APPENDIX A
CVSIM AND WATER RESOURCE ANALYSIS METHODOLOGY

CARMEL VALLEY SIMULATION MODEL (CVSIM)

CVSIM is a mathematical model operated on a computer that simulates the hydrology and water management operations of the Monterey Peninsula area. The District developed the model as a planning tool to evaluate the impacts of various water supply alternatives.

Description

The computer model describes the Monterey Peninsula Water Resource System (MPWRS), which consists of the Carmel River drainage basin, the Carmel Valley aquifer, and the Seaside Coastal subbasin. The model operates on a daily time step. The model uses reconstructed values for daily streamflows above Los Padres Reservoir and at nine tributaries of the Carmel River. The reconstructed streamflows are based on U. S. Geological Survey (USGS) data recorded at Robles del Rio between October 1957 and September 1987. Mainstem flows were reconstructed by "routing" the recorded mean daily flow at Robles del Rio upstream through the system. In this routing the flow was adjusted for tributary inflows, reservoir losses, and diversions. Tributary inflows were estimated using regression equations developed for each tributary based on USGS data at Robles del Rio and MPWMD flow measurements on the selected tributaries.

Daily reconstructed flows for the 1957 to 1987 period were aggregated into monthly sums and reordered to represent the daily flow record from October 1901 to September 1957. The reordering was based on the monthly flow record at San Clemente that had been reconstructed by the U. S. Army Corps of Engineers (USCE). The USCE reconstruction was based on a correlation between annual flows of the Carmel River at San Clemente and Arroyo Seco near Soledad for the years 1938 to 1978.

System Representation

For Los Padres and San Clemente Reservoirs, the model simulates the following water movements: inflows, diversions, and reservoir effects (releases, spills, evaporation, and leakage). Figure A-1 shows reconstructed annual flows for the Carmel River at the San Clemente and Los Padres Dams. For the lower Carmel River watershed, the model simulates the following flows: upstream mainstem inflow, reconstructed tributary inflows, pumpage, and aquifer effects (recharge, subsurface flow, evapotranspiration, and baseflow). For purposes of analysis, the Carmel Valley Aquifer is divided into four subbasins: AQ1, AQ2, AQ3, and AQ4. For the Seaside Coastal subbasin, the model simulates subsurface inflow, outflow, and pumpage. Aquifer effects from recharge and evapotranspiration are included in the estimate of subsurface inflow.

System Parameters

The model specifies the following parameters in simulating MPWRS:

Storage: Reservoir usable storage equals total storage minus sedimentation volume. Usable storage for the Carmel Valley aquifer is the portion of total storage that is above the perforations of the existing Cal- Am wells and can be pumped without resulting in seawater intrusion or adverse environmental impacts to the Lagoon. Usable storage for the Seaside Coastal subbasin is the portion of total inland storage that is above mean sea level. It should be noted that all storage calculations in CVSIM assume that aquifer depletions and associated drawdowns are distributed uniformly. Thus, CVSIM storage estimates represent regionalized values and do not reflect localized impacts.

Inflows: The daily streamflows recorded by the U.S. Geological Survey on the Carmel River at Robles del Rio for the period 1957 to 1987 were used to develop a relationship between daily streamflows and monthly streamflows. Estimates of daily streamflows for each of the tributaries were made by correlation with the flow at Robles del Rio.

Demand: Water demand consists of municipal supply and instream flow requirements (i.e. fishery flow releases). Municipal use includes supply by California-American Water Company (Cal-Am) and non-Cal-Am demand (which includes pumpage by small distribution systems and private well pumpers). Municipal demands increase up to a maximum of 2.5 percent per year during dry conditions and 5.0 percent per year during critically-dry conditions. During wet conditions, demands decrease up to 8.0 percent per year. Instream flow releases for the steelhead fishery depend on whether existing facilities or future facilities are modeled.

Operational Capacities: The model specifies maximum facility capacities for both Cal-Am facilities and non-Cal-Am facilities. For the Cal-Am system, the capacities include surface water diversion, groundwater pumping, and water treatment facilities. In CVSIM, surface water diversions at San Clemente Dam are limited according to an operation schedule that was developed as part of an interim agreement involving MPWMD, Cal-Am, and CDFG. The operation was designed to satisfy an annual surface water diversion target of 29 percent of total Cal-Am system production. For non-Cal-Am users, groundwater production limits the operational capacities. Specific functions relate well pumping capacity to groundwater storage in each aquifer subbasin.

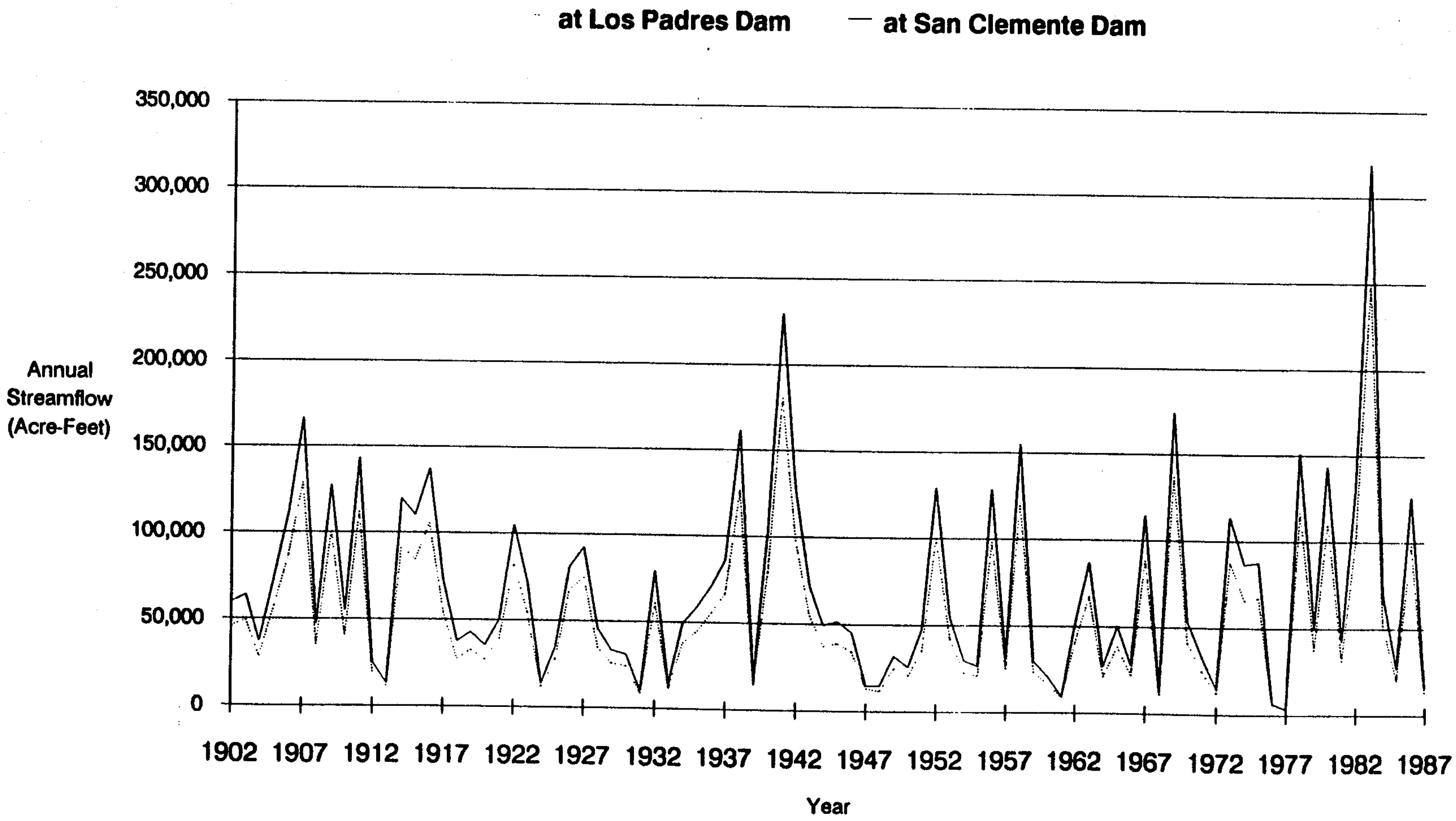
Hydrologic Processes: The water balance equations for the surface and subsurface reservoirs include the following hydrologic processes:

- Aquifer recharge
- Baseflow
- Subsurface flow
- Riparian evapotranspiration
- Reservoir evaporation and leakage

CVSIM Management and Operations

Operation of MPWRS by conjunctive-use management maximizes the benefits from the surface and groundwater resources. The operating rules reflect District policy and are consistent with present and projected Cal-Am production facilities. All water management decisions operate in a real-time context based on comparisons between system supply and demand. The model considers both short-term (daily) and long-term (seasonal and annual) comparisons. General water management decisions are made at the beginning of each month in a downstream, sequential order. Specific water production sequences and fishery flow releases are determined daily.

FIGURE A-1
RECONSTRUCTED ANNUAL FLOWS
1902 to 1987



Source: CVSIM, 1989.

Model Calibration

CVSIM was calibrated in March 1987 using two flow periods: 1976-1978 and 1984-1985. The 1976-1978 period was chosen because it represents the critical dry period and includes an above-normal year. The 1984-1985 period was used because it represents a below-normal period and includes pumpage from Cal-Am's four new wells in the lower Carmel Valley subbasins. The emphasis in the calibration was placed on the 1976-1978 period; this is the project design period and, from a water management perspective, is the most critical period. Observed data were available at two mainstem flow sites (Robles del Rio and near Carmel), two reservoirs (Los Padres and San Clemente), and two subbasins of the Carmel Valley aquifer (AQ3 and AQ4).

During the calibration process, the simulated groundwater levels in Subbasin AQ3 of the Carmel Valley aquifer were less than the observed groundwater levels for the period 1976 to 1978. To bring the values closer to agreement, daily subsurface inflow into Subbasin AQ3 was increased from 0.50 acre feet to 7.62 acre feet. The subsurface outflow to Subbasin AQ4 is 2.43 acre feet per day. The difference between inflow to and outflow from Subbasin AQ3 is 5.19 acre feet per day, or 1,894 acre feet per year. The source of the higher subsurface inflow is uncertain; it may be from increased seepage from the sandstone formation along the valley walls during extreme, prolonged drawdown conditions, from septic tank seepage, or from subsurface inflow from Subbasin AQ2. Or the increase could be the result of inaccuracies and limitations in the data available for the calibration period.

Additional calibration work on the CVSIM model will be performed in 1990. Recent data (i.e., 1988 and 1989) will be used.

WATER RESOURCE IMPACT ANALYSIS

CVSIM simplifies the complex hydrologic and operational system of MPWRS by representing the Carmel River, the Carmel Valley aquifer, and the Seaside Coastal subbasin as a series of interconnected reservoirs and aquifer subbasins. The simulated streamflows for the Carmel River are based on mainstream and tributary flows, aquifer recharge, evapotranspiration, and pumpage effects. The Seaside aquifer is simulated as a completely separate aquifer with no hydrologic connection to Carmel River or the Carmel Valley aquifer. For the Seaside aquifer, a single value inflow represents net inflow.

