_\cdot^\cdot$, $L_\cdot^\cdot$ and the release R, with the state variables for month t encircled.

For the given definition of g.(•), the system will be stationary (in a periodic manner) if the following condition holds:

$$g_{mT+t}(S_i^t, Q_k^t, R) = g_t(S_i^t, Q_k^t, R) \qquad \forall m, t, i \text{ and } k \tag{3.3}$$

Assuming Conditions (3.1), (3.2) and (3.3) hold, an optimal steady-state release policy can now be derived from the solution procedure to follow.

Applying the conservation of mass equation

$$S_\ell^{t-1} = S_i^t + Q_k^t - R - L(S_i^t, Q_k^t, R) \tag{3.4}$$

Algorithm 1 uses a backward induction solution scheme, computing $f^n(\cdot)$ for $n \geq 1$ from the recursive relation

$$f^n(S_i^t, Q_j^{t+1}) = \operatorname*{Min}_R \left[\sum_k P_{jk}^t \cdot \{ g_t(S_i^t, Q_k^t, R) + \beta \cdot f^{n-1}(S_\ell^{t-1}, Q_k^t) \} \right]$$

$$\begin{aligned} t &= 1, \ldots, 12 \\ t+1 &= 1 \quad \text{if } t = 12 \\ t-1 &= 12 \quad \text{if } t = 1 \end{aligned} \tag{3.5}$$

where

$$R = S_i^t - S_\ell^{t-1} + Q_k^t - L(S_i^t, Q_k^t, R) \qquad \text{if } S_{min} \leq S_\ell^{t-1} \leq S_{max} \tag{3.6a}$$

$$\left.\begin{aligned} S_\ell^{t-1} &= S_{max} \\ R &= S_i^t + Q_k^t - S_{max} - L(S_i^t, Q_k^t, R) \end{aligned}\right\} \quad \text{if } S_\ell^{t-1} > S_{max} \tag{3.6b}$$

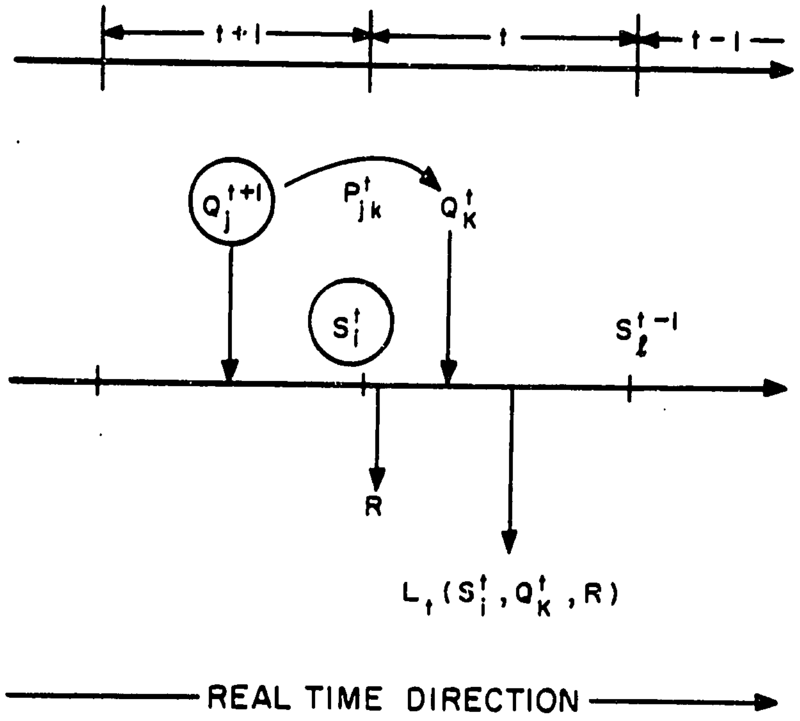


Figure 3.2

Relationship Between State Variables (Encircled)

and Decision Variable for Steady-State Algorithm 1

$$\left.\begin{aligned} S_\ell^{t-1} &= S_{min} \\ R &= S_i^t + Q_k^t - S_{min} - L(S_i^t,\ Q_k^t,\ R) \end{aligned}\right\} \quad \text{if } S_\ell^{t-1} < S_{min} \quad (3.6c)$$

Constraints are imposed on releases such that feasible storage volumes always result.

Su and Deininger (1972) show that arbitrary values can be assigned to the boundary conditions $f^o(\cdot)$, and are here taken as

$$f^o(S_i^t,\ Q_j^{t+1}) = 0 \qquad \forall i,\ j \qquad (3.7)$$

Using Condition (3.7), for n = 1 (it can be assumed that t = 1 with no loss of generality), Equation (3.5) yields

$$f^1(S_i^1,\ Q_j^2) = \underset{R}{\text{Min}}\left[\sum_k P_{jk}^1 \cdot \{g_1(S_i^1,\ Q_k^1,\ R)\}\right] \qquad \forall i,\ j \quad (3.8)$$

For one step backward in time (n = 2), the recursion gives

$$f^2(S_i^2,\ Q_j^3) = \underset{R}{\text{Min}}\left[\sum_k P_{jk}^2 \cdot \{g_2(S_i^2,\ Q_k^2,\ R) \ + \beta \cdot f^1(S_\ell^1,\ Q_k^2)\}\right] \quad \forall i,\ j \qquad (3.9)$$

In a similar manner, $f^3(\cdot)$ is computed from $f^2(\cdot)$, and so on. Su and Deininger (1972) indicate how the recursive computations using Equation (3.5) converge upon an optimal reservoir release policy for both the undiscounted and discounted case. In particular, assuming that Conditions (3.1), (3.2) and (3.3) hold, two important results proved by Su and Deininger are:

1) In the undiscounted case, for arbitrary values of $f^o(\cdot)$,

$$\lim_{m\to\infty} f^{(m+1)T+t}(S_i^t, Q_j^{t+1}) - f^{mT+t}(S_i^t, Q_j^{t+1}) = c \qquad \forall i, j, t \qquad (3.10)$$

where c is the minimum expected annual cost of operating the system over an infinite time horizon.

2) In the discounted case, for arbitrary values of $f^o(\cdot)$,

$$\lim_{m\to\infty} f^{mT+t}(S_i^t, Q_j^{t+1}) = f^{t^*}(S_i^t, Q_j^{t+1}) \qquad \forall i, j, t \qquad (3.11)$$

where $f^{t^*}(S_i^t, Q_j^{t+1})$ is interpreted as the unique minimum expected cost of operating the system over an infinite time horizon, starting in state (S_i^t, Q_j^{t+1}) for time period t.

For the undiscounted case, Su and Deininger (1972) show that upper and lower bounds on c monotonically converge. When the bounds on c are sufficiently tight (as defined by the user), the final cycle (m') of computer releases $R^{m'T+t}(S_i^t, Q_j^{t+1})$ is the optimal reservoir control policy.

For the discounted case, upper and lower bounds monotonically converge to $f^{t^*}(S_i^t, Q_j^{t+1})$ for all i, j and t (Su and Deininger, 1972), but convergence criteria must be applied separately to each state (S_i^t, Q_j^{t+1}). Thus, when bounds are sufficiently tight for each state, the control policy will again be the last cycle of optimal releases $R^{m'T+t}(\cdot,\cdot)$. Further details on the convergence process for both the undiscounted and discounted case can be found in Section 5.3 with a complete explanation given in Su and Deininger (1972).

Finally, the closed-loop control approach suggested by Algorithm 1 is schematically outlined in Figure 3.3.

3.3 Algorithm 2

The second algorithm is similar to those utilized by Alarcon and Marks (1979) and El Assiouti, et al. (1979). As stated earlier, the essential difference from Algorithm 1 is the definition of the state variable inflow. Due to the otherwise similar definitions and equations to Algorithm 1, only the revisions are presented here. Concluding this section is a brief discussion on some operational considerations associated with each algorithm.

Assuming that Conditions (3.1) and (3.2) hold, the following revised definitions can be given as:

Q_j^t = inflow state variable for time period t, equal to the j^{th} discrete value of the inflow occurring <u>during month t</u>

P_{jk}^t = probability of occurrence of inflow k during time period t-1 given that in time period t inflow j occurs

The optimal release decision for month t with n (=mT + t) periods left in the planning horizon, previously defined as $R^n(S_i^t, Q_j^{t+1})$, becomes $R^n(S_i^t, Q_j^t)$. The minimum expected cost associated with this decision is now $f^n(S_i^t, Q_j^t)$. The new relationship between the state and decision variables is illustrated in Figure 3.4, with the state variables for month t encircled. As can be seen from the figure, the release decision must be made assuming that the inflow for time period t is known.

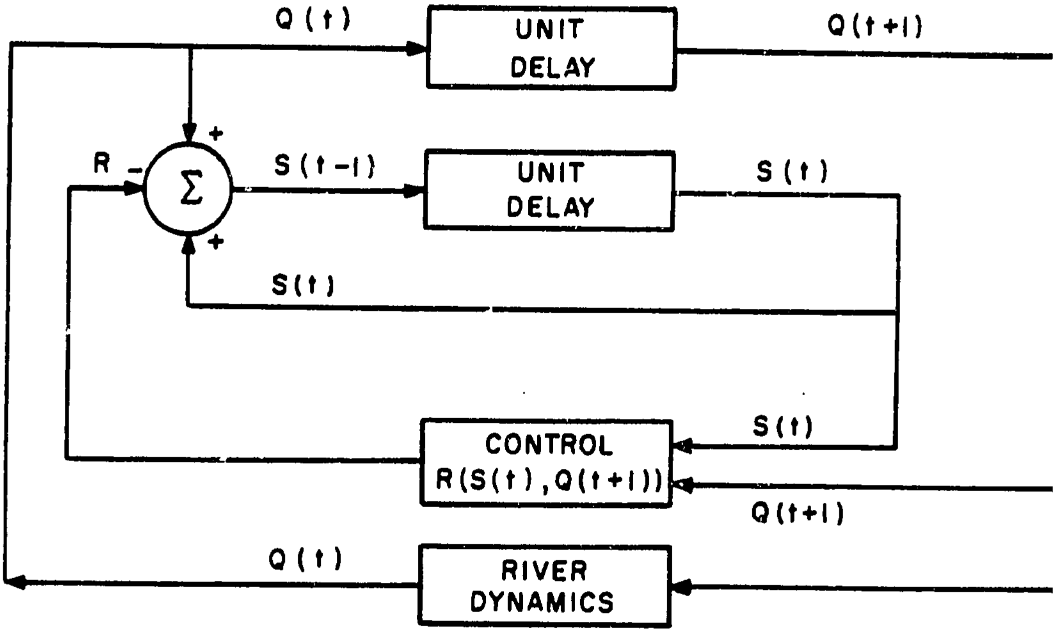


Figure 3.3

Schematic Diagram of Control Scheme for Steady-State Algorithm

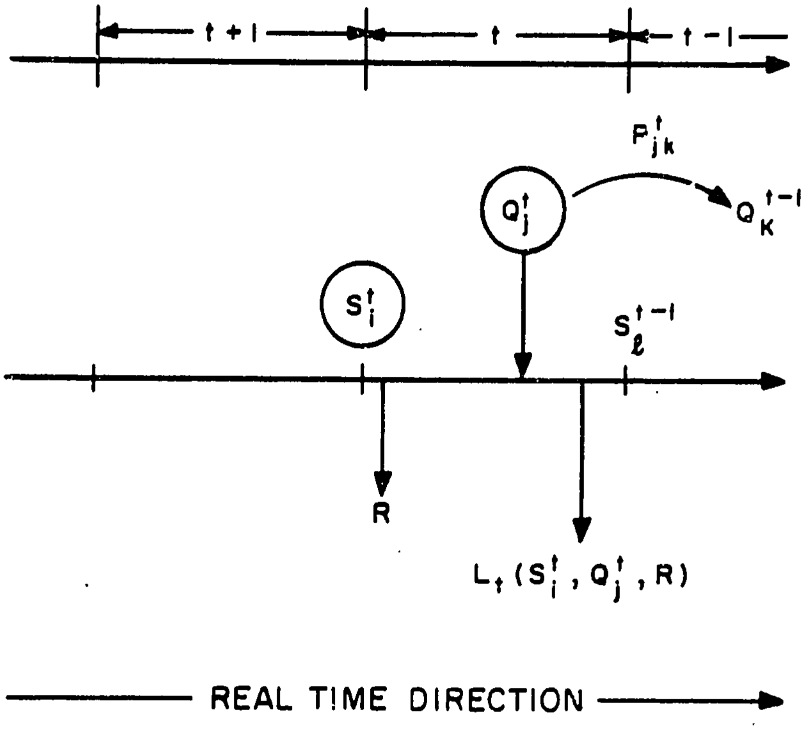


Figure 3.4

Relationship Between State Variables (Encircled)
and Decision Variable for Steady-State Algorithm 2

Condition (3.3) again is assumed to hold, and the state equation (Equation (3.4)) remains unchanged.

The recursive relation (Equation (3.5)) is now written as

$$f^n(S_i^t, Q_j^t) = \underset{R}{\mathrm{Min}} \left[g_t(S_i^t, Q_j^t, R) + \beta \cdot \{ \sum_k P_{jk}^t \cdot f^{n-1}(S_\ell^{t-1}, Q_k^{t-1}) \} \right] \qquad \forall i, j \qquad (3.12)$$

from which it should be clear that the inflow of the current time period (i.e., the upcoming month) is no longer treated as a stochastic variable.

As with Algorithm 1, the solution procedure is initialized with arbitrary boundary conditions (see Equation (3.7)), and the recursive application of Equation (3.12) yields behavior such as that of Equation (3.10) in the undiscounted case, and of Equation (3.11) in the discounted case. Figure 3.5 illustrates a schematic representation of the closed-loop control approach of Algorithm 2, under the assumption that a perfect forecast is available to identify Q_j^t.

The fact that Algorithm 2 predicates release decisions partially upon the inflow of the upcoming period, which is unknown in a stochastic system, requires that one of two conditions be met. The first condition allows for release decisions to change as the particular time period evolves. Thus, an initial decision can be based upon an imperfect forecast (if one is available), and adjustments can be made according to (e.g.) daily inflow observations, until the inflow for the period is known (i.e., on the last day of the month). When this condition is not applicable, the second condition must hold, which requires the availability of a perfect one month lead forecast for all future time periods.

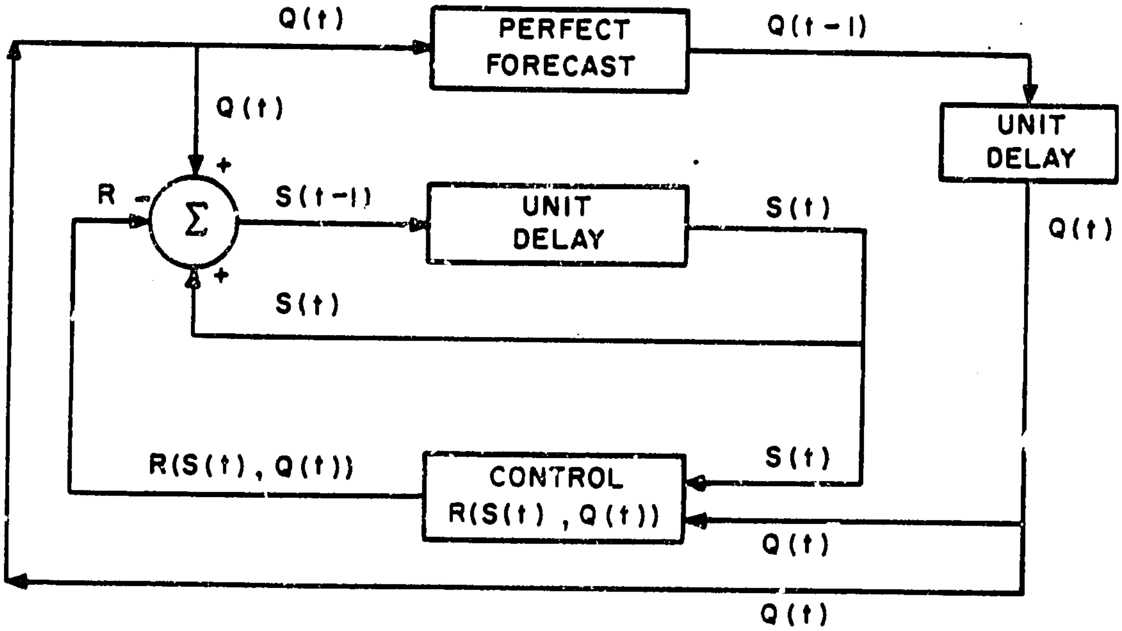


Figure 3.5

Schematic Diagram of Control Scheme for Steady-State Algorithm 2

Assuming the Availability of Perfect Forecast

If, in fact, perfect lead one predictions are not available, which is generally the case, Algorithm 2 will lead to suboptimal, possibly degenerating solutions. To illustrate this point, when n = 1 (assuming boundary conditions (3.7)), Equation (3.12) yields

$$f^1(S_i^1, Q_j^1) = \underset{R}{\text{Min}}[g_1(S_i^1, Q_j^1, R)] \qquad \forall i, j \qquad (3.13)$$

Equation (3.13) is easily solved for R if Q_j^1 is not stochastic. However, if the forecast for Q_j^1 is different from the true observation, the derived optimal release $R^1(S_i^1, Q_j^1)$ will actually be suboptimal, and the value $f^1(S_i^1, Q_j^1)$ will deviate from that which would result with the true optimal release. Since $f^2(\cdot)$ is calculated from $f^1(\cdot)$, the optimal releases $R^2(\cdot,\cdot)$ will not only be based upon imperfect state information at that time step, but the boundary values $f^1(\cdot)$ will also be potentially misleading. Because convergence upon steady-state conditions requires several cycles of calculations, introducing imperfect state information at each time step might very likely result in suboptimal control policies.

3.4 Discrete Representation of Reservoir Inflows and Corresponding Transition Probabilities

Inherent in the stochastic dynamic programming algorithms in this study is the representation of reservoir inflows as a discrete random process. In this section, the methodology employed by Alarcon and Marks (1979) to determine discrete inflow values and the corresponding transition probabilities for each month is reviewed. It will be important in later discussions.

Assuming the distribution for each month to be normal or lognormal, the random variable 'inflow during period t' can be discretized into N values (where N is chosen by the user) using the following procedure:

1) Derive the marginal probability density function (pdf) from historical monthly inflow data (i.e., calculate the sample mean and variance). The marginal pdf can be written as $f_{Q_t}(q_t)$.
2) Divide the domain of the random variable into N intervals such that the area under the pdf for the interval corresponding to the largest values of inflow is Γ, and the remaining portion of the domain is divided into N-1 equiprobable intervals (see Figure 3.6, with N = 5). The values defining the intervals are called X_k^t (k = 1, ..., N-1).
3) For each of the N intervals, the median is chosen as the representative value. These are the discrete values Q_j^t (j = 1, ..., N), and are shown in Figure 3.6.

To derive the corresponding transition probabilities, it is first assumed that any two consecutive months are multivariate normally distributed (after transformation of any lognormal distributions). Using the definition for P_{jk}^t given in Algorithm 1, the j^{th}, k^{th} element of the transition matrix can be calculated from the following:

$$\int_{-\infty}^{x_4^t} f_{Q_t}(q_t)\,dq_t = \int_{x_4^t}^{x_3^t} \cdot = \int_{x_3^t}^{x_2^t} \cdot = \int_{x_2^t}^{x_1^t} \cdot = \frac{1-\Gamma}{4}$$

$$\int_{-\infty}^{Q_5^t} f_{Q_t}(q_t)\,dq_t = \int_{x_4^t}^{Q_4^t} \cdot = \int_{x_3^t}^{Q_3^t} \cdot \quad \int_{x_2^t}^{Q_2^t} \cdot = \frac{1-\Gamma}{8}$$

$$\int_{x_1^t}^{\infty} f_{Q_t}(q_t)\,dq_t = \Gamma$$

$$\int_{x_1^t}^{Q_1^t} f_{Q_t}(q_t)\,dq_t = \frac{\Gamma}{2}$$

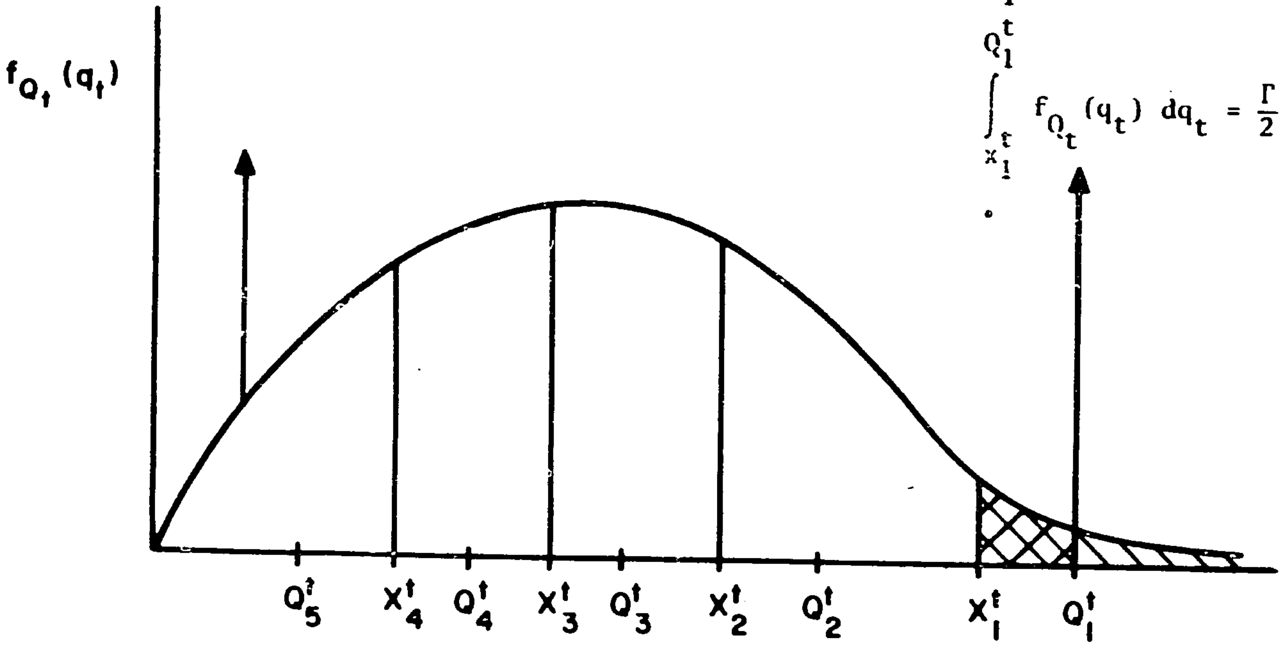


Figure 3.6

Discretization of Variable Inflow During Month 't'

1) Derive the joint pdf for month t+1 and month t, i.e., $f_{Q_{t+1},Q_t}(q_{t+1}, q_t)$. Notice that this simply requires the marginal pdf for both months and the monthly lag-one correlation coefficient.

2) From the joint pdf, derive the conditional pdf, which can be written as

$$f_{Q_t/Q_{t+1}}(q_t/q_{t+1}) = \frac{f_{Q_{t+1},Q_t}(q_{t+1}, q_t)}{f_{Q_{t+1}}(q_{t+1})} \qquad (3.14)$$

3) Given the conditional pdf in step 2, the j^{th} row of the transition probabilities P^t_{jk} can be computed as:

$$P^t_{j1} = \int_{X^t_1}^{\infty} f_{Q_t/Q_{t+1}}(q_t/Q^{t+1}_j)\, dq_t \quad ; \quad k = 1 \qquad (3.15a)$$

$$P^t_{jk} = \int_{X^t_k}^{X^t_{k-1}} f_{Q_t/Q_{t-1}}(q_t/Q^{t+1}_j)\, dq_t \quad ; \; 1 < k < N \qquad (3.15b)$$

$$P^t_{jN} = \int_{-\infty}^{X^t_{N-1}} f_{Q_t/Q_{t+1}}(q_t/Q^{t+1}_j)\, dq_t \quad ; \quad k = N \qquad (3.15c)$$

where

$$f_{Q_t/Q_{t+1}}(q_t/Q^{t+1}_j) = \int_{X^{t+1}_1}^{\infty} f_{Q_t/Q_{t+1}}(q_t/q_{t+1})\, dq_{t+1} ; \; j = 1 \qquad (3.16a)$$

$$= \int_{X^{t+1}_j}^{X^{t+1}_{j-1}} f_{Q_t/Q_{t+1}}(q_t/q_{t+1})\, dq_{t+1} \; ; \; j \neq 1 \text{ or } N \qquad (3.16b)$$

$$= \int_{-\infty}^{X_{N-1}^{t+1}} f_{Q_t/Q_{t+1}}(q_t/q_{t+1})\, dq_{t+1} \quad ; \; j = N \quad (3.16c)$$

4) Step 3 is repeated for all j (j = 1, ..., N), and then the entire procedure is repeated for each t (t = 1, ..., 12).

As pointed out by Curry and Bras (1980), the assumption that any two consecutive months are multivariate normally distributed is not rigorously justifiable. However, it is further mentioned that with large β (> .05) and relatively coarse discretization, the sensitivity of the transition probabilities to different joint pdf's is weakened, and the a priori assumption of normal densities is appropriate.

3.5 Objective Function and Constraints

Perhaps the most critical element of an optimization model is the objective function, which quantifies the returns (benefits and/or costs) associated with the degree to which the system objectives are met for a given decision (release). In Section 2.3, three major objectives of High Dam releases were discussed in some detail, of which drought and flood protection were the two most important. Due to the multi-objective nature of these releases, formulating an appropriate objective function requires a tradeoff of complexity for tractability. The objective function finally developed for this study (defined as $g_{.}(\cdot)$ in Section 3.2) is based upon the consideration of several issues, and three of these issues are presented in the following paragraphs.

First, computationally, it is advantageous to use an objective function that is either convex or concave with respect to the release R (see Alarcon and Marks (1979), Section 3.3.4). Since targets can be specified for all objectives, a convex penalty function can easily be arrived at, whereas a benefit function might be more difficult to quantify and would probably offer no new information.

Second, due to the stochastic nature of Lake Nasser inflows, irrigation deficits and excessive releases cannot be avoided with certainty. This excludes the possibility of constraining the feasible region of releases in an effort to reduce the objective space.

Finally, given that all three objectives are to be included in the objective function, a weighting system must be incorporated to reflect priorities.

Based upon these considerations, an objective function of the following form is used:

$$g_t(\cdot,\ \cdot,\ R) = a_1(T_I^t - R)^{b_1} + a_2(R - T_D)^{b_2} + a_3(T_E^t - P)^{b_3} \quad (3.17)$$

where

$g_t(\cdot, \cdot, R)$ = costs incurred from irrigation deficits, downstream degradation and power generation deficits during month t when the initial storage and current month's inflow are $(\cdot, \cdot)$ and the release is R

T_I^t = irrigation target for month t (milliard m^3)

T_D = release above which channel degradation occurs (milliard m^3/month)

T_E^t = power target during month t (10^3 GWH/month)
taken to be 1280 GWH/month for all t

P = power generated during month t (10^3 GWH/month)

a_1, a_2, a_3 = tradeoff coefficients (≥ 0)

b_1, b_2, b_3 = exponentials (≥ 1)

$a_1 = 0$ if $T_I^t \leq R$

$a_2 = 0$ if $R \leq T_D$

$a_3 = 0$ if $T_E^t \leq P$

$R \geq 0$

For the experiments performed in this study, two sets of values are used for the tradeoff coefficients, while in all cases $b_1 = b_2 = b_3 = 2$.

The first set of tradeoff values are given as:

$$a_1 = 1 \times 10^7 \qquad a_2 = 1 \times 10^4 \qquad a_3 = 1 \times 10^3$$

Though these values are arbitrary, it can be seen that for the given values of b_i (i = 1, 2, 3), the first 0.1 milliard m^3 by which a downstream demand target is missed incurs a penalty 10^3 times more than the first 0.1 milliard m^3 of a release exceeding T_D, which in turn is 10 times more costly than the first 100 GWH by which a hydropower target is missed. This clearly indicates a heavy preference for meeting downstream demands, while the least preference is given to power generation, though meeting power targets is still clearly an objective. The fact that the values of the exponential (b_i) coefficients are greater than one indicate an increasing marginal cost for each additional unit by which a target is not met.

The second set of tradeoff values, given as

$$a_1 = 0 \qquad a_2 = 0 \qquad a_3 = 1 \times 10^3$$

result in an objective function identical to that used both by Alarcon and Marks (1979) and El Assiouti, et al. (1979). However, those works impose the additional constraint that

$$T_I^t \leq R \leq T_D \tag{3.18}$$

As mentioned earlier in this section, such a constraint cannot be guaranteed to hold in practice, and thus will not be included here.

3.6 Summary

This chapter has presented two stochastic dynamic programming algorithms differing in their definitions of the state space. Algorithm 2 requires perfect lead one forecasts of streamflow, which are generally not available. Hence, steady-state reservoir release policies in this study will be derived using Algorithm 1, for which a computer code, user's manual and sample input and output are given in Appendix B.

Chapter 4

A REAL-TIME ADAPTIVE CLOSED-LOOP CONTROL ALGORITHM

4.1 Nonstationary Systems

In control theory terms, there are two fundamental approaches from which release policies (controls) can be derived. The first is an 'open-loop' strategy, where releases R(n) are specified for all time periods n = 1, 2, ..., N at the beginning of an N-period planning horizon. The second approach is a 'closed-loop' strategy, where each release R(n), n = 1, 2, ..., N, is given as a function of the state of the system, to be observed at time period n. From these classifications, the algorithms of Chapter 3 can be seen to be closed-loop.

For stationary systems, a closed-loop control approach can easily be applied, as both the state space and the parameters of the system are well-defined over an infinite time horizon. However, in real-time reservoir operation, the system is actually nonstationary, because new information is available at each time period with which the system's parameters can be updated. In particular, the stochastic process of reservoir inflow can be described with reduced variances for a finite distance into the future using a forecasting model such as that presented in Section 2.4.2. Similarly, the objective function might be updated due to changes in irrigation requirements, energy demands and objective priorities. In general, then, $Q_{\cdot}^{\cdot}$, $P_{\cdot}^{\cdot}$ and $G_{\cdot}(\cdot)$ (as defined in Section 3.2) are a function of absolute time, in which case the algorithms of Chapter 3 can no longer be applied.

To incorporate such information, Verhaeghe (1977) suggests solving a boundary value problem at each time step described as follows. For the current time period M, a boundary function $B[\overline{X}_i(M - M_o)]$ is approximated, for some future time period M_o, representing the expected value of being in state $\overline{X}_i$ at $M - M_o$ periods into the future ($M > M_o$ using the time indices of Figure 3.1), where $\overline{X}_i$ is a vector of state variables. Using this boundary function, an $M - M_o$ stage optimization problem can be solved, incorporating forecasted information over this finite time horizon to derive the optimal control $R^M(\cdot)$. Verhaeghe (1977) refers to the forecasted time interval as an open-loop period, and the overall control approach as being "open-closed loop" in nature, as defined by Schweppe (1973). A basic difficulty encountered by Verhaeghe (1977) is the limited lead of the forecast, resulting from the inability of his forecasting technique (a linear regression) to predict several time periods into the future with any significant accuracy. However, using a maximum open-loop interval of two time periods, improved reservoir performance is observed in comparing the open-closed loop to the closed-loop (steady-state) approach.

Expanding on the above concepts, Curry and Bras (1980) propose a methodology for deriving revised discrete parameter values of the first-order Markov chain (i.e., $Q_i^{\cdot}$ and $P_i^{\cdot}$) over a finite time horizon using multi-lead forecasts from Model 2.3. Based upon the accuracy of higher lead forecasts, a boundary value problem is likewise solved, where the location of the boundary is chosen as a function of the $R^2(\ )$ statistics presented in Table 2.3. Though the overall approach is similar to Verhaeghe's, the solution over the forecasted time interval is based on a backward moving dynamic programming algorithm, with optimal release decisions at each stage given as a function of the revised states of the system. Thus, the finite horizon problem is actually closed-loop.

Terming this approach a "real-time adaptive closed-loop control" algorithm, the logic can be summarized as follows:

1. For the current time period M, determine maximum lead time K_M for which forecasted inflows are significant (e.g., $R^2 \geq 0.2$).
2. Using forecasts for time period M, M - 1, ..., M - K_M+1, derive $\hat{Q}$: and $\hat{P}$: for these forecasted time periods (the symbol "^" denotes forecast dependent).
3. Determine boundary values $B(S_i^{(M-K_M)}, \hat{Q}_j^{M-K_M+1})$ at K_M time periods into the future (using the state variables of Algorithm 1, Chapter 3).
4. Solve a K_M stage (i.e., finite horizon) stochastic dynamic program over the forecasted interval, recursively calculating $\hat{R}^{M-K_M+1}(\cdot)$, $\hat{R}^{M-K_M+2}(\cdot)$, ..., $\hat{R}^M(\cdot)$.
5. Take the immediate control action $\hat{R}^M(\cdot)$.
6. Let M = M-1 and go to step 1.

It should be noted that the above steps can be extended to include the updating of any other parameters as well, particularly the objective function.

The major advantage of solving a nonstationary system is that forecasted information can be incorporated that otherwise must be precluded when using the steady-state algorithms of Chapter 3. It should be clear that real-time (i.e., absolute time) information cannot be incorporated into the algorithms of the previous chapter because 1) the available information for future time periods cannot be represented by a state variable and 2) the resulting nonstationary system is not subject to convergence conditions. For the solution procedure suggested here, a further advantage can be seen in the reduction of computational requirements, as the optimal control for each time period results from the solution of a finite horizon (generally twelve time periods or less) stochastic dynamic program.

The primary difficulty that might arise with an adaptive approach is the specification of an appropriate boundary function B( ). The boundary function can essentially be interpreted as representing the value of being in a particular state of the system (amount of stored water and previous inflow class) at the beginning of time period $M - K_M$, which in turn should incorporate all currently available information for the planning horizon beyond the chosen boundary. Even with the adaptive approach, the planning horizon is still assumed to be infinite.

In this chapter, the "real-time adaptive closed-loop control" algorithm proposed by Curry and Bras (1980) is presented. Specific features to be discussed are the approximation of the boundary function (Section 4.2) and the derivation of revised parameter values that form the first-order Markov chain characterizing reservoir inflows (Section 4.3). Closing the chapter is a brief comparison between the adaptive algorithm presented here and Algorithm 1 of Chapter 3.

4.2 Presentation of Adaptive Algorithm

Letting K_M denote the number of time periods from the present (M) for which inflow forecasts are generated, define the following variables:

$\hat{Q}_j^n$ = the j^{th} discrete value of inflow for time period n ($M \geq n \geq M - K_M + 1$)

$\hat{P}_{jk}^n$ = the probability of occurrence of inflow $\hat{Q}_k^n$ during time period n given that in time period n+1 $\hat{Q}_j^{n+1}$ was realized ($M \geq n \geq M - K_M + 1$)

$\hat{g}_n(S_i^n, \hat{Q}_k^n, R)$ = the return function for time period n describing costs incurred when the storage is S_i^n, the inflow is $\hat{Q}_k^n$ and the release is R, based upon revised irrigation targets, energy demands, objective preference structure, etc.

where the symbol "^" denotes dependence upon real-time information.

Assuming for now that boundary conditions $B(S_i^{M-K_M}, \hat{Q}_j^{M-K_M+1})$ are available for time period $M - K_M$, a finite horizon stochastic dynamic programming algorithm can be utilized to solve for the optimal release $\hat{R}^M(\cdot)$ using the recursion equation

$$f^n(S_i^n, \hat{Q}_j^{n+1}) = \min_R \left[\sum_k \hat{P}_{jk}^n \cdot \{\hat{g}_n(S_i^n, \hat{Q}_k^n, R) + \beta \cdot f^{n-1}(S_\ell^{n-1}, \hat{Q}_k^n)\} \right]$$

$$M \geq n \geq M - K_M + 1 \qquad (4.1)$$

where

$$f^{M-K_M}(S_\ell^{M-K_M}, \hat{Q}_k^{M-K_M+1}) = B(S_\ell^{M-K_M}, \hat{Q}_k^{M-K_M+1}) \qquad (4.2)$$

The state equation (Equation (3.4)) and constraints 3.6a, b and c are assumed to hold. However, conditions 3.1, 3.2 and 3.3 are no longer enforced.

To derive the boundary conditions $B(S_i^{M-K_M}, \hat{Q}_j^{M-K_M+1})$, one can take advantage of the fact that as the lead of the forecast increases, the amount of extra information contained in these forecasts eventually becomes negligible compared to the sample statistics employed in the steady-state approach. This implies that beyond K_M periods into the future, the stochastic process of inflow can best be described by the sample statistics, suggesting that inflows for the time interval $M-K_M$, $M-K_M-1$, $M-K_M-2$, ..., be characterized by a periodically stationary process. If, in fact, conditions 3.1 and 3.2 are assumed to hold beyond the forecasted interval, and if condition 3.3 is likewise enforced for this interval, then the boundary conditions $B(S_i^{M-K_M}, \hat{Q}^{M-K_M+1})$ can be directly evaluated using the steady-state approach of Chapter 3. Figure 4.1 illustrates the equivalent in indices and times of the suggested nonstationary system and the stationary result of Chapter 3 (Algorithm 1). From this figure, the boundary conditions can be seen to represent the expected value (at time period $M - K_M$) of stored water and the inflow of period $M-K_M+1$, when faced with periodic stationary conditions from that time on. Figure 4.2 schematizes the relationship between states, boundary conditions and decision variables of the suggested adaptive control system. Notice how information from a stationary infinite horizon solution is transferred to a finite horizon, nonstationary, dynamic programming scheme.

To define the exact nature of the boundary conditions, recall from Section 3.2 that for the undiscounted case

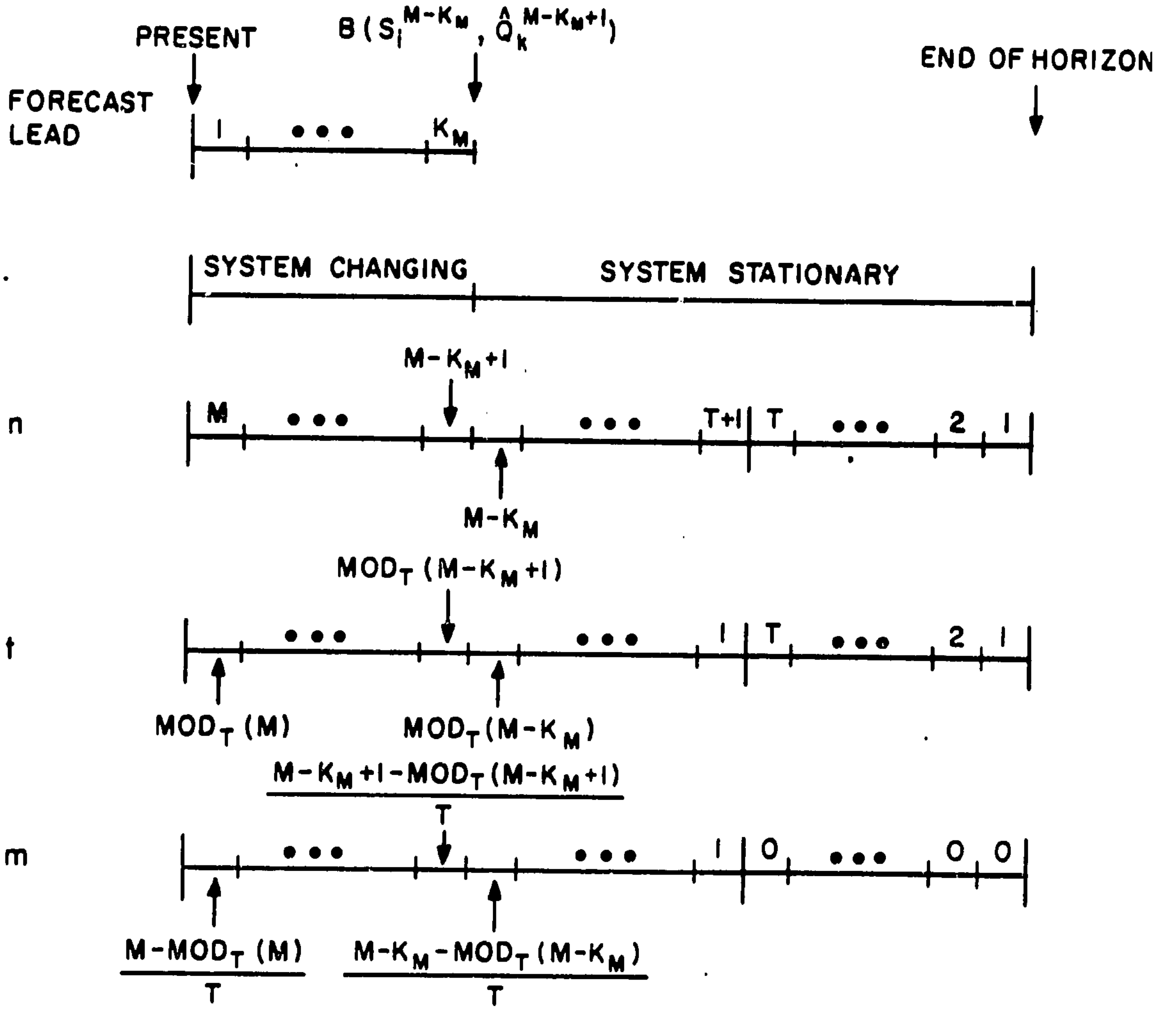


Figure 4.1

Indices and Time Intervals of Adaptive Control Solution

in Relation to Steady-State Solution

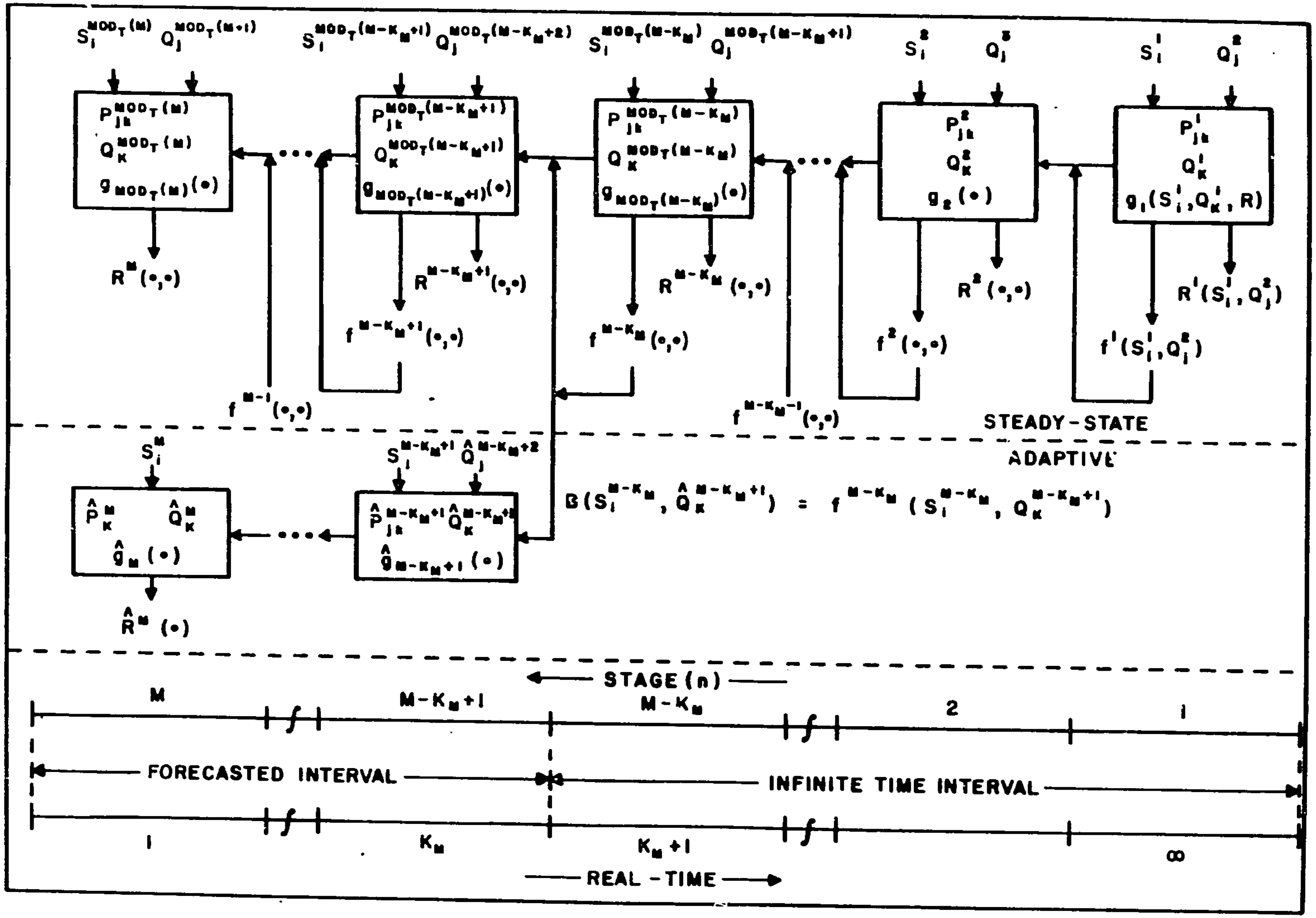


Figure 4.2

Transferal of Information from Steady-State Solution to Adaptive Control Algorithm

$$\lim_{m\to\infty}\left(f^{(m+1)T+t}(S_i^t, Q_j^{t+1}) - f^{mT+t}(S_i^t, Q_j^{t+1})\right) = c \qquad \forall i, j, t \tag{4.3}$$

where c is the unique minimum annual cost of operating the system over an infinite horizon (assuming conditions 3.1, 3.2 and 3.3). Su and Deininger generalize the results of Howard (1960), White (1963) and Odini (1969) to show that

$$\lim_{m\to\infty} f^{mT+t}(S_i^t, Q_j^{t+1}) = mc + w_t(i, j) \qquad \forall i, j, t \tag{4.4}$$

which leads to

$$\lim_{m\to\infty}\left(f^{mT+t}(S_i^t, Q_j^{t+1}) - f^{mT+t}(S_k^t, Q_\ell^{t+1})\right) = w_t(i, j) - w_t(k, \ell) \qquad \forall i, j, k, \ell, t \tag{4.5}$$

where $w_t(\cdot)$ is the intercept of the linear asymptote of $f^{mT+t}(\cdot)$.

Assuming that the desired convergence upon c occurs during cycle m', the desired boundary values of Equation (4.2) can be approximated as[1]

$$\hat{B}(S_i^{M-K_M}, \hat{Q}_j^{M-K_M+1}) = f^{m'T+\tau}(S_i^\tau, Q_j^{\tau+1}) - f^{m'T+\tau}(S_k^\tau, Q_\ell^{\tau+1}) \approx w_\tau(i, j) - \omega_\tau(k, \ell) \qquad \forall i, j \tag{4.6}$$

where $\tau = \mathrm{MOD}_T(M - K_M)$, $\tau + 1 = 1$ if $\mathrm{MOD}_T(M - K_M) = 12$, k and ℓ are fixed and $\hat{B}(\cdot)$ denotes approximation for $B(\cdot)$. Equation (4.6) thus expresses boundary values for all states (i, j) relative to some fixed state (k, ℓ).

For the discounted case (assuming condition 3.1, 3.2 and 3.3),

---

[1] $\mathrm{MOD}_T(I)$ is the fractional remainder of I/T multiplied by T

it was shown in Section 3.2 that

$$\lim_{m\to\infty} f^{mT+t}(S_i^t, Q_j^{t+1}) = f^{t^*}(S_i^t, Q_j^{t+1}) \qquad \forall i, j, t \qquad (4.7)$$

where $f^{t^*}(\cdot)$ is the unique minimum expected cost of operating the system over an infinite horizon, when the system starts in state $(\cdot)$ during time period t. Assuming again that the desired convergence occurs during cycle m', the boundary values of Equation (4.2) in the discounted case can be approximated as

$$\hat{B}(S_i^{M-K_M}, \hat{Q}_j^{M-K_M+1}) = f^{\tau^*}(S_i^{\tau}, Q_j^{\tau+1}) - f^{\tau^*}(S_k^{\tau}, Q_\ell^{\tau+1}) \qquad (4.8)$$

where τ, k, ℓ and $\hat{B}(\cdot)$ are defined as before.

Thus, the boundary values of Equation (4.2) for both the undiscounted and discounted case can be tabulated using the relationships of Equations (4.6) and (4.8), respectively. Introducing the updated values $\hat{Q}_{\cdot}^{\cdot}$ and $\hat{P}_{\cdot}^{\cdot}$ (to be discussed in the following section) and $\hat{g}_{\cdot}(\cdot)$, the optimal control $\hat{R}^M(\cdot)$ can be determined with the derived boundary function by solving a K_M stage stochastic dynamic program over the forecasted time interval.

4.3 Revision of Inflow States and Transition Probabilities Using Multi-Lead Forecasts

In Section 2.4.2, a multivariate autoregressive forecasting model was presented capable of generating multi-lead forecasts. An important characteristic of these forecasts is that they are normally distributed random variables, where the normality results from the assumption that the residuals are a Gaussian noise. The mean of each random variable is given by the point forecast (see Section 2.4.2)

$$\hat{\underline{Y}}(k, i) = \hat{\underline{\underline{\Pi}}}_i \begin{vmatrix} \underline{Y}(k, i-1) \\ \underline{Y}(k, i-2) \\ \vdots \\ \underline{Y}(k, i-n_1(i)) \end{vmatrix} + \hat{\underline{U}}'(i) \qquad (4.9)$$

with the variance of each prediction in the vector $\hat{\underline{Y}}$ given by

$$V_j(\ell, i) = [1 - R_j^2(\ell, i)] \quad S^2(i, j) \qquad (4.10)$$

where

$V_j(\ell, i)$ = variance of true observation about the point forecast for station j

ℓ = lead-time of forecast (ℓ = 1, 2, ..., 12)

i = index denoting the month (i = 1 for January, i = 2 for February, etc.)

$R_j^2(\ell, i)$ = percentage of historical variance of month i and station j explained by a lead forecast of month i ($0 \leq R_j^2(\ell, i) \leq 1$)

$S^2(i, j)$ = historical variance of month i, station j

The forecast variances for Wadi Halfa can readily be evaluated for all months with lead-times ranging from one to twelve months, using the data in Tables 2.1 and 2.3.

Since each forecast is given by a normal distribution, representative discrete values can be determined from the straightforward application of the discretization scheme presented in Section 3.4.

To derive transition probabilities corresponding to these updated inflow states, Curry and Bras (1980) assume that any two contiguous forecasted months are multivariate normal, with parameters being the respective forecasted means and variances and the historical lag-one correlation coefficient between the two months. Based upon this assumption, transition probabilities can be calculated in a manner identical to that used for the steady-state case as presented in Section 3.4.

Retaining the historical lag-one correlation coefficient is clearly an approximation, as the revision of the marginal distributions using forecasted inflows from model 2.3 necessarily alters the underlying correlation structure. However, two points can be cited to substantiate this approximation. First, the lag-one correlation is essentially an indicator of the likelihood that above (below) average inflows will be followed in the next time period by above (below) average inflows. It does not seem unreasonable to assume that this behavior will persist. Second, forecasted inflow distributions will in general have much tighter variances relative to the historical variances. Hence, the sensitivity of the derived control to the correlation coefficient will be reduced. In the limit, solutions based upon perfect forecasts will not be a function of the correlation structure at all.

An exception to the above derivation of transition probabilities arises for the transition from period M+1 to period M (i.e., the extreme left hand side of Figure 4.1). The forecast for time period M (lead-one) is based entirely upon known past inflows at all explanatory locations. Any dependence of inflows during time period M on previous inflows (including time period M+1) is fully accounted for in the forecasted marginal distribution. Thus, the conditional distribution of inflows for time period M is taken identical to the marginal distribution, which is equivalent to setting $\rho_{M+1,M} = 0$. Resulting from this observation is the representation of the derived control for time period M as only a function of storage.

4.4 Review of Steady-State and Adaptive Reservoir Control

Before presenting the results of Chapters 5 and 6, some significant features characterizing the steady-state and the adaptive approach to reservoir control should first be reviewed.

The basis for deriving steady-state release policies is the assumption of a stationary system, allowing for the use of a closed-loop control approach. Optimal controls can thus be given for all future time periods as a function of the state of the system. As defined by Algorithm 1 of Chapter 3, the state of the system for each time period consists of two state variables, the initial storage and the previous month's inflow. It should be realized that steady-state release policies assume that all possible information has been taken into account beforehand. However, actual releases are derived in real-time, as future states of the system are not known with certainty.

On the other hand, adaptive release policies are derived only for the current time period. The derivations of future release policies are delayed such that for all time periods the most recent information can be utilized. Such an approach must necessarily address a nonstationary system, since information available in a particular time period differs from information of another time period. Further, as indicated in Section 4.3, the inflow of the previous month is implicitly incorporated into the solution procedure via the forecasting equation. Thus, the derived immediate control at each point is represented only as a function of the state variable storage.

Improved reservoir performance that might be observed using the adaptive approach is essentially dependent upon two factors. First is the validity of retaining historical lag-one correlation coefficients between forecasted months, in spite of the shifting and variance reduction of these inflow distributions. Second is the nature of the system being analyzed, as the degree of unpredictability of future inflows and the degree to which the system is already constrained will certainly influence the amount of additional benefits realized. In the following chapters, both steady-state and adaptive release policies will be applied to the High Aswan Dam - Lake Nasser system in Egypt, with discussion focusing upon an in depth comparison between the two control schemes. Appendix C gives a computer program listing of the simulation model to be used in the subsequent analysis, in which the adaptive control algorithm is included.

Chapter 5

QUALITATIVE ANALYSIS OF ALTERNATE CONTROL SCHEMES

5.1 Introduction

The evaluation of alternative control schemes for the High Aswan Dam - Lake Nasser system is best conducted from two standpoints. First, a qualitative analysis can be performed involving the examination of behavioral characteristics displayed by different release policies. This will be the subject of the current chapter. Such an analysis provides insight into model behavior, for both the steady-state and the adaptive control algorithm, as system parameters are varied. It further serves the purpose of illustrating the effects of incorporating inflow forecasts generated from the model of Section 2.4.2. Subsequently, a quantitative analysis can be performed by comparing the outputs of a simulation model, which will be the subject of Chapter 6.

In this chapter, steady-state release policies are derived from Algorithm 1 of Chapter 3, based upon the data provided in Chapter 2. Additional inputs to the steady-state algorithm include the discrete values of storage and inflow, which are presented in Section 5.2.

To outline the remaining contents of this chapter, Section 5.3 discusses some computational aspects of both the steady-state and the adaptive control algorithms. In Section 5.4, steady-state release policies are presented in graphical form for several system configurations, with discussion focusing upon observed differences between the individual policies. Specific parameters to be varied include objective function coefficients, the discount rate, inclusion of Toshka spillway, Sudan abstractions and the degradation causing release. Finally, Section 5.5 presents selected adaptive release policies based upon forecasts of different years. These results are then compared to corresponding steady-state release policies given in Section 5.4.

5.2 Discretization of State Variables

5.2.1 Discrete Values of Steady-State Inflow Parameters

In Section 3.4, a methodology was presented for obtaining discrete values Q_i' and P_i' of the first-order Markov chain characterizing the inflow process. This methodology is applied here using data presented in Table 2.1 and Figure 2.6.

To compute representative discrete inflow values Q_i', the following two assumptions are made:

1. The sample statistics in Table 2.1 represent a deregulated inflow process, which implies that Sudan abstractions and losses at Gebel Aulia Reservoir (in Sudan) are zero over the time period from which the statistics are derived (1912-1965).
2. Future Sudan abstractions and Gebel Aulia Reservoir losses are a deterministic process following the distribution given in Figure 2.6.

In fact, the data presented in Table 2.1 is derived from regulated Wadi Halfa streamflow data. However, a comparison with supposedly deregulated flows at Aswan (Table 5.1) reveals the existence of only

Month	Mean*	STDV	Lag-1	XMAX*	XMIN*	NOR/LOG-NOR
1	3.86	0.77	0.394	6.908	1.72	Log-Normal
2	2.67	0.81	0.378	5.96	1.15	Log-Normal
3	2.13	0.87	0.270	6.336	1.07	Log-Normal
4	1.60	0.72	0.262	5.281	0.95	Log-Normal
5	1.57	0.57	0.189	4.015	0.80	Log-Normal
6	1.77	0.55	0.221	3.766	0.90	Log-Normal
7	4.50	1.29	0.578	8.770	1.74	Normal
8	18.63	4.08	0.868	26.998	6.50	Normal
9	22.04	3.84	0.804	30.993	12.20	Normal
10	15.24	3.00	0.820	22.800	7.54	Normal
11	7.84	1.93	0.801	13.300	4.12	Normal
12	5.09	0.95	0.720	7.880	2.83	Normal

* md

Table 5.1

Statistics of Deregulated Flows at Aswan (1912-1965)

(Ministry of Irrigation, 1979)

minor statistical differences. The most significant similarity between the two data sets lies in the mean annual inflow. Since the expected annual inflow is not appreciably affected, the use of regulated data seems reasonable. Furthermore, this work places more emphasis upon illustrating the differences between two control schemes as opposed to providing actual operating rules for the High Aswan Dam.

Given the above assumptions, the historical mean monthly inflows into Lake Nasser for each month are reduced by the corresponding deterministic amount indicated by Figure 2.6 to arrive at future expected monthly inflow values. Tables 5.2a and b then give the resulting discrete inflow values for each month assuming Sudan abstractions and Gebel Aulia losses total 16.5 and 18.5 milliard m^3 per year, respectively. Table 5.3 presents the transition probabilities between the discrete states given in Tables 5.2a and b. Notice that the transition probabilities are identical in both cases, only the definition of the discrete inflow values changes.

5.2.2 Discrete Values of Storage

Using the storage discretization scheme suggested by Alarcon and Marks (1979), representative values are given in Table 5.4, based upon a maximum storage of 168.9 milliard m^3 and a minimum storage of 32.7 milliard m^3. For the given 25 discrete storage values, the equivalent in elevation can be approximated by the stage-storage function

$$h = 79.9734 + 0.0369801 \cdot S + 18.8705 \cdot \ln(S) \qquad (5.1)$$

while the area can be approximated from the relationship

Table 5.2a

Discrete Monthly Inflow Values for Sudan Losses of 16.5 md per year*

(for parameter values N = 5, Γ = 0.05)

1	3.458	2.483	1.897	1.471	0.973
2	2.636	1.656	1.100	0.713	0.284
3	2.871	1.908	1.367	0.993	0.583
4	2.910	2.220	1.721	1.304	0.743
5	3.301	2.104	1.484	1.081	0.667
6	3.139	1.930	1.294	0.876	0.441
7	6.760	5.228	4.123	3.198	1.954
8	25.865	22.000	19.212	16.877	13.738
9	27.422	23.637	20.907	18.621	15.546
10	18.648	15.493	13.217	11.312	8.750
11	8.505	6.732	5.454	4.383	2.944
12	4.432	3.561	2.933	2.406	1.699

Table 5.2b

Discrete Monthly Inflow Values for Sudan Losses of 18.5 md per year*

(for parameter values N = 5, Γ = 0.05)

1	3.251	2.276	1.690	1.262	0.766
2	2.464	1.484	0.928	0.541	0.112
3	2.752	1.789	1.248	0.874	0.464
4	2.852	2.162	1.663	1.246	0.685
5	3.244	2.047	1.427	1.024	0.610
6	3.039	1.830	1.194	0.776	0.341
7	6.589	5.057	3.952	3.027	1.783
8	25.726	21.861	19.073	16.738	13.599
9	27.182	23.397	20.667	18.381	15.306
10	18.388	15.233	12.958	11.053	8.491
11	8.246	6.473	5.195	4.124	2.685
12	4.212	3.341	2.713	2.186	1.479

---

*Inflow values given in milliards.

Period
From To

$$\begin{array}{cccccc} & & & \text{To} & & \\ & 0.5558 & 0.4354 & 0.0087 & 0.0001 & 0.0000 \\ & 0.0484 & 0.6679 & 0.2518 & 0.0312 & 0.0007 \\ \text{From} & 0.0015 & 0.2320 & 0.4769 & 0.2606 & 0.0290 \\ & 0.0000 & 0.0347 & 0.2622 & 0.4934 & 0.2097 \\ & 0.0000 & 0.0005 & 0.0224 & 0.2332 & 0.7439 \end{array}$$

Dec - Jan

$$\begin{array}{cccccc} & & & \text{To} & & \\ & 0.2181 & 0.4623 & 0.2016 & 0.0915 & 0.0265 \\ & 0.0889 & 0.3713 & 0.2710 & 0.1828 & 0.0860 \\ \text{From} & 0.0394 & 0.2656 & 0.2767 & 0.2486 & 0.1697 \\ & 0.0178 & 0.1789 & 0.2488 & 0.2843 & 0.2702 \\ & 0.0052 & 0.0890 & 0.1804 & 0.2851 & 0.4403 \end{array}$$

Jan - Feb

$$\begin{array}{cccccc} & & & \text{To} & & \\ & 0.1282 & 0.3704 & 0.2423 & 0.1666 & 0.0925 \\ & 0.0761 & 0.3059 & 0.2546 & 0.2116 & 0.1518 \\ \text{From} & 0.0499 & 0.2536 & 0.2503 & 0.2386 & 0.2076 \\ & 0.0340 & 0.2100 & 0.2385 & 0.2550 & 0.2625 \\ & 0.0194 & 0.1556 & 0.2129 & 0.2656 & 0.3465 \end{array}$$

Feb - Mar

$$\begin{array}{cccccc} & & & \text{To} & & \\ & 0.2583 & 0.4897 & 0.1748 & 0.0638 & 0.0134 \\ & 0.0906 & 0.4013 & 0.2771 & 0.1675 & 0.0635 \\ \text{From} & 0.0333 & 0.2692 & 0.2919 & 0.2540 & 0.1516 \\ & 0.0122 & 0.1631 & 0.2543 & 0.3006 & 0.2698 \\ & 0.0025 & 0.0653 & 0.1629 & 0.2909 & 0.4784 \end{array}$$

Mar - Apr

$$\begin{array}{cccccc} & & & \text{To} & & \\ & 0.3230 & 0.5163 & 0.1267 & 0.0305 & 0.0035 \\ & 0.0887 & 0.4520 & 0.2844 & 0.1394 & 0.0355 \\ \text{From} & 0.0233 & 0.2716 & 0.3207 & 0.2625 & 0.1219 \\ & 0.0057 & 0.1352 & 0.2630 & 0.3312 & 0.2649 \\ & 0.0006 & 0.0354 & 0.1311 & 0.2954 & 0.5375 \end{array}$$

Apr - May

$$\begin{array}{cccccc} & & & \text{To} & & \\ & 0.2153 & 0.4602 & 0.2033 & 0.0935 & 0.0277 \\ & 0.0887 & 0.3693 & 0.2705 & 0.1838 & 0.0877 \\ \text{From} & 0.0398 & 0.2654 & 0.2757 & 0.2483 & 0.1708 \\ & 0.0182 & 0.1799 & 0.2484 & 0.2833 & 0.2702 \\ & 0.0054 & 0.0908 & 0.1815 & 0.2847 & 0.4376 \end{array}$$

May - Jun

Table 5.3

Transition Matrices for Discrete Inflow States of Tables 5.2a and b

	To					Period From To
From	0.1265	0.3682	0.2427	0.1682	0.0944	Jun - Jul
	0.0757	0.3046	0.2543	0.2122	0.1532	
	0.0500	0.2534	0.2499	0.2385	0.2082	
	0.0344	0.2106	0.2384	0.2545	0.2621	
	0.0198	0.1571	0.2134	0.2651	0.3446	
	To					
From	0.2834	0.5025	0.1566	0.0492	0.0083	Jul - Aug
	0.0905	0.4205	0.2804	0.1572	0.0514	
	0.0294	0.2706	0.3023	0.2574	0.1403	
	0.0094	0.1527	0.2578	0.3117	0.2684	
	0.0015	0.0525	0.1511	0.2934	0.5015	
	To					
From	0.4550	0.5019	0.0403	0.0027	0.0001	Aug - Sep
	0.0705	0.5689	0.2808	0.0736	0.0062	
	0.0071	0.2595	0.3986	0.2712	0.0636	
	0.0005	0.0739	0.2724	0.4126	0.2406	
	0.0000	0.0054	0.0617	0.2777	0.6552	
	To					
From	0.5990	0.3975	0.0035	0.0000	0.0000	Sep - Oct
	0.0384	0.7112	0.2314	0.0187	0.0003	
	0.0006	0.2159	0.5154	0.2496	0.0185	
	0.0000	0.0225	0.2511	0.5330	0.1934	
	0.0000	0.0001	0.0123	0.2065	0.7811	
	To					
From	0.5804	0.4143	0.0053	0.0000	0.0000	Oct - Nov
	0.0427	0.6926	0.2408	0.0235	0.0004	
	0.0009	0.2231	0.4985	0.2548	0.0227	
	0.0000	0.0274	0.2564	0.5156	0.2006	
	0.0000	0.0002	0.0162	0.2185	0.7651	
	To					
From	0.6828	0.3169	0.0003	0.0000	0.0000	Nov - Dec
	0.0208	0.7934	0.1808	0.0050	0.0000	
	0.0001	0.1788	0.5985	0.2168	0.0058	
	0.0000	0.0074	0.2178	0.6176	0.1572	
	0.0000	0.0000	0.0026	0.1475	0.8499	

Table 5.3 (cont'd)

Transition Matrices for Discrete Inflow States of Tables 5.2a and b

State Number	Storage (md)	Elevation (meters)	Area (km^2)
1	168.90	183.00	6747.1
2	165.94	182.57	6652.3
3	160.02	181.66	6461.7
4	154.10	180.73	6269.5
5	148.18	179.78	6075.8
6	142.25	178.79	5880.3
7	136.33	177.77	5682.9
8	130.41	176.71	5483.4
9	124.49	175.61	5281.7
10	118.57	174.47	5077.5
11	112.65	173.29	4870.6
12	106.73	172.05	4660.6
13	100.81	170.75	4447.3
14	94.89	169.39	4230.2
15	88.96	167.96	4008.9
16	83.04	166.44	3782.6
17	77.12	164.83	3550.9
18	71.20	163.10	3312.6
19	65.28	161.24	3066.8
20	59.36	159.23	2811.9
21	53.44	157.03	2546.1
22	47.52	154.59	2266.9
23	41.60	151.86	1970.5
24	35.67	148.74	1651.7
25	32.71	147.00	1481.6

Table 5.4

Storage-Elevation-Area Relationship for Lake Nasser

$$A = -3164.28 + 25.4914 \cdot S + 1092.92 \cdot \ln(S) \qquad (5.2)$$

where

h = elevation (meters above sea level)
A = area (km^2)
S = storage (milliard m^3)

Both of these relationships are adopted from Alarcon and Marks (1979).

