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The development of hydroelectric facilities in regions where power demands are met primarily by thermal generating facilities assumes that the hydroelectric generation will be used for supplying power during peak demand periods. Consequently the planning of hydroelectric facilities requires consideration of both the capacity and energy components of power supply. In a system of hydroplants in various interacting configurations and many thermal plants with varying efficiencies and at various locations with respect to load centers, it is a complicated process to develop operation rules that match supplies with demands. This paper is directed toward the development of a long-term operation plan for a system of reservoirs in the Arkansas River, White River and Red River basins.

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SYSTEM SIMULATION FOR INTEGRATED USE OF HYDROELECTRIC AND THERMAL POWER GENERATION

by

Augustine J. Fredrich[1] and Leo R. Beard[2]

INTRODUCTION

The development of hydroelectric generating facilities in regions where power demands are met primarily by thermal generating facilities is usually based on the assumption that the hydroelectric generation will be used for supplying power primarily during peak demand periods. As a result of this assumption, the planning of hydroelectric facilities requires consideration of both the capacity and energy components of power supply. The demands for electrical energy can vary greatly from minute-to-minute, day-to-day, and month-to-month. The generation of electrical energy must be varied accordingly because the storage of large amounts of electrical energy for instant use is not technologically feasible. Hydroelectric generation is particularly useful in meeting the sudden, short-term demands for power because hydroelectric units can be placed "on-line" with little or no preparation, provided that the capacity of the hydroelectric installation is large enough to meet the demands, and provided that water is available in a sufficient quantity to meet the energy requirements associated with these demands.

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The relationship between capacity requirements and the associated energy requirements is not constant because of variations in the length of periods of peak capacity demands. However, the energy requirements for peaking operation of hydroelectric projects often are assumed to follow very closely the seasonal variation in total energy requirements in a power supply area. Thus, from a knowledge of the capacity available from hydroelectric installations and a knowledge of seasonal variation in total energy requirements for a given power supply area, it is possible to determine the capacity and energy demands on a hydroelectric system.

In some cases, hydrologic conditions do not permit the generation of hydroelectric energy in exact conformance with the seasonal variations in power demands--particularly during periods of adverse streamflow conditions. Since the rate of water availability does not correspond exactly to the rate of water need for power generation, water must often be stored in anticipation of future periods of high need. These periods may be hours, days or even years away. The exact amount of storage needed cannot be determined, since future demands and supplies cannot be forecasted accurately. In order to provide sufficient contingency to assure that an adequate supply of electrical energy will be available in the future, combinations of past supply and demand events are examined, and rules are formulated that would give a high degree of assurance of dependable supplies. In a system of many hydroplants in various interacting configurations and many thermal plants with varying efficiencies and at various locations with respect to load centers, it is an extremely complicated process to develop operation rules that most effectively match supplies from available power sources with demands.

When changes in operational objectives during the life of a project necessitate purchases of thermal energy to fulfill marketing commitments or when, for any reason, it becomes necessary to consider integrated operation of thermal and hydroelectric resources, the availability and cost of thermal energy can become an important factor in both short-term and long-term operation decisions. It often becomes necessary to integrate some consideration of the thermal energy resources into hydrologic studies of the operation of hydroelectric projects in order to develop operation plans that will provide for optimal use of the hydroelectric resource. The work described in this paper is directed toward the development of a long-term operation plan for a system of federally-owned reservoir projects in the Arkansas River, White River and Red River basins under such a condition.

THE ARKANSAS-WHITE-RED SYSTEM

Twenty-three reservoirs in the states of Arkansas, Oklahoma and Missouri (figure 1) comprise the Arkansas-White-Red (AWR) system. One reservoir, constructed and owned by an investor-owned utility, began operation in 1913. The first federally-owned project began operation in 1944. The reservoir projects each serve one or more of the following purposes: flood control, hydroelectric power, navigation, water supply, recreation, water quality control and fish and wildlife enhancement.

Two of the projects are owned and operated by the Grand River Dam Authority of the state of Oklahoma, one project is owned and operated by an investor-owned utility, and the remaining 20 projects are owned and operated by the federal government. There are hydroelectric installations at 13 of the federally-owned projects and at each of the three non-federal projects. Power generating facilities are under construction at three additional federal projects. Although the three river basins are hydraulically independent, the federal hydroelectric installations are electrically interconnected so that they can be operated as a system.