The Carmel Valley aquifer has four subbasins, designated as AQ1, AQ2, AQ3, and AQ4. Groundwater flow is estimated for each subbasin based on aquifer hydraulic conductivity, energy gradient, and aquifer cross-sectional area. Mathematical equations based on a set of monthly percolation-runoff-drawdown curves developed by the U. S. Army Corps of Engineers for Carmel River are used to simulate surface water recharge to the groundwater. CVSIM assumes all groundwater recharge (to the Carmel Valley aquifer) comes from Carmel River via infiltration, and aquifer drawdown within each subbasin is assumed uniform. Flow from the aquifer to the river occurs in CVSIM whenever maximum aquifer storage capacity is exceeded. During these periods, any water in excess of the maximum aquifer storage is added to the surface flow.

There are several ways to analyze the output from a simulation model such as CVSIM. Since the model relies on historic data, a comparison of two model runs may show a model parameter (streamflow at a certain location, for example) higher for one run than another for part of the record, and lower for other portions of the record. A year-to-year comparison of these two runs may prove inconclusive. This can be avoided by analyzing the data statistically and representing the output probabilistically over the entire simulation period.

Probability Analysis

The probabilistic approach is used for several reasons. Although the 86-year hydrologic record from 1902 to 1987 is the basis of the model, it most likely would not repeat itself in the same order, and it does not represent the possible range of hydrologic events in the next 86 years. The probabilistic approach allows for the analysis of the entire record and evaluation of the frequency (chance) in any year that an event (flow in the river over 100 cfs, for example) would be exceeded (exceedance probability). Comparing the chance associated with exceeding various benchmark flows helps detect average changes over the long term between the alternatives and avoids the bias associated with a year-to-year comparison.

The output associated with a model parameter was ranked and probabilities were assigned based on the Weibull plotting position (Haan 1977). The parameter and its associated probabilities were plotted and a curve drawn between the points. For each water supply option, exceedance probability curves were developed by Jones & Stokes Associates using the CVSIM output for each parameter (such as surface flow or usable groundwater storage in the aquifer subbasins). By plotting these monthly exceedance curves for each water supply option comparisons can be made quickly and easily (see Figures A-2 through A-21).

The exceedance probability analysis presents results in terms of each month of the year. The data contained in each graph represents the magnitude of a model parameter for each year in the 86-year simulation. The parameter will be maximum on the left-hand side of the graph, indicating a small exceedance probability. That is, the larger the magnitude of the variable, the smaller the chance of observing a larger event. These data are generally associated with wet periods. On the right-hand side of the graph is the smallest observed magnitude of the parameter, indicating the greatest chance of observing a larger event. This is generally related to drought periods. In between the two extremes are the more frequently observed events. The median value (associated with 50 percent probability) represents a point where it is equiprobable to observe events of larger or smaller magnitudes.

It is important to note that there is no time scale associated with this analysis (except the indirect association with the 86-year simulation period used to generate the results). Adjoining points on the probability graphs do not necessarily represent adjoining years in the simulation period. The descending graph from left to right therefore represents an increase in the frequency (chance) of exceeding a given magnitude of a parameter, and not an increase in time.

Parameters Analyzed

Carmel River streamflow was analyzed at San Clemente, Robles del Rio, the Narrows, Near Carmel and the Lagoon. Generally, changes in water resources due to a project do not affect water resources so much as it affects wildlife, vegetation, recreation, or other uses of water. An exception to this is groundwater storage. If a project causes groundwater overdraft (groundwater use in excess of the safe yield of the aquifer), land subsidence, loss of aquifer storage capacity, or saltwater intrusion may occur, permanently altering the resource.

The surface water results are presented for three stations: the Narrows, Near Carmel, and the Lagoon (Figure A-20). The stations upstream of the Narrows do not experience significant trends except during extreme droughts and therefore are not presented.

The discussion of the streamflow results are presented for each month of the year but concentrate on summer and early fall, primarily for two reasons. Generally, only small changes were detected between the various supply options during the mid-fall through spring period. Secondly, summer is when the demand on the resource (wildlife, vegetation, and recreation) is the greatest. Portions of Carmel River dry out during summer, and, therefore, changes in the frequency of no-flow periods between options was assessed.

Mean monthly flows also provide an estimate of the magnitude of flow. The mean flows for summer are presented.

Groundwater resources were examined in several ways. First, it was recognized that periods of maximum groundwater storage were important (in terms of usable water and the interaction between groundwater and surface water). As the groundwater is drawn down from maximum levels, groundwater ceases discharging to the river and the river begins to lose a portion of its flow to the groundwater (through seepage). Also, at or near maximum groundwater storage, the water table may contact depressions in the streambed and fill the depressions with groundwater. This "ponded" water may be present even with little or no streamflow. As the water table declines, these areas dry out. The change in the frequency of maximum storage was also assessed.

During periods when groundwater is not at maximum storage, the changes in the usable storage between the supply options is important. Usable storage is important in terms of the frequency of storage being insufficient to meet demands or in quantities that make extraction expensive. For example, if a private water user incurs difficulty (higher pumping costs or reduced groundwater yields) if the usable storage drops below 2,000 acre-feet, then an increase in the chance that storage would exceed 2,000 acre-feet represents an increase in the level of protection against such difficulties. Conversely, a decrease in the frequency of storage exceeding 2,000 acre-feet represents an increased risk to the groundwater user. The frequency of storage being greater than this level is, therefore, an important element and was assessed.

The frequency of drawdown (measured from the streambed to the water table) being less than 4, 8, 12, 16, and 20 feet was investigated using the results of CVSIM and Technical Memorandum 86-06 (Monterey Peninsula Water Management District 1986). TM 86-06 gives a correlation between aquifer subbasin levels and the usable aquifer storage values given in the CVSIM results. Two drawdown levels in the examined range, four and eight feet, are vegetation stress indicators (Section C,"Vegetation," of Chapter IV). The supply options were compared based on their effect on drawdown in each subbasin. It should be noted that CVSIM treats drawdown as a uniform amount across the aquifer. The actual drawdown near a pumping well will be greater due to the effect of the pump.

The Seaside Coastal subbasin was addressed separately because it is a separate element within CVSIM. Similar exceedance probability curves were developed for the subbasin and analyzed for maximum storage, minimum storage, and storage throughout the 86-year simulation period.