5.3 Computational Considerations

To perform the numerical calculations for both the steady-state and the adaptive algorithms, certain computational considerations must be made.

A primary consideration is the increment used in the search procedure for the optimal release. Naturally, incrementing the release too coarsely will generally render release decisions far from the optimum, while too fine an increment becomes computationally burdensome. Given the rapid rate at which costs accrue from insufficient or excessive releases, an increment of 0.1 milliard m^3 per month is used, in spite of the resulting large computational requirements. Further, releases are limited to a maximum value of 10.0 milliard m^3 per month, as higher releases, though feasible, will result only in very unusual circumstances (they have never been observed) where high reservoir elevations are combined with numerous severely high inflows. In these cases, mathematically derived release decisions will be precluded by the forced releases dictated by system constraints (i.e., maximum storage).

Another consideration arises from the fact that the term

S_ℓ^{t-1} appearing in the recursion equation (3.5) will in general be different from the specified discrete storage values for which f^{n-1} was previously tabulated. However, Alarcon and Marks (1979) justify the use of a linear interpolation scheme, allowing the approximation of $f^{n-1}(S_\ell^{t-1}, Q_k^t)$ from the values $f^{n-1}(S_m^{t-1}, Q_k^t)$ and $f^{n-1}(S_{m+1}^{t-1}, Q_k^t)$, where $S_m^{t-1} > S_\ell^{t-1} > S_{m+1}^{t-1}$. Such a scheme is applicable in the case where $g_t(\cdot)$ is a continuous function of the decision variable, as this implies that $f^n(\cdot)$ is a continuous function of the state (Hadley, 1964). Since $g_t(\cdot)$ used here meets this criterion, a linear interpolation scheme is adopted for both the steady-state and the adaptive algorithms.

Finally, for the steady-state solutions, the desired degree of convergence must be specified.

In the undiscounted case, there must be convergence upon the estimate of c (see Equation (3.10)). For arbitrary t (1, 2, ..., 12), c can be estimated at any stage of calculations from the expression

$$c \approx \frac{U_t^m + L_t^m}{2} \tag{5.3}$$

where U_t^m is an upper bound on c determined at cycle m+1 and month t, given by

$$U_t^m = \max_{i,j} \left[f^{(m+1)T+t}(S_i^t, Q_j^{t+1}) - f^{mT+t}(S_i^t, Q_j^{t+1})\right] \tag{5.4}$$

and L_t^m is a corresponding lower bound on c, given by

$$L_t^m = \min_{i,j} \left[f^{(m+1)T+t}(S_i^t, Q_j^{t+1}) - f^{mT+t}(S_i^t, Q_j^{t+1})\right] \tag{5.5}$$

Su and Deininger (1972) show that U_t^m monotonically decreases with increasing m into c, while L_t^m monotonically increases with increasing m into c. Therefore, the sequence of differences $U_t^m - L_t^m$ for m = 0, 1, 2, ..., converges (exponentially) to zero. This implies that

$$\lim_{m\to\infty} U_t^m = \lim_{m\to\infty} L_t^m = c \tag{5.6}$$

which is consistent with the result given in Equation (3.10). With these results, the maximum error associated with the estimate of c at cycle m+1 in Equation (5.3) is simply

$$e_{max} = \frac{U_t^m - L_t^m}{2} \tag{5.7}$$

Allowing for a maximum error of 100•ε percent, calculations are terminated immediately after cycle m'+1 if

$$e_{max} \leq \varepsilon \cdot L_t^{m'} \tag{5.8}$$

For this study, ε is set equal to 0.01, and convergence is checked for only when t = 1 (i.e., n = 13, 25, 37, ...).

In the discounted case, convergence is into unique values $f^{t*}(S_i^t, Q_j^{t+1})$, dependent on each state (S_i^t, Q_j^{t+1}). Following a procedure similar to the undiscounted case, $f^{t*}(\cdot)$ can be estimated for any t from the expression

$$f^{t*}(S_i^t, Q_j^{t+1}) \approx \frac{U_t^m(i, j) + L_t^m(i, j)}{2} \qquad \forall i, j \tag{5.9}$$

where $U_t^m(i, j)$ is an upper bound on $f^{t*}(S_i^t, Q_j^{t+1})$ at cycle m+1 and month t, given by

$$U_t^m(i, j) = f^{mT+t}(S_i^t, Q_j^{t+1}) + (1-r^T)^{-1} \cdot \max_{k,\ell} [f^{(m+1)T+t}(S_k^t, Q_\ell^{t+1}) - f^{mT+t}(S_k^t, Q_\ell^{t+1})] \qquad \forall i, j \qquad (5.10)$$

and $L_t^m(i, j)$ is the corresponding lower bound on $f^{t^*}(S_i^t, Q_j^{t+1})$, given by

$$L_t^m(i, j) = f^{mT+t}(S_i^t, Q_j^{t+1}) + (1-r^T)^{-1} \cdot \min_{k,\ell} (f^{(m+1)T+t}(S_k^t, Q_\ell^{t+1}) - f^{mT+t}(S_k^t, Q_\ell^{t+1})] \qquad \forall i, j \qquad (5.11)$$

With these definitions of $U_t^m(i, j)$ and $L_t^m(i, j)$, Su and Deininger (1972) show that for all m,

$$L_t^m(i, j) \leq f^{t^*}(S_i^t, Q_j^{t+1}) \leq U_t^m(i, j) \qquad \forall i, j \qquad (5.12)$$

Further, $U_t^m(i, j)$ monotonically decreases to $f^{t^*}(S_i^t, Q_j^{t+1})$ as m increases, and $L_t^m(i, j)$ monotonically increases to $f^{t^*}(S_i^t, Q_j^{t+1})$ as m increases. Thus, the estimate of $f^{t^*}(S_i^t, Q_j^{t+1})$ given in Equation (5.9) has an associated maximum error at cycle m+1 of

$$e_{max}(i, j) = \frac{U_t^m(i, j) - L_t^m(i, j)}{2} \qquad \forall i, j \qquad (5.13)$$

Allowing a maximum error of $100 \cdot \varepsilon(i, j)$ percent, the procedure can be terminated at cycle m'+1 if for all states (S_i^t, Q_j^{t+1})

$$e_{max}(i, j) \leq \varepsilon(i, j) \cdot L_t^{m'}(i, j) \qquad \forall i, j \qquad (5.14)$$

For the discounted case, this study sets $\varepsilon(i, j)$ equal to 0.01 for all i and j. Again, convergence is tested only when $t = 1$.

5.4 Steady-State Release Policies

Using the discrete storage, inflow and transition probability values of Section 5.2 and the computational considerations of Section 5.3, the steady-state algorithm is applied to eleven different system configurations, which are presented in Table 5.5. In the analysis to follow, discussion focuses upon selected monthly release policies from six of these experiments (i.e., system configurations), illustrating effects associated with the five variables of Table 5.5. Figures 5.1-5.12 are provided for discussion purposes.

5.4.1 Experiment 1 - General Characteristics

For all experiments, several distinct characteristics of the derived steady-state release policies can be observed. Experiment 1 is used to illustrate these general characteristics, providing a basis for subsequent discussions on alternate parameter sets.

Displayed in Figures 5.1, 5.2 and 5.3 are the steady-state release policies of (respectively) February, May and September for Experiment 1. Optimal release decisions, given on the ordinate of each graph, are plotted as a function of the two state variables. Storage (expressed in terms of elevation by Equation (5.1)) is given by the abscissa, and the previous month's inflow (discretized into five values) is given by one of five separate curves on each graph. Squares in the upper curve and triangles in the lower indicate the location of the discrete values of storage (elevation) given in Table 5.4. From these figures, four significant features can be noticed.

Experiment	Objective* Function	r**	Toshka	Sudan*** Losses	T_D****
1	1	0	No	16.5	7.6
2	1	0	No	16.5	8.4
3	1	0	No	18.5	7.6
4	1	0	Yes	16.5	7.6
5	1	0	Yes	18.5	7.6
6	1	0.01	No	16.5	7.6
7	1	0.01	No	16.5	8.4
8	1	0.01	Yes	16.5	7.6
9	1	0.01	Yes	18.5	7.6
10	2	0	No	16.5	7.6
11	2	0.01	No	16.5	7.6

* $1 \rightarrow a_1 = 10^7$; $a_2 = 10^4$; $a_3 = 10^3$

$2 \rightarrow a_1 = 0$; $a_2 = 0$; $a_3 = 10^3$

** Monthly Discount Rate

*** Annual Losses to Sudan Abstractions and Gebel Aulia Reservoir (md)

**** Erosion Causing Release (md/month)

Table 5.5

System Configurations for which Steady-State Release Policies are Derived

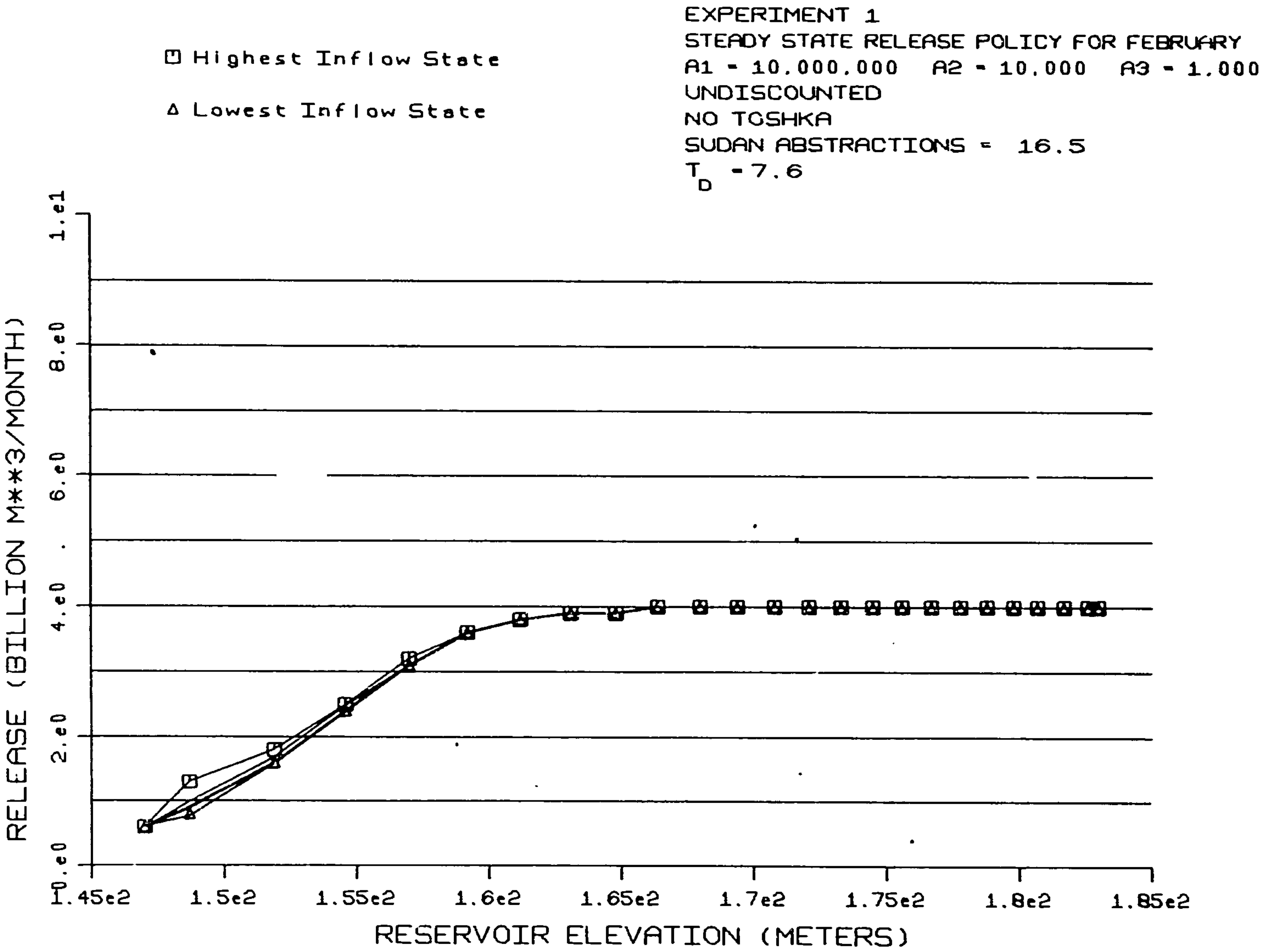


Figure 5.1
Steady-State Release Policy of February for Experiment 1

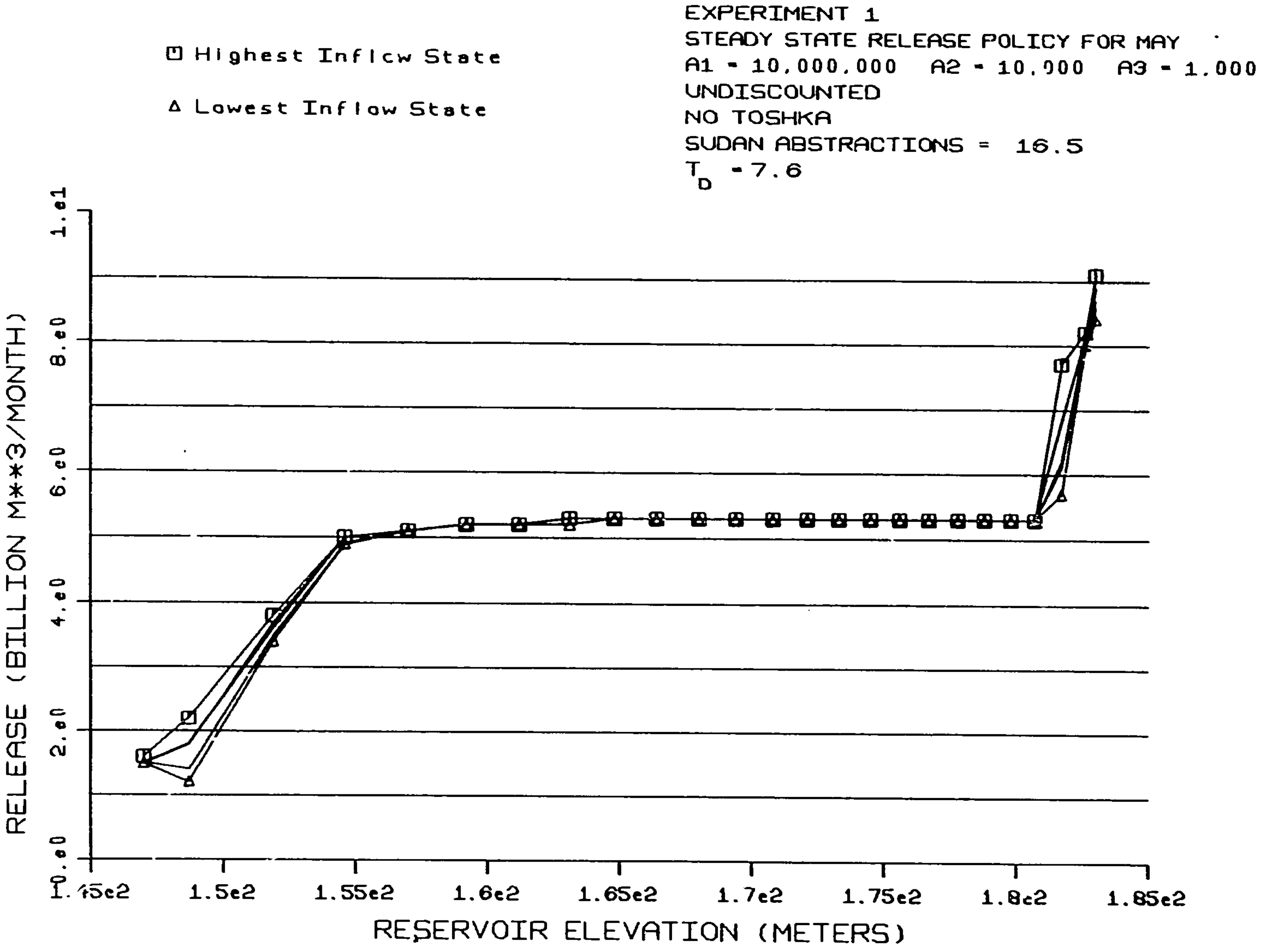


Figure 5.2
Steady-State Release Policy of May for Experiment 1

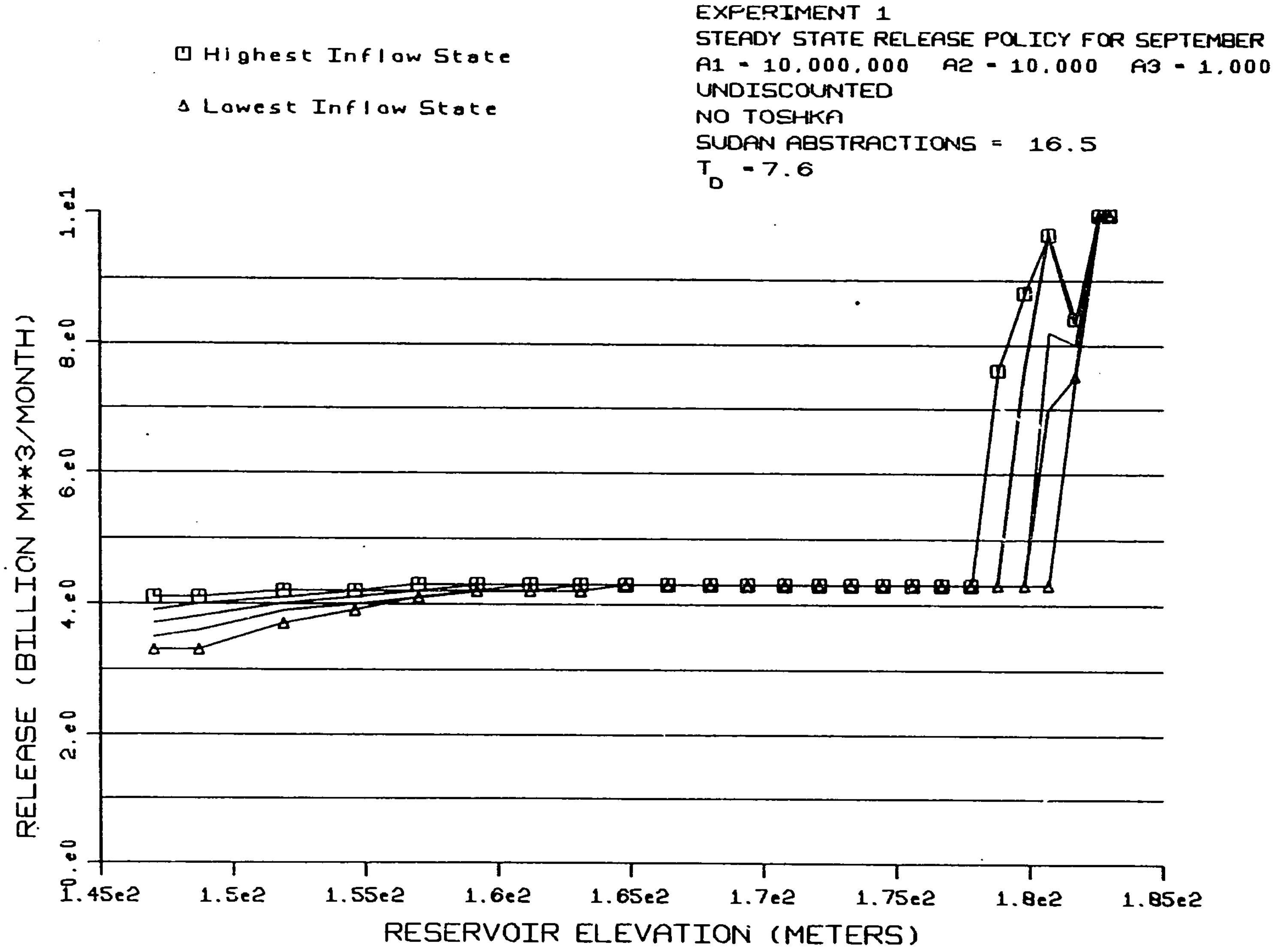


Figure 5.3
Steady-State Release Policy of September for Experiment 1

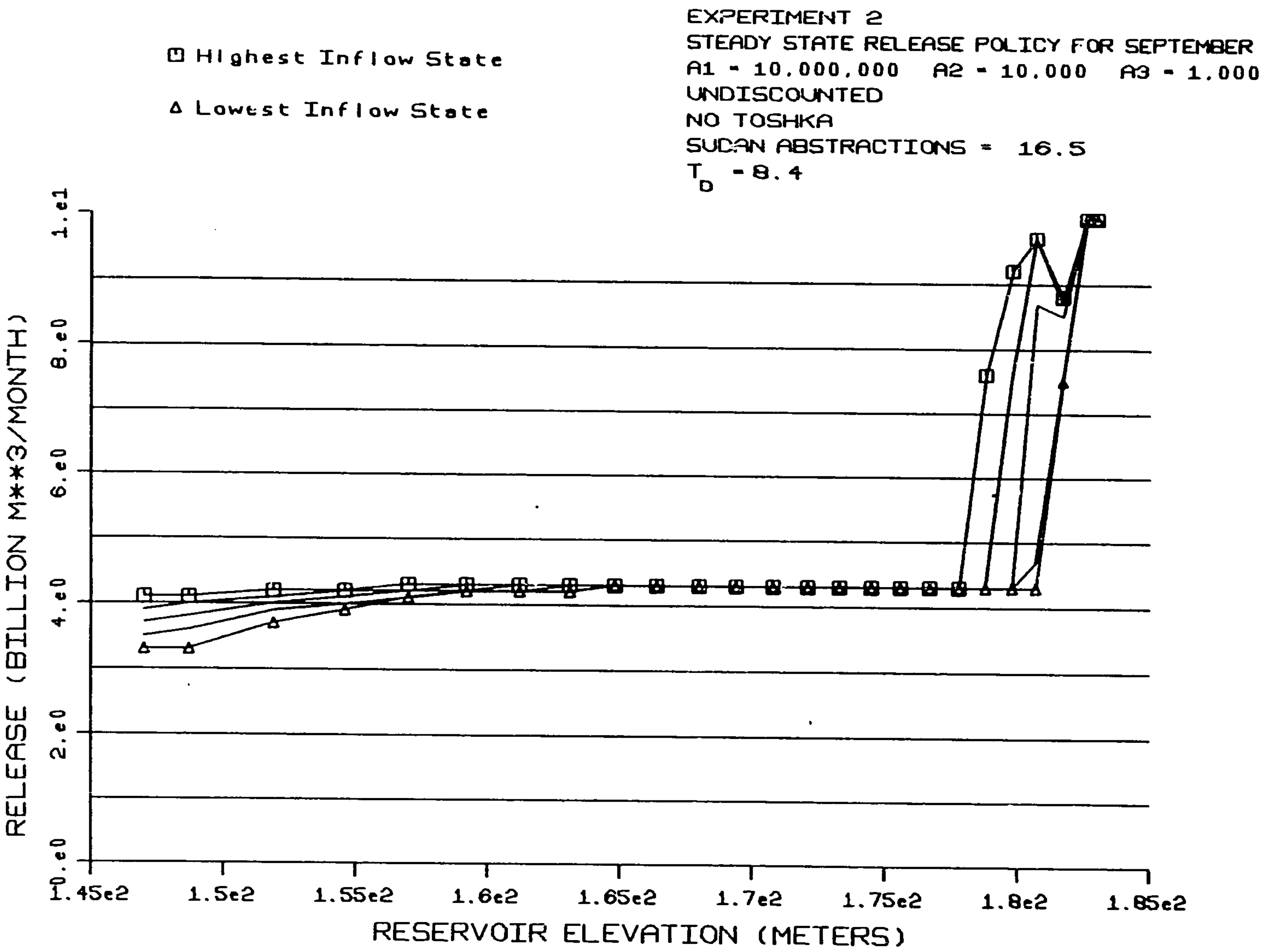


Figure 5.4
Steady-State Release Policy of September for Experiment 2

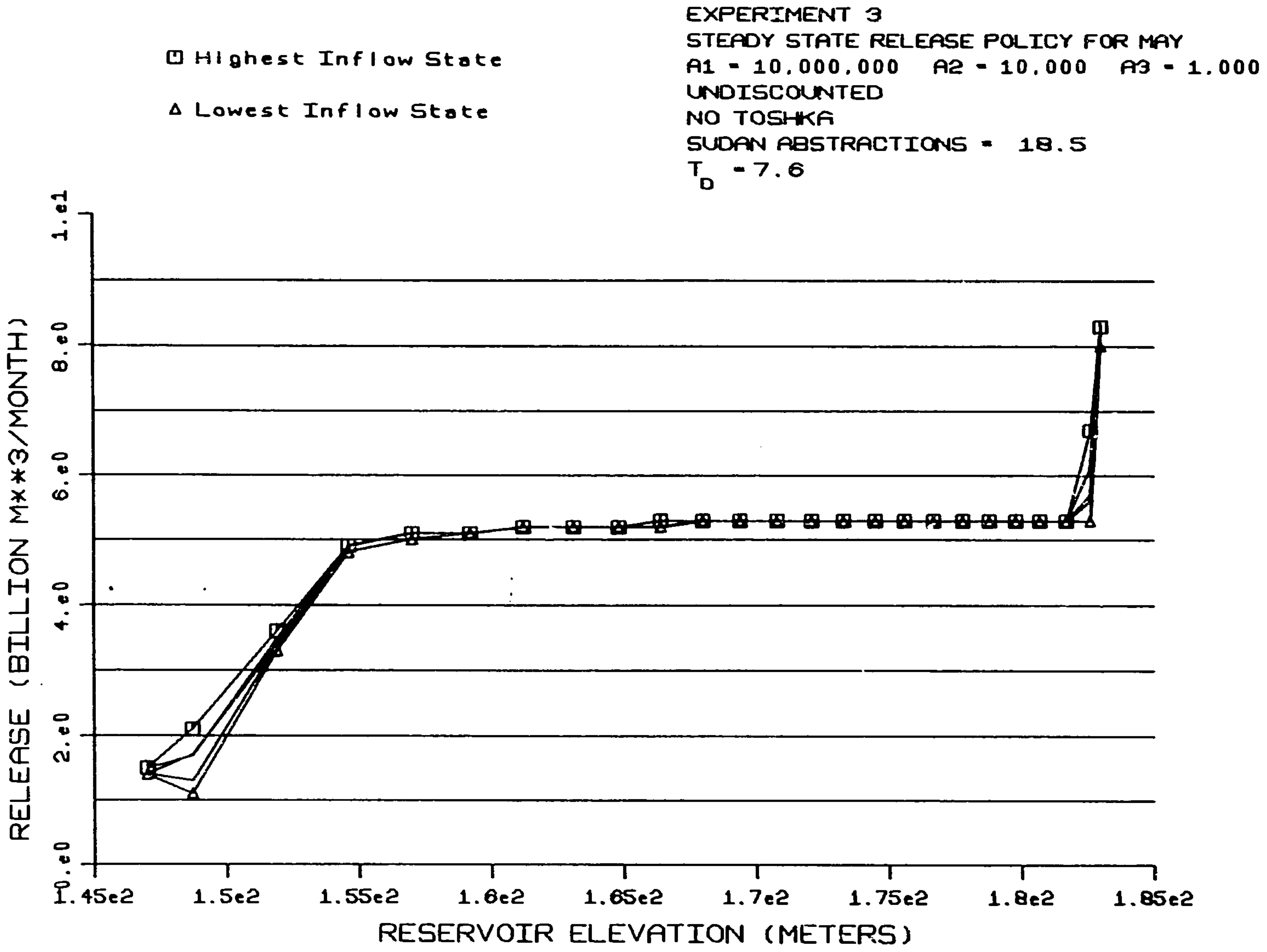


Figure 5.5
Steady-State Release Policy of May for Experiment 3

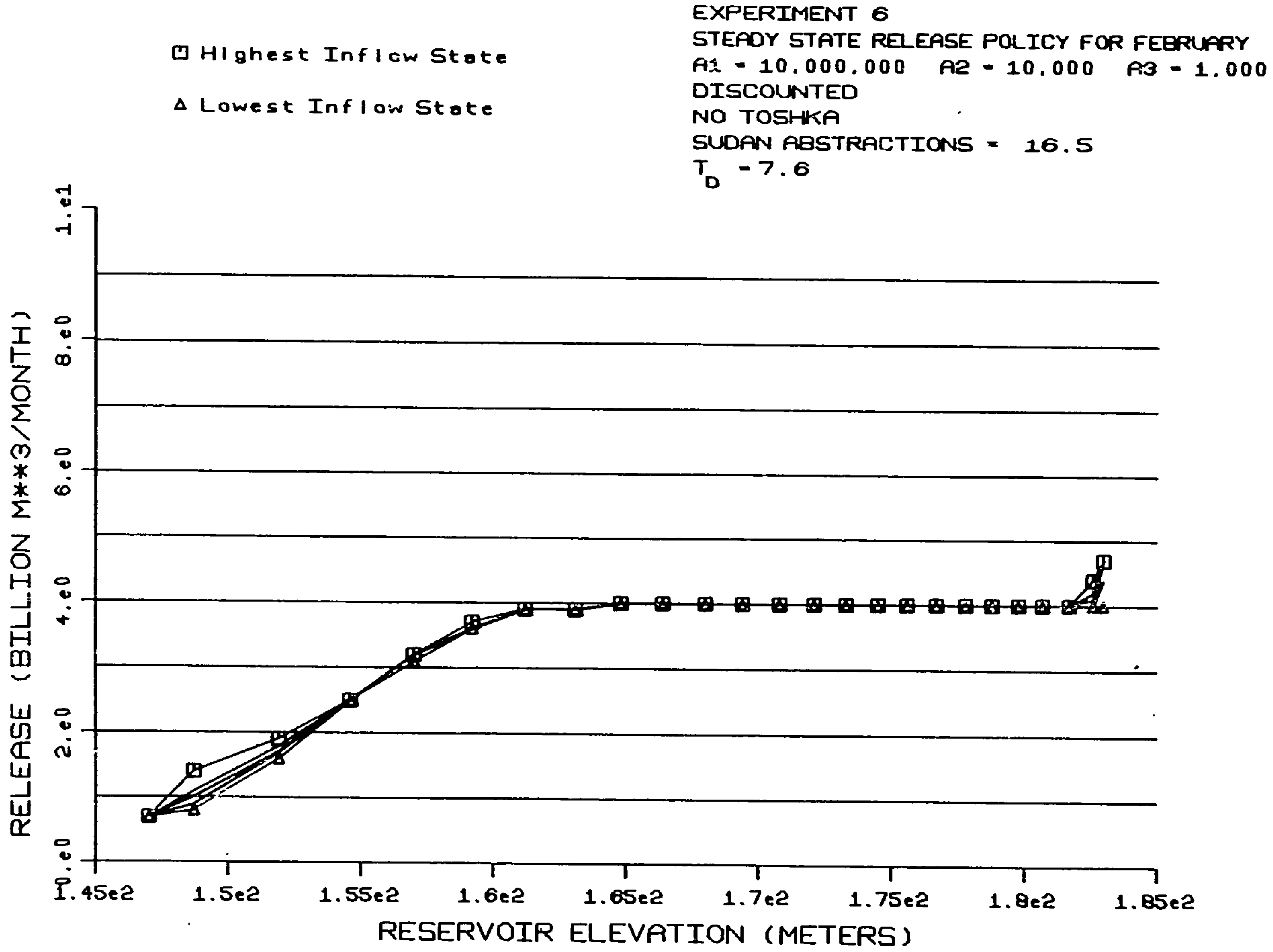


Figure 5.6
Steady-State Release Policy of February for Experiment 6

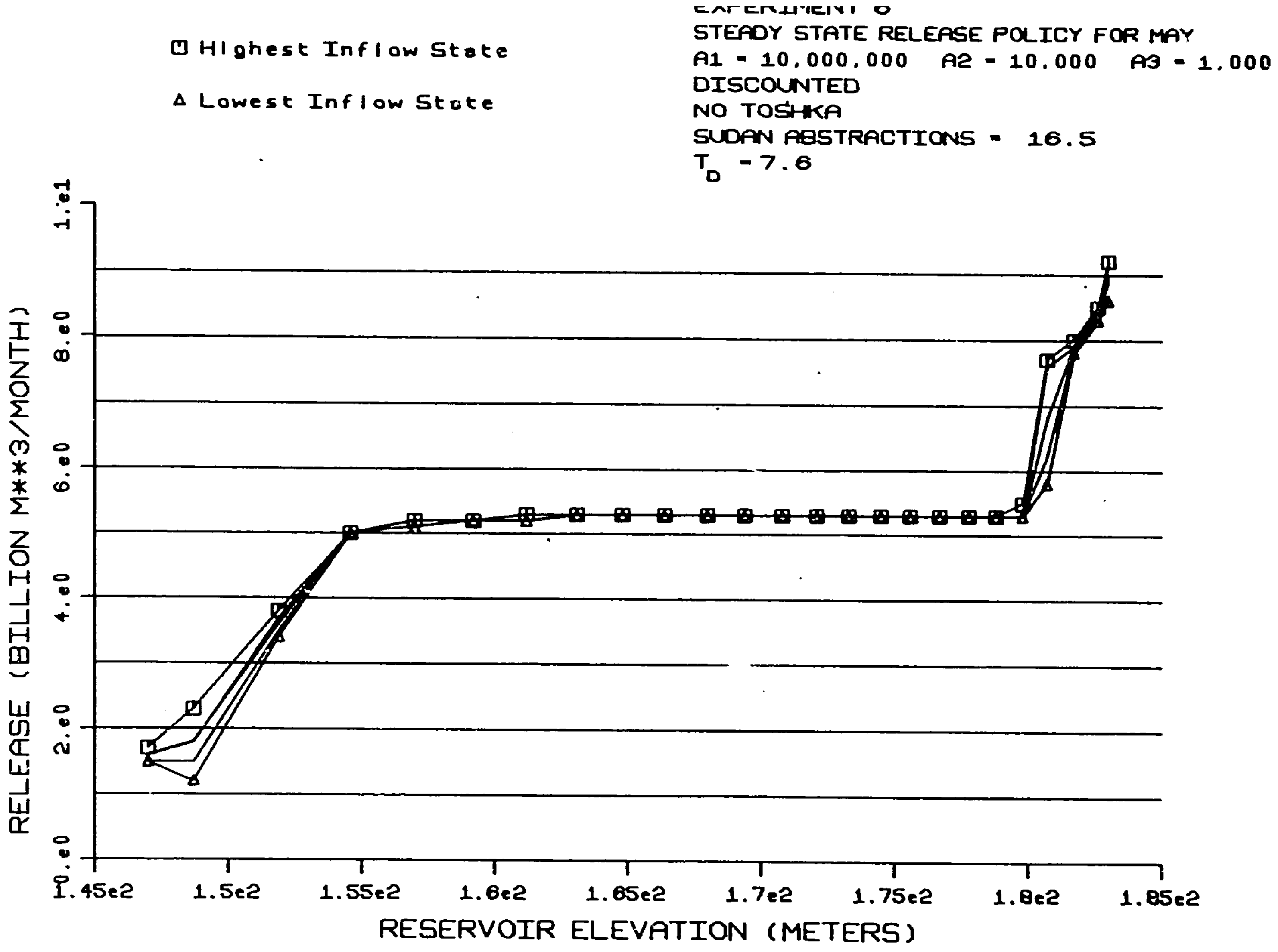


Figure 5.7
Steady-State Release Policy of May for Experiment 6

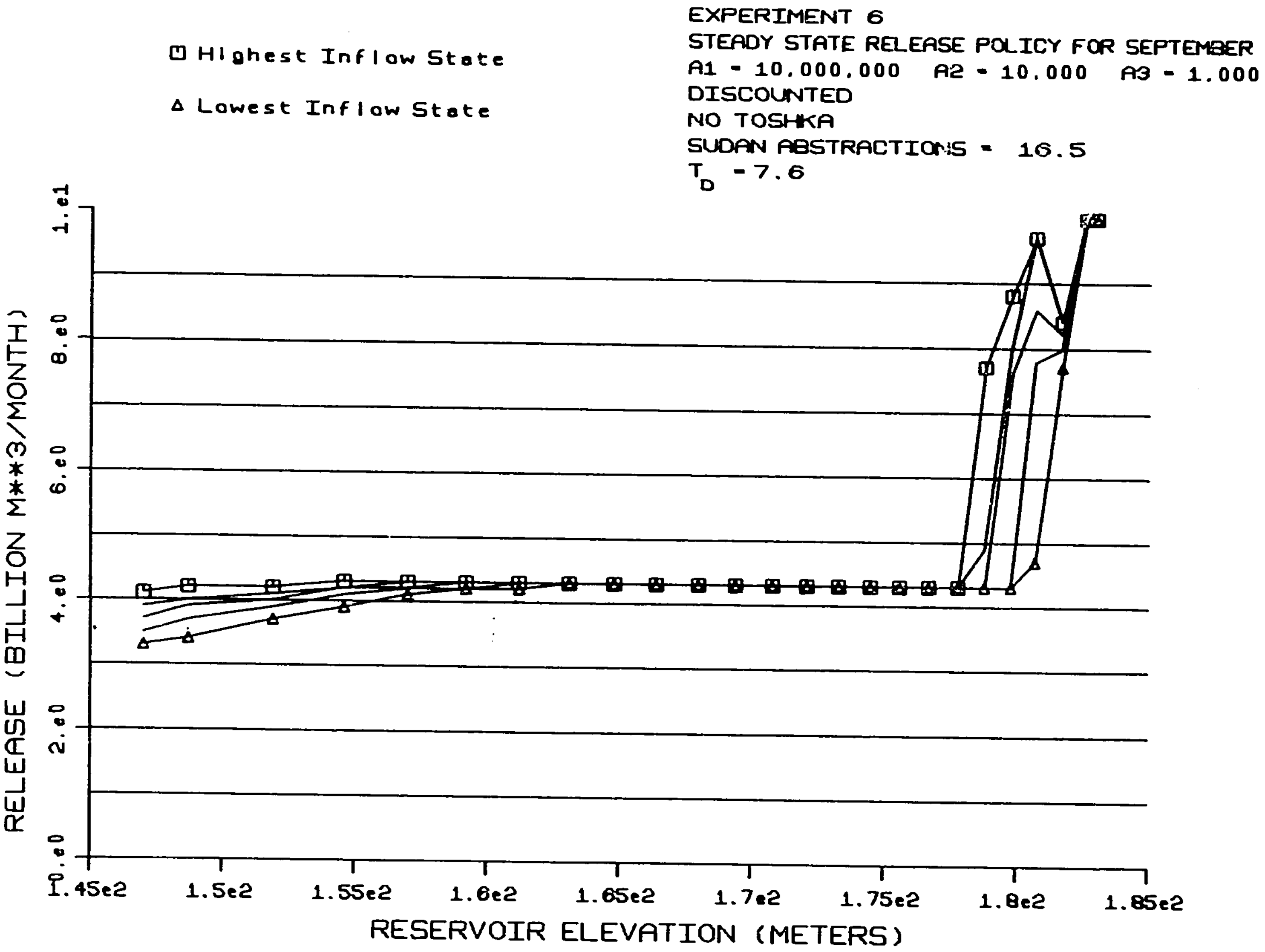


Figure 5.8
Steady-State Release Policy of September for Experiment 6

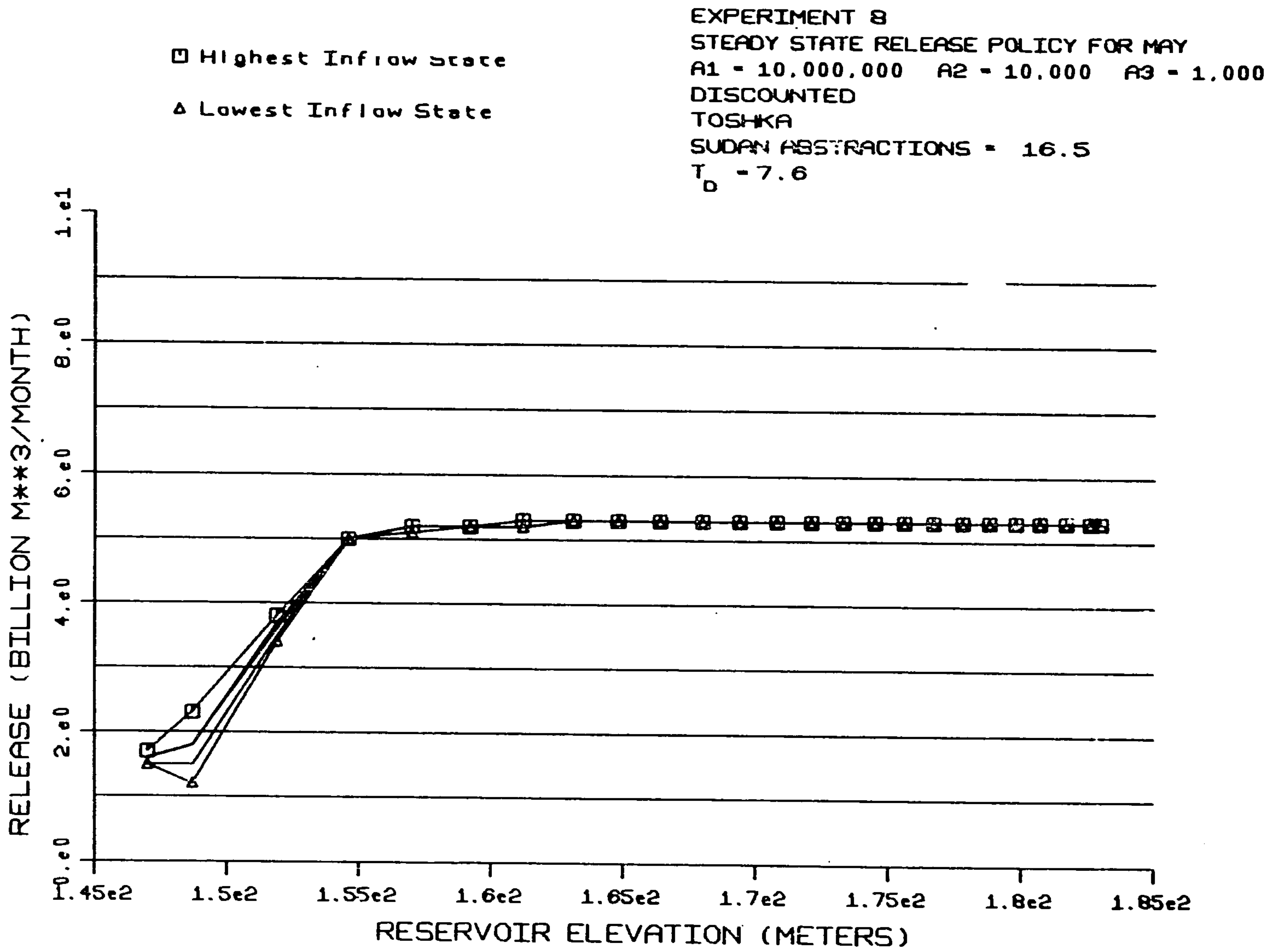


Figure 5.9
Steady-State Release Policy of May for Experiment 8

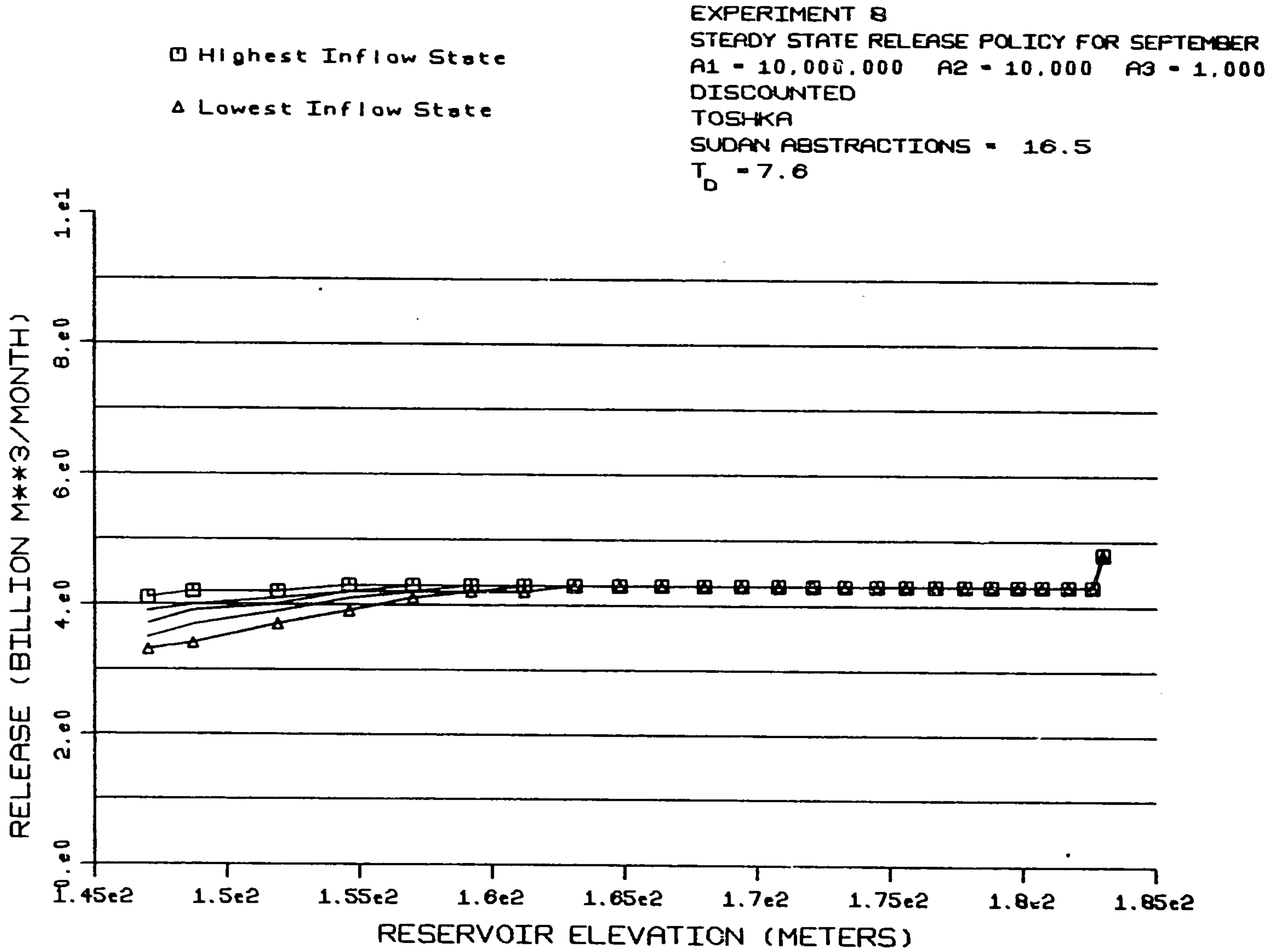


Figure 5.10
Steady-State Release Policy of September for Experiment 8

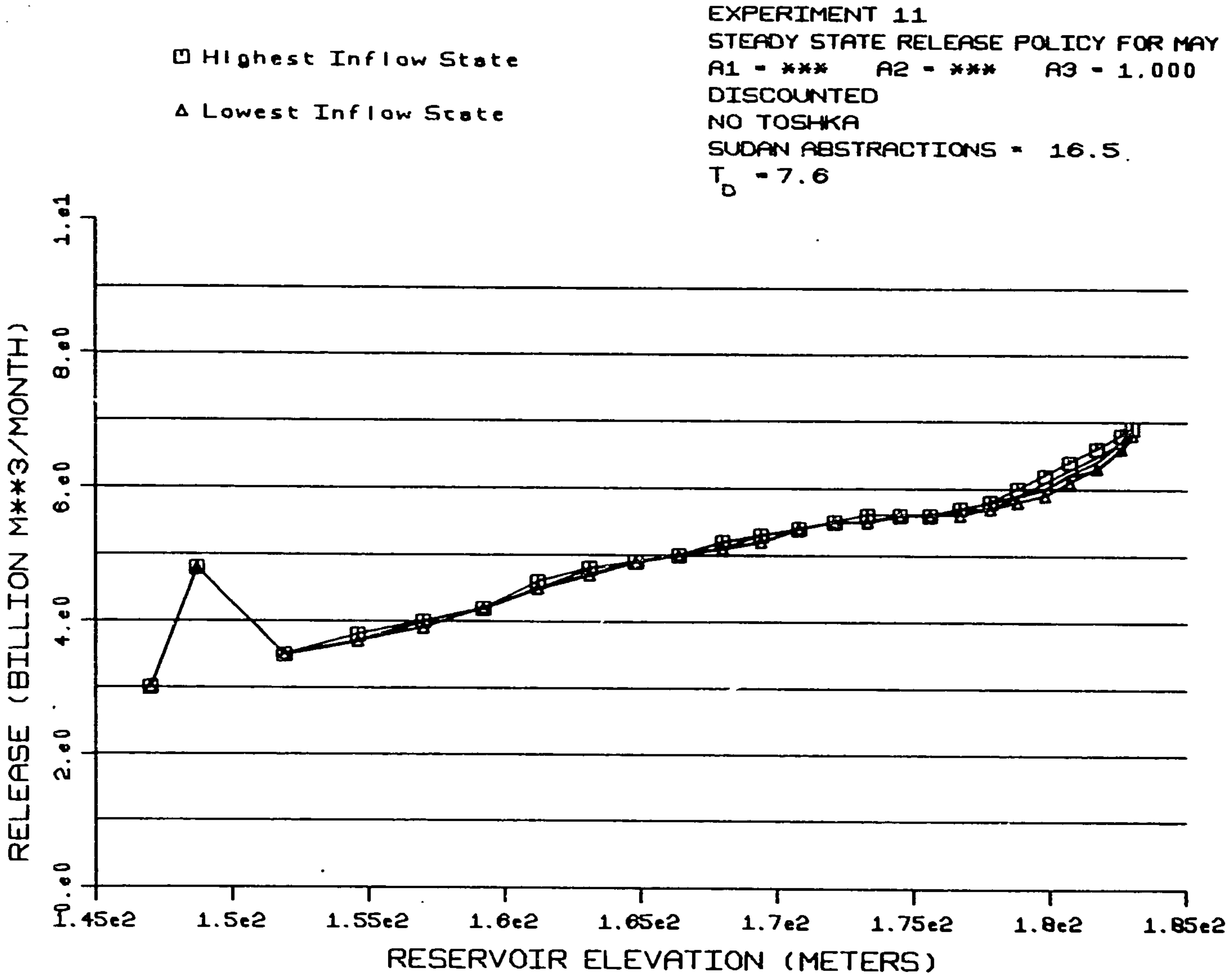


Figure 5.11
Steady-State Release Policy of May for Experiment 11

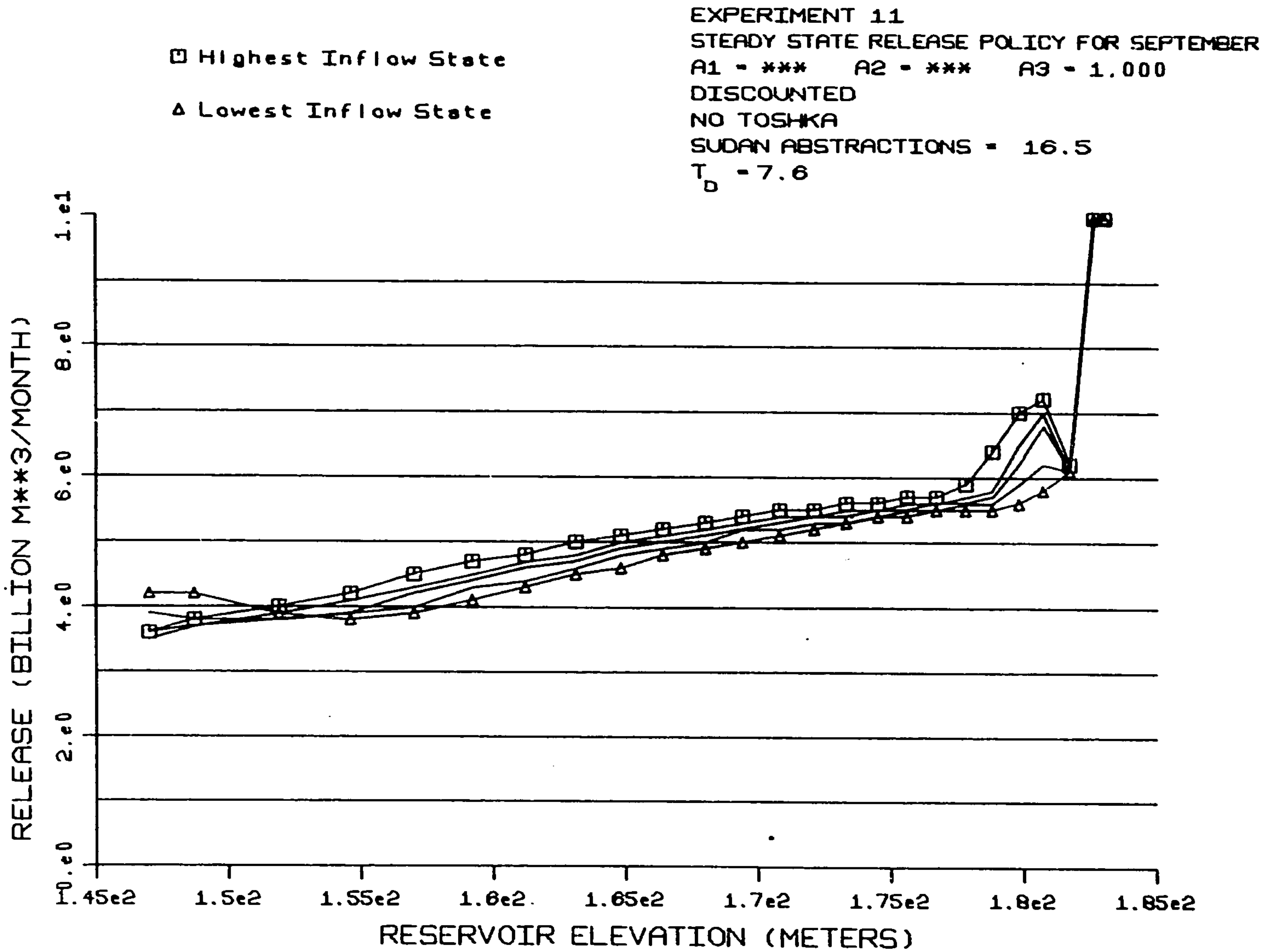


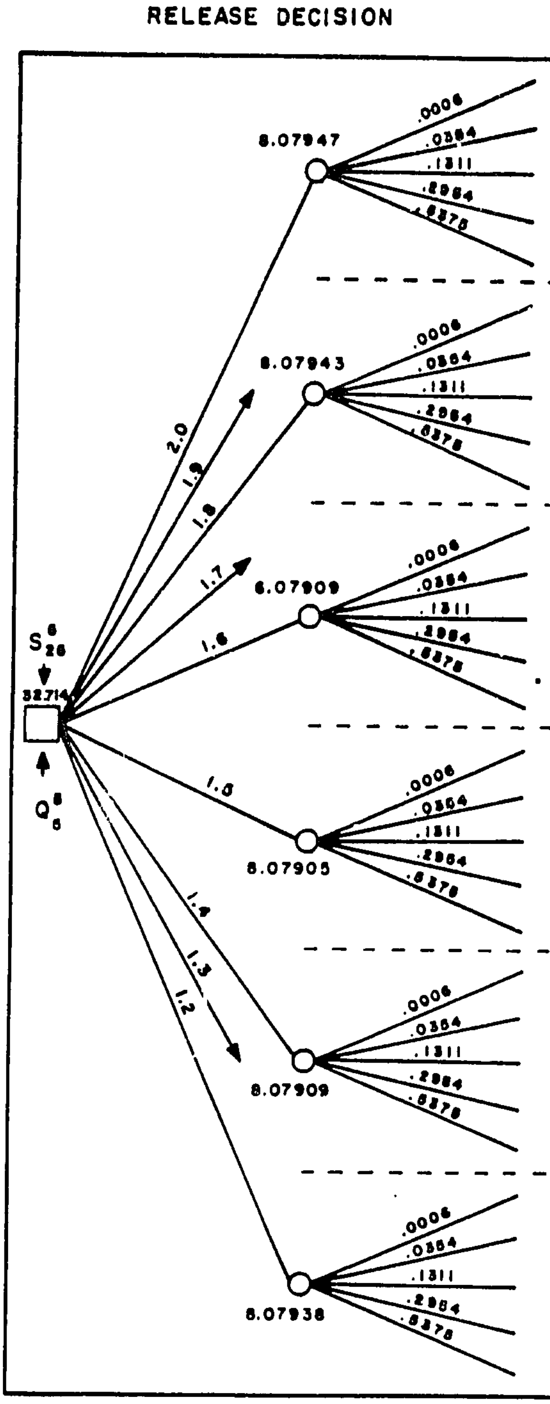
Figure 5.12
Steady-State Release Policy of September for Experiment 11

First is the sensitivity of a given monthly release policy to the previous month's inflow. For example, in Figure 5.1, the lack of differentiation between the five curves indicates that the release for February is not very dependent upon the inflow of January. On the other hand, the release for September (Figure 5.3) can be highly dependent upon the inflow of August, while May (Figure 5.2) shows a moderate dependence upon April's inflow. This variable dependence upon the inflow state can be attributed to several factors. The lag-one correlation coefficient is probably the most influential since higher lag-one correlation coefficients directly imply higher dependence, and vice versa. However, of comparative influence is the monthly inflow variance. A tight variance for a particular month will tend to dampen any correlation with the previous month, as the discretized inflow states will be very similar. In the limit, a variance of zero for a given month will result in identical curves for each inflow state, since the upcoming inflow is deterministic. Conversely, months with a large variance will tend to exhibit a more pronounced dependence upon the previous inflow, assuming the correlation is non-zero. Considering these two factors alone, the observed behavior of Figures 5.1-5.3 is consistent with the sample statistics presented in Table 2.1. Of course, other factors can contribute to the separation of release curves for different inflow states, including the objective function, the increment used in the optimal release search and the degree to which convergence has occurred. These factors will not be discussed here.

A second feature is the sometimes unexpected behavior of monthly release policies at extremely low and high reservoir elevations. The release policy of May (Figure 5.2) implies that for the two lowest inflow states (two lowest curves), smaller releases are recommended for elevation 148.74 m (storage = 35.67 md) than for the lower elevation of 147.0 m (storage = 32.71 md). Similarly, during the month of September (Figure 5.3), a dip occurs in the operating rules of very high inflow states (at high elevations) indicating smaller releases for higher elevations, again a counterintuitive result. These local aberrations can be traced to discontinuities introduced in the solution by constraints in reservoir storage (Equations 3.6b and c) and necessary state discretization.

The above is best illustrated by studying the search for optimal releases given the lowest possible inflow state in May combined with the lowest and second lowest storage states. The two states investigated are then represented by vectors $(S_{25}^{8}, Q_{5}^{9}) = (32.71, 0.743)$ and $(S_{24}^{8}, Q_{5}^{9}) = (35.67, 0.743)$. The above storages correspond to elevations 147.0 m and 148.74 m (from Table 5.4).

Figures 5.13 and 5.14 schematize the search procedure. The starting square at the left represents the state, and the branching rays are possible releases over which the search for optimality occurs. Adjacent to each circle is the expected cost of the decision, where expectation is performed using the inflow probabilities given in the next set of branching rays. Columns 1 through 5 give respectively the possible inflows, resulting storages (after imposing constraints

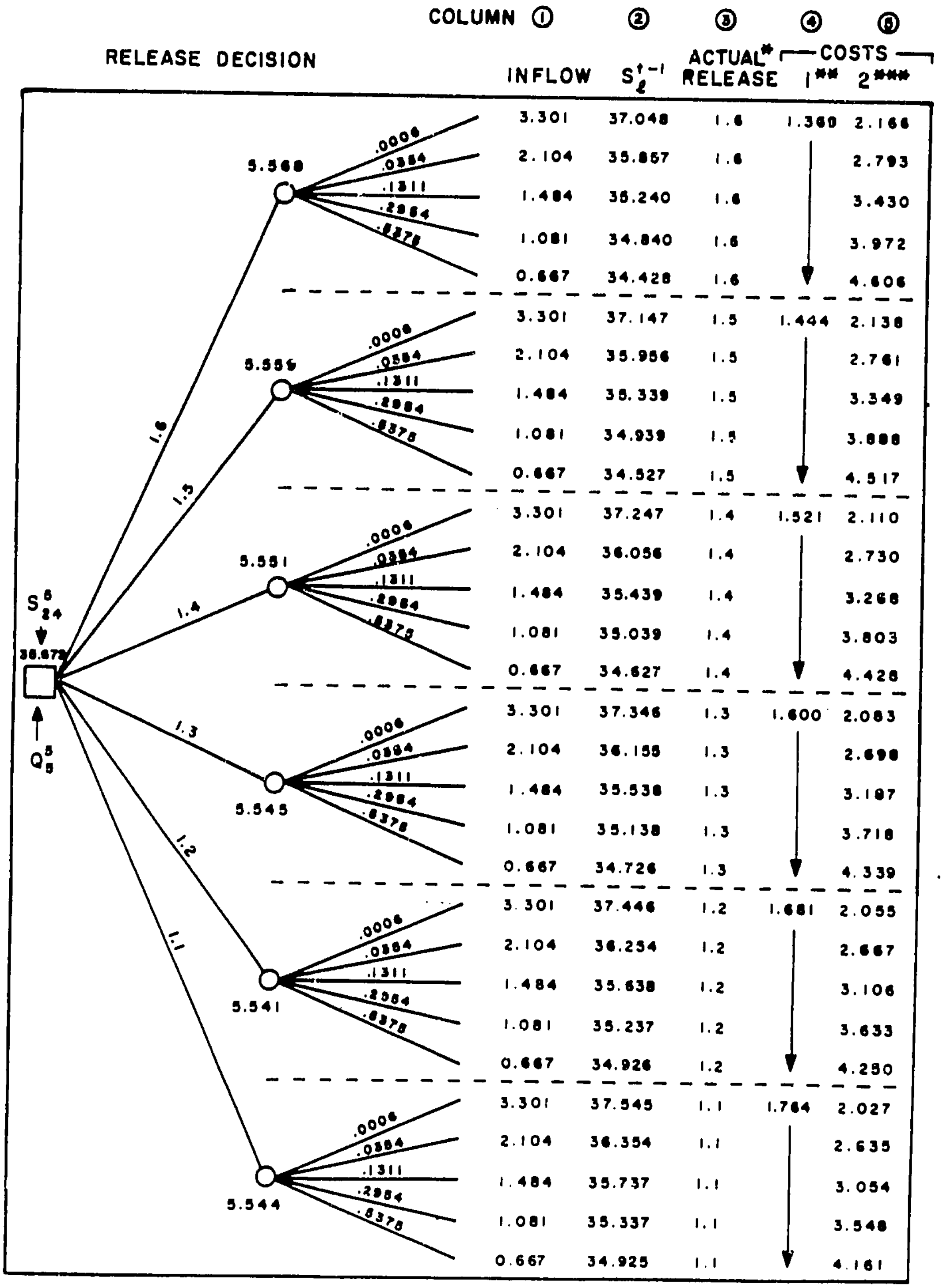


COLUMN ① INFLOW	② S_{ℓ}^{t-1} *	③ ACTUAL* RELEASE	④ COSTS 1**	⑤ COSTS 2***
3.301	33.722	2.0	1.08962	3.90660
2.104	32.714	1.816	1.21403	5.11907
1.484	32.714	1.196	1.68452	5.48803
1.081	32.714	0.793	2.03120	5.78433
0.667	32.714	0.379	2.42141	6.14276
3.301	33.921	1.8	1.22502	3.76833
2.104	32.730	1.8	1.22502	5.10708
1.484	32.714	1.196	1.68452	5.48803
1.081	32.714	0.793	2.03120	5.78433
0.667	32.714	0.379	2.42141	6.14276
3.301	34.120	1.6	1.36902	3.63007
2.104	32.929	1.8	1.36902	4.95470
1.484	32.714	1.196	1.68452	5.48803
1.081	32.714	0.793	2.03120	5.78433
0.687	32.714	0.379	2.42141	6.14276
3.301	34.219	1.5	1.44402	3.56094
2.104	33.028	1.5	1.44402	4.87851
1.484	32.714	1.196	1.68452	5.48803
1.081	32.714	0.793	2.03120	5.78433
0.667	32.714	0.379	2.42141	6.14276
3.301	34.319	1.4	1.52102	3.49181
2.104	33.128	1.4	1.52102	4.80232
1.484	32.714	1.196	1.68452	5.48803
1.081	32.714	0.793	2.03120	5.78433
0.867	32.714	0.379	2.42141	6.14276
3.301	34.517	1.2	1.66102	3.35354
2.104	33.327	1.2	1.68102	4.64994
1.484	32.714	1.196	1.68452	5.46803
1.081	32.714	0.793	2.03120	5.78433
0.667	32.714	0.379	2.42141	6.14276

* As given by constraints 3.6 a, b and c.
** Immediate costs, based upon releases in column 3 (units in 10^{-8})
*** Future expected (units in 10^{-8})

Figure 5.13

Optimal Release Search for May Starting from Lowest Storage State and Lowest Inflow State



COLUMN ① INFLOW	② S_ℓ^{t-1}	③ ACTUAL* RELEASE	④ COSTS 1**	⑤ COSTS 2***
3.301	37.048	1.6	1.360	2.166
2.104	35.857	1.6		2.793
1.484	35.240	1.6		3.430
1.081	34.840	1.6		3.972
0.667	34.428	1.6		4.606
3.301	37.147	1.5	1.444	2.138
2.104	35.956	1.5		2.761
1.484	35.339	1.5		3.349
1.081	34.939	1.5		3.888
0.667	34.527	1.5		4.517
3.301	37.247	1.4	1.521	2.110
2.104	36.056	1.4		2.730
1.484	35.439	1.4		3.268
1.081	35.039	1.4		3.803
0.667	34.627	1.4		4.428
3.301	37.346	1.3	1.600	2.083
2.104	36.155	1.3		2.698
1.484	35.538	1.3		3.187
1.081	35.138	1.3		3.718
0.667	34.726	1.3		4.339
3.301	37.446	1.2	1.681	2.055
2.104	36.254	1.2		2.667
1.484	35.638	1.2		3.106
1.081	35.237	1.2		3.633
0.667	34.926	1.2		4.250
3.301	37.545	1.1	1.764	2.027
2.104	36.354	1.1		2.635
1.484	35.737	1.1		3.054
1.081	35.337	1.1		3.548
0.667	34.925	1.1		4.161

* As given by constraints 3.6 a, b and c .