Operation rules for the individual reservoir projects were formulated during the planning and design stages of project development. These rules have been modified through the years to reflect changes in operation objectives and to account for some form of system operation. However, current operation rules do not account for all of the system interactions that are believed to be significant. In particular, the current operation rules do not completely consider the system power operation of the interconnected power installations. A study to develop new system operation rules is currently underway. The primary objective of this study is to develop system operation rules that will provide for optimal use of the hydroelectric resources of the system without adversely affecting any of the other approved purposes for which the system operates.

POWER OPERATION CONSIDERATIONS

The first federal projects in the AWR system were large, multiple-purpose, storage reservoirs with relatively large amounts of power drawdown storage. The large amount of power drawdown storage permitted the generation of large amounts of hydroelectric energy. Consequently, the hydroelectric installations operated at relatively high (25 to 40 percent) plant factors; that is, the ratio of average annual generation to installed capacity was relatively high. However, as the demands for power in this region increased in the 1950's, the demand for peaking capacity to meet short-duration peak loads increased. In order to meet the demands for peaking capacity, it was desirable to decrease the power drawdown so that the higher head necessary to produce the installed capacity could be maintained throughout periods of adverse streamflow conditions. This increased the minimum peaking capability of the projects, but the resultant loss of power drawdown storage effected a substantial loss in energy generation--particularly during periods of low streamflow when a significant portion of the energy generation is derived from stored water. This loss in energy was partially offset by a reduction in the energy required to support the peaking capacity. However, the energy requirement reduction did not fully offset the loss in energy incurred by reduction of the power drawdown storage, and it became necessary to consider thermal energy purchases to augment the supply of hydroelectric energy during periods of adverse streamflow.

The requirements for purchased thermal energy increased when several run-of-river power installations with relatively large installed capacities were developed as part of the Arkansas River Navigation Project. These projects are capable of producing large amounts of energy during normal and unusually high streamflow conditions; but because there is little or no storage available at the project sites, their energy production is greatly reduced during periods of low streamflow. To some extent, hydrologic diversity among the three river basins is expected to provide hydroelectric energy that can be used to support the peaking capacity of the entire system if periods of low streamflow are not too long or if the low streamflow conditions do not prevail throughout the system. However, experience has indicated that marketability of the output from these projects can be enhanced if thermal purchases can be scheduled during severe droughts and during some other below-normal streamflow conditions.

The Southwestern Power Administration has the responsibility for marketing the power output from the federal projects. This federal agency must secure contracts for sale of the capacity and energy and must also enter into contracts for purchase of thermal energy, if purchased energy is necessary to improve the marketability of the output from the federal projects. Since this agency does not own thermal generating facilities, the thermal energy must be purchased through contracts at costs which are dictated by the quantity of energy required and the availability of energy at the time that purchases are needed. Contractual arrangements for the sale of energy from the federal projects have resulted in a division of the power projects in the interconnected system. As shown on the schematic diagram in figure 2, the output of two federal projects, Table Rock and Bull Shoals on the White River, is combined for sale in one power market. The output of the remaining federally-owned projects is combined for sale in a different power market. The three non-federal projects, which contribute no power generation to the federal system--but which do affect the water conditions in the system, in effect form a third system. Each system has a different seasonal variation of capacity and energy requirements and a different set of operating constraints. The hydrologic studies necessary to develop a comprehensive operation plan for these systems are obviously complex--even from the standpoint of power alone. When the operation constraints resulting from the operation for other purposes are added to the study, it becomes obvious that some type of relatively detailed analysis will be necessary to achieve satisfactory system operation plans.

THE AWR SYSTEM OPERATION STUDY

The development of a system operation plan for the AWR system is based on a sequential hydrologic routing (operation simulation study) of 46 years of historical monthly streamflow data. The hydrologic conditions during this 46-year period vary considerably, and it is believed that the results of the studies will provide representative appraisals of the system performance under both high and low streamflow conditions as well as a representative appraisal of the long-term performance of the system. A basic description of the digital simulation model used for these routing studies is contained in a computer program description entitled "HEC-3, Reservoir Systems Analysis" (4). The hydrologic and physical data used in the analysis of the system is contained in a report entitled "AWR System Conservation Studies: Volume 1, Basic Data" (5). The general study procedure has been described in several earlier technical papers (1), (2), (3).

Traditionally, sequential routing studies for analyzing the operation of reservoir projects or systems have specified system and project power generation requirements in terms of energy alone, despite the fact that capacity requirements are at least as important in systems where the primary purpose of hydroelectric generation is to supply peak load demands. A pseudo-capacity requirement in the form of minimum at-site energy requirements is sometimes used to insure that some generation is possible at all times--thus guaranteeing that the capacity of the project would be available to meet peak capacity demands. Also, most routings of this type include a provision for calculating the minimum peaking capability of each project during each period as a function of the minimum head during the period. This permits an after-the-fact appraisal of the peaking capability of the project, but it does not permit consideration of peaking capability requirements in determining the operation for any given period.

