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ENVIRONMENTAL MANAGEMENT OF MULTIPURPOSE RESERVOIRS SUBJECT TO FLUCTUATION FLOOD POOLS

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1. INTRODUCTION

Within the last two decades four large multipurpose reservoirs have been constructed by the Corps of Engineers in Iowa. They are the Coralville, Rathbun, Red Rock and Saylorville Reservoirs (Fig. 1). Coralville Reservoir is the oldest (with operations beginning in 1958) and Saylorville is the newest (with operations beginning in 1977). In addition, several smaller multi-purpose reservoirs have been constructed during the past few years by various state and local agencies, such as the Iowa Conservation Commission and the various county conservation boards. Two, Pleasant Creek at Palo and Lake Panorama at Panora, involve electric utility companies and recreation interests.

All these reservoirs are providing valuable services to the people of Iowa. Storage of water in these reservoirs provides water supply, flood peak reduction, erosion and sediment control, low head hydroelectric power generation, low flow augmentation and recreation. However, the potential for conflicts between the competing users of water in a multipurpose reservoir project always exists.

The large fluctuations in the water level within the flood pool of a reservoir often causes severe impacts on the shoreline areas that are heavily used for recreation. These impacts may be so severe that the estimated recreation use of the area is never fully realized. Maximizing the use of a reservoir for hydroelectric power requires maintaining a high, stable pool elevation. This complements the recreational use but competes for the storage volume for retaining floods. Sedimentation within the conservation pool reduces the volume of water stored at a

Fig. 1. Map of Iowa showing locations of major reservoirs.

given water surface elevation and thereby reduces the recreational potential of the reservoir.

Major problems with shoreline erosion and severe impacts on shoreline terrestrial vegetation at elevations between summer conservation pool and maximum flood pool have been observed at Coralville, Rathbun and Red Rock Reservoirs. Extensive tree kill within the flood pool has occurred at these sites. Many acres of mud flats remain after the water levels recede. In areas with greater slopes, shoreline erosion has removed all the topsoil and left behind only bedrock. These impacts have detracted from the uses of these reservoirs for recreation and have led to increased public pressure to do something about this problem at Iowa's reservoirs.

Public concern gave way to strong anti-reservoir sentiments as final stages of construction of the Saylorville Reservoir were undertaken in the early 1970s. The Saylorville Reservoir flood pool will periodically inundate an environmentally sensitive and scenic area within the Ledges State Park, one of Central Iowa's most popular recreational parks. The areas within the park that are periodically subject to inundation will certainly be damaged as they are flooded. This public opposition to reservoir construction culminated in a "Save the Ledges" movement and a law suit being filed to require the Corps of Engineers to evaluate alternative means of protecting these sensitive park areas. This legal action did result in a temporary restraining order being issued in 1973, delaying the completion of the closure of the dam. An out-or-court settlement was reached which required (1) modifications in the release schedule for Saylorville Reservoir, thereby reducing the frequency of flooding in the lower portions of the Ledges State Park, (2) purchase of additional timbered non-flood plain land at the Ledges State Park to replace the loss of wildlife habitat and recreational lands in the flood plain, (3) purchase of a "green belt" below Saylorville Reservoir to allow for the higher release rates and (4) development of a vegetative management plan to mitigate impacts on the terrestrial vegetation. Saylorville Reservoir was completed and placed in operation during the summer of 1977.

Heavy snow cover during the winter of 1978-79, coupled with a rapid snow melt and heavy rains in March 1979, led to flooding in many areas of Iowa. Saylorville Reservoir was instrumental in helping to reduce flooding in the City of Des Moines due to the high streamflow; however, the lower Ledges State Park was flooded to a depth of about 24 ft. This provided an opportunity to observe the initial inundation impact on the lower Ledges State Park, for an early spring event.

This research project began because of the severe impacts on the shoreline and the terrestrial vegetation observed at Coralville and Red Rock Reservoirs and the concern for the effects of Saylorville on the lower portions of the Ledges State Park. A multidisciplinary research team was assembled to look at the problems of impacts from fluctuating water levels on shoreline vegetation and to develop control strategies and vegetative management alternatives. A system analysis approach was chosen to look at the components of the system; that is, the hydrologic inputs to the reservoir, the hydraulic operations of the reservoir, the plant successional pattern after exposure of a site, the vegetative impacts due to flooding, and the vegetative management alternatives.