** Immediate costs, based upon releases in column 3 (units in 10^{-8})

*** Future expected (units in 10^{-8})

Figure 5.14

Optimal Release Search for May Starting from Second Lowest Storage State and Lowest Inflow State when binding), implied releases (which may differ from initiating value due to storage constraints), immediate costs and expected future costs ($f^{\cdot}(S_i^7, Q_j^8)$, from Table 5.6).

From Figure 5.13 (Columns 2 and 3), it is clear that the storage constraint given by Equation (3.6c) is binding for all releases above 1.2 md and the three lowest inflows, thus altering the release and final storage. The constraint is not binding when the storage state is 35.67 (148.74 m elevation) as Figure 5.14 indicates. The minimum expected cost is shown to occur for a potential 1.5 md release for the lower storage (Figure 5.13) and 1.2 md for the higher storage (Figure 5.14). However, the decision to release 1.5 md for the lower storage state is seen to be conditional upon the occurrence of a sufficient inflow, while the 1.2 md release for the higher storage state is unconditional. In fact, the "optimal" suggested 1.5 md release in Figure 5.13 will rarely occur since the actual release will usually be determined (with over 0.95 probability) by the storage constraint, giving releases not only much less than 1.5, but also much less than 1.2 md (see 1.5 md releases in Column 3, Figure 5.13). The same explanation holds for the two highest inflow states and the storage state of 160.02 (elevation = 181.66) for September. In these cases, the suggested release of 8.4 md will be superseded by system constraint considerations with 0.997 and 0.920 probabilities for the highest and second highest inflow states respectively, with actual releases generally exceeding 10.0 md. It should be noted that such releases are extremely high, but it is unlikely that the system would ever be in such a state.

Storage State (md)	Inflow State (md)				
	3.301	2.104	1.484	1.081	0.667
168.90	-428109	-481760	-517936	-545945	-578795
165.94	-573509	-615291	-643530	-665266	-690688
160.02	-775689	-794457	-806830	-816151	-826894
154.10	-861359	-862875	-864281	-865522	-866208
148.18	-860392	-849937	-840734	-832490	-821674
142.25	-769835	-742189	-720635	-702475	-679646
136.33	-584660	-539908	-506119	-478150	-443445
130.41	-305376	-243450	-197324	-159429	-112657
124.49	69889	150241	209743	258473	318481
118.57	551278	652668	727553	788799	864156
112.65	1156606	1283105	1376451	1452770	1546664
106.73	1913105	2070647	2186916	2282010	2399054
100.81	2880491	3057637	3203271	3322485	3469349
94.89	4054455	4305834	4490197	4641312	4827716
88.96	5586588	5906024	6142861	6337315	6577556
83.04	7576028	7992730	8302463	8556282	8872725
77.12	10215705	10770932	11184994	11526543	11950408
71.20	13818109	14579408	15149660	15621689	16209412
65.28	18927962	20004892	20809843	21478002	22312830
59.36	26446953	28042598	29245778	30247885	31504316
53.44	38024026	40490133	42351437	43896547	45811984
47.52	56017733	59877420	62818732	65297971	68372109
41.60	89713124	97397820	103098378	107698134	113457225
35.67	254888044	285059120	307528016	326003740	348837496
32.71	460699100	511906452	548802664	578433176	614275512

Table 5.6

Expected Future Costs for Discrete States of June

Calculated During Cycle of Convergence

A third feature to be noticed is that each monthly release policy essentially reproduces the zone concept found in the current operating philosophy. For example, Figures 5.1-5.12 each display a continuous range of elevations for which only the monthly downstream demands are released regardless of the inflow state. Since the operating rule for this range of elevations is identical to that currently used for Zone C of Figure 2.3 (see Section 2.3.5 for current operating rules), this range of elevations will henceforth be referred to as the conservation zone. Likewise, both a buffer zone (equivalent to Zone B of Figure 2.3) and a flood zone (Zones D and E of Figure 2.3) can be designated for steady-state release policies, being those regions of live storage below and above the conservation zone. Using these classifications, the zone locations for Figures 5.1-5.10 are given in Figure 5.15. From the figure, it can be seen that the zone locations are a function not only of the system configuration, but of the month as well.

As a final observation, notice that each monthly policy appears to exhibit a different release attitude in relation to the proximity of the flood season. Comparing Figures 5.1-5.3, the release policy for February is clearly the most conservative, showing a conservation zone extending upward to the maximum reservoir elevation of 183.0 m. This behavior actually is not unusual, since the flood season is still five months away and the lag-one correlation coefficients cannot be expected to contain significant information on upcoming flood magnitudes. The release policy for May (Figure 5.2) is obviously less conservative from several viewpoints. First, Figure 5.2 shows that flood control measures

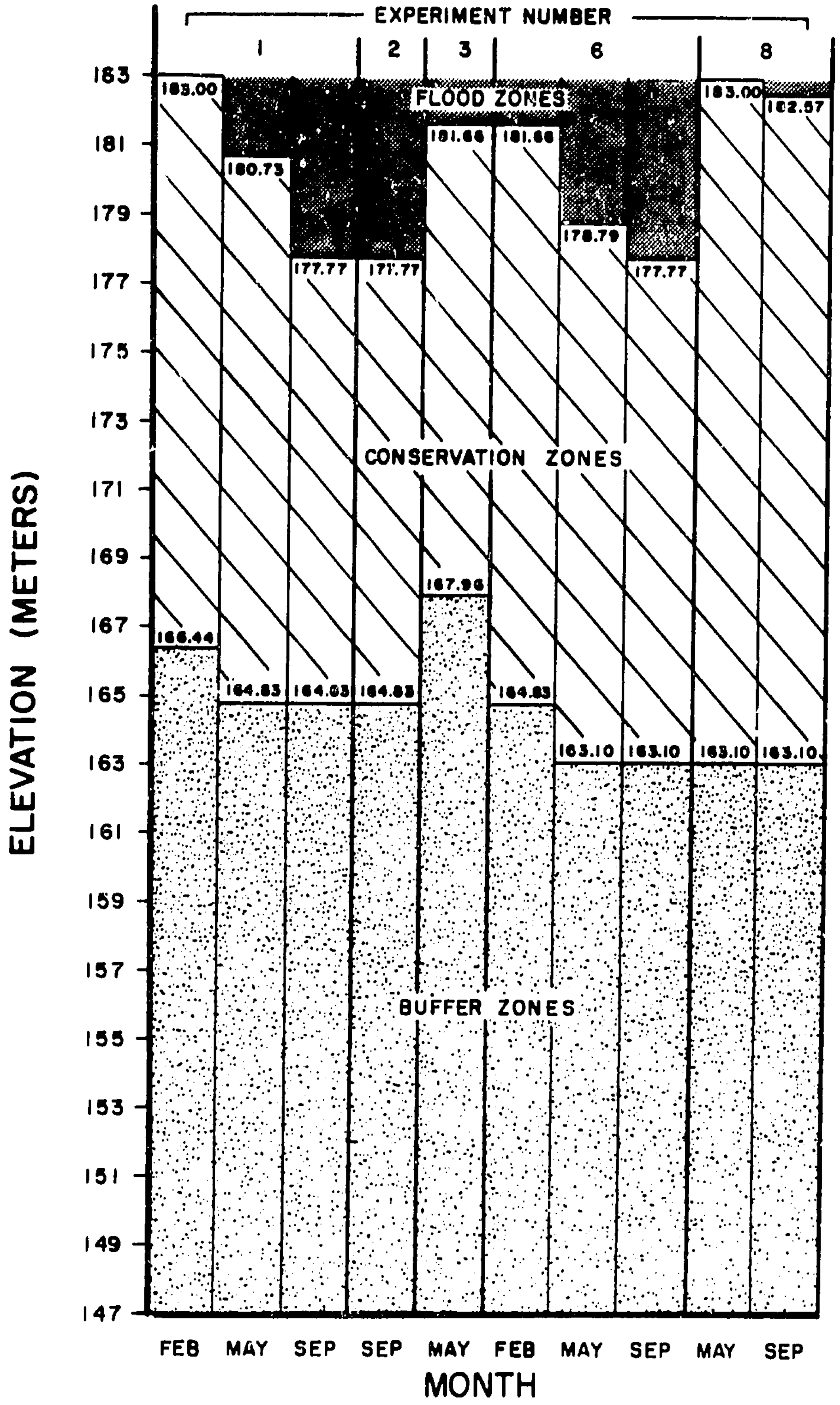


Figure 5.15

Zone Locations for Selected Steady-State Release Policies now exist for high reservoir elevations. Second, the conservation zone extends downward to the lower elevation of 164.83 m. Third, the operating rules of the buffer zone do not call for major deficit releases until the reservoir elevation drops below 154.59 m, unlike the February release policy. Altogether, these observations comply with the fact that the flood season is now only three months ahead. Finally, the release policy for the flood month of September shows a much more pronounced flood zone, as to be expected. Further, the buffer zone operating rules show much less sensitivity to reservoir elevations, perceiving that even the lowest of inflows will not leave a depleted reservoir. This overall trend can be observed in all monthly release policies of Experiment 1, with conservation minded policies of November through March developing to flood preparation policies of April to July, culminating in flood control policies of August through October.

The above discussion can be extended to all experiments performed here, with the exception of Experiments 10 and 11, where the zone concept is not displayed. In the remainder of this section, release policies for February, May and September will be presented for alternate parameter sets in order to illustrate changes in zone locations and their corresponding operating rules.

5.4.2 Experiment 2 - Degradation Causing Release

As indicated in Table 5.5, Experiment 2 differs from Experiment 1 in the designation of T_D (see Equation 3.17). Degradation causing releases are now assumed to be those over 8.4 md.

The monthly release policies displaying any sensitivity to this modification are the months of April through September, but changes are almost negligible. For the remaining months of October through March, results are identical to those of Experiment 1. The most sensitive month, September, exhibits changes in the flood zone operation (relative to Figure 5.3). However, the observed differences in Figure 5.4 cannot be considered significant to flood management policies. Given this lack of sensitivity to variations in the degradation causing releases (T_D), this parameter will be fixed at 7.6 md for the rest of the performed experiments.

5.4.3 Experiment 3 - Sudan Abstractions

Experiment 3 investigates the effects of increasing annual water losses in Sudan from 16.5 to 18.5 md, the latter being the amount allocated to the Sudan by the 1959 Nile Agreement. Discrete inflow values are now those given in Table 5.2b. Changes are well illustrated by the new release policy for May (Figure 5.5). The resulting lower releases seen in the flood zone can be expected, since less water is now available annually to meet downstream demands. Some change can also be noticed in each zone location, with an upward shift of the buffer and conservation zones taking place due to the need to conserve water. In fact, this is a common result in the release policies for all months, as illustrated in Figure 5.16. From this figure, an upward shift averaging more than three meters can be observed in the monthly upper bounds of the buffer zone. The upper bound of the conservation zone, whenever possible, likewise shifts upward, considerably reducing

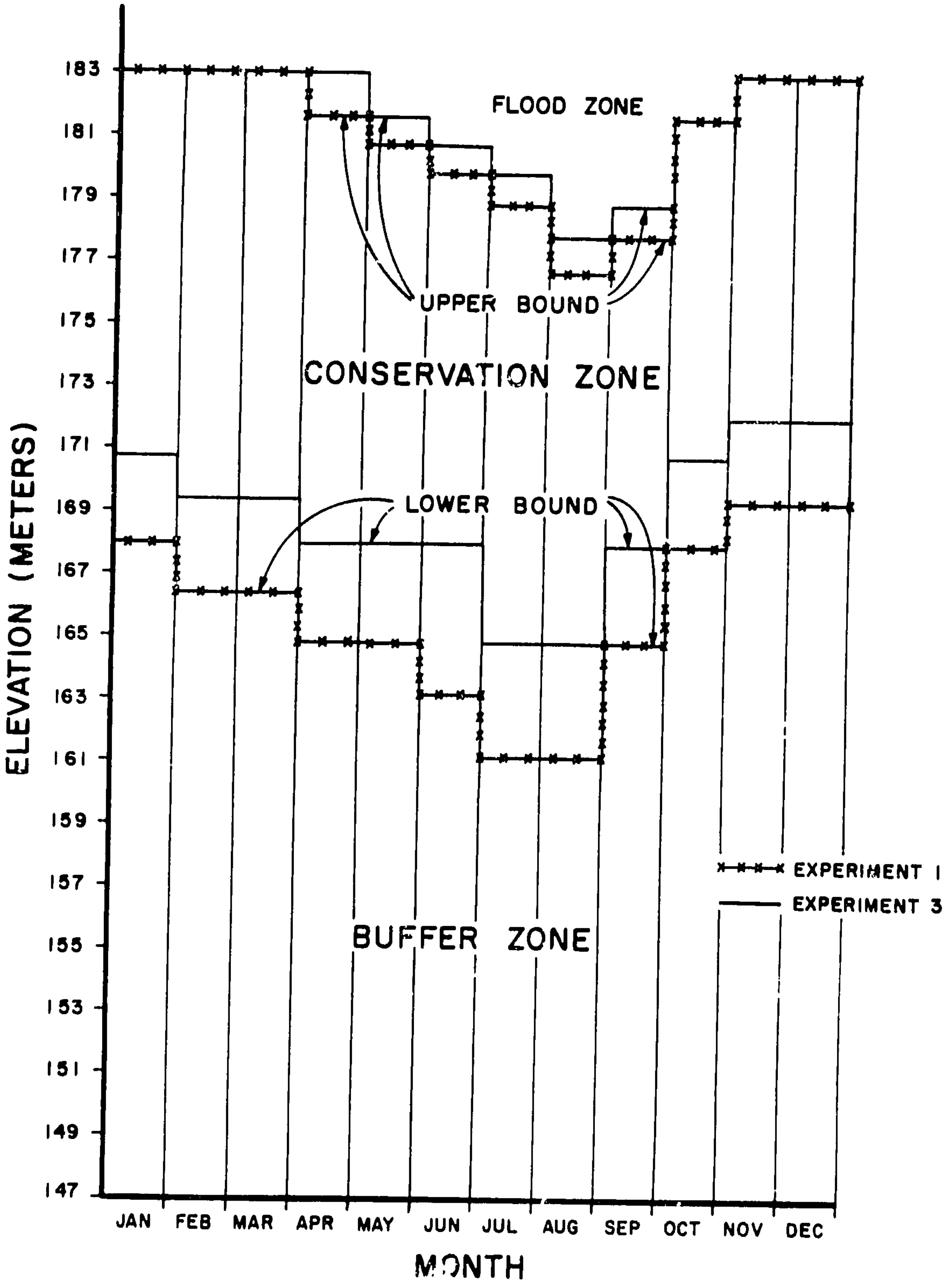


Figure 5.16

Shift in Zone Locations Resulting from Increase in Sudan Abstractions the area in which flood zone operating rules apply.

5.4.4 Experiment 6 - Discount Rate

Thus far, each set of monthly steady-state release policies have been derived using a zero discount rate. However, such an assumption is difficult to justify. To examine the effects of discounting future expected costs, Experiment 6 reproduces Experiment 1 using a monthly discount rate of 0.01. Resulting release policies for February, May and September are given in Figures 5.6, 5.7 and 5.8, respectively, which, when compared to Figures 5.1, 5.2 and 5.3, show a distinct change in attitude towards conserving water.

Notice first the lowering of the buffer zone's upper bound for all months. This implies that downstream demands are now met for low elevations that led to deficits in the undiscounted case, which clearly illustrates the increased value given to the present and near future (the distant future taking on less importance).

Also notice the change occurring in releases at higher elevations. For example, the release policy of February (Figure 5.6) now has a small flood zone, while the flood zone of May (Figure 5.7) is now larger and less inclined to conserve water. Likewise, the discounted September policy (Figure 5.8) releases larger quantities of water for corresponding elevations compared to the undiscounted case.

The tradeoff taking place between present and future concerns can alternately be construed as a tradeoff between different objectives of the system. For the given objective function, the dominating component of future expected costs is that associated with releases not meeting downstream demands. Without discounting, the derived release policies attempt to meet these downstream demands placing equal importance on near and distance future months. Hence, little emphasis is given to secondary objectives of the present. By discounting future costs, the attention previously given to meeting future downstream demands is shifted to more immediate concerns, like those of flood control and power generation. This explains why, for example, the policy for February will sometimes release more than the downstream demands as shown in Figure 5.6.

Generally, the monthly release policies illustrated here seem to demonstrate a more realistic and acceptable behavior when compared to the policies derived without discounting in Experiment 1. The final two experiments to be presented will likewise discount future costs.

5.4.5 Experiment 8 - Toshka Spillway

As mentioned in Section 2.3.3, the Toshka spillway is an unregulated facility on Lake Nasser recently constructed to divert waters to a desert depression. The intention of this spillway is to eliminate excessive releases, causing downstream degradation. As constructed, uncontrolled spills to Toshka begin at an elevation of 178 m, five meters below the maximum reservoir elevation.

In Experiment 8, Toshka spillway is assumed to operate with discharges approximated by the equation (Attia, 1980)

$$\begin{aligned} Q &= 19.0 \cdot (H - 178.0)^{5/3} && H > 178.0 \\ &= 0 && H \leq 178.0 \end{aligned}$$

where

Q = discharge to Toshka depression (million m^3 per day)

H = reservoir elevation (meters)

The remaining system parameters are identical to those of Experiment 6.

A look at the resulting release policies of May (Figure 5.9) and September (Figure 5.10) reveals the most conservative operating rules seen thus far. These two months typify the release attitudes of all months in Experiment 8, with conservation zones extending to the maximum reservoir elevation of 183.0 m for all but the months of June through September. Notice, however, that even for the flood month of September, it will be highly improbable to make a release above the downstream demand, since a reservoir elevation of 182.57 m (beginning of flood zone for September) would be difficult to achieve given that spills to Toshka start at the much lower elevation of 178.0 m.

The conservative release policies can be explained by the following logic. First, for the given objective function, it is important to maintain high reservoir elevations in order to avoid future irrigation deficits. Of course, the most desirable elevations depend upon the particular month. Consequently, spillage to Toshka depression will at times be unavoidable as high inflows will occasionally coincide with high reservoir elevations. This additional source of water losses effectively decreases the average annual net inflow to Lake Nasser, requiring conservation measures even at very high reservoir elevations. It might be suggested that spills to Toshka be circumvented by releasing in excess of downstream demands for, e.g., elevations just below 178 m, hence maintaining lower reservoir elevations. However, such an approach would in itself be contradictory to the need for conserving water. The preference shown here, then, is to concede spills to Toshka while generally releasing the downstream demands only.

5.4.6 Experiment 11 - The Objective Function

The purpose of Experiment 11 is to illustrate how monthly release policies might change for a different objective function. As displayed in Table 5.5, the monthly release policies of this experiment are based only upon minimizing costs due to power generation deficits, with flood control and meeting downstream demands no longer being an objective.

A predictable result of this new objective function is the disappearance of distinct zones seen in previous release policies. This can be observed in both the release policy of May (Figure 5.11) and September (Figure 5.12), where optimal releases are shown to gradually decrease in magnitude for decreasing elevations.

An interesting feature for May releases is the relatively high release of 4.9 md at the low elevation of 148.74 m. Clearly, the concern for conserving water no longer exists. Such an attitude is likewise reflected in September releases, where it can be seen in Figure 5.12 that the release curves representing different inflow states actually intersect. Thus, at low elevations, higher releases are recommended for lower expected inflows (correlation with August is positive) in an effort to generate more hydropower.

The conclusion to be reached here is that the derived operating rules indeed strongly depend upon the objective function, suggesting the need to define the system objectives as accurately as possible.

5.5 Adaptive Release Policies

Completing the qualitative analysis of this chapter is the presentation of several adaptive release policies derived from the algorithm of Chapter 4. Multi-lead forecasts are generated from the model of Section 2.4.2, with forecast lead-times for each monthly release policy given as follows:

	Forecast from beginning of											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lead-time (months)	6	6	5	4	3	12	12	11	10	9	8	7

The required boundary conditions for each monthly release policy, as suggested in Section 4.2, are extracted from the final cycle of calculations of the appropriate steady-state solution, specified by the particular system configuration (see Table 5.5).

The results presented in this section are based upon two alternate parameter sets, those used in Experiments 6 and 8 of Table 5.5. Variations in adaptive release policies using other system configurations of Table 5.5 yield results similar to those seen in the previous section, and will not be discussed here. Experiments 6 and 8 differ only in the inclusion of Toshka spillway. Designating these adaptive policies as Experiments 6A and 8A, respectively, release policies of selected years for the months of February, May and September are shown in Figures

5.17-5.20, corresponding to the multi-lead forecasts in Tables 5.7-5.9.

5.5.1 Experiment 6A

Figures 5.17, 5.18 and 5.19 each show three separate curves representing release policies of the same month for different years. Significant features displayed by these adaptive release policies can be identified by comparing each set of monthly adaptive policies to the corresponding steady-state solution. It should be mentioned that though the release policies are given only as a function of storage (see discussion in Section 4.3), in practice even this is not necessary, since the adaptive control generally cannot be derived until the beginning of the particular time period, at which time the storage will actually be known.

It is informative first to examine the multi-lead forecasts in Tables 5.7-5.9, in particular, the forecasting model's ability to predict extreme events. For example, the inflows of January through June of 1965 (Table 5.9) are generally about twice the magnitude of the historical mean. These unusually high inflows are predicted very well in both the February and May forecasts (Tables 5.7 and 5.8). In fact, even the forecast from September of 1964 (Table 5.9) shows predictions well above the mean inflow for these months, in spite of the relatively high lead-times. Notice also how successive forecasts of May and June of 1965 become increasingly more accurate with decreasing lead-times. These respective inflows of 4.17 and 4.52 (actual observations) are predicted from the previous September, at leads of nine and ten months, to be 3.32 and 3.50 md, respectively (Table 5.9). In the following February, May and June are predicted at leads four and five

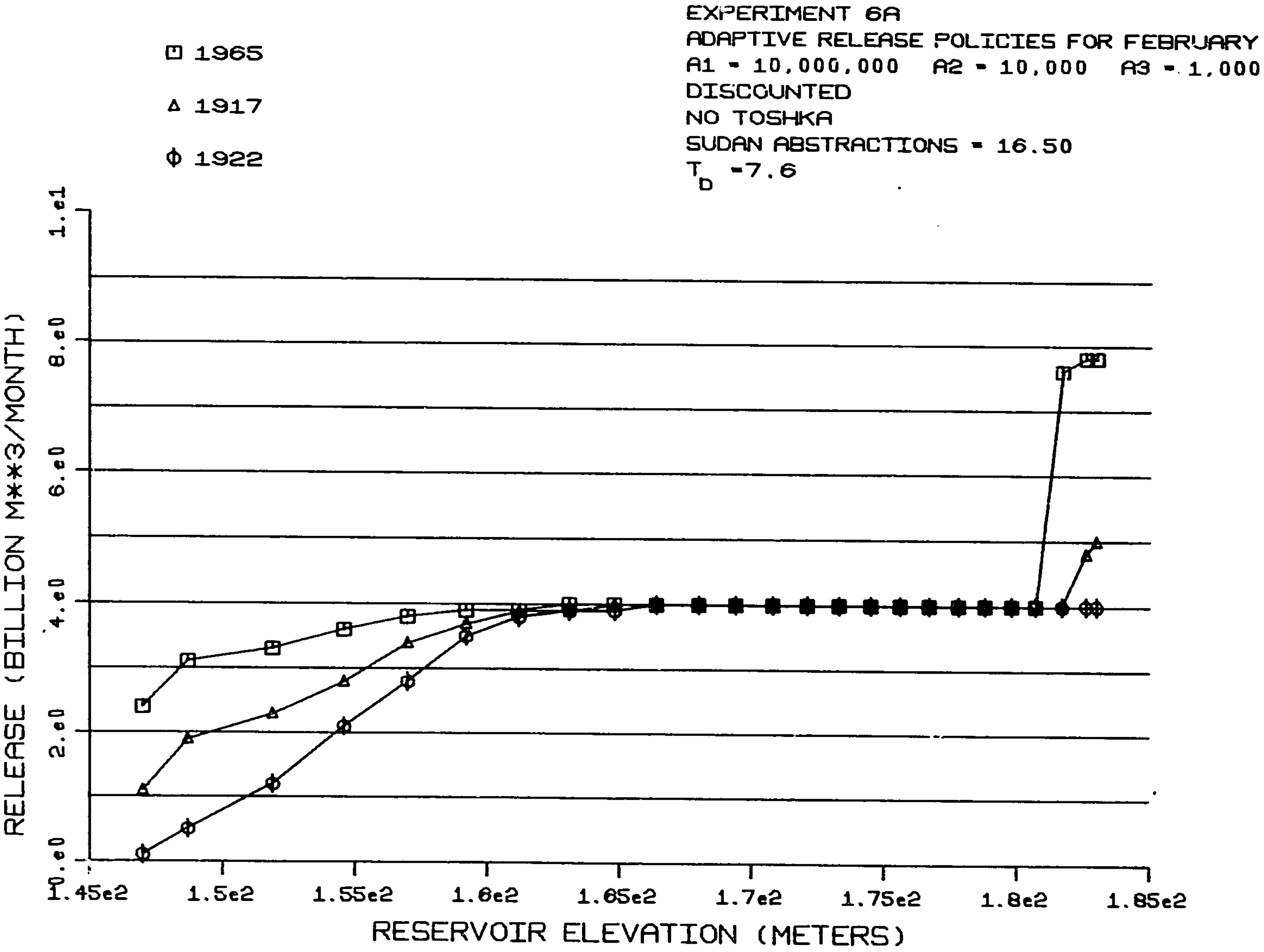


Figure 5.17
Selected Adaptive Release Policies of February for Experiment 6A

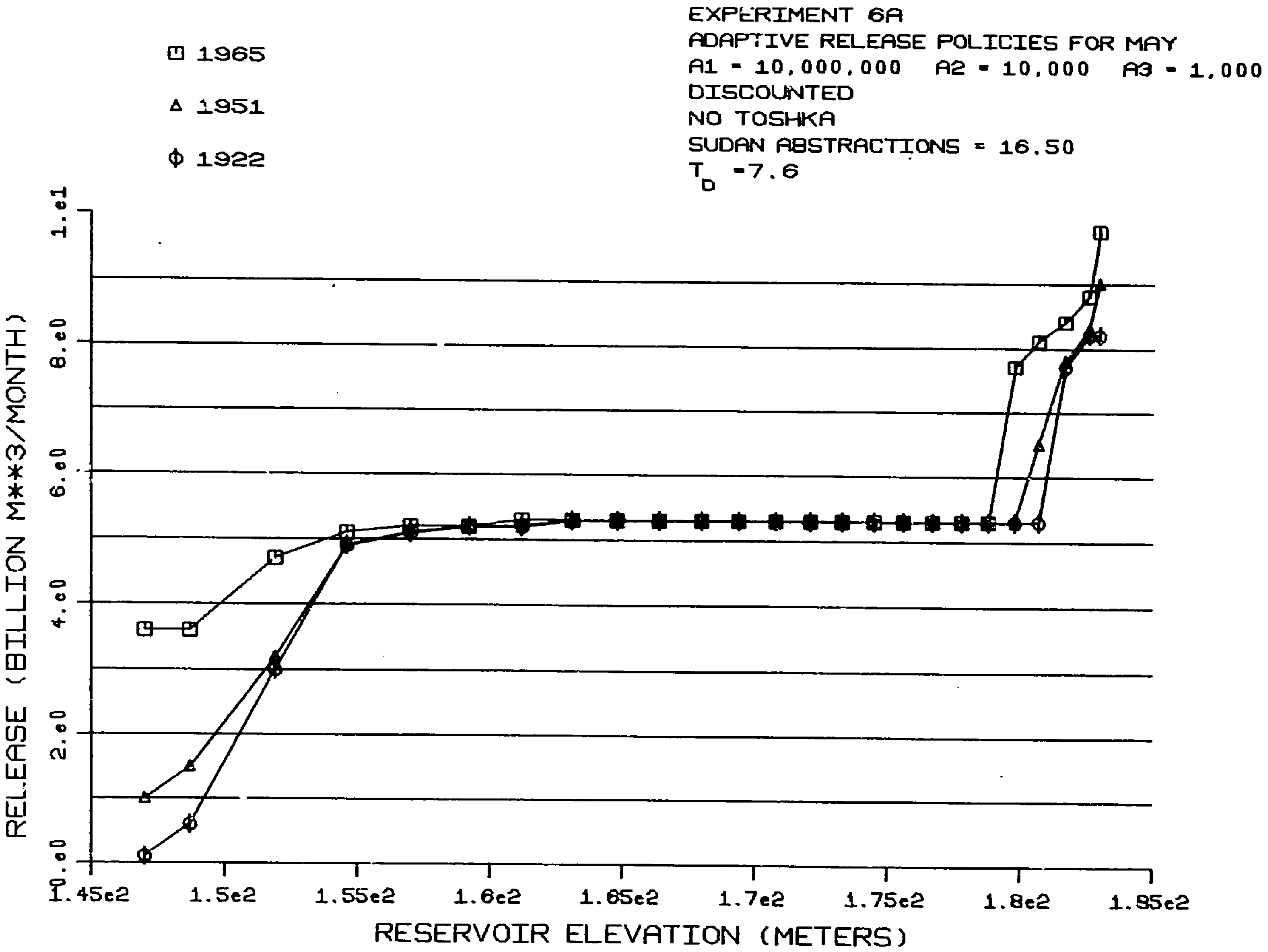


Figure 5.18
Selected Adaptive Release Policies of May for Experiment 6A

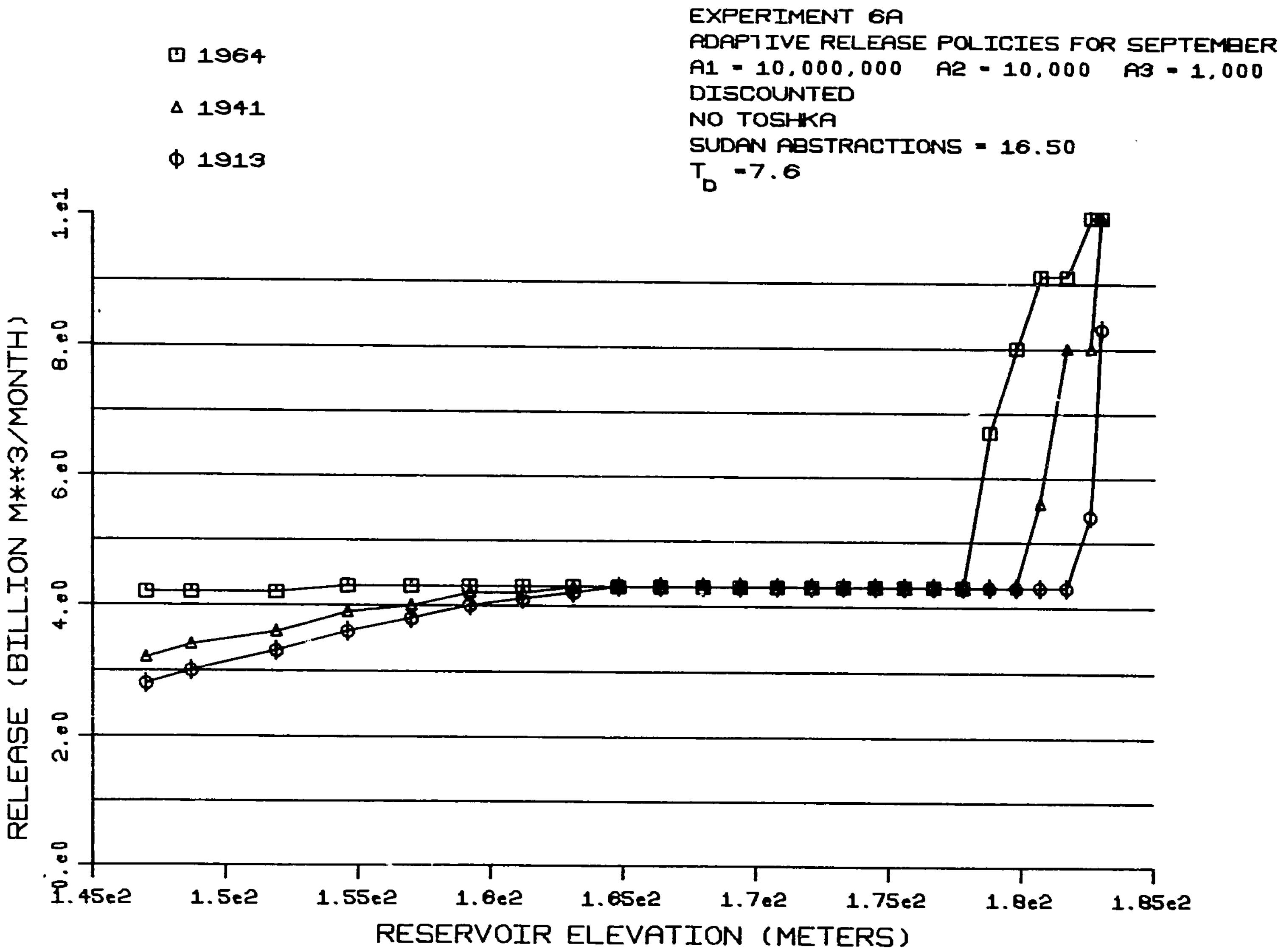


Figure 5.19
Selected Adaptive Release Policies of September for Experiment 6A

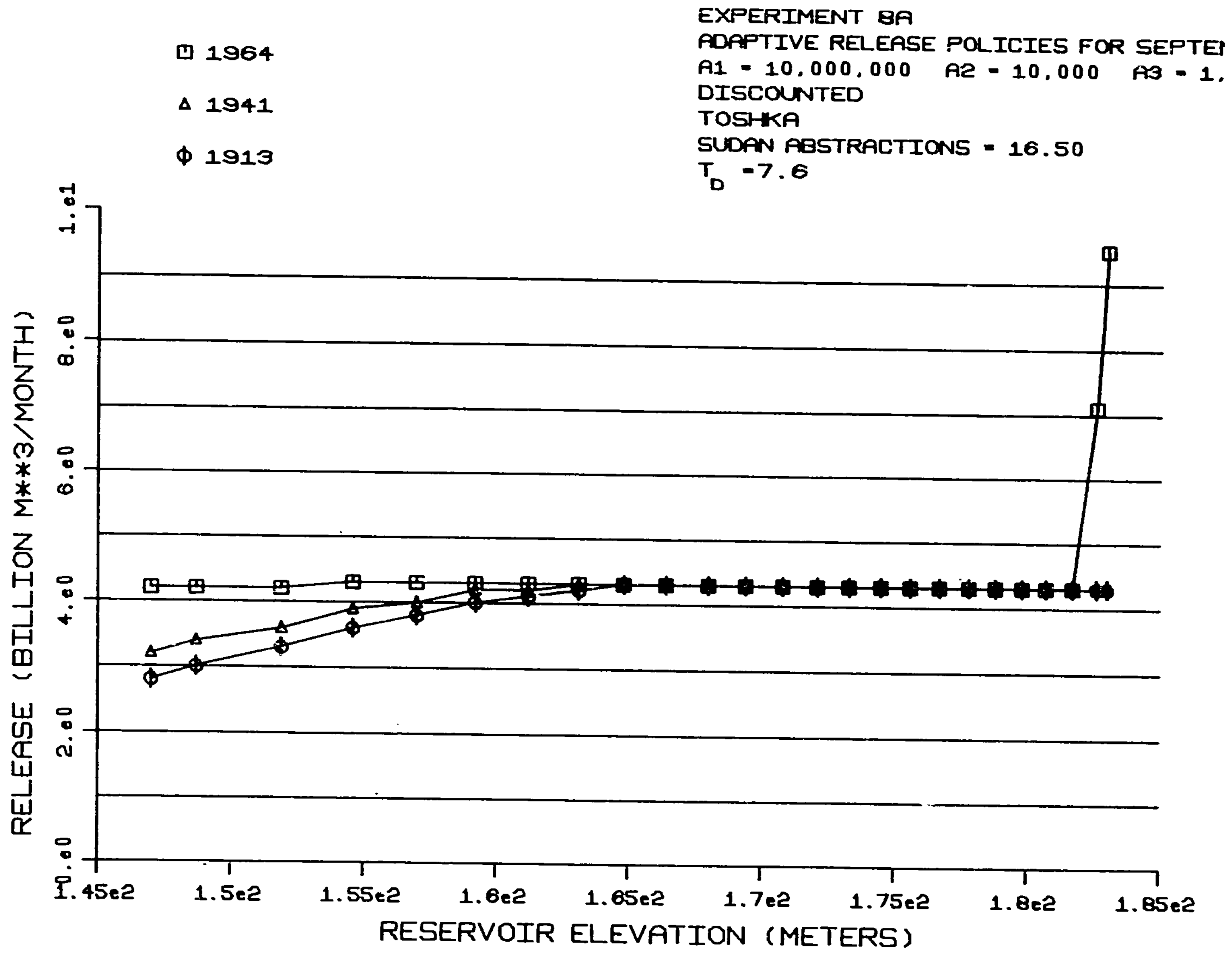


Figure 5.20
Selected Adaptive Release Policies of September for Experiment 8A

Lead	Forecasts - Observations						Forecast	Sample Statistics	
	1917		1922		1965				
	For.	Obs.	For.	Obs.	For.	Obs.	St. Dev.	Mean	St. Dev.
1	4.03	4.13	2.04	1.96	4.97	5.08	0.14	2.45	0.69
2	3.52	3.79	1.76	1.38	4.55	4.39	0.35	2.28	0.67
3	2.56	2.41	1.59	1.05	3.31	3.58	0.30	2.04	0.69
4	2.49	1.76	1.17	0.88	4.07	4.17	0.28	1.92	0.76
5	2.58	2.08	1.54	1.00	4.17	4.52	0.53	2.07	0.78
6	4.14	5.83	4.58	3.82	6.61	5.82	1.35	5.17	1.53

Table 5.7
Lead 6 Forecasts and Actual Observations from Beginning of February for the Years 1917, 1922 and 1965

Lead	Forecasts - Observations						Forecast	Sample Statistics	
	1922		1951		1965				
	For.	Obs.	For.	Obs.	For.	Obs.	St. Dev.	Mean	St. Dev.
1	0.72	0.88	2.17	1.99	4.18	4.17	0.10	1.92	0.76
2	1.16	1.00	1.80	1.30	4.54	4.52	0.43	2.07	0.78
3	4.64	3.82	4.59	3.40	6.54	5.82	1.34	5.17	1.53

Table 5.8
Lead 3 Forecasts and Actual Observations from Beginning of May for the Years 1922, 1951 and 1965

Lead	Forecasts - Observations						Forecast	Sample Statistics	
	1913		1941		1964				
	For.	Obs.	For.	Obs.	For.	Obs.	St. Dev.	Mean	St. Dev.
1	14.92	13.40	17.57	15.10	24.52	25.70	2.01	21.99	3.78
2	10.72	7.86	13.34	11.10	16.10	16.40	2.39	14.61	3.15
3	6.11	4.14	6.26	7.43	7.47	9.45	1.57	7.17	1.77
4	3.83	3.02	3.92	3.99	6.00	5.85	0.64	4.54	0.87
5	2.08	2.10	2.10	2.99	4.05	5.75	0.44	3.51	0.74
6	1.57	1.42	1.59	2.08	3.89	5.08	0.42	2.45	0.69
7	2.02	1.29	2.04	2.54	3.90	4.39	0.48	2.28	0.67
8	1.42	1.10	1.92	2.52	3.32	3.58	0.38	2.04	0.69
9	1.33	1.18	1.56	1.81	3.50	4.17	0.45	1.92	0.76
10	1.75	1.14	1.78	1.92	3.53	4.52	0.60	2.07	0.78

Table 5.9
Lead 10 Forecasts and Actual Observations from Beginning of September for the Years 1913, 1941 and 1964

months to be 4.07 and 4.17 (Table 5.7). Finally, at leads one and two months, the predictions are given in Table 5.8 as 4.18 and 4.57 md, almost identical to the actual observations. Characteristics such as those given above are strong motivating factors for updating information when deriving controls for a stochastic system.

To see how the control solution is affected by the incorporation of forecasts, consider the adaptive release policies for February of 1917, 1922 and 1965 (Figure 5.17). The most conservative release policy is that of 1922, with optimal releases shown to be similar or lower than even the lowest curve of the corresponding steady-state solution (see Figure 5.6). At the other extreme is the release policy for 1965, where optimal releases for low and high elevations are now much higher than those of the highest steady-state release curve. Finally, the release curve for 1917 can be seen to practically match the steady-state release curve of the highest discrete inflow state.

Now consider Table 5.7, presenting the multi-lead forecasts upon which the individual adaptive solutions for February are based. Starting with the forecast of 1917, predictions for February and March are far above the respective historical mean flows. The predictions for April through June moderately exceed their respective means, while the forecast for July is seen to be below that month's historical mean. With the exception of July, then, the inflows for the next half year are expected to be much higher than usual. Hence, it seems reasonable that the derived adaptive policy agrees closely with the highest curve of the steady-state solution, as the positive lag-one correlation coefficients used in the steady-state solution perpetuate the expectation of high inflows over the near future. The release curve for 1965 indicates that unusually high inflows are expected. As previously mentioned, the forecast from February, 1965, in fact consists of extreme predictions, being the highest set of lead-six predictions from all February's between 1913 and 1965 inclusive. The resulting high optimal releases should then be expected, as the steady-state solution fails to perceive and account for extreme events such as the 1965 inflows of February through June. The remaining forecast, that for 1922, shows predictions at all leads to be below the historical average inflows. Again, the resulting adaptive release policy reflects the given forecast, showing no flood zone and very conservative release rules for the buffer zone.

Adaptive release policies for May of 1922 and 1951, illustrated in Figure 5.18, display similar results to those of February. The release policy for 1922 responds to below average forecasts (given in Table 5.8) much in the same way that the February, 1922, policy does. This can be seen by comparing the 1922 adaptive policies of February and May (Figures 5.17 and 5.18) to their respective steady-state policies (Figures 5.6 and 5.7). For the three month lead forecast of 1951 (Table 5.8), the lead-one prediction is just above the historical mean, while the lead two and three predictions show that below average inflows are expected. The resulting 1951 adaptive policy can be seen to compare closely with the steady-state release curve of the second lowest inflow state. Since both curves are based upon the expectation of slightly lower than average inflows over the near future, such a result seems very reasonable.

February and May adaptive release policies differ in their response to 1965. As with February, 1965, the forecast from May, 1965, shows extremely high predictions for May and June, followed by a very high prediction of the July inflow. However, the resulting adaptive policy for May, 1965, shows flood zone releases to be no greater than those of the highest steady-state curve (Figure 5.7), unlike February, even though buffer zone releases for both months are much higher than the steady-state results. It appears, then, that drought management in May is much more sensitive to the incorporation of forecasts than flood management. Conversely, February releases for extreme elevations are equally sensitive to forecasts. Whether this difference in behavior can be entirely or partially attributed to the differences in forecast lead times or to the location of each month within the annual hydrologic cycle is not immediately clear. However, one of the implications is that forecasting over a large lead from a month early in the normal drought period (such as February) might be very important to flood control, perhaps more important than a low lead forecast closer to the flood (like May).

A final point can be made with the release policies of September (Figure 5.19). First, notice that the forecasts in Table 5.9 for the years 1913 and 1941 are very similar for all but the lead one and two predictions, and even these do not differ considerably. However, the resulting adaptive release policies differ appreciably. Unlike the importance placed upon large forecast lead times for months early in the drought period (discussed above), what is suggested for

September adaptive release policies is that the majority of the significant information lies almost entirely in the lower lead forecasts. Such a conclusion might be substantiated by the fact that, in the month of September, concern is more with handling the generally large inflows of September and October (and perhaps November), while the inflows of December and beyond are of minimal importance. The overall implication from the discussion in this section is that choosing a forecast lead time for each month should not only consider the accuracy, but also the usefulness of the information contained in the higher lead forecasts.

Though only a few selected adaptive release policies have been presented, the following results hold in general:

1. The derived adaptive policies are compatible with the multi-lead forecasts upon which they are based.
2. Adaptive solutions reflecting extreme events often differ considerably from corresponding steady-state solutions.
3. Multi-lead forecasts significantly influence drought management for all months.
4. Relative to steady-state solutions, adaptive solutions show modifications in flood management to be greatest for months early in the drought period (December, January, February), suggesting the importance of flood prevention measures well before the actual flood arrives.
5. The amount of useful information contained in higher lead forecasts depends not only on the prediction accuracy, but also upon the location of the month within the annual

inflow cycle.

The following experiment will consider the effect of the Toshka spillway on the adaptive release policies.

5.5.2 Experiment 8A

Figure 5.20 illustrates the resulting adaptive release policies of September when the Toshka spillway is considered. Shown are the same years discussed in Experiment 6A (see Figure 5.19). The given release policies of Figure 5.20 are thus based upon the forecasts presented in Table 5.9 .

Recall from Experiment 8 that Toshka spillway essentially eliminates the occurrence of releases above downstream demands except at the highest elevations of the flood months. This result likewise holds for adaptive release policies. In Figure 5.20, only the high forecast of 1964 produces release decisions greater than downstream demands, but such releases occur only for elevations above 181.66 m. In Experiment 6A, the same forecast results in releases above downstream demands starting at the much lower elevation of 177.77 m. Further consistency can be seen in the unchanging buffer zone release rules for Experiments 6A and 8A, a result also found in the steady-state experiments. Though not presented here, adaptive release policies for all other months continue to be conservative.

From a qualitative standpoint, these results suggest that with the inclusion of Toshka spillway, forecasting inflows will probably be of little significance in the overall operation of the High Dam. The only changes likely to be seen are modifications in drought management.

To gain further insight into the observed differences of each control scheme and the different system configurations, a simulation analysis is performed in the following chapter.

Chapter 6

SIMULATION ANALYSIS

6.1 Performance Criteria

The simulation model used in this study is a simple water balance model, designed to implement one of three alternative control schemes. Both the steady-state and the adaptive control schemes have been discussed in detail. The third control approach is a heuristic policy similar to that used by Alarcon and Marks (1979), given by the following procedure:

1) Define an alert storage level for each month.
2) If the reservoir storage for a given month is below the alert storage level defined in (1), release the irrigation target only.
3) Otherwise, release what is necessary to draw the reservoir level down to the subsequent month's alert storage level. However, monthly releases shall never exceed 10.0 md unless the maximum reservoir storage constraint is violated.
4) For reservoir elevations below 160 m, invoke sliding scale, with releases being some fraction of the monthly downstream demand. Details for this procedure can be found in Thompson and Marks (1981).

The alert storage levels used here are those proposed by Joint Research Project IBM/EXWAP (1980), and can be tabulated in terms of elevation (m) as follows:

JAN	FEB	MAR	APR	MAY	JUN
179.98	179.58	179.03	178.40	177.75	176.94
JUL	AUG	SEP	OCT	NOV	DEC
175.82	175.00	183.00	182.43	181.04	180.20

These prescribed elevations are intended to draw the reservoir down to level 175.0 m by August 1 of each year for flood control purposes.

To examine the efficiency of the alternative control schemes, three performance measures will be considered. They consist of : 1) the frequency and average magnitude of irrigation deficits; 2) the frequency and average magnitude of degradation causing releases and 3) the average annual and firm power generation. It should be noted that the first two measures are explicit objectives given in the objective function (for Experiment 1 through 9 of Table 5.5), while annual average and firm power generation cannot be considered as such. Nevertheless, they are reasonable measures of performance for hydropower production. Other factors to be examined include average annual releases, releases through and around turbines, evaporation, costs, spills to Toshka and monthly reservoir elevations. All simulation runs use Wadihalfa streamflow data from 1912 to 1965 and an initial reservoir elevation of 180.0 m.

This chapter first investigates the use of the different control schemes for a given system configuration. From this analysis, issues concerning both the value of forecasted information and the performance of the adaptive control can be addressed. Subsequently, effects associated with varying system parameters are examined, providing insight to system capabilities (relative to the system objectives) for different system configurations. Table 6.1 details the various simulation runs.

6.2 Analysis of Alternate Control Schemes

This section analyses the alternate control schemes for three different system configurations. Statistics for the various performance criteria and other behavioral aspects are presented in Tables 6.2, 6.3 and 6.4 for the simulation runs of Experiments 1, 6 and 8.

6.2.1 Runs 1H, 1S and 1A

Before comparing each control scheme based on Experiment 1 in terms of explicit High Dam objectives (as given by the objective function), certain general behavioral characteristics should first be pointed out. Looking first at average annual releases and evaporation (Table 6.3) notice that the heuristic policy incurs lower evaporation losses relative to both the steady-state and the adaptive policies, hence releasing more water downstream as well as through the turbines. The steady-state and adaptive policies release relatively similar quantities annually but releases bypassing the turbines are seen to be higher with the steady-state policy, and even higher with the heuristic policy. Intuitively, the relative total release and evaporation statistics are reasonable, due to the fact that the heuristic policy attempts to maintain levels at or below the alert storage levels, often requiring releases greater than the downstream demands. On the other hand, the steady-state and adaptive policies continue to release only the downstream demands for much higher elevations, which can be seen from the release policies in Figures 5.1, 5.2, 5.3 and 5.17. This allows

Run*	Objective** Function	Discount Rate	Toshka	Sudan Abstractions	Degradation Causing Release
1H	1	-	No	16.5	7.6
1S	↓	0	↓	↓	↓
1A		0			
2H	1	-	No	16.5	8.4
2S	↓	0	↓	↓	↓
3H	1	-	No	18.5	7.6
3S	↓	0	↓	↓	↓
4H	1	-	Yes	16.5	7.6
4S	↓	0	↓	↓	↓
5H	1	-	Yes	18.5	7.6
5S	↓	0	↓	↓	↓
6H	1	-	No	16.5	7.6
6S	↓	0.01	↓	↓	↓
6A		0.01			
7H	1	-	No	16.5	8.4
7S	↓	0.01	↓	↓	↓
8H	1	-	Yes	16.5	7.6
8S	↓	0.01	↓	↓	↓
8A		0.01			
9H	1	-	Yes	18.5	7.6
9S	↓	0.01	↓	↓	↓
10H	2	-	No	16.5	7.6
10S	↓	0	↓	↓	↓
11H	2	-	No	16.5	7.6
11S	↓	0.01	↓	↓	↓

* H = Heuristic S = Steady State A = Adaptive

** 1 → $a_1=1x10^7$: $a_2=1x10^4$; $a_3=1x10^3$: 2 → $a_1=0$ $a_2=0$ $a_3=1x10^3$

Table 6.1

Performed Simulation Runs and Corresponding System Configurations

Run*	Irrigation Deficits		Excessive Releases		Power Generation	
	Number	Average Deficit	Number	Average Excessive Release (md)	Firm (GWH)	Average Annual (GWH)
1H	0	0.00	16	9.02	393	8094
1S	0	0.00	10	8.09	378	8151
1A	0	0.00	5	7.87	378	8170
6H	0	0.00	16	9.02	393	8094
6S	0	0.00	11	7.92	376	8160
6A	0	0.00	8	7.71	394	8185
8H	0	0.00	6	8.56	365	7889
8S	0	0.00	0	-	362	7787
8A	0	0.00	0	-	362	7787

* H = Heuristic S = Steady-State A = Adaptive

Table 6.2

Simulation Outputs of Experiments 1, 6 and 8 for Three Performance Criteria

Run	Releases*			Evaporation*	Spills* To Toshka	Average Annual Costs	Years Exceeding D/S Demands
	Through Turbine	Bypass Turbine	Total				
1H	56.92	0.48	57.40	13.7	-	13916	10
1S	56.11	0.14	56.25	14.5	-	5735	7
1A	56.23	0.07	56.30	14.5	-	5083	8
6H	56.92	0.48	57.40	13.7	-	13916	10
6S	56.36	0.12	56.48	14.4	-	5315	10
6A	56.54	0.05	56.59	14.3	-	5007	9
8H	56.11	0.12	56.23	13.6	1.3	7562	5
8S	55.50	0.00	55.50	13.6	1.9	5362	0
8A	55.50	0.00	55.50	13.6	1.9	5362	0

* Average Annual (md)

Table 6.3

Annual Statistics of Experiments 1, 6 and 8 for Secondary Performance Measures

Month Run	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1H	462 (3.6)	569 (4.1)	597 (4.3)	574 (4.2)	795 (5.4)	995 (6.6)	1061 (7.1)	934 (6.3)	592 (4.3)	569 (4.2)	552 (4.2)	393 (3.2)
1S	451 (3.4)	563 (4.0)	596 (4.2)	593 (4.2)	808 (5.4)	1013 (6.6)	1086 (7.1)	969 (6.4)	627 (4.4)	546 (3.9)	521 (3.7)	378 (3.0)
1A	454 (3.4)	579 (4.1)	612 (4.3)	594 (4.2)	808 (5.4)	1009 (6.5)	1085 (7.0)	960 (6.3)	622 (4.4)	550 (3.9)	520 (3.7)	378 (3.0)
6H	462 (3.6)	569 (4.1)	597 (4.3)	574 (4.2)	795 (5.4)	995 (6.6)	1061 (7.1)	934 (6.3)	592 (4.3)	569 (4.2)	552 (4.2)	393 (3.2)
6S	454 (3.4)	565 (4.0)	619 (4.3)	598 (4.3)	808 (5.4)	1010 (6.6)	1081 (7.1)	970 (6.4)	623 (4.4)	541 (3.9)	513 (3.7)	376 (3.0)
6A	467 (3.5)	586 (4.1)	612 (4.3)	596 (4.3)	807 (5.4)	1007 (6.5)	1079 (7.0)	962 (6.3)	626 (4.4)	543 (3.9)	507 (3.7)	394 (3.1)
8H	436 (3.4)	554 (4.0)	591 (4.3)	567 (4.2)	784 (5.4)	981 (6.5)	1050 (7.0)	930 (6.3)	589 (4.3)	531 (3.9)	512 (3.8)	365 (3.0)
8S	436 (3.4)	546 (4.0)	578 (4.2)	552 (4.1)	769 (5.3)	977 (6.5)	1050 (7.0)	932 (6.3)	590 (4.3)	514 (3.8)	481 (3.6)	362 (3.0)
8A	436 (3.4)	546 (4.0)	578 (4.2)	552 (4.1)	769 (5.3)	977 (6.5)	1050 (7.0)	932 (6.3)	590 (4.3)	514 (3.8)	481 (3.6)	362 (3.0)
Targets	1280 (3.4)	1280 (4.0)	1280 (4.2)	1280 (4.1)	1280 (5.3)	1280 (6.5)	1280 (7.0)	1280 (6.3)	1280 (4.3)	1280 (3.8)	1280 (3.6)	1280 (3.0)

* Numbers in parentheses are average monthly releases

Table 6.4 Average Monthly Power Generation (GWH) and Releases (md) for Experiments 1, 6 and 8 the reservoir levels to attain generally higher elevations. Figure 6.1 shows the maximum, average and minimum reservoir elevations occurring in runs 1H, 1S and 1A, clearly illustrating the tendency for the heuristic policy to operate at lower elevations. However, in spite of the higher annual releases of the heuristic policy, the steady-state and the adaptive policies give, respectively, increasingly better performance in terms of the established criteria.

The primary objective of the system, as indicated by the tradeoff coefficients of the objective function, is to conserve water in an effort to meet both present and future downstream demands. Though Table 6.2 shows all three release policies incurring zero deficit releases, a major difference exists in the minimum monthly elevations occurring over the period of simulation, with the heuristic policy dropping to significantly lower levels (Figure 6.1). Maintaining the highest minimum monthly elevations for all months is the adaptive policy, while steady-state minimum elevations are slightly lower. These results indicate that both the steady-state and the adaptive policies are more conscious of the undesirability of low reservoir elevations, complying with the given objective function.

Releases causing downstream degradation are most frequent and of the highest average magnitudes for the heuristic policy, and least frequent and of the lowest magnitudes for the adaptive policy (Table 6.2). Since similar results can be seen in Experiment 6, discussion on key points concerning this result will be postponed to Section 6.2.2.

Looking at monthly hydropower generation, all three policies show very similar trends, producing the most power in July and the least in December (Table 6.4). Since monthly energy demands in Egypt are fairly uniform throughout the year, it would be preferable to have a corresponding uniform distribution of power production. However, if one considers that only ten out of fifty-three simulated years show releases above the downstream demands for the heuristic policy (Table 6.3), and only seven and eight years for runs 1S and 1A respectively, there is clearly little leeway available for optimizing power generation. To achieve a more uniform distribution of power production, the objective of optimizing power generation could be emphasized more or monthly downstream demands could be made more uniform. The first of these possibilities is considered in Section 6.3.5, while the second is analyzed in Thompson and Marks (1981) and will not be discussed here. However, for the given demand schedule, water supply and objective function of Experiment 1, uniform power production cannot be achieved even with the use of optimization techniques.

Considering hydropower generation on an annual basis brings up an interesting issue. The adaptive policy can be seen to generate the most power, the steady-state policy generating a little less, and the heuristic policy generating the least (Table 6.2). Recalling that the heuristic policy releases the most water annually, but maintains lower reservoir elevations, one might conclude that it is preferable to release less water at higher elevations to maximize power generation. This cannot be entirely substantiated, though, as the steady-state policy operates at the highest elevations (Figure 6.1), while the adaptive policy generates the most power. However, there does appear to be some relationship between amounts of water forced to bypass the turbines

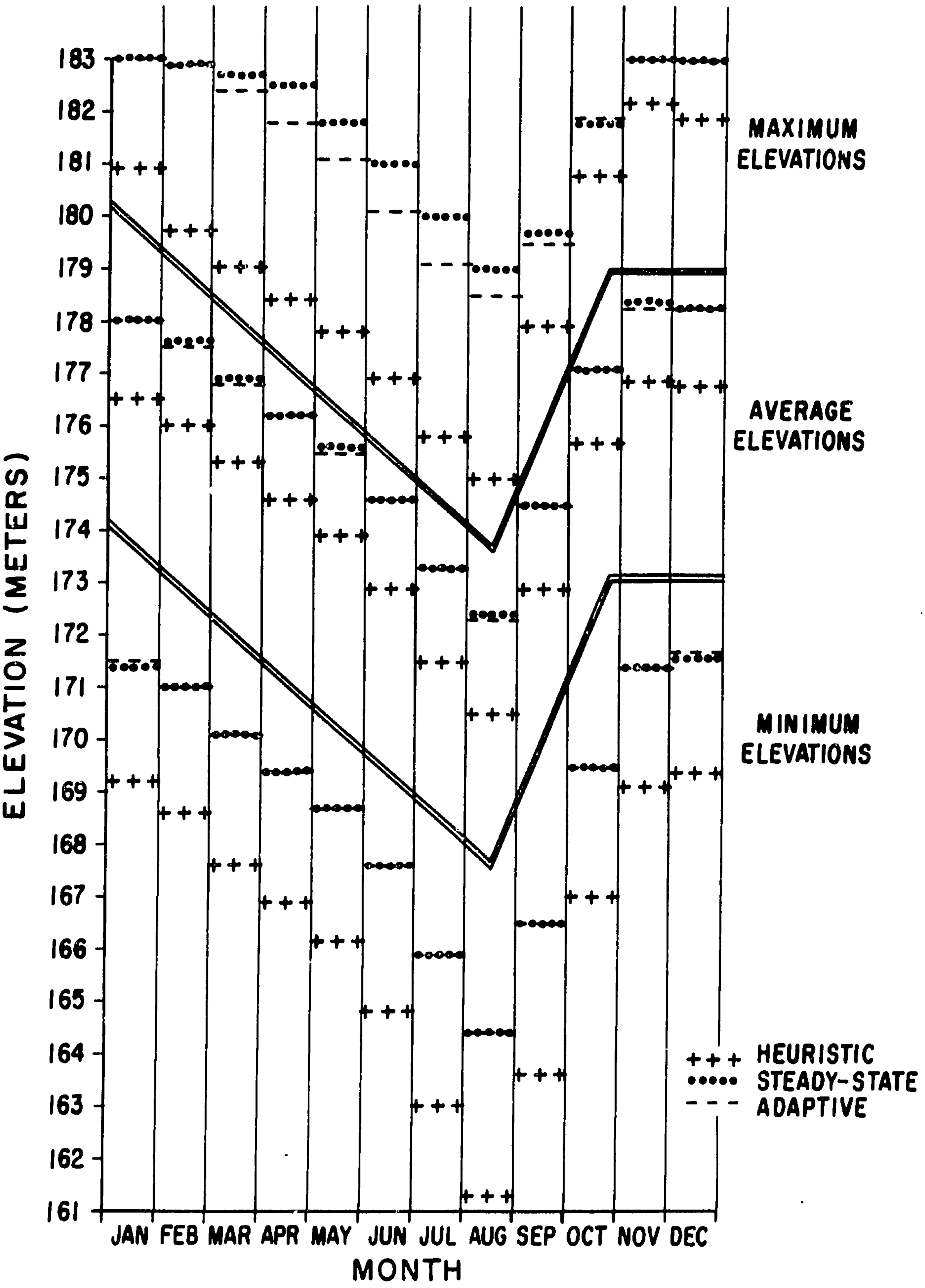


Figure 6.1

Maximum, Average and Minimum Monthly Reservoir Elevations for Simulation Runs 1H, 1S and 1A

(due to turbine capacities) and the amount of annual hydropower generation. Looking at Table 6.3, the adaptive control scheme is seen to bypass half that of the steady-state control, while the heuristic policy bypasses more than three times that of the steady-state control Suggested here, then, is that maximization of annual hydropower generation may not only be dependent upon the issue of low head/high releases vs. high head/low releases but also on the ability of the operating policy (over the long run) to avoid water bypassing the turbines.

6.2.2 Runs 6H, 6S and 6A

The general results presented for Runs 1H, 1S and 1A can be extended to the discounted case of Experiment 6. In particular, reservoir elevations (Figure 6.2), irrigation deficits, excessive releases and power generation show similar trends when comparing the outputs of each control scheme. Thus, observations concerning degradation causing releases, deferred from the previous discussion, will be the major focus of Runs 6H, 6S and 6A.

Recall from Table 6.2 that the most frequent and most severe excessive (i.e. degradation causing) releases occur with the heuristic policy. For both Experiments 1 and 6, the frequency and magnitudes of excessive releases are reduced with the steady-state release policy, while further improvement can be observed using the adaptive policy. Notice also from Figure 6.1 that, over the 53 years of simulation, the heuristic policy lowers the reservoir elevation to 175 meters by August 1 every year as intended. Conversely, the steady-state and the

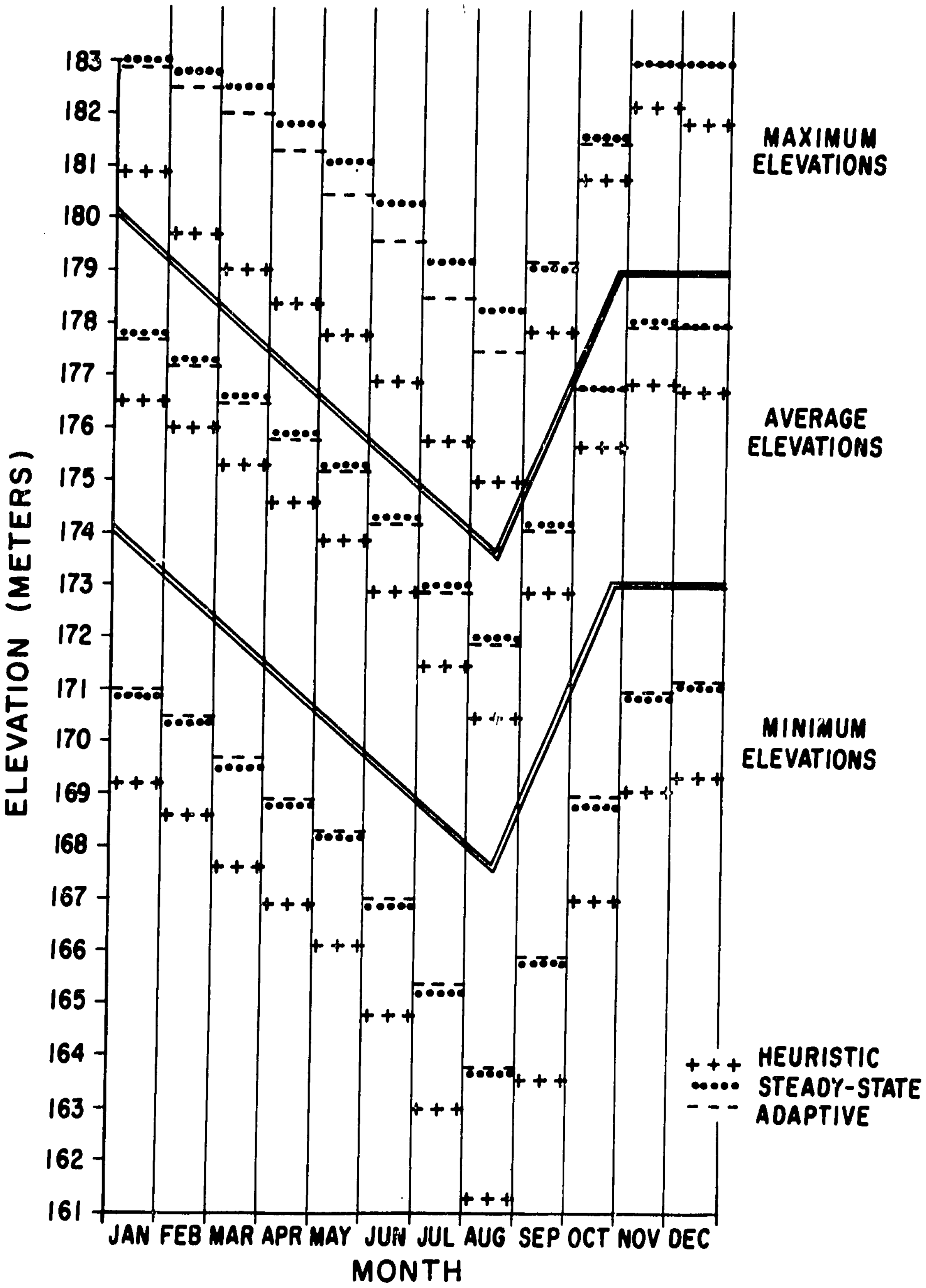


Figure 6.2

Maximum, Average and Minimum Monthly Reservoir Elevations for Simulation Runs 6H, 6S and 6A

adaptive policies are at or below 175 meters by August 1 only 75% of the time, yet both control schemes for each experiment perform better in excessive releases. An explanation of this result can be given with the aid of Tables 6.5a, b and c, which illustrate the simulated years of 1964 and 1965 for Runs 6H, 6S and 6A, respectively.