In the type of analysis required for studying the operation of the AWR system, none of the preceding methods of representing the hydroelectric generation requirements are completely satisfactory. The AWR hydroelectric system is essentially committed to supplying power to meet peak demands, and the energy requirements associated with the peak capacity demands are relatively small. Consequently, variations in energy demands do not fully reflect the variations in demand on the hydroelectric system.

Because the hydroelectric energy availability from the system as a whole and from individual projects within the system varies widely in response to extreme variations in hydrologic conditions, it is not feasible to use energy alone as a measure of hydroelectric generation. There are, for example, cases when high streamflow on the Arkansas River produces enough energy from the run-of-river projects on that stream alone to more than meet the system energy requirements, although the capacity associated with this energy is less than one-third of the system capacity requirement. This condition is illustrated on figure 3. The load-duration curve which the system is to supply is shown as curve ACFG. The area within this curve is the energy requirement for the month. The energy generated at two run-of-river projects with a combined available capacity of 270 megawatts is shown by the rectangle ABEG. The energy represented by the portion of the rectangle labeled DEF exceeds the unsatisfied energy requirement (area BCD) but is not useable in meeting the load. If one were analyzing energy alone, it would be concluded that the requirement had been satisfied, since the energy generated exceeds the energy required.

The foregoing type of anomaly, as well as the necessity for a relatively accurate determination of the quantity and timing of thermal energy purchases, dictated that the power requirement should be specified in terms of both capacity and energy for this study. A direct solution to the development of optimum operation rules is not available. The technique used consists of postulating (a) a set of guide curves that determine when and how much hydroelectric power will be generated in relation to current demands and the availability of thermal power and (b) a set of storage balance curves that determine the distribution of water release among the various reservoirs in the water resource system. These sets of curves are tested with respect to historical hydrologic conditions and modified as necessary to improve the overall system performance.

INTEGRATION OF HYDROELECTRIC AND THERMAL RESOURCES

In order to obtain an accurate representation of the system power requirements, it is desirable to specify the requirements in terms of the system load-duration curve. If the power generation from the hydroelectric system can be scheduled to conform closely with the load-duration curve, it is virtually certain that the projects can be operated in real time to meet the power demands. Furthermore, the magnitude of required thermal energy purchases will be more accurately defined. In the case of the AWR system, monthly load-duration curves for the power requirements imposed on the hydroelectric system could be developed from contractual obligations. The load-duration curves shown in figures 3 and 4 are typical curves for this system. Because the system supplies power primarily to meet peak power demands, the base load (the power demand which exists 100 percent of the time) is very small and the load factor (ratio of average demand to maximum demand) for the hydroelectric system is much lower than the load factor for an entire power supply region.

In order to avoid the problems created by specifying system power demands in terms of energy alone, a computation technique was developed to permit specification of the system power demand in terms of monthly load-duration curves. Each monthly load-duration curve is divided into segments along the horizontal, or percent-of-time, axis. Any number of segments may be used, and the segments may vary in size. Each segment is specified in terms of energy requirement for the segment (ratio of segment area to total area under the load curve) and time duration (percent of time during the month that the energy must be generated). The objective of the segmentation is to obtain, for each month, a set of energy requirement segments that, in composite, form a representation of the load-duration curve. A typical segmetation of a load-duration curve is shown on figure 4.

The load-duration information is used in the allocation of system power demands to determine the contribution that each project must make to meet the system demand. The allocation of power generation requirements to the projects in the system is based on the level of storage at the project (relative to other projects in the system) and on the total system power requirement for the segment. Each segment is analyzed separately, beginning with the segment which has the greatest capacity demand. The energy required at each project to meet the demand in each segment is calculated, and the total energy required from each project each month is determined by obtaining for each project the sum of the segmental energy requirements for that month. A representation of the total project energy generation for each project and a possible arrangement that would satisfy the system load requirement is shown on figure 4.

The necessity for thermal energy purchases in a given period is dependent upon the state of the system in that period. The decision parameter controlling thermal energy purchases is system energy in storage. System guide curves composed of monthly target system energy-in-storage values are determined on the basis of thermal purchases required to meet system power demands under the most adverse streamflow conditions experienced or anticipated. A specified maximum thermal energy purchase is associated with each guide curve. The guide curves, when properly defined, serve the same purpose for a hydroelectric power system that operating rule curves or flood control diagrams serve for a water supply or water control system. They define system states which, based on historical hydrologic sequences, indicate the necessity for modification of operation objectives and operation policies. The set of guide curves shown in figure 5 illustrates the nature of the guide curves contemplated for use in the AWR system.