FIGURE A-2
EXCEEDANCE PROBABILITY
Carmel River at the Narrows in January

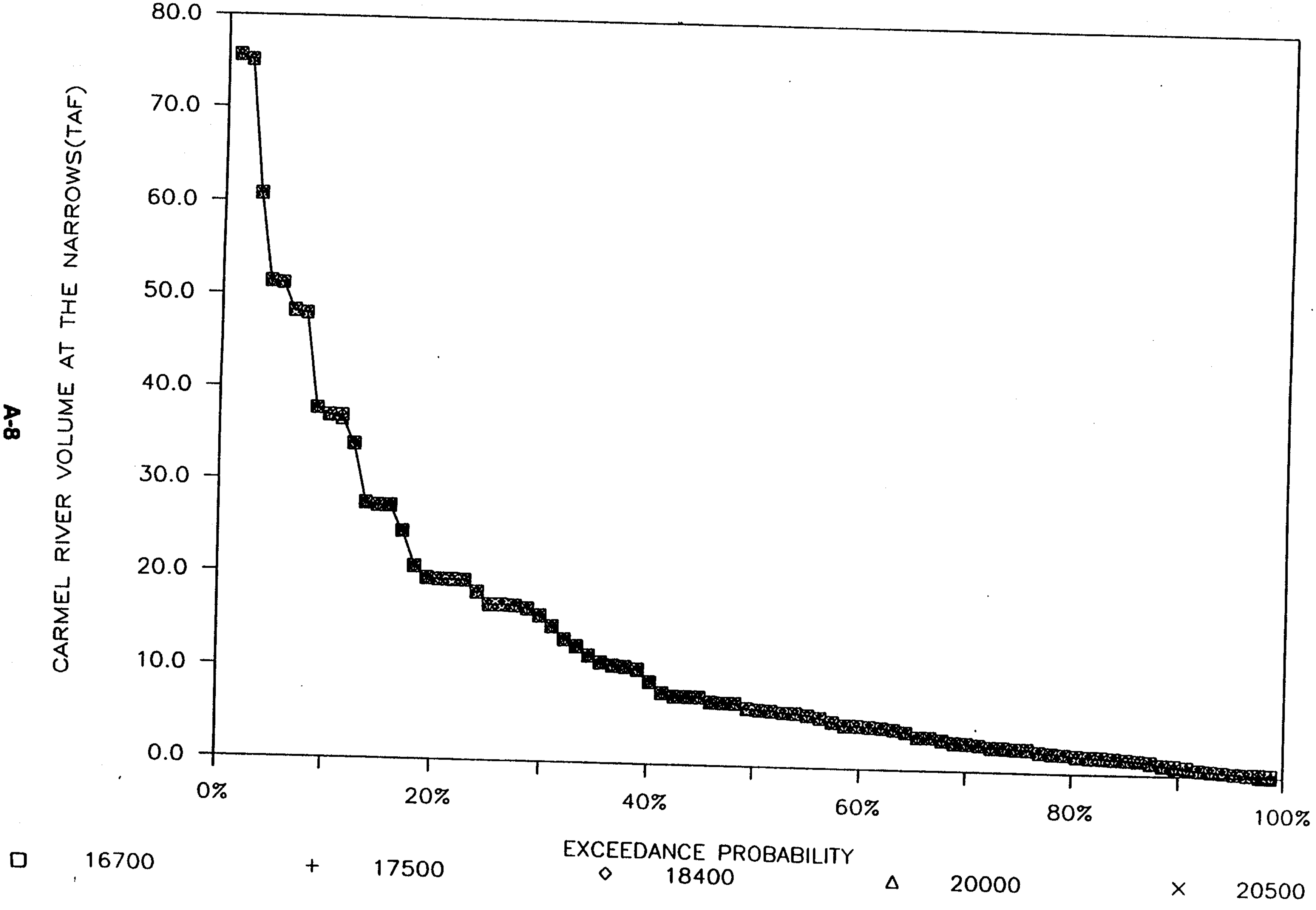


FIGURE A-3
EXCEEDANCE PROBABILITY
Carmel River at the Narrows in August

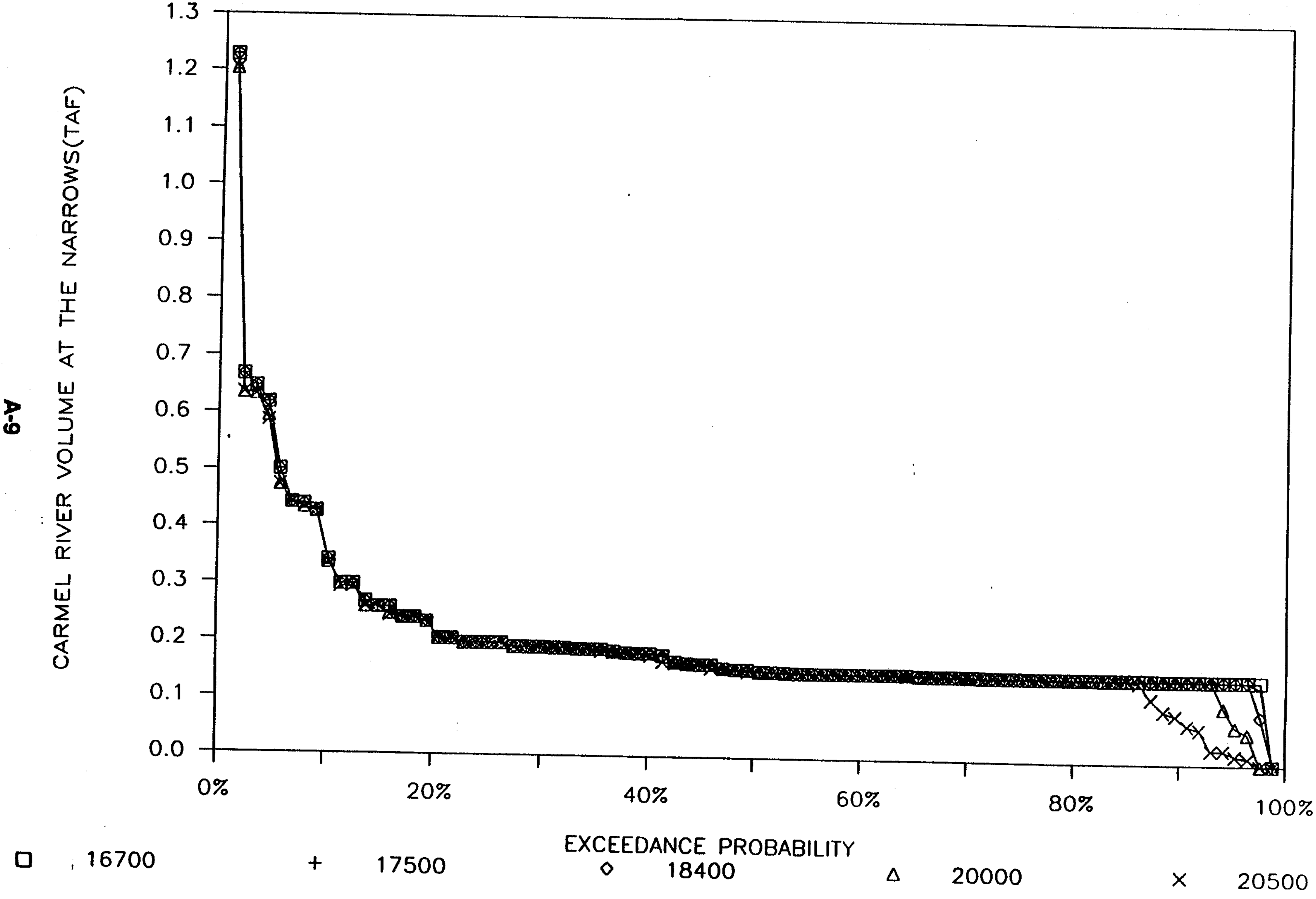


FIGURE A-4
EXCEEDANCE PROBABILITY
Carmel River Near Carmel in January

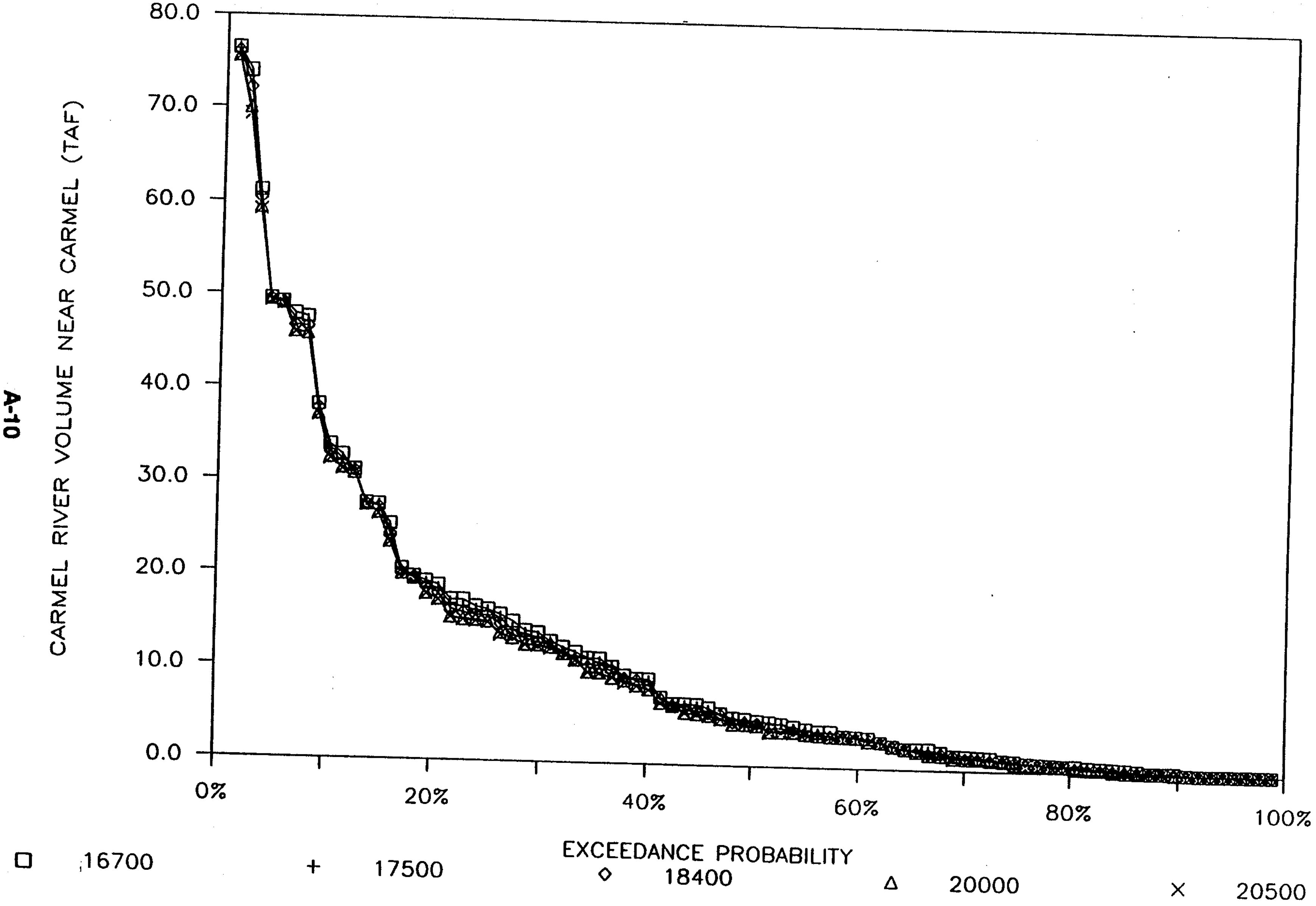


FIGURE A-5