Over the period of January through July of 1964, where inflows are all above average, the heuristic policy (Table 6.5a) requires an excessive release for July to draw the reservoir down to 175 m by August 1, 1964. Of the following twelve inflows (August 1964 through July 1965), the first five continue to be very high, while the next six (composing the drought period) turn out to be extreme events (i.e., extremely high). In an effort to maintain monthly reservoir elevations at or below the alert storage levels, the heuristic policy incurs several more excessive releases, with two of these releases being the maximum allowable of 10.0 md.

Using the steady-state control scheme (Table 6.5b), the same inflows are handled much differently. First, the July 1964 excessive release of 9.26 md seen with the heuristic policy now gets divided between the releases of July, August and September of 1964, all releases being less than 7.6 md. Menawhile the reservoir elevations are allowed to rise higher than the imposed alert storage levels of the heuristic policy, leading to a full reservoir by December of 1964. The extreme events that follow, coupled with the high reservoir elevation, eventually result in a series of excessive releases from April through August of 1965. However, these magnitudes do not approach the 9.26 md or 10.0 md releases seen with the heuristic policy. On the other hand, the

Table 6.5a
Simulation of Years 1964 and 1965 for Run 6H

YEAR	MONTH	ELEVATION INITIAL	ELEVATION FINAL	INFLOW* (BCM)	RELEASE (BCM)	BYPASS TURBINES	POWER	COST
1964	1	179.2	178.9	2.59	3.40	-	462	669
	2	178.9	178.4	1.82	4.00	-	576	495
	3	178.4	177.9	1.89	4.20	-	610	448
	4	177.9	177.4	2.22	4.10	-	585	482
	5	177.4	176.8	3.16	5.30	-	815	216
	6	176.8	175.8	3.28	7.40	-	1215	4
	7	175.8	175.0	6.51	9.26	1.55	1259	27542
	8	175.0	177.9	23.75	6.30	-	1003	76
	9	177.9	180.8	23.72	4.30	-	644	404
	10	180.8	181.2	14.26	10.00	2.70	1261	57600
	11	181.2	180.5	7.32	10.00	2.69	1261	57600
	12	180.5	180.0	4.04	5.71	-	934	119
1965	1	180.0	179.6	4.04	5.36	-	860	176
	2	179.6	179.0	3.66	6.54	-	1088	37
	3	179.0	178.4	3.42	6.30	-	1032	61
	4	178.4	177.8	3.10	5.74	-	914	133
	5	177.8	176.9	3.70	7.61	0.06	1260	1
	6	176.9	175.8	3.70	8.31	0.69	1260	5109
	7	175.8	175.0	4.41	7.17	-	1156	15
	8	175.0	176.1	13.65	6.30	-	990	84
	9	176.1	177.5	13.62	4.30	-	615	441
	10	177.5	178.0	8.86	3.80	-	527	566
	11	178.0	177.9	4.47	3.60	-	490	623
	12	177.9	177.7	3.10	3.00	-	370	827

*After Sudan abstractions and Gebel Aulia losses

Table 6.5b
Simulation of Years 1964 and 1965 for Run 6S

YEAR	MONTH	ELEVATION INITIAL	ELEVATION FINAL	INFLOWS* (BCM)	RELEASE (BCM)	BYPASS TURBINES	POWER	COST
1964	1	180.1	179.8	2.59	3.40	-	472	652
	2	179.8	179.3	1.82	4.00	-	587	480
	3	179.3	178.8	1.89	4.20	-	621	434
	4	178.8	178.3	2.22	4.10	-	595	468
	5	178.3	177.8	3.16	5.30	-	826	205
	6	177.8	177.0	3.28	6.50	-	1054	51
	7	177.0	176.6	6.51	7.12	-	1167	13
	8	176.6	179.1	23.75	7.41	-	1240	2
	9	179.1	181.5	23.72	6.91	-	1175	11
	10	181.5	182.8	14.26	3.80	-	570	504
	11	182.8	183.0	7.32	4.13	-	641	407
	12	183.0	182.9	4.04	3.00	-	415	748
1965	1	182.9	182.8	4.04	3.85	-	585	482
	2	182.8	182.5	3.66	4.56	-	725	307
	3	182.5	181.8	3.42	7.44	0.20	1261	0
	4	181.8	180.9	3.10	7.73	0.45	1261	173
	5	180.9	180.1	3.70	7.76	0.44	1260	269
	6	180.1	179.2	3.70	7.83	0.44	1260	524
	7	179.2	178.2	4.41	8.27	0.82	1260	4461
	8	178.2	178.9	13.65	8.04	0.58	1260	1967
	9	178.9	180.1	13.62	4.30	-	646	402
	10	180.1	180.6	8.86	3.80	-	555	525
	11	180.6	180.5	4.47	3.60	-	517	582
	12	180.5	180.3	3.10	3.00	-	396	782

*After Sudan abstractions and Gebel Aulia losses

Table 6.5c
Simulation of Years 1964 and 1965 for Run 6A

YEAR	MONTH	ELEVATION		INFLOW* (BCM)	RELEASE (BCM)	BYPASS TURBINES	POWER	COST
		INITIAL	FINAL					
1964	1	180.2	179.9	2.59	3.40	-	473	651
	2	179.9	179.4	1.82	4.00	-	588	478
	3	179.4	178.9	1.89	4.20	-	622	432
	4	178.9	178.4	2.22	4.10	-	597	466
	5	178.4	177.9	3.16	5.30	-	828	204
	6	177.9	177.0	3.28	6.58	-	1072	43
	7	177.0	176.7	6.51	7.00	-	1146	18
	8	176.7	179.2	23.75	7.66	0.15	1260	34
	9	179.2	181.5	23.72	7.21	-	1235	2
	10	181.5	182.8	14.26	3.80	-	570	504
	11	182.8	182.9	7.32	4.61	-	737	294
	12	182.9	182.4	4.04	6.01	-	1019	68
1965	1	182.4	181.8	4.04	6.69	-	1150	16
	2	181.8	181.1	3.66	7.64	0.37	1261	16
	3	181.1	180.7	3.42	5.52	-	904	141
	4	180.7	179.8	3.10	7.37	0.03	1261	0
	5	179.8	179.0	3.70	7.71	0.31	1261	128
	6	179.0	178.0	3.70	7.65	0.18	1260	22
	7	178.0	177.3	4.41	7.21	-	1197	6
	8	177.3	178.3	13.65	6.30	-	1020	67
	9	178.3	179.5	13.62	4.30	-	639	411
	10	179.5	180.0	8.86	3.80	-	550	533
	11	180.0	179.9	4.47	3.60	-	512	589
	12	179.9	179.7	3.10	3.00	-	391	790

*After Sudan abstractions and Gebel Aulia losses excessive releases could have been avoided with knowledge of the upcoming extreme events, as the releases for October 1964 through February 1965 could have been increased.

With the adaptive control scheme, reservoir elevations are likewise allowed to rise very high during 1964. By the end of October 1964, the reservoir attains a near maximum elevation of 182.8 m (Table 6.5c), as does Run 6S (Table 6.5b). However, the subsequent adaptive release decisions for November 1964 through February 1965 are seen to be much higher than those derived from the steady-state solution. By the end of February 1965, the reservoir has been drawn down to an elevation 1.7 m lower than the steady-state release policy. Recalling the sample release curves in Figures 5.17-5.19, it should be clear that such high releases are not just in response to the high reservoir elevations, but to the generated forecasts as well. For example, a release of only 4.0 md would be recommended for February 1965, if the forecast was that generated from February 1922 (Figure 5.17 and Table 5.7), in spite of the high elevation of 181.8 m. However, the forecasts for 1965 result in releases well above the downstream demands, preparing the system for the extreme events to come. Ultimately, excessive releases are reduced both in frequency and average magnitude, with the additional benefit that less water bypasses the turbines. In fact, in terms of power generation, the adaptive control scheme produces an amount of power over the period January 1964 - September 1965 equivalent to that produced by the steady-state control scheme over all months of 1964 and 1965 combined. This results in spite of an average reservoir elevation of

179.66 m and a total release of 120.66 md over the 21 month period of the adaptive control, compared to the 24 month average reservoir elevation of 180.11 m and total release of 130.05 md with the steady-state control. Thus, the adaptive control is seen here to produce power more efficiently in addition to preventing downstream degradation.

To conclude the discussion of Experiments 1 and 6, consider the costs incurred over each simulation run. A result common to Experiments 1 and 6 is the significant reduction in costs using the adaptive control as opposed to the steady-state control scheme, while the heuristic policy incurs considerably higher costs relative to both dynamic programming control schemes. Recalling that each simulation run generates similar amounts of power and further experience no irrigation deficits, the cost differences can almost entirely be attributed to the frequency and magnitudes of degradation causing releases occurring in each simulation. The implication here is that although the primary system objective is to meet present and future irrigation needs, flooding (and channel degradation) is the more difficult objective to properly manage. It is reasonable, then, to expect lower operating costs with the adaptive control, as the incorporation of multi-lead forecasts clearly allows the best management of incoming floods, preventing costly high releases.

6.2.3 Runs 8H, 8S and 8A

With the inclusion of Toshka spillway, benefits previously seen due to forecasting inflows are now completely eliminated. Over 53 years of simulation, neither the steady-state nor the adaptive control simulation runs show monthly releases differing from monthly irrigation targets, hence generating identical results. Though releases never exceed the scheduled monthly downstream demand, losses to Toshka lead to generally lower reservoir elevations, as illustrated in Figure 6.3.

From Figures 5.9, 5.10 and 5.20, the first result is entirely predictable, as neither the steady-state nor the adaptive release curves exceed monthly irrigation targets except for high reservoir elevations (which are nearly impossible to attain). In the discussion of these curves, it was suggested that release decisions could only focus upon the primary objective of meeting irrigation targets, given the objective function tradeoff coefficients and the limited water supply. Table 6.3 verifies this, showing no irrigation deficits, but Toshka spills amount to an annual average of 1.9 md, hence reducing the average annual water supply. Concerns relative to flooding are thus alleviated, but any leeway available for optimizing power generation is eradicated. Apparently, even with the availability of forecasted inflows, the system (with Toshka spillway) is too constrained to allow for releases above the irrigation targets.

6.3 Sensitivity Analysis of System Parameters

Following is a sensitivity analysis performed upon the system parameters given in Table 6.1. Tables 6.6, 6.7 and 6.8 present output statistics for both heuristic and steady-state simulation runs of those experiments not covered in Section 6.2. Discussion will focus primarily upon comparison of steady-state simulation runs.

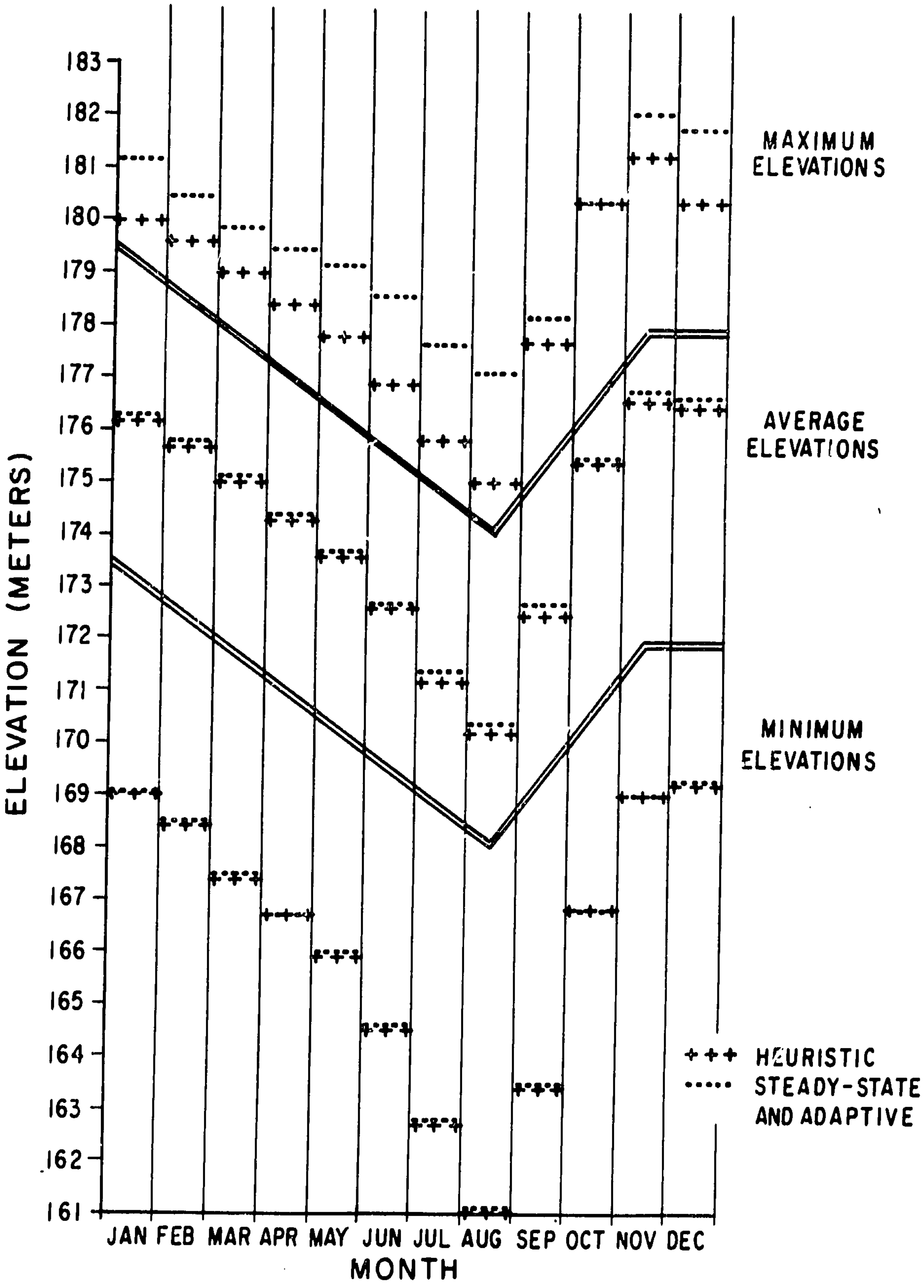


Figure 6.3

Maximum, Average and Minimum Monthly Reservoir Elevations for Simulation Runs 8H, 8S and 8A

Run*	Irrigation Deficits		Excessive Releases		Power Generation	
	Number	Average Deficit	Number	Average Excessive Release (10^9 m^3)	Firm (GWH)	Average Annual (GWH)
2H	0	0.00	9	9.80	393	8094
2S	0	0.00	4	9.00	379	8148
3H	0	0.00	5	8.73	369	7679
3S	67	0.08	2	8.22	357	7701
4H	0	0.00	6	8.56	365	7889
4S	2	0.04	0	-	362	7787
5H	0	0.00	3	8.40	349	7572
5S	90	0.08	0	-	348	7529
7H	0	0.00	9	9.80	393	8094
7S	0	0.00	3	8.74	377	8146
9H	0	0.00	3	8.40	349	7572
9S	43	0.06	0	-	348	7520
10H	0	0.00	16**	9.02	393	8094
10S	215	1.47	2**	10.00	671	8232
11H	0	0.00	16**	9.02	393	8094
11S	201	1.20	0**	-	626	7992

* H = Heuristic S = Steady-State

** Releases above 7.6 md

Table 6.6

Simulation Outputs of Remaining Experiments for Three Performance Criteria

Run	Releases*			Evaporation*	Spills* To Toshka	Average Annual Costs	Years Exceeding D/S Demands
	Through Turbine	Bypass Turbine	Total				
2H	56.92	0.48	57.40	13.7	-	8675	10
2S	56.08	0.15	56.23	14.5	-	5292	7
3H	56.30	0.12	56.42	12.7	-	7785	6
3S	55.45	0.03	55.48	13.4	-	92847	2
4H	56.11	0.13	56.24	13.6	1.3	7562	5
4S	55.49	0.00	55.49	13.6	1.9	5972	0
5H	55.91	0.05	55.96	12.6	0.6	6219	3
5S	55.36	0.00	55.36	12.8	0.8	131848	0
7H	56.92	0.48	57.40	13.7	-	8675	10
7S	56.25	0.19	56.44	14.4	-	5115	9
9H	55.91	0.05	55.96	12.6	0.6	6219	3
9S	55.45	0.00	55.45	12.8	0.8	46308	0
10H	56.92	0.48	57.40	13.7	-	5106	10
10S	56.03	0.12	56.15	14.7	-	4341	27
11H	56.92	0.48	57.40	13.7	-	5106	10
11S	60.25	0.00	60.25	11.3	-	4638	47

*Average Annual (md)

Table 6.7

Annual Statistics of Remaining Experiments for Secondary Performance Measures

Run \ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2S	452 (3.4)	564 (4.0)	596 (4.2)	590 (4.2)	807 (5.4)	1012 (6.5)	1087 (7.1)	969 (6.4)	627 (4.4)	546 (3.9)	521 (3.7)	379 (3.0)
3S	431 (3.4)	540 (4.0)	571 (4.2)	545 (4.1)	762 (5.3)	968 (6.5)	1038 (7.0)	924 (6.3)	583 (4.3)	508 (3.8)	474 (3.6)	357 (3.0)
4S	436 (3.4)	546 (4.0)	578 (4.2)	552 (4.1)	769 (5.3)	977 (6.5)	1050 (7.0)	932 (6.3)	590 (4.3)	514 (3.8)	481 (3.6)	362 (3.0)
5S	421 (3.4)	529 (4.0)	558 (4.2)	533 (4.1)	746 (5.3)	946 (6.5)	1015 (7.0)	901 (6.3)	571 (4.3)	497 (3.8)	465 (3.6)	348 (3.0)
7S	450 (3.4)	561 (4.0)	615 (4.3)	598 (4.3)	806 (5.4)	1008 (6.6)	1083 (7.1)	972 (6.4)	621 (4.4)	544 (3.9)	514 (3.7)	377 (3.0)
9S	421 (3.4)	528 (4.0)	558 (4.2)	533 (4.1)	744 (5.3)	944 (6.5)	1012 (7.0)	899 (6.3)	570 (4.3)	497 (3.8)	465 (3.6)	348 (3.0)
10S	687 (4.6)	689 (4.6)	688 (4.7)	688 (4.7)	689 (4.8)	687 (4.8)	671 (4.8)	681 (4.8)	683 (4.6)	692 (4.7)	692 (4.6)	685 (4.6)
11S	682 (5.0)	679 (5.0)	666 (5.0)	659 (5.0)	652 (5.1)	647 (5.1)	626 (5.1)	645 (5.1)	677 (5.0)	689 (5.0)	686 (4.9)	685 (4.9)

* Numbers in parentheses are average monthly releases

Table 6.8

Average Monthly Power Generation (GWH) and Releases (md) for Remaining Experiments

6.3.1 Degradation Causing Release (T_D)

Comparing Experiments 1 and 2, we can study the effect of different values of T_D (7.6 and 8.4 md). Principally, excessive releases are affected, while all other tabulated outputs (Tables 6.2-6.8) remain essentially unchanged. Presented in Table 6.9 are released above both 7.6 and 8.4 md observed in each simulation run from which two points become evident. First, the value of T_D does alter flood management, with the lower value (7.6 md) resulting in lower average magnitudes of releases above both 7.6 and 8.4 md. Second, though it is not known exactly what release magnitude will cause downstream erosion, attempts to keep releases below 7.6 md can generally be successful. Further, this assertion is made under the assumption that Sudan abstractions are only 16.5 md annually, rather than 18.5 md. Adopting a value of 7.6 md for T_D, then, is not operationally unmanageable, and perhaps as a precautionary measure such a value might be preferable.

A comparison of Runs 6S and 7S, which is just the discounted version of Runs 1S and 2S, shows similar results, with high releases being avoided more successfully by Run 6S in terms of average magnitude and total excessive water released than Run 7S.

6.3.2 Sudan Abstractions

Effects associated with the annual amount of water allocated to Sudan can be seen from comparisons of Experiment 1 with 3, Experiment 4 with 5 and Experiment 8 with 9.

From Tables 6.2-6.8, the following results hold in general:

Run	T_D^*	Releases above 7.6			Releases above 8.4		
		#	Avg. Magnitude	Total Excess	#	Avg. Magnitude	Total Excess
1H and 2H	-	16	9.02	22.72	9	9.80	12.60
1S	7.6	10	8.09	4.90	4	8.55	0.60
2S	8.4	7	8.45	5.95	4	9.00	2.40

[*] Value assigned in derivation of steady-state release policy

Table 6.9

Statistics on Excessive Releases for Simulation Runs 1H, 1S, 2H and 2S

1. Irrigation deficits occur frequently with Sudan allocations of 18.5 md when steady-state release policies are used, while no deficits occur using the heuristic policy.
2. Power generation appreciably decreases when Sudan allocations are increased to 18.5 md (from 16.5 md).
3. When the Sudan allocation is 16.5 md per year (Experiments 1, 4 and 8), steady-state release policies incur lower costs relative to the heuristic policy. For allocations of 18.5 md per year, the heuristic policy incurs the lower costs.

The first result follows directly from Figure 5.15, where it was shown that increasing Sudan allocations tended to raise the upper bound of each month's buffer zone, resulting from the decrease in average annual water availability. The second result is also to be expected, as less water is available to the system for power generation when Sudan allocations are increased. A point to be made with the third result is that over a finite length simulation period, it cannot be guaranteed that an optimization control scheme will reduce operating costs relative to a more intuitively derived control scheme. Clearly, factors other than incurred costs must be considered. For example, both average and minimum elevations for Runs 3H, 5H and 9H are lower than those of Runs 3S, 5S and 9S, respectively, with some differences being greater than 2 meters. This clearly results from the near-sighted nature of the heuristic policy, which continually releases the full irrigation target in spite of dangerously low reservoir elevations.

The steady-state release policies for Experiments 3, 5 and 9 further decrease the number and magnitudes of excessive releases occurring with the heuristic policy, while generating similar amounts of hydropower. Finally, given the low average annual inflow of Experiments 3, 5 and 9, it is reasonable for an operating policy to incur deficits, as this is an indication that the likelihood of an inadequate future water supply is being considered at each decision point.

6.3.3 Discount Rate

A general behavioral characteristic of discounted policies, when Toshka is not included, is that the reservoir is operated at lower levels relative to the corresponding undiscounted simulation runs. Run 6S operates the reservoir 0.2 m lower than Run 1S (see Figures 6.1 and 6.2), while Run 7S operates the reservoir 0.3 m lower than Run 2S. These lower elevations result in lower amounts of evaporation, and hence release more water annually (Tables 6.3 and 6.7). As previously mentioned in Section 5.5.3, it appears that the fear of incurring future irrigation deficits is less with the discounted policies. This would result from the future being weighted less heavily, therefore, operating the reservoir at lower elevations is not perceived to be as dangerous.

The above argument is further substantiated by the improved performance in excessive releases with the discounted policies (Tables 6.2 and 6.6). In effect, a tradeoff between flood management and conservation storage seems to result with the discounted cases (Runs 6S, 6A and 7S), as improvements in excessive releases occur at the expense of maintaining lower reservoir elevations.

Comparing Experiment 4 with 8 and Experiment 5 with 9, where Toshka is now included, the type of results seen above no longer hold. In fact, the most significant result is the decrease in irrigation deficits with the discounted policies which seems contradictory to the above argument. However, in this case, a tradeoff between flood management and conservation storage is not an issue, as Toshka eliminates the need for flood management.

6.3.4 Toshka Spillway

For all steady-state and adaptive simulation runs where Toshka spillway is included, the most significant result is that monthly releases never exceed the irrigation target. A look at Figures 5.9, 5.10 and 5.20 suggest that precisely such a result should occur, as releases above monthly irrigation targets are recommended only for high reservoir elevations that are essentially impossible to attain.

Spillage to Toshka ranges from 0.8 to 1.9 md per year (averaged over 53 years of simulation), with all spills occurring during the months of October through February. Simulation runs with Toshka show average reservoir elevations to be one to two meters lower than the corresponding simulation run without Toshka. Similarly, minimum elevations occurring with Toshka range from 1.3 to 2.5 meters lower than simulations without Toshka.

Relative to the system objectives, then, the following observations can be made for simulation runs (steady-state and adaptive) with Toshka:

1. The danger of excessive releases is completely alleviated.
2. Irrigation deficits are much more common.
3. The combination of lower reservoir elevations and lower releases produce much less hydropower.

6.3.5 The Objective Function

The final configurations to be considered are those using an objective function concerned with power generation only. Setting the tradeoff coefficients corresponding to both irrigation targets and downstream degradation to zero, the system objective is to minimize power generation deficits for all months over an infinite time horizon. Runs 10S and 11S give simulation results for undiscounted and discounted steady-state release policies respectively.

In contrast to Runs 1S and 6S, Runs 10S and 11S show frequent releases below the irrigation targets (Table 6.6). Such a result clearly illustrates the incompatibility of the given irrigation schedule with optimal power generation. On the other hand, an improvement can be seen in terms of excessive releases. Both results can essentially be attributed to the more uniform pattern of releases, which in turn is a direct result of the new objective function.

Comparing Run 10S to 11S, the issue of high head/low releases vs. low head/high releases once again arises. Run 10S, operating at higher elevations, incurs additional evaporation losses of 3.4 md per year relative to Run 11S, consequently sending much less water through the turbines. However, more than 200 GWH above Run 11S are generated each year (averaged over the simulation period), indicating that a high head/low release approach is preferable for maximizing power generation.

Overall, the two different objective functions considered here lead to significantly different operating policies. From the above results, the need to appropriately quantify the system objectives when using optimization techniques is clearly illustrated.

Chapter 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Based upon the qualitative analysis of Chapter 5 and the simulation results of Chapter 6, conclusions can be reached upon both the High Aswan Dam - Lake Nasser system capabilities and the value of the adaptive control scheme.

The level of fulfillment of objectives of the High Dam - Lake Nasser system depends on various system parameters. Recall that the objectives were: meeting irrigation targets, preventing excessive releases, and optimizing power generation. For example, should Toshka spillway operate as an unregulated flood control facility, spillage to Toshka depression will reduce the average annual net inflow to the system, which may limit releases to never exceed the irrigation requirements. Subsequently, power generation will continue to be a function of the irrigation schedule. On the other hand, downstream degradation will no longer be a concern, as Toshka spillway can adequately handle execessively high inflows. A similar result holds if Sudan uses their entire allocation of 18.5 md per year. In this case, however, satisfying irrigation requirements will lead to dangerously low reservoir elevations if future reservoir inflows maintain the historical annual mean values.. For the less confined system configurations, where Toshka spillway is assumed not to exist and Sudan abstractions are only 16.5 md per year, both the steady-state and the adaptive control schemes are of the greatest use, as some leeway exists between water supply and demand. For these cases, the additional available water is allocated over time such that annual power generation will be increased relative to the heuristic policy, while problems related to downstream degradation will be considerably reduced.

Assessing the adaptive control scheme, the degree to which improved system performance will occur is again dependent upon the system configuration. For the more confined system configuration where Toshka spillway is operating, it is unlikely that additional benefits relative to the steady-state control scheme will result. However, with a less confined system (no Toshka spillway and annual Sudan abstractions of 16.5 md), considerable improvements can be expected. The most significant benefit is likely to be seen in flood control. Of particular interest is the importance of forecasts at the beginning of each drought period, as it is sometimes beneficial to release above the irrigation requirements in the event that a high series of inflows is to follow.

A final point to be made is that the use of different objective functions leads to widely varying results. Hence, all conclusions presented above are based upon the objective functions used in this study. Further imporvement in system performance can be expected if a more representative objective function can be qualified.

7.2 Recommendations

Given the spectrum of results presented in the previous two chapters, determination of the parameter values for the High Aswan Dam - Lake Nasser system is an essential component to the use of the dynamic programming algorithms presented here. Of paramount importance is the development of an objective function that accurately reflects the multi-objective nature of the system under study, and research in this area is definitely recommended.

Further research on optimal High Aswan Dam control is also suggested for system configurations that incorporate some Upper Nile development projects. In particular, the adaptive control scheme may be especially useful as the water supply increasingly exceeds the downstream demands.

Finally, the adaptive control scheme should be tested on other regulatory facilities under different hydrologic regimes. The benefits related to the incorporation of forecasts may be very system specific.

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APPENDIX A

MONTHLY STREAMFLOW DATA FOR THE NILE RIVER (1912-1965)

This Appendix contains monthly streamflow observations for eight Nile basin stations recorded over the years 1912-1965, whose locations are schematically illustrated in Figure 2.8. The data presented here are actual observations abstracted from The Nile Basin (1971). No attempt was made to deregulate the data to obtain naturalized flows.

HISTORICAL MONTHLY STREAMFLOW AT WADI HALFA (10**6 CUBIC METERS)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1912	3880	2540	1920	1450	1230	1080	3700	20800	19600	11100	6100	4580
1913	3650	2310	1870	1430	1360	1800	2230	7680	13400	7860	4140	3020
1914	2100	1420	1290	1100	1180	1140	2900	22900	22300	18000	10500	6260
1915	4190	2930	2050	1380	1290	1600	3080	12300	16400	15000	7840	4910
1916	3510	2170	1500	1180	1130	1320	6100	27100	31700	23200	12200	7060
1917	5340	4130	3790	2410	1760	2080	5830	19600	31500	24200	11600	6880
1918	5350	4350	4810	4540	4340	3460	6300	15600	18800	11900	6670	5010
1919	3700	2390	2070	1620	1470	1680	5070	19200	22400	13000	6260	4500
1920	3430	2050	1590	1310	1220	1970	6230	20700	19100	15800	8710	5180
1921	3800	2180	1680	1300	1120	1380	3300	17900	21500	15200	7140	4580
1922	3420	1960	1380	1050	880	1000	3820	19300	25500	17000	8130	5060
1923	3650	1970	1260	1130	1520	2370	5000	22500	23100	16700	6970	4790
1924	3730	2400	1650	1240	1400	1550	5730	19600	23300	14500	7900	5290
1925	3760	2470	1820	1370	1290	1630	4440	15700	17900	12800	5940	4090
1926	3390	2230	1820	1690	1760	2700	4960	21600	23100	14900	7500	4810
1927	3850	2740	1960	1590	1570	1500	4750	18300	20300	13700	5510	3670
1928	2590	1690	1460	1330	1720	2710	7520	19900	21000	12200	6610	4350
1929	3480	2230	1810	1450	1790	3770	10000	25400	25800	18700	9320	5210
1930	4210	2870	2210	1730	1740	1910	5590	19700	18500	11500	5230	3660
1931	2720	1640	1470	1260	1340	1200	3370	16900	21600	14800	7920	4420
1932	3440	2010	1670	1360	1390	1980	5070	20200	23400	15900	7300	4680
1933	4200	3380	2730	1670	1760	1930	3810	14400	22800	15100	8690	5660
1934	4190	2710	2010	1670	1660	1820	7600	22100	24400	16500	7400	5020
1935	4200	2850	2140	1730	1840	2680	8000	22900	24200	17200	7520	4950
1936	3950	2640	2230	1770	1730	1800	6230	20000	25600	15600	6890	4200
1937	3170	1900	1650	1450	1400	1800	4840	21600	23600	13500	5790	4310
1938	3350	2090	2210	1670	1470	1600	4520	23800	27000	19800	8850	5260
1939	4120	3160	2340	2140	2220	2170	4230	14000	18400	12400	7580	4360
1940	3160	2080	2500	1830	1350	1550	3430	16200	18200	9780	4280	2990
1941	2040	1820	2150	1670	1150	1930	4430	13300	15100	11100	7430	3990
1942	2990	2080	2540	2520	1810	1920	5450	22400	21000	14500	5570	3810
1943	3030	1850	2500	2220	1610	1560	3280	17000	24300	12900	6090	3530
1944	2670	1700	2570	2450	1800	2130	5190	18300	18500	12100	5040	3640
1945	2610	1880	2750	2230	1500	2010	3890	16000	19600	15900	8000	4890
1946	3700	2290	2510	2470	2130	1610	7370	26900	27700	14600	8230	5200
1947	3990	3080	3060	2600	2860	2920	3480	16400	22900	13900	5760	4060
1948	3410	2680	2500	2560	2200	1830	5860	17500	19200	15500	8690	4560
1949	3490	2590	2410	2520	2550	2010	4630	18500	20200	13200	6960	4380
1950	3750	2720	2540	2510	2720	2270	5430	22400	23300	14100	5910	3780
1951	3110	1890	2320	2420	1990	1300	3400	16500	18200	11900	7610	4420
1952	3040	2320	2760	2250	1590	1490	3930	15790	20450	11400	5300	3280
1953	2490	1830	2320	2420	1510	1740	5200	23000	20400	12700	5430	3620
1954	2560	1790	2550	2350	1650	1440	6870	25200	27600	19000	7370	4490
1955	3520	2580	2150	2430	2530	2390	5030	19900	22900	17200	6400	4090
1956	3410	2730	2470	2590	2720	2630	6660	20100	20800	17900	11100	5260
1957	3750	3020	2480	2920	3070	3390	4770	18600	19500	8530	4360	3020

1958	!	2320	1680	2170	2400	1770	1610	5920	25200	22700	15200	7150	4540
1959	!	3220	2310	2280	2540	2270	1860	5970	19500	27800	14800	8470	4350
1960	!	3120	2220	2230	2530	2500	1800	4480	17400	20400	13500	5370	3140
1961	!	2550	1780	2310	2600	2030	1510	6550	23200	26800	17400	7560	4920
1962	!	3670	2760	2590	2970	2980	3220	5000	17400	22600	15500	5830	4020
1963	!	3350	2820	2560	2820	3250	3590	6990	22100	19700	10600	4680	4560
1964	!	4300	3240	2860	2700	3630	4100	7920	24900	25700	16400	9450	5850
1965	!	5750	5080	4390	3580	4170	4520	5920	14800	15600	11000	6600	4910

HISTORICAL MONTHLY STREAMFLOW AT ATBARA (10**6 CUBIC METERS)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1912	30	5	0	0	0	126	1990	6990	3330	407	136	46
1913	34	3	0	0	0	0	593	2350	1690	210	32	5
1914	0	0	0	0	0	10	1570	7180	3280	1030	331	82
1915	25	3	0	0	0	136	858	3060	2750	684	146	35
1916	5	0	0	0	0	79	5160	13200	6440	1540	454	173
1917	68	10	0	0	0	221	1240	4430	7410	1210	270	95
1918	35	9	0	0	3	22	1050	3620	1200	390	67	8
1919	0	0	0	0	0	100	1790	4650	2910	457	79	2
1920	0	0	0	0	0	219	1960	6040	2600	922	200	43
1921	0	0	0	0	0	50	1150	5520	3430	776	147	12
1922	0	0	0	0	0	43	1990	7900	6470	1000	169	17
1923	0	0	0	0	0	72	1280	6100	3680	725	139	45
1924	12	0	0	0	0	64	2490	6080	4460	774	259	58
1925	0	0	0	0	0	48	1120	3950	2020	466	74	0
1926	0	0	0	0	0	0	2020	4580	3340	624	142	0
1927	0	0	0	0	0	55	1610	4350	2750	615	75	0
1928	0	0	0	0	0	173	1300	4670	2350	476	105	0
1929	0	0	0	0	0	236	2530	7240	3760	974	165	36
1930	0	0	0	0	0	41	2370	4170	2510	449	110	19
1931	0	0	9	0	0	22	1060	5520	3550	931	186	54
1932	0	0	0	0	0	7	1930	6330	4360	813	145	49
1933	0	0	0	0	0	0	374	3640	4190	994	290	119
1934	8	0	0	0	0	333	2830	7420	3300	1040	171	66
1935	0	0	0	0	6	232	1460	5040	4850	1130	192	66
1936	0	0	0	0	0	0	1740	5580	4750	810	176	64
1937	0	0	0	0	0	9	1560	6400	3780	750	154	47
1938	0	0	0	0	0	0	1590	7360	4820	1380	260	93
1939	0	0	0	0	0	13	1270	3970	2580	820	190	39
1940	0	0	0	0	0	0	1070	4700	2230	390	73	28
1941	0	0	0	0	0	37	799	3090	1710	562	274	60
1942	0	0	0	0	0	0	1600	5420	3220	807	150	59
1943	0	0	0	0	0	0	1270	6010	5640	998	234	69
1944	25	8	0	0	0	0	2360	5390	2720	593	125	50
1945	17	0	0	0	123	295	1210	4510	3810	1390	290	82
1946	16	0	0	0	0	316	2440	10680	3750	901	294	102
1947	37	17	1	0	0	34	893	4940	3350	826	145	70
1948	39	13	0	0	0	231	1650	4580	2990	990	191	69
1949	50	13	0	0	0	92	1090	4110	3180	834	183	81
1950	59	0	0	0	0	0	2190	6550	4930	832	182	92
1951	54	2	0	0	0	31	1680	4570	2860	856	314	115
1952	46	0	0	0	0	0	1120	4950	3260	637	137	44
1953	18	1	0	0	0	212	2060	7350	3710	950	216	112
1954	62	19	2	0	0	171	2310	9020	6880	2140	384	163
1955	0	0	0	0	0	0	1030	5250	5010	1860	298	76
1956	0	0	0	0	0	0	1940	6020	3790	1940	607	158
1957	112	61	29	16	9	72	774	5270	3140	410	109	71

1958 !	57	37	5	0	0	97	1540	7360	4020	1110	207	81
1959 !	44	14	2	0	0	0	1740	8240	5550	1100	337	129
1960 !	59	24	5	0	0	8	1510	4200	3330	805	170	55
1961 !	22	4	0	0	0	47	4440	6130	4630	1200	253	155
1962 !	67	25	6	0	0	0	1180	6050	4490	1000	230	158
1963 !	44	18	0	0	15	17	1450	5050	3350	812	149	103
1964 !	37	23	7	0	0	0	2040	7230	4760	917	191	18
1965 !	165	135	0	0	15	40	1120	3960	2260	324	35	0

HISTORICAL MONTHLY STREAMFLOW AT TAMANIAT (10**6 CUBIC METERS)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1912	3320	2280	1830	1450	1380	2010	6500	16800	14800	7820	5030	3900
1913	2960	1810	1650	1410	1870	2050	3270	8740	10800	5710	3470	2370
1914	1710	1280	1310	1230	1420	1820	5970	20100	17500	14900	9170	5520
1915	4240	2830	2100	1470	1820	2650	4960	10000	12800	11000	6270	4600
1916	3360	2140	1690	1510	1630	2460	8430	21800	23800	20500	10300	6440
1917	4940	4090	3380	2140	2100	2910	8280	18100	25400	21000	8980	6200
1918	5050	3920	4110	4390	4480	4490	7780	14800	16500	9690	5820	4390
1919	3220	2270	2100	1700	1710	3020	7620	17900	19700	9780	5110	3750
1920	2690	1690	1720	1410	1440	3150	7290	15900	15200	13100	6490	4580
1921	3410	2010	1860	1540	1500	2440	5100	15800	16400	11500	5500	4140
1922	2930	1750	1340	950	1050	2060	5920	18100	18800	13400	5980	4330
1923	3360	1670	1420	1330	1700	3440	7320	18300	18100	10900	5410	4410
1924	3320	1980	1530	1560	1810	2360	6990	16600	18900	10300	6450	4410
1925	3370	1980	1600	1280	1680	2840	5820	14500	13300	9310	4860	3790
1926	2800	1720	1700	1630	2230	3320	6410	18700	17500	11300	5810	4510
1927	3600	2340	1900	1680	1660	2490	6440	16300	14400	9700	4350	3300
1928	2070	1510	1520	1670	2660	3380	9460	18200	17000	9690	5110	4120
1929	3050	1890	1700	1590	2980	5510	11600	20200	21200	15300	6620	4630
1930	3670	2330	2020	1750	2090	2830	7630	18900	17100	8210	4110	3190
1931	2130	1460	1410	1350	1300	2150	5580	16500	18300	11600	5500	3890
1932	2760	1710	1610	1390	1740	2880	6260	17300	15000	11700	5530	4400
1933	4070	3150	2300	1860	2060	2660	4960	14600	17800	12400	6600	4940
1934	3730	2180	1890	1720	1980	2830	8180	18800	18500	12100	5840	4620
1935	3790	2420	1980	1840	2170	3760	10200	20000	20000	13800	5940	4350
1936	3350	2300	2160	1740	1840	2440	7960	18000	20100	11400	5200	3770
1937	2640	1720	1770	1520	1710	2580	7460	18300	18000	9050	4650	3810
1938	2780	2080	2070	1600	1610	2200	7740	19600	21300	15200	5990	4320
1939	3460	2630	2170	2330	2300	2840	5730	13100	14600	9630	5450	3900
1940	2580	2410	2500	1620	1620	2150	4110	15900	14300	7030	3380	2580
1941	1960	2110	2180	1370	1420	3160	5310	12900	12100	10000	5880	3370
1942	2730	2120	2620	2430	1710	2580	7120	18200	14800	11200	4360	3510
1943	2310	2340	2590	2120	1720	1860	4950	15400	16500	8970	4450	3140
1944	2010	2610	2800	2380	1930	2710	6190	14800	12800	7590	3860	2810
1945	2000	2270	2580	2140	1550	2670	5250	13800	15700	12300	6370	4220
1946	3180	2120	2930	2520	1860	2570	8840	24100	20400	11100	6130	4700
1947	3860	3040	3030	2950	3090	3030	4660	16900	17600	10100	4580	3900
1948	3310	2570	2950	2660	2170	3170	7890	16600	15900	13700	6460	4020
1949	3200	2110	2830	2840	2450	3030	7120	16600	16300	10800	5290	4070
1950	3460	2620	2840	2850	2980	2750	6160	17100	17000	10700	4660	3600
1951	3060	1880	2940	2790	1660	2120	4460	14600	12200	10200	5240	3680
1952	2530	2650	2640	2080	1590	2160	5780	15400	14100	8910	3940	3070
1953	2270	1980	2830	2160	1740	2400	7040	17800	13900	8610	4280	3320
1954	2150	2350	2760	2420	1510	2460	8450	20700	20600	13500	5430	4160
1955	3400	2360	2650	2920	3120	2740	7190	18100	18000	12900	5070	3920
1956	3310	2490	2810	2710	2950	3290	6900	18000	15900	17000	7510	4370
1957	3620	2660	2850	3090	3350	3970	5790	17100	13700	5500	3510	2720

1958	!	2140	2060	2380	2380	1620	2700	7560	20200	16100	12000	5470	3720
1959	!	3160	2100	2730	2690	2230	2410	5510	15800	19900	11400	5990	3910
1960	!	2960	2240	2820	2860	2520	2370	6240	16300	15600	10600	4090	3050
1961	!	2400	2000	2890	2900	1840	2110	8160	18900	20200	14100	5770	4590
1962	!	3700	2770	3060	3310	3440	4080	5560	16000	16500	11200	4700	3920
1963	!	3220	2720	2640	3050	3830	3660	8010	19000	15300	8590	4140	4460
1964	!	4150	3360	3100	3370	4240	4490	9330	21200	20800	15000	8050	5910
1965	!	5800	4830	4270	3660	4910	4570	5860	13600	12300	10900	5640	4680

HISTORICAL MONTHLY STREAMFLOW AT KHARTOUM (10**6 CUBIC METERS)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1912	1340	824	576	324	207	848	5910	15900	11400	4390	2210	1230
1913	870	473	351	217	566	466	1880	7520	8620	3000	1140	590
1914	340	203	166	158	246	734	5250	19000	14300	11300	5720	2260
1915	1250	680	478	318	461	971	3320	8060	11300	8430	3510	1840
1916	942	537	358	250	368	828	6760	20200	21500	16100	6050	2960
1917	1730	1020	835	551	645	1410	7300	17700	22900	15800	4820	2500
1918	1290	780	625	337	400	1170	5370	12900	11300	5000	2000	1150
1919	726	438	321	175	241	1120	6200	16800	17300	5180	2220	1230
1920	646	368	358	303	313	1650	6170	13200	11400	8750	3170	1870
1921	388	435	347	202	259	865	3410	14600	14500	7350	2310	1180
1922	727	388	297	171	175	801	4570	16000	16100	8990	2560	1350
1923	782	507	375	454	569	2000	5890	16500	13900	7290	2850	1700
1924	848	572	420	414	497	1000	5890	15000	15600	7200	3800	1830
1925	860	493	436	304	417	1260	3340	13300	10700	6010	2070	1110
1926	644	454	507	535	1090	1710	5590	18900	15100	7950	2440	1480
1927	813	456	464	416	391	1290	5450	16200	12900	5900	1660	860
1928	500	299	301	420	1110	1720	8100	17100	12800	6090	2170	1180
1929	632	386	343	355	1380	3610	10300	18600	18400	11300	3240	1700
1930	1020	622	535	374	578	1370	6330	14700	12200	4750	1680	859
1931	460	273	282	350	215	868	3570	14800	15100	8630	2440	1100
1932	577	345	316	235	516	1240	4890	15600	15900	8070	2090	1040
1933	649	349	384	251	495	1030	3220	13200	15100	8400	2940	1470
1934	721	361	395	351	442	1260	7020	18200	14900	8530	2620	1470
1935	891	483	440	464	756	2190	9450	20300	18400	9140	2760	1540
1936	914	621	583	513	547	913	7170	17400	16700	7580	2200	1050
1937	611	387	464	365	433	1050	6470	17500	14600	5600	1950	1100
1938	528	397	426	316	373	995	7380	18800	18200	11700	3290	1460
1939	771	496	489	397	550	1170	4680	12100	11200	7160	2920	1230
1940	655	393	401	302	353	851	2940	16000	12700	4070	1120	697
1941	333	261	302	153	359	1940	4830	11400	10900	7110	2900	1100
1942	557	330	537	409	511	1010	6560	18000	14200	8210	1860	912
1943	477	352	327	257	422	439	4050	15800	15200	6750	2290	974
1944	509	377	280	259	542	778	4380	13800	11400	4910	1310	634
1945	398	266	276	210	392	849	3810	13400	14800	9600	3490	1380
1946	656	387	329	338	380	1250	7750	23000	18000	7970	2950	1500
1947	785	507	533	747	570	799	3630	16400	16300	7280	1990	1270
1948	597	424	591	343	332	1760	7320	14600	14400	10800	3670	1440
1949	777	483	453	438	268	1750	6190	15900	15200	7910	2310	1430
1950	824	446	368	436	75[illegible]	1330	5390	16500	16300	8270	1880	916
1951	518	348	394	356	289	889	3570	14400	11000	8180	3170	1450
1952	738	461	428	293	410	770	4860	15400	13500	7050	1810	860
1953	533	321	338	233	486	1100	6230	18000	12600	6260	1930	1070
1954	710	440	389	310	278	1090	7800	20000	18200	10500	2600	1300
1955	925	635	425	457	613	1160	5980	17600	16200	10200	2570	1450
1956	896	467	401	365	541	1230	6500	15700	13100	14500	4490	1690
1957	997	587	797	1140	759	1500	4270	16400	11800	3570	1270	756

1958 !	450	389	215	275	344	1330	6600	19000	14400	9370	2960	1410
1959 !	867	482	475	297	540	810	3970	14200	17800	9210	3890	1740
1960 !	950	563	462	438	498	807	5190	17000	14300	7930	1940	966
1961 !	450	324	354	402	460	850	7340	17400	16300	11000	2920	1990
1962 !	883	480	392	383	427	1280	3870	15300	14500	6830	1830	978
1963 !	450	280	168	300	970	1120	5180	16700	12900	4780	1320	1040
1964 !	658	284	136	168	453	984	7460	19300	17300	11200	3380	1340
1965 !	748	433	205	204	466	637	3120	12400	9690	6980	2020	1100

HISTORICAL MONTHLY STREAMFLOW AT SENNAR (10**6 CUBIC METERS)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1912	1060	608	401	231	143	1210	5460	15500	10400	3960	1950	994
1913	622	328	222	140	463	280	1940	6940	7580	2230	705	305
1914	164	70	63	113	84	638	5860	17700	12900	10700	5730	2250
1915	1160	634	437	276	570	1170	3550	9880	12400	8440	3250	1490
1916	779	394	211	140	312	861	7500	20000	18300	13200	5610	2790
1917	1540	874	657	444	600	1500	8250	19400	21200	13300	4690	2530
1918	1450	947	719	584	982	2010	6100	14100	10600	4720	2150	1130
1919	654	429	276	146	343	1450	6850	14500	13000	3970	1790	966
1920	606	416	370	233	497	1860	7130	13300	10800	8330	3030	1450
1921	788	439	295	164	307	1050	3730	14100	12300	6250	2360	1230
1922	702	389	265	173	247	1020	5090	15600	13700	7840	2680	1300
1923	731	445	403	463	811	1920	6800	14500	13200	6030	2800	1540
1924	783	511	369	489	516	1280	6490	15100	13300	6010	3450	1650
1925	953	527	393	261	460	1730	4350	12900	9670	5120	1810	1100
1926	619	405	580	510	1240	1810	6630	17200	14000	7030	2250	1370
1927	706	455	465	430	331	1700	6240	14300	10700	5240	1310	804
1928	426	318	393	627	1470	2240	8440	16700	11400	5140	2040	1180
1929	669	505	483	572	1860	3960	10500	18700	16600	10000	2920	1660
1930	952	658	594	539	722	1520	6580	14000	11100	3940	1480	844
1931	440	289	307	395	226	1140	4360	15100	13000	7520	2010	1010
1932	473	361	331	222	779	1390	5920	15800	14900	6770	1810	1020
1933	537	387	374	335	573	1170	3890	13000	13800	7320	2540	1340
1934	630	362	424	360	496	1540	7150	18000	13100	7050	2200	1340
1935	719	440	420	529	1020	2600	10100	17900	15500	8010	2340	1460
1936	843	639	540	542	603	1330	7940	16300	14400	5640	1520	1040
1937	573	400	426	353	560	1320	7170	17200	12800	4460	1710	1050
1938	506	354	421	294	421	1460	8560	18700	16400	9910	2750	1430
1939	749	48[illegible]	489	424	687	1530	4980	11400	10700	6140	2490	1180
1940	621	417	371	309	388	1050	3490	14900	9900	3440	984	572
1941	267	235	233	152	626	2420	5610	11700	9520	6420	2540	1100
1942	501	310	687	363	660	1330	7450	16400	12100	6340	1610	875
1943	434	360	548	242	498	614	4810	15100	13300	5560	1880	998
1944	471	415	289	280	820	1410	5780	13700	10500	4210	1280	801
1945	369	304	244	216	776	1380	5390	12900	13900	8140	3210	1570
1946	782	439	430	362	391	1800	9060	24000	15000	7060	2730	1380
1947	671	465	516	701	502	922	4230	15900	13200	5320	1670	1150
1948	490	388	544	260	357	2310	7150	13600	13100	9310	3140	1340
1949	648	423	413	446	417	1870	6650	15600	13900	6400	1910	1240
1950	712	411	333	478	852	1570	5970	15000	13800	5190	1490	859
1951	410	347	368	342	368	1000	4000	14400	9150	7180	2760	1370
1952	648	476	429	324	438	959	5530	14500	11000	5800	1560	805
1953	471	302	309	230	554	1010	6290	16400	10400	3070	1700	998
1954	649	408	363	284	343	120	7950	18900	16200	8600	2330	1200
1955	852	554	404	460	688	1310	6930	16500	15500	8280	2190	1250
1956	720	434	390	398	510	1540	6660	14700	11600	12500	3510	1530
1957	862	479	866	1170	719	1580	5400	16200	10400	3200	1090	740

1958	!	486	490	252	330	398	1780	7320	18200	13200	9020	2680	1340
1959	!	939	590	492	294	673	1030	4830	14700	15100	8040	3150	1530
1960	!	939	563	427	486	607	1180	6160	15300	13000	6350	1760	862
1961	!	434	331	266	457	437	951	6800	14900	15900	9710	2980	1980
1962	!	869	344	360	338	477	1700	4350	13400	12800	7180	1740	818
1963	!	376	213	166	319	1200	1420	5690	16000	11300	4220	1520	1050
1964	!	533	281	84	155	365	1350	8090	18200	15600	9430	2580	1290
1965	!	687	330	117	401	360	973	3880	12400	8570	5870	1780	1020

HISTORICAL MONTHLY STREAMFLOW AT ROSEIRES (10**6 CUBIC METERS)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1912	856	573	358	233	248	1450	5930	14200	8690	3440	1620	871
1913	576	352	272	260	604	396	2320	6620	6090	2140	743	319
1914	190	143	146	232	187	975	5660	16900	11400	8850	4610	1740
1915	873	468	337	227	560	1250	3640	8190	11100	6940	2960	1350
1916	726	410	240	219	490	1390	7450	19400	16800	10900	4500	2210
1917	1190	670	500	372	632	1760	8210	18400	21100	10900	3910	2030
1918	1160	753	649	540	949	1990	5950	12600	8670	3860	1720	883
1919	700	464	318	162	500	1600	7200	15100	13100	4280	1800	942
1920	625	393	396	227	982	2210	7230	12700	7710	7350	2860	1320
1921	778	468	306	204	428	1290	4330	15000	12300	5690	2190	1100
1922	640	384	268	184	371	1460	5510	14200	12200	6850	2330	1220
1923	707	428	412	478	1080	1930	6890	18000	13100	5160	2380	1530
1924	804	535	385	530	564	1830	6960	15100	13900	5930	3540	1630
1925	922	524	399	291	701	2030	4890	12900	9900	5280	2380	1160
1926	722	427	398	354	1850	1990	7320	17300	14000	7060	2670	1550
1927	797	436	400	242	266	1850	6130	12500	9080	5220	1840	990
1928	573	315	254	413	1540	2250	8900	17600	11900	5760	2560	1330
1929	752	467	334	373	1880	4130	11000	19300	16600	9890	3230	1890
1930	1070	622	459	526	608	1610	7090	14300	11300	4280	2020	1080
1931	630	344	257	192	221	1450	4890	15300	12700	7520	2570	1200
1932	675	383	259	203	747	1570	6260	16000	15500	7140	2240	1210
1933	707	419	327	248	512	1210	4510	13300	13400	7130	2900	1510
1934	805	452	317	280	452	1700	7620	17900	12700	7390	2750	1590
1935	878	485	360	[illegible]	1100	2590	10900	18900	16700	8100	2830	1590
1936	999	746	471	[illegible]	535	1510	8410	16400	14700	5760	2330	1360
1937	824	478	371	256	598	1370	7360	17000	13100	4810	2280	1270
1938	696	383	384	217	370	1660	9120	19000	16500	10000	3230	1610
1939	932	541	405	364	650	1630	5620	11800	10800	6500	2910	1390
1940	792	470	334	243	345	1090	3950	15100	10200	3870	1580	836
1941	475	291	208	126	733	2350	6170	12200	10100	7040	3070	1350
1942	661	370	715	288	556	1420	8070	16600	12900	6870	2210	1210
1943	764	419	289	222	419	864	5070	14800	13800	5940	2410	1230
1944	684	400	281	246	765	1580	6370	14400	11000	4190	1900	1040
1945	616	344	225	180	756	1390	5660	12700	13700	8490	3530	1690
1946	945	502	326	292	335	1820	9480	25200	15200	7227	3030	1580
1947	906	517	461	688	415	1040	4920	17100	14900	6580	2250	1380
1948	734	500	438	212	348	2580	7730	14500	14000	10200	3530	1590
1949	893	500	419	354	439	2070	7740	16000	13900	6600	2490	1680
1950	937	474	359	508	802	1720	5940	15100	13900	5570	2090	1190
1951	718	405	350	243	382	1170	4540	15500	9670	7440	3160	1540
1952	763	425	321	245	361	1150	6020	15300	11500	6510	2170	1110
1953	616	336	280	248	569	912	6850	17700	11200	5840	2330	1290
1954	768	431	320	252	304	1630	8690	18100	15000	8570	3040	1620
1955	1100	599	379	459	669	1500	7500	16800	15300	8750	3050	1640
1956	911	514	382	467	440	2330	7160	15000	12000	14100	4320	1950
1957	1090	605	1100	1290	706	1780	5660	17200	10500	3720	1720	1000

1958 !	590	398	256	319	382	1870	7780	19000	13800	9670	3410	1790
1959 !	1050	642	456	283	610	1100	5380	16200	16100	9290	3850	1980
1960 !	1190	714	536	405	547	1310	7040	16300	13600	6980	2450	2230
1961 !	794	509	366	502	361	1410	8990	17300	16800	11100	3550	2230
1962 !	1150	602	489	289	558	1700	5350	15100	14200	8940	2560	1460
1963 !	881	483	400	416	1250	1520	6140	16900	12500	4860	2620	2300
1964 !	944	565	340	396	443	1670	8870	16900	14600	10600	3720	1950
1965 !	1150	665	448	433	277	1200	4760	13400	9420	7200	3070	1750

HISTORICAL MONTHLY STREAMFLOW AT MALAKAL (10**6 CUBIC METERS)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1912	1880	1460	1370	1220	1190	1580	2310	2920	3160	3310	3070	2710
1913	1810	1390	1460	1330	1710	1720	2250	2620	2730	2950	2220	1630
1914	1450	1230	1310	1260	1310	1630	2170	2730	3230	3590	3380	3340
1915	2600	1460	1390	1300	1510	1850	2440	2820	2980	3270	3270	3050
1916	1950	1410	1360	1300	1460	1840	2500	2910	3400	3990	4080	4280
1917	4280	3240	2270	1860	2010	2390	2880	3230	3520	4140	4400	4810
1918	4970	4620	4840	2880	2450	2910	3330	3800	4010	4000	3610	2930
1919	2190	1810	1800	1580	1760	2260	2810	3160	3220	3500	3460	2880
1920	1870	1490	1420	1240	1450	1990	2380	2630	2740	3040	2960	2760
1921	1750	1240	1230	1130	1430	1720	2210	2500	2580	2870	2710	2600
1922	1500	1040	963	860	1040	1560	2110	2440	2540	2860	2860	2820
1923	1710	1040	1060	1300	1410	2010	2460	2940	3160	3360	3070	2960
1924	1830	1320	1270	1310	1540	1680	2180	2490	2620	2940	2640	2810
1925	1860	1270	1290	1210	1470	1830	2360	2660	2750	2990	2880	2590
1926	1650	1180	1340	1240	1590	1970	2310	2680	2880	3330	3150	3090
1927	2500	1400	1390	1310	1340	1700	2250	2560	2650	2850	2710	1810
1928	1400	1170	1200	1320	1820	2070	2490	2850	2980	3300	3240	3080
1929	1920	1410	1410	1360	1960	2300	2690	2870	2990	3310	3150	3080
1930	2180	1430	1400	1340	1530	1830	2340	2630	2670	2830	2670	2040
1931	1550	1190	1250	1200	1270	1690	2310	2640	2670	3180	3160	2810
1932	1680	1360	1360	1310	1510	2000	2470	2840	3120	3690	3720	3870
1933	3420	1820	1670	1600	1670	1960	2420	3130	3450	3730	3660	3420
1934	2300	1510	1540	1460	1680	1970	2590	2940	3150	3420	3380	3410
1935	2420	1520	1520	1510	1720	2230	2700	2930	2970	3180	3120	3070
1936	1980	1570	1470	1310	1570	2030	2390	2620	2750	2980	2880	2400
1937	1640	1320	1340	1240	1540	1980	2320	2620	2960	3320	3080	2750
1938	1800	1350	1430	1380	1530	1900	2430	2710	2860	3300	3290	3400
1939	3170	1780	1600	1430	1750	2160	2540	2710	2790	3030	3000	2530
1940	1650	1350	1370	1280	1370	1730	2190	2490	2590	2790	2630	1900
1941	1460	1190	1240	1160	1340	1940	2360	2620	2710	2880	2840	2910
1942	2050	1330	1440	1210	1480	1940	2380	2690	2960	3140	3000	2730
1943	1640	1259	1340	1310	1510	1730	2210	2590	2740	2950	2900	2510
1944	1600	1320	1320	1320	1600	2040	2420	2670	2810	3080	2860	2400
1945	1670	1270	1270	1070	1230	1810	2260	2570	2810	3240	3150	3110
1946	2290	1310	1220	1060	1220	1700	2260	2950	3510	3780	3740	3880
1947	3780	2340	1460	1420	1560	1930	2410	2720	2920	3270	3210	3350
1948	2700	1510	1440	1320	1480	2000	2450	2720	2890	3140	3150	3340
1949	2940	1730	1520	1450	1450	1920	2370	2720	3010	3440	3280	3340
1950	3080	1710	1480	1420	1710	1960	2430	2820	3090	3420	3300	3180
1951	2210	1350	1350	1160	1190	1630	2110	2330	2460	2690	2650	2620
1952	1780	1270	1220	1180	1420	1740	2190	2470	2570	2780	2750	2560
1953	1670	1260	1280	1250	1430	1750	2200	2600	2770	3040	2970	2450
1954	1710	1250	1290	1290	1360	1780	2320	2770	3130	3490	3360	3220
1955	2610	1590	1400	1400	1500	1930	2350	2590	2790	3080	3040	3090
1956	2840	1970	1580	1540	1820	2080	2480	2750	3000	3320	3180	3240
1957	3040	1780	1650	1790	1600	2060	2450	2740	2790	2960	2800	2340

1958 !	1600	1280	1290	1130	1380	1750	2340	2670	2840	3110	2960	3010
1959 !	2220	1360	1380	1240	1560	1910	2300	2530	2680	2920	2860	2940
1960 !	2320	1430	1400	1320	1610	1950	2390	2640	2680	2840	2780	2730
1961 !	1820	1320	1380	1380	1380	1730	2310	2850	3220	3730	3430	3400
1962 !	3300	2700	2420	1810	1900	2260	2720	3060	3240	3530	3500	3730
1963 !	3760	2950	2270	1830	2350	2610	3020	3450	3880	4630	4680	4760
1964 !	3930	3100	2890	2480	2440	2560	3170	4150	5200	6090	6210	6420
1965 !	6060	4460	3800	3070	2800	2800	3500	4050	4200	4560	4400	4130

HISTORICAL MONTHLY STREAMFLOW AT MONGALLA (10**6 CUBIC METERS)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1912	1670	1380	1380	1430	1610	1550	2300	2920	3000	2200	2040	1950
1913	1480	1370	1470	1650	2340	2320	2480	2440	1880	1810	1930	1820
1914	1680	1400	1530	1430	1860	1700	2040	2810	2590	2660	3270	2500
1915	2010	1710	1870	1900	2330	2340	2260	2620	2620	2970	2790	2270
1916	1990	1730	1780	1910	2490	2920	3300	4080	5250	4810	4040	3590
1917	3200	2850	3060	3060	4380	4910	4990	5420	6430	7350	5300	4850
1918	4850	4080	4410	4110	4320	3970	3950	4010	3610	3650	3180	2990
1919	2770	2330	2390	2360	2660	2380	3010	2780	2860	2700	2570	2380
1920	2320	1760	1660	1860	2200	2310	2340	2560	2190	2480	2140	1990
1921	1530	1220	1200	1120	1190	1200	1630	1830	1580	1650	1290	1180
1922	1070	891	999	1050	1250	1160	1240	1560	1950	1550	1460	1080
1923	983	801	853	913	1430	1330	2090	2850	1930	2200	2170	1780
1924	1640	1440	1420	1650	1910	1550	1600	1720	1930	2020	1920	1660
1925	1540	1300	1430	1450	1370	1520	1560	1860	1610	1520	1750	1650
1926	1390	1180	1300	1470	1880	1660	2370	3130	2750	3020	2400	2350
1927	2230	1940	2090	2150	2240	2230	2260	2340	2220	2260	2090	1990
1928	1850	1620	1640	1960	3830	2620	2520	2330	2060	2380	2000	1830
1929	1700	1440	1480	1510	2240	1760	1780	1950	1930	2000	1880	1660
1930	1540	1320	1500	1750	1940	1800	1820	2040	2120	2370	2440	2060
1931	1960	1680	1880	1940	2300	2180	2760	3300	3130	3020	2470	2410
1932	2250	1940	2180	2060	2680	2380	2960	3720	3570	3480	2760	2650
1933	2480	2180	2350	2260	2500	2280	2570	2680	3410	3040	2470	2350
1934	2180	1810	1910	1930	2420	2130	2480	3080	2460	1990	1960	1890
1935	1760	1500	1590	1670	2340	2170	2280	2130	2260	2240	1820	1720
1936	1600	1420	1560	1600	1860	2040	2210	2490	2450	2310	1940	1900
1937	1810	1630	1730	1890	2500	2250	2910	3170	2350	2650	2730	2510
1938	2310	2000	2100	2060	2430	2550	2570	3470	3110	2810	2470	2270
1939	2140	1830	1940	2120	2190	2020	2220	2300	2140	2010	2120	1900
1940	1720	1530	1610	1710	2230	1730	2050	2500	2100	1760	1630	1680
1941	1580	1320	1560	1520	2150	2760	2100	1980	1970	1970	1920	2040
1942	1890	1650	1940	1960	2600	2650	3100	3760	3990	3130	2720	2730
1943	2610	2210	2270	2170	2460	2530	2760	2750	2640	2270	1950	1840
1944	1710	1450	1510	1540	2140	1610	1950	1830	1970	1950	1600	1450
1945	1320	1070	1070	936	1510	1550	1790	2300	2200	1920	1520	1500
1946	1280	1100	1120	1190	1600	2100	1870	3260	2690	2280	1900	1620
1947	1510	1340	1500	1850	2210	2000	2590	3300	3350	3310	2440	2510
1948	2340	2090	2150	2060	2350	2540	2770	3130	3430	3620	2940	2480
1949	2220	1890	1960	1860	2160	2050	2600	2690	2890	2470	1910	1770
1950	1630	1350	1410	1530	1660	1560	1880	2720	2580	2880	1710	1450
1951	1350	1130	1190	1310	1510	1560	1510	1890	1450	1870	2120	2100
1952	1870	1640	1680	1910	2400	2180	2420	3530	3180	3150	2400	2250
1953	1990	1660	1690	1610	1910	1950	2130	2340	1680	1920	1900	1650
1954	1510	1280	1380	1520	1910	1800	2020	2690	3010	2230	1870	1700
1955	1640	1440	1510	1500	1740	1530	1690	2200	2860	3060	2370	1780
1956	1620	1430	1490	1640	1950	1850	1940	2500	3060	3010	2100	1860
1957	1780	1570	1780	1940	2380	2690	2170	2480	2090	2080	1960	1910

```
1958 !   1810   1570   1700   1730   2080   2100   2770   2870   2520   2470   1940   1880
1959 !   1760   1490   1580   1550   2120   1910   1900   2440   2390   2220   2030   1820
1960 !   1630   1490   1680   1830   2090   1860   2210   2500   2640   2780   2350   2040
1961 !   1900   1620   1770   1790   2010   2040   2590   3550   3730   4250   4730   4080
1962 !   3450   5040   3560   3660   4330   4090   4700   4890   5000   5040   4520   4370
1963 !   4420   3890   4280   4790   6050   5640   5500   5540   5310   4970   5010   5070
1964 !   4390   3740   3860   4510   5290   4940   5720   6320   6860   7340   5760   5270
1965 !   5260   4530   4780   4570   4740   4430   4580   4810   4440   5040   4900   4840
```