In the sequential routing study, the system energy in storage is calculated each month based on the projected withdrawals of energy from storage due to hydroelectric generation in that month. The calculated value is then compared with the target guide curve value for that month. If the actual energy in storage is below a target guide curve value, thermal energy purchases are scheduled. The thermal energy purchase is limited to the maximum energy purchase associated with the particular guide curve or to the thermal energy purchase which will reduce the hydroelectric generation so that system energy in storage just reaches the target guide curve value. The purchased thermal energy is then treated as an available resource along with the hydroelectric resources in meeting the system power requirements for that month.

SUMMARY AND CONCLUSIONS

The ability to simulate both capacity and energy demands on a hydroelectric system and the capability for including simulation of thermal resources is a significant step toward developing an operation plan that will provide for optimal utilization of the hydroelectric resource. The computer program used in the AWR system studies has the capability for associating economic benefits or costs to the outputs of the system. This suggests that the variations in costs of purchased thermal energy could be included as a consideration in both short-term and long-range operation decisions. However, since the AWR system serves a number of purposes other than hydroelectric power and since the benefits from some of these purposes are difficult to measure, it appears that a mathematically optimized system operation plan will not be obtainable in the near future. What is possible though is to simulate the operation of the system under a series of operation plans, each of which would provide different levels of service to the various purposes. The results of each plan, in terms of costs of thermal energy purchased and revenue lost through reduction of hydroelectric generation, could then be evaluated and weighed against the services provided to other purposes.

The techniques described herein for the integration of hydroelectric and thermal resources in meeting power demands in a system with both storage and run-of-river hydroelectric projects provide a tool for much more realistic analysis of the operation of such systems. Through proper use of this tool, it should be possible to develop system operation plans that will minimize purchases of thermal energy and maximize the use of the hydroelectric resources.

ACKNOWLEDGEMENTS

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REFERENCES

1. Davis, C. Pat, and Fredrich, Augustine J., "Development of System Operation Rules for an Existing System by Simulation," Technical Paper No. 31, The Hydrologic Engineering Center, U. S. Army Corps of Engineers, Davis, California, 1971.

2. Fredrich, Augustine J., "Hydroelectric Power Analysis in Reservoir Systems," Technical Paper No. 24, The Hydrologic Engineering Center, U. S. Army Corps of Engineers, Davis, California, 1970.

3. Fredrich, Augustine J., "Digital Simulation of an Existing Water Resources System," Proceedings of the IEEE-ORSA Joint National Conference on Major Systems, Anaheim, California, 1971.

4. U. S. Army Corps of Engineers, "HEC-3: Reservoir System Analysis," Generalized Computer Program Description, The Hydrologic Engineering Center, Davis, California, 1971.

5. U. S. Army Corps of Engineers, "Arkansas-White-Red Rivers: System Conservation Studies, Volume 1, Basic Data," Southwestern Division, Dallas, Texas, 1970.