EXCEEDANCE PROBABILITY
Carmel River Near Carmel August

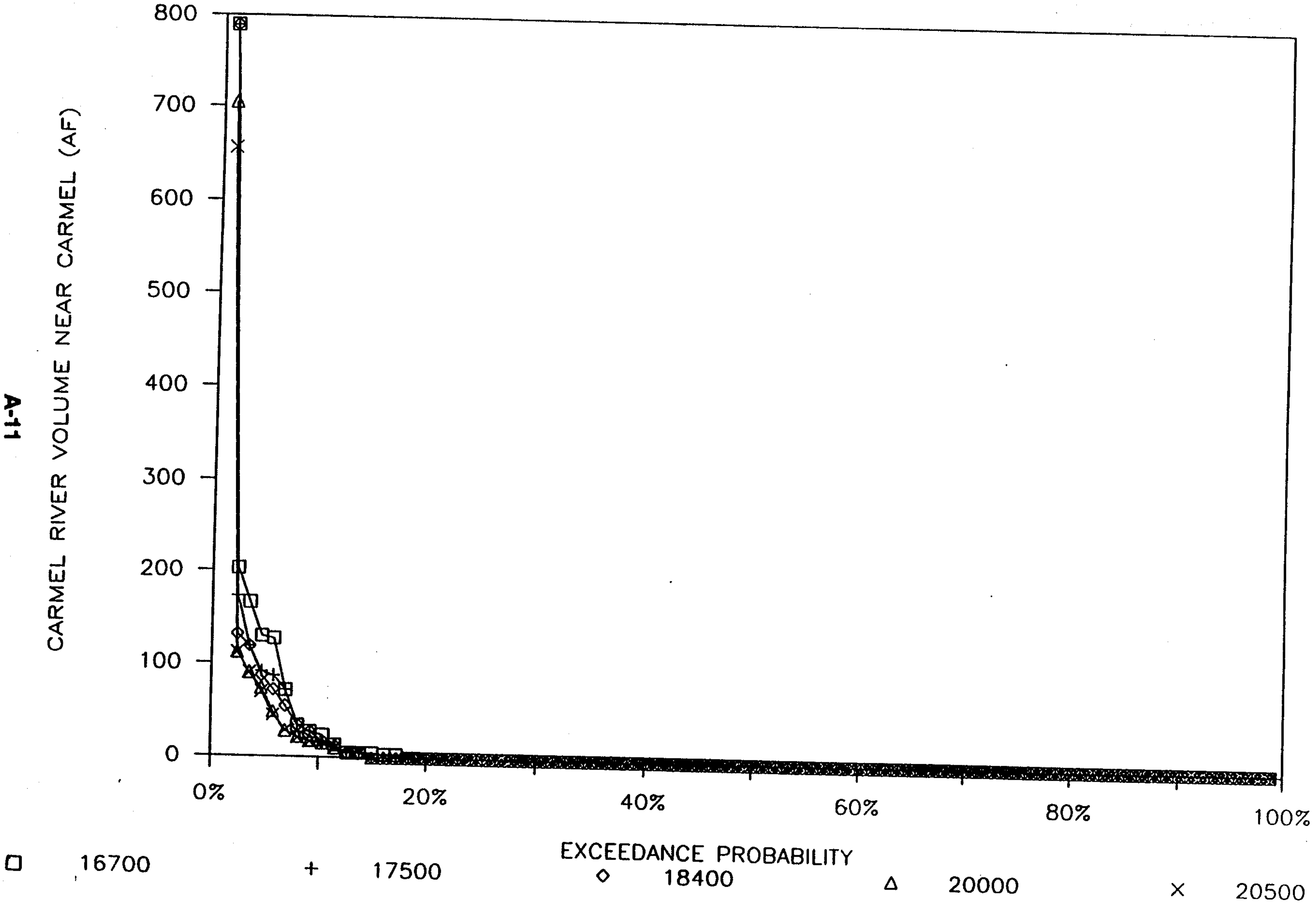


FIGURE A-6
EXCEEDANCE PROBABILITY
Carmel River at the Lagoon in January

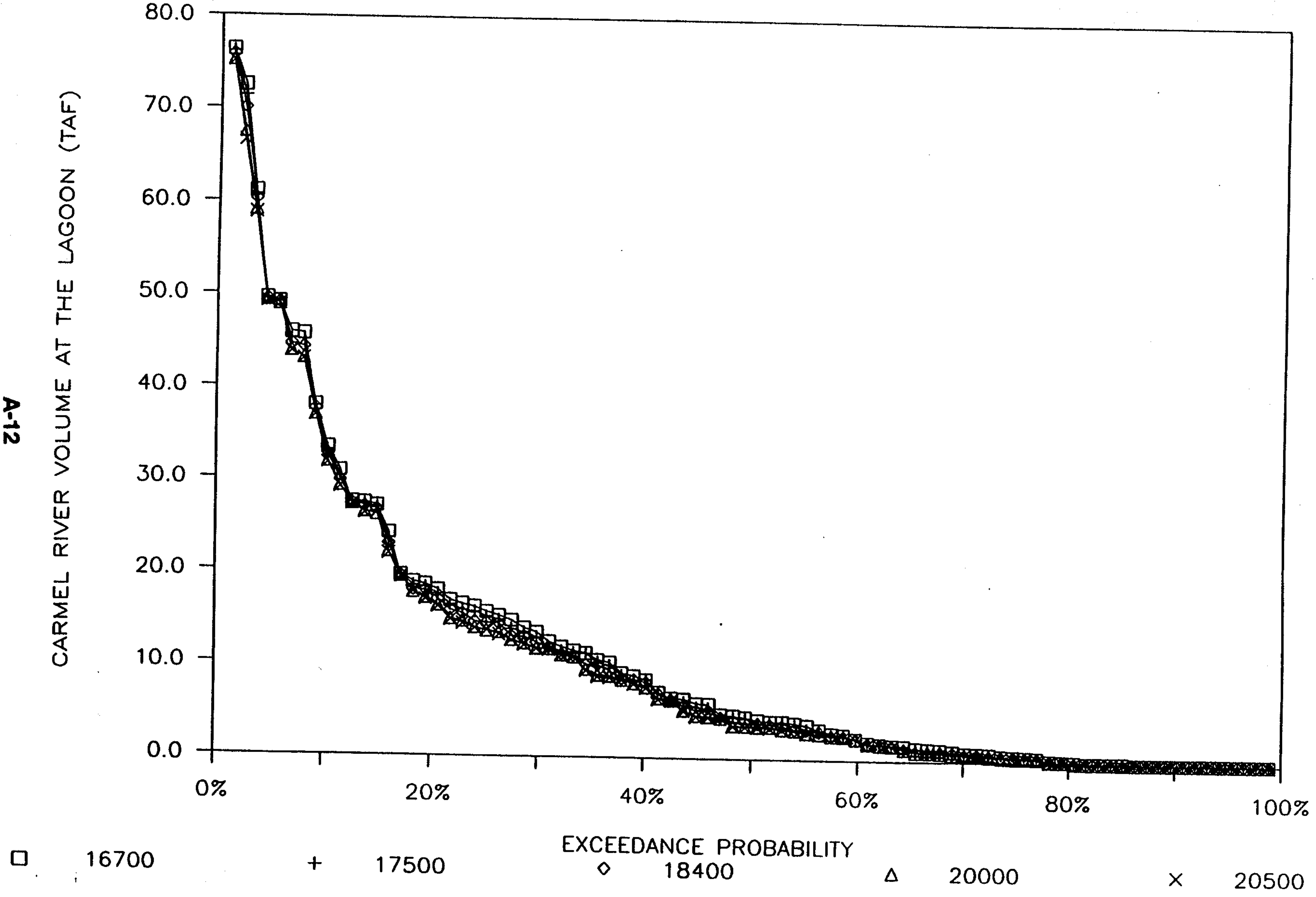


FIGURE A-7
EXCEEDANCE PROBABILITY
Carmel River at the Lagoon in August

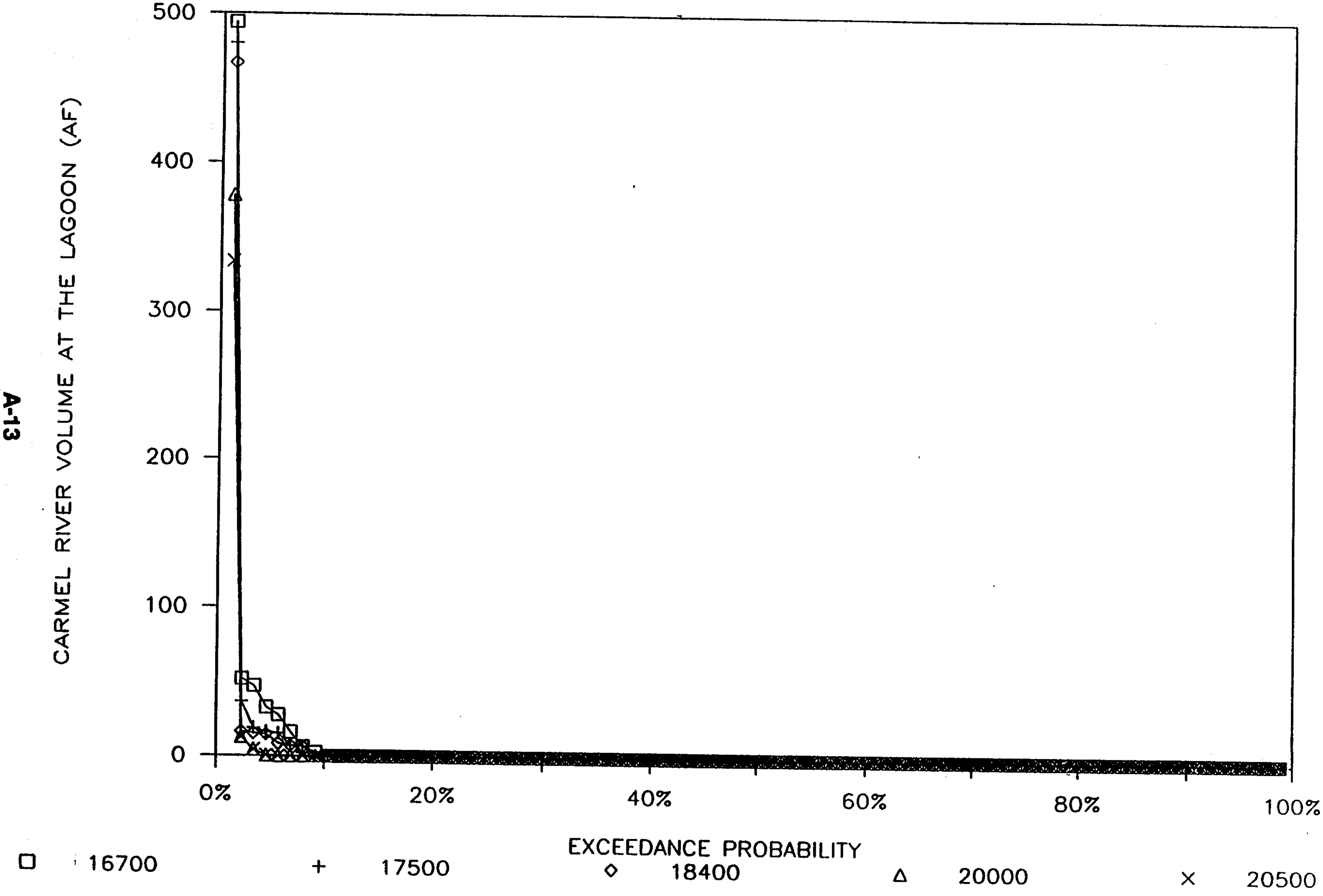


FIGURE A-8
EXCEEDANCE PROBABILITY