The specific objectives of this research were:

- To develop mathematical models of the operation of a multipurpose reservoir subject to fluctuating water levels within the flood pool;
- To develop simulation models for rooted vegetative growth and succession within a reservoir area subject to periodic flooding;
- To develop a conceptual model of plant damage due to flooding; and
- To develop procedures for environmental management around multi-purpose reservoirs.

2. IOWA'S RESERVOIR EXPERIENCE

There are four major multipurpose reservoirs in Iowa where shoreline erosion and vegetative impacts have been observed. The fluctuations in water level, reservoir shape, and physical environment of the reservoirs are sufficiently different that a short discussion of each reservoir will be presented. In addition, a summary of the observed shoreline erosion and terrestrial vegetation impacts will be presented.

Vegetation submersed beneath flood waters for the first time usually suffers damage. The extent of the damage depends largely on the season of the year, the duration of flooding, the depth of water, and the amount of erosion by wave action. This holds true for vegetation dominated by herbaceous as well as woody plants. Damage is understandable because of the drastic change in the soil environment in which the root systems grow, from the normal well-drained and aerated condition prior to flooding to a water-saturated and nonaerated condition during flooding. Even flood plain vegetation, which is naturally inundated beneath flood waters at various times, is damaged if the duration of flooding exceeds certain tolerance limits. These tolerances differ greatly between species and less so between individuals of the same species growing on slightly different sites. Although duration of flooding appears to be the major component in causing damage, the season of the year and depth of inundation are important. Less damage would occur if plants were dormant when inundated, such as in winter or early spring, or if the depth of water was shallow. Erosion by wave action, particularly on steep slopes, is only slightly modified by the presence of vegetation. Cutting away of soil and subsoil is extensive where winds sweep across a long fetch, especially if the vegetation has been weakened by prior flooding.

Partially submersed trees may not show damage during the time the water level is up, even throughout most of the growing season, but evidence of damage appears the following year in smaller and fewer leaves, die-back of small branches, and dead patches of bark on the main trunk toward the base of the tree. Depending on the extent of damage, the tree may recover or it may continue to deteriorate. Wood rotting organisms, invading the tree through the damaged cambium may cause rapid decay and breakdown of the tree in a few years. To avoid this lingering process of deterioration, trees are often removed prior to the initial flooding, so that the visual impact is softened (Fig. 2).

2.1. Coralville Reservoir

Coralville Reservoir is a multipurpose reservoir designed to protect life and property downstream from flooding, low flow augmentation, and to provide water based recreational opportunities for eastern Iowa. Located on the Iowa River about 3.5 miles upstream of Iowa City, Iowa, Coralville Reservoir provides about 4,900 acres of water surface for recreation at the normal lake level of 680 ft mean sea level (msl). At full flood pool level elevation 712 msl, the reservoir provides about 475,000 acre-feet of storage and covers about 24,800 acres extending upstream some 41 miles.

Coralville Reservoir was authorized by Congress in 1938 for flood control, recreation and low flow augmentation during droughts. Construction

Fig. 2. Dead trees and loss of soil by wave action on rather level shoreline of Red Rock Lake, Highway 14 bridge in background to the east; photographed in early summer 1976, two years after last inundation.

trees occurred until the extended flooding of 1973 at which time these trees were flooded for the first time since establishment. Damage resulted, especially where trees were totally submersed, but in some areas this zone of trees has continued to screen the view of the more severely damaged vegetation toward the channel.

Erosion of soil and subsoil materials is closely related to slope angle and the amount of wave action. The steeper the slope and the more exposed the site to a long fetch, the greater the erosion. Exposure of bare rock and subsoil in the lower one-third of Coralville indicate loss of from one to several feet of material. Above State Highway 218, erosion is limited to occasional sloughing of the channel banks with little opportunity for slope erosion to occur because of the gentle gradient. On the other hand, sediment deposits of eroded soil and vetetational debris are much greater above Highway 218 because of the constriction in the lake at the highway and railroad bridges, and the flatter valley topography.

2.2. Red Rock Reservoir

Red Rock Reservoir is a multipurpose reservoir located on the Des Moines River about 40 miles downstream of the City of Des Moines. The reservoir was originally justified as part of the comprehensive plan for flood control and other purposes in the Upper Mississippi River. The stated purposes are flood control, low flow augmentation and recreation. Construction was begun in 1960 with completion in 1968 at a total cost of $83,200,000.