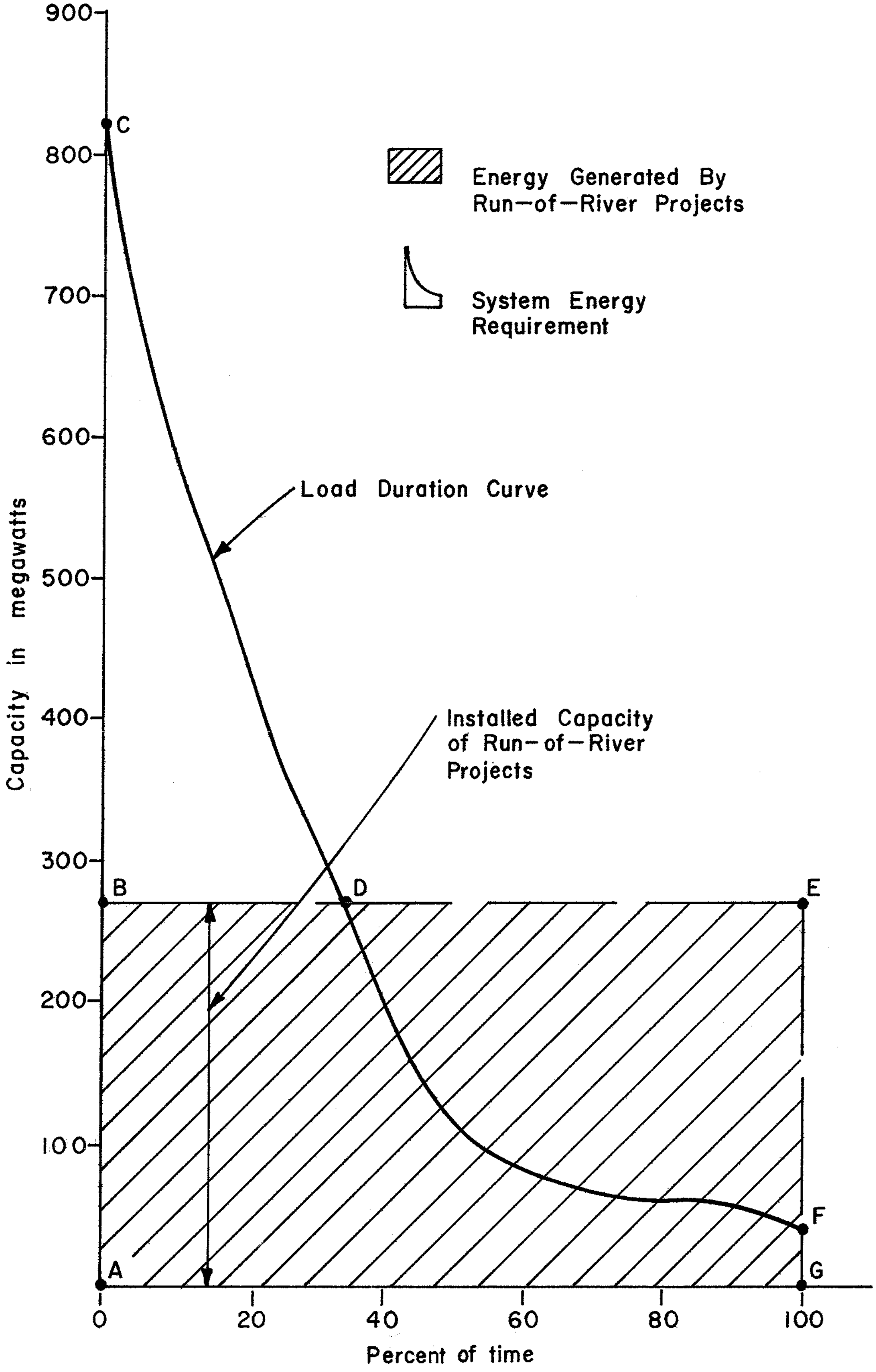
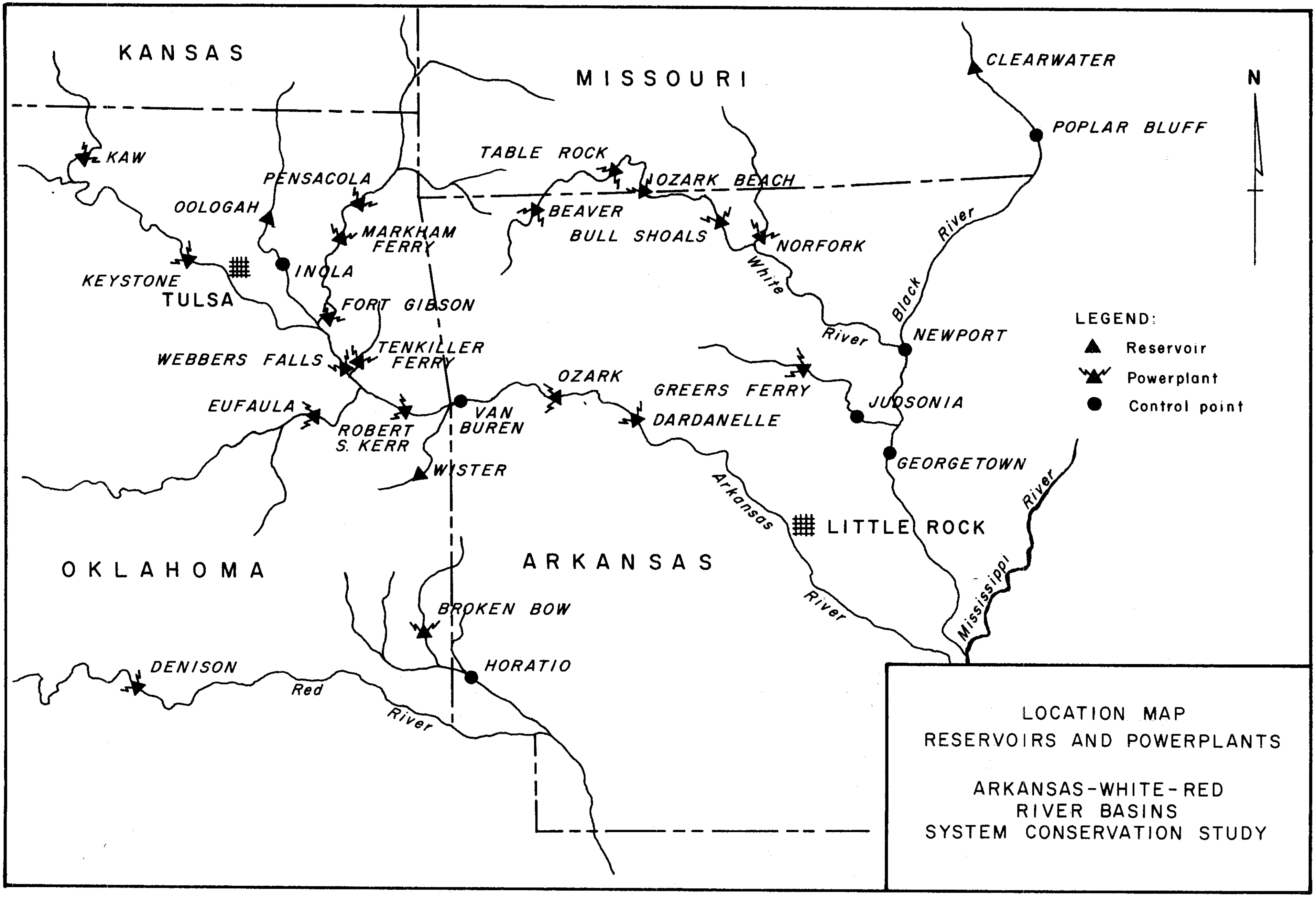