Subbasin A1 Usable Storage in January

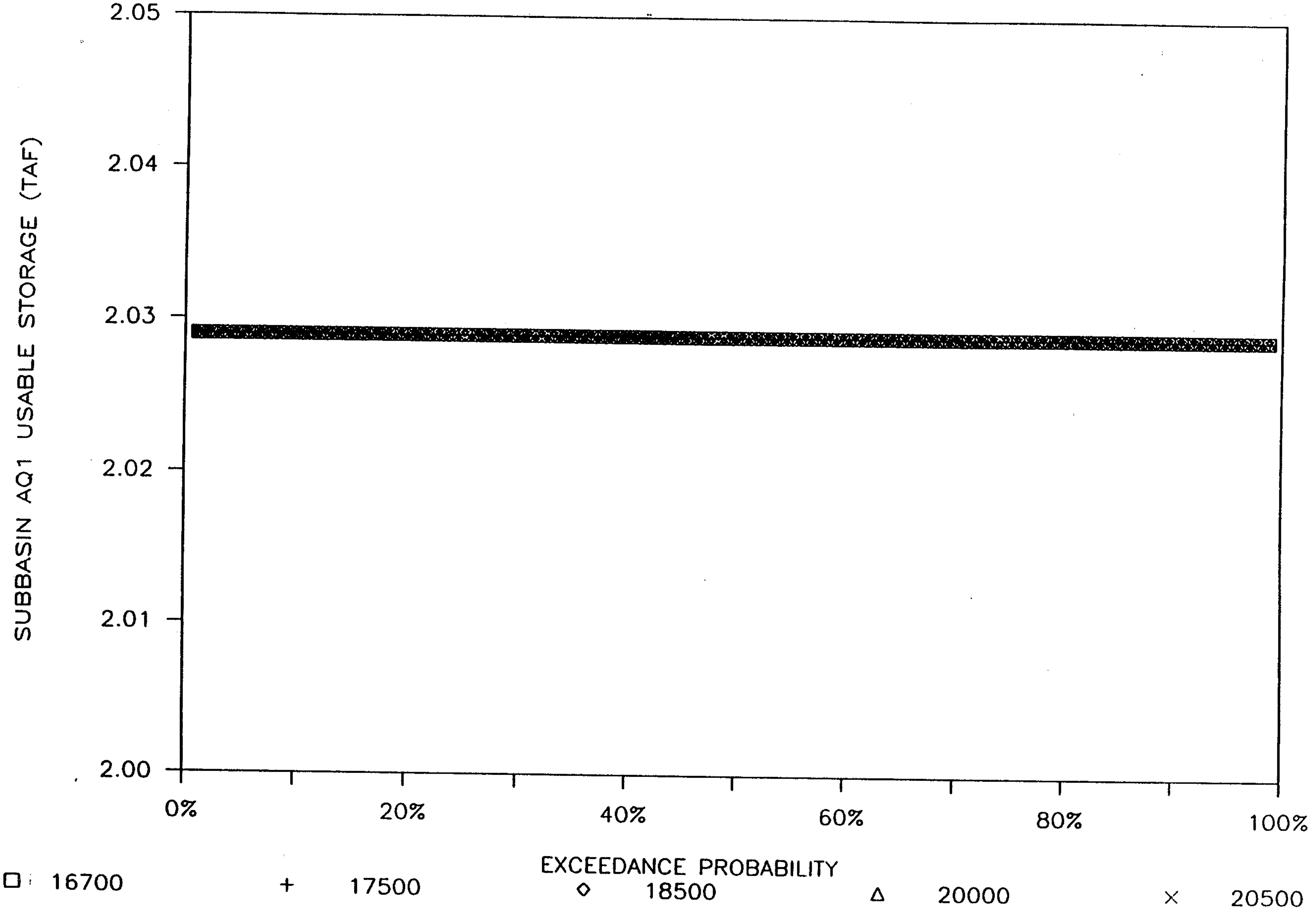


FIGURE A-9
EXCEEDANCE PROBABILITY
Subbasain A1 Usable Storage in August

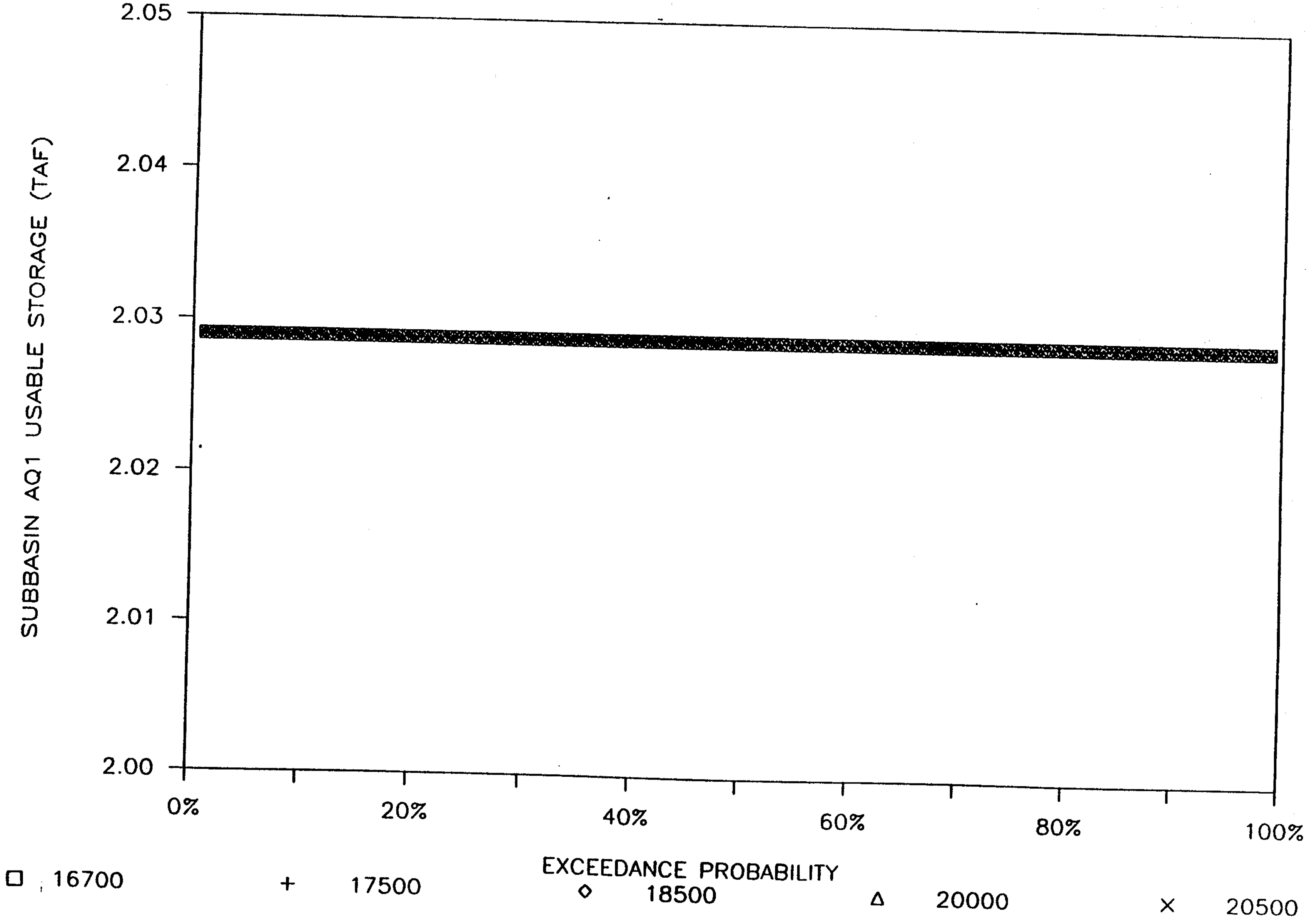


FIGURE A-10
EXCEEDANCE PROBABILITY
Subbasin A2 Usable Storage in January

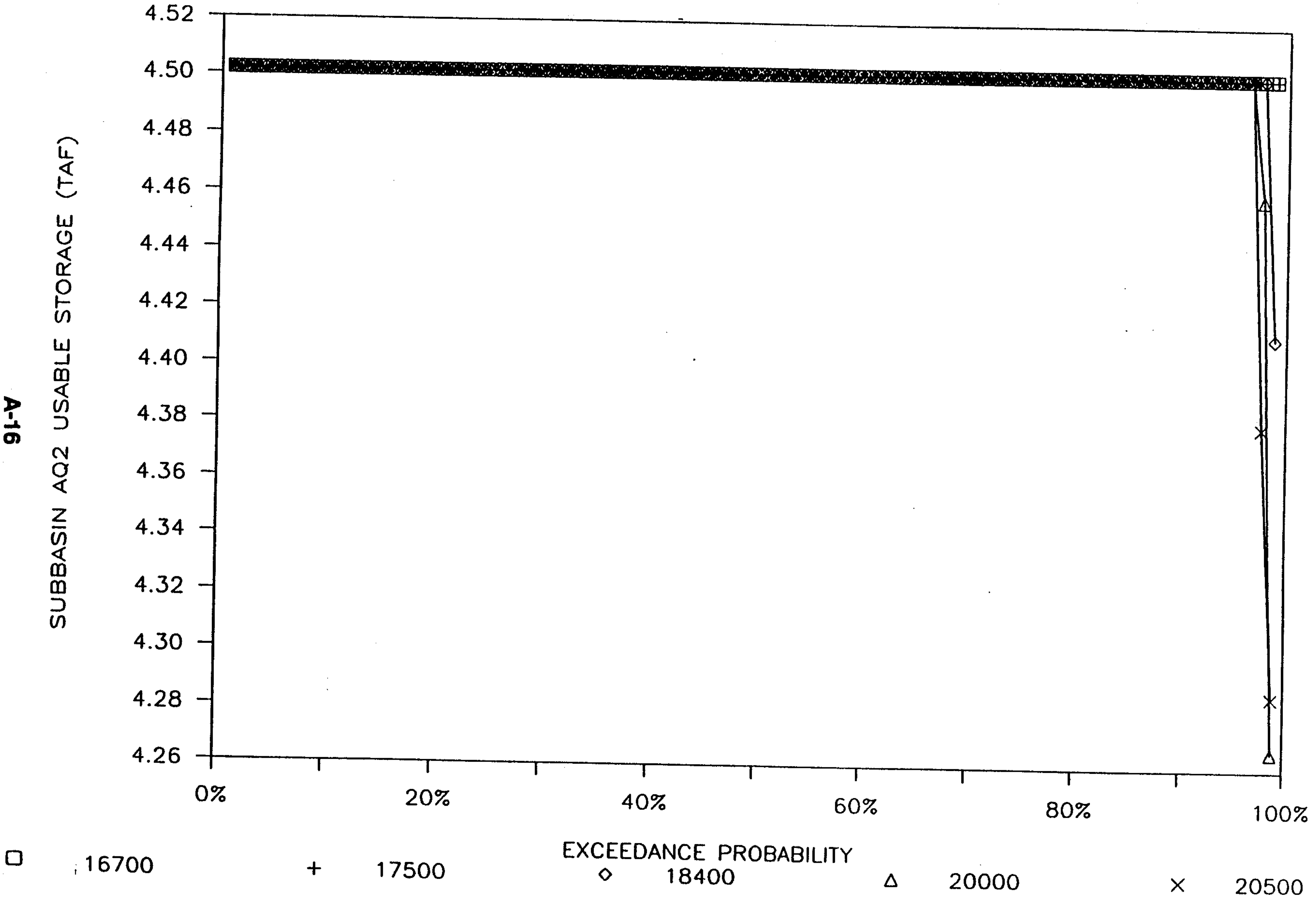


FIGURE A-11
EXCEEDANCE PROBABILITY
Subbasain A2 Usable Storage in August