The dam is an earth fill structure with a crest length of 5,676 ft and a maximum height above the streambed of about 110 ft. Conservation pool elevation is 725 msl with a maximum operating flood pool elevation of 780 msl. Thus, the maximum fluctuation in the water level is about 55 ft.

The spillway has five bays, each 41 ft wide, with tainter gates to control the outflow. The spillway crest is at elevation 736 msl. Fourteen gated outlet conduits, each 5 ft wide by 9 ft high, provide normal outlet capability.

At full flood control pool, elevation 780 msl, 65,500 acres of land are inundated by a pool that extends about 33.5 valley miles upstream. At conservation pool level, elevation 725 msl, 8,950 acres are inundated. The conservation pool, 90,000 acre-feet, is to provide for initial sediment storage and water conservation storage for an estimated 100-year project life. Flood control storage of 1,740,000 acre-feet is provided between elevations 725 msl and 780 msl. The drainage area at the dam is about 12,300 square miles.

The valley section of Red Rock Reservoir is characterized as a broad, flat section. As a result, a small rise in the water level inundates large areas of land. Also, limestone and sandstone bedrock is located near the surface, covered at many sites with only a thin layer of soil.

A procedure, similar to that used at Coralville, was followed in the clearing of trees at Lake Red Rock. Clearing above Highway 14 bridge was minimal and below the bridge it was limited to the level of the conservation pool, elevation 725 msl. High water occurred soon after completion of the dam in 1969, and soon the landscape, as viewed from the bridge, was transformed from cultivated fields and scattered bands of trees to extensive beds of woody debris, mud, annual weedy species and dead trees (Figs. 4 and 5). Near the conservation pool level were extensive stands of foxtail (Setaria spp.), smartweed (Polygonum spp.) and ragweed (Ambrosia spp.) by midsummer of 1970, 1971 and 1972. Other areas, influenced by old road beds and debris drift lines, supported different species including annual sunflower (Helianthus annuus), water hemp (Acnida tamariscina), and barnyard grass (Echinochloa crus-galli). Flat areas near the conservation pool level, which were subjected to minor water level fluctuations throughout the growing season of the aforementioned years, supported semiaquatic species.

Extensive beds of sandbar willow (Salix spp.); (Fig. 6) and scattered cottonwood (Populus deltoides), established soon after the water receded from the mud flats, persisted through moderate flood periods; however, the high water that occurred during the entire growing season of 1973 killed even the most water tolerant species of marsh plants, including willow and arrowhead (Sagittaria latifolia). Aquatic smartweed (Polygonum coccineum) survived best.

The impact of the 1973 flooding was dramatic and extensive. Slope forests were killed almost to the high water line near the elevation 780 msl, but the damage did not appear so dramatic until the water receded in late 1973 and vegetation reappeared in the spring and summer of 1974. Little herbaceous regrowth occurred until the 1975 growing season. Removal of dead standing trees was begun in visually sensitive areas such as the State Highway 14 bridge. Where wave action was extensive on steep slopes the loss of soil and subsoil material was extensive (Fig. 7).

Fig. 4. Red Rock Lake facing upstream from north end of Highway 14 bridge with water level at approximately 750' m.s.l., wave action erosion visible to high water mark at approximately 778'; photographed early summer, 1974.

Fig. 5. Same view as in Fig. 4 at conservation pool level approximately 728' m.s.l., showing remnants of trees in former site of the community of Red Rock; photographed summer, 1975.

Fig. 6. Aquatic smartweed, Polygonum coccineum, a perennial plant with shoots more than 8 feet long surviving 10 feet inundation through 1973 growing season; sandbar willow killed in immediate background and cottonwood 50% killed in far background; Runnells area of Red Rock Lake; photographed 22 August 1974.

Fig. 7. Erosion slopes near Red Rock Lake dam with water at conservation pool level; high water reached approximately 50 feet higher as shown by erosion line on slopes; photographed 15 August 1974.