APPENDIX B

COMPUTER PROGRAM LISTING FOR STEADY-STATE STOCHASTIC DYNAMIC PROGRAM (ALGORITHM 1)

This Appendix gives a computer program listing of steady-state Algorithm 1 presented in Section 3.2. A sample input and output for experiment 1 of Table 5.5 are provided for illustrative purposes.

```
C  ***********************************************************************
C  *                                                                     *
C  *  THIS PROGRAM IS AN INFINITE HORIZON STOCHASTIC DYNAMIC             *
C  *  PROGRAMMING ALGORITHM USED TO DERIVE STEADY-STATE RESERVOIR        *
C  *  OPERATING RULES.  THE THEORETICAL FORMULATION CAN BE FOUND         *
C  *  IN BUCHANAN AND BRAS, "STUDY OF A REAL-TIME ADAPTIVE CLOSED-       *
C  *  LOOP CONTROL ALGORITHM FOR RESERVOIR OPERATION", 1981,             *
C  *  CHAPTER 3, SECTION 2.                                              *
C  *                                                                     *
C  *  THE MAIN PROGRAM CALLS SUBROUTINES WITH THE FOLLOWING FUNCTIONS:*
C  *                                                                     *
C  *      SUBROUTINE DATADP - READS IN AND WRITES OUT DATA               *
C  *      SUBROUTINE DISCST - DISCRETIZES STORAGE INTO REPRESENTATIVE *
C  *                          VALUES OVER THE LIVE STORAGE RANGE         *
C  *      SUBROUTINE DYNPRO - PERFORMS CALCULATIONS OF DYNAMIC           *
C  *                          PROGRAM ALGORITHM 1 OF CHAPTER 3           *
C  *                                                                     *
C  ***********************************************************************
      CALL DATADP
      CALL DISCST
      CALL DYNPRO
      STOP
      END
C  ***********************************************************************
C  ***********************************************************************
```

```
C ******************************************************************
      SUBROUTINE DATADP
C ******************************************************************
C *                                                                *
C *  THIS SUBROUTINE READS IN AND WRITES OUT DATA.  DEFINITIONS OF  *
C *  THE VARIABLES EL, FACTOR, GENMAX, NELEV, RELMAX, SLOPE, XO AND *
C *  YO ARE GIVEN IN SUBROUTINE BENEF1.  THE REMAINING DEFINITIONS  *
C *  ARE AS FOLLOWS (IN ALPHABETICAL ORDER):                        *
C *                                                                *
C *    DELTAR - RELEASE INCREMENT IN OPTIMAL RELEASE SEARCH         *
C *    EPS    - CONVERGENCE FACTOR USED TO TERMINATE CALCULATIONS   *
C *             (SEE EQUATION 5.8 AND 5.14)                         *
C *    EVRATE - EVAPORATIONS RATES (MM/MONTH)                       *
C *    ITOSH  - EQUALS ZERO IF TOSHKA SPILLWAY NOT INCLUDED         *
C *             NOT EQUAL TO ZERO IF TOSHKA SPILLWAY INCLUDED       *
C *    NIT    - NUMBER OF ITERATIONS USED IN CALCULATING WATER LOSSES*
C *             (SEE SUBROUTINE FINSTO)                             *
C *    NP     - NUMBER OF PERIODS PER CYCLE (I.E. NUMBER OF MONTHS) *
C *    NQ     - NUMBER OF DISCRETE INFLOW STATES PER MONTH          *
C *    NS     - NUMBER OF DISCRETE STORAGE STATES PER MONTH         *
C *    NWR    - FILE NUMBER FOR OUTPUT                              *
C *    NY     - MAXIMUM NUMBER OF CYCLES OF CALCULATIONS            *
C *    NY1    - EQUALS NY-1                                         *
C *    PEN1   - =1 IF POWER GENERATION IS AN OBJECTIVE              *
C *             =0 IF NOT                                           *
C *    PEN2   - =1 IF MEETING IRRIGATION DEMANDS IS AN OBJECTIVE    *
C *             =0 IF NOT                                           *
C *    PEN3   - =1 IF AVOIDING RELEASES ABOVE RC IS AN OBJECTIVE    *
C *             =0 IF NOT                                           *
C *    PENG   - = ALOG10(A3) (SEE OBJECTIVE FUNCTION, EQUATION 3.18, *
C *               BUCHANAN AND BRAS (1981)                          *
C *    PERSUD - MONTHLY PERCENTAGES OF TOTAL SUDAN ABSTRACTIONS     *
C *    PIRR   - = ALOG10(A1) (SEE EQUATION 3.18)                    *
C *    PREL   - = ALOG10(A2) (SEE EQUATION 3.18)                    *
C *    PTRAN  - TRANSITION PROBABILITIES OF DISCRETE INFLOW STATES  *
C *    Q2     - DISCRETE INFLOW STATES                              *
C *    RATE   - MONTHLY DISCOUNT RATE                               *
C *    RC     - RELEASE ABOVE WHICH DOWNSTREAN DEGRADATION OCCURS   *
C *    RMAX   - MAXIMUM RELEASE CONSIDERED IN OPTIMAL RELEASE SEARCH *
C *    SMAX   - MAXIMUM RESERVOIR STORAGE                           *
C *    SMIN   - MINIMUM RESERVOIR STORAGE                           *
C *    STL    - MAXIMUM STORAGE BEFORE SPILLS TO TOSHKA START       *
C *    SUDGEB - MONTHLY QUANTITIES OF SUDAN ABSTRACTIONS COMBINED   *
C *             WITH GEBEL AULIA LOSSES                             *
C *    TARGE  - MONTHLY ENERGY TARGETS                              *
C *    TARGI  - MONTHLY IRRIGATION TARGETS                          *
C *    TOTSUD - TOTAL ANNUAL SUDAN ABSTRACTIONS AND GEBEL AULIA     *
C *             LOSSES (SUDGEB(I) = PERSUD(I) * TOTSUD)             *
C *    XPE    - A3 IN EQUATION 3.18                                 *
C *    XPI    - A1 IN EQUATION 3.18                                 *
C *    XPR    - A2 IN EQUATION 3.18                                 *
```

```
C  *                                                                      *
C  ************************************************************************
      COMMON/A1/NY,NP,NS,NQ,NIT,NWR
      COMMON/A2/Q2(12,5),PTRAN(12,5,5)
      COMMON/A3/TARGI(12),TARGE(12),EVRATE(12),SUDGEB(12)
      COMMON/A4/RMAX,SMAX,SMIN,DELTAR,RATE,ITOSH,STL
      COMMON/A6/RC,XPE,XPI,XPR,PEN1,PEN2,PEN3,PENG,PIRR,PREL
      COMMON/A7/GENMAX(21),RELMAX(21),EL(21),X0(21),Y0(21),SLOPE(21)
      COMMON/A8/FACTOR,NELEV
      COMMON/B1/NY1
      COMMON/B2/EPS
      DIMENSION PERSUD(12)
      N5=1
      READ(N5,)NY,NP,NS,NQ,NWR,NIT,EPS,RC,ITOSH
      NY1=NY-1
      STL=200.0
      IF(ITOSH.NE.0)STL=137.5
      DO 20 I=1,NP
   20 READ(2,)(Q2(I,J),J=1,NQ)
      DO 30 I=1,NP
      DO 30 J=1,NQ
   30 READ(2,)(PTRAN(I,J,K),K=1,NQ)
      READ(N5,)TOTSUD
      READ(N5,)(PERSUD(I),I=1,NP)
      DO 40 II=1,NP
   40 SUDGEB(II)=TOTSUD*PERSUD(II)
C
C  *** ADJUST INFLOW STATES TO ACCOUNT FOR SUDAN LOSSES ***
C
      DO 45 I=1,NP
      DO 45 J=1,NQ
      Q2(I,J)=Q2(I,J)-SUDGEB(I)
   45 IF(Q2(I,J).LT.0.)Q2(I,J)=0.
      READ(N5,)(TARGI(I),I=1,NP)
      READ(N5,)RMAX,SMAX,SMIN,DELTAR,RATE
      READ(N5,)(TARGE(I),I=1,NP)
      READ(N5,)(EVRATE(I),I=1,NP)
      READ(N5,)PENG,PIRR,PREL
      XPE=10.**PENG
      XPI=10.**PIRR
      XPR=10.**PREL
      READ(N5,)PEN1,PEN2,PEN3
      READ(N5,)FACTOR,NELEV
      DO 485 IM=1,NELEV
      READ(N5,)GENMAX(IM),RELMAX(IM),EL(IM),X0(IM),Y0(IM)
  485 SLOPE(IM)=((GENMAX(IM)-Y0(IM))/(RELMAX(IM)-X0(IM)))
      WRITE(NWR,500)
  500 FORMAT(///,84('*'),/)
      WRITE(NWR,505)
  505 FORMAT(6X,'SEQUENTIAL OPERATING POLICY-INPUT DATA',/)
      WRITE(NWR,510)NY,NP,NS,NQ
```

```
510  FORMAT(6X,'MAXIMUM NUMBER OF CYCLES  ',I5,/,6X,'PERIODS PER YEAR',
    &10X,I5,/,6X,'STORAGE STATES',12X,I5,/,6X,'INFLOW STATES ',12X,I5)
     IF(ITOSH.NE.0)WRITE(NWR,511)
     IF(ITOSH.EQ.0)WRITE(NWR,512)
511  FORMAT(6X,'TOSHKA SPILLWAY OPERATING')
512  FORMAT(6X,'TOSHKA SPILLWAY NOT OPERATING')
     WRITE(NWR,515)
515  FORMAT(/,6X,'IRRIGATION TARGETS (BCM/PERIOD)',/)
     WRITE(NWR,520)(TARGI(I),I=1,NP)
520  FORMAT(5X,15F8.2)
521  FORMAT(5X,15F8.1)
     WRITE(NWR,525)
525  FORMAT(/,6X,'ENERGY TARGETS (GWH/PERIOD)',/)
     WRITE(NWR,521)(TARGE(I),I=1,NP)
     WRITE(NWR,530)
530  FORMAT(/,6X,'EVAPORATION RATES BY PERIOD (MM/PERIOD)',/)
     WRITE(NWR,520)(EVRATE(I),I=1,NP)
     WRITE(NWR,535)RMAX,RC,DELTAR,SMAX,RATE,TOTSUD
535  FORMAT(/,6X,'MAX.RELEASE    ',F10.1,/,6X,'CRITICAL RELEASE  ',
    &F10.1,/,6X,'DELTA FOR OPT.REL.',
    &'SEARCH',F10.1,/,6X,'MAX.STORAGE',F10.1,
    &/,6X,'DISCOUNT RATE',F10.3,/,6X,'SUDAN ABSTRACTIONS',F8.2)
     WRITE(NWR,540)
540  FORMAT(/,84('*'),/,84('*'),//)
     WRITE(NWR,545)
545  FORMAT(1X,'PERIOD',12X,'MONTHLY DISCRETIZED INFLOWS',/)
     DO 548 I=1,NP
 548 WRITE(NWR,550)I,(Q2(I,J),J=1,NQ)
550  FORMAT(2X,I3,5F10.1)
     WRITE(NWR,565)
565  FORMAT(//,84('*'),8(/),84('*'))
     WRITE(NWR,570)
570  FORMAT(74X,'**PERIOD**',/,74X,'*',8X,'*')
     WRITE(NWR,575)
575  FORMAT(28X,'TRANSITION PROBABILITIES',22X,'FROM    TO')
     DO 603 II=1,NP
     II1=II-1
     IF(II1.LT.1)II1=12
     WRITE(NWR,580)
580  FORMAT(15X,25('-'),' TO ',26('-'))
     WRITE(NWR,585)
585  FORMAT(15X,'!',53X,'!')
     DO 598 IQ=1,NQ
     IF((IQ.EQ.1).OR.(IQ.EQ.NQ))WRITE(NWR,590)(PTRAN(II,IQ,K),K=1,NQ)
590  FORMAT(8X,'-',1X,5F12.5)
     IF((IQ.EQ.2).OR.(IQ.EQ.NQ-1))WRITE(NWR,595)(PTRAN(II,IQ,K),K=1,NQ)
595  FORMAT(7X,'!',2X,5F12.5)
598  IF(IQ.EQ.3)WRITE(NWR,600)(PTRAN(II,IQ,K),K=1,NQ),II1,II
600  FORMAT(1X,'FROM -!  ',5F12.5,5X,I2,2X,'-',2X,I2)
603  CONTINUE
     WRITE(NWR,605)
```

```
 605  FORMAT(/,84('*'))
      WRITE(NWR,610)
 610  FORMAT(6X,'OBJECTIVE FUNCTION:   LOSS(RL,S,Q)= L1 + L2 + L3 ',//,
     &28X,'WHERE RL = RELEASE IN BCM/PERIOD',/,
     &34X,'S = INITIAL STORAGE (ELEVATION)',/,
     &34X,'Q = INFLOW IN BCM/PERIOD',/,
     &34X,'L1 = LOSSES DUE TO NOT MEETING ENERGY TARGET',/,
     &34X,'L2 = LOSSES DUE TO NOT MEETING IRRIGATION TARGET',/,
     &34X,'L3 = LOSSES DUE TO EROSION CAUSING RELEASES (I.E. VERY ',
     &'HIGH RELEASES)',/)
      WRITE(NWR,615)
 615  FORMAT(12X,'LOSS TERMS:',//,17X,
     &'L1 = ((TARGE(I)-GN)**2)*(10**PENG)*(PEN1)     IF TARGE(I) > GN',
     &/,20X,'= 0.',40X,'OTHERWISE',/,17X,
     &'L2 = ((RL-TARGI(I))**2)*(10**PIRR)*(PEN2)',5X,
     &'IF TARGI(I) > RL',/,20X,'= 0.',40X,'OTHERWISE',/,17X,
     &'L3 = ((RL-RC)**2)*(10**PREL)*(PEN3)',7X,
     &'IF RL > RC',/,20X,'= 0.',40X,'OTHERWISE',/)
      WRITE(NWR,620)
 620  FORMAT(17X,'WHERE TARGE(I) = ENERGY TARGET FOR PERIOD I',/,
     &23X,'TARGI(I) = IRRIGATION TARGET FOR PERIOD I',/,
     &23X,'GN = POTENTIAL ENERGY GENERATION (A FUNCTION OF RL,S AND ',
     &'Q)',/,23X,'RC = CRITICAL RELEASE ABOVE WHICH EROSION OCCURS',
     &/,23X,'PENG = ENERGY DEFICIT PENALTY COEFFICIENT',/,
     &23X,'PIRR = IRRIGATION DEFICIT PENALTY COEFFICIENT',/,
     &23X,'PREL = EXCESSIVE RELEASE PENALTY COEFFICIENT',/,
     &23X,'PEN1,PEN2,PEN3 = 0. OR 1.0',/)
      WRITE(NWR,625)PENG,PIRR,PREL,PEN1,PEN2,PEN3
 625  FORMAT(12X,'FOR THIS RUN:',/,17X,'PENG = ',F8.3,10X,
     &'PIRR = ',F8.3,10X,
     &'PREL = ',F8.3,/,17X,'PEN1 = ',F3.1,5X,
     &'PEN2 = ',F3.1,5X,
     &'PEN3 = ',F3.1,//)
      RETURN
      END
C   *********************************************************************
C   *********************************************************************
```

```
C **********************************************************************
      SUBROUTINE DISCST
C **********************************************************************
C *                                                                    *
C *  THIS SUBROUTINE DISCRETIZES THE STATE VARIABLE STORAGE INTO       *
C *  "NS" REPRESENTATIVE VALUES.  SMAX CAN BE REPLACED WITH A          *
C *  VARIABLE ALERT STORAGE LEVEL FOR EACH MONTH IF DESIRED.           *
C *  HOWEVER, IN THE FOLLOWING, DISCRETE STORAGE VALUES WILL BE        *
C *  IDENTICAL FOR EACH MONTH.                                         *
C *                                                                    *
C *  VARIABLE DEFINITIONS:                                             *
C *                                                                    *
C *      ST(I,J)   = DISCRETE STORAGE VALUE J FOR MONTH I              *
C *      HEAD(I,J) = ELEVATION CORRESPONDING TO ST(I,J)                *
C *                                                                    *
C **********************************************************************
      COMMON/A1/NY,NP,NS,NQ,NIT,NWR
      COMMON/A4/RMAX,SMAX,SMIN,DELTAR,RATE,ITOSH,STL
      COMMON/B4/ST(12,25),HEAD(12,25)
      NS1=NS-1
      NS2=NS-2
      DO 20 I=1,NP
      ST(I,1)=SMAX
      ST(I,NS)=SMIN
      XX=(SMAX-SMIN)/NS2
      DO 10 J=2,NS1
   10 ST(I,J)=SMIN+XX*(NS2+1.5-J)
   20 CONTINUE
      DO 140 I=1,NP
      DO 140 J=1,NS
      Z=ST(I,J)
  140 HEAD(I,J)=H(Z)
      WRITE(NWR,150)
  150 FORMAT(2(/),3(84('*'),/))
      RETURN
      END
C **********************************************************************
C **********************************************************************
```

```
C ********************************************************************
      SUBROUTINE DYNPRO
C ********************************************************************
C *                                                                  *
C *  THIS SUBROUTINE IS THE ACTUAL DYNAMIC PROGRAMMING ALGORITHM.    *
C *  ALL COMMENTS PERTAIN TO THE WORK "STUDY OF A REAL-TIME ADAPTIVE *
C *  CLOSED-LOOP CONTROL ALGORITHM FOR RESERVOIR OPERATION" BY       *
C *  BUCHANAN AND BRAS (1981).                                       *
C *                                                                  *
C *  VARIABLES NOT PREVIOUSLY DEFINED ARE (IN ALPHABETICAL ORDER):   *
C *                                                                  *
C *     BL     = LOWER ESTIMATE OF EXPECTED VALUE (EQUATION 5.11)    *
C *              USED FOR THE DISCOUNTED CASE                        *
C *     BMNLOS = LOWER ESTIMATE ON AVERAGE ANNUAL COST FOR           *
C *              UNDISCOUNTED CASE (EQUATION 5.5)                    *
C *     BMXLOS = UPPER ESTIMATE ON AVERAGE ANNUAL COST FOR           *
C *              UNDISCOUNTED CASE (EQUATION 5.4)                    *
C *     BOUN   = EXPECTED VALUE OF OPTIMAL RELEASE DECISION          *
C *              CALCULATED DURING CYCLE OF CONVERGENCE              *
C *     BU     = UPPER ESTIMATE OF EXPECTED VALUE (EQUATION 5.10)    *
C *              USED FOR DISCOUNTED CASE                            *
C *     CBAR   = C IN EQUATION 3.10 (MINIMUM AVERAGE ANNUAL COST)    *
C *     DISFAC = ONE STEP DISCOUNT FACTOR                            *
C *     EMAX   = EMAX IN EQUATION 5.7, 5.8                           *
C *     ERMAX  = EMAX(I,J) IN EQUATION 5.13, 5.14                    *
C *     F1     = F(N-1) IN EQUATION 3.5 (ALREADY CALCULATED)         *
C *     F2     = F(N) IN EQUATION 3.5 (TO BE CALCULATED)             *
C *     GEN    = POWER GENERATION (GWH)                              *
C *     ICOUNT = CONVERGENCE INDEX (EQUALS 0 IF CONVERGENCE HAS      *
C *              NOT BEEN OBTAINED YET                               *
C *     PRBN   = BOUNDARY VALUES USED TO INITIALIZE EACH CYCLE OF    *
C *              CALCULATIONS                                        *
C *     REL    = OPTIMAL RELEASE DECISIONS CALCULATED DURING         *
C *              CYCLE OF CONVERGENCE                                *
C *     RO     = OPTIMAL RELEASE DECISIONS CALCULATED FOR ANY        *
C *              STATE AND THE CURRENT BOUNDARY CONDITIONS           *
C *     TOSH   = SPILLS TO TOSHKA                                    *
C *     XLOSS  = COSTS INCURRED OVER ONE CYCLE OF CALCULATIONS       *
C *                                                                  *
C ********************************************************************
      COMMON/A1/NY,NP,NS,NQ,NIT,NWR
      COMMON/A2/Q2(12,5),PTRAN(12,5,5)
      COMMON/A3/TARGI(12),TARGE(12),EVRATE(12),SUDGEB(12)
      COMMON/A4/RMAX,SMAX,SMIN,DELTAR,RATE,ITOSH,STL
      COMMON/A5/F1(25,5),F2(25,5),RO(25,5)
      COMMON/A6/RC,XPE,XPI,XPR,PEN1,PEN2,PEN3,PENG,PIRR,PREL
      COMMON/A7/GENMAX(21),RELMAX(21),EL(21),XO(21),YO(21),SLOPE(21)
      COMMON/A8/FACTOR,NELEV
      COMMON/A9/REL(12,25,5),BOUN(12,25,5)
      COMMON/B1/NY1
      COMMON/B2/EPS
```

```
      COMMON/B3/ERMAX(25,5),BU(25,5),BL(25,5),PRBN(25,5),XLOSS(25,5)
      COMMON/B4/ST(12,25),HEAD(12,25)
      DIMENSION TOSH(25,5),GEN(25,5)
C ---------------------------------------------------------------
C        INITIALIZE PROGRAM WITH BOUNDARY CONDITIONS (EQUATION 3.7)
C ---------------------------------------------------------------
      DO 10 I=1,NS
      DO 10 J=1,NQ
      F2(I,J)=0.
   10 PRBN(I,J)=F2(I,J)
      ICOUNT=0
      EMAX=0.
      BMNLOS=0.
      BMXLOS=0.
      DISFAC=1./(1.-RATE**NP)
C ---------------------------------------------------------------
C        BEGIN RECURSIVE APPLICATION OF EQUATION 3.5
C        "IY" IS THE TIME INDEX "M" IN FIGURE 3.1
C        "IP" IS THE TIME INDEX "T" (LOWERCASE) IN FIGURE 3.1
C ---------------------------------------------------------------
      DO 1000 IY=1,NY
      DO 1000 IP=1,NP
      IT=NP+1-IP
      IT1=IT+1
      IF(IT1.GT.NP)IT1=1
      ITM1=IT-1
      IF(ITM1.EQ.0)ITM1=12
C ---------------------------------------------------------------
C        THE VARIABLES "IS" AND "IQ" ARE THE SUBSCRIPTS "I" AND "J"
C        RESPECTIVELY IN EQUATION 3.5
C ---------------------------------------------------------------
      DO 100 IS=1,NS
      STOR=ST(IT,IS)
      DO 99 IQ=1,NQ
      JQ=IQ-1
      X=1.E30
C ---------------------------------------------------------------
C        INITIALIZE OPTIMAL RELEASE SEARCH WITH SOME NOMINAL VALUE
C        GIVEN BY "RMAX"
C ---------------------------------------------------------------
      RAUX=RMAX
      IF(IQ.GT.1)RAUX=RO(IS,JQ)+2.0
      IF(RAUX.GT.RMAX)RAUX=RMAX
   60 XLITLH=0.
      GNN=0.
      RT=0.
C ---------------------------------------------------------------
C        THE DO 85 LOOP PERFORMS THE OPERATION OF SUMMING OVER K
C        IN EQUATION 3.4.  CONSTRAINTS 3.6B AND C ARE ENFORCED
C        WHEN INFEASIBLE FINAL STORAGE VOLUMES RESULT.
C ---------------------------------------------------------------
```

```
      DO 85 N=1,NQ
      YY=Q2(IT,N)
      CALL FINSTO(IT,YY,STOR,RAUX,SF,RT1,EV1)
      RELS=RAUX
      IF(SF.LE.SMAX)GO TO 65
      SF=SMAX
      CALL EVTOSH(STOR,SF,IT,EV1,RT1)
      RELS=STOR-SF+YY-EV1-RT1
      CALL FINSTO(IT,YY,STOR,RELS,SF,RT1,EV1)
      IF(SF.LE.SMAX)GO TO 80
      RELS=RELS+SF-SMAX
      SF=SMAX
      GO TO 80
   65 IF(SF.GE.SMIN)GO TO 80
      IF(N.GT.1)GO TO 70
      IF(RAUX.GT.0.)GO TO 95
      RAUX=0.
      XLITLH=1.E30
      GNN=0.
      RT=0.
      GO TO 90
   70 SF=SMIN
      CALL EVTOSH(STOR,SF,IT,EV1,RT1)
      RELS=STOR-SF+YY-EV1-RT1
      IF(RELS.LT.0.)GO TO 75
      CALL FINSTO(IT,YY,STOR,RELS,SF,RT1,EV1)
      IF(SF.GE.SMIN)GO TO 80
      RELS=RELS-SMIN+SF
      IF(RELS.LT.0.)GO TO 75
      SF=SMIN
      GO TO 80
   75 RELS=0.
      CALL FINSTO(IT,YY,STOR,RELS,SF,RT1,EV1)
   80 CALL BENEF1(RELS,STOR,SF,IT,B0,GN,RELTUR,SPILL)
      CALL IDENTS(SF,J1,J2,ALFA1,ALFA2,IT)
      GNN=GNN+PTRAN(IT,IQ,N)*GN
      RT=RT+PTRAN(IT,IQ,N)*RT1
   85 XLITLH=XLITLH+(1./(1.+RATE))*PTRAN(IT,IQ,N)*
     &(B0+(F2(J1,N)*ALFA1+F2(J2,N)*ALFA2))
C ---------------------------------------------------------------
C       END OF DO 85 LOOP
C ---------------------------------------------------------------
      IF(XLITLH.GE.X)GO TO 99
   90 X=XLITLH
      F1(IS,IQ)=X
      R0(IS,IQ)=RAUX
      TOSH(IS,IQ)=RT
      GEN(IS,IQ)=GNN
   95 IF(RAUX.LE.0.)GO TO 99
      RAUX=RAUX-DELTAR
      IF(RAUX.LE.0)RAUX=0.
```

```
      GO TO 60
   99 CONTINUE
  100 CONTINUE
C -----------------------------------------------------------------
C        ALL STATES ARE ANALYZED.  IF IP = NP, CONVERGENCE IS
C        TESTED FOR.  IF CONVERGENCE HAS ALREADY BEEN ATTAINED,
C        OPTIMAL RELEASES AND CORRESPONDING EXPECTED VALUES OF
C        EACH DECISION ARE STORED.
C -----------------------------------------------------------------
      DO 110 I=1,NS
      DO 110 J=1,NQ
      F2(I,J)=F1(I,J)
      IF((ICOUNT.EQ.1).OR.(IY.EQ.NY))REL(IT,I,J)=RO(I,J)
  110 IF((ICOUNT.EQ.1).OR.(IY.EQ.NY))BOUN(IT,I,J)=F1(I,J)
      IF(IT.NE.1)GO TO 200
      ZETA=F2(6,3)
      BMXLOS=-1.E30
      BMNLOS=1.E30
      DO 120 I=1,NS
      DO 120 J=1,NQ
      XLOSS(I,J)=F2(I,J)-PRBN(I,J)
      IF(XLOSS(I,J).GT.BMXLOS)BMXLOS=XLOSS(I,J)
  120 IF(XLOSS(I,J).LT.BMNLOS)BMNLOS=XLOSS(I,J)
      IF(RATE.NE.0.)GO TO 125
      DG=BMXLOS-BMNLOS
      EMAX=DG/(2.*AMIN1(ABS(BMNLOS),ABS(BMXLOS)))
      CBAR=(BMXLOS+BMNLOS)/2.
      IF(EMAX.LT.EPS)ICOUNT=ICOUNT+1
C -----------------------------------------------------------------
C        END OF TEST FOR CONVERGENCE.
C -----------------------------------------------------------------
      GO TO 128
  125 EMAX=-1.E30
      DO 126 I=1,NS
      DO 126 J=1,NQ
      BU(I,J)=PRBN(I,J)+DISFAC*BMXLOS
      BL(I,J)=PRBN(I,J)+DISFAC*BMNLOS
      ERMAX(I,J)=DISFAC*(BMXLOS-BMNLOS)/(2.*AMIN1(ABS(BU(I,J)),
     &ABS(BL(I,J))))
  126 IF(ERMAX(I,J).GT.EMAX)EMAX=ERMAX(I,J)
      IF(EMAX.LT.EPS)ICOUNT=ICOUNT+1
      DG=BMXLOS-BMNLOS
      CBAR=(BMNLOS+BMXLOS)/2.
  128 DO 129 I=1,NS
      DO 129 J=1,NQ
      F2(I,J)=F2(I,J)-ZETA
  129 PRBN(I,J)=F2(I,J)
      WRITE(NWR,130)IY
  130 FORMAT(54X,'*****  CYCLE ',I2,'  *****',/)
      WRITE(NWR,140)
  140 FORMAT(20X,'(INCREASE OVER PREVIOUS BOUNDARY)',27X,'(NEW BOUN',
```

```
     &'DARY)',/)
      WRITE(NWR,150)(Q2(ITM1,J),J=1,NQ),(Q2(ITM1,J),J=1,NQ)
  150 FORMAT(1X,'INFLOWS',1X,5F10.1,5X,5(4X,F4.1,5X))
      WRITE(NWR,160)
  160 FORMAT(1X,'STORAGE (HEAD)')
      DO 170 I=1,NS
      XX=ST(IT,I)
  170 WRITE(NWR,180)XX,(XLOSS(I,J),J=1,NQ),(PRBN(I,J),J=1,NQ)
  180 FORMAT(6F10.1,1X,'!',5(1X,F12.1))
      WRITE(NWR,190)DG,CBAR,BMNLOS,BMXLOS
  190 FORMAT(/,1X,'DELTA LOSSES =',F12.1,'  AVERAGE LOSS =',
     &F12.1,'  MIN. DELTA LOSS =',F12.1,
     &'  MAX. DELTA LOSS =',F12.1,//)
      IF((IT.EQ.1).AND.(ICOUNT.EQ.1))GO TO 1000
  200 IF((IY.EQ.NY).OR.(ICOUNT.GE.1))GO TO 205
      GO TO 1000
  205 WRITE(NWR,210)IT
  210 FORMAT(/,40X,'*** OPERATING POLICY FOR PERIOD',I4,
     &'***',/)
      WRITE(NWR,215)
  215 FORMAT(4X,'FIRST ROW: RELEASE AND OBJ. FUNCT.',/,
     &4X,'SECOND ROW: GENERATION(GWH) AND RELEASE TO TOSHKA',//)
      WRITE(NWR,220)(Q2(ITM1,MO),MO=1,NQ)
  220 FORMAT(1X,'STORAGE (HEAD)',1X,'!',5(9X,F4.1,9X,'!'))
      DO 240 I=1,NS
      XX=ST(IT,I)
      WRITE(NWR,225)
  225 FORMAT(1X,131('-'))
      WRITE(NWR,230)XX,(RO(I,J),F1(I,J),J=1,NQ)
  230 FORMAT(1X,F9.1,6X,'!',5(1X,F6.1,1X,F13.1,1X,'!'))
      WRITE(NWR,235)HEAD(IT,I),(GEN(I,J),TOSH(I,J),J=1,NQ)
  235 FORMAT(4X,'(',F5.1,')',5X,'!',5(1X,F6.1,1X,F13.1,1X,'!'))
  240 CONTINUE
      IF((IT.EQ.1).AND.(ICOUNT.EQ.2))GO TO 1001
 1000 CONTINUE
C -------------------------------------------------------------
C       CONVERGENCE HAS NOW BEEN ATTAINED.  VALUES OF OPTIMAL
C       RELEASES FOR EACH DISCRETE STATE OF EACH MONTH IS STORED
C       IN THE VARIABLE REL(I,J,K), AND THE CORRESPONDING VALUE
C       OF EACH RELEASE DECISION IS STORED IN THE VARIABLE
C       BOUN(I,J,K).  THE REMAINING OUTPUT IS USED AS INPUT
C       TO THE SIMULATION MODEL.
C -------------------------------------------------------------
 1001 CONTINUE
      WRITE(3,2000)NP,NS,NQ,ITOSH
      WRITE(3,2001)RMAX,SMAX,SMIN,DELTAR,RATE
      WRITE(3,2002)PENG,PIRR,PREL,PEN1,PEN2,PEN3,RC,FACTOR,NELEV
      WRITE(3,2003)(SUDGEB(I),I=1,NP)
      WRITE(3,2005)(TARGI(I),I=1,NP)
      WRITE(3,2005)(TARGE(I),I=1,NP)
      WRITE(3,2006)(EVRATE(I),I=1,NP)
```

```
      DO 1111 I=1,NELEV
 1111 WRITE(3,1112)GENMAX(I),RELMAX(I),EL(I),XO(I),YO(I),SLOPE(I)
 1112 FORMAT(6F10.4)
      DO 1115 I=1,NP
      DO 1115 J=1,NS
      WRITE(3,2007)(REL(I,J,K),K=1,NQ)
 1115 WRITE(4,2007)(REL(I,J,K),K=1,NQ)
 2000 FORMAT(4I5)
 2001 FORMAT(2F8.1,3F8.4)
 2002 FORMAT(8F8.1,I5)
 2003 FORMAT(12F8.5)
 2004 FORMAT(12F10.3)
 2005 FORMAT(12F8.1)
 2006 FORMAT(12F8.2)
 2007 FORMAT(5F10.1)
      DO 1120 I=1,NP
      DO 1120 J=1,NQ
 1120 WRITE(3,2008)(PTRAN(I,J,K),K=1,NQ)
      DO 1125 I=1,NP
      DO 1125 J=1,NS
 1125 WRITE(3,2009)(BOUN(I,J,K),K=1,NQ)
      DO 1130 I=1,NP
 1130 WRITE(3,2010)(Q2(I,J),J=1,NQ)
 2008 FORMAT(5F10.5)
 2009 FORMAT(5F20.2)
 2010 FORMAT(5F10.1)
      DO 1135 I=1,NS
 1135 WRITE(4,2011)(HEAD(J,I),J=1,NP)
 2011 FORMAT(12F10.1)
      RETURN
      END
C    *******************************************************************
C    *******************************************************************
```

```
C  *********************************************************************
      FUNCTION H(V)
C  *********************************************************************
C  *                                                                   *
C  *  THIS FUNCTION CALCULATES THE RESERVOIR ELEVATION FOR STORAGE "V"*
C  *                                                                   *
C  *********************************************************************
      H=79.9734+.0369801*V+18.8705*ALOG(V)
      RETURN
      END
C  *********************************************************************
C  *********************************************************************
C  *********************************************************************
      FUNCTION AREA(V)
C  *********************************************************************
C  *                                                                   *
C  *  THIS FUNCTION CALCULATES THE RESERVOIR SURFACE AREA FOR A        *
C  *  GIVEN STORAGE "V".                                               *
C  *                                                                   *
C  *********************************************************************
      AREA=-3164.28+25.4914*V+1092.92*ALOG(V)
      RETURN
      END
C  *********************************************************************
C  *********************************************************************
C  *********************************************************************
      FUNCTION XTOSH(V)
C  *********************************************************************
C  *                                                                   *
C  *  THIS FUNCTION CALCULATES THE RELEASE TO TOSHKA FOR A GIVEN       *
C  *  STORAGE "V".                                                     *
C  *                                                                   *
C  *********************************************************************
      COMMON/A4/RMAX,SMAX,SMIN,DELTAR,RATE,ITOSH,STL
      IF(V.GT.STL)GOTO10
      XTOSH=0.
      GOTO100
   10 Z=H(V)
      IF(Z.LT.178.0)Z=178.0
      Y=H(SMAX)
      IF(Z.GT.Y)Z=Y
      XTOSH=19.0*(Z-178.0)**1.667
      XTOSH=XTOSH*30.4/1000.
  100 RETURN
      END
C  *********************************************************************
C  *********************************************************************
```

```
C *******************************************************************
      SUBROUTINE FINSTO(IT,YY,STOR,RAUX,SF,RT,EV)
C *******************************************************************
C *                                                                 *
C *  THIS SUBROUTINE CALCULATES THE FINAL STORAGE "SF" FOR INITIAL  *
C *  STORAGE "STOR", RELEASE "RAUX", INFLOW "YY", LOSSES TO TOSHKA  *
C *  "RT" AND LOSSES TO EVAPORATION "EV".  LOSSES ARE CALCULATED    *
C *  USING AN ITERATIVE PROCEDURE.  THE CALLING ARGUMENT "IT"       *
C *  INDICATES THE PARTICULAR MONTH.                                *
C *                                                                 *
C *******************************************************************
      COMMON/A1/NY,NP,NS,NQ,NIT,NWR
      CALL EVTOSH(STOR,STOR,IT,EV1,RT1)
      XX=STOR+YY-RAUX
      SF=XX-EV1-RT1
      DO 10 I=1,NIT
      CALL EVTOSH(STOR,SF,IT,EV,RT)
      SF=XX-EV-RT
      IF(ABS(RT-RT1).LE.0.001*RT.AND.ABS(EV-EV1).LE.0.001*EV)GOTO20
      RT1=RT
      EV1=EV
   10 CONTINUE
   20 RETURN
      END
C *******************************************************************
C *******************************************************************
```

```
C ************************************************************************
      SUBROUTINE IDENTS(SF,J1,J2,ALFA1,ALFA2,IT)
C ************************************************************************
C *                                                                      *
C *  THIS SUBROUTINE IS USED FOR INTERPOLATION PURPOSES.  AS            *
C *  DISCUSSED IN SECTION 5.3 (COMPUTATIONAL CONSIDERATIONS), THE       *
C *  FINAL STORAGE "SF" IN GENERAL WILL NOT BE EQUAL TO ANY OF THE      *
C *  DISCRETE VALUES OF THE STATE VARIABLE STORAGE.  THE RETURN         *
C *  ARGUMENTS "J1" AND "J2" ARE THE SUBSCRIPT VALUES FOR THE TWO       *
C *  DISCRETE STORAGE VALUES IMMEDIATELY ABOVE AND BELOW THE FINAL      *
C *  STORAGE.  THE ARGUMENTS "ALFA1" AND "ALFA2" ARE WEIGHTS            *
C *  (SUMMING TO UNITY) INDICATING THE PROXIMITY OF "SF" TO BOTH        *
C *  ST(IT,J1) AND ST(IT,J2).  THE ARGUMENT "IT" INDICATES THE MONTH.*
C *                                                                      *
C ************************************************************************
      COMMON/A1/NY,NP,NS,NQ,NIT,NWR
      COMMON/A4/RMAX,SMAX,SMIN,DELTAR,RATE,ITOSH,STL
      NS2=NS-2
      VUT=SMAX-SMIN
      X=(NS2)*(1.-(SF-SMIN)/VUT)
      IF(X.LT.0.5)GOTO10
      Y=NS2-.5
      IF(X.GE.Y)GOTO20
      J1=X+1.5
      J2=X+2.5
      ALFA1=J2-1.5-X
      ALFA2=X+1.5-J1
      GOTO100
   10 J1=1
      J2=2
      ALFA2=X/.5
      ALFA1=1.-ALFA2
      GOTO100
   20 IF(X.GT.NS2)GOTO30
      Y=X-Y
      J1=NS-1
      J2=NS
      ALFA2=Y/.5
      ALFA1=1.-ALFA2
      GOTO100
   30 Y=X-NS2
      J1=NS-1
      J2=NS
      ALFA1=-Y/.5
      ALFA2=1.-ALFA1
  100 RETURN
      END
C ************************************************************************
C ************************************************************************
```

```
C  *********************************************************************
      SUBROUTINE EVTOSH(S1,S2,IT,EV,RT)
C  *********************************************************************
C  *                                                                   *
C  *  THIS SUBROUTINE CALCULATES EVAPORATION LOSSES "EV" AND RELEASES *
C  *  TO TOSHKA "RT" FOR AN INITIAL STORAGE "S1" AND A FINAL STORAGE  *
C  *  "S2".  THE CALLING ARGUMENT "IT" INDICATES THE MONTH.            *
C  *                                                                   *
C  *********************************************************************
      COMMON/A3/TARGI(12),TARGE(12),EVRATE(12),SUDGEB(12)
      A1=AREA(S1)
      T1=XTOSH(S1)
      A2=AREA(S2)
      T2=XTOSH(S2)
      RT=(T1+T2)/2.
      IF(RT.LT.0.)RT=0.
      EV=EVRATE(IT)*(A1+A2)/2.
      EV=EV*1.E-06
      RETURN
      END
C  *********************************************************************
C  *********************************************************************
```

```
C  ********************************************************************
      SUBROUTINE BENEF1(RAUX,STOR,SF,IT,BO,GN,RELTUR,SPILL)
C  ********************************************************************
C  *                                                                  *
C  *  THIS SUBROUTINE FIRST CALCULATES POWER GENERATION BASED UPON    *
C  *  THE AVERAGE MONTHLY RESERVOIR ELEVATION AND THE GIVEN RELEASE.  *
C  *                                                                  *
C  *  SUBSEQUENTLY, COSTS ARE CALCULATED ACCORDING TO EQUATION 3.18   *
C  *  OF BUCHANAN AND BRAS (1981).                                    *
C  *                                                                  *
C  *  INPUTS FROM THE CALL STATEMENT ARE (IN ALPHABETICAL ORDER):     *
C  *      IT     - IDENTIFIES MONTH                                   *
C  *      RAUX   - RELEASE                                            *
C  *      SF     - FINAL STORAGE (CALCULATED IN SUBROUTINE FINSTO)    *
C  *      STOR   - INITIAL STORAGE (A DISCRETE STORAGE STATE)         *
C  *                                                                  *
C  *  VALUES RETURNED FROM THIS SUBROUTINE ARE:                       *
C  *      BO     - TOTAL COSTS                                        *
C  *      GN     - POWER GENERATION (GWH)                             *
C  *      RELTUR - RELEASE THROUGH TURBINES                           *
C  *      SPILL  - RELEASE BYPASSING TURBINES (DUE TO TURBINE CAPACITY*
C  *                                                                  *
C  *  DEFINITIONS OF REMAINING VARIABLES ARE (IN ALPHABETICAL ORDER): *
C  *      ALFA1  - A WEIGHT (BASED UPON INITIAL ELEVATION)            *
C  *      ALFA2  - A WEIGHT (BASED UPON FINAL ELEVATION)              *
C  *      EL     - DISCRETE ELEVATION FOR WHICH POWER GENERATION      *
C  *               VERSUS RELEASE CURVE IS AVAILABLE (SEE FIGURE 2.6  *
C  *               OF BUCHANAN AND BRAS (1981))                       *
C  *      FACTOR - LOAD FACTOR                                        *
C  *      GENMAX - MAXIMUM POSSIBLE POWER GENERATION FOR EACH VALUE   *
C  *               OF EL                                              *
C  *      GN1    - POWER GENERATION FOR GIVEN RELEASE AND DISCRETE    *
C  *               VALUE OF EL IMMEDIATELY GREATER THAN AVERAGE       *
C  *               ELEVATION.  GN2 IS SIMILAR, BUT CORRESPONDS TO     *
C  *               IMMEDIATELY LOWER ELEVATION                        *
      COMMON/A3/TARGI(12),TARGE(12),EVRATE(12),SUDGEB(12)
      COMMON/A6/RC,XPE,XPI,XPR,PEN1,PEN2,PEN3,PENG,PIRR,PREL
      COMMON/A7/GENMAX(21),RELMAX(21),EL(21),X0(21),Y0(21),SLOPE(21)
      COMMON/A8/FACTOR,NELEV
      H1=H(STOR)
      H2=H(SF)
      HAVER=(H1+H2)/2.
      IF(RAUX.GT.0.001)GO TO 5
      GN=0.
      GO TO 250
    5 CONTINUE
      DO 10 I=1,NELEV
      IF(HAVER.LE.EL(I))GO TO 10
      J1=I-1
      J2=I
      GO TO 20
```

```
   10 CONTINUE
   20 RELTUR=RAUX
      SPILL=0.
      ALFA1=(HAVER-EL(J2))/(EL(J1)-EL(J2))
      ALFA2=1.-ALFA1
      R2=ALFA1*RELMAX(J1)+ALFA2*RELMAX(J2)
      IF(RAUX.GT.R2)GO TO 100
      GN1=SLOPE(J1)*(RAUX-X0(J1))+Y0(J1)
      GN2=SLOPE(J2)*(RAUX-X0(J2))+Y0(J2)
      GO TO 200
  100 GN1=GENMAX(J1)
      GN2=GENMAX(J2)
      RELTUR=R2
      SPILL=RAUX-R2
  200 GN=(ALFA1*GN1+ALFA2*GN2)*FACTOR
      IF(GN.LT.0.)GN=0.
  250 B0=DIM(TARGE(IT),GN)*DIM(TARGE(IT),GN)
      B0=B0*XPE*PEN1
      IF(RAUX.LE.RC)GO TO 300
      B0=B0+(RAUX-RC)*(RAUX-RC)*XPR*PEN3
  300 IF(RAUX.LT.TARGI(IT))B0=B0+(TARGI(IT)-RAUX)*(TARGI(IT)-RAUX)
     &*XPI*PEN2
      RETURN
      END
C    *******************************************************************
C    *******************************************************************
```

```
THIS IS A SAMPLE INPUT THAT IS READ OFF OF FILE 1.  DATA THAT IS
READ OFF OF FILE 2 CAN BE FOUND IN TABLES 5.2a AND 5.3.


 100 12 25   5   9   5   0.01   7.6   0
  16.50
 .1037  .0859  .0591  .0292  .0285  .0496  .0854  .0698  .1199  .1296  .1294  .1099
 3.4  4.0  4.2  4.1  5.3  6.5  7.0  6.3  4.3  3.8  3.6  3.0
 10.0  168.9  32.7144   0.10   0.00
 1280.0 1280.0 1280.0 1280.0 1280.0 1280.0 1280.0 1280.0 1280.0 1280.0 1280.0 1280.0
 178.2  137.7  105.3  148.5  194.4  237.6  275.4  307.8  324.0  307.8  267.3  216.0
 -3.0  7.0  4.0
  1.0  1.0  1.0
 1.00   21
 1262.1    7.175    184.    2.627    347.5
 1261.4    7.243    182.    2.627    332.7
 1260.7    7.352    180.    2.627    318.8
 1260.0    7.500    178.    2.627    296.4
 1259.3    7.645    176.    2.627    282.4
 1258.6    7.852    174.    2.627    272.9
 1257.9    8.018    172.    2.627    259.7
 1257.2    8.161    170.    2.627    245.8
 1256.5    8.378    168.    2.627    234.2
 1250.5    8.679    166.    2.627    219.4
 1241.9    8.866    164.    2.627    202.2
 1224.4    9.127    162.    2.627    188.7
 1177.7    9.070    160.    2.627    178.0
 1110.4    9.019    158.    2.627    162.1
 1055.4    8.916    156.    2.627    143.2
  970.7    8.729    154.    2.627    124.7
  912.7    8.576    152.    2.627    109.6
  838.3    8.375    150.    2.627     94.6
  755.2    8.161    148.    2.627     81.7
  633.5    7.852    146.    2.627     70.9
  502.7    7.500    144.    2.627     51.6
```

```
**********************************************************************

     SEQUENTIAL OPERATING POLICY-INPUT DATA

     MAXIMUM NUMBER OF CYCLES     100
     PERIODS PER YEAR              12
     STORAGE STATES                25
     INFLOW STATES                  5
     TUSHKA SPILLWAY NOT OPERATING

     IRRIGATION TARGETS (BCM/PERIOD)

        3.40     4.00     4.20     4.10     5.30     6.50     7.00     6.30     4.30     3.30     3.60     3.00

     ENERGY TARGETS (GWH/PERIOD)

      1280.0   1280.0   1280.0   1280.0   1280.0   1280.0   1280.0   1280.0   1280.0   1280.0   1280.0   1280.0

     EVAPORATION RATES BY PERIOD (MM/PERIOD)

      179.20   137.70   105.30   146.50   194.40   237.60   275.40   307.80   324.00   307.30   267.30   216.00

     MAX.RELEASE            10.0
     CRITICAL RELEASE           7.6
     DELTA FOR OPT.REL.SEARCH       0.1
     MAX.STORAGE     168.9
     DISCOUNT RATE      0.000
     SUDAN ABSTRACTIONS   16.50

**********************************************************************
**********************************************************************


 PERIOD              MONTHLY DISCRETIZED INFLOWS

    1        3.5        2.5        1.9        1.5        1.0
    2        2.6        1.7        1.1        0.7        0.3
    3        2.9        1.9        1.4        1.0        0.6
    4        2.9        2.2        1.7        1.3        0.7
    5        3.3        2.1        1.5        1.1        0.7
    6        3.1        1.9        1.3        0.9        0.4
    7        6.8        5.2        4.1        3.2        2.0
    8       25.0       22.0       19.2       16.9       13.7
    9       27.4       23.6       20.9       18.6       15.5
   10       18.6       15.5       13.2       11.3        8.8
   11        8.5        6.7        5.5        4.4        2.9
   12        4.4        3.6        2.9        2.4        1.7

**********************************************************************
```

```
***************************************************************************
                                                                  **PERIOD**
                                                                  *        *
                    TRANSITION PROBABILITIES                      FROM    TO
            ------------------------ TO -------------------------
            !                                                   !
       -    0.55580   0.43540   0.00870   0.00010   0.00000
       !    0.04840   0.66790   0.25180   0.03120   0.00070
FROM  -!    0.00150   0.23200   0.47690   0.26060   0.02900      12   -   1
       !    0.00000   0.03470   0.26220   0.49340   0.20970
       -    0.00000   0.00050   0.02240   0.23320   0.74390
            ------------------------ TO -------------------------
            !                                                   !
       -    0.21810   0.46230   0.20160   0.09150   0.02650
       !    0.08890   0.37130   0.27100   0.18280   0.08600
FROM  -!    0.03940   0.26560   0.27670   0.24860   0.16970       1   -   2
       !    0.01780   0.17890   0.24880   0.28430   0.27020
       -    0.00520   0.08900   0.18040   0.28510   0.44030
            ------------------------ TO -------------------------
            !                                                   !
       -    0.12820   0.37040   0.24230   0.16660   0.09250
       !    0.07610   0.30590   0.25460   0.21160   0.15180
FROM  -!    0.04990   0.25360   0.25030   0.23860   0.20760       2   -   3
       !    0.03400   0.21000   0.23850   0.25500   0.26250
       -    0.01940   0.15560   0.21290   0.26560   0.34650
            ------------------------ TO -------------------------
            !                                                   !
       -    0.25830   0.48970   0.17480   0.06380   0.01340
       !    0.09060   0.40130   0.27710   0.16750   0.06350
FROM  -!    0.03330   0.26920   0.29190   0.25400   0.15160       3   -   4
       !    0.01220   0.16310   0.25430   0.30060   0.26980
       -    0.00250   0.05530   0.16290   0.30090   0.47840
            ------------------------ TO -------------------------
            !                                                   !
       -    0.32300   0.51630   0.12670   0.03050   0.00350
       !    0.08870   0.45200   0.28440   0.13940   0.03550
FROM  -!    0.02330   0.27160   0.32070   0.26250   0.12190       4   -   5
       !    0.00570   0.13520   0.26300   0.33120   0.26490
       -    0.00060   0.03540   0.13110   0.29540   0.53750
            ------------------------ TO -------------------------
            !                                                   !
       -    0.21530   0.46020   0.20330   0.09350   0.02770
       !    0.08870   0.36930   0.27050   0.18380   0.08770
FROM  -!    0.03980   0.26540   0.27570   0.24830   0.17080       5   -   6
       !    0.01820   0.17990   0.24840   0.28330   0.27020
       -    0.00540   0.09080   0.18150   0.28470   0.43760
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                     ------------------------- TO --------------------------
                     !                                                     !
             -       0.12650    0.36820    0.24270    0.16820    0.09440
           !         0.07570    0.30460    0.25430    0.21220    0.15320
   FROM  -!          0.05000    0.25340    0.24990    0.23850    0.20820         6   -   7
           !         0.03440    0.21060    0.23840    0.25450    0.26210
             -       0.01930    0.15710    0.21340    0.26510    0.34460
                     ------------------------- TO --------------------------
                     !                                                     !
             -       0.28340    0.50250    0.15660    0.04920    0.00830
           !         0.09050    0.42050    0.28040    0.15720    0.05140
   FROM  -!          0.02940    0.27060    0.30230    0.25740    0.14030         7   -   8
           !         0.00940    0.15270    0.25780    0.31170    0.26840
             -       0.00150    0.05250    0.15110    0.29340    0.50150
                     ------------------------- TO --------------------------
                     !                                                     !
             -       0.45500    0.50190    0.04030    0.00270    0.00010
           !         0.07050    0.56890    0.28080    0.07360    0.00620
   FROM  -!          0.00710    0.25950    0.39860    0.27120    0.06360         8   -   9
           !         0.00050    0.07390    0.27240    0.41260    0.24060
             -       0.00030    0.00540    0.06170    0.27770    0.65520
                     ------------------------- TO --------------------------
                     !                                                     !
             -       0.59900    0.39750    0.00350    0.00000    0.00000
           !         0.03840    0.71120    0.23140    0.01870    0.00030
   FROM  -!          0.00060    0.21590    0.51540    0.24960    0.01850         9   -   10
           !         0.00000    0.02250    0.25110    0.53300    0.19340
             -       0.00000    0.00010    0.01230    0.20650    0.78110
                     ------------------------- TO --------------------------
                     !                                                     !
             -       0.58040    0.41430    0.00530    0.00000    0.00000
           !         0.04270    0.69260    0.24080    0.02350    0.00040
   FROM  -!          0.00090    0.22310    0.49850    0.25480    0.02270         10  -   11
           !         0.00000    0.02740    0.25640    0.51560    0.20060
             -       0.00000    0.00020    0.01620    0.21850    0.76510
                     ------------------------- TO --------------------------
                     !                                                     !
             -       0.68280    0.31690    0.00030    0.00000    0.00000
           !         0.02080    0.79340    0.18080    0.00500    0.00000
   FROM  -!          0.00010    0.17880    0.59850    0.21680    0.00580         11  -   12
           !         0.00000    0.00740    0.21780    0.61760    0.15720
             -       0.00000    0.00000    0.00260    0.14750    0.84990

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C    ***********************************************************************

      OBJECTIVE FUNCTION:    LOSS(RL,S,Q)= L1 + L2 + L3

                             WHERE RL = RELEASE IN BCM/PERIOD
                                    S = INITIAL STORAGE (ELEVATION)
                                    Q = INFLOW IN BCM/PERIOD
                                   L1 = LOSSES DUE TO NOT MEETING ENERGY TARGET
                                   L2 = LOSSES DUE TO NOT MEETING IRRIGATION TARGET
                                   L3 = LOSSES DUE TO EROSION CAUSING RELEASES (I.E. VERY HIGH RELEASES)
          LOSS TERMS:

             L1 = ((TARGE(I)-GN)**2)*(10**PENG)*(PEN1)      IF TARGE(I) > GN
                = 0.                                         OTHERWISE
             L2 = ((RL-TARGI(I))**2)*(10**PIRR)*(PEN2)      IF TARGI(I) > RL
                = 0.                                         OTHERWISE
             L3 = ((RL-RC)**2)*(10**PREL)*(PEN3)            IF RL > RC
                = 0.                                         OTHERWISE

             WHERE TARGE(I) = ENERGY TARGET FOR PERIOD I
                   TARGI(I) = IRRIGATION TARGET FOR PERIOD I
                   GN = POTENTIAL ENERGY GENERATION (A FUNCTION OF RL,S AND Q)
                   RC = CRITICAL RELEASE ABOVE WHICH EROSION OCCURS
                   PENG = ENERGY DEFICIT PENALTY COEFFICIENT
                   PIRR = IRRIGATION DEFICIT PENALTY COEFFICIENT
                   PREL = EXCESSIVE RELEASE PENALTY COEFFICIENT
                   PEN1,PEN2,PEN3 = 0. OR 1.0

          FOR THIS RUN:
             PENG =    -3.000            PIRR =     7.000             PREL =     4.000
             PEN1 = 1.0       PEN2 = 1.0       PEN3 = 1.0


   ************************************************************************
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                                                                   *****  CYCLE  1  *****
                              (INCREASE OVER PREVIOUS BOUNDARY)                                      (NEW BOUNDARY)
INFLOWS           4.4          3.6          2.9          2.4          1.7                4.4           3.6          2.9          2.4          1.7
STORAGE (HEAD)
     168.9     2679.7      2106.6      1744.4      1452.8      1163.9 !          2593.6        2020.5       1653.3       1366.7       1077.7
     165.9      917.1       622.5       525.4       459.2       394.5 !           831.0         536.4        439.2        373.1        308.3
     160.0       86.8        44.1        38.3        36.7        35.6 !             0.7         -42.0        -47.8        -49.4        -50.6
     154.1       34.6        35.0        36.9        38.8        40.9 !           -51.6         -51.2        -49.3        -47.4        -45.3
     148.2       50.2        54.0        57.1        59.9        63.0 !           -35.9         -32.2        -29.0        -26.2        -23.2
     142.3       76.5        81.8        86.1        90.0        94.1 !            -9.6          -4.3          0.0          3.9          8.0
     136.3      112.7       120.0       126.1       131.5       137.3 !            26.5          33.9         40.0         45.4         51.2
     130.4      163.4       173.7       182.0       189.3       197.3 !            77.3          87.6         95.8        103.2        111.1
     124.5      233.4       247.2       258.1       267.8       278.2 !           147.3         161.1        172.0        181.7        192.1
     118.6      326.0       343.7       357.6       370.0       383.3 !           239.9         257.6        271.5        283.9        297.1
     112.6      443.3       466.2       483.8       499.4       516.2 !           357.7         380.1        397.7        413.3        430.0
     106.7      592.7       620.6       642.5       661.9       682.7 !           506.6         534.5        556.4        575.8        596.6
     100.8      776.2       813.0       840.8       865.7       892.5 !           692.1         726.9        754.7        779.6        806.4
      94.9     1016.3      1063.3      1103.4      1139.6      1179.9 !           930.1         977.2       1017.3       1053.7       1093.8
      89.0     1362.8      1437.5      1497.0      1555.4      1620.6 !          1276.7        1351.3       1410.9       1469.3       1534.4
      83.0     2001.8      2118.2      2201.2      2268.4      2339.7 !          1915.6        2032.0       2115.0       2182.3       2253.6
      77.1    17719.3     29718.6     39665.1     49155.3     60077.0 !         17633.2       29632.4      39579.0      49069.2      59990.9
      71.2   438094.9    737671.1    981799.5   1212415.8   1475656.5 !        438008.8      737585.0     981713.3    1212329.7    1475570.4
      65.3  4678858.8   7137985.4   9087930.610909564.912970234.1 !       4676772.6     7137897.3    9087844.5   10909478.8   12970148.0
      59.425144279.033606122.540093930.046029173.052602175.5 !      25144193.0    33606036.5   40093844.0   46029087.0   52602089.5
      53.483265597.099608619.0******************************** !      83265511.0    99608533.0  113109511.0  125434920.0  138896100.0
      47.5**************************************************** !     196231206.0   221684524.0  243707552.0  263301294.0  285148312.0
      41.6**************************************************** !     378957492.0   415963004.0  444600688.0  471004104.0  500679740.0
      35.7**************************************************** !     641193704.0   692140184.0  729271976.0  762394336.0  797778544.0
      32.7**************************************************** !     795743088.0   859643344.0  905935640.0  946808880.0  990726080.0
DELTA LOSSES = 990726136.0  AVERAGE LOSS = 495363100.0  MIN. DELTA LOSS =           34.6  MAX. DELTA LOSS = 990726168.0
                                                                   *****  CYCLE  3  *****
                              (INCREASE OVER PREVIOUS BOUNDARY)                                      (NEW BOUNDARY)
INFLOWS           4.4          3.6          2.9          2.4          1.7                4.4           3.6          2.9          2.4          1.7
STORAGE (HEAD)
     168.9     1083.6      1124.5      1153.9      1179.6      1207.0 !           229.3        -293.5       -619.7       -879.6      -1134.8
     165.9     1200.1      1243.0      1273.8      1300.6      1329.1 !         -1390.6       -1531.4      -1689.5      -1721.7      -1750.2
     160.0     1456.2      1482.6      1507.2      1528.6      1560.0 !         -1895.2       -1900.4      -1871.8      -1845.6      -1806.0
     154.1     1733.1      1787.8      1823.6      1866.7      1912.7 !         -1589.2       -1517.3      -1460.9      -1408.4      -1346.6
     148.2     2162.7      2244.2      2302.1      2354.2      2410.0 !         -1027.7        -919.7       -840.9       -769.8       -693.4
     142.3     2762.7      2874.0      2952.1      3019.4      3090.7 !          -251.0        -105.2          0.0         92.2        190.8
     136.3     3611.3      3776.5      3893.5      3995.1      4102.6 !           829.7        1040.4       1193.1       1327.9       1472.5
     130.4     4859.6      5152.0      5366.6      5556.      5761.1 !          2392.3        2746.1       3008.9       3244.1       3500.5
     124.5     7404.8      8232.4      8861.1      9430.5     10055.2 !          5382.6        6296.6       6991.2       7621.3       8316.5
     118.6    15038.6     17669.3     19679.3     21509.9     23536.5 !         13684.6       16443.4      18546.9      20458.7      22571.3
     112.6    38311.1     45100.5     52025.1     57401.9     63335.8 !         38109.4       46142.6      52247.0      57783.5      63890.5
     106.7   103634.9    124290.0    139687.1    153978.3    169469.9 !        105895.3      127452.6     143755.0     158497.3     174717.8
     100.8   266004.1    314247.5    350394.0    382895.4    418478.4 !        279854.5      333296.5     373531.6     409817.9     449649.5
      94.9   622899.4    722007.3    795627.1    861472.3    933223.2 !        695507.1      819401.1     912322.7     995930.5    1087521.1
      89.0  1315871.7   1494634.2   1626158.7   1743194.3   1870029.0 !       1629480.6     1900407.7    2102882.3    2284666.8    2483426.2
      83.0  2501914.0   2783978.3   2989434.8   3170954.1   3366578.4 !       3608853.3     4164751.8    4578261.7    4948479.6    5352246.7
      77.1  4274211.7   4658033.1   4935234.8   5178965.5   5440454.6 !       7526536.4     8581876.6    9363395.5   10061148.0   10820307.3
      71.2  6594335.5   7078327.0   7425189.6   7728411.5   8051885.0 !      14822396.6    16819464.8   18302187.3   19628221.5   21073100.3
      65.3  9341229.5   9820214.010138421.010412152.810717242.8 !      29148044.3    33641064.5   37027113.0   40093210.5   43471147.0
      59.411878124.512205493.012438908.512659261.012889804.0 !      60619386.0    70680226.0   78319428.0   85254483.0   92876336.0
      53.413733495.013941414.014080350.014211000.014349608.0 !     127489074.0   144808192.0  159049572.0  172023580.0  186170926.0
      47.514846024.015022714.015076068.015141720.015207584.0 !     245896604.0   272229296.0  294548944.0  314464456.0  336638376.0
      41.615484552.015563196.015614656.015641452.015681208.0 !     431787348.0   469182972.0  498075200.0  524610936.0  554481224.0
      35.715767096.015815352.015843808.015864744.015893880.0 !     695346192.0   746523544.0  783793408.0  817018456.0  852543976.0
      32.715852944.015876040.015892456.015907272.015923488.0 !     850285160.0   914300728.0  960675744.0 1001623472.0 1045622760.0
DELTA LOSSES =  15922404.5  AVERAGE LOSS =   7962285.8  MIN. DELTA LOSS =         1083.6  MAX. DELTA LOSS =  15923488.0
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                                                        *****  CYCLE  5  *****
                        (INCREASE OVER PREVIOUS BOUNDARY)                                           (NEW BOUNDARY)
INFLOWS         4.4          3.6          2.9          2.4          1.7             4.4            3.6            2.9            2.4            1.7
STORAGE (HEAD)
     168.9    7996.8       8172.6       8291.9       8390.6       8487.5 !      -17736.2       -17796.6       -18142.7       -18252.1       -18356.5
     165.9    8592.5       8675.3       8732.7       8754.4       8779.7 !      -18510.3       -18589.1       -18545.7       -18517.3       -18483.2
     160.0    9244.5       9341.4       9435.5       9460.3       9516.9 !      -17965.1       -17923.2       -17710.3       -17607.9       -17496.3
     154.1    9990.3      10231.9      10417.6      10592.1      10785.2 !      -16475.5       -16071.0       -15762.3       -15481.4       -15170.9
     148.2   12272.5      13072.9      13681.5      14234.0      14843.5 !      -12875.8       -11790.8       -10972.5       -10233.7        -9422.2
     142.3   18767.0      20610.1      21983.3      23213.6      24556.2 !       -4208.0        -1797.0            0.0         1610.5         3368.3
     136.3   32466.5      36037.5      38679.5      41036.7      43599.8 !       14008.8        18946.0        22436.3        25646.3        29142.7
     130.4   58068.6      64510.1      69258.9      73486.6      78074.3 !       49742.6        59082.5        66034.2        72186.5        78914.9
     124.5  103097.3     114136.6     122247.2     129452.6     137256.6 !      117703.6       135300.6       148321.8       159941.6       172577.0
     118.6  178469.9     196463.7     209646.1     221327.4     233954.1 !      243901.6       276259.4       300165.4       321477.7       344632.9
     112.5  298520.3     326531.4     346892.1     364900.8     384326.7 !      472726.7       530835.9       573647.5       611804.2       653224.4
     106.7  480741.1     522176.7     551971.2     578350.6     606744.0 !      878073.1       979950.4      1054987.8      1121758.9      1194181.1
     100.8  744371.5     801626.4     843289.1     879962.8     919346.0 !     1581024.7      1756331.0      1885304.8      1999991.4      2124305.9
      94.9 1104906.3    1181296.1    1236368.3    1284723.2    1336526.1 !     2780468.8      3078582.0      3297789.8      3492654.3      3703817.2
      89.0 1573976.7    1669493.5    1737997.9    1797949.6    1861974.5 !     4807819.3      5311700.3      5632099.7      6011306.4      6367986.4
      83.0 2146007.9    2256223.9    2334705.4    2403072.9    2475766.4 !     8208835.3      9050769.1      9669382.0     10218673.0     10813463.3
      77.1 2784531.5    2907214.9    2994674.6    3070867.6    3152005.5 !    13803012.3     15169385.5     16207104.1     17111462.8     18090957.5
      71.2 3498846.3    3627336.3    3718149.0    3796886.5    3880170.5 !    23037354.0     25395974.0     27134214.0     28681782.3     30361094.3
      65.3 4196354.0    4309243.0    4389459.0    4458393.0    4530566.5 !    39359022.0     44157258.0     47771498.0     51033903.5     54617900.5
      59.4 4793292.0    4870911.0    4928520.0    4977481.0    5028245.0 !    72521793.0     82806796.0     90614610.0     97692913.0    105463557.0
      53.4 5208144.0    5255434.0    5285862.0    5315092.0    5345550.0 !   140605966.0    158064700.0    172393640.0    185452770.0    199689740.0
      47.5 5453602.0    5491184.0    5502128.0    5515888.0    5529568.0 !   259732280.0    286175756.0    308528292.0    328484548.0    350699072.0
      41.6 5587276.0    5605920.0    5616652.0    5622204.0    5630472.0 !   446019180.0    483467812.0    512391820.0    538944008.0    568838776.0
      35.7 5650736.0    5660784.0    5666858.0    5671304.0    5677336.0 !   709761856.0    760968338.0    798256848.0    831494944.0    867038344.0
      32.7 5669728.0    5674248.0    5677664.0    5680728.0    5683912.0 !   864756264.0    928785344.0    975170584.0   1016127408.0   1060136280.0
DELTA LOSSES =   5675915.3  AVERAGE LOSS =   2845954.4  MIN. DELTA LOSS =       7996.8  MAX. DELTA LOSS =   5683912.0
                                                        *****  CYCLE  7  *****
                        (INCREASE OVER PREVIOUS BOUNDARY)                                           (NEW BOUNDARY)
INFLOWS         4.4          3.6          2.9          2.4          1.7             4.4            3.6            2.9            2.4            1.7
STORAGE (HEAD)
     168.9   32218.2      32362.3      32465.8      32570.2      32679.2 !     -102483.8      -102358.0      -102257.1      -102153.3      -102044.9
     165.9   32830.2      32973.3      33076.5      33163.1      33301.5 !     -101913.1      -101734.3      -101585.0      -101447.4      -101297.4
     160.0   34235.1      34880.5      35386.9      35854.2      36379.9 !      -99277.3       -98278.9       -97496.4       -96774.3       -95965.0
     154.1   40053.6      41840.9      43179.9      44382.7      45699.2 !      -89618.4       -86527.3       -84190.1       -82078.2       -79755.5
     148.2   53163.2      56460.8      58882.3      61031.7      63359.2 !      -65549.9       -59087.6       -54302.5       -50032.6       -45388.4
     142.3   75546.1      80698.5      84453.3      87771.2      91348.8 !      -19547.2        -8275.6            0.0         7347.6        15303.2
     136.3  109466.9     115992.1     122458.2     127279.2     132467.6 !       58069.2        76441.7        89895.1       101821.7       114716.0
     130.4  158180.6     168766.8     176437.4     183192.9     190452.5 !      182908.4       212130.2       233503.6       252439.3       272897.3
     124.5  225770.9     240202.8     250636.4     259812.9     269660.6 !      379833.7       425697.9       459218.1       488902.1       520957.9
     118.6  315761.3     335860.6     347637.7     361738.8     374707.5 !      686879.6       758180.5       810261.5       856367.1       906139.5
     112.6  435734.5     460272.4     477932.1     493422.1     507997.8 !     1161548.6      1271592.1      1351937.4      1423047.4      1499793.4
     106.7  586778.7     617351.3     639301.0     658525.6     679069.7 !     1890611.3      2059549.8      2182860.2      2291979.2      2409727.0
     100.8  772734.5     809607.2     836011.1     859100.3     883734.5 !     3005778.2      3264410.0      3453539.1      3620730.9      3801146.3
      94.9  994282.0    1037206.4    1067853.6    1094605.3    1123094.8 !     4711718.8      5109757.4      5400811.1      5658297.7      5936242.5
      89.0 1248595.4    1296389.8    1330378.6    1359975.1    1391415.6 !     7336943.9      7955250.2      8407176.0      8807451.1      9239718.5
      83.0 1526722.6    1576580.9    1610207.6    1639383.9    1671435.0 !    11408058.5     12372682.3     13076383.5     13699831.4     14373308.0
      77.1 1811155.8    1863765.5    1901025.0    1933393.5    1967678.8 !    17731764.8     19218915.8     20329898.5     21315082.0     22380174.5
      71.2 2111626.0    2163068.5    2199228.0    2230494.3    2263449.5 !    27687683.0     30176389.0     32006183.0     33632965.5     35395845.5
      65.3 2387553.5    2431573.5    2462297.0    2488567.5    2516014.0 !    44708466.0     49619490.0     53312068.5     56641687.5     60295951.0
      59.4 2515194.0    2645110.0    2666687.0    2684963.0    2703842.0 !    78456007.0     88815380.0     96678719.0    103804051.0    111623310.0
      53.4 2770512.0    2787710.0    2799396.0    2810390.0    2820706.0 !   146937182.0    164440276.0    178799414.0    191886942.0    206152022.0
      47.5 2861644.0    2875416.0    2879368.0    2884420.0    2889408.0 !   266298770.0    292778076.0    315140664.0    335109984.0    357337448.0
      41.6 2910880.0    2917696.0    2921520.0    2923672.0    2926688.0 !   452713004.0    490179308.0    519113484.0    545670952.0    575573560.0
      35.7 2934552.0    2938248.0    2940488.0    2942096.0    2944304.0 !   716516784.0    767733416.0    805027168.0    838269448.0    873818576.0
      32.7 2941558.0    2943328.0    2944528.0    2945656.0    2946792.0 !   871529584.0    935562944.0    981951352.0   1022911072.0   1066922904.0
DELTA LOSSES =   2914573.8  AVERAGE LOSS =   1489505.1  MIN. DELTA LOSS =      32218.2  MAX. DELTA LOSS =   2946792.0
```

```
                                              *****  CYCLE  9  *****
                    (INCREASE OVER PREVIOUS BOUNDARY)                             (NEW BOUNDARY)
INFLOWS        4.4        3.6        2.9        2.4        1.7           4.4          3.6          2.9          2.4          1.7
STORAGE (HEAD)
   168.9     71494.8    71615.7    71657.5    71813.2    72114.6 !    -250061.2    -249360.4    -249685.5    -249426.2    -248944.0
   165.9     72444.7    72964.5    73377.4    73765.2    74207.6 !    -248068.9    -247123.8    -246353.0    -245633.7    -244814.5
   160.0     77493.9    79123.6    80553.4    81461.5    82679.9 !    -237127.5    -233284.7    -230343.3    -227668.5    -224706.1
   154.1     89605.3    92681.7    94939.0    96940.4    99107.1 !    -205737.3    -196972.5    -190459.7    -184638.6    -178293.9
   148.2    110146.0   114759.7   118062.8   121003.4   124155.9 !    -143253.9    -128038.1    -116891.0    -107010.6     -96324.6
   142.3    139584.6   145821.8   150326.5   154284.4   159530.9 !     -40570.3     -17101.1          0.0      15110.7      31403.8
   136.3    178842.3   186955.5   192799.7   197926.5   203418.0 !     114508.2     149126.6     174302.8     196525.2     220458.4
   130.4    229269.5   239508.4   245866.2   253317.2   260215.6 !     341172.3     391372.1     427850.8     460036.9     494683.0
   124.5    292267.3   304872.3   313916.6   321833.5   330292.4 !     668185.8     740452.4     792948.5     839260.5     889099.7
   118.6    369135.6   384308.9   395177.4   404681.9   414825.7 !    1137407.5    1241165.0    1316531.0    1383019.8    1454566.7
   112.6    460886.6   479750.5   491523.7   502682.7   514576.5 !    1809636.5    1958650.3    2066912.6    2162428.9    2265216.5
   106.7    567797.3   588545.0   603209.4   616006.5   629632.0 !    2773804.0    2988416.2    3144369.0    3281993.5    3430128.7
   100.8    690154.4   713215.6   729641.2   743958.7   757183.3 !    4161946.7    4472916.7    4699023.7    4898655.9    5113589.1
    94.9    826039.4   851222.0   869115.9   884691.6   901228.0 !    6176496.7    6632534.2    6964504.3    7257804.4    7573799.9
    89.0    972842.3   999363.9  1018135.5  1034435.8  1051692.3 !    9139948.9    9819953.3   10315609.9   10753889.0   11226434.9
    83.0   1122733.6  1149336.3  1168133.1  1184440.8  1201686.1 !   13562941.8   14587930.9   15335920.4   15997825.0   16712002.5
    77.1   1274724.5  1301554.5  1320496.3  1336925.3  1354287.5 !   20212778.3   21793687.5   22949720.8   23973995.3   25080424.0
    71.2   1428961.0  1452280.5  1470106.5  1485507.0  1501709.0 !   30560829.8   33110413.3   34982922.5   36646614.0   38448340.5
    65.3   1562679.5  1584019.0  1598804.0  1611493.5  1624725.5 !   47907200.5   52869584.0   56597769.5   59957928.0   63644060.0
    59.4   1673133.0  1686935.0  1697220.0  1705934.0  1714920.0 !   81920662.0   92313348.0  100201520.0  107347888.0  115188853.0
    53.4   1746776.0  1754914.0  1760425.0  1765626.0  1770248.0 !  150579596.0  168102374.0  182474866.0  195574968.0  209851236.0
    47.5   1789866.0  1796348.0  1798160.0  1800568.0  1802940.0 !  270045464.0  296540450.0  318907496.0  338882600.0  361115768.0
    41.6   1813112.0  1816316.0  1818148.0  1819104.0  1820512.0 !  455515916.0  493989980.0  522928608.0  549488392.0  579394424.0
    35.7   1824288.0  1826032.0  1827080.0  1827840.0  1828848.0 !  720346760.0  771567608.0  808863860.0  842108000.0  877659592.0
    32.7   1827656.0  1828432.0  1828992.0  1829512.0  1830024.0 !  875367720.0  939402912.0  985792704.0 1026753672.0 1070766768.0
DELTA LOSSES =    1758529.2  AVERAGE LOSS =     950759.4  MIN. DELTA LOSS =     71494.8  MAX. DELTA LOSS =    1830024.0
                                              *****  CYCLE 11  *****
                    (INCREASE OVER PREVIOUS BOUNDARY)                             (NEW BOUNDARY)
INFLOWS        4.4        3.6        2.9        2.4        1.7           4.4          3.6          2.9          2.4          1.7
STORAGE (HEAD)
   168.9    114372.3   114705.3   115035.3   115426.4   115976.9 !    -420245.2    -419578.6    -418887.8    -417945.5    -416477.9
   165.9    116480.9   117465.4   118222.6   118912.3   119679.6 !    -414615.9    -411875.9    -409725.7    -407745.4    -405519.6
   160.0    124438.7   126522.4   128236.6   129673.4   131235.8 !    -398771.3    -390728.1    -374671.3    -369217.7    -363228.0
   154.1    139341.1   142751.7   145223.4   147410.1   149759.1 !    -328298.2    -312771.0    -301338.7    -291179.0    -280158.6
   148.2    161183.8   165793.8   169101.1   172011.7   175132.6 !    -222166.1    -197653.2    -179793.3    -164019.3    -147007.5
   142.3    189884.2   195708.0   199893.4   203558.7   207480.4 !     -61130.5     -25704.3          0.0      22650.7      47016.3
   136.3    225696.6   232809.4   237909.1   242369.5   247134.5 !     167869.2     217306.7     253119.4     284651.3     318535.9
   130.4    269982.0   277443.6   283499.1   288790.1   294435.4 !     485151.2     553222.3     602503.6     645883.5     692479.9
   124.5    320046.4   327897.8   336936.7   343081.8   349631.3 !     920492.7    1013836.1    1081406.3    1140886.7    1204768.8
   118.6    379068.1   390319.0   398346.0   405348.2   412803.5 !    1516504.4    1644629.3    1737396.5    1819073.7    1906801.2
   112.6    446716.6   458626.6   467609.6   475439.3   483767.1 !    2324272.9    2510920.8    2638875.8    2751571.1    2872640.4
   106.7    520542.9   534401.1   544257.2   552840.3   561959.5 !    3462274.8    3707577.8    3895376.2    4042039.1    4210401.6
   100.8    601895.6   616820.4   627418.0   636638.8   646424.3 !    5031124.8    5375477.0    5625310.3    5845586.1    6082443.4
    94.9    688899.8   704516.1   715753.1   725432.3   735690.3 !    7240791.9    7732302.5    8089427.3    8404598.1    8743782.5
    89.0    779569.5   795503.9   806751.6   816506.1   826818.8 !   10409456.3   11125766.9   11647043.8   12107533.5   12603555.8
    83.0    869018.4   884600.9   895617.5   905183.3   915301.0 !   15036788.9   16097438.1   16870603.8   17554365.3   18291654.3
    77.1    957995.5   973433.8   984330.8   993781.3  1003758.0 !   21890708.0   23507094.8   24688166.0   25734159.0   26863528.5
    71.2   1045340.8  1059631.0  1069633.0  1078279.0  1087358.5 !   32439814.3   35022476.0   36918192.5   38601908.5   40424682.0
    65.3   1121505.5  1133341.5  1141537.5  1148567.5  1155892.0 !   49962701.0   54952597.0   58699839.0   62076340.0   65779507.5
    59.4   1182719.0  1190315.0  1195968.0  1200759.0  1205695.0 !   84116480.0   94578355.0  102430200.0  109587729.0  117440195.0
    53.4   1223238.0  1227688.0  1230696.0  1233544.0  1236074.0 !  152871784.0  170404942.0  184784450.0  197891198.0  212173372.0
    47.5   1246840.0  1250336.0  1251280.0  1252636.0  1253964.0 !  272392700.0  298895944.0  321265092.0  341243348.0  363479624.0
    41.6   1259564.0  1261308.0  1262304.0  1262832.0  1263600.0 !  458892808.0  496370948.0  525311904.0  551872904.0  581780736.0
    35.7   1265712.0  1266648.0  1267224.0  1267640.0  1268192.0 !  722737960.0  773961008.0  811258592.0  844503688.0  880056592.0
    32.7   1267568.0  1267976.0  1268288.0  1268576.0  1268848.0 !  877763248.0  941799392.0  988189888.0 1029151520.0 1073165272.0
DELTA LOSSES =    1154475.7  AVERAGE LOSS =     691610.1  MIN. DELTA LOSS =    114372.3  MAX. DELTA LOSS =    1268848.0
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                                                        *****  CYCLE 13  *****
                    (INCREASE OVER PREVIOUS BOUNDARY)                                   (NEW BOUNDARY)
INFLOWS          4.4         3.6         2.9         2.4         1.7              4.4           3.5           2.9           2.4           1.7
STORAGE (HEAD)
      168.9  156546.4   157102.3   157555.2   158037.0   158668.4 !      -579991.3     -578267.8     -576710.0     -574832.9     -572125.2
      165.9  159103.1   160190.8   161010.9   161763.3   162587.4 !      -569339.9     -564452.3     -560665.1     -557202.8     -553337.8
      160.0  167343.4   169459.8   171013.8   172391.2   173883.7 !      -526968.6     -514522.3     -505400.8     -497139.4     -488104.6
      154.1  181360.7   184475.3   186713.7   188680.6   190793.7 !      -437759.1     -415340.7     -399780.9     -385552.6     -370158.6
      148.2  200861.2   204856.3   207729.1   210244.9   212938.2 !      -291231.7     -258382.5     -234524.3     -213494.1     -190855.4
      142.3  225446.6   230320.9   233814.3   236868.0   240130.1 !       -78739.5      -33058.3           0.0       29081.8       60319.9
      136.3  255037.1   260780.7   264887.4   268472.8   272297.1 !       212692.6      274311.1      318838.7      357982.5      399988.9
      130.4  289567.5   296165.6   300874.9   304962.7   309358.7 !       503408.8      685535.4      744940.4      797110.8      853075.0
      124.5  329936.1   336363.8   341657.4   345271.2   351181.1 !      1123133.6     1232480.9     1311463.5     1380894.7     1455370.2
      118.6  372971.1   381186.3   387033.2   392125.7   397539.9 !      1814258.3     1960218.7     2065687.0     2158030.6     2257927.7
      112.6  421387.1   430320.7   436670.0   442196.4   449060.0 !      2737380.2     2933564.2     3075411.8     3200203.0     3334124.0
      106.7  473727.3   483272.4   490046.3   495937.7   502188.4 !      3980081.0     4246400.6     4439121.8     4608767.5     4790909.2
      100.8  529318.9   539330.0   546423.9   552588.7   559122.3 !      5671570.9     6038110.2     6303673.1     6537622.7     6786976.7
       94.9  587259.9   597542.3   604814.9   611128.5   617811.0 !      8009874.6     8524312.9     8897661.4     9226920.6     9581020.8
       89.0  646211.0   656412.4   663504.1   669936.9   676418.9 !     11310179.1    12049355.4    12536757.9    13061224.6    13572011.5
       83.0  703160.6   712992.9   719932.3   725951.5   732309.5 !     16065299.5    17148078.5    17936872.3    18634183.5    19385791.5
       77.1  758914.8   768553.5   775333.0   781203.3   787389.6 !     23044826.5    24682983.5    25879371.5    26938628.0    28081979.0
       71.2  813092.8   821958.5   827993.0   833287.5   836846.5 !     33716393.5    36318941.5    38228541.0    39924259.0    41759635.5
       65.3  859749.5   866945.0   871922.0   876192.5   880637.5 !     51345056.0    56351301.0    60109856.5    63496062.0    67209334.0
       59.4  896941.0   901529.0   904944.0   907837.0   910816.0 !     85585357.0    96006173.0   103915291.0   111079408.0   118938654.0
       53.4  921426.0   924108.0   925918.0   927632.0   929156.0 !    154394382.0   171933543.0   186317282.0   199427938.0   213713582.0
       47.5  935560.0   937760.0   938328.0   939136.0   939936.0 !    273947696.0   300455624.0   322826172.0   342806272.0   365044368.0
       41.6  943324.0   944375.0   944950.0   945296.0   945760.0 !    460465248.0   497945776.0   526888108.0   553449816.0   583358704.0
       35.7  947024.0   947592.0   947928.0   948184.0   948520.0 !    724318832.0   775543176.0   812841523.0   846087200.0   881640864.0
       32.7  948144.0   948392.0   948584.0   948752.0   948912.0 !    879340664.0   943383369.0   989774250.0  1030736304.0  1074750432.0
DELTA LOSSES =     792355.6  AVERAGE LOSS =     552729.2  MIN. DELTA LOSS =     156546.4  MAX. DELTA LOSS =     948912.0
                                                        *****  CYCLE 15  *****
                    (INCREASE OVER PREVIOUS BOUNDARY)                                   (NEW BOUNDARY)
INFLOWS          4.4         3.6         2.9         2.4         1.7              4.4           3.6           2.9           2.4           1.7
STORAGE (HEAD)
      168.9  193131.0   193682.5   194125.8   194584.6   195171.3 !      -714682.8     -711340.0     -709380.5     -706563.8     -702647.7
      165.9  195474.9   196483.9   197238.9   197913.6   198655.6 !      -699156.4     -692213.4     -686873.9     -682013.5     -676609.5
      160.0  202781.6   204575.9   205923.4   207097.6   208367.6 !      -641615.4     -625468.3     -613463.8     -602740.0     -591041.0
      154.1  214643.5   217206.0   219055.6   220678.7   222420.6 !      -527487.4     -500164.7     -480202.3     -462548.5     -443477.6
      148.2  230625.3   233854.2   236172.2   238200.0   240368.7 !      -347189.6     -307496.1     -278723.0     -253391.9     -226152.6
      142.3  250341.9   254198.7   256953.3   259368.1   261940.1 !       -92833.0      -38937.8           0.0       34217.3       70937.3
      136.3  273583.1   278033.6   281210.5   283981.4   286933.9 !       248181.1      319324.0      370653.2      415730.5      464060.9
      130.4  300149.4   305156.5   308724.5   311833.4   315142.2 !       695846.0      755790.7      855821.9      914682.4      977768.5
      124.5  329822.0   335344.2   339273.5   342694.7   346332.1 !      1279486.2     1400766.9     1488244.0     1565073.0     1647415.6
      118.6  352349.9   366337.1   372591.6   376293.6   380225.6 !      2041011.3     2199971.4     2314650.7     2415467.3     2523509.2
      112.6  397423.8   403811.2   408344.3   412286.2   416469.0 !      3040396.8     3250513.1     3402251.8     3535646.0     3678698.1
      106.7  434641.4   441343.9   446094.1   450221.8   454597.4 !      4364384.4     4645387.3     4848519.1     5027211.4     5218946.1
      100.8  473484.3   480395.5   485258.3   489536.0   494034.2 !      6141070.4     6522814.6     6799141.1     7042439.3     7303694.9
       94.9  513313.1   520373.0   525240.9   529525.0   534055.5 !      8567080.5     9096953.3     9481203.3     9819931.4    10184042.1
       89.0  553234.5   560072.6   564884.1   569059.0   573460.3 !     11955618.6    12709946.5    13258022.1    13741734.1    14262278.9
       83.0  591289.6   597797.0   602385.5   606363.8   610562.8 !     16795124.8    17892368.0    18691363.0    19397520.0    20158466.5
       77.1  628091.8   634401.5   638835.8   642673.8   646715.6 !     23856507.5    25508727.8    26715001.3    27782814.8    28935179.3
       71.2  663484.5   669171.0   673145.0   676577.5   680176.5 !     34607000.5    37222253.0    39140735.0    40844120.5    42687541.0
       65.3  693712.5   698346.5   701551.5   704301.0   707160.0 !     52303213.0    57319329.5    61095559.0    64477917.0    68197591.0
       59.4  717661.0   720604.0   722793.0   724651.0   726561.0 !     86597114.0    97024524.0   104938548.0   112106825.0   119970349.0
       53.4  733375.0   735094.0   736254.0   737356.0   738330.0 !    155441340.0   172984456.0   187370692.0   200483818.0   214771644.0
       47.5  742508.0   743852.0   744220.0   744740.0   745252.0 !    275015120.0   301526369.0   323697436.0   343878708.0   366117952.0
       41.6  747436.0   748112.0   748492.0   748696.0   749000.0 !    461543724.0   499025764.0   527968949.0   554531112.0   584440664.0
       35.7  749816.0   750176.0   750392.0   750560.0   750768.0 !    725402640.0   776627792.0   813926632.0   847172656.0   882726784.0
       32.7  750536.0   750599.0   750808.0   750912.0   751008.0 !    880432080.0   944469120.0   990860280.0  1031822552.0  1075836912.0
DELTA LOSSES =     557877.0  AVERAGE LOSS =     472069.5  MIN. DELTA LOSS =     193131.0  MAX. DELTA LOSS =     751008.0
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                                                          *****  CYCLE 17  *****
                        (INCREASE OVER PREVIOUS BOUNDARY)                                  (NEW BOUNDARY)
INFLOWS          4.4         3.6         2.9         2.4         1.7           4.4          3.6          2.9          2.4          1.7
STORAGE (HEAD)