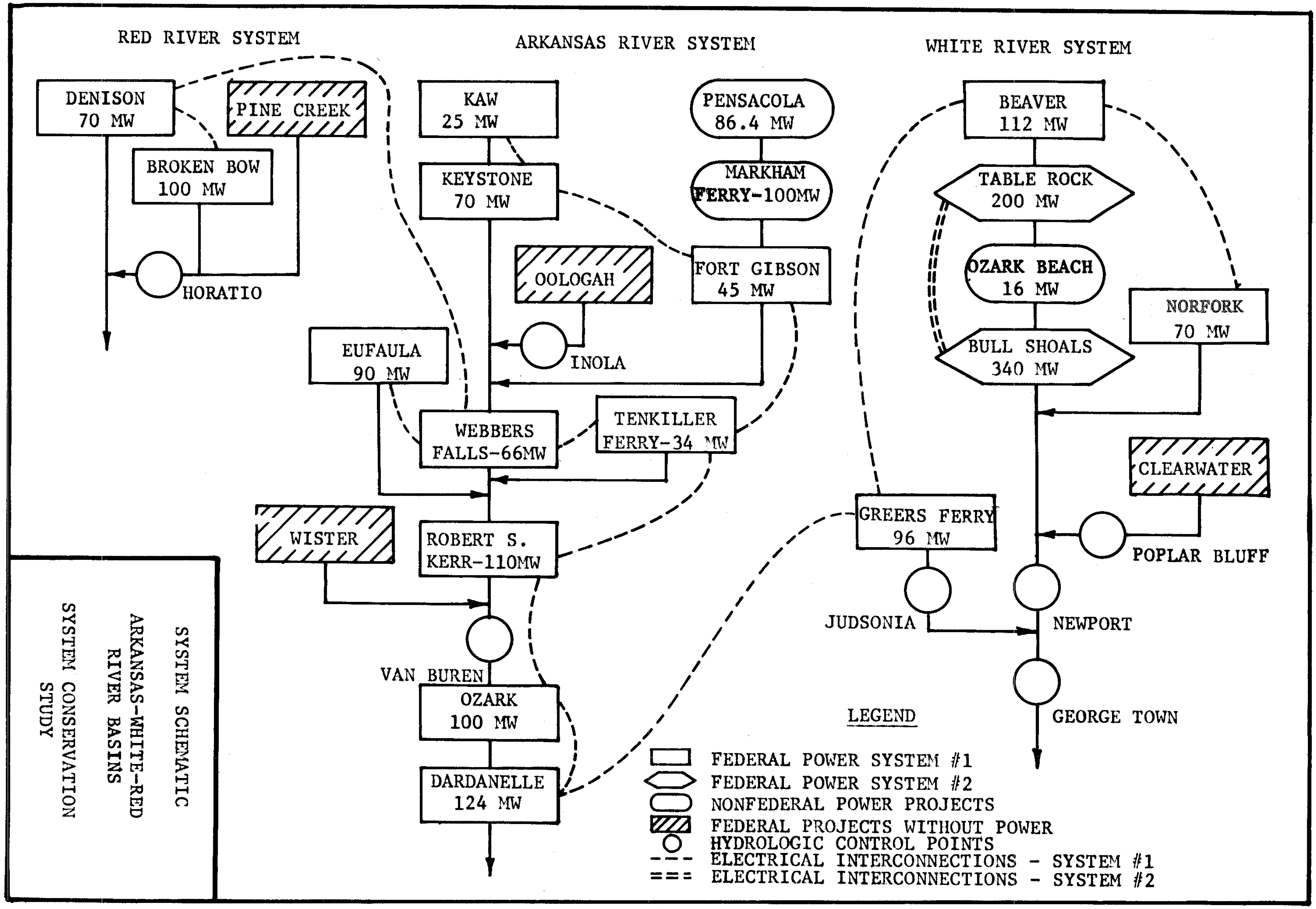