Undercutting of sandstone bluffs along the south shoreline provided a new view of the bedrock geological strata. Upstream, the damage to vegetation was less extensive because the water level remained limited to the upper flood plain of the original river. Deposits of silt and debris were observed several feet in thickness in some sites with layers of a few inches deposited on occasionally cultivated fields (Figs. 8 and 9). Weed control and removal of flood debris are problems to contend with when these areas are reopened for cultivation each spring (Figs. 10 and 11).

2.3. Rathbun Reservoir

Rathbun Reservoir is a multipurpose reservoir located on the Chariton River near the town of Rathbun, Iowa. The project was authorized by Congress in 1954 as a flood control and water conservation project. Construction began on the dam in 1964 with completion in 1968 at a total cost of about $26,000,000.

The dam is a rolled earthfill embankment approximately 10,600 ft in length at the crest and a maximum height of 102 ft above the existing streambed. The normal conservation pool covers about 11,000 acres at elevation 904 msl and has about 213,000 acre-feet of water in storage. Flood storage is provided between elevations 904 msl and 926 msl. A total flood storage volume of 339,000 acre-feet is available.

Normal outflow from Rathbun Reservoir is through a single gated horseshoe conduit that is 11 ft in diameter. Outflows up to 5,000 cubic feet per second (cfs) in magnitude are possible through this conduit at maximum flood pool elevation. An emergency uncontrolled notch

Fig. 8. Siltation has deposited more than 4 feet of material on boat ramp and adjacent banks in 8 years of operation of Red Rock Lake project; this view in upper third of reservoir downstream from Runnels; photographed early summer, 1976.

Fig. 9. Silt deposit of 1/2 inch light material and 2 1/2 inches of dark material on cultivated flatland in upper third of Red Rock Lake near point from which the upper photograph was made; photographed early summer, 1976.

Fig. 10. Cornfield following inundation by flood waters of Red Rock Lake and deposit of silt and woody debris in upper third of Red Rock Lake; photographed 8 July 1974.

Fig. 11. Debris on road adjacent to cornfield shown in upper figure; photographed 8 July 1974.

spillway is located in an excavated channel about 3,000 ft west of the south abutment of the dam and discharges into the adjacent drainage area of Little Walnut Creek.

The early impact of high water, which affected both Coralville and Red Rock soon after construction, did not occur until 1973 with Rathbun. Then the flood level rose 14 ft above the conservation pool level of 904 ft msl causing tree kill in the upper portions of the project similar to that observed in Coralville and Red Rock Reservoirs. Wave erosion was less severe than at the other reservoirs and public criticism was less noticeable. An important reason for the lack of criticism is the shape of the valley and the small difference between conservation pool level and maximum flood level (22 ft); however, it may also be significant that a major highway does not cross the center of the lake as is the case for Red Rock and Coralville.

2.4. Saylorville Reservoir

Saylorville Reservoir is a multipurpose reservoir located on the Des Moines River about five miles upstream from the northern city limits of Des Moines, Iowa. The project was authorized by the Flood Control Act of 1958 with stated purposes of flood control, low flow augmentation and recreation. Construction on the dam began in 1965 with completion in 1977 at a total cost with recreation facilities of about $100,000,000.

The dam is an earthfill structure with a crest length of 6,750 ft and a maximum height above the streambed of about 120 ft. Conservation pool elevation is 833 msl with a maximum operating flood control pool at elevation 890 msl. Thus, the maximum fluctuation in the water level at Saylorville Reservoir is 57 ft.

The spillway consists of an uncontrolled concrete crest ogee weir, 430 ft in length. The spillway crest is at elevation 884 msl. A single 22 ft diameter reinforced concrete circular conduit with gates provides the normal outlet from the reservoir. The reservoir operating plan calls for surcharging the reservoir to elevation 890 msl (6 ft above the spillway crest) by reducing the outflow through the conduit.

At full flood control pool, elevation 890 msl, the reservoir water surface will occupy 16,700 acres of land and extend about 54 valley miles upstream. At conservation pool, elevation 833 msl, the reservoir has an area of 5,400 acres and extends upstream about 17 valley miles. The conservation pool contains about 74,000 acre-feet of storage for sediment, recreation and low flow augmentation. The flood pool provides storage of 602,000 acre-feet of water above the conservation pool between elevations 833 msl and 890 msl. The drainage area upstream from the dam is about 5,800 square miles.

Saylorville Reservoir will periodically inundate portions of two parks, the Ledges State Park and Polk County's Jester Park. Additional recreational areas have been constructed or are planned for construction around Saylorville Reservoir.