    168.9   222730.5   223206.2   223584.6   223971.0   224458.7 !     -821725.0    -817891.3    -814643.1    -811018.2    -806078.1
    165.9   224737.1   225564.6   226185.8   226743.5   227355.7 !     -802027.0    -793345.6    -786700.4    -780667.6    -773976.3
    160.0   230726.6   232182.8   233246.1   234185.2   235199.8 !     -731887.2    -712652.4    -698391.8    -685674.6    -671821.3
    154.1   240170.8   242185.4   243639.0   244911.7   246277.9 !     -597691.0    -566072.1    -543011.3    -522639.9    -500654.1
    148.2   252674.1   255180.4   256973.0   258549.6   260229.6 !     -390698.7    -345544.2    -313025.3    -284331.4    -253496.8
    142.3   267911.8   270869.9   272984.4   274829.8   276798.3 !     -103715.2     -43474.7          0.0      38177.2      79121.9
    136.3   285660.8   289032.5   291437.1   293533.0   295765.1 !      275410.5     353806.9     410310.4     459898.1     513032.2
    130.4   305703.0   309449.5   312116.6   314439.1   316909.5 !      766234.6     867262.8     940049.7    1003923.1    1072342.0
    124.5   327814.0   331894.6   334795.2   337319.2   340001.1 !     1397627.2    1527737.9    1621493.2    1703786.1    1791935.3
    118.6   351755.1   356124.7   359226.3   361924.4   364788.1 !     2211007.6    2379451.4    2500894.8    2607539.2    2721798.5
    112.6   377257.6   381863.5   385129.2   387967.3   390977.3 !     3265790.9    3485932.4    3644780.6    3784354.4    3933961.1
    106.7   404001.5   408779.0   412161.9   415099.9   418212.6 !     4648037.3    4939467.9    5149983.8    5335091.8    5533623.9
    100.8   431500.3   436473.6   439912.4   442910.2   446075.5 !     6485008.0    6877417.4    7161285.4    7411131.9    7679317.8
     94.9   459597.1   464473.0   467914.6   470899.3   474053.6 !     8972332.4    9512903.6    9904711.3   10249984.8   10621019.8
     89.0   487370.5   492093.8   495417.5   498295.4   501330.4 !    12421847.9   13186564.1   13741951.4   14231994.3   14759216.8
     83.0   513603.8   518063.0   521205.3   523929.5   526803.3 !    17319078.3   18426143.8   19232069.3   19944230.5   20711511.8
     77.1   538760.0   543074.5   545090.5   548701.0   551448.5 !    24435966.8   26097667.3   27310600.3   28384177.5   29542609.5
     71.2   562826.0   566672.5   567359.5   571679.0   574111.5 !    35239573.0   37863329.0   39787755.5   41496267.0   43345065.5
     65.3   583239.0   586362.5   588522.5   590376.0   592304.0 !    52980941.5   58004466.5   61774973.5   65171429.5   68895356.0
     59.4   599367.0   601349.0   602824.0   604073.0   605356.0 !    87310525.0   97742518.0  105659602.0  112830643.0  120697008.0
     53.4   609942.0   611098.0   611875.0   612514.0   613266.0 !   156178144.0  173723816.0  188111776.0  201226538.0  215515812.0
     47.5   616068.0   616975.0   617216.0   617568.0   617908.0 !   275765504.0  302278452.0  324650356.0  344632408.0  366872412.0
     41.6   619368.0   619824.0   620076.0   620216.0   620416.0 !   462301436.0  499764476.0  528728232.0  555290688.0  585200672.0
     35.7   620976.0   621216.0   621352.0   621472.0   621616.0 !   726163880.0  777389563.0  814683728.0  847934992.0  883489440.0
     32.7   621448.0   621552.0   621632.0   621704.0   621776.0 !   881194384.0  945231656.0  991622992.0 1032585416.0 1076599936.0
DELTA LOSSES =     399045.5  AVERAGE LOSS =     422253.3  MIN. DELTA LOSS =     222730.5  MAX. DELTA LOSS =     621776.0
                                                          *****  CYCLE 19  *****
                        (INCREASE OVER PREVIOUS BOUNDARY)                                  (NEW BOUNDARY)
INFLOWS          4.4         3.6         2.9         2.4         1.7           4.4          3.6          2.9          2.4          1.7
STORAGE (HEAD)
    168.9   245349.8   245791.4   246135.9   246476.7   246894.1 !     -904985.2    -900238.6    -896273.8    -891936.3    -886119.1
    165.9   247073.9   247768.4   248285.5   248747.4   249252.1 !     -881651.3    -871510.9    -863775.9    -856768.0    -849309.6
    160.0   251939.5   253081.8   253913.6   254647.0   255438.1 !     -801191.7    -779521.2    -763485.9    -749203.0    -733660.3
    154.1   259281.6   260828.8   261943.3   262920.1   263967.4 !     -651305.0    -616370.9    -590921.0    -568455.5    -544224.5
    148.2   269849.7   270756.9   272123.9   273318.6   274595.2 !     -423790.1    -374639.1    -339083.3    -307822.6    -274244.8
    142.3   280410.9   282643.5   284239.5   285629.9   287113.5 !     -111954.7     -46909.5          0.0      41172.9      85312.2
    136.3   293769.4   296293.6   298092.7   299660.1   301328.8 !      295945.3     379786.2     440170.6     493139.9     549875.2
    130.4   308733.4   311515.7   313495.1   315218.1   317050.2 !      819066.1     926107.1    1003172.6    1070770.5    1143150.0
    124.5   325111.4   328117.8   330253.5   332111.2   334084.4 !     1485875.6    1622495.9    1720876.4    1807192.8    1899615.9
    118.6   342706.5   345900.7   348167.1   350137.1   352227.7 !     2337377.0    2512750.1    2639110.7    2750028.9    2868825.5
    112.6   361305.2   364646.6   367014.2   369071.0   371251.7 !     3432530.1    3659933.4    3823928.1    3967973.2    4122320.7
    106.7   380663.3   384103.6   386536.1   388651.7   390890.3 !     4856870.4    5155791.3    5371608.3    5561319.3    5764726.6
    100.8   400495.8   403980.4   406442.8   408579.3   410839.6 !     6737042.0    7137050.8    7426290.9    7680796.9    7953913.9
     94.9   420476.1   423939.4   426332.3   428500.1   430737.8 !     9267961.4    9816097.8   10213242.5   10563143.3   10939067.8
     89.0   440168.5   443502.9   445847.8   447877.4   450017.5 !    12760512.0   13532522.0   14093040.0   14587524.0   15119429.5
     83.0   458660.0   461790.3   463994.5   465905.0   467920.0 !    17698209.5   18812137.0   19622887.5   20339235.0   21110931.8
     77.1   476309.3   479307.8   481413.5   483235.5   485152.8 !    24853774.3   26522051.8   27739603.5   28817177.5   29979815.8
     71.2   493085.0   495760.0   497627.5   499240.5   500931.0 !    35694185.5   38323312.5   40252339.5   41964394.0   43816904.5
     65.3   507270.5   509437.5   510935.5   512221.0   513558.0 !    53466704.5   58494991.5   62268799.5   65668069.0   69394941.0
     59.4   518452.0   519825.0   520846.0   521710.0   522599.0 !    87820656.0   98255668.0  106175195.0  113348138.0  121216457.0
     53.4   525776.0   526572.0   527110.0   527618.0   528070.0 !   156704574.0  174252000.0  188641140.0  201757024.0  216047292.0
     47.5   530016.0   530636.0   530812.0   531044.0   531280.0 !   276301252.0  302815568.0  325137848.0  345170424.0  367410948.0
     41.6   532300.0   532608.0   532784.0   532880.0   533005.0 !   462842208.0  500325928.0  529270072.0  555832736.0  585743016.0
     35.7   533408.0   533568.0   533664.0   533736.0   533840.0 !   726707080.0  777933136.0  815232504.0  848478928.0  884033592.0
     32.7   533736.0   533800.0   533856.0   533896.0   533952.0 !   881738312.0  945775744.0  992167184.0 1033129720.0 1077144352.0
DELTA LOSSES =     288602.2  AVERAGE LOSS =     389650.9  MIN. DELTA LOSS =     245349.8  MAX. DELTA LOSS =     533952.0
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                                                        *****  CYCLE 21  *****
                  (INCRFASE OVER PREVIOUS BOUNDARY)                                          (NEW BOUNDARY)
INFLOWS        4.4         3.6         2.9         2.4         1.7               4.4           3.6           2.9           2.4           1.7
STORAGE (HEAD)
    168.9  262822.4  263170.0  263440.4  263706.5  264030.5 !     -968240.5     -962754.7     -958214.0     -953308.8     -946799.0
    165.9  264160.8  264698.2  265097.7  265454.1  265843.2 !     -942049.0     -930753.6     -922168.4     -914397.2     -905805.4
    160.0  267295.3  268765.5  269398.4  269956.1  270557.3 !     -853583.7     -839943.1     -812647.4     -797165.7     -780330.5
    154.1  273467.4  274635.8  275477.2  276214.5  277004.8 !     -691713.6     -654264.3     -627002.9     -602949.9     -577017.3
    148.2  280680.1  282113.4  283140.4  284037.7  284996.3 !     -448664.7     -396424.5     -358655.1     -325460.3     -289816.1
    142.3  289353.0  291022.4  292214.6  293254.3  294362.7 !     -118129.4      -49481.1           0.0       43416.6       89947.9
    136.3  299323.8  301201.5  302539.2  303704.3  304944.5 !      311293.5      399190.7      462465.2      517952.0      577366.9
    130.4  310435.3  312474.1  313953.2  315232.3  316586.7 !      858428.3      969922.4     1050155.0     1120509.1     1195818.8
    124.5  322533.7  324746.7  326315.1  327684.6  329135.5 !     1551416.8     1692329.6     1794613.7     1883890.0     1979455.4
    118.6  335464.0  337803.1  339461.9  340903.6  342433.0 !     2430931.9     2611377.0     2741334.9     2855379.7     2977493.4
    112.6  349061.8  351496.0  353220.0  354717.6  356304.7 !     3555581.4     3785269.6     3956007.9     4103304.8     4261098.8
    106.7  363143.4  365537.1  367401.3  368932.6  370553.9 !     5010505.4     5314347.2     5534499.2     5727539.3     5934471.6
    100.8  377501.1  380015.4  381791.8  383332.8  384962.5 !     6921896.8     7327377.0     7620482.9     7878342.6     8155007.0
     94.9  391902.8  394391.6  396146.8  397608.0  399275.3 !     9484163.8    10037721.1    10438689.5    10791904.5    11171330.1
     89.0  406741.6  408428.9  410107.5  411560.3  413091.4 !    13007518.8    13784733.3    14348911.1    14846562.4    15381806.6
     83.0  419270.4  421504.0  423074.5  424439.0  425876.0 !    17974062.8    19092363.0    19907045.0    20626365.8    21401198.0
     77.1  431853.5  433985.0  435432.8  436778.0  438140.5 !    25157057.3    26830021.5    28050842.0    29131244.3    30296858.3
     71.2  443775.5  445672.5  446996.5  448140.0  449338.0 !    36023537.0    38657308.0    40588729.5    42303282.0    44158410.5
     65.3  453831.0  455364.0  456424.5  457333.5  458276.0 !    53618032.0    58849670.5    62625786.0    66027052.5    69755990.0
     59.4  461740.0  462712.0  463432.0  464044.0  464571.0 !    82189478.0    93626411.0   106547513.0   113721795.0   121591487.0
     53.4  466914.0  467476.0  467856.0  468216.0  468534.0 !   157084508.0   174633164.0   189923136.0   202139810.0   216430774.0
     47.5  469908.0  470345.0  470464.0  470676.0  470804.0 !   276687732.0   303203012.0   325575544.0   345558500.0   367799392.0
     41.6  471516.0  471735.0  471560.0  471928.0  472024.0 !   463232212.0   500716416.0   529660832.0   556223640.0   586134128.0
     35.7  472304.0  472416.0  472496.0  472544.0  472616.0 !   727098784.0   773325096.0   815624632.0   848871168.0   884425976.0
     32.7  472544.0  472600.0  472624.0  472664.0  472688.0 !   882130536.0   946168080.0   992559600.0  1033522216.0  1077536912.0
DELTA LOSSES =    209865.6  AVERAGE LOSS =     367755.2  MIN. DELTA LOSS =    262822.4  MAX. DELTA LOSS =    472688.0
                                                        *****  CYCLE 23  *****
                  (INCRFASE OVER PREVIOUS BOUNDARY)                                          (NEW BOUNDARY)
INFLOWS        4.4         3.6         2.9         2.4         1.7               4.4           3.6           2.9           2.4           1.7
STORAGE (HEAD)
    168.9  275925.6  276199.1  276410.3  276617.4  276867.1 !    -1015712.4    -1009545.7    -1004654.9     -999309.2     -992265.9
    165.9  276959.3  277371.9  277677.8  277950.4  278247.5 !     -987312.7     -975139.7     -965894.5     -957539.6     -948311.1
    160.0  279800.3  280455.6  280931.8  281351.2  281803.0 !     -892751.6     -867300.4     -849379.5     -832994.7     -815186.3
    154.1  283983.6  284557.0  285465.8  286036.7  286627.0 !     -721868.4     -682534.8     -653916.6     -628674.9     -601468.5
    148.2  289354.3  290436.0  291200.9  291869.0  292582.8 !     -457198.1     -412652.1     -373230.9     -338593.1     -301407.3
    142.3  295822.1  297062.0  297947.3  298719.1  299541.9 !     -122722.1      -51394.2           0.0       45084.8       93394.5
    136.3  303219.5  304609.6  305599.8  306462.1  307379.7 !      322691.1      413594.9      479011.0      536362.8      597762.6
    130.4  311437.2  312956.6  314030.8  314976.7  315975.6 !      887603.1     1002385.7     1084956.4     1157344.9     1234817.0
    124.5  320356.2  321984.0  323139.6  324144.4  325211.2 !     1599900.3     1744339.1     1849126.5     1940579.3     2038456.8
    118.6  329857.6  331572.5  332768.5  333845.0  334965.7 !     2500000.9     2684163.6     2816757.5     2933092.7     3057636.1
    112.6  339817.3  341596.3  342856.0  343950.0  345109.3 !     3646245.4     3882792.9     4053264.2     4202934.5     4363243.8
    106.7  350059.1  351916 1  353201.0  354316.2  355496.8 !     5123479.3     5431765.8     5654207.4     5849668.9     6059164.6
    100.8  360550.4  36237 .3  363657.3  364786.1  365969.4 !     7057565.6     7467014.1     7752922.6     8025213.4     8302449.0
     94.9  371004.0  372806.9  374073.0  375179.6  376343.3 !     9642547.0    10200023.9    10603755.9    10959356.1    11341321.6
     89.0  381238.8  382963.9  384176.4  385225.6  386331.6 !    13184156.6    13969123.3    14535939.0    15035873.1    15573523.5
     83.0  390792.3  392401.5  393535.0  394517.0  395552.3 !    18175484.6    19297789.3    20114437.3    20835895.8    21612981.5
     77.1  399857.3  401391.0  402467.8  403399.3  404379.3 !    25378243.5    27054517.5    28277683.0    29360113.5    30527861.8
     71.2  408430.0  409791.5  410743.0  411564.0  412424.0 !    36263364.0    38900101.0    40833594.5    42549935.0    44406937.5
     65.3  415648.5  416748.0  417509.0  418160.5  418838.0 !    54073587.5    59107621.0    62885393.0    66288079.5    70018495.0
     59.4  421322.0  422018.0  422533.0  422971.0  423420.0 !    88457396.0    98895944.0   106818072.0   113993307.0   121863979.0
     53.4  425028.0  425452.0  425704.0  425962.0  426188.0 !   157350504.0   174910040.0   189300604.0   202417842.0   216709300.0
     47.5  427172.0  427490.0  427564.0  427692.0  427812.0 !   276968396.0   303484560.0   325857080.0   345840304.0   368081456.0
     41.6  428320.0  428480.0  428572.0  428616.0  428688.0 !   463515396.0   500999944.0   529944556.0   556507464.0   586418112.0
     35.7  428880.0  428952.0  429008.0  429048.0  429088.0 !   727383184.0   778609680.0   815909320.0   849155936.0   884710848.0
     32.7  429064.0  429080.0  429104.0  429128.0  429152.0 !   882415312.0   946452720.0   992844496.0  1033807168.0  1077821904.0
DELTA LOSSES =    153226.4  AVERAGE LOSS =     352539.9  MIN. DELTA LOSS =    275925.6  MAX. DELTA LOSS =    429152.0
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                                                     *****  CYCLE 25  *****
                         (INCREASE OVER PREVIOUS BOUNDARY)                                        (NEW BOUNDARY)
INFLOWS           4.4          3.6          2.9          2.4          1.7             4.4           3.6           2.9           2.4           1.7
STORAGE (HEAD)
    168.9  285739.8  285944.4  286102.5  286256.8  286443.2 !    -1051060.5    -1044552.3    -1039220.0    -1033541.3    -1026095.6
    165.9  286511.5  286819.2  287047.4  287250.7  287472.2 !    -1020994.8    -1008157.1     -993419.1     -989625.2     -979918.2
    160.0  288628.7  289116.6  289471.1  289783.2  290119.5 !     -921860.4     -895855.2     -870668.6     -859609.5     -841074.5
    154.1  291740.7  292389.7  292856.9  293266.2  293704.7 !     -744253.4     -703517.2     -673889.4     -647763.3     -619609.1
    148.2  295739.0  296530.9  297095.0  297593.4  298122.5 !     -480941.2     -424683.3     -384035.9     -346327.0     -309997.2
    142.3  300521.7  301439.3  302094.3  302665.4  303274.1 !     -126123.7      -52811.0           0.0       46320.1       95946.4
    136.3  305992.2  307019.3  307742.9  308386.5  309064.0 !      331123.5      424249.3      491247.5      549977.0      612842.9
    130.4  312056.7  313176.3  313972.2  314664.7  315400.5 !      909161.5     1026369.1     1110662.1     1184549.8     1263615.2
    124.5  318624.8  319821.9  320671.5  321410.2  322194.4 !     1635681.3     1783213.1     1889341.0     1982394.0     2081970.3
    118.6  325607.3  326965.7  327757.9  328533.0  329355.1 !     2550909.3     2737799.4     2872326.7     2990342.1     3116667.3
    112.6  332911.5  334214.3  335135.7  335937.6  336786.3 !     3712986.2     3952358.5     4124829.9     4276237.0     4438386.6
    106.7  340436.7  341764.3  342703.6  343518.5  344381.0 !     5206539.3     5517706.5     5742185.3     5939414.4     6150781.5
    100.8  348071.3  349403.7  350344.5  351160.6  352023.4 !     7157189.5     7569529.9     7867480.6     8129542.6     8410651.1
     94.9  355692.9  357005.6  357931.3  358732.9  359580.0 !     9758714.6    10319341.9    10724783.5    11082135.1    11465929.9
     89.0  363142.0  364396.0  365277.3  366039.5  366843.5 !    13320500.6    14104190.9    14672921.0    15174511.6    15713907.8
     83.0  370083.3  371251.3  372074.5  372787.0  373538.0 !    18322908.3    19447750.8    20266187.0    20989193.8    21767911.8
     77.1  376661.0  377772.8  378552.8  379227.8  379937.5 !    25539960.8    27219551.5    28443512.8    29527410.8    30696702.0
     71.2  382872.5  383858.5  384547.0  385141.0  385763.5 !    36438585.5    39077465.5    41012455.5    42730087.5    44588443.5
     65.3  388098.5  388893.0  389443.0  389914.5  390403.0 !    54260170.5    59295933.5    63074900.5    66478612.5    70210092.0
     59.4  392200.0  392703.0  393076.0  393393.0  393716.0 !    88652900.0    99092440.0   107015472.0   114191404.0   122062783.0
     53.4  394878.0  395168.0  395364.0  395556.0  395720.0 !   157561836.0   175112706.0   189502998.0   202620640.0   216912458.0
     47.5  396428.0  396656.0  396724.0  396804.0  396896.0 !   277173096.0   303689556.0   326062412.0   346045820.0   368287160.0
     41.6  397268.0  397376.0  397440.0  397472.0  397528.0 !   463721912.0   501205700.0   530151456.0   556714440.0   586625192.0
     35.7  397664.0  397728.0  397760.0  397784.0  397824.0 !   727590576.0   773817208.0   816116912.0   849363592.0   884918584.0
     32.7  397792.0  397808.0  397840.0  397856.0  397872.0 !   882622960.0   946660624.0   993052248.0  1034014960.0  1078029728.0
DELTA LOSSES =     112132.2  AVERAGE LOSS =     341505.9  MIN. DELTA LOSS =     285739.8  MAX. DELTA LOSS =     397872.0
                                                     *****  CYCLE 27  *****
                         (INCREASE OVER PREVIOUS BOUNDARY)                                        (NEW BOUNDARY)
INFLOWS           4.4          3.6          2.9          2.4          1.7             4.4           3.6           2.9           2.4           1.7
STORAGE (HEAD)
    168.9  292989.3  293144.3  293263.5  293379.4  293519.0 !    -1077269.5    -1070427.0    -1064837.6    -1058908.8    -1051161.8
    165.9  293569.3  293799.6  293970.2  294122.1  294287.6 !    -1045952.3    -1032617.7    -1022511.5    -1013389.7    -1003325.4
    160.0  295149.4  295512.1  295775.4  296007.3  296257.1 !     -943407.0     -916618.5     -896863.0     -879303.1     -860228.7
    154.1  297459.6  297940.4  298236.4  298589.4  298914.1 !     -760809.0     -719033.7     -688657.9     -661876.6     -633020.5
    148.2  300415.1  301004.5  301423.7  301789.8  302180.9 !     -491098.0     -433573.9     -392019.7     -355518.8     -316343.0
    142.3  303952.7  304630.0  305113.4  305534.9  305984.0 !     -128635.6      -53357.2           0.0       47232.2       97830.6
    136.3  307988.7  308745.5  309284.4  309753.6  310252.8 !      337347.4      432111.1      500276.0      560021.3      623968.2
    130.4  312457.1  313291.4  313867.3  314377.0  314918.6 !      925059.8     1044051.5     1129614.3     1204605.8     1284844.2
    124.5  317290.5  318170.6  318795.3  319338.3  319914.8 !     1662047.9     1811486.1     1918967.3     2013196.5     2114021.7
    118.6  322422.2  323345.2  324001.3  324570.3  325173.3 !     2588393.4     2777236.0     2913232.8     3032481.1     3160114.2
    112.6  327783.3  328738.7  329414.9  330002.2  330624.4 !     3762088.7     4003531.8     4177469.2     4330149.3     4493647.6
    106.7  333299.5  334272.1  334959.6  335556.4  336187.9 !     5267599.8     5580375.8     5806845.5     6005368.6     6218105.1
    100.8  338886.9  339863.6  340551.6  341148.4  341779.4 !     7230370.7     7644824.8     7944267.9     8207624.3     8490101.6
     94.9  344462.0  345421.1  346097.1  346683.1  347301.8 !     9843983.9    10406592.0    10813600.4    11172223.4    11557360.4
     89.0  349962.9  350813.0  351456.9  352017.5  352603.8 !    13417575.1    14203251.0    14773376.8    15276175.3    15816843.8
     83.0  354967.3  355819.3  356412.0  356938.3  357485.8 !    18430974.3    19557665.5    20377403.3    21101537.8    21881444.3
     77.1  359762.0  360571.3  361140.3  361631.5  362148.5 !    25658434.0    27338982.5    28564979.0    29649943.0    30820357.0
     71.2  364286.0  365003.5  365505.0  365936.5  366390.0 !    36566881.5    39207319.0    41143397.5    42861967.5    44721307.5
     65.3  368088.5  368667.5  369067.0  369409.5  369766.0 !    54396724.5    59433744.0    63213577.5    66618034.5    70350289.0
     59.4  371073.0  371438.0  371705.0  371938.0  372174.0 !    88795934.0    99236268.0   107159896.0   114336319.0   122208212.0
     53.4  373020.0  373230.0  373374.0  373508.0  373630.0 !   157709102.0   175259730.0   189651030.0   202768966.0   217061046.0
     47.5  374146.0  374308.0  374360.0  374420.0  374484.0 !   277322804.0   303839628.0   324212576.0   346196123.0   368437604.0
     41.6  374760.0  374840.0  374884.0  374896.0  374944.0 !   463872944.0   501357916.0   530302768.0   556865800.0   586776632.0
     35.7  375048.0  375080.0  375104.0  375136.0  375160.0 !   727742240.0   778968960.0   816268728.0   849515456.0   885070504.0
     32.7  375136.0  375152.0  375152.0  375176.0  375200.0 !   882774816.0   946812520.0   993204160.0  1034166904.0  1078181712.0
DELTA LOSSES =      82210.7  AVERAGE LOSS =     334094.7  MIN. DELTA LOSS =     292989.3  MAX. DELTA LOSS =     375200.0
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                                                     *****  CYCLE 29  *****
                        (INCREASE OVER PREVIOUS BOUNDARY)                                  (NEW BOUNDARY)
INFLOWS         4.4         3.6         2.9         2.4         1.7           4.4          3.6          2.9          2.4          1.7
STORAGE (HEAD)
    168.9  298343.9  298458.3  298545.4  298632.1  298735.5 !    -1096670.5   -1089580.8   -1083801.0   -1077687.0   -1069716.6
    165.9  298773.0  298943.5  299073.0  299182.5  299305.2 !    -1064425.9   -1050722.6   -1040343.1   -1030977.9   -1020648.4
    160.0  299944.0  300213.1  300403.5  300580.5  300765.8 !     -959348.8    -931979.6    -911800.5    -893868.6    -874393.5
    154.1  301656.3  302012.9  302269.1  302493.5  302733.9 !     -773046.7    -730501.1    -699571.1    -672304.4    -642928.2
    148.2  303846.9  304279.4  304539.1  304859.6  305148.4 !     -496597.7    -440137.8    -397913.5    -360827.4    -321026.5
    142.3  306456.3  306955.9  307312.5  307623.3  307954.6 !     -130486.7     -54529.0          0.0      47905.0      99220.4
    136.3  309432.3  309989.9  310385.9  310732.6  311100.4 !      341936.0     437907.0     506931.4     567425.2     632168.3
    130.4  312723.6  313330.3  313751.5  314136.6  314535.1 !      936774.6    1057080.2    1143576.3    1219380.6    1300482.3
    124.5  315280.0  316927.1  317396.4  317785.5  318209.3 !     1681464.9    1832305.0    1940781.0    2035875.0    2137618.2
    118.6  320052.1  320730.9  321212.0  321630.1  322073.3 !     2615982.1    2806345.4    2943334.8    3063488.7    3192082.2
    112.6  323989.3  324690.5  325186.9  325617.8  326074.4 !     3798208.6    4041171.3    4216184.4    4369798.4    4534286.3
    106.7  328036.9  328750.2  329254.4  329691.9  330155.0 !     5312491.9    5627313.9    5854376.7    6053848.1    6267588.5
    100.8  332135.0  332849.1  333355.3  333790.6  334252.9 !     7284146.1    7700148.3    8000684.6    8264989.1    8548468.5
     94.9  336217.9  336920.0  337415.1  337844.0  338296.9 !     9906611.3   10470542.0   10878823.9   11238376.9   11624496.0
     89.0  340209.8  340870.4  341340.9  341748.0  342177.0 !    13488839.4   14275967.3   14847113.6   15350795.0   15892394.1
     83.0  343936.0  344528.8  344967.3  345347.0  345747.3 !    18510274.8   19638317.0   20459035.5   21183963.8   21964738.8
     77.1  347411.0  348002.8  348419.0  348777.3  349155.3 !    25745337.5   27427070.3   28654066.0   29739810.8   30911044.5
     71.2  350717.0  351240.0  351606.5  351922.0  352253.0 !    36660957.0   39302531.0   41239403.5   42958659.0   44818716.5
     65.3  353494.0  353916.5  354208.0  354458.5  354718.0 !    54496826.5   59534762.0   63315229.5   66720229.5   70453048.0
     59.4  355672.0  355939.0  356137.0  356304.0  356477.0 !    85900763.0   99341675.0  107265734.0  114442522.0  122314790.0
     53.4  357094.0  357248.0  357354.0  357452.0  357540.0 !   157817018.0  175367984.0  189759503.0  202877660.0  217169928.0
     47.5  357920.0  358032.0  358058.0  358116.0  358160.0 !   277432504.0  303949588.0  326322604.0  346306260.0  368547832.0
     41.6  358360.0  358420.0  358452.0  358472.0  358504.0 !   463983596.0  501458700.0  530413624.0  556976704.0  586887592.0
     35.7  358584.0  358616.0  358624.0  358640.0  358656.0 !   727853360.0  779080160.0  816379960.0  849626720.0  885181800.0
     32.7  358648.0  358656.0  358664.0  358672.0  358688.0 !   882886072.0  946923808.0  993315480.0 1034278240.0 1078293072.0
DELTA LOSSES =      60344.1  AVERAGE LOSS =      326516.0  MIN. DELTA LOSS =      298343.9  MAX. DELTA LOSS =      358688.0
                                                     *****  CYCLE 31  *****
                        (INCREASE OVER PREVIOUS BOUNDARY)                                  (NEW BOUNDARY)
INFLOWS         4.4         3.6         2.9         2.4         1.7           4.4          3.6          2.9          2.4          1.7
STORAGE (HEAD)
    168.9  302302.1  302386.9  302452.1  302515.6  302592.0 !    -1110992.4   -1103719.5   -1097798.6   -1091547.3   -1083411.6
    165.9  302619.6  302745.7  302839.2  302922.4  303013.0 !    -1078061.0   -1064084.9   -1053503.4   -1043958.1   -1033432.4
    160.0  303484.9  303683.5  303827.7  303954.6  304091.4 !     -971111.9    -943311.8    -922821.6    -904614.9    -884843.8
    154.1  304748.3  305011.6  305209.6  305366.1  305543.4 !     -782074.0    -738959.7    -707620.5    -679995.6    -650235.6
    148.2  306364.3  306583.2  306911.5  307110.9  307323.9 !     -504128.3    -444977.9    -402259.3    -364741.4    -324479.6
    142.3  308287.9  308656.1  308918.9  309147.9  309392.0 !     -131854.7     -55197.9          0.0      48400.9     100244.8
    136.3  310480.5  310691.2  311183.5  311438.0  311706.9 !      345317.4     442177.5     511835.0     572879.9     638209.5
    130.4  312903.7  313350.2  313667.6  313943.6  314230.9 !      945403.5    1066676.0    1153859.9    1230261.4    1311998.3
    124.5  315520.4  315926.4  316334.1  316627.7  316939.4 !     1695761.2    1847632.1    1956839.7    2052569.7    2154987.9
    118.6  318294.1  318793.1  319146.7  319453.9  319779.6 !     2636286.5    2827730.8    2965486.2    3086305.6    3215604.8
    112.6  321187.3  321702.4  322067.0  322383.5  322718.8 !     3824781.2    4068859.8    4244662.9    4398962.7    4564177.1
    106.7  324159.8  324683.4  325053.5  325374.7  325714.6 !     5345505.4    5661361.9    5869326.8    6089494.2    6303971.3
    100.8  327167.7  327691.6  328061.5  328382.2  328721.5 !     7323677.7    7740815.4    8042153.6    8307153.3    8591368.1
     94.9  330162.6  330677.5  331041.6  331355.1  331687.1 !     9952634.1   10517581.1   10926749.8   11286984.5   11673823.5
     89.0  333083.0  333573.6  333914.4  334216.9  334531.3 !    13541192.6   14329384.1   14901278.3   15405606.5   15947887.1
     83.0  335798.5  336254.8  336575.5  336853.8  337147.0 !    18568515.0   19697546.5   20518931.0   21244492.5   22025903.3
     77.1  338365.8  338799.0  339103.0  339366.0  339643.0 !    25809144.5   27491816.8   28719472.0   29805787.0   30977620.8
     71.2  340786.5  341170.0  341437.5  341669.0  341911.0 !    36730012.0   39372419.5   41309871.5   43029628.5   44890211.0
     65.3  342820.0  343129.0  343342.5  343525.0  343715.0 !    54570291.0   59608396.5   63339827.0   66795224.0   70528455.0
     59.4  344413.0  344609.0  344753.0  344876.0  345003.0 !    88977684.0   99419019.0  107343392.0  114520447.0  122392988.0
     53.4  345454.0  345570.0  345644.0  345716.0  345780.0 !   157896196.0  175447408.0  189839098.0  202957406.0  217249812.0
     47.5  346052.0  346144.0  346164.0  346204.0  346232.0 !   277512980.0  304030256.0  326403328.0  346387056.0  368628700.0
     41.6  346376.0  346416.0  346448.0  346456.0  346472.0 !   464064776.0  501549972.0  530494960.0  557058064.0  586968984.0
     35.7  346520.0  346568.0  346568.0  346568.0  346592.0 !   727934872.0  779161728.0  816461568.0  849708336.0  885263464.0
     32.7  346576.0  346592.0  346592.0  346608.0  346608.0 !   882967696.0  947005456.0  993397136.0 1034359920.0 1078374768.0
DELTA LOSSES =      44305.9  AVERAGE LOSS =      324455.1  MIN. DELTA LOSS =      302302.1  MAX. DELTA LOSS =      346608.0
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                                                      *****  CYCLE 33  *****
                      (INCREASE OVER PREVIOUS BOUNDARY)                                     (NEW BOUNDARY)
INFLOWS          4.4         3.6         2.9         2.4         1.7            4.4              3.6            2.9            2.4            1.7
STORAGE (HEAD)
      168.9  305220.0   305283.0   305331.4   305378.3   305434.9 !   -1121549.9     -1114140.9     -1108115.5     -1101762.6     -1093504.6
      165.9  305455.1   305548.3   305617.3   305679.7   305745.7 !   -1086110.2     -1073932.5     -1063201.5     -1053523.3     -1042852.8
      160.0  306093.8   306240.2   306346.5   306440.1   306540.9 !    -979778.8      -951661.6      -930941.5      -912532.2      -892542.9
      154.1  307025.3   307218.9   307359.1   307480.1   307610.7 !    -758724.2      -745190.9      -713550.2      -685661.2      -655618.3
      148.2  308215.4   308450.3   308618.4   308765.3   308922.2 !    -508201.8      -448542.8      -405460.1      -367624.2      -327022.7
      142.3  309632.0   309903.1   310096.6   310265.2   310444.9 !    -132860.7       -55616.8            0.0        48766.1       100999.1
      136.3  311246.2   311549.4   311763.6   311950.9   312150.2 !     347806.9       445321.7       515445.1       576895.7       642656.9
      130.4  313029.4   313357.9   313591.4   313794.5   314010.2 !     951755.2      1073739.3      1161428.8      1238270.1      1320474.3
      124.5  314954.4   315304.4   315552.8   315768.7   315997.8 !    1706282.2      1858911.4      1968657.0      2064854.6      2167769.2
      118.6  316994.0   317360.8   317620.7   317846.5   318086.0 !    2651225.7      2843464.4      2981783.0      3103091.6      3232909.5
      112.6  319120.7   319499.0   319767.0   319999.7   320246.0 !    3844327.4      4089225.9      4265609.5      4420413.3      4586161.5
      106.7  321304.8   321689.4   321961.2   322197.1   322446.8 !    5369783.8      5686573.6      5915027.4      6115705.9      6330723.9
      100.3  323513.8   323899.7   324170.3   324405.7   324654.9 !    7352742.5      7770714.0      8072640.6      8338150.7      8622905.3
       94.9  325713.0   326090.9   326357.3   326588.1   326831.9 !    9986464.1     10552330.3     10961976.1     11322711.1     11710078.4
       89.0  327856.4   328216.5   328469.6   328688.4   328919.1 !   13579667.6     14368639.5     14941082.1     15445884.6     15988665.3
       83.0  329848.8   330193.3   330419.9   330623.3   330838.3 !   18611307.5     19741064.3     20562959.5     21288963.8     22070840.5
       77.1  331732.3   332049.8   332272.6   332465.8   332668.8 !   25856019.0     27539380.3     28767519.0     29854252.0     31026525.5
       71.2  333507.0   333788.0   333985.0   334154.0   334332.0 !   36780735.0     39423750.5     41361630.0     43081754.0     44942721.5
       65.3  334996.5   335224.0   335380.5   335515.0   335655.0 !   54624244.0     59663341.0     63444611.5     66850299.5     70583833.0
       59.4  336166.0   336310.0   336417.0   336506.0   336599.0 !   89034171.0     99475816.0    107400420.0    114577670.0    122450412.0
       53.4  336930.0   337010.0   337070.0   337122.0   337170.0 !  157954338.0    175505726.0    189897540.0    203015964.0    217308472.0
       47.5  337368.0   337436.0   337452.0   337476.0   337504.0 !  277572080.0    304089500.0    326462604.0    346446388.0    368688088.0
       41.6  337612.0   337640.0   337656.0   337664.0   337680.0 !  464124392.0    501609560.0    530554684.0    557117808.0    587028760.0
       35.7  337720.0   337744.0   337752.0   337760.0   337768.0 !  727994736.0    779221632.0    816521488.0    849768280.0    885323416.0
       32.7  337752.0   337760.0   337776.0   337784.0   337792.0 !  883027624.0    947065400.0    993457104.0 1034419896.0 1078434752.0
DELTA LOSSES =      32572.0  AVERAGE LOSS =      321506.0  MIN. DELTA LOSS =     305220.0  MAX. DELTA LOSS =     337792.0
                                                      *****  CYCLE 35  *****
                      (INCREASE OVER PREVIOUS BOUNDARY)                                     (NEW BOUNDARY)
INFLOWS          4.4         3.6         2.9         2.4         1.7            4.4              3.6            2.9            2.4            1.7
STORAGE (HEAD)
      168.9  307370.0   307416.4   307452.1   307486.8   307528.4 !   -1129326.1     -1121816.5     -1115713.8     -1109285.9     -1100937.6
      165.9  307543.3   307612.0   307662.9   307708.2   307757.5 !   -1095511.0     -1081184.5     -1070343.5     -1060567.2     -1049789.8
      160.0  308014.1   308121.9   308200.2   308269.1   308343.4 !    -986160.4      -957809.9      -936920.1      -918361.5      -898211.4
      154.1  308700.1   308842.6   308945.2   309035.0   309131.2 !    -793620.2      -749778.3      -717915.6      -689832.0      -659580.9
      148.2  309576.3   309749.2   309873.0   309981.1   310096.6 !    -511200.5      -451167.0      -407816.1      -369746.1      -328894.6
      142.3  310619.0   310818.6   310960.9   311085.0   311217.3 !    -133601.1       -55925.1            0.0        49034.9       101554.3
      136.5  311806.9   312029.3   312187.6   312325.4   312472.0 !     349639.1       447635.5       518101.8       579850.9       645929.7
      130.4  313118.9   313360.5   313532.2   313681.6   313840.3 !     956429.0      1078936.5      1166997.9      1244162.8      1326710.8
      124.5  314534.7   314792.1   314974.8   315133.6   315302.1 !    1714022.8      1867209.5      1977350.8      2073892.3      2177172.0
      118.6  316034.5   316304.2   316495.3   316661.3   316837.4 !    2662215.       2855038.0      2993770.5      3115438.7      3245638.0
      112.6  317598.0   317875.1   318073.1   318244.0   318425.2 !    3858703..      4104204.9      4281015.0      4436189.0      4602329.7
      106.7  319203.3   319486.0   319685.6   319859.1   320042.5 !    5387637.7      5705039.8      5933926.4      6134980.6      6350396.0
      100.8  320826.6   321109.3   321308.8   321481.7   321664.8 !    7374113.4      7792697.2      8095056.2      8360941.2      8646092.1
       94.9  322441.9   322719.6   322915.3   323084.8   323263.9 !   10011335.0     10577302.8     10987872.6     11348975.1     11736730.3
       89.0  324016.5   324280.8   324465.5   324627.3   324796.6 !   13607949.8     14397494.5     14970339.6     15475490.6     16018638.3
       83.0  325479.8   325725.3   325398.0   326048.0   326206.0 !   18642759.8     19773049.3     20595319.0     21321647.8     22103867.0
       77.1  326862.3   327075.5   327259.5   327401.0   327550.0 !   25890467.3     27574334.5     28802828.0     29889868.0     31062464.3
       71.2  328164.5   328371.5   328515.5   328640.5   328771.0 !   36818006.5     39461470.5     41399662.0     43120056.0     44981306.0
       65.3  329260.0   329425.5   329541.0   329639.0   329741.0 !   54663889.0     59703345.5     63484865.0     66890767.0     70624522.0
       59.4  330117.0   330220.0   330298.0   330366.0   330434.0 !   89075675.0     99517546.0    107442319.0    114619714.0    122492602.0
       53.4  330674.0   330734.0   330774.0   330816.0   330850.0 !  157997052.0    175548576.0    189940476.0    203058984.0    217351566.0
       47.5  330996.0   331048.0   331064.0   331080.0   331096.0 !  277615492.0    304133016.0    326506156.0    346489976.0    368731712.0
       41.6  331176.0   331204.0   331216.0   331216.0   331224.0 !  464168184.0    501653504.0    530598556.0    557161696.0    587072672.0
       35.7  331264.0   331280.0   331280.0   331288.0   331288.0 !  728038720.0    779265640.0    816565512.0    849812312.0    885367464.0
       32.7  331288.0   331280.0   331288.0   331296.0   331296.0 !  883071656.0    947109448.0    993501160.0 1034463952.0 1078478816.0
DELTA LOSSES =      23926.0  AVERAGE LOSS =      319333.0  MIN. DELTA LOSS =     307370.0  MAX. DELTA LOSS =     331296.0
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                                                          *****  CYCLE 37  *****
                          (INCREASE OVER PREVIOUS BOUNDARY)                                      (NEW BOUNDARY)
INFLOWS          4.4         3.6         2.9         2.4         1.7            4.4            3.6            2.9            2.4            1.7
STORAGE (HEAD)
     169.9  308953.2  308987.4  309013.7  309039.2  309069.9 !   -1135049.3    -1127465.7    -1121306.1    -1114822.9    -1106408.2
     165.9  309080.8  309131.4  309168.9  309202.2  309238.5 !   -1100957.8    -1086521.9    -1075599.7    -1065751.2    -1054895.1
     160.0  309427.3  309505.7  309564.3  309615.0  309669.7 !    -990856.8     -962334.4     -941319.8     -922651.4     -902383.0
     154.1  309932.2  310037.1  310112.6  310178.7  310249.4 !    -797223.1     -753154.1     -721127.9     -692901.3     -662496.8
     148.2  310577.0  310704.2  310795.3  310874.9  310959.8 !    -513407.0     -453097.9     -409549.8     -371307.5     -330272.0
     142.3  311344.2  311491.0  311595.8  311697.1  311784.4 !    -134145.8      -56152.0           0.0       49232.6      101962.7
     136.4  312218.1  312381.7  312498.2  312599.6  312707.4 !     350987.1      449337.8      520056.4      582025.1      648337.5
     130.4  313183.2  313360.9  313487.2  313597.1  313713.8 !     959867.3     1082759.8     1171094.3     1248497.6     1331298.4
     124.5  314224.5  314413.5  314546.1  314664.9  314788.8 !    1719716.6     1873313.4     1983745.7     2080540.1     2184088.2
     118.6  315327.4  315525.7  315666.3  315788.3  315917.7 !    2670297.9     2863550.3     3002587.3     3124519.9     3254999.6
     112.6  316476.9  316681.3  316826.1  316951.9  317084.9 !    3869276.6     4115220.9     4292344.6     4447790.9     4614219.9
     106.7  317657.0  317864.6  318011.5  318139.0  318273.9 !    5430767.1     5718619.1     5947824.0     6149154.1     6364861.8
     100.8  318850.2  319057.8  319204.4  319331.6  319466.0 !    7389827.6     7808861.4     8111538.0     8377698.6     8663140.8
      94.9  320037.1  320241.3  320385.0  320509.8  320641.1 !   10029621.1    10596530.9    11006912.3    11368264.6    11756324.8
      89.0  321194.0  321389.4  321524.0  321642.9  321767.4 !   13628741.9    14418707.8    14991843.5    15497255.5    16040672.9
      83.0  322268.8  322449.8  322576.8  322686.8  322802.5 !   18665880.8    19796561.5    20619106.8    21345673.8    22128144.3
      77.1  323284.8  323455.8  323576.3  323680.0  323789.8 !   25915789.8    27600027.8    28828781.8    29916047.0    31088880.3
      71.2  324242.5  324394.5  324499.5  324590.5  324686.5 !   36845403.0    39489195.0    41427615.5    43148207.0    45009664.5
      65.3  325045.5  325158.0  325252.5  325325.0  325400.0 !   54693025.0    59732747.0    63514449.0    66920508.0    70654426.0
      59.4  325674.0  325754.0  325811.0  325860.0  325909.0 !   89106175.0    99548216.0   107473113.0   114650612.0   122523609.0
      53.4  326082.0  326130.0  326162.0  326188.0  326214.0 !  158028442.0   175580364.0   189972030.0   203090600.0   217383238.0
      47.5  326316.0  326360.0  326372.0  326384.0  326400.0 !  277647396.0   304165000.0   326538155.0   346522008.0   368763776.0
      41.6  326452.0  326472.0  326484.0  326480.0  326488.0 !  464200364.0   501685728.0   530630804.0   557193952.0   587104944.0
      35.7  326512.0  326520.0  326528.0  326528.0  326536.0 !  728071032.0   779297968.0   816597864.0   849844672.0   885399840.0
      32.7  326536.0  326520.0  326528.0  326544.0  326528.0 !  883104024.0   947141816.0   993553528.0  1034496336.0  1078511184.0
DELTA LOSSES =     17590.8  AVERAGE LOSS =    317748.6  MIN. DELTA LOSS =    308953.2  MAX. DELTA LOSS =    326544.0
                                                          *****  CYCLE 39  *****
                          (INCREASE OVER PREVIOUS BOUNDARY)                                      (NEW BOUNDARY)
INFLOWS          4.4         3.6         2.9         2.4         1.7            4.4            3.6            2.9            2.4            1.7
STORAGE (HEAD)
     169.9  310117.3  310142.6  310162.1  310180.9  310203.6 !   -1139261.0    -1131622.7    -1125421.1    -1118897.1    -1110433.4
     165.9  310211.6  310248.9  310276.5  310301.1  310327.9 !   -1104965.7    -1090449.1    -1079467.1    -1069565.4    -1058651.3
     160.0  310467.0  310525.4  310567.8  310605.2  310645.4 !    -994312.1     -965663.2     -944556.7     -925807.4     -905451.9
     154.1  310838.6  310915.7  310971.2  311019.8  311071.9 !    -799873.7     -755637.5     -723491.1     -695159.2     -664641.9
     148.2  311312.9  311406.5  311473.5  311532.0  311594.5 !    -515030.2     -454518.4     -410825.1     -372456.1     -331285.3
     142.3  311877.3  311985.3  312062.3  312129.5  312201.0 !    -134546.6      -56318.8           0.0       49378.1      102263.2
     136.4  312520.1  312640.4  312726.0  312800.6  312879.9 !     351978.7      450589.9      521494.0      583624.3      650108.6
     130.4  313229.9  313360.6  313453.5  313534.3  313620.1 !     962396.4     1085571.9     1174108.1     1251685.9     1334672.7
     124.5  313995.7  314134.9  314233.6  314319.5  314410.6 !    1723904.5     1877802.8     1988449.0     2085429.4     2189174.9
     118.6  314806.7  314952.5  315055.8  315145.5  315240.7 !    2676242.5     2869310.8     3009071.5     3131198.5     3261884.4
     112.6  315651.9  315802.3  315908.6  316001.1  316098.9 !    3877052.1     4123322.2     4300676.3     4456322.8     4622963.8
     106.7  316519.4  316672.2  316780.1  316873.8  316972.9 !    5410421.9     5728604.8     5958043.5     6159576.5     6375498.9
     100.8  317396.6  317549.2  317656.9  317750.7  317849.4 !    7401382.4     7820747.0     8123657.2     8390020.5     8675676.6
      94.9  318269.4  318419.1  318524.9  318616.5  318713.3 !   10043066.6    10610301.1    11020911.5    11382482.3    11770732.0
      89.0  319115.6  319262.5  319362.8  319449.6  319540.9 !   13644029.4    14434304.6    15037662.8    15513257.9    16056873.3
      83.0  319909.3  320042.3  320135.3  320216.3  320301.6 !   18682879.8    19813847.8    20636595.3    21363337.8    22145993.0
      77.1  320656.0  320782.0  320870.5  320946.5  321027.3 !   25934406.0    27619917.0    28847862.5    29935293.3    31108300.5
      71.2  321359.0  321471.0  321543.5  321615.5  321686.0 !   36865542.5    39509576.5    41443165.5    43168902.5    45030512.5
      65.3  321950.0  322040.5  322102.0  322155.0  322210.0 !   54714444.5    59754361.0    63536197.5    66942371.5    70676410.0
      59.4  322413.0  322471.0  322510.0  322547.0  322584.0 !   89128599.0    99570763.0   107495749.0   114673326.0   122546402.0
      53.4  322712.0  322748.0  322768.0  322788.0  322808.0 !  158051522.0   175603214.0   189995226.0   203113842.0   217406520.0
      47.5  322892.0  322912.0  322920.0  322928.0  322940.0 !  277670856.0   304188504.0   326561676.0   346545548.0   368787336.0
      41.6  322988.0  323000.0  323004.0  323008.0  323016.0 !  464224028.0   501709412.0   530654496.0   557217656.0   587128564.0
      35.7  323016.0  323040.0  323024.0  323048.0  323048.0 !  728094784.0   779321744.0   816621632.0   849868456.0   885423632.0
      32.7  323040.0  323056.0  323032.0  323040.0  323040.0 !  883127800.0   947165616.0   993557320.0  1034520128.0  1078535008.0
DELTA LOSSES =     12938.7  AVERAGE LOSS =    316586.7  MIN. DELTA LOSS =    310117.3  MAX. DELTA LOSS =    323056.0
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                                                     *****  CYCLE 41  *****
                        (INCREASE OVER PREVIOUS BOUNDARY)                                          (NEW BOUNDARY)
INFLOWS          4.4          3.6          2.9          2.4          1.7             4.4           3.6           2.9           2.4           1.7
STORAGE (HEAD)
     168.9   310973.5   310992.2   311006.6   311020.5   311037.2 !   -1142361.4    -1134682.6    -1128449.9    -1121895.8    -1113395.9
     165.9   311043.1   311070.6   311090.9   311109.1   311125.8 !   -1107915.5    -1093339.3    -1082313.2    -1072372.3    -1061415.5
     160.0   311231.3   311274.3   311305.5   311333.0   311362.6 !    -996854.3     -963112.3     -946938.2     -928129.4     -907709.8
     154.1   311504.4   311561.5   311602.4   311638.2   311676.5 !    -801823.6     -757464.5     -725229.6     -696820.2     -666220.0
     148.2   311853.8   311922.6   311971.9   312015.0   312060.9 !    -516224.3     -455563.4     -411763.3     -373301.0     -332030.6
     142.3   312269.0   312349.4   312405.1   312454.5   312507.1 !    -134841.3      -56441.6           0.0       49485.1      102484.3
     136.3   312741.8   312830.3   312893.3   312948.1   313006.5 !     352708.0      451510.9      522551.5      584800.5      651411.2
     130.4   313263.9   313360.0   313421.3   313497.7   313550.8 !     964256.5     1087540.3     1176324.4     1254030.9     1337154.5
     124.5   313827.0   313929.4   314002.0   314065.2   314132.2 !    1726984.5     1851104.5     1991908.1     2089025.3     2192915.9
     118.6   314423.5   314530.7   314606.6   314672.6   314742.6 !    2680614.4     2874414.9     3013840.2     3136110.2     3266947.6
     112.6   315044.9   315155.5   315233.7   315301.7   315373.7 !    3882770.3     4129279.8     4306803.4     4452597.1     4629394.1
     106.7   315682.9   315795.1   315874.6   315943.4   316016.3 !    5417521.9     5735949.1     5955558.6     6167240.9     6383321.2
     100.8   316327.7   316439.9   316519.3   316587.9   316660.5 !    7409879.4     7829487.3     8132569.2     8399081.0     8684894.6
      94.9   316969.1   317079.4   317157.3   317224.4   317295.5 !   10052953.1    10620426.5    11031205.4    11392921.9    11781325.5
      89.0   317594.1   317699.3   317772.9   317836.8   317904.1 !   13655269.8    14445772.4    15019290.4    15525023.9    16068785.0
      83.0   318175.0   318272.3   318341.0   318400.5   318463.3 !   18695378.5    19826557.5    20649454.0    21376325.3    22159116.3
      77.1   318723.8   318816.5   318881.0   318936.8   318996.3 !   25946007.3    27632804.8    28861890.8    29949443.3    31122578.8
      71.2   319240.5   319322.0   319379.0   319428.5   319481.0 !   36880335.5    39524561.0    41463274.0    43184118.0    45045840.0
      65.3   319674.5   319741.0   319785.5   319825.0   319867.0 !   54730192.0    59770251.0    63552186.5    66958445.0    70692572.0
      59.4   320015.0   320057.0   320089.0   320115.0   320141.0 !   89145092.0    99587335.0   107512390.0   114690024.0   122563158.0
      53.4   320234.0   320260.0   320278.0   320292.0   320306.0 !  155068484.0   175620228.0   190012278.0   203130926.0   217423634.0
      47.5   320368.0   320392.0   320392.0   320400.0   320408.0 !  277688100.0   304205796.0   326578972.0   346562664.0   368804668.0
      41.6   320440.0   320444.0   320456.0   320456.0   320464.0 !  464241424.0   501726324.0   530671928.0   557235088.0   587146104.0
      35.7   320480.0   320472.0   320472.0   320480.0   320480.0 !  728112256.0   779339208.0   816639112.0   849885944.0   885441120.0
      32.7   320480.0   320488.0   320480.0   320480.0   320464.0 !  883145288.0   947183096.0   993574808.0  1034537624.0  1078552496.0
DELTA LOSSES =      9514.5  AVERAGE LOSS =    315730.8  MIN. DELTA LOSS =    310973.5  MAX. DELTA LOSS =    320488.0
                                                     *****  CYCLE 43  *****
                        (INCREASE OVER PREVIOUS BOUNDARY)                                          (NEW BOUNDARY)
INFLOWS          4.4          3.6          2.9          2.4          1.7             4.4           3.6           2.9           2.4           1.7
STORAGE (HEAD)
     168.9   311603.8   311617.5   311628.2   311638.4   311650.7 !   -1144642.4    -1136933.8    -1130678.2    -1124102.0    -1115575.5
     165.9   311655.0   311675.3   311690.2   311703.6   311718.1 !   -1110085.7    -1095465.6    -1084407.1    -1074437.3    -1063449.0
     160.0   311793.5   311825.1   311848.1   311868.3   311890.1 !    -998724.6     -969914.1     -948690.2     -929837.6     -909370.8
     154.1   311994.7   312036.5   312066.5   312092.8   312121.0 !    -803258.1     -758308.5     -726509.5     -698042.1     -667380.8
     148.2   312251.4   312302.1   312339.3   312370.0   312403.8 !    -517102.7     -456332.0     -412453.4     -373922.5     -332578.9
     142.3   312556.9   312615.3   312657.0   312693.3   312732.0 !    -135058.2      -56531.9           0.0       49563.8      102646.8
     136.3   312904.6   312959.7   313016.1   313056.4   313099.3 !     353244.4      452148.4      523329.3      585665.7      652369.4
     130.4   313288.6   313359.3   313409.5   313453.2   313499.7 !     965624.6     1089161.5     1177954.5     1255755.7     1338979.8
     124.5   313702.8   313778.1   313831.5   313877.9   313927.2 !    1729249.8     1883532.9     1994452.2     2091667.9     2195667.3
     118.6   314141.4   314220.3   314276.1   314324.6   314376.1 !    2683829.7     2877300.9     3017347.2     3139722.4     3270671.3
     112.6   314598.4   314679.6   314737.2   314787.1   314840.1 !    3886275.5     4133561.1     4311309.5     4467211.3     4634123.0
     106.7   315067.6   315150.0   315208.4   315259.0   315312.6 !    5422743.4     5741349.3     5971085.4     6172877.3     6389073.6
     100.8   315541.5   315624.1   315682.3   315733.0   315786.4 !    7416127.9     7835914.6     8139122.7     8405744.1     8691673.4
      94.9   316013.3   316094.5   316151.5   316201.0   316253.3 !   10060223.6    10627872.5    11038774.9    11400598.8    11789115.6
      89.0   316473.0   316549.9   316604.1   316651.0   316700.5 !   13663535.8    14454205.3    15027840.8    15533675.6    16077544.0
      83.0   316900.0   316971.5   317021.8   317065.5   317111.6 !   18704569.0    19835903.5    20658909.0    21365874.8    22168765.8
      77.1   317303.3   317371.0   317419.3   317460.3   317504.0 !   25956157.8    27643016.8    28872206.0    29959848.3    31133077.8
      71.2   317683.0   317743.0   317785.5   317822.0   317860.0 !   36891238.5    39535579.5    41474383.5    43195306.5    45057110.5
      65.3   318001.5   318051.5   318085.5   318112.5   318143.0 !   54741771.0    59781935.5    63563943.5    66970264.0    70704455.0
      59.4   318252.0   318284.0   318307.0   318326.0   318346.0 !   89157204.0    99599523.0   107524627.0   114702302.0   122575479.0
      53.4   318414.0   318432.0   318444.0   318456.0   318466.0 !  158080962.0   175632744.0   190024815.0   203143492.0   217436220.0
      47.5   318512.0   318524.0   318524.0   318532.0   318532.0 !  277700780.0   304218500.0   326591688.0   346575592.0   368817404.0
      41.6   318552.0   318564.0   318568.0   318568.0   318576.0 !  464254204.0   501739628.0   530684736.0   557247904.0   587158928.0
      35.7   318576.0   318600.0   318592.0   318592.0   318592.0 !  728125088.0   779352072.0   816651976.0   849898800.0   885453984.0
      32.7   318608.0   318600.0   318600.0   318600.0   318608.0 !  883158152.0   947195960.0   993587688.0  1034550496.0  1078565376.0
DELTA LOSSES =      7004.2  AVERAGE LOSS =    315105.9  MIN. DELTA LOSS =    311603.8  MAX. DELTA LOSS =    318608.0
```

```
                                        *****  CYCLE 44  *****

                    (INCREASE OVER PREVIOUS BOUNDARY)                                        (NEW BOUNDARY)

INFLOWS          4.4          3.6          2.9          2.4          1.7              4.4            3.6            2.9            2.4            1.7
STORAGE (HEAD)
     168.9   311853.5   311865.3   311874.3   311883.1   311893.6 !    -1145545.6    -1137825.2    -1131560.5    -1124975.5    -1116438.5
     165.9   311897.3   311914.7   311927.6   311939.0   311951.4 !    -1110945.0    -1095307.6    -1085236.2    -1075254.9    -1064254.2
     160.0   312016.1   312043.2   312062.9   312080.3   312098.9 !     -999465.2     -970627.5     -949383.9     -930514.0     -910028.6
     154.1   312188.7   312224.5   312250.3   312272.8   312297.0 !     -803626.1     -759340.7     -727014.9     -698526.0     -667840.5
     148.2   312408.9   312452.3   312483.4   312510.6   312539.6 !     -517450.5     -456636.4     -412726.7     -374168.6     -332796.0
     142.3   312670.8   312720.9   312756.7   312787.8   312821.0 !     -135140.0      -56567.6          0.0       49595.0      102711.2
     136.3   312969.1   313024.9   313064.6   313099.2   313136.0 !      353456.8      452456.6      523537.3      586008.3      652748.8
     130.4   313298.3   313359.0   313402.0   313439.5   313479.3 !      966166.3     1089763.6     1178599.9     1256438.5     1339702.5
     124.5   313653.5   313719.1   313763.9   313803.7   313846.0 !     1730146.7     1884494.3     1995459.5     2092717.0     2196756.7
     118.6   314029.7   314097.3   314145.3   314186.8   314230.9 !     2685102.7     2879141.6     3018735.8     3141152.5     3272145.6
     112.5   314421.6   314491.3   314540.6   314583.4   314628.8 !     3898640.5     4135395.6     4313093.5     4469038.1     4635995.2
     106.7   314823.8   314894.6   314944.6   314985.1   315033.9 !     5424810.5     5743486.2     5973273.4     6175108.7     6391350.9
     100.8   315230.4   315301.2   315351.2   315394.5   315440.4 !     7418601.7     7838459.1     8141717.3     8408362.0     8694357.1
      94.9   315634.8   315704.4   315753.4   315795.6   315840.4 !    10063101.8    10630820.3    11041771.6    11403637.8    11792199.4
      89.0   316028.4   316094.6   316141.1   316181.5   316223.6 !    13566407.5    14457543.3    15031225.3    15537100.5    16081011.0
      83.0   316394.0   316455.3   316499.0   316536.5   316576.0 !    18708206.3    19839602.5    20662651.3    21359654.5    22172585.0
      77.1   316740.5   316798.5   316839.5   316875.0   316912.0 !    25962141.5    27647059.5    28876238.8    29963966.5    31137233.0
      71.2   317066.5   317118.0   317154.0   317185.0   317217.5 !    36895546.5    39539941.0    41478781.0    43199735.0    45061571.5
      65.3   317341.0   317381.5   317409.5   317435.0   317461.0 !    54746355.5    59786560.5    63568596.5    66974942.5    70709159.0
      59.4   317555.0   317581.0   317599.0   317616.0   317633.0 !    89162002.0    99604347.0   107529469.0   114707161.0   122580355.0
      53.4   317694.0   317710.0   317725.0   317730.0   317738.0 !   156085900.0   175637698.0   190029782.0   203148466.0   217441202.0
      47.5   317772.0   317786.0   317792.0   317796.0   317804.0 !   277705796.0   304223532.0   326596724.0   345580632.0   368822452.0
      41.5   317820.0   317828.0   317832.0   317832.0   317832.0 !   464259268.0   501744700.0   530639812.0   557252976.0   587164000.0
      35.7   317848.0   317840.0   317856.0   317856.0   317856.0 !   728130176.0   779357152.0   816657072.0   849903896.0   885459080.0
      32.7   317856.0   317848.0   317843.0   317856.0   317856.0 !   683163248.0   947261048.0   993592776.0  1034555592.0  1078570480.0

DELTA LOSSES =      6002.5  AVERAGE LOSS =    314854.7  MIN. DELTA LOSS =    311853.5  MAX. DELTA LOSS =    317856.0


                                        *** OPERATING POLICY FOR PERIOD  12***

    FIRST ROW: RELEASE AND OBJ. FUNCT.
    SECOND ROW: GENERATION(GWH) AND RELEASE TO TOSHKA


STORAGE (HEAD) !            8.5             !            6.7             !            5.5             !            4.4             !            2.9             !
---------------------------------------------------------------------------------------------------------------------------------------------------------------
     168.9     !    3.0     -1138169.0 !    3.0     -1121625.0 !    3.0     -1106225.0 !    3.0     -1090432.0 !    3.0     -1070679.2 !
    (133.0)    !  415.0            0.0 !  414.6            0.0 !  414.3            0.0 !  414.0            0.0 !  413.7            0.0 !
---------------------------------------------------------------------------------------------------------------------------------------------------------------
     165.9     !    3.0     -1099502.6 !    3.0     -1072534.1 !    3.0     -1049144.7 !    3.0     -1025850.5 !    3.0      -997387.1 !
    (142.6)    !  411.7            0.0 !  411.4            0.0 !  411.1            0.0 !  410.3            0.0 !  410.4            0.0 !
---------------------------------------------------------------------------------------------------------------------------------------------------------------
     160.0     !    3.0      -980570.6 !    3.0      -932597.6 !    3.0      -892547.9 !    3.0      -853620.2 !    3.0      -807361.7 !
    (151.7)    !  405.1            0.0 !  404.7            0.0 !  404.4            0.0 !  404.2            0.0 !  403.8            0.0 !
---------------------------------------------------------------------------------------------------------------------------------------------------------------
     154.1     !    3.0      -777352.7 !    3.0      -707207.7 !    3.0      -649358.4 !    3.0      -593751.7 !    3.0      -528610.7 !
    (130.7)    !  398.3            0.0 !  397.9            0.0 !  397.6            0.0 !  397.4            0.0 !  397.0            0.0 !
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     148.2     !    3.0      -485238.7 !    3.0      -390738.6 !    3.0      -313994.6 !    3.0      -240591.4 !    3.0      -155218.3 !
    (179.5)    !  393.6            0.0 !  390.0            0.0 !  389.5            0.0 !  389.1            0.0 !  388.5            0.0 !
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                                        -----------------------------------------------------------------------------------------------------
   136.3      !     3.0      396912.7 !    3.0       547950.1 !    3.0       670421.3 !    3.0       787299.0 !    3.0       922507.1 !
  (177.8)     !   370.0           0.0 !  369.4            0.0 !  369.0            0.0 !  368.7            0.0 !  368.2            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   130.4      !     3.0     1015272.2 !    3.0      1202901.7 !    3.0      1355553.3 !    3.0      1501321.1 !    3.0      1669856.5 !
  (176.7)     !   361.0           0.0 !  360.5            0.0 !  360.1            0.0 !  359.7            0.0 !  359.2            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   124.5      !     3.0     1785243.3 !    3.0      2019599.0 !    3.0      2209454.2 !    3.0      2391930.1 !    3.0      2602969.8 !
  (175.6)     !   352.7           0.0 !  352.4            0.0 !  352.1            0.0 !  351.8            0.0 !  351.4            0.0 !
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   118.6      !     3.0     2746726.2 !    3.0      3038967.0 !    3.0      3279663.1 !    3.0      3510190.5 !    3.0      3777062.8 !
  (174.5)     !   346.1           0.0 !  345.7            0.0 !  345.4            0.0 !  345.1            0.0 !  344.7            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   112.6      !     3.0     3957488.3 !    3.0      4327634.7 !    3.0      4635161.9 !    3.0      4930328.3 !    3.0      5272560.6 !
  (173.3)     !   338.2           0.0 !  337.7            0.0 !  337.3            0.0 !  336.9            0.0 !  336.4            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   106.7      !     3.0     5501641.6 !    3.0      5977645.1 !    3.0      6377335.5 !    3.0      6761974.1 !    3.0      7208931.6 !
  (172.1)     !   329.2           0.0 !  328.7            0.0 !  328.4            0.0 !  328.1            0.0 !  327.7            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   100.8      !     3.0     7504431.6 !    3.0      8128541.0 !    3.0      8659673.1 !    3.0      9172504.6 !    3.0      9770236.6 !
  (170.9)     !   321.4           0.0 !  321.0            0.0 !  320.6            0.0 !  320.3            0.0 !  319.8            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
    94.9      !     3.0    10153715.0 !    3.0     10927709.8 !    3.0     11723024.8 !    3.0     12425978.8 !    3.0     13248207.1 !
  (169.4)     !   312.1           0.0 !  311.4            0.0 !  310.9            0.0 !  310.4            0.0 !  309.8            0.0 !
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    89.0      !     3.0    13772128.9 !    3.0     14970007.9 !    3.0     15947968.4 !    3.0     16938138.0 !    2.9     18098499.0 !
  (168.0)     !   300.4           0.0 !  299.7            0.0 !  299.1            0.0 !  298.6            0.0 !  280.3            0.0 !
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    83.0      !     3.0    18919102.3 !    2.9     20428916.3 !    2.9     21895163.3 !    2.9     23329564.5 !    2.9     25021891.8 !
  (165.4)     !   287.2           0.0 !  269.3            0.0 !  268.7            0.0 !  268.2            0.0 !  267.5            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
    77.1      !     2.9    26028295.5 !    2.9     28390930.0 !    2.9     30610413.0 !    2.9     32796781.8 !    2.9     35394019.5 !
  (164.3)     !   255.8           0.0 !  254.9            0.0 !  254.3            0.0 !  253.6            0.0 !  252.8            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
    71.2      !     2.9    36870452.0 !    2.9     40553513.5 !    2.8     44212606.5 !    2.8     47937609.0 !    2.8     52496718.0 !
  (163.1)     !   241.3           0.0 !  240.5            0.0 !  223.7            0.0 !  223.2            0.0 !  222.5            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
    65.3      !     2.8    54655952.0 !    2.8     61225997.5 !    2.7     68099706.0 !    2.6     75285665.0 !    2.6     84348931.0 !
  (161.2)     !   212.6           0.0 !  211.9            0.0 !  195.8            0.0 !  179.7            0.0 !  179.1            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
    59.4      !     2.7    83398531.0 !    2.6    101219636.0 !    2.4    113369397.0 !    2.3    126741070.0 !    2.2    143680294.0 !
  (159.2)     !   184.2           0.0 !  168.1            0.0 !  137.1            0.0 !  121.4            0.0 !  105.6            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
    53.4      !     2.4   153052040.0 !    2.3    175169740.0 !    2.2    195437158.0 !    1.9    216549874.0 !    1.8    243596500.0 !
  (157.3)     !   121.7           0.0 !  106.0            0.0 !   90.5            0.0 !   46.2            0.0 !   30.7            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
    47.5      !     2.0   262130360.0 !    1.9    296843276.0 !    1.8    327340480.0 !    1.7    358024260.0 !    1.3    394903544.0 !
  (154.6)     !    44.3           0.0 !   29.2            0.0 !   14.3            0.0 !    0.1            0.0 !    0.0            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
    41.6      !     1.4   427737372.0 !    1.3    477701560.0 !    1.3    519622276.0 !    1.2    560503696.0 !    1.2    608533192.0 !
  (151.3)     !     0.0           0.0 !    0.0            0.0 !    0.0            0.0 !    0.0            0.0 !    0.0            0.0 !
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    35.7      !     0.7   658172840.0 !    0.7    725960296.0 !    0.6    781038440.0 !    0.5    834032128.0 !    0.5    895209128.0 !
  (143.7)     !     0.0           0.0 !    0.0            0.0 !    0.0            0.0 !    0.0            0.0 !    0.0            0.0 !
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    32.7      !     0.6   791916296.0 !    0.3    866742240.0 !    0.1    930888784.0 !    0.0    992965984.0 !    0.0   1066418976.0 !
  (147.0)     !     0.0           0.0 !    0.0            0.0 !    0.0            0.0 !    0.0            0.0 !    0.0            0.0 !
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                              *** OPERATING POLICY FOR PERIOD    9***

   FIRST ROW: RELEASE AND OBJ. FUNCT.
   SECOND ROW: GENERATION(GWH) AND RELEASE TO TOSHKA

STORAGE (HEAD) !          25.9          !          22.0          !          19.2          !          16.9          !          13.7          !
-------------------------------------------------------------------------------------------------------------------------------------------
   168.9       !   10.0     1750478.3 !   10.0      873039.4 !   10.0      313350.1 !   10.0     -101797.7 !   10.0     -496277.4 !
  (183.0)      ! 1261.9           0.0 ! 1261.6           0.0 ! 1261.8           0.0 ! 1261.8           0.0 ! 1261.8           0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   165.9       !   10.0      927192.1 !   10.0      198082.1 !   10.0     -242908.3 !   10.0     -550642.0 !   10.0     -821165.4 !
  (182.6)      ! 1261.8           0.0 ! 1261.6           0.0 ! 1261.7           0.0 ! 1261.7           0.0 ! 1261.7           0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   160.0       !    8.4     -195881.5 !    8.3     -632368.6 !    8.0     -841407.1 !    7.5     -951846.3 !    7.5    -1015764.9 !
  (181.7)      ! 1261.6           0.0 ! 1261.4           0.0 ! 1261.5           0.0 ! 1261.5          -0.0 ! 1261.5           0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   154.1       !    9.7     -735821.1 !    9.7     -956351.7 !    8.2     -993531.5 !    7.0     -991109.8 !    4.3     -983463.2 !
  (180.7)      ! 1261.4           0.0 ! 1261.1           0.0 ! 1261.2           0.0 ! 1206.7           0.0 !  667.9           0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   148.2       !    8.9     -998731.7 !    7.6    -1037568.9 !    4.3    -1013116.6 !    4.3     -955423.6 !    4.3     -841380.9 !
  (179.9)      ! 1261.1           0.0 ! 1260.9           0.0 !  660.3           0.0 !  658.6           0.0 !  657.2           0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   142.3       !    7.6    -1072439.7 !    4.3    -1029994.2 !    4.3     -930699.8 !    4.3     -796777.6 !    4.3     -606231.5 !
  (178.8)      ! 1260.8           0.0 !  652.8           0.0 !  651.3           0.0 !  649.7           0.0 !  647.8           0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   136.3       !    4.3    -1036232.6 !    4.3     -909492.9 !    4.3     -739169.3 !    4.3     -544220.0 !    4.3     -281857.8 !
  (177.3)      !  644.3           0.0 !  641.9           0.0 !  640.9           0.0 !  638.3           0.0 !  636.3           0.0 !
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   130.4       !    4.3     -905349.3 !    4.3     -702316.2 !    4.3     -464038.5 !    4.3     -203141.9 !    4.3      138670.3 !
  (176.7)      !  632.6           0.0 !  630.1           0.0 !  628.4           0.0 !  626.7           0.0 !  624.9           0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   124.5       !    4.3     -694851.2 !    4.3     -411715.4 !    4.3      -98271.5 !    4.3      236705.0 !    4.3      668957.9 !
  (175.6)      !  621.6           0.0 !  619.3           0.0 !  617.6           0.0 !  615.9           0.0 !  614.1           0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   118.6       !    4.3     -400591.4 !    4.3      -28517.5 !    4.3      369975.9 !    4.3      790549.8 !    4.3     1329532.3 !
  (174.5)      !  610.6           0.0 !  608.2           0.0 !  606.5           0.0 !  604.9           0.0 !  603.1           0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   112.6       !    4.3      -13361.6 !    4.3      455912.2 !    4.3      957232.7 !    4.3     1480747.5 !    4.3     2150563.6 !
  (173.3)      !  599.6           0.0 !  597.3           0.0 !  595.5           0.0 !  593.9           0.0 !  592.0           0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   106.7       !    4.3      477418.0 !    4.3     1068168.0 !    4.3     1688271.8 !    4.3     2340169.4 !    4.3     3175839.9 !
  (172.1)      !  588.4           0.0 !  586.0           0.0 !  584.2           0.0 !  582.5           0.0 !  580.6           0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
   100.8       !    4.3     1091345.9 !    4.3     1826171.9 !    4.3     2600065.5 !    4.3     3417199.7 !    4.3     4469140.9 !
  (170.9)      !  576.9           0.0 !  574.4           0.0 !  572.6           0.0 !  570.9           0.0 !  569.0           0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
    94.9       !    4.3     1854330.5 !    4.3     2771784.4 !    4.3     3745512.2 !    4.3     4781271.8 !    4.3     6123266.7 !
  (169.4)      !  565.7           0.0 !  563.5           0.0 !  561.9           0.0 !  560.4           0.0 !  558.7           0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
    89.0       !    4.3     2806113.9 !    4.3     3960198.3 !    4.3     5201505.9 !    4.3     6535290.4 !    4.3     8278019.5 !
  (168.0)      !  555.2           0.0 !  552.6           0.0 !  550.4           0.0 !  548.2           0.0 !  545.6           0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
    83.0       !    4.3     4031132.4 !    4.3     5472925.9 !    4.3     7082974.7 !    4.3     8834646.6 !    4.3    11146332.4 !
  (166.4)      !  549.5           0.0 !  537.3           0.0 !  534.8           0.0 !  532.3           0.0 !  529.3           0.0 !
-------------------------------------------------------------------------------------------------------------------------------------------
    77.1       !    4.3     5521395.6 !    4.3     7431433.0 !    4.3     9563684.3 !    4.3    11915536.8 !    4.3    15051584.3 !
```

```
   (164.8)     !  522.5           0.0 !  518.4           0.0 !  515.2           0.0 !  512.2           0.0 !  508.7           0.0 !
------------------------------------------------------------------------------------------------------------------------------
    71.2       !    4.3     7488668.1 !    4.3    10020499.1 !    4.3    12912179.0 !    4.3    16148826.0 !    4.2    20497452.5 !
   (163.1)     !  501.3           0.0 !  498.1           0.0 !  495.1           0.0 !  492.4           0.0 !  472.5           0.0 !
------------------------------------------------------------------------------------------------------------------------------
    65.3       !    4.3    10087605.3 !    4.3    13522748.9 !    4.3    17552116.5 !    4.2    22137976.8 !    4.2    28412424.0 !
   (161.2)     !  482.2           0.0 !  478.0           0.0 !  474.6           0.0 !  455.2           0.0 !  451.6           0.0 !
------------------------------------------------------------------------------------------------------------------------------
    59.4       !    4.3    13599844.9 !    4.3    18394171.8 !    4.2    24209989.5 !    4.2    31077963.3 !    4.2    40759506.0 !
   (159.2)     !  459.5           0.0 !  455.4           0.0 !  436.7           0.0 !  434.5           0.0 !  431.8           0.0 !
------------------------------------------------------------------------------------------------------------------------------
    53.4       !    4.3    18461349.8 !    4.2    25400753.0 !    4.2    34338680.5 !    4.1    45314972.0 !    4.1    61047760.0 !
   (157.0)     !  441.0           0.0 !  421.8           0.0 !  416.2           0.0 !  399.4           0.0 !  395.1           0.0 !
------------------------------------------------------------------------------------------------------------------------------
    47.5       !    4.2    25415226.8 !    4.2    36110688.5 !    4.1    50675453.5 !    4.0    68847200.0 !    3.9    94971040.0 !
   (154.6)     !  399.5           0.0 !  394.2           0.0 !  375.6           0.0 !  357.4           0.0 !  338.7           0.0 !
------------------------------------------------------------------------------------------------------------------------------
    41.6       !    4.2    36004046.0 !    4.1    53446274.0 !    4.0    77748595.0 !    3.9   107655579.0 !    3.7   149760324.0 !
   (151.9)     !  370.5           0.0 !  350.9           0.0 !  332.1           0.0 !  313.8           0.0 !  281.0           0.0 !
------------------------------------------------------------------------------------------------------------------------------
    35.7       !    4.1    53172244.5 !    4.0    82275905.0 !    3.5   121830357.0 !    3.6   168744246.0 !    3.3   232551254.0 !
   (148.7)     !  323.7           0.0 !  304.9           0.0 !  273.8           0.0 !  243.3           0.0 !  199.2           0.0 !
------------------------------------------------------------------------------------------------------------------------------
    32.7       !    4.1    66203269.5 !    3.9   103211081.0 !    3.7   152115164.0 !    3.5   209585194.0 !    3.3   288759296.0 !
   (147.0)     !  307.9           0.0 !  275.8           0.0 !  245.2           0.0 !  215.3           0.0 !  185.1           0.0 !


                                       *** OPERATING POLICY FOR PERIOD   5***

   FIRST ROW: RELEASE AND OBJ. FUNCT.
   SECOND ROW: GENERATION(GWH) AND RELEASE TO TOSHKA


STORAGE (HEAD) !         3.3          !         2.1          !         1.5          !         1.1          !         0.7          !
------------------------------------------------------------------------------------------------------------------------------
   168.9       !   10.0     -428139.0 !   10.0     -481760.8 !    9.8     -517936.6 !    9.6     -545945.4 !    9.5     -578795.7 !
   (133.0)     ! 1261.5           0.0 ! 1261.5           0.0 ! 1261.5           0.0 ! 1261.5           0.0 ! 1261.5           0.0 !
------------------------------------------------------------------------------------------------------------------------------
   165.7       !   10.0     -573509.5 !    9.8     -615291.4 !    9.7     -643530.3 !    9.6     -665266.9 !    9.5     -690688.9 !
   (132.6)     ! 1261.5           0.0 ! 1261.3           0.0 ! 1261.3           0.0 ! 1261.3           0.0 ! 1261.3           0.0 !
------------------------------------------------------------------------------------------------------------------------------
   160.0       !    8.6     -775639.6 !    8.5     -794467.2 !    8.4     -806330.6 !    8.4     -816151.8 !    8.3     -826894.3 !
   (131.7)     ! 1261.1           0.0 ! 1261.0           0.0 ! 1261.0           0.0 ! 1261.0           0.0 ! 1261.0           0.0 !
------------------------------------------------------------------------------------------------------------------------------
   154.1       !    7.6     -861359.2 !    7.6     -862875.5 !    6.5     -864281.1 !    6.5     -865522.9 !    6.5     -866208.6 !
   (130.7)     ! 1260.8           0.0 ! 1260.7           0.0 ! 1092.0           0.0 ! 1091.8           0.0 ! 1091.6           0.0 !
------------------------------------------------------------------------------------------------------------------------------
   148.2       !    6.5     -860392.9 !    6.5     -849937.5 !    6.5     -840734.4 !    6.5     -832490.4 !    6.5     -821674.2 !
   (179.8)     ! 1080.0           0.0 ! 1079.6           0.0 ! 1079.3           0.0 ! 1079.1           0.0 ! 1078.8           0.0 !
------------------------------------------------------------------------------------------------------------------------------
   142.3       !    6.5     -769555.3 !    6.5     -742189.2 !    6.5     -720635.8 !    6.5     -702475.2 !    6.5     -679646.6 !
   (178.8)     ! 1066.4           0.0 ! 1065.9           0.0 ! 1065.6           0.0 ! 1065.4           0.0 ! 1065.1           0.0 !
------------------------------------------------------------------------------------------------------------------------------
   136.4       !    6.5     -584660.6 !    6.5     -539908.1 !    6.5     -506119.3 !    6.5     -478150.7 !    6.5     -443445.7 !
   (177.8)     ! 1052.6           0.0 ! 1052.1           0.0 ! 1051.8           0.0 ! 1051.6           0.0 ! 1051.3           0.0 !
------------------------------------------------------------------------------------------------------------------------------
   130.4       !    6.5     -305376.4 !    6.5     -243450.2 !    6.5     -197324.7 !    6.5     -159429.2 !    6.5     -112657.5 !
   (176.7)     ! 1038.4           0.0 ! 1038.0           0.0 ! 1037.7           0.0 ! 1037.4           0.0 ! 1037.1           0.0 !
```