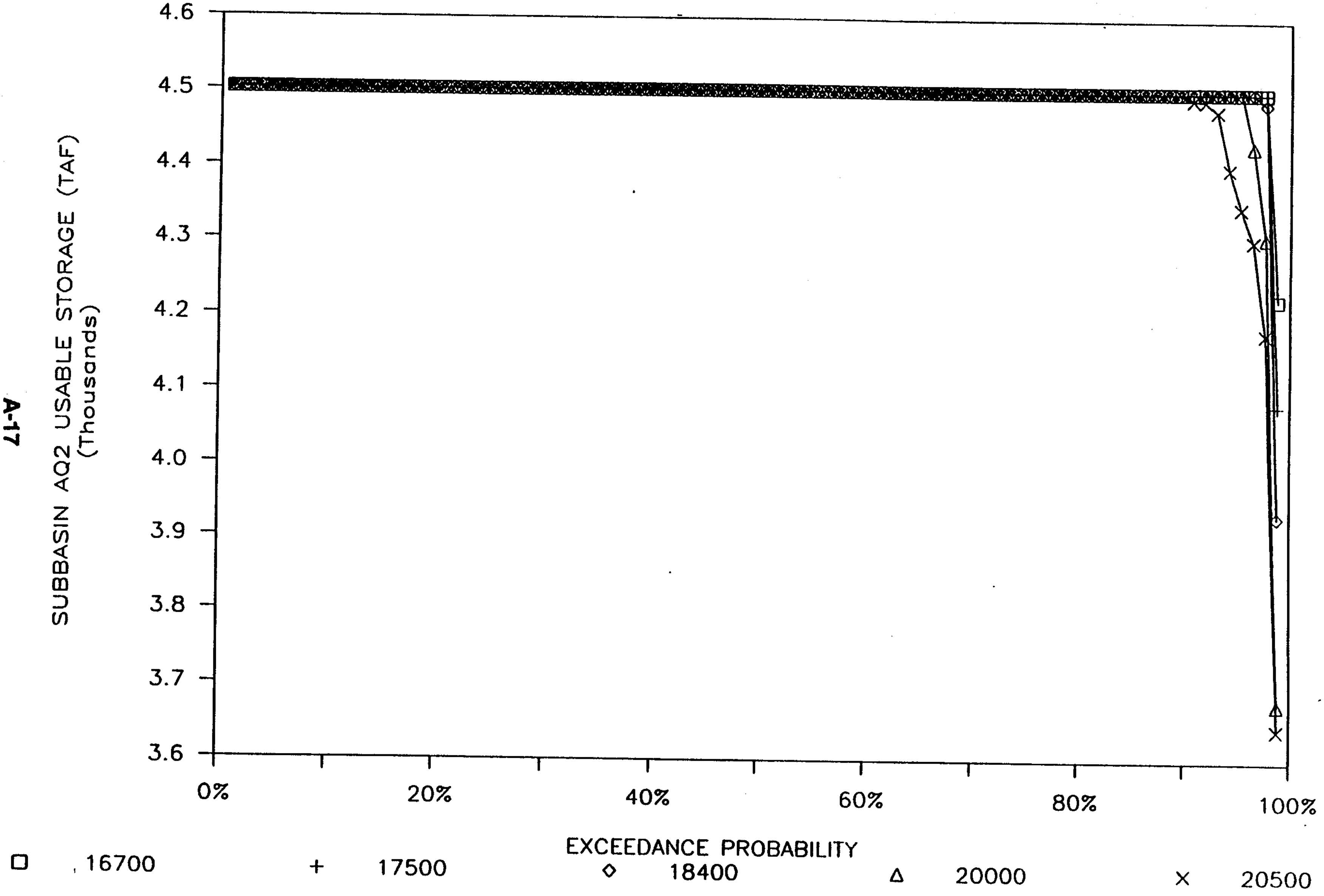


FIGURE A-12
EXCEEDANCE PROBABILITY
Subbasin A3 Usable Storage in January

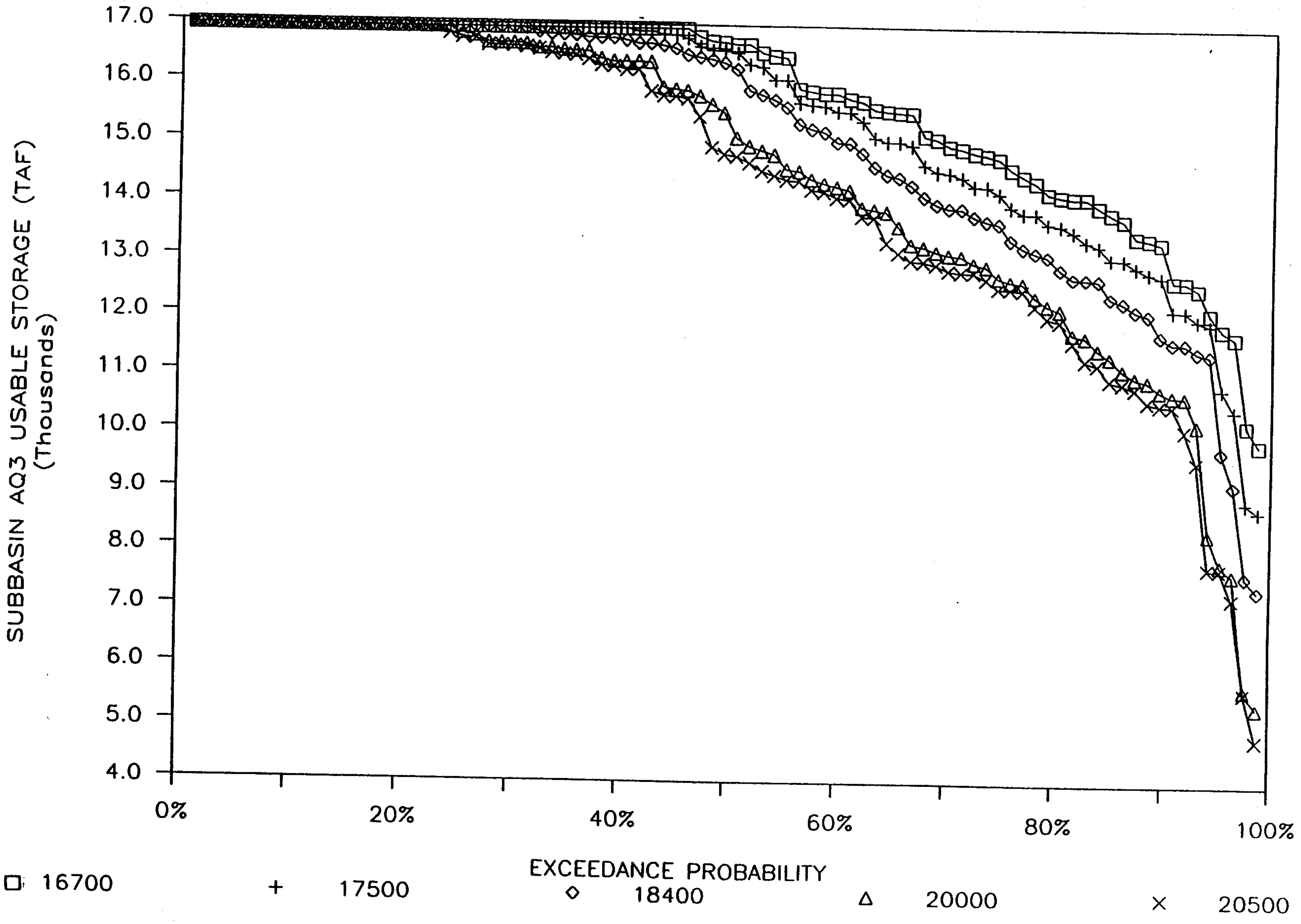


FIGURE A-13
EXCEEDANCE PROBABILITY
Subbasin A4 Usable Storage in August

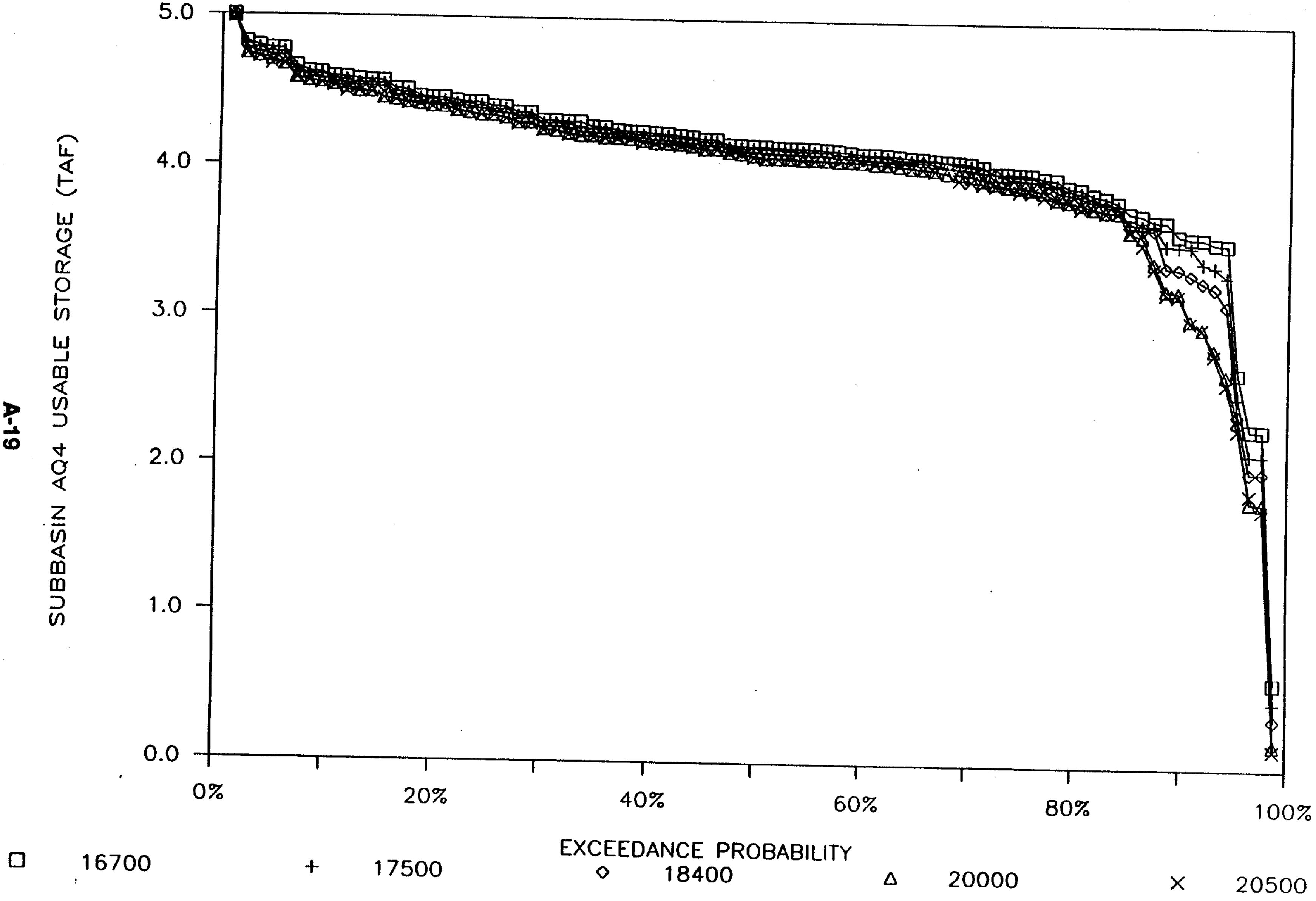


FIGURE A-14
EXCEEDANCE PROBABILITY
Seaside Subbasin Usable Storage in January