The valley section at Saylorville is quite different from those previously discussed. The Des Moines River through much of this reach is heavily incised in a rather deep narrow valley. This is easily seen by the relatively low storage volume and small surface area at Saylorville compared to the other reservoirs in Iowa. Steeper slopes and thin soil layers over Pennsylvania age shale deposits may cause more extensive bank stabilization problems.

All trees were cleared in Saylorville Reservoir up to elevation 860 msl. Selective clearing of the least water tolerant trees in high visability areas was conducted up to elevation 870 msl. This is a significant departure from the clearing done at the other reservoirs. However, no observations of vegetative impacts have been made, since the reservoir only went into operation in 1977. Test plots located in Jester Park at various elevations have been carefully inventoried so data on tree responses can be observed during the next few years.

Spring flooding in 1979 resulted in a peak water surface elevation of 883.75 msl. The lower portion of the Ledges State Park, initially flooded on March 1979, was inundated for about 30 days. The impacts of this flooding will be carefully followed during the next few years.

In summary, the vegetative impact in two of the three reservoirs has been severe because of extremely high flood waters of sufficient duration to kill significant numbers of trees. In Red Rock and Coralville the first high flood was less damaging than the second, during which time extensive shoreline erosion occurred, in part due to weakened vegetative cover. Stands of small trees of cottonwood and willow that might have survived had they been large were killed by the 1973 inundation at Red Rock.

3. VEGETATIVE SUCCESSION

3.1. Concept of Succession

During periods of environmental stability on a site, the growth of plants and associated animals follows a general sequence of change called succession. Species colonizing bare ground are soon replaced by species more adapted to severe competition or increased shading. Populations of plants and animals are replaced by others as the conditions of the site change, largely brought on by the growth of the plants and animals themselves. This process continues as long as the environment does not exceed the tolerance levels of establishing organisms. The structure of the plant and animal community becomes more complex with increased diversity of species, greater biomass, and fewer species dominating the vegetation. In other words, the interactions become more complex and the community is said to be mature or climax. As long as the environment remains relatively stable the mature community changes very little. Individuals die and are replaced by individuals of the same species, in contrast to earlier stages in which they are more often replaced by other species. Thus, the plant and animal species established in the climax are usually quite different from those in early successional communities.

When environmental disturbance occurs, such as flooding, plowing, severe erosion, fire, etc., which destroys vegetative structure, the vegetation responds by undergoing secondary succession. The disturbance creates an immature vegetation which must undergo a period of reestablishment and recovery before reaching the mature or climax state again. If the disturbance is so severe that all traces of the earlier vegetation are destroyed--i.e., soil, organic matter; seeds, propagules-- then the change which follows on the site is called primary succession. Secondary succession occurs in a time frame of decades and centuries, primary succession of centuries and milleniums.

Classical ecological studies have described examples of succession in considerable detail. Discussions of secondary succession, in particular, are extensive in ecological literature. However, relatively little has been done on secondary succession of vegetation in fluctuating-level reservoirs. These relatively recently constructed structures have provided little stimulus for research until the last decade. Work underway at the U.S. Army Corps of Engineers Waterways Experiment Station at Vicksburg, Mississippi, is attempting to assemble all available research literature on succession as applied to management of vegetation along reservoir shorelines.

3.2. Response of Vegetation to Flooding Disturbance at Lake Red Rock

The following responses of vegetation to flooding are based on site visits to Red Rock Reservoir during the first seven years of operation.

1. The flat flood plain that is regularly inundated every one to three years is immediately colonized by herbaceous weedy species and woody plants such as cottonwood and willow. Abundant seeds of the herbaceous species are usually available in the muddy deposits, sometimes germinating in the edges of cracks which develop as the mud dries (Fig. 9). Seeds of cottonwood and willow are drifted in on air currents and germination must occur quickly (one week or so) before the surface dries

out. These are very short-lived seeds in contrast with many of the herbaceous species whose seeds may survive for years before germination. Variations from one mudflat to another and from year to year are due to the quantities of seed available, the time of exposure, the depth of recent silt deposits, rate of drawdown, and different weather patterns.