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  124.5      !    6.5       69389.0 !    6.5     150241.7 !    6.5     209743.9 !    6.5     258473.4 !    6.5     318181.4 !
 (175.6)     ! 1020.8           0.0 ! 1020.2          0.0 ! 1019.8          0.0 ! 1019.5          0.0 ! 1019.1          0.0 !
--------------------------------------------------------------------------------------------------------------------------------
  118.6      !    6.5      551273.2 !    6.5     652668.1 !    6.5     727553.7 !    6.5     788799.6 !    6.5     864156.2 !
 (174.5)     ! 1002.2           0.0 ! 1001.7          0.0 ! 1001.3          0.0 ! 1001.0          0.0 ! 1000.7          0.0 !
--------------------------------------------------------------------------------------------------------------------------------
  112.6      !    6.5     1156606.5 !    6.5    1263106.1 !    6.5    1376451.7 !    6.5    1452770.4 !    6.5    1546664.3 !
 (173.3)     !  986.1           0.0 !  985.5          0.0 !  985.2          0.0 !  984.9          0.0 !  984.6          0.0 !
--------------------------------------------------------------------------------------------------------------------------------
  106.7      !    6.5     1913105.4 !    6.5    2070647.8 !    6.5    2186916.7 !    6.5    2282010.0 !    6.5    2399054.8 !
 (172.1)     !  970.5           0.0 !  970.0          0.0 !  969.7          0.0 !  969.5          0.0 !  969.2          0.0 !
--------------------------------------------------------------------------------------------------------------------------------
  100.8      !    6.5     2860491.5 !    6.5    3057637.5 !    6.5    3203271.4 !    6.5    3322485.1 !    6.5    3469349.5 !
 (170.8)     !  955.8           0.0 !  955.2          0.0 !  954.9          0.0 !  954.6          0.0 !  954.2          0.0 !
--------------------------------------------------------------------------------------------------------------------------------
   94.7      !    6.5     4056655.1 !    6.5    4305834.6 !    6.5    4490197.4 !    6.5    4541312.4 !    6.5    4827716.1 !
 (169.4)     !  934.1           0.0 !  933.4          0.0 !  932.9          0.0 !  932.5          0.0 !  932.1          0.0 !
--------------------------------------------------------------------------------------------------------------------------------
   89.0      !    6.5     5580583.5 !    6.5    5906024.0 !    6.5    6142361.6 !    6.5    6337315.4 !    6.5    6577566.7 !
 (168.0)     !  905.5           0.0 !  905.4          0.0 !  904.7          0.0 !  904.1          0.0 !  903.5          0.0 !
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   83.0      !    6.5     7576028.6 !    6.5    7992730.1 !    6.5    8302463.5 !    6.5    8557282.1 !    6.5    8872725.1 !
 (166.4)     !  874.5           0.0 !  873.6          0.0 !  873.1          0.0 !  872.6          0.0 !  872.1          0.0 !
--------------------------------------------------------------------------------------------------------------------------------
   77.1      !    6.5    10215705.5 !    6.5   10770932.0 !    6.5   11184794.3 !    6.5   11526543.1 !    6.5   11950408.5 !
 (164.9)     !  848.1           0.0 !  847.0          0.0 !  846.3          0.0 !  845.8          0.0 !  845.1          0.0 !
--------------------------------------------------------------------------------------------------------------------------------
   71.2      !    6.5    13516109.9 !    6.5   14579408.5 !    6.5   15149660.1 !    6.5   15621689.1 !    6.5   16209412.8 !
 (163.1)     !  811.3           0.0 !  810.0          0.0 !  809.2          0.0 !  808.5          0.0 !  807.8          0.0 !
--------------------------------------------------------------------------------------------------------------------------------
   65.3      !    6.5    18927962.0 !    6.4   20004872.0 !    6.4   20809843.5 !    6.4   21478002.5 !    6.4   22312830.8 !
 (161.2)     !  733.7           0.0 !  767.5          0.0 !  766.9          0.0 !  766.4          0.0 !  765.9          0.0 !
--------------------------------------------------------------------------------------------------------------------------------
   59.4      !    6.4    25446953.3 !    6.4   28042598.3 !    6.4   29245775.0 !    6.4   30247385.5 !    6.4   31504316.5 !
 (159.2)     !  727.7           0.0 !  726.2          0.0 !  725.2          0.0 !  724.4          0.0 !  723.5          0.0 !
--------------------------------------------------------------------------------------------------------------------------------
   53.4      !    6.4    36024026.5 !    6.4   40490133.0 !    6.4   42351437.0 !    6.3   43896547.0 !    6.3   45811984.5 !
 (157.0)     !  690.1           0.0 !  688.7          0.0 !  687.7          0.0 !  672.8          0.0 !  671.9          0.0 !
--------------------------------------------------------------------------------------------------------------------------------
   47.5      !    6.3    50017733.5 !    6.3   59377420.0 !    6.3   62816732.5 !    6.3   65297971.5 !    6.2   68372109.0 !
 (154.5)     !  629.1           0.0 !  627.7          0.0 !  626.7          0.0 !  625.9          0.0 !  611.7          0.0 !
--------------------------------------------------------------------------------------------------------------------------------
   41.6      !    6.1    89713124.0 !    6.0   97397820.0 !    5.9  103098378.0 !    5.9  107698134.0 !    5.9  113457225.0 !
 (151.7)     !  555.2           0.0 !  540.8          0.0 !  527.0          0.0 !  526.1          0.0 !  525.1          0.0 !
--------------------------------------------------------------------------------------------------------------------------------
   35.7      !    4.9   254888044.0 !    4.9  285059120.0 !    4.9  307528016.0 !    4.9  326003740.0 !    4.9  348837496.0 !
 (148.7)     !  291.4           0.0 !  257.1          0.0 !  230.7          0.0 !  209.0          0.0 !  182.7          0.0 !
--------------------------------------------------------------------------------------------------------------------------------
   32.7      !    2.7   460699100.0 !    2.7  511906452.0 !    2.7  548802664.0 !    2.7  578433176.0 !    2.7  614275512.0 !
 (147.0)     !   13.4           0.0 !    7.6          0.0 !    3.4          0.0 !    1.6          0.0 !    0.5          0.0 !

                                         *** OPERATING POLICY FOR PERIOD   5***

   FIRST ROW: RELEASE AND OBJ. FUNCT.
   SECOND ROW: GENERATION(GWH) AND RELEASE TO TOSHKA

STORAGE (HEAD) !          2.9         !          2.2         !          1.7         !          1.3         !          0.7         !
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     168.9      !      9.1     -739244.0 !      8.9     -765531.9 !      8.7     -782622.9 !      8.6     -794806.0 !      8.4     -808076.4 !
   (183.0)      ! 1261.5             0.0 ! 1261.4             0.0 ! 1261.5             0.0 ! 1261.4             0.0 ! 1261.6             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
     165.9      !      8.2     -800159.7 !      8.1     -813951.0 !      8.1     -822947.5 !      8.0     -829372.6 !      8.0     -836409.9 !
   (182.6)      ! 1261.4             0.0 ! 1261.3             0.0 ! 1261.4             0.0 ! 1261.3             0.0 ! 1261.5             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
     160.0      !      7.7     -859042.9 !      6.8     -860099.3 !      6.2     -860446.1 !      6.1     -861341.9 !      5.7     -862982.1 !
   (181.7)      ! 1261.1             0.0 ! 1162.8             0.0 ! 1043.0             0.0 ! 1022.7             0.0 !  942.8             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
     154.1      !      5.3     -853736.6 !      5.3     -847522.4 !      5.3     -841900.0 !      5.3     -836541.9 !      5.3     -830064.9 !
   (180.7)      !  854.9             0.0 !  854.4             0.0 !  854.2             0.0 !  853.9             0.0 !  853.8             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
     148.2      !      5.3     -777780.7 !      5.3     -754217.1 !      5.3     -735944.4 !      5.3     -720494.9 !      5.3     -702559.6 !
   (179.8)      !  843.9             0.0 !  843.2             0.0 !  842.9             0.0 !  842.6             0.0 !  842.5             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
     142.3      !      5.3     -609158.9 !      5.3     -557716.8 !      5.3     -536671.1 !      5.3     -511166.2 !      5.3     -481861.8 !
   (178.9)      !  831.4             0.0 !  830.7             0.0 !  830.4             0.0 !  830.0             0.0 !  829.9             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
     136.3      !      5.3     -347451.7 !      5.3     -288142.5 !      5.3     -244278.8 !      5.3     -208680.4 !      5.3     -167914.8 !
   (177.8)      !  819.0             0.0 !  818.4             0.0 !  818.1             0.0 !  817.7             0.0 !  817.6             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
     130.4      !      5.3        9173.8 !      5.3       87217.7 !      5.3      144640.2 !      5.3      193967.2 !      5.3      243999.9 !
   (176.7)      !  806.6             0.0 !  806.0             0.0 !  805.7             0.0 !  805.3             0.0 !  805.2             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
     124.5      !      5.3      459114.7 !      5.3      568202.3 !      5.3      640977.2 !      5.3      699498.6 !      5.3      766541.8 !
   (175.6)      !  792.9             0.0 !  792.2             0.0 !  791.8             0.0 !  791.4             0.0 !  791.3             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
     118.6      !      5.3     1048474.5 !      5.3     1172409.3 !      5.3     1263405.5 !      5.3     1336442.3 !      5.3     1420215.3 !
   (174.5)      !  778.3             0.0 !  777.5             0.0 !  777.2             0.0 !  776.8             0.0 !  776.6             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
     112.6      !      5.3     1772222.5 !      5.3     1926661.4 !      5.3     2040113.2 !      5.3     2131382.0 !      5.3     2235567.1 !
   (173.3)      !  764.6             0.0 !  763.9             0.0 !  763.6             0.0 !  763.2             0.0 !  763.0             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
     106.7      !      5.3     2676993.2 !      5.3     2870133.0 !      5.3     3012164.4 !      5.3     3126310.5 !      5.3     3256960.7 !
   (172.1)      !  751.2             0.0 !  750.6             0.0 !  750.3             0.0 !  750.0             0.0 !  749.8             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
     100.8      !      5.3     3816054.5 !      5.3     4059804.6 !      5.3     4239313.8 !      5.3     4383230.1 !      5.3     4549007.9 !
   (170.8)      !  738.9             0.0 !  738.3             0.0 !  738.0             0.0 !  737.6             0.0 !  737.4             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
      94.9      !      5.3     5267321.1 !      5.3     5579132.4 !      5.3     5909163.9 !      5.3     5993702.4 !      5.3     6206575.0 !
   (169.4)      !  721.9             0.0 !  721.0             0.0 !  720.5             0.0 !  720.0             0.0 !  719.7             0.0 !
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      89.0      !      5.3     7145620.1 !      5.3     7551307.3 !      5.3     7851168.5 !      5.3     8091987.3 !      5.3     8370149.9 !
   (168.0)      !  700.5             0.0 !  699.5             0.0 !  698.6             0.0 '  697.9             0.0 !  697.4             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
      83.0      !      5.3     9623992.3 !      5.3    10162858.0 !      5.3    10562066.6 !      5.3    10883163.9 !      5.3    11254569.1 !
   (166.4)      !  674.2             0.0 !  673.1             0.0 !  672.5             0.0 !  671.9             0.0 !  671.5             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
      77.1      !      5.3    12981307.6 !      5.3    13717256.9 !      5.3    14264260.8 !      5.3    14705192.6 !      5.3    15216008.8 !
   (164.6)      !  651.3             0.0 !  650.6             0.0 !  650.0             0.0 !  649.4             0.0 !  649.0             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
      71.2      !      5.3    17689994.0 !      5.3    18728932.0 !      5.3    19501813.5 !      5.3    20125690.3 !      5.2    20849017.3 !
   (163.1)      !  623.7             0.0 !  622.2             0.0 !  621.4             0.0 !  620.6             0.0 !  604.2             0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------
      65.3      !      5.2    24523902.5 !      5.2    26050160.0 !      5.2    27190004.0 !      5.2    28113048.5 !      5.2    29185233.3 !
   (161.2)      !  584.5             0.0 !  583.5             0.0 !  582.9             0.0 !  582.3             0.0 !  581.9             0.0 !
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      59.4      !      5.2    34893847.0 !      5.2    37236930.5 !      5.2    38987989.5 !      5.2    40406309.0 !      5.2    42051709.0 !
   (159.2)      !  554.1             0.0 !  552.4             0.0 !  551.4             0.0 !  550.5             0.0 !  549.7             0.0 !
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    53.4       !    5.1    50922310.0 !     5.1     54568537.0 !     5.1     57303909.5 !     5.1     59526739.5 !     5.1     62110288.5 !
  (157.0)      !  507.1           0.0 !   505.5            0.0 !   504.6            0.0 !   503.8            0.0 !   503.1            0.0 !
-----------------------------------------------------------------------------------------------------------------------------------------
    47.5       !    5.0    79346466.0 !     5.0     86139450.0 !     5.0     91243695.0 !     4.9     95393597.0 !     4.9    100191544.0 !
  (154.6)      !  454.9           0.0 !   453.2            0.0 !   452.2            0.0 !   437.7            0.0 !   437.0            0.0 !
-----------------------------------------------------------------------------------------------------------------------------------------
    41.6       !    3.8   175971476.0 !     3.7    201591168.0 !     3.6    220605686.0 !     3.5    235979908.0 !     3.4    253684932.0 !
  (151.9)      !  261.6           0.0 !   247.0            0.0 !   233.1            0.0 !   219.4            0.0 !   205.7            0.0 !
-----------------------------------------------------------------------------------------------------------------------------------------
    35.7       !    2.2   400118340.0 !     1.8    448465868.0 !     1.8    467699684.0 !     1.4    519344788.0 !     1.2    554168288.0 !
  (148.7)      !   32.6           0.0 !     0.0            0.0 !     0.0            0.0 !     0.0            0.0 !     0.0            0.0 !
-----------------------------------------------------------------------------------------------------------------------------------------
    32.7       !    1.6   605674896.0 !     1.5    673424984.0 !     1.5    722959704.0 !     1.5    762608224.0 !     1.5    807971936.0 !
  (147.0)      !    0.0           0.0 !     0.0            0.0 !     0.0            0.0 !     0.0            0.0 !     0.0            0.0 !


                                         *** OPERATING POLICY FOR PERIOD   2***

    FIRST ROW: RELEASE AND OBJ. FUNCT.
    SECOND ROW: GENERATION(GWH) AND RELEASE TO TOSHKA

STORAGE (HEAD) !            3.5          !           2.5          !           1.9          !           1.5          !           1.0          !
-----------------------------------------------------------------------------------------------------------------------------------------
   163.9       !    4.0     -847459.9 !     4.0      -844894.6 !     4.0      -842781.5 !     4.0      -841159.1 !     4.0      -838944.1 !
  (183.0)      !  614.5           0.0 !   614.3            0.0 !   614.1            0.0 !   614.1            0.0 !   613.9            0.0 !
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   165.9       !    4.0     -825332.5 !     4.0      -821485.6 !     4.0      -818603.2 !     4.0      -816418.4 !     4.0      -813569.0 !
  (182.6)      !  611.3           0.0 !   611.1            0.0 !   610.9            0.0 !   610.8            0.0 !   610.7            0.0 !
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   160.0       !    4.0     -737521.5 !     4.0      -727468.8 !     4.0      -720115.0 !     4.0      -714354.1 !     4.0      -707225.2 !
  (181.7)      !  604.0           0.0 !   603.8            0.0 !   603.6            0.0 !   603.5            0.0 !   603.3            0.0 !
-----------------------------------------------------------------------------------------------------------------------------------------
   154.1       !    4.0     -567127.7 !     4.0      -549472.1 !     4.0      -536855.9 !     4.0      -526902.5 !     4.0      -514802.2 !
  (180.7)      !  596.1           0.0 !   595.9            0.0 !   595.7            0.0 !   595.6            0.0 !   595.4            0.0 !
-----------------------------------------------------------------------------------------------------------------------------------------
   148.2       !    4.0     -305925.7 !     4.0      -280528.3 !     4.0      -262495.2 !     4.0      -248214.0 !     4.0      -231003.3 !
  (179.8)      !  586.6           0.0 !   586.3            0.0 !   586.0            0.0 !   585.9            0.0 !   585.6            0.0 !
-----------------------------------------------------------------------------------------------------------------------------------------
   142.3       !    4.0       50026.7 !     4.0        83597.9 !     4.0       107350.5 !     4.0       126220.9 !     4.0       148838.9 !
  (178.8)      !  575.2           0.0 !   574.9            0.0 !   574.6            0.0 !   574.5            0.0 !   574.2            0.0 !
-----------------------------------------------------------------------------------------------------------------------------------------
   136.3       !    4.0      509321.0 !     4.0       552039.6 !     4.0       582197.9 !     4.0       606224.9 !     4.0       634912.3 !
  (177.8)      !  564.3           0.0 !   564.0            0.0 !   563.7            0.0 !   563.6            0.0 !   563.4            0.0 !
-----------------------------------------------------------------------------------------------------------------------------------------
   130.4       !    4.0     1087733.2 !     4.0      1141234.5 !     4.0      1178951.7 !     4.0      1209075.7 !     4.0      1244937.3 !
  (176.7)      !  553.8           0.0 !   553.5            0.0 !   553.2            0.0 !   553.1            0.0 !   552.9            0.0 !
-----------------------------------------------------------------------------------------------------------------------------------------
   124.5       !    4.0     1809890.1 !     4.0      1876642.6 !     4.0      1923652.5 !     4.0      1961279.2 !     4.0      2005972.8 !
  (175.5)      !  543.6           0.0 !   543.3            0.0 !   543.1            0.0 !   543.0            0.0 !   542.7            0.0 !
-----------------------------------------------------------------------------------------------------------------------------------------
   118.6       !    4.0     2712077.9 !     4.0      2795667.9 !     4.0      2854499.3 !     4.0      2901673.9 !     4.0      2957616.1 !
  (174.5)      !  533.4           0.0 !   533.1            0.0 !   532.9            0.0 !   532.8            0.0 !   532.5            0.0 !
-----------------------------------------------------------------------------------------------------------------------------------------
   112.6       !    4.0     3847025.3 !     4.0      3952672.6 !     4.0      4027007.5 !     4.0      4086699.8 !     4.0      4157408.6 !
  (173.3)      !  522.7           0.0 !   522.4            0.0 !   522.1            0.0 !   522.0            0.0 !   521.8            0.0 !
-----------------------------------------------------------------------------------------------------------------------------------------
   106.7       !    4.0     5291605.1 !     4.0      5426946.9 !     4.0      5522176.8 !     4.0      5598736.0 !     4.0      5689365.6 !
```

```
  (172.1)     !  511.9            0.0 !  511.6            0.0 !  511.4            0.0 !  511.3            0.0 !  511.1            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------
   100.8      !    4.0      7159285.1 !    4.0      7335690.5 !    4.0      7459844.3 !    4.0      7559734.3 !    4.0      7677965.8 !
  (170.8)     !  502.1            0.0 !  501.8            0.0 !  501.6            0.0 !  501.5            0.0 !  501.2            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------
    94.9      !    4.0      9623434.8 !    4.0      9858585.4 !    4.0     10024178.9 !    4.0     10157481.6 !    4.0     10315309.0 !
  (169.4)     !  489.1            0.0 !  488.6            0.0 !  488.3            0.0 !  488.1            0.0 !  487.8            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------
    89.0      !    4.0     12961431.5 !    4.0     13284179.9 !    4.0     13511622.3 !    4.0     13694765.5 !    4.0     13911766.4 !
  (168.0)     !  473.2            0.0 !  472.6            0.0 !  472.2            0.0 !  472.0            0.0 !  471.6            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------
    83.0      !    4.0     17620381.5 !    4.0     18076481.3 !    4.0     18398457.5 !    4.0     18657722.3 !    4.0     18965218.5 !
  (166.4)     !  454.0            0.0 !  453.5            0.0 !  453.1            0.0 !  452.8            0.0 !  452.4            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------
    77.1      !    3.9     24305317.8 !    3.9     24973423.5 !    3.9     25445413.3 !    3.9     25825491.5 !    3.9     26276926.8 !
  (164.8)     !  419.1            0.0 !  418.5            0.0 !  418.1            0.0 !  417.9            0.0 !  417.5            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------
    71.2      !    3.9     34283329.5 !    3.9     35298577.0 !    3.9     36016540.5 !    3.9     35594470.5 !    3.9     37281773.5 !
  (163.1)     !  399.3            0.0 !  398.7            0.0 !  398.3            0.0 !  398.0            0.0 !  397.6            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------
    65.7      !    3.8     50004544.0 !    3.8     51652126.0 !    3.8     52820297.5 !    3.8     53760996.0 !    3.8     54882526.5 !
  (161.2)     !  366.4            0.0 !  365.9            0.0 !  365.6            0.0 !  365.4            0.0 !  365.1            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------
    59.4      !    3.6     80690297.0 !    3.6     84359401.0 !    3.6     86986424.0 !    3.6     89108966.0 !    3.6     91660477.0 !
  (159.2)     !  315.5            0.0 !  314.8            0.0 !  314.3            0.0 !  314.0            0.0 !  313.5            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------
    53.4      !    3.2    145358634.0 !    3.1    153374472.0 !    3.1    159089914.0 !    3.1    163694968.0 !    3.1    169228860.0 !
  (157.0)     !  233.0            0.0 !  217.9            0.0 !  217.5            0.0 !  217.1            0.0 !  216.7            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------
    47.5      !    2.5    254795990.0 !    2.5    279217252.0 !    2.4    289457368.0 !    2.4    297649440.0 !    2.4    307453064.0 !
  (154.6)     !  109.9            0.0 !  109.3            0.0 !   95.0            0.0 !   94.7            0.0 !   94.2            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------
    41.6      !    1.8    457861404.0 !    1.7    478826468.0 !    1.6    493964612.0 !    1.6    506266520.0 !    1.6    521102344.0 !
  (151.9)     !    0.0            0.0 !    0.0            0.0 !    0.0            0.0 !    0.0            0.0 !    0.0            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------
    35.7      !    1.3    741117592.0 !    1.0    768314840.0 !    0.9    788373528.0 !    0.9    803371408.0 !    0.8    823741952.0 !
  (148.7)     !    0.0            0.0 !    0.0            0.0 !    0.0            0.0 !    0.0            0.0 !    0.0            0.0 !
-------------------------------------------------------------------------------------------------------------------------------------
    32.7      !    0.6    929792240.0 !    0.5    962615000.0 !    0.6    985859280.0 !    0.6   1004550088.0 !    0.6   1026880824.0 !
  (147.0)     !    0.0            0.0 !    0.0            0.0 !    0.0            0.0 !    0.0            0.0 !    0.0            0.0 !
                                                   *****  CYCLE 45  *****

                        (INCREASE OVER PREVIOUS BOUNDARY)                                        (NEW BOUNDARY)

INFLOWS           4.4        3.6        2.9        2.4        1.7             4.4          3.6          2.9          2.4          1.7
STORAGE (HEAD)
     163.9   312067.5   312077.7   312085.4   312093.0   312102.0 !   -1146320.1   -1138589.6   -1132317.2   -1125724.7   -1117178.6
     165.9   312105.2   312120.1   312131.1   312140.9   312151.6 !   -1111682.0   -1097029.7   -1085947.3   -1075956.2   -1064944.8
     160.0   312207.0   312230.3   312247.2   312262.1   312276.1 !   -1000100.3    -971239.3    -949976.9    -931094.1    -910592.6
     154.1   312355.0   312385.7   312407.8   312427.2   312447.9 !    -804313.2    -759797.1    -727449.2    -698940.9    -668234.7
     148.2   312543.9   312581.1   312607.8   312631.1   312656.0 !    -517748.8    -456897.4    -412961.0    -374379.7    -332982.1
     142.3   312765.5   312811.5   312842.1   312866.9   312897.3 !    -135217.6     -56598.3          0.0      49621.7     102766.4
     136.3   313024.3   313072.2   313105.2   313135.9   313167.5 !     353639.0     452685.6     523901.4     586302.1     653074.1
     130.4   313306.7   313358.7   313395.6   313427.8   313461.9 !     966630.5    1090280.4    1179153.4    1257024.2    1340322.3
     124.5   313611.3   313665.6   313705.9   313740.1   313776.3 !    1730915.9    1885318.8    1996323.3    2093614.9    2197590.9
     118.5   313933.8   313991.8   314032.8   314068.6   314106.4 !    2686194.4    2880291.2    3019926.5    3142379.0    3273409.9
     112.6   314269.9   314329.7   314371.9   314408.7   314447.6 !    3890068.3    4136883.3    4314623.3    4470604.7    4637600.7
     106.7   314614.8   314675.5   314718.4   314755.6   314795.1 !    5426583.1    5745319.6    5975149.7    6177022.2    6393303.9
     100.8   314963.4   315024.0   315065.9   315104.0   315143.3 !    7420723.0    7840641.0    8143942.0    8410643.9    8696658.3
      94.9   315310.1   315369.6   315411.5   315447.9   315486.4 !   10065569.8   10633347.8   11044341.0   11406243.5   11794843.6
```

```
  89.0  315647.9  315704.5  315744.4  315778.6  315815.0 !    13669613.3    14460405.6    15034127.5    15540037.0    16083983.9
  83.0  315961.8  316014.0  316051.3  316083.5  316117.3 !    18711325.8    19842774.3    20665860.3    21392895.8    22175860.0
  77.1  316257.8  316308.3  316343.3  316373.8  316406.0 !    25965557.0    27650524.5    28879789.3    29967498.0    31140796.8
  71.2  316537.0  316582.0  316613.0  316637.0  316667.0 !    36899243.5    39543681.0    41482552.0    43203532.0    45065396.5
  65.3  316771.5  316807.5  316832.5  316853.5  316876.0 !    54750285.0    59790526.0    63572587.0    66978954.0    70713193.0
  59.4  316955.0  316977.0  316996.0  317010.0  317024.0 !    89166115.0    97508432.0   107533623.0   114711329.0   122584537.0
  53.4  317074.0  317086.0  317096.0  317106.0  317112.0 !   158090132.0   175641942.0   190034036.0   203152730.0   217445472.0
  47.5  317144.0  317152.0  317156.0  317160.0  317164.0 !   277713096.0   304227340.0   326601035.0   346584948.0   368826772.0
  41.6  317164.0  317184.0  317192.0  317200.0  317200.0 !   464263608.0   501749040.0   530694160.0   557257336.0   587168360.0
  35.7  317208.0  317192.0  317192.0  317200.0  317200.0 !   726134544.0   779361504.0   816661424.0   849908256.0   885463440.0
  32.7  317192.0  317215.0  317208.0  317200.0  317184.0 !   883167600.0   947205424.0   993597144.0  1034559952.0  1078574816.0

DELTA LOSSES =      5145.4  AVERAGE LOSS =     314641.3  MIN. DELTA LOSS =     312067.6  MAX. DELTA LOSS =     317216.0



                                        *** OPERATING POLICY FOR PERIOD    1***

     FIRST ROW: RELEASE AND OBJ. FUNCT.
     SECOND ROW: GENERATION(GWH) AND RELEASE TO TOSHKA

STORAGE (HEAD) !              4.4            !             3.6            !              2.9           !              2.4           !              1.7            !
--------------------------------------------------------------------------------------------------------------------------------------------------------------------
     168.9     !     3.4      -833478.0 !     3.4      -825747.5 !     3.4      -819475.1 !     3.4      -812882.5 !     3.4      -804336.5 !
    (183.0)    !  494.7            0.0 !  494.4            0.0 !  494.1            0.0 !  493.9            0.0 !  493.7            0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------------------------------
     165.9     !     3.4      -798339.9 !     3.4      -784187.5 !     3.4      -773105.1 !     3.4      -763114.0 !     3.4      -752102.6 !
    (182.4)    !  491.5            0.0 !  491.1            0.0 !  490.9            0.0 !  490.7            0.0 !  490.4            0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------------------------------
     160.0     !     3.4      -687259.2 !     3.4      -658397.2 !     3.4      -637136.3 !     3.4      -618252.0 !     3.4      -597750.5 !
    (181.7)    !  484.7            0.0 !  484.3            0.0 !  484.0            0.0 !  483.8            0.0 !  483.5            0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------------------------------
     154.1     !     3.4      -491471.1 !     3.4      -446954.9 !     3.4      -414607.1 !     3.4      -386098.8 !     3.4      -355392.6 !
    (180.7)    !  477.5            0.0 !  477.0            0.0 !  476.8            0.0 !  476.5            0.0 !  476.3            0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------------------------------
     148.2     !     3.4      -204906.7 !     3.4      -144055.3 !     3.4      -100118.9 !     3.4       -61537.6 !     3.4       -20140.0 !
    (179.8)    !  468.7            0.0 !  468.3            0.0 !  467.9            0.0 !  467.6            0.0 !  467.2            0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------------------------------
     142.3     !     3.4       177624.5 !     3.4       256243.8 !     3.4       312842.1 !     3.4       362463.8 !     3.4       415608.5 !
    (178.8)    !  459.2            0.0 !  457.6            0.0 !  457.1            0.0 !  456.8            0.0 !  456.4            0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------------------------------
     136.3     !     3.4       566481.1 !     3.4       765528.7 !     3.4       836743.5 !     3.4       899144.2 !     3.4       965916.2 !
    (177.8)    !  447.7            0.0 !  447.2            0.0 !  446.5            0.0 !  446.5            0.0 !  446.2            0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------------------------------
     130.4     !     3.4      1279473.0 !     3.4      1403122.5 !     3.4      1491795.5 !     3.4      1569866.3 !     3.4      1653164.4 !
    (176.7)    !  438.1            0.0 !  437.6            0.0 !  437.2            0.0 !  436.9            0.0 !  436.6            0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------------------------------
     124.5     !     3.4      2043758.0 !     3.4      2198161.0 !     3.4      2309165.4 !     3.4      2406457.1 !     3.4      2510533.0 !
    (175.5)    !  429.2            0.0 !  428.8            0.0 !  428.5            0.0 !  428.2            0.0 !  428.0            0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------------------------------
     118.6     !     3.4      2999036.5 !     3.4      3193133.3 !     3.4      3332768.7 !     3.4      3455221.1 !     3.4      3586252.0 !
    (174.5)    !  421.2            0.0 !  420.7            0.0 !  420.4            0.0 !  420.1            0.0 !  419.8            0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------------------------------
     112.6     !     3.4      4202910.4 !     3.4      4449725.4 !     3.4      4627465.4 !     3.4      4783446.8 !     3.4      4950442.8 !
    (173.3)    !  412.1            0.0 !  411.5            0.0 !  411.1            0.0 !  410.8            0.0 !  410.5            0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------------------------------
     106.7     !     3.4      5739425.3 !     3.4      6058161.7 !     3.4      6287991.3 !     3.4      6489864.3 !     3.4      6706146.0 !
    (172.1)    !  402.3            0.0 !  401.8            0.0 !  401.5            0.0 !  401.2            0.0 !  400.9            0.0 !
--------------------------------------------------------------------------------------------------------------------------------------------------------------------
```