Figure 3 - Load duration curve - January



LOCATION MAP
RESERVOIRS AND POWERPLANTS

ARKANSAS-WHITE-RED
RIVER BASINS
SYSTEM CONSERVATION STUDY



SYSTEM SCHEMATIC

ARKANSAS-WHITE-RED
RIVER BASINS

SYSTEM CONSERVATION
STUDY

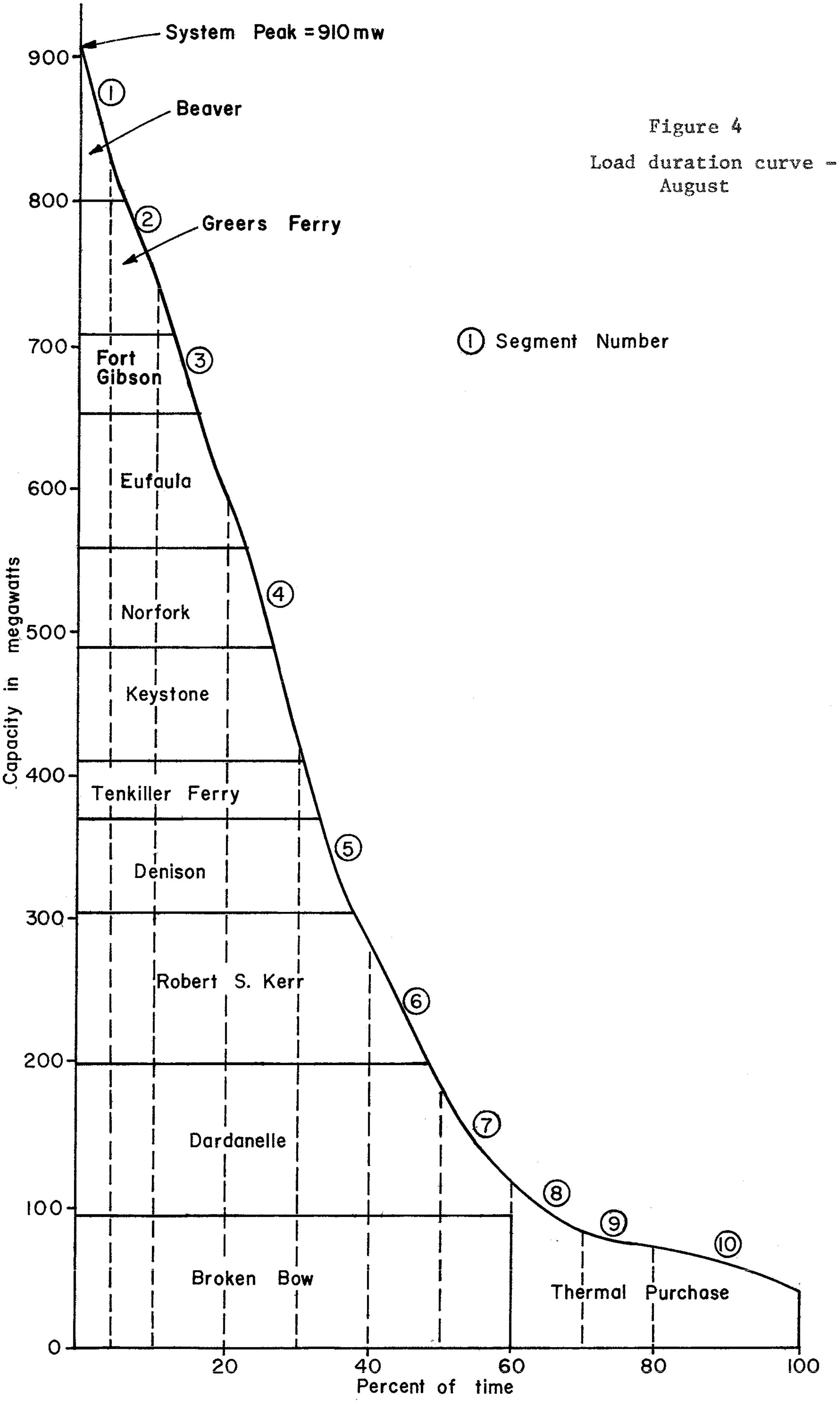