Often the herbaceous species are weeds that were abundant in cultivated crops on the site prior to flooding. Smartweed (Polygonum pensylvanicum) and foxtail (Setaria spp.) were exceedingly abundant in the first years following inundation near the State Highway 14 bridge crossing. By 1972 there were a few perennial herbaceous species coming into the mudflats, including Virginia wild rye (Elymus virginiana), a native prairie species.

With excessive amounts of silt deposition there may be few seedlings emerging until cracking occurs. Rapid growth of a few seedlings, however, will cover the ground by the end of the growing season if exposed early enough. During the 1974 growing season exposure of mudflats after mid July and early August did not allow enough time for vegetative establishment; thus the mudflats were thinly covered with vegetation by fall.

A similar constraint occurs with timing of mud exposure and seed dispersal of cottonwood and willow. Seeds falling on dry and cracked mud or among well-established herbaceous plants have little chance to establish before the growing season ends.

In 1972 numerous colonies of aquatic vascular plants, mainly water smartweed (Polygonum coccineum) and arrowhead (Sagittaria sp.) had become established in the shallow water of the mudflats, but the extreme depth and duration of water in 1973 completely killed them upstream from the

State Highway 14 bridge mudflats. Near the crossing at Runnells, in water depths of approximately 10 ft, the water smartweed survived well the 1973 inundation in contrast to densely established beds of sandbar willow which were heavily damaged (Fig. 6).

Expansion of populations of nut sedge (probably Cyperus erythrorhyzos) in the mudflats of Red Rock and Coralville has occurred in recent years. This plant species behaves as a weak perennial, and is one of the few native marsh species persisting with any abundance in the reservoir system along with smartweed and arrowhead.

2. Upper flatland that is occasionally inundated (at a frequency of one in five to ten years) can still be leased for crop production with a certain risk probability (Fig. 10). Debris and weed control problems complicate management; however, less silting usually occurs here than on lower flatland areas. Some perennial herbaceous species may survive inundation, particularly water smartweed and hemp dogbane (Apocynum sp.). Often, dense regrowth of trees occurs. More typical than any of the perennial species for this area is giant ragweed (Ambrosia trifida) forming dense stands to heights of 10 ft.

The response of individual trees of the same species is unpredictable. In an upland grove of 13 bur oaks (Quercus macrocarpa) only two individuals survived the 1973 flooding (Fig. 12). The rest were dead by July 1974 without any apparent difference in water elevation, soil properties, or other site characteristics.

Nearer the original flood plain near Runnells in the upper one-third of Red Rock Reservoir approximately half the cottonwood trees died following the 1973 inundation (visible in the background of Fig. 5). A

Fig. 12. Difference in response within a species is shown by these bur oak trees in upper third of Red Rock Lake; of 13 trees, two remained alive through inundations; photographed late summer 1974.

Fig. 13. Storm damage to flood plain forest, Red Rock Reservoir, Runnels area; cottonwood, grapevines, and poison ivy partially remaining, 1974; photographed 22 August 1974.

windstorm did extensive damage passing through the forest of flood damaged trees (Fig. 13).

3. On gently sloping land the response of vegetation to flooding is complicated by wave action and erosion. Unless severe erosion occurs, the vegetation rather quickly recovers from short periods of inundation. Where the vegetation is dominated by perennial herbaceous species as in a pasture situation, the response is a thinning out of the established plants and an invasion of annuals such as ragweed (*Ambrosia artemisiifolia*), daisy fleabane (*Erigeron strigosum*) and biennials such as thistles (*Cirsium discolor*, *C. altissimum* and *C. vulgare*) and evening primrose (*Oenothera biennis*). Often the white aster (*Aster pilosus*) establishes within the first few years as a short-lived perennial. The high water mark may be visible for some years after the water recedes because of the striking appearance of these species.

Few tree species can withstand long inundation on gentle slopes where wave action is vigorous. The high water level of 1973 either physically removed trees or killed them to within a few yards of the high water mark. In some cases severe erosion occurred at the high water line, eroding away the tree roots. Because of the extreme situation in 1973 during which the water level remained high throughout the growing season, there was little opportunity to measure susceptibility differences between species.

4. On steep slopes erosion has been severe, extensive and uncontrolled by vegetative cover. Vegetation on steep slopes, once damaged, has minimal recovery because of substrate removal. Erosion to bedrock

has occurred along south shores of Lake Red Rock from the State Highway 14 bridge to the dam (Fig. 7). No recovery of vegetation is anticipated during the projected life of this reservoir in these areas.