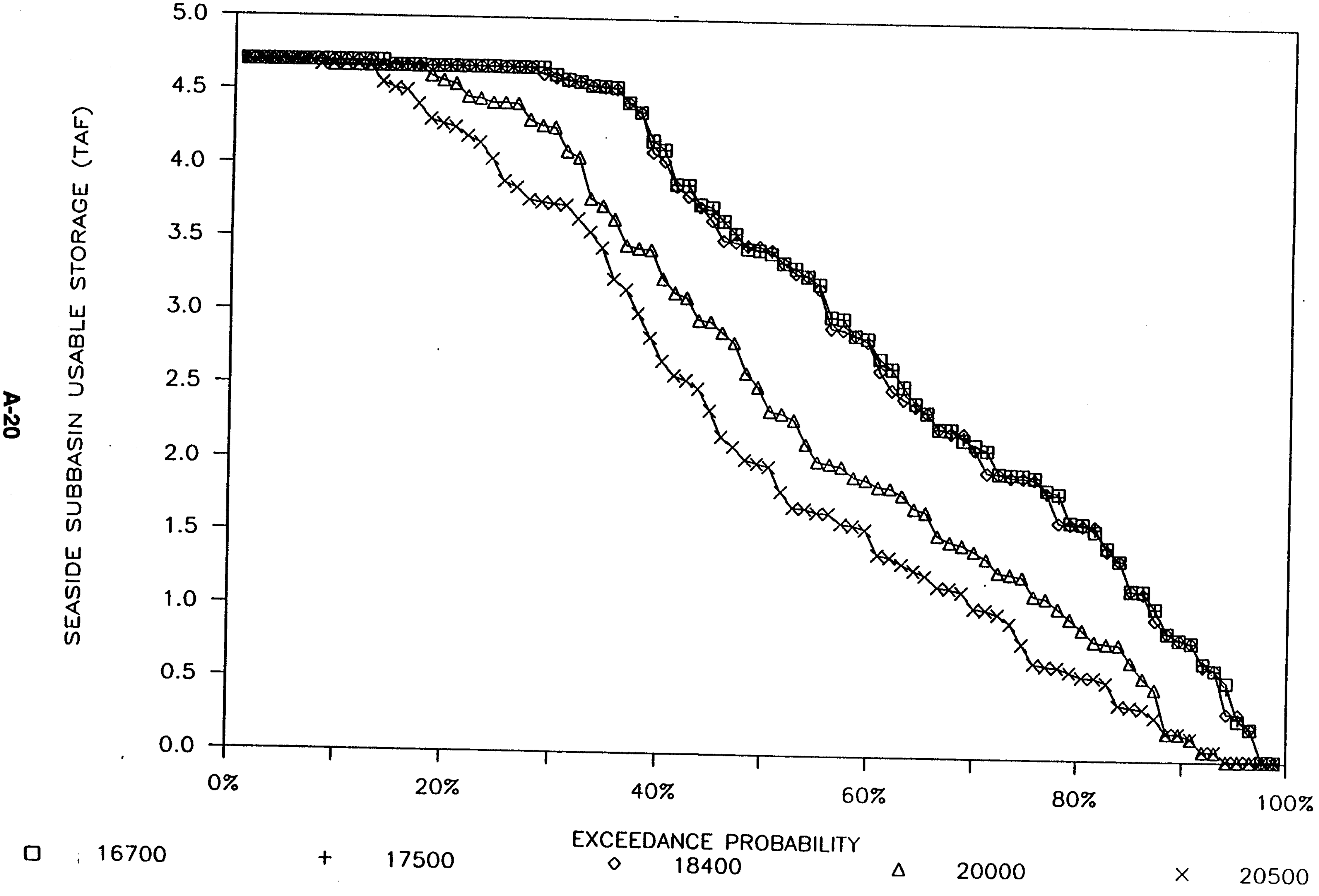


FIGURE A-15
EXCEEDANCE PROBABILITY
Seaside Subbasain Usable Storage in August

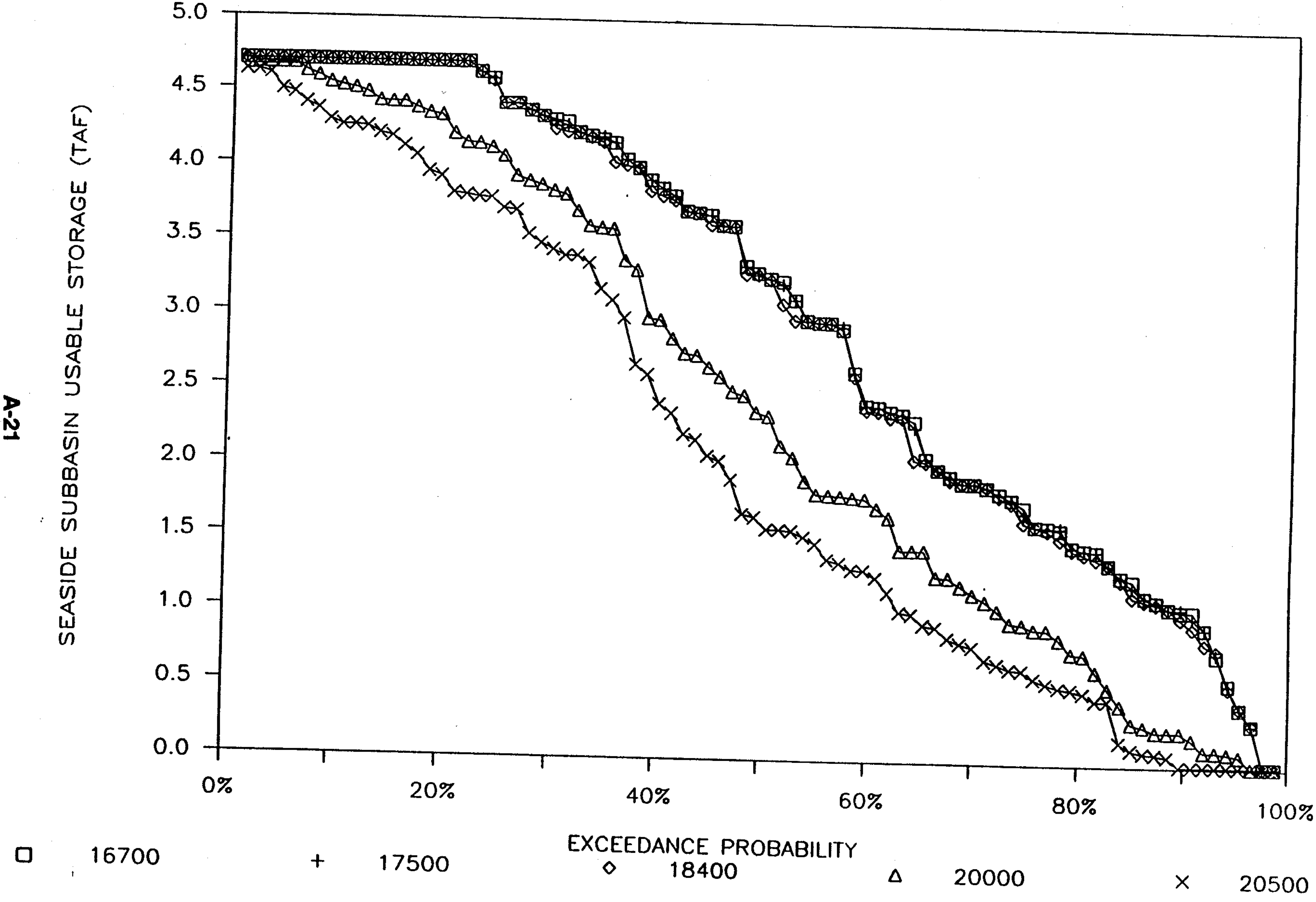


FIGURE A-16
EXCEEDANCE PROBABILITY
Seaside Subbasain Usable Storage in September

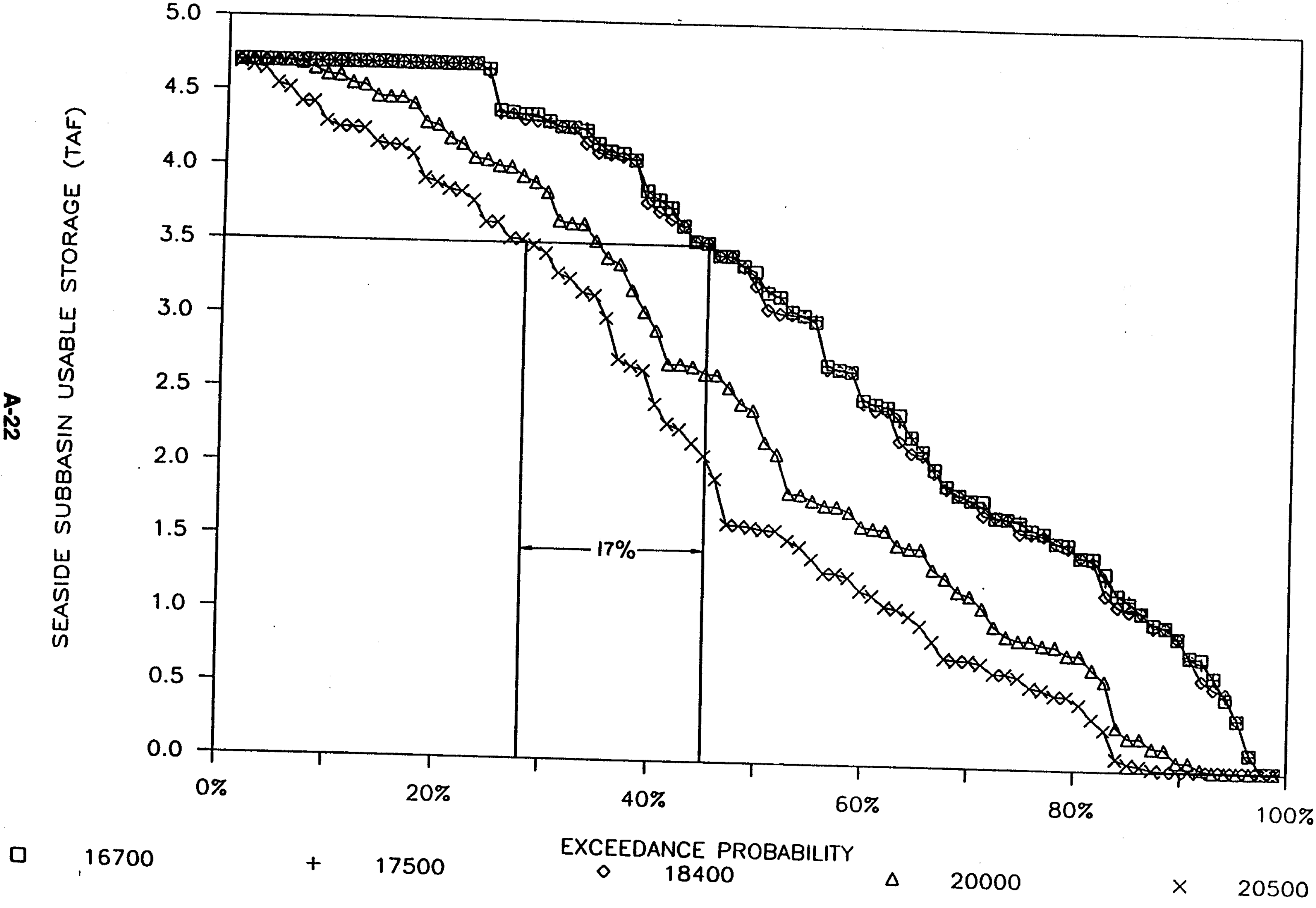


FIGURE A-17
CARMEL RIVER FLOW NEAR CARMEL
1902 to 1919

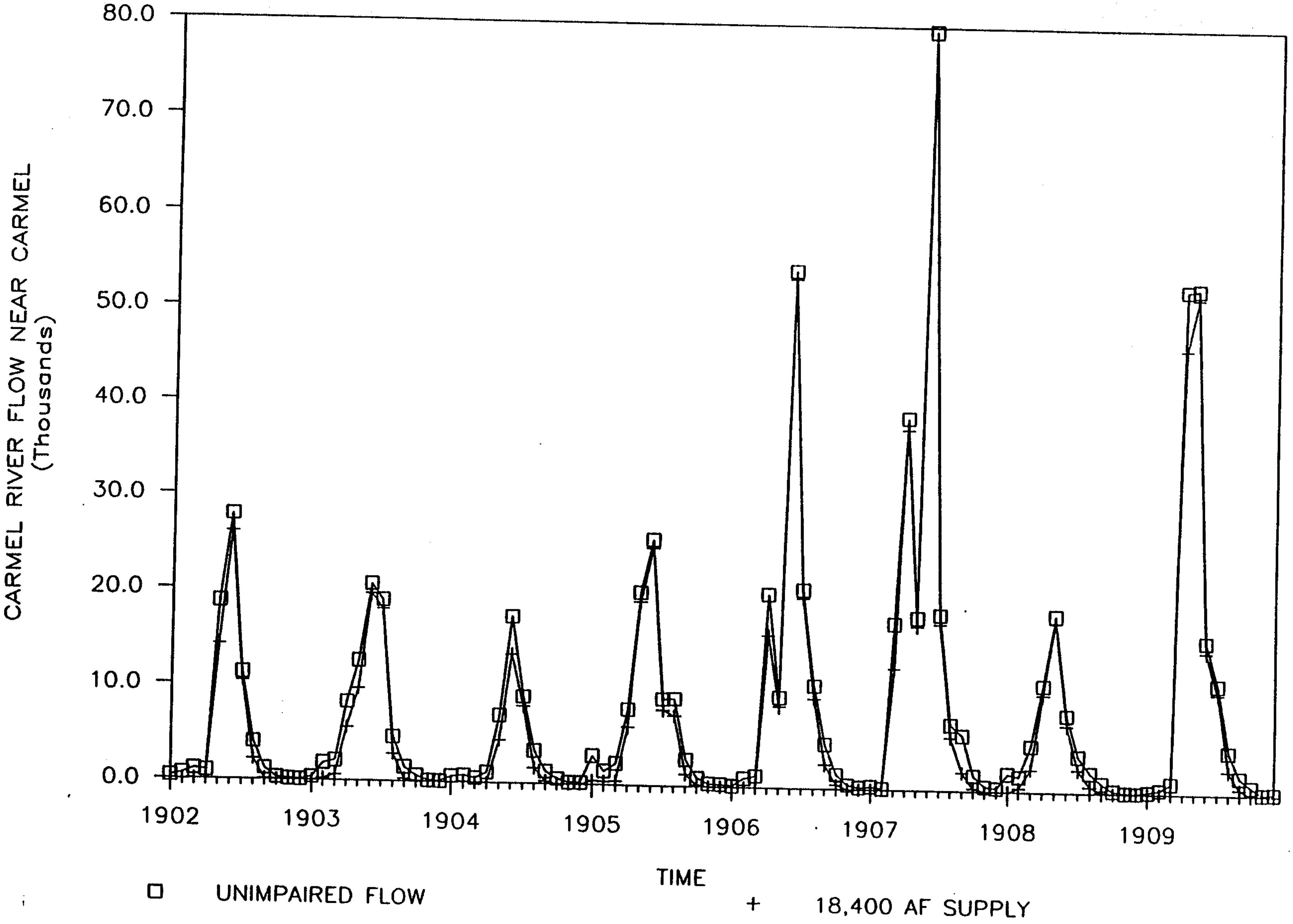