Figure 4

Load duration curve - August

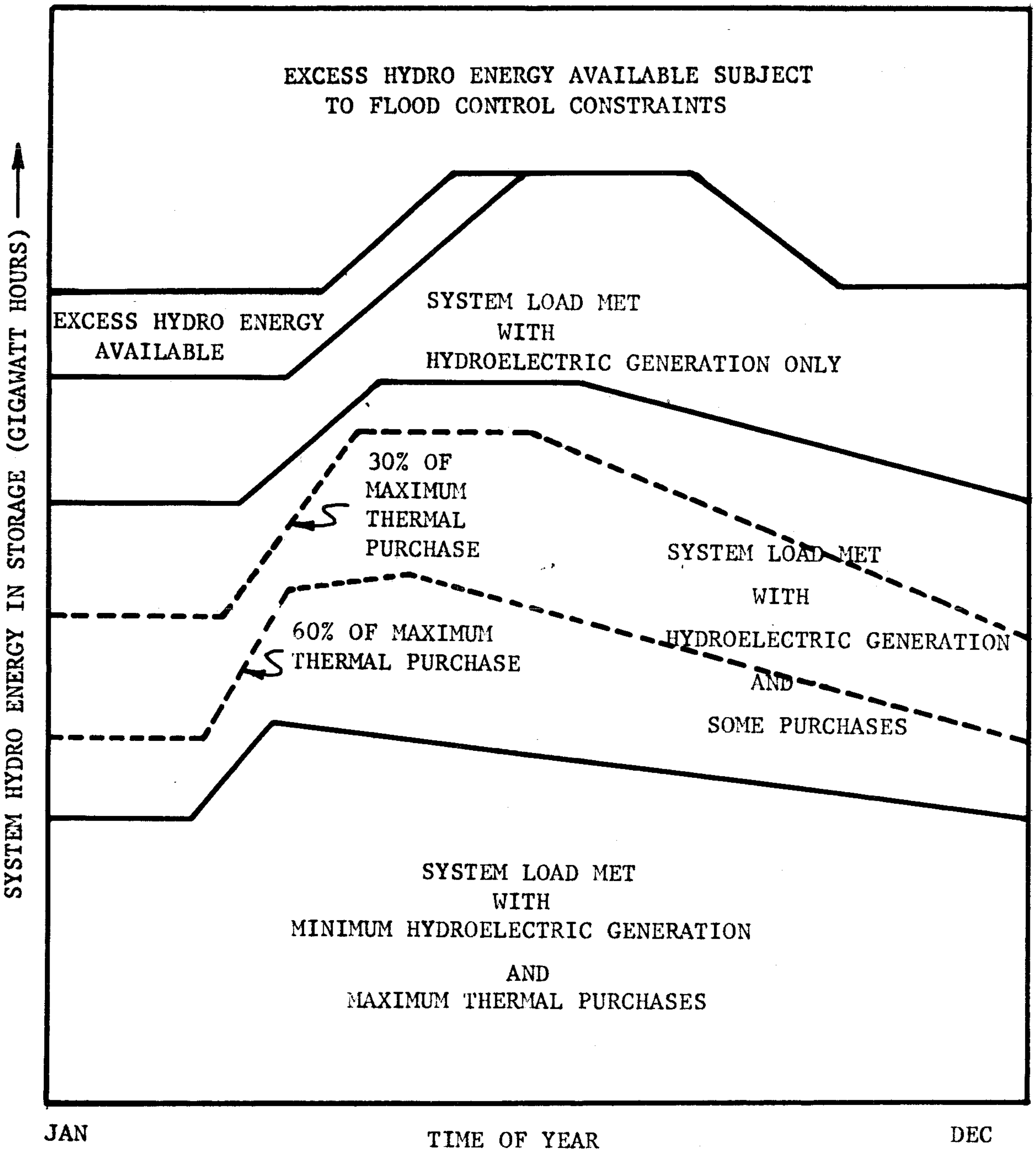


ILLUSTRATION OF SYSTEM
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RIVER BASINS
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