Observations near Runnells on riprap slopes where cottonwood trees have established in soil between the boulders suggest similar possibilities whenever steep slopes are exposed to severe wave action. Ideally, the riprap should be in place before the wave action occurs.

In contrast with the impact of fluctuating water levels on steep slope forest is the naturally developed forest showing a high degree of slope stability (Fig. 14). With a minimum fluctuation in water level, the natural forest or pasture vegetation commonly extends uninterrupted to the water's edge, as it does along the shorelines of Lake McBride (Fig. 15), a stable level subimpoundment of Coralville Reservoir.

3.3. Variations in Species Dominance

Observations by Wilson (1973) were concentrated in areas of frequent inundation adjacent to the State Highway 14 bridge over Lake Red Rock. Following the first flooding in 1969 these flats became thickly covered with annual herbaceous species, except for dense stands of willow and scattered cottonwood. Controlled releases of flood waters limited variations in elevation to less than one meter for a period. This allowed striking patterns to develop among the annual species; e.g., giant ragweed dominated high ground, smartweed (*Polygonum pensylvanicum*) the extensive flat ground and velvet leaf (*Abutilon theophrasti*) the small depressions. Variations of this pattern were repeated in other years; however, the

Fig. 14. Bur oak woodland on slopes of Saylorville Lake subject to inundation in Jester Park; large tree to the left is approximately 150 years old; understory is mainly ironwood; photographed in late fall, 1976.

Fig. 15. Relatively stable shoreline of Lake McBride with woodland and pasture vegetation retained to the water edge because of negligible wave action and water level fluctuation after eleven years of operation; photographed 26 August 1971.

high water of 1973 completely erased any successional progress. Of the ten zones that Wilson describes for this area based on dominance, all but two are dominated by annual weedy species (Table 1).

Observations beyond the annual stage of succession have not been extensive. Sufficient time has not elapsed between floodings to allow much change beyond the biennial and weak perennial stage.

Table 1. Variations in dominance by annual species in relatively level mudflat topography of Red Rock Lake near State Highway 14 bridge, August, 1971; Zone 10 is nearest the water, Zone 1 is one meter higher in elevation. (After Wilson, 1973.)

Zone	Dominant Species
1	*Amaranthus hybridis*, *Chenopodium alba*
2	*Ambrosia trifida* in higher positions within the zone; also *Bidens polylepis* in lower areas
3	*Setaria viridis* dominant with Bidens sp. and *Ambrosia trifida* occurring often
4	*Polygonum pensylvanicum* with *Xanthium* sp. and *Conyza canadensis* occurring on higher spots
5	*Setaria viridis* with *Polygonum*, *Conyza* and *Setaria lutescens* as associates
6	*Populus deltoides* (cottonwood saplings)
7	*Salix* spp. (dense willow thickets)
8	*Echinochloa crus-galli*, sometimes mixed with *Salix*, *Bidens*, *Polygonum* or *Populus*
9	*Acnida tamariscinus*, sometimes with *Xanthium* as a codominant
10	*Cyperus* spp.

3.4. Successional Compartments

Our understanding of reservoir shoreline vegetation response is a synthesis of the qualitative observations made at Coralville, Red Rock, and Rathbun Reservoirs over the past ten years, the small amount of information available in the literature and the basic principles of the field of plant ecology. It can be summarized as follows:

1. At any site on the reservoir shoreline the vegetation is undergoing succession.

Figure 16 shows a block diagram of the general pattern of succession in central Iowa's reservoirs. Some of the common species in each of the general ecological groups shown in Fig. 16 are identified in Table 2.

Since none of the reservoirs in central Iowa are older than twenty years, it is obvious that the sequence in Fig. 16 has not been observed to completion. However, other studies of succession in central Iowa have noted the same general pattern, including the species composition of the several stages (Warner and Aikman 1943).

Note in Fig. 16 that both the herbaceous and water tolerant tree branches of the successional pattern can be found together at the same site. However, the importance of the two branches relative to one another will vary with site conditions. This is discussed below.

2. At some point in this successional sequence another flood event will occur. The site will be inundated and vegetation kill will begin.

The major killing effects of inundations on vegetation appear to be:

1. Saturation of the root zone preventing adequate root aeration;