FIGURE A-18
CARMEL RIVER FLOW NEAR CARMEL
1920 to 1929

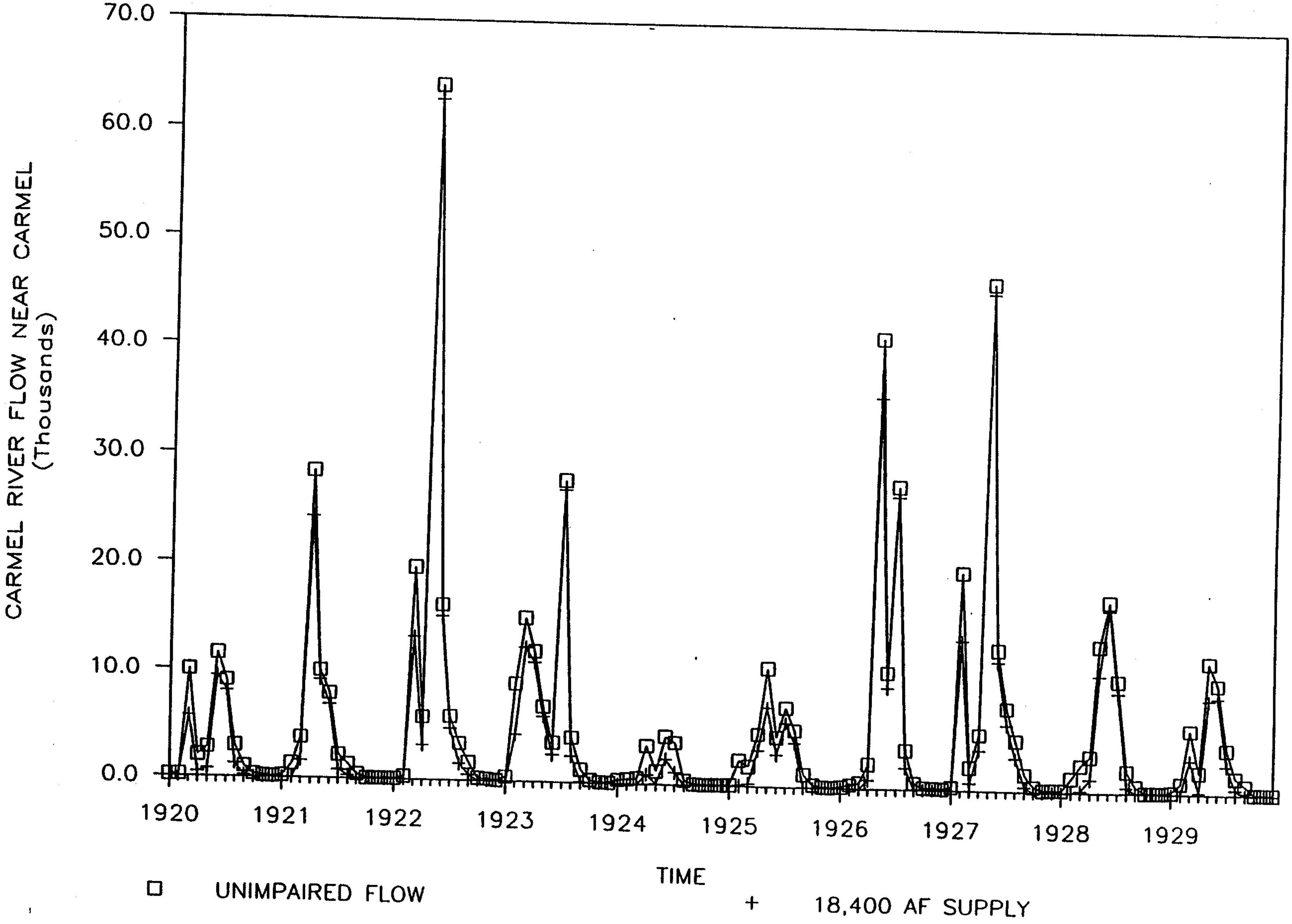


FIGURE A-19
CARMEL RIVER FLOW NEAR CARMEL
1930 to 1939

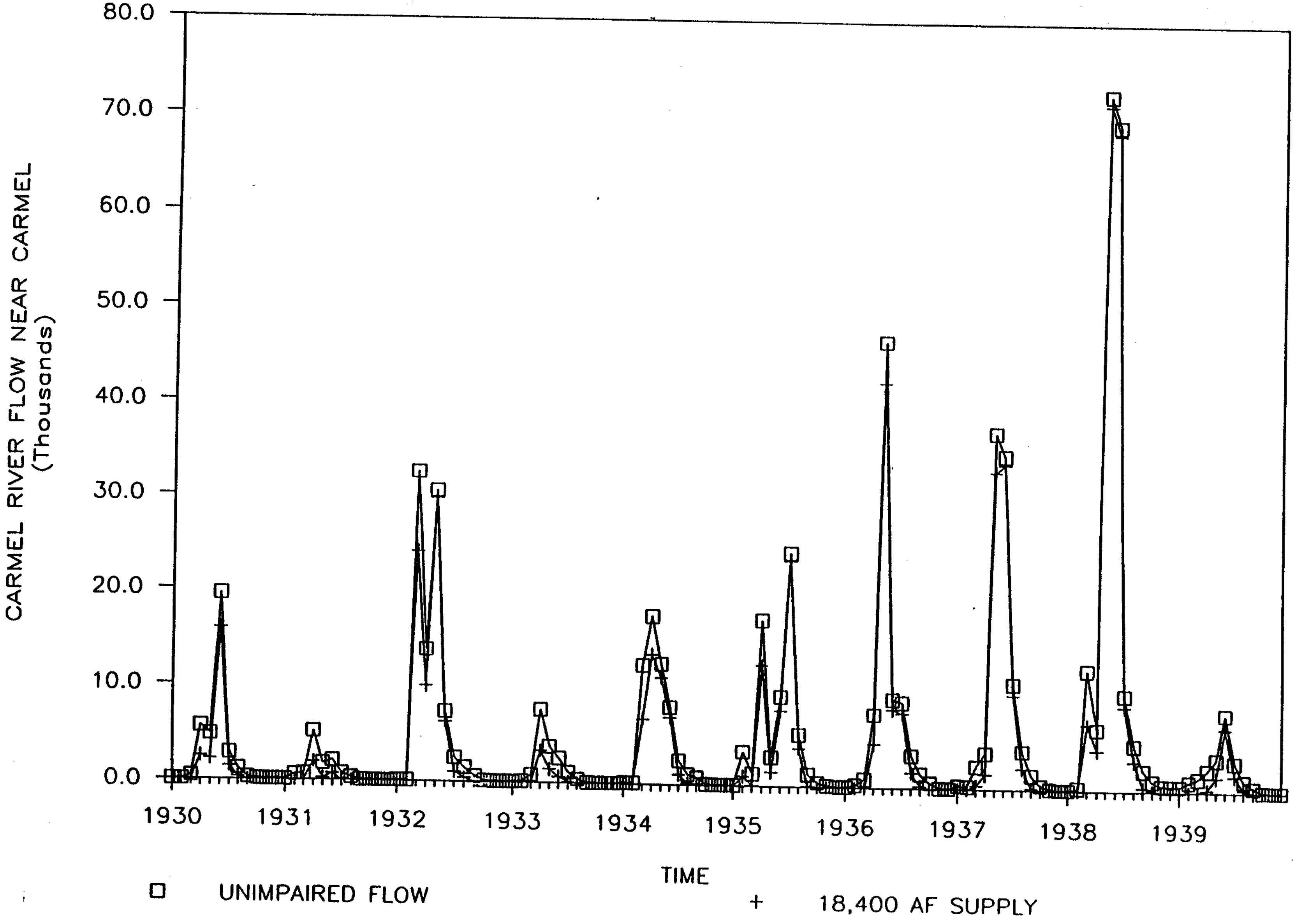


FIGURE A-20
CARMEL RIVER FLOW NEAR CARMEL
1940 to 1949

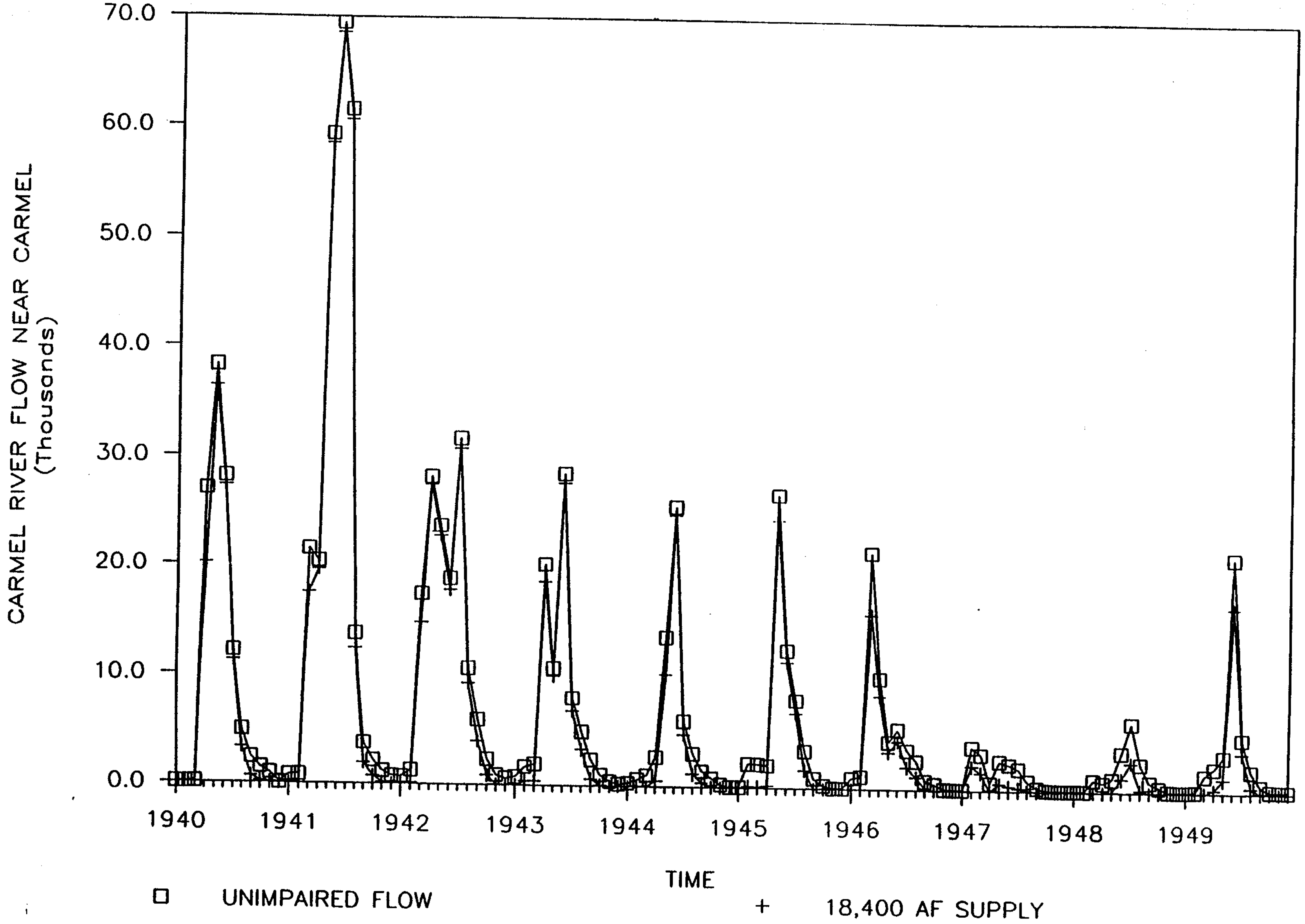


FIGURE A-21
CARMEL RIVER FLOW NEAR CARMEL
1980 to 1987