```
  100.8    !   3.4     7733565.1 !   3.4     8153483.1 !   3.4     8456784.1 !   3.4     8723486.0 !   3.4     9009500.4 !
 (170.8)   ! 393.8           0.0 ! 393.3           0.0 ! 392.9           0.0 ! 392.6           0.0 ! 392.3           0.0 !
---------------------------------------------------------------------------------------------------------------------------
   94.9    !   3.4    10379411.9 !   3.4    10946189.9 !   3.4    11357183.1 !   3.4    11719085.6 !   3.4    12107685.8 !
 (169.4)   ! 383.0           0.0 ! 382.3           0.0 ! 381.6           0.0 ! 381.3           0.0 ! 380.9           0.0 !
---------------------------------------------------------------------------------------------------------------------------
   89.0    !   3.4    13982455.4 !   3.4    14773247.8 !   3.4    15346969.6 !   3.4    15852879.1 !   3.4    16396826.0 !
 (168.0)   ! 369.8           0.0 ! 368.9           0.0 ! 368.3           0.0 ! 367.8           0.0 ! 367.3           0.0 !
---------------------------------------------------------------------------------------------------------------------------
   83.0    !   3.3    19024158.0 !   3.3    20155616.5 !   3.3    20976702.5 !   3.3    21705738.0 !   3.3    22488702.3 !
 (166.4)   ! 337.2           0.0 ! 336.3           0.0 ! 335.7           0.0 ! 335.2           0.0 ! 334.6           0.0 !
---------------------------------------------------------------------------------------------------------------------------
   77.1    !   3.3    26278399.3 !   3.3    27963366.8 !   3.3    29192632.0 !   3.3    30280340.3 !   3.3    31453639.0 !
 (164.5)   ! 321.2           0.0 ! 320.3           0.0 ! 319.6           0.0 ! 319.1           0.0 ! 318.5           0.0 !
---------------------------------------------------------------------------------------------------------------------------
   71.2    !   3.3    37212745.5 !   3.3    39456523.0 !   3.3    41795394.0 !   3.3    43516374.0 !   3.3    45378238.5 !
 (163.1)   ! 304.9           0.0 ! 303.9           0.0 ! 303.3           0.0 ! 302.7           0.0 ! 302.1           0.0 !
---------------------------------------------------------------------------------------------------------------------------
   65.3    !   3.1    55063127.0 !   3.1    60103368.0 !   3.1    63885429.0 !   3.1    67291796.0 !   3.1    71026035.0 !
 (161.2)   ! 258.5           0.0 ! 257.9           0.0 ! 257.4           0.0 ! 257.0           0.0 ! 256.6           0.0 !
---------------------------------------------------------------------------------------------------------------------------
   59.4    !   2.9    99478957.0 !   2.9    99921324.0 !   2.9   107846465.0 !   2.8   115024171.0 !   2.6   122897379.0 !
 (159.2)   ! 212.9           0.0 ! 196.8           0.0 ! 196.1           0.0 ! 195.5           0.0 ! 194.9           0.0 !
---------------------------------------------------------------------------------------------------------------------------
   53.4    !   2.6   153402274.0 !   2.4   175954784.0 !   2.3   190346373.0 !   2.3   203465572.0 !   2.2   217758314.0 !
 (157.3)   ! 149.9           0.0 ! 118.7           0.0 ! 103.4           0.0 ! 102.7           0.0 !  87.6           0.0 !
---------------------------------------------------------------------------------------------------------------------------
   47.5    !   2.1   278022949.0 !   2.1   304540684.0 !   1.8   326913380.0 !   1.7   345597792.0 !   1.6   369139616.0 !
 (154.6)   !  56.6           0.0 !  55.5           0.0 !  12.9           0.0 !   0.0           0.0 !   0.0           0.0 !
---------------------------------------------------------------------------------------------------------------------------
   41.6    !   1.7   464576452.0 !   1.6   502961884.0 !   1.5   531007004.0 !   1.2   557570176.0 !   1.1   587481200.0 !
 (151.7)   !   0.0           0.0 !   0.0           0.0 !   0.0           0.0 !   0.0           0.0 !   0.0           0.0 !
---------------------------------------------------------------------------------------------------------------------------
   35.7    !   1.3   729447364.0 !   1.0   779674344.0 !   0.9   816974264.0 !   0.7   850221696.0 !   0.7   865776280.0 !
 (148.7)   !   0.0           0.0 !   0.0           0.0 !   0.0           0.0 !   0.0           0.0 !   0.0           0.0 !
---------------------------------------------------------------------------------------------------------------------------
   32.7    !   0.3   883480440.0 !   0.2   947518264.0 !   0.1   993909984.0 !   0.0  1034872792.0 !   0.0  1078887664.0 !
 (147.0)   !   0.0           0.0 !   0.0           0.0 !   0.0           0.0 !   0.0           0.0 !   0.0           0.0 !
```

APPENDIX C

COMPUTER PROGRAM LISTING OF SIMULATION MODEL WITH ADAPTIVE CONTROL ALGORITHM

```
C ********************************************************************
C *                                                                  *
C *  THIS PROGRAM IS A SIMULATION MODEL OF THE HIGH ASWAN DAM - LAKE *
C *  NASSER SYSTEM.  AS PROGRAMMED, THERE ARE THREE ALTERNATIVE      *
C *  OPERATING POLICIES (CONTROL SCHEMES) THAT CAN BE IMPLEMENTED:   *
C *                                                                  *
C *      1) A HEURISTIC POLICY                                       *
C *      2) A STEADY-STATE RELEASE POLICY                            *
C *      3) A REAL-TIME ADAPTIVE RELEASE POLICY                      *
C *                                                                  *
C *  BOTH THE HEURISTIC AND THE STEADY-STATE RELEASE POLICIES TAKE   *
C *  APPROXIMATELY 20 CPU SECONDS TO SIMULATE 53 YEARS OF MONTHLY    *
C *  STREAMFLOW DATA, WHILE THE ADAPTIVE POLICY TAKES APPROXIMATELY  *
C *  50 CPU HOURS FOR THE FORECAST LEAD-TIMES GIVEN IN CHAPTER 5.    *
C *  THE LARGE CPU REQUIREMENT WITH THE ADAPTIVE CONTROL SCHEME IS   *
C *  DUE TO THE FACT THAT AN OPTIMIZATION PROBLEM MUST BE SOLVED AT  *
C *  EACH TIME STEP OF THE SIMULATION.                               *
C *                                                                  *
C *  EACH SUBROUTINE IS INDIVIDUALLY COMMENTED TO EXPLAIN ITS        *
C *  FUNCTION.  SUBROUTINES FINSTO,EVTOSH AND BENEF1 ARE IDENTICAL   *
C *  TO THAT WHICH IS LISTED IN THE STEADY-STATE DYNAMIC PROGRAM     *
C *  GIVEN IN APPENDIX B.  THE SAME HOLDS FOR FUNCTIONS H, AREA AND  *
C *  XTOSH.                                                          *
C *                                                                  *
C ********************************************************************
      CALL DATA
      CALL SIMULA
      STOP
      END
C ********************************************************************
C ********************************************************************
```

```
C  *********************************************************************
      SUBROUTINE DATA
C  *********************************************************************
C  *                                                                   *
C  *  THIS SUBROUTINE READS IN AND WRITES OUT DATA.  DATA READ ON      *
C  *  FILE 10 IS GENERAL INFORMATION.  DATA READ ON FILE 11 IS OUTPUT *
C  *  FROM THE STEADY-STATE DYNAMIC PROGRAMMING ALGORITHM.  DATA READ *
C  *  ON FILE 12 IS FOR THE PURPOSE OF FORECASTING INFLOWS AND         *
C  *  DERIVING ADAPTIVE RELEASE CURVES.                                *
C  *                                                                   *
C  *  DEFINITIONS OF VARIABLES ARE (IN ALPHABETICAL ORDER)             *
C  *                                                                   *
C  *      GEBAUL - LOSSES AT GEBAUL AULIA RESERVOIR                    *
C  *      HTRAN  - SAME AS PTRAN (IN INITIAL FORM)                     *
C  *      JLEAD  - LEAD OF FORECAST                                    *
C  *      KWR    - CONTROL ARGUMENT FOR LESS DETAILED OUTPUT           *
C  *      LEAD   - VARIABLE LEAD OF FORECAST FOR EACH MONTH            *
C  *      QMEAN  - MEAN INFLOWS AT ASWAN                               *
C  *      SAL    - ALERT STORAGE LEVELS FOR HEURISTIC POLICY           *
C  *                                                                   *
C  *  REMAINING DEFINITIONS ARE GIVEN IN SUBROUTINES WHERE THEY APPEAR*
C  *                                                                   *
C  *********************************************************************
      COMMON/A1/NY,NP,NS,NQ,NIT,NWR
      COMMON/A2/Q2(12,5),PTRAN(12,5,5)
      COMMON/A3/TARGI(12),TARGE(12),EVRATE(12),SUDGEB(12)
      COMMON/A4/RMAX,SMAX,SMIN,DELTAR,RATE,ITOSH,STL
      COMMON/A6/RC,XPE,XPI,XPR,PEN1,PEN2,PEN3,PENG,PIRR,PREL
      COMMON/A7/GENMAX(21),RELMAX(21),EL(21),X0(21),Y0(21),SLOPE(21)
      COMMON/A8/FACTOR,NELEV
      COMMON/A9/REL(12,25,5),BOUN(12,25,5)
      COMMON/C1/QQ(8,60,12),HTRAN(12,5,5)
      COMMON/C2/COEF(8,12,12,8),RSQUAR(12,12)
      COMMON/C3/UNVCON(12),UNVCOE(12,12),UNVRSQ(12,12)
      COMMON/C4/STDV(12),RHO(12),CONST(12,8)
      COMMON/C5/QMEAN(12),SAL(12),GEBAUL(12)
      COMMON/C6/KWR,IPOL,IFORE,IPERF,IUNIV,IVAR
      COMMON/C7/JLEAD,LEAD(12)
C  ************************************
C
C  ENTER IPOL = 1 FOR HEURISTIC POLICY,  ANYTHING ELSE OTHERWISE
C  ENTER IFORE = 0 FOR STEADY STATE, ANYTHING ELSE FOR FORECAST
C  ENTER IPERF = 1 FOR PERFECT FORECAST, ANYTHING ELSE OTHERWISE
C  ENTER IUNIV = 1 FOR UNIVARIATE FORECAST, ANYTHING ELSE OTHERWISE
C  ENTER IVAR = 1 FOR VARIABLE LEAD, ANYTHING ELSE OTHERWISE
      READ(11,)NP,NS,NQ,ITOSH
      READ(10,)IPOL,IFORE,IPERF,IUNIV,IVAR,JLEAD
      READ(10,)NY,NIT,KWR,NWR
      IF((IPOL.EQ.1).AND.(IFORE.NE.0))GO TO 5
      GO TO 9
    5 PRINT,'  FORECASTING SHOULD NOT',
```

```
     &' BE USED WITH HEURISTIC POLICY'
      PRINT,' IPOL = ',IPOL
      PRINT,' IFORE =',IFORE
      STOP
    9 CONTINUE
      DO 10 I=1,NP
   10 READ(10,)(Q2(I,J),J=1,NQ)
      READ(10,)(GEBAUL(I),I=1,NP)
      READ(10,)(QMEAN(I),I=1,NP)
      READ(10,)(SAL(I),I=1,NP)
      READ(10,)(LEAD(I),I=1,NP)
      MXLEAD=0
      MNLEAD=12
      DO 15 I=1,NP
      IF(LEAD(I).LT.MNLEAD)MNLEAD=LEAD(I)
   15 IF(LEAD(I).GT.MXLEAD)MXLEAD=LEAD(I)
C    *************************************
      READ(11,)RMAX,SMAX,SMIN,DELTAR,RATE
      READ(11,)PENG,PIRR,PREL,PEN1,PEN2,PEN3,RC,FACTOR,NELEV
      XPE=10.**PENG
      XPI=10.**PIRR
      XPR=10.**PREL
      READ(11,)(SUDGEB(I),I=1,NP)
      READ(11,)(TARGI(I),I=1,NP)
      READ(11,)(TARGE(I),I=1,NP)
      READ(11,)(EVRATE(I),I=1,NP)
      DO 25 I=1,NELEV
   25 READ(11,)GENMAX(I),RELMAX(I),EL(I),XO(I),YO(I),SLOPE(I)
      DO 30 I=1,NP
      DO 30 J=1,NS
   30 READ(11,)(REL(I,J,K),K=1,NQ)
      DO 35 I=1,NP
      DO 35 J=1,NQ
      READ(11,)(PTRAN(I,J,K),K=1,NQ)
      DO 35 KK=1,NQ
   35 HTRAN(I,J,KK)=PTRAN(I,J,KK)
      DO 38 I=1,NP
      DO 38 J=1,NS
   38 READ(11,)(BOUN(I,J,K),K=1,NQ)
C    *************************************
C    *************************************
      NSTATN=8
      NY1=NY+1
      DO 50 I=1,NSTATN
      DO 50 J=1,NY1
   50 READ(12,)(QQ(I,J,K),K=1,NP)
      IF(IFORE.EQ.0)GO TO 80
      DO 60 I=1,8
      DO 60 J=1,12
      DO 60 K=1,12
   60 READ(12,)(COEF(I,J,K,L),L=1,8)
```

```
      DO 65 I=1,12
   65 READ(12,)(RSQUAR(I,J),J=1,12)
      DO 70 I=1,12
   70 READ(12,)(CONST(I,J),J=1,8)
      READ(12,)(STDV(I),I=1,12)
      READ(12,)(RHO(I),I=1,12)
      READ(12,)(UNVCON(I),I=1,NP)
      DO 72 I=1,12
   72 READ(12,)(UNVRSQ(I,J),J=1,12)
      DO 74 I=1,12
   74 READ(12,)(UNVCOE(I,J),J=1,12)
C ****************************************
   80 SUDTOT=0.
      DO 82 I=1,12
   82 SUDTOT=SUDTOT+SUDGEB(I)
      STL=200.0
      IF(ITOSH.NE.0)STL=137.5
      DO 83 I=1,NP
      DO 83 J=1,NQ
      Q2(I,J)=Q2(I,J)-SUDGEB(I)
   83 IF(Q2(I,J).LT.0.)Q2(I,J)=0.
      IF(IPOL.NE.1)WRITE(NWR,100)
      IF(IPOL.EQ.1)WRITE(NWR,110)
      IF(IPOL.EQ.1)GO TO 90
      WRITE(NWR,130)
      IF(IFORE.EQ.0)WRITE(NWR,135)
      IF(IFORE.EQ.0)GO TO 90
      IF(IPERF.EQ.1)WRITE(NWR,138)JLEAD
      IF(IPERF.EQ.1)GO TO 90
      IF((IVAR.NE.1).AND.(IUNIV.EQ.1))WRITE(NWR,140)JLEAD
      IF((IVAR.NE.1).AND.(IUNIV.NE.1))WRITE(NWR,145)JLEAD
      IF((IVAR.EQ.1).AND.(IUNIV.EQ.1))WRITE(NWR,150)MNLEAD,MXLEAD
      IF((IVAR.EQ.1).AND.(IUNIV.NE.1))WRITE(NWR,155)MNLEAD,MXLEAD
   90 IF(IPOL.EQ.1)WRITE(NWR,160)
      WRITE(NWR,170)NY,NP
      WRITE(NWR,180)
      WRITE(NWR,190)RMAX,RC,SUDTOT
      IF(ITOSH.EQ.0)WRITE(NWR,200)
      IF(ITOSH.NE.0)WRITE(NWR,210)
      WRITE(NWR,215)RATE
      WRITE(NWR,220)
      WRITE(NWR,230)(EVRATE(I),I=1,NP)
      WRITE(NWR,240)(SAL(I),I=1,NP)
      WRITE(NWR,250)(TARGI(I),I=1,NP)
      WRITE(NWR,260)(TARGE(I),I=1,NP)
      WRITE(NWR,270)
      WRITE(NWR,280)PENG,PIRR,PREL,PEN1,PEN2,PEN3
  100 FORMAT(/,' THIS SIMULATION USES A DYNAMIC PROGRAM POLICY WITH ',
     &'THE FOLLOWING STATE VARIABLES:',/,'     1) CURRENT ELEVATION ',
     &'OF LAKE NASSER')
  110 FORMAT(/,' THIS SIMULATION USES A HEURISTIC POLICY',/)
```

```
130  FORMAT('     2) PREVIOUS MONTHLY DISCHARGE AT WADIHALFA',/)
135  FORMAT(' REAL-TIME ADAPTIVE CONTROL IS NOT IMPLEMENTED',//)
138  FORMAT(' REAL TIME ADAPTIVE CONTROL IS IMPLEMENTED, USING ',
    &'A CONSTANT',/,' PERFECT FORECAST LEAD OF ',I2,' PERIODS',/)
140  FORMAT(' REAL TIME ADAPTIVE CONTROL IS IMPLEMENTED, USING ',
    &'A CONSTANT',/,' UNIVARIATE FORECAST LEAD OF ',I2,' PERIODS',/)
145  FORMAT(' REAL TIME ADAPTIVE CONTROL IS IMPLEMENTED, USING ',
    &'A CONSTANT',/,' MULTIVARIATE FORECAST LEAD OF ',I2,' PERIODS',/)
150  FORMAT(' REAL TIME ADAPTIVE CONTROL IS IMPLEMENTED USING ',
    &'A VARIABLE LEAD UNIVARIATE FORECAST',/,' WITH LEADS RANGING ',
    &'FROM ',I2,' TO ',I2,' PERIODS',/)
155  FORMAT(' REAL TIME ADAPTIVE CONTROL IS IMPLEMENTED USING ',
    &'A VARIABLE LEAD MULTIVARIATE FORECAST',/,' WITH LEADS RANGING ',
    &'FROM ',I2,' TO ',I2,' PERIODS',/)
160  FORMAT(4(/))
170  FORMAT(' NUMBER OF YEARS SIMULATED = ',I2,'  (1913-1965)',/,
    &' PERIODS PER YEAR = ',I2,/)
180  FORMAT(' INPUT PARAMETERS:',/)
190  FORMAT(5X,'1) MAXIMUM RELEASE = ',F4.1,/,5X,'2) ',
    &'CRITICAL RELEASE = ',F3.1,/,5X,'3) SUDAN ABSTRACTIONS',
    &' = ',F5.2)
200  FORMAT(5X,'4) NO TOSHKA')
210  FORMAT(5X,'4) TOSHKA')
215  FORMAT(5X,'5) MONTHLY DISCOUNT RATE',F8.4,/)
220  FORMAT(' MONTHLY INPUT PARAMETERS:   JAN    FEB  ',
    &'  MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT  ',
    &'  NOV    DEC',/)
230  FORMAT('   EVAPORATION RATES        ',12(1X,F5.1,1X),/)
240  FORMAT('   HEURISTIC ALERT STOR     ',12(1X,F5.1,1X),/)
250  FORMAT('   IRRIGATION TARGETS       ',12(2X,F3.1,2X),/)
260  FORMAT('   ENERGY TARGETS           ',12(1X,F5.0,1X),/)
270  FORMAT(' THE OBJECTIVE FUNCTION OF THIS SYSTEM IS ',
    &'OF THE FORM:',//,10X,'LOSS(RL,S,Q) = L1 + L2 + L3',//,
    &10X,'WHERE RL = RELEASE IN BCM/PERIOD',/,
    &16X,'S = INITIAL STORAGE (ELEVATION)',/,
    &16X,'Q = INFLOW IN BCM/PERIOD',/,
    &16X,'L1 = LOSSES DUE TO NOT MEETING ENERGY TARGET',/,
    &16X,'L2 = LOSSES DUE TO NOT MEETING IRRIGATION REQUIREMENTS',/,
    &16X,'L3 = LOSSES DUE TO EXCESSIVE RELEASES',//,5X,
    &'LOSS TERMS:',/,
    &10X,'L1 = ((TARGE(I)-GN)**2)*(10**PENG)*PEN1',
    &'     IF TARGE(I) > GN',/,13X,'= 0',38X,'OTHERWISE',/,
    &10X,'L2 = ((TARGI(I)-RL)**2)*(10**PIRR)*PEN2',5X,
    &'IF TARGI(I) > RL',/,13X,'= 0',38X,'OTHERWISE',/,
    &10X,'L3 = ((RL-RC)**2)*(10**PREL)*PEN3',11X,
    &'IF RL > RCRITI',/,13X,'= 0',38X,'OTHERWISE',//,
    &10X,'WHERE TARGE(I) = ENERGY TARGET FOR PERIOD I',/,
    &16X,'TARGI(I) = IRRIGATION TARGET FOR PERIOD I',/,
    &16X,'GN = POTENTIAL ENERGY GENERATION (A FUNCTION OF RL,S AND Q)',
    &/,16X,'RCRITI = CRITICAL RELEASE ABOVE WHICH EROSION OCCURS',/,
    &16X,'PENG = ENERGY DEFICIT PENALTY COEFFICIENT',/,
```

```
     &16X,'PIRR = IRRIGATION DEFICIT PENALTY COEFFICIENT',/,
     &16X,'PREL = EXCESSIVE RELEASE PENALTY COEFFICIENT',/,
     &16X,'PEN1, PEN2 AND PEN3 = 0 OR 1')
 280  FORMAT(/,5X,'THE POLICY USED IN THIS SIMULATION WAS DERIVED',
     &' WITH THE FOLLOWING VALUES:',/,8X,'PENG = ',F4.1,5X,
     &'PIRR = ',F4.1,'     PREL = ',F3.1,5X,'PEN1 = ',F3.1,
     &5X,'PEN2 = ',F3.1,5X,'PEN3 = ',F3.1)
      RETURN
      END
C  **********************************************************************
C  **********************************************************************
```

```
C ********************************************************************
     SUBROUTINE SIMULA
C ********************************************************************
C *                                                                  *
C *  THIS SUBROUTINE DIRECTS THE STEP BY STEP DECISION MAKING        *
C *  PROCESS FOR THE PARTICULAR CONTROL SCHEME THAT IS DESIGINATED   *
C *  IN SUBROUTINE DATA.  DEFINITION OF OUTPUT VARIABLES ARE:        *
C *                                                                  *
C *      ANR    - ANNUAL RELEASE                                     *
C *      ANT    - ANNUAL RELEASE TO TOSHKA                           *
C *      ANB    - ANNUAL BENEFITS (COSTS)                            *
C *      ANG    - ANNUAL POWER GENERATION                            *
C *      ANRLT  - ANNUAL RELEASE THROUGH TURBINES                    *
C *      ANSP   - ANNUAL RELEASE BYPASSING TURBINES                  *
C *      ANEV   - ANNUAL EVAPORATION                                 *
C *      ANP    - ANNUAL RELEASE IN EXCESS OF IRRIGATION TARGETS     *
C *      IEP4   - NUMBER OF RELEASES IN EXCESS OF DEGRADATION        *
C *               CAUSING RELEASE                                    *
C *      NRT    - NUMBER OF RELEASE TO TOSHKA                        *
C *      NIR    - NUMBER OF IRRIGATION DEFICITS                      *
C *      IAUG   - NUMBER OF CHANGED RELEASE DECISIONS (DUE TO        *
C *               SYSTEM CONSTRAINTS                                 *
C *      STG    _ MONTHLY VALUES OF STORAGE                          *
C *      EVMON  - MONTHLY EVAPORATION                                *
C *      RL     - MONTHLY RELEASE                                    *
C *      SPTOSH - MONTHLY SPILL TO TOSHKA                            *
C *      PLSIRR - MONTHLY SURPLUS RELEASE ABOVE IRRIGATION TARGET    *
C *      GEN    - MONTHLY POWER GENERATION                           *
C * OTHER VARIABLES TO BE DEFINED ARE:                               *
C *                                                                  *
C *      STORO  - INITIAL STORAGE                                    *
C *      XX     - PREVIOUS MONTH'S INFLOW                            *
C *      YX     - CURRENT MONTH'S INFLOW                             *
C *                                                                  *
C ********************************************************************
      COMMON/A1/NY,NP,NS,NQ,NIT,NWR
      COMMON/A2/Q2(12,5),PTRAN(12,5,5)
      COMMON/A3/TARGI(12),TARGE(12),EVRATE(12),SUDGEB(12)
      COMMON/A4/RMAX,SMAX,SMIN,DELTAR,RATE,ITOSH,STL
      COMMON/A6/RC,XPE,XPI,XPR,PEN1,PEN2,PEN3,PENG,PIRR,PREL
      COMMON/C1/QQ(8,60,12),HTRAN(12,5,5)
      COMMON/C6/KWR,IPOL,IFORE,IPERF,IUNIV,IVAR
      COMMON/C7/JLEAD,LEAD(12)
      COMMON/C8/IY
      DIMENSION ANR(60),ANREXC(60),ANT(60),ANB(60),ANG(60)
      DIMENSION ANP(60),ANEV(60),ANSP(60),ANRLT(60)
      DIMENSION YY(10),EVMON(60,12),SP(60,12),PLSIRR(60,12)
      DIMENSION STG(60,12),RL(60,12),RLT(60,12)
      DIMENSION SPTOSH(60,12),GEN(60,12),RELEV(12)
      READ(10,)STORO
      SF=STORO
```

```
      NY1=NY+1
      NY2=NY+2
      DO 2 I=1,NY
      ANR(I)=0.
      ANREXC(I)=0.
      ANT(I)=0.
      ANB(I)=0.
      ANG(I)=0.
      ANRLT(I)=0.
      ANSP(I)=0.
      ANEV(I)=0.
      ANP(I)=0.
    2 CONTINUE
      NREXC=0
      IEP4=0
      NRT=0
      NIR=0
      IAUG=0
      DO 1000 IY=2,NY1
      JY=IY-1
      IX=JY+3
      IZ=(IX/4)*4
      IF(IX.NE.IZ)GOTO40
      IF(KWR.GT.0)GOTO40
      WRITE(NWR,41)
   41 FORMAT(/,14X,5('-'),'ELEVATION',5('-'),10X,9('-'),'RELEASE DECIS',
     &'ION',9('-'),2X,8('-'),'SPILL',8('-'))
      WRITE(NWR,42)
   42 FORMAT(' YEAR  MONTH  ! INITIAL   FINAL !  INFLOW  ! INIT.  FINA',
     &'L   TURBINE  BYPASS !  ! TOSHKA   OVER DAM !   POWER(GWH)',
     &'    COST    IR+ EV',/)
   40 CONTINUE
      DO 2000 IP=1,NP
      IF(IVAR.EQ.1)JLEAD=LEAD(IP)
      STOR=SF
      IF(IFORE.NE.0)CALL FORCST(JLEAD,JY,IP)
      IF(IFORE.NE.0)CALL DISCIN(JLEAD,IP)
      IF(IFORE.NE.0)CALL FNDYNP(JLEAD,IP,IY)
      IA=IY
      IPM1=IP-1
      IF(IPM1.EQ.0)IA=IY-1
      IF(IPM1.EQ.0)IPM1=12
      STG(JY,IP)=H(STOR)
      HSTOR=STG(JY,IP)
      REXC=0.
      TARGIP=0.
      XX=QQ(1,IA,IPM1)/1000.-SUDGEB(IPM1)
      YX=QQ(1,IY,IP)/1000.-SUDGEB(IP)
      IF(XX.LE.0.)XX=0.
      IF(YX.LE.0.)YX=0.
      CALL DECIDE(XX,STOR,IP,RR)
```

```
      CALL FINSTO(IP,YX,STOR,RR,SF,RT,EV)
      R1=RR
      TARGIP=R1-TARGI(IP)
      IF(SMAX.GE.SF)GOTO50
      CALL EVTOSH(STOR,SMAX,IP,EV,RT)
      R1=STOR+YX-EV-RT-SMAX
      SF=SMAX
      IF(R1.GT.RMAX)REXC=R1-RMAX
      TARGIP=R1-TARGI(IP)
      GO TO 51
 50   IF(SF.GE.SMIN)GO TO 51
      R1=RR+.1
      DO 45 IJ=1,100
      R1=R1-.1
      CALL FINSTO(IP,YX,STOR,R1,SF,RT,EV)
      IF(SF.GE.SMIN)GO TO 49
      IF(R1.LE.0.01)GO TO 49
 45   CONTINUE
 49   IF(R1.LT.0.)R1=0.
      TARGIP=R1-TARGI(IP)
 51   CALL BENEF1(R1,STOR,SF,IP,BB,GN,RELTUR,SPILL)
      HHSTOR=H(SF)
      IF((TARGIP.LT.0.).AND.(TARGIP.GT.-0.005))TARGIP=0.
      IF(KWR.GT.0)GOTO70
      IF(IP.EQ.1)WRITE(NWR,65)JY,IP,HSTOR,HHSTOR,YX,RR,R1,RELTUR,SPILL,
     &RT,REXC,GN,BB,TARGIP,EV
 65   FORMAT(1X,I3,4X,I2,6X,F6.2,3X,F6.2,4X,F6.3,3X,F5.2,2X,F5.2,
     &5X,F4.2,5X,F4.2,7X,F5.2,5X,F5.2,9X,F6.1,3X,F8.1,1X,F5.2,1X,F3.1)
      IF(IP.NE.1)WRITE(NWR,66)IP,HSTOR,HHSTOR,YX,RR,R1,RELTUR,SPILL,
     &RT,REXC,GN,BB,TARGIP,EV
 66   FORMAT(8X,I2,6X,F6.2,3X,F6.2,4X,F6.3,3X,F5.2,2X,F5.2,5X,F4.2,
     &5X,F4.2,7X,F5.2,5X,F5.2,9X,F6.1,3X,F8.1,1X,F5.2,1X,F3.1)
      IF(IP.EQ.12)WRITE(NWR,67)
 67   FORMAT(/)
 70   ANR(JY)=ANR(JY)+R1
      ANREXC(JY)=ANREXC(JY)+REXC
      ANT(JY)=ANT(JY)+RT
      ANB(JY)=ANB(JY)+BB
      ANG(JY)=ANG(JY)+GN
      ANP(JY)=ANP(JY)+TARGIP
      ANEV(JY)=ANEV(JY)+EV
      ANSP(JY)=ANSP(JY)+SPILL
      ANRLT(JY)=ANRLT(JY)+RELTUR
      SP(JY,IP)=SPILL
      RLT(JY,IP)=RELTUR
      GEN(JY,IP)=GN
      RL(JY,IP)=R1
      EVMON(JY,IP)=EV
      SPTOSH(JY,IP)=RT
      PLSIRR(JY,IP)=TARGIP
      IF(REXC.GT.0.)NREXC=NREXC+1
```

```
      IF(RT.GT.0.)NRT=NRT+1
      IF(R1.LT.(TARGI(IP)*0.995))NIR=NIR+1
      IF(R1.GT.RC)IEP4=IEP4+1
      IF(RR.NE.R1)IAUG=IAUG+1
      WRITE(18)STOR
      WRITE(18)RR,SF,RT,EV,R1,TARGIP,BB,GN,RELTUR,SPILL,REXC
 2000 CONTINUE
 1000 CONTINUE
      IF(KWR.GT.0)GO TO 999
      WRITE(NWR,997)
 997  FORMAT(40(/))
 999  IF(KWR.GT.1)GOTO80
      WRITE(NWR,87)
  87  FORMAT(//,1X,49('*'),' ANNUAL OUTPUT ',49('*'),//,
     &9X,22('-'),'RELEASES',22('-'),/,1X,
     &'YEAR     ! DECISION     TURBINE    BYPASS    TOSHKA    OVER DAM !',
     &'     POWER(GWH)     COSTS     EVAPORATION     IRR. TARGET +',/)
      DO 86 IY=1,NY
      IIY=IY+1912
      WRITE(NWR,85)IIY,ANR(IY),ANRLT(IY),ANSP(IY),ANT(IY),
     &ANREXC(IY),ANG(IY),ANB(IY),ANEV(IY),ANP(IY)
  85  FORMAT(1X,I4,F12.2,F12.3,2F9.2,F10.2,F16.1,F11.1,F12.3,F16.3)
   86 CONTINUE
      WRITE(NWR,89)
  89  FORMAT(/)
   80 CONTINUE
      WRITE(NWR,90)(I,I=10,101,10)
   90 FORMAT(' *CUM.FREQ*(PERCENT)  ',10(I4,4X),7X,'MEAN',7X,'STND.DEV',
     &'.',/)
      CALL HISTOG(ANR,YY,YMEAN,YSTD)
      WRITE(NWR,201)(YY(I),I=1,10),YMEAN,YSTD
      CALL HISTOG(ANRLT,YY,YMEAN,YSTD)
      WRITE(NWR,202)(YY(I),I=1,10),YMEAN,YSTD
      CALL HISTOG(ANSP,YY,YMEAN,YSTD)
      WRITE(NWR,203)(YY(I),I=1,10),YMEAN,YSTD
      CALL HISTOG(ANT,YY,YMEAN,YSTD)
      WRITE(NWR,204)(YY(I),I=1,10),YMEAN,YSTD
      CALL HISTOG(ANREXC,YY,YMEAN,YSTD)
      WRITE(NWR,205)(YY(I),I=1,10),YMEAN,YSTD
      CALL HISTOG(ANG,YY,YMEAN,YSTD)
      WRITE(NWR,206)(YY(I),I=1,10),YMEAN,YSTD
      CALL HISTOG(ANB,YY,YMEAN,YSTD)
      WRITE(NWR,207)(YY(I),I=1,10),YMEAN,YSTD
      CALL HISTOG(ANEV,YY,YMEAN,YSTD)
      WRITE(NWR,208)(YY(I),I=1,10),YMEAN,YSTD
      CALL HISTOG(ANP,YY,YMEAN,YSTD)
      WRITE(NWR,209)(YY(I),I=1,10),YMEAN,YSTD
 201  FORMAT(1X,'ANNUAL RELEASE    ',10F8.1,F14.1,F15.1)
 202  FORMAT(1X,'ANNUAL TURBINE    ',10F8.1,F14.1,F15.1)
 203  FORMAT(1X,'ANNUAL BYPASS     ',10F8.1,F14.1,F15.1)
 204  FORMAT(1X,'ANNUAL TOSHKA     ',10F8.1,F14.1,F15.1)
```

```
205   FORMAT(1X,'ANNUAL OVER DAM    ',10F8.1,F14.1,F15.1)
206   FORMAT(1X,'ANNUAL GENERATION ',10F8.1,F14.1,F15.1)
207   FORMAT(1X,'ANNUAL COSTS      ',10F8.1,F14.1,F15.1)
208   FORMAT(1X,'ANNUAL EVAPORATION',10F8.1,F14.1,F15.1)
209   FORMAT(1X,'ANNUAL IRRIG. +   ',10F8.1,F14.1,F15.1)
      WRITE(NWR,84)
 84   FORMAT(/,60X,'***',/)
      DO 212 J=1,NP
      DO 211 I=1,NY
211   ANR(I)=STG(I,J)
      CALL HISTOG(ANR,YY,YMEAN,YSTD)
      RELEV(J)=ANR(1)
212   WRITE(NWR,301)J,(YY(I),I=1,10),YMEAN,YSTD
      WRITE(NWR,84)
      DO 214 J=1,NP
      DO 213 I=1,NY
213   ANR(I)=RL(I,J)
      CALL HISTOG(ANR,YY,YMEAN,YSTD)
214   WRITE(NWR,302)J,(YY(I),I=1,10),YMEAN,YSTD
      WRITE(NWR,84)
      DO 216 J=1,NP
      DO 215 I=1,NY
215   ANR(I)=RLT(I,J)
      CALL HISTOG(ANR,YY,YMEAN,YSTD)
216   WRITE(NWR,303)J,(YY(I),I=1,10),YMEAN,YSTD
      WRITE(NWR,84)
      WRITE(NWR,89)
      WRITE(NWR,90)(I,I=10,101,10)
      DO 218 J=1,NP
      DO 217 I=1,NY
217   ANR(I)=SP(I,J)
      CALL HISTOG(ANR,YY,YMEAN,YSTD)
218   WRITE(NWR,304)J,(YY(I),I=1,10),YMEAN,YSTD
      WRITE(NWR,84)
      DO 220 J=1,NP
      DO 219 I=1,NY
219   ANR(I)=SPTOSH(I,J)
      CALL HISTOG(ANR,YY,YMEAN,YSTD)
220   WRITE(NWR,305)J,(YY(I),I=1,10),YMEAN,YSTD
      WRITE(NWR,84)
      DO 222 J=1,NP
      DO 221 I=1,NY
221   ANR(I)=GEN(I,J)
      CALL HISTOG(ANR,YY,YMEAN,YSTD)
222   WRITE(NWR,306)J,(YY(I),I=1,10),YMEAN,YSTD
      WRITE(NWR,84)
      DO 224 J=1,NP
      DO 223 I=1,NY
223   ANR(I)=EVMON(I,J)
      CALL HISTOG(ANR,YY,YMEAN,YSTD)
224   WRITE(NWR,307)J,(YY(I),I=1,10),YMEAN,YSTD
```

```
      WRITE(NWR,89)
      WRITE(NWR,90)(I,I=10,101,10)
      DO 226 J=1,NP
      DO 225 I=1,NY
  225 ANR(I)=PLSIRR(I,J)
      CALL HISTOG(ANR,YY,YMEAN,YSTD)
  226 WRITE(NWR,308)J,(YY(I),I=1,10),YMEAN,YSTD
      WRITE(NWR,84)
  301 FORMAT(1X,'ELEVATION-MONTH ',I2,10F8.1,F14.1,F15.1)
  302 FORMAT(1X,'RELEASE-MONTH   ',I2,10F8.1,F14.1,F15.1)
  303 FORMAT(1X,'TURBINE-MONTH   ',I2,10F8.1,F14.1,F15.1)
  304 FORMAT(1X,'BYPASS-MONTH    ',I2,10F8.1,F14.1,F15.1)
  305 FORMAT(1X,'TOSHKA-MONTH    ',I2,10F8.1,F14.1,F15.1)
  306 FORMAT(1X,'GENERATION-MONTH',I2,10F8.1,F14.1,F15.1)
  307 FORMAT(1X,'EVAPOR.-MONTH   ',I2,10F8.1,F14.1,F15.1)
  308 FORMAT(1X,'IRRIG.+-MONTH   ',I2,10F8.1,F14.1,F15.1)
  309 FORMAT(//,1X,'MINIMUM MONTHLY ELEVATIONS',/,'  JAN    FEB',
     &'    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT',
     &'    NOV    DEC',/,12(2X,F5.1),//)
      WRITE(NWR,309)(RELEV(I),I=1,NP)
      WRITE(NWR,64)NREXC,NRT,NIR,RC,IEP4,IAUG
   64 FORMAT(1X,'NUMBER OF SPILLS OVER DAM = ',I3,/,
     &1X,'NUMBER OF RELEASES TO TOSHKA = ',I3,/,
     &1X,'NUMBER OF IRRIGATION DEFICITS = ',I3,/,
     &1X,'NUMBER OF RELEASES ABOVE',F4.1,' BCM = ',I3,/,
     &1X,'NUMBER OF DECISIONS CHANGED DURING MONTH = ',I3)
      RETURN
      END
C     ********************************************************************
C     ********************************************************************
```

```
C ******************************************************************
      SUBROUTINE HISTOG(Y,XY,YMEAN,YSTD)
C ******************************************************************
C *                                                                *
C     THIS ROUTINE CALCULATES THE CUMULATIVE FREQUENCY DISTRIBUTION
C     FOR VECTOR Y, USING TEN POINTS TO PRESENT THE DISTRIBUTION,
C     AND THE MEAN AND STD. DEVIATION OF Y
C *                                                                *
C ******************************************************************
      COMMON/A1/NY,NP,NS,NQ,NIT,NWR
      DIMENSION Y(100),XY(100)
      YMEAN=0.
      YSTD=0.
      NY1=NY-1
      DO 100 I=1,NY1
      IPLUS1=I+1
      DO 100 J=IPLUS1,NY
      IF(Y(I).LE.Y(J))GOTO100
      AUX=Y(J)
      Y(J)=Y(I)
      Y(I)=AUX
  100 CONTINUE
      X=NY/10.
      XX=0.
      DO 200 I=1,10
      XX=XX+X
      K=XX+.5
      IF(K.EQ.0)GOTO250
      XY(I)=Y(K)
      GOTO200
  250 XY(I)=0.
  200 CONTINUE
      DO 300 I=1,NY
      YMEAN=YMEAN+Y(I)
  300 YSTD=YSTD+Y(I)*Y(I)
      YMEAN=YMEAN/NY
      Z=(YSTD-NY*YMEAN*YMEAN)/(NY-1)
      IF(Z.LT.0.)Z=0.
      YSTD=SQRT(Z)
      RETURN
      END
C ******************************************************************
C ******************************************************************
```

```
C   ********************************************************************
      SUBROUTINE IDENTS(SF,J1,J2,ALFA1,ALFA2,IT,ICALL)
C   ********************************************************************
C   *                                                                  *
C   *  THIS SUBROUTINE PERFORMS THE SAME FUNCTION AS SUBROUTINE IDENTS *
C   *  IN APPENDIX B.                                                  *
C   *                                                                  *
C   ********************************************************************
      COMMON/A1/NY,NP,NS,NQ,NIT,NWR
      COMMON/A3/TARGI(12),TARGE(12),EVRATE(12),SUDGEB(12)
      COMMON/A4/RMAX,SMAX,SMIN,DELTAR,RATE,ITOSH,STL
      COMMON/C6/KWR,IPOL,IFORE,IPERF,IUNIV,IVAR
      COMMON/C9/ST1(25),ST2(25),RLS(25,5)
      NS2=NS-2
      IT1=IT+1
      IF(IT1.GT.NP)IT1=1
      IF(IFORE.EQ.0)VUT=SMAX-SMIN
      IF((IFORE.NE.0).AND.(ICALL.EQ.0))VUT=ST2(1)-SMIN
      IF((IFORE.NE.0).AND.(ICALL.EQ.1))VUT=ST1(1)-SMIN
      X=(NS2)*(1.-(SF-SMIN)/VUT)
      IF(X.LT.0.5)GOTO10
      Y=NS2-.5
      IF(X.GE.Y)GOTO20
      J1=X+1.5
      J2=X+2.5
      ALFA1=J2-1.5-X
      ALFA2=X+1.5-J1
      GOTO100
   10 J1=1
      J2=2
      ALFA2=X/.5
      ALFA1=1.-ALFA2
      GOTO100
   20 IF(X.GT.NS2)GOTO30
      Y=X-Y
      J1=NS-1
      J2=NS
      ALFA2=Y/.5
      ALFA1=1.-ALFA2
      GOTO100
   30 Y=X-NS2
      J1=NS-1
      J2=NS
      ALFA1=-Y/.5
      ALFA2=1.-ALFA1
  100 RETURN
      END
C   ********************************************************************
C   ********************************************************************
```

```
C  ***********************************************************************
      SUBROUTINE DECIDE(XX,STOR,IP,RR)
C  ***********************************************************************
C  *                                                                     *
C  *  THIS SUBROUTINE DETERMINES THE RELEASE FOR ANY OF THE THREE        *
C  *  CONTROL SCHEMES.  THE PARTICULAR CONTROL SCHEME TO BE USED IS      *
C  *  CARRIED THROUGH THE VARIABLES IPOL AND IFORE IN COMMON BLOCK C6.*
C  *  THE CALLING ARGUMENTS ARE DEFINED BY THE FOLLOWING:                *
C  *                                                                     *
C  *      XX      - PREVIOUS MONTH'S INFLOW                              *
C  *      STOR    - STORAGE AT THE BEGINNING OF THE MONTH                *
C  *      IP      - DESIGNATES THE MONTH                                 *
C  *      RR      - RETURN VALUE, SPECIFYING THE RELEASE                 *
C  *                                                                     *
C  *  OTHER VARIABLES TO BE DEFINED ARE:                             *
C  *                                                                     *
C  *      REL     - MATRIX OF RELEASE DECISIONS FOR STEADY-STATE         *
C  *                CONTROL SCHEME                                       *
C  *      RLS     - MATRIX OF RELEASE DECISIONS FOR ADAPTIVE CONTROL     *
C  *                SCHEME                                               *
C  *                                                                     *
C  ***********************************************************************
      COMMON/A1/NY,NP,NS,NQ,NIT,NWR
      COMMON/A2/Q2(12,5),PTRAN(12,5,5)
      COMMON/A3/TARGI(12),TARGE(12),EVRATE(12),SUDGEB(12)
      COMMON/A4/RMAX,SMAX,SMIN,DELTAR,RATE,ITOSH,STL
      COMMON/A9/REL(12,25,5),BOUN(12,25,5)
      COMMON/C1/QQ(8,60,12),HTRAN(12,5,5)
      COMMON/C5/QMEAN(12),SAL(12),GEBAUL(12)
      COMMON/C6/KWR,IPOL,IFORE,IPERF,IUNIV,IVAR
      COMMON/C8/IY
      COMMON/C9/ST1(25),ST2(25),RLS(25,5)
      IF(IPOL.EQ.1)GOTO400
      IF(STOR.GE.SMIN)GO TO 5
      RR=TARGI(IP)+.1
      FF=QQ(1,IY,IP)/1000.-SUDGEB(IP)
      DO 8 IJ=1,100
      RR=RR-.1
      CALL FINSTO(IP,FF,STOR,RR,SF,RT,EV)
      IF(SF.GE.SMIN)GO TO 9
      IF(RR.LE.0.01)GO TO 9
    8 CONTINUE
    9 IF(RR.LT.0.01)RR=0.
      GO TO 300
    5 IT=IP-1
      CALL IDENTS(STOR,J1,J2,ALFA1,ALFA2,IT,1)
      IL1=IP-1
      IF(IL1.EQ.0)IL1=NP
      IF(XX.GE.Q2(IL1,1))GOTO10
      IF(XX.LT.Q2(IL1,NQ))GOTO20
      DO 30 I=2,NQ
```

```
      IF(XX.LT.Q2(IL1,I))GOTO30
      I1=I-1
      I2=I
      GOTO35
   30 CONTINUE
   35 X=Q2(IL1,I1)-Q2(IL1,I2)
      Y=Q2(IL1,I1)-XX
      X=Y/X
      BETA2=X
      BETA1=1.-X
      GOTO50
   10 I1=1
      BETA1=1.
      I2=2
      BETA2=0.
      GOTO50
   20 I1=NQ-1
      I2=NQ
      BETA1=0.
      BETA2=1.
   50 IF(IFORE.EQ.0)R1=REL(IP,J1,I1)*ALFA1+REL(IP,J2,I1)*ALFA2
      IF(IFORE.EQ.0)R2=REL(IP,J1,I2)*ALFA1+REL(IP,J2,I2)*ALFA2
      IF(IFORE.NE.0)R1=RLS(J1,I1)*ALFA1+RLS(J2,I1)*ALFA2
      IF(IFORE.NE.0)R2=RLS(J1,I2)*ALFA1+RLS(J2,I2)*ALFA2
      RR=R1*BETA1+R2*BETA2
      GOTO300
C     ----------------------------------------
C
C    BEGINNING OF HEURISTIC RELEASE POLICY
C
C     ----------------------------------------
  400 IF(STOR.LT.61.2)GOTO200
      IP1=IP+1
      IF(IP1.GT.NP)IP1=1
      RR=TARGI(IP)
      FF=QQ(1,IY,IP)/1000.-SUDGEB(IP)
      CALL FINSTO(IP,FF,STOR,RR,SX,RT,EV)
      IF(SX.LE.SAL(IP1))GOTO300
      RR=RR+SX-SAL(IP1)
      RR=AMIN1(RR,RMAX)
      GOTO300
  200 CONTINUE
      IF((IP.LT.5).OR.(IP.GT.10))GO TO 33
      RR=TARGI(IP)
      GO TO 300
33    IA=IY
      IM1=IP-1
      IF(IM1.GT.0)GO TO 61
      IM1=12
      IA=IY-1
61    X=XX+SUDGEB(IM1)-GEBAUL(IM1)
```

```
      Y=QMEAN(IM1)
      IA=IY
      DO 60 I=1,3
      IT=IP-I
      IM1=IT-1
      IF(IT.GE.2)GO TO 65
      IF(IT.EQ.1)GO TO 62
      IF(IT.EQ.0)GO TO 63
      IF(IT.LT.0)GO TO 64
   62 IM1=NP
      IA=IY-1
      GO TO 65
   63 IT=NP
      IM1=NP-1
      IA=IY-1
      GO TO 65
   64 IT=NP+IP-I
      IM1=IT-1
      IA=IY-1
   65 XYZ=QQ(1,IA,IM1)/1000.-SUDGEB(IM1)
      X=X+XYZ+SUDGEB(IM1)-GEBAUL(IM1)
      Y=Y+QMEAN(IM1)
   60 CONTINUE
      ALFA=X/Y
      RR=TARGI(IP)*ALFA
      RR=AMIN1(RR,TARGI(IP))
  300 CONTINUE
      RETURN
      END
C     ******************************************************************
C     ******************************************************************
```

```
C  **********************************************************************
      SUBROUTINE FORCST(JLEAD,IY,JMONTH)
C  **********************************************************************
C  *                                                                    *
C  THIS PART OF THE SIMULATION DOES A 'JLEAD' FORECAST OF THE
C  INFLOW AT WADIHALFA.  THE FORECAST COEFFICIENTS ARE DERIVED
C  FROM A GENERALIZED LEAST SQUARES APPROACH IN CURRY & BRAS (1980).
C  MONTHLY INFLOWS ARE FORECASTED.
C
C     DESCRIPTION OF VARIABLES:
C
C      INPUT:
C
C        JLEAD  = LENGTH OF FORECAST INTO THE FUTURE
C        IY     = YEAR OF RELEASE DECISION TO BE MADE
C        IP     = MONTH OF RELEASE DECISION TO BE MADE
C        QQ     = MATRIX OF HISTORICAL INFLOWS AT NILE RIVER LOCATIONS
C        COEF   = MATRIX OF FORECAST COEFFICIENTS (SEE CURRY & BRAS)
C                 FOR MULTIVARIATE MODEL
C        RSQUAR = MATRIX OF VARIANCE REDUCTION FACTORS (I.E. RSQUARE)
C                 FOR MULTIVARIATE MODEL
C        STDV   = MONTHLY HISTORICAL STANDARD DEVIATIONS
C        RHO    = MONTHLY HISTORICAL LAG-ONE CORRELATION COEFFICIENTS
C        CONST  = MATRIX OF CONSTANTS DERIVED IN LEAST SQUARES FOR
C                 MULTIVARIATE MODEL
C        UNVCON = MATRIX OF CONSTANTS DERIVED IN LEAST SQUARES FOR
C                 UNIVARIATE CASE
C        UNVCOE = MATRIX OF FORECAST COEFFICIENTS FOR UNIVARIATE
C                 MODEL
C        UNVRSQ = RSQUARE STATISTICS FOR UNIVARIATE FORECASTING
C
C      OUTPUT:
C
C        YM(I)  = POINT FORECAST FOR MONTH I
C        YS(I)  = STANDARD DEVIATION OF ACTUAL FLOW AROUND FORECAST
C
C  **********************************************************************
      COMMON/C1/QQ(8,60,12),HTRAN(12,5,5)
      COMMON/C2/COEF(8,12,12,8),RSQUAR(12,12)
      COMMON/C3/UNVCON(12),UNVCOE(12,12),UNVRSQ(12,12)
      COMMON/C4/STDV(12),RHO(12),CONST(12,8)
      COMMON/C6/KWR,IPOL,IFORE,IPERF,IUNIV,IVAR
      COMMON/C10/YM(12),YS(12),YRO(12)
      DIMENSION FLOW(8,60,12)
      DOUBLE PRECISION YS
      NYEARS=54
      NSTATN=8
      IF(IUNIV.EQ.1)NSTATN=1
      DO 10 I=1,NSTATN
      DO 10 J=1,NYEARS
      DO 10 K=1,12
```

```
   10 FLOW(I,J,K)=QQ(I,J,K)
      IYEAR=IY+1
      KMONTH=JMONTH+JLEAD-1
      ICOUNT=0
      DO 150 I=JMONTH,KMONTH,1
      ICOUNT=ICOUNT+1
      IMONTH=I
      JYEAR=IYEAR
      IF(I.GT.12)JYEAR=IYEAR+1
      IF(I.GT.12)IMONTH=I-12
      IF(IPERF.EQ.1)GO TO 145
      DO 140 J=1,NSTATN
      FF=CONST(IMONTH,J)
      IF(IUNIV.EQ.1)FF=UNVCON(IMONTH)
      DO 120 K=1,NSTATN
      DO 120 L=1,12
      KYEAR=IYEAR
      IT=I-L
      IF(IT.GT.12)GO TO 50
      IF(IT.LT.1)GO TO 41
      GO TO 119
   41 IT=IT+12
      KYEAR=IYEAR-1
      GO TO 119
   50 IT=IT-12
      KYEAR=IYEAR+1
  119 IF(IUNIV.NE.1)FF=FF+FLOW(K,KYEAR,IT)*COEF(J,IMONTH,L,K)
      IF(IUNIV.EQ.1)FF=FF+FLOW(1,KYEAR,IT)*UNVCOE(IMONTH,L)
  120 CONTINUE
      FLOW(J,JYEAR,IMONTH)=FF
  140 IF(FF.LT.0.)FLOW(J,JYEAR,IMONTH)=0.
      M=I-JMONTH+1
      R=RSQUAR(M,IMONTH)
      IF(IUNIV.EQ.1)R=UNVRSQ(M,IMONTH)
      V=STDV(IMONTH)*STDV(IMONTH)
      V=V*(1.-R)
      YS(ICOUNT)=SQRT(V)
      GO TO 147
  145 YS(ICOUNT)=.000000000001D0
      GO TO 148
  147 YM(ICOUNT)=FLOW(1,JYEAR,IMONTH)/1000.
      GO TO 150
  148 YM(ICOUNT)=QQ(1,JYEAR,IMONTH)/1000.
  150 YRO(ICOUNT)=RHO(IMONTH)
      RETURN
      END
C     ********************************************************************
C     ********************************************************************
```

```
C  ****************************************************************
      SUBROUTINE DISCIN(JLEAD,IP)
C  ****************************************************************
C  *                                                              *
C  THIS PART OF THE SIMULATION TAKES THE MEANS AND STANDARD
C  DEVIATIONS DERIVED IN SUBROUTINE FORCST AND DISCRETIZES THESE
C  DISTRIBUTIONS INTO 'NQ' DISCRETE VALUES
C
C     DESCRIPTION OF VARIABLES:
C
C      INPUT:
C
C        JLEAD  = LENGTH OF FORECAST INTO THE FUTURE (ALSO EQUALS
C                 NUMBER OF VARIABLES)
C        NQ     = NUMBER OF INFLOW STATES PER VARIABLE
C        YM(I)  = MEAN OF VARIABLE I
C        YS(I)  = STANDARD DEVIATION OF VARIABLE I
C        YRO(I) = LAG-ONE CORRELATION COEFFICIENT OF VARIABLE I
C
C      OUTPUT:
C        Q2(I,J)=J-TH INFLOW OF VARIABLE I
C
C  SUBROUTINES INGA AND GAUSS ARE NUMERICAL PROCEDURES FOR LOCATING
C  THE VALUES OF X AND Q IN FIGURE 3.2 OF BUCHANAN AND BRAS (1981)
C
C  ****************************************************************
     COMMON/A1/NY,NP,NS,NQ,NIT,NWR
     COMMON/A2/Q2(12,5),PTRAN(12,5,5)
     COMMON/C10/YM(12),YS(12),YRO(12)
     COMMON/C11/GAM
     DOUBLE PRECISION YS
     NT=JLEAD
     GAM=0.05
     NT1=NT-1
     DO 10 I=1,NT
     II=I+IP-1
     IF(II.GT.12)II=II-12
     M=NQ
     M1=M-1
     X=(1.-GAM)/M1
     Z=-X/2.
     DO 20 J=1,M1
     Z=Z+X
     CALL INGA(0.,1.,W,Z)
     JJ=NQ-J+1
     Q2(II,JJ)=W*YS(I)+YM(I)
     IF(Q2(II,JJ).LT.0.)Q2(II,JJ)=0.
  20 CONTINUE
     Z=1.-GAM/2.
     CALL INGA(0.,1.,W,Z)
 10  Q2(II,1)=W*YS(I)+YM(I)
     RETURN
     END
```

```
   SUBROUTINE GAUSS(XM,XS,X,P)
   X1=(X-XM)/XS
   X2=X1
   IF(X1.LT.0.)X1=-X1
   B1=.31938153
   B2=-.3565638
   B3=1.7814779
   B4=-1.821256
   B5=1.3302744
   R=.2316419
   T=1./(1.+R*X1)
   C=-X1*X1/2.
   IF(C.LE.-78.)GOTO10
   F=EXP(-X1*X1/2.)/2.5066283
   GOTO20
10 F=0.
20 CONTINUE
   Q=F*(B1*T+B2*T*T+B3*T*T*T+B4*T*T*T*T+B5*T*T*T*T*T)
   P=1.-Q
   IF(X2.LT.0.)P=Q
   RETURN
   END
```

```
      SUBROUTINE INGA(XM,XS,X,P)
      Q=1.-P
      IF(P.LT.0.5)Q=P
      T=SQRT(ALOG(1./(Q*Q)))
      C0=2.515517
      C1=.802853
      C2=.010328
      D1=1.432788
      D2=.189269
      D3=.001308
      XNUM=C0+C1*T+C2*T*T
      XDEN=1.+D1*T+D2*T*T+D3*T*T*T
      X=T-XNUM/XDEN
      IF(P.LT.0.5)X=-X
      X=X*XS+XM
      RETURN
      END
C  *******************************************************************
C  *******************************************************************
```

```
C *********************************************************************
      SUBROUTINE FNDYNP(JLEAD,IP,IY)
C *********************************************************************
C *                                                                   *
C *  SUBROUTINE FNDYNP ORGANIZES A FINITE HORIZON STOCHASTIC          *
C *  DYNAMIC PROGRAM.  SUBROUTINE STORDS IS USED FOR STORAGE          *
C *  DISCRETIZATION, WHILE SUBROUTINE DYNPRO IS VERY SIMILAR TO       *
C *  SUBROUTINE DYNPRO IN APPENDIX B.                                *
C *                                                                   *
C *********************************************************************
      COMMON/A1/NY,NP,NS,NQ,NIT,NWR
      COMMON/A2/Q2(12,5),PTRAN(12,5,5)
      COMMON/A3/TARGI(12),TARGE(12),EVRATE(12),SUDGEB(12)
      COMMON/A9/REL(12,25,5),BOUN(12,25,5)
      COMMON/C1/QQ(8,60,12),HTRAN(12,5,5)
      COMMON/C12/F2(25,5)
      DO 5 I=1,NP
      DO 5 J=1,NQ
      DO 5 K=1,NQ
    5 PTRAN(I,J,K)=HTRAN(I,J,K)
      JMONTH=IP
      DO 10 I=1,JLEAD
      II=I+JMONTH-1
      IF(II.GT.NP)II=II-NP
      DO 10 J=1,NQ
      Q2(II,J)=Q2(II,J)-SUDGEB(II)
   10 IF(Q2(II,J).LT.0.)Q2(II,J)=0.
      MM=JMONTH+JLEAD
      IF(MM.GT.NP)MM=MM-NP
      DO 20 I=1,NS
      DO 20 J=1,NQ
   20 F2(I,J)=BOUN(MM,I,J)
      CALL STORDS
      CALL DYNPRO(JMONTH,JLEAD,IY)
      RETURN
      END
C *********************************************************************
C *********************************************************************
```

```
C  ******************************************************************
      SUBROUTINE STORDS
      COMMON/A1/NY,NP,NS,NQ,NIT,NWR
      COMMON/A4/RMAX,SMAX,SMIN,DELTAR,RATE,ITOSH,STL
      COMMON/C9/ST1(25),ST2(25),RLS(25,5)
      NS1=NS-1
      NS2=NS-2
      ST1(1)=SMAX
      ST1(NS)=SMIN
      XX=(ST1(1)-SMIN)/NS2
      DO 30 J=2,NS1
   30 ST1(J)=SMIN+XX*(NS2+1.5-J)
      DO 40 I=1,NS
   40 ST2(I)=ST1(I)
      RETURN
      END
C  ******************************************************************
C  ******************************************************************
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C    *******************************************************************
      SUBROUTINE DYNPRO(JMONTH,JLEAD,IY)
      COMMON/A1/NY,NP,NS,NQ,NIT,NWR
      COMMON/A2/Q2(12,5),PTRAN(12,5,5)
      COMMON/A3/TARGI(12),TARGE(12),EVRATE(12),SUDGEB(12)
      COMMON/A4/RMAX,SMAX,SMIN,DELTAR,RATE,ITOSH,STL
      COMMON/C1/QQ(8,60,12),HTRAN(12,5,5)
      COMMON/C6/KWR,IPOL,IFORE,IPERF,IUNIV,IVAR
      COMMON/C9/ST1(25),ST2(25),RLS(25,5)
      COMMON/C11/GAM
      COMMON/C12/F2(25,5)
      DIMENSION F1(25,5)
      JY=IY
      IP1=JMONTH-1
      IF(IP1.EQ.0)JY=IY-1
      IF(IP1.EQ.0)IP1=NP
      DO 5 J=1,NQ
      PTRAN(JMONTH,J,1)=GAM
      DO 5 K=2,NQ,1
    5 PTRAN(JMONTH,J,K)=(1.-GAM)/FLOAT(NQ)
      DO 6 I=1,NQ
    6 Q2(IP1,I)=QQ(1,JY,IP1)/1000.-SUDGEB(IP1)
      DO 1000 IP=1,JLEAD
      IT=JMONTH+JLEAD-IP
      IT1=IT+1
      IF(IT.GT.NP)IT=IT-NP
      ITM1=IT-1
      IF(ITM1.EQ.0)ITM1=NP
      IF(IT1.GT.NP)IT1=IT1-NP
      DO 100 IS=1,NS
      STOR=ST1(IS)
      DO 99 IQ=1,NQ
      JQ=IQ-1
      IF(IPERF.NE.1)GO TO 12
      IF(IQ.GT.1)F1(IS,IQ)=F1(IS,JQ)
      IF(IQ.GT.1)RLS(IS,IQ)=RLS(IS,JQ)
      IF(IQ.GT.1)GO TO 99
   12 X=1.E30
      RAUX=RMAX
      IF(IQ.GT.1)RAUX=RLS(IS,JQ)+2.0
      IF(RAUX.GT.RMAX)RAUX=RMAX
   50 XLITLH=0.
      NN=NQ
      IF(IPERF.EQ.1)NN=1
      DO 55 N=1,NN
      IF(IPERF.EQ.1)PTRAN(IT,IQ,N)=1.0
      YY=Q2(IT,N)
      CALL FINSTO(IT,YY,STOR,RAUX,SF,RT,EV)
      RELS=RAUX
      IF(SF.LE.SMAX)GO TO 51
      SF=SMAX
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      CALL EVTOSH(STOR,SF,IT,EV1,RT1)
      RELS=STOR-SF+YY-EV1-RT1
      CALL FINSTO(IT,YY,STOR,RELS,SF,RT,EV)
      IF(SF.LE.SMAX)GO TO 52
      RELS=RELS+SF-SMAX
      SF=SMAX
      GO TO 52
   51 IF(SF.GE.SMIN)GO TO 52
      IF(N.GT.1)GO TO 54
      IF(RAUX.GT.0.)GO TO 60
      RAUX=0.
      XLITLH=1.E30
      GO TO 57
   54 SF=SMIN
      CALL EVTOSH(STOR,SF,IT,EV1,RT1)
      RELS=STOR-SF+YY-EV1-RT1
      IF(RELS.LT.0.)GO TO 53
      CALL FINSTO(IT,YY,STOR,RELS,SF,RT,EV)
      IF(SF.GE.SMIN)GO TO 52
      RELS=RELS-SMIN+SF
      IF(RELS.LT.0.)GO TO 53
      SF=SMIN
      GO TO 52
   53 RELS=0.
      CALL FINSTO(IT,YY,STOR,RELS,SF,RT,EV)
   52 CALL BENEF1(RELS,STOR,SF,IT,BB,GN,RELTUR,SPILL)
      CALL IDENTS(SF,J1,J2,ALFA1,ALFA2,IT,0)
   55 XLITLH=XLITLH+(1./(1.+RATE))*PTRAN(IT,IQ,N)*(BB
     &+(F2(J1,N)*ALFA1+F2(J2,N)*ALFA2))
      IF(XLITLH.GE.X)GO TO 99
   57 X=XLITLH
      F1(IS,IQ)=X
      RLS(IS,IQ)=RAUX
   60 IF(RAUX.LE.0.)GO TO 99
      RAUX=RAUX-DELTAR
      IF(RAUX.LE.0.)RAUX=0.
      GO TO 50
   99 CONTINUE
  100 CONTINUE
      DO 110 I=1,NS
      DO 110 J=1,NQ
  110 F2(I,J)=F1(I,J)
 1000 CONTINUE
      RETURN
      END
C    ***************************************************************
C    ****************************************************************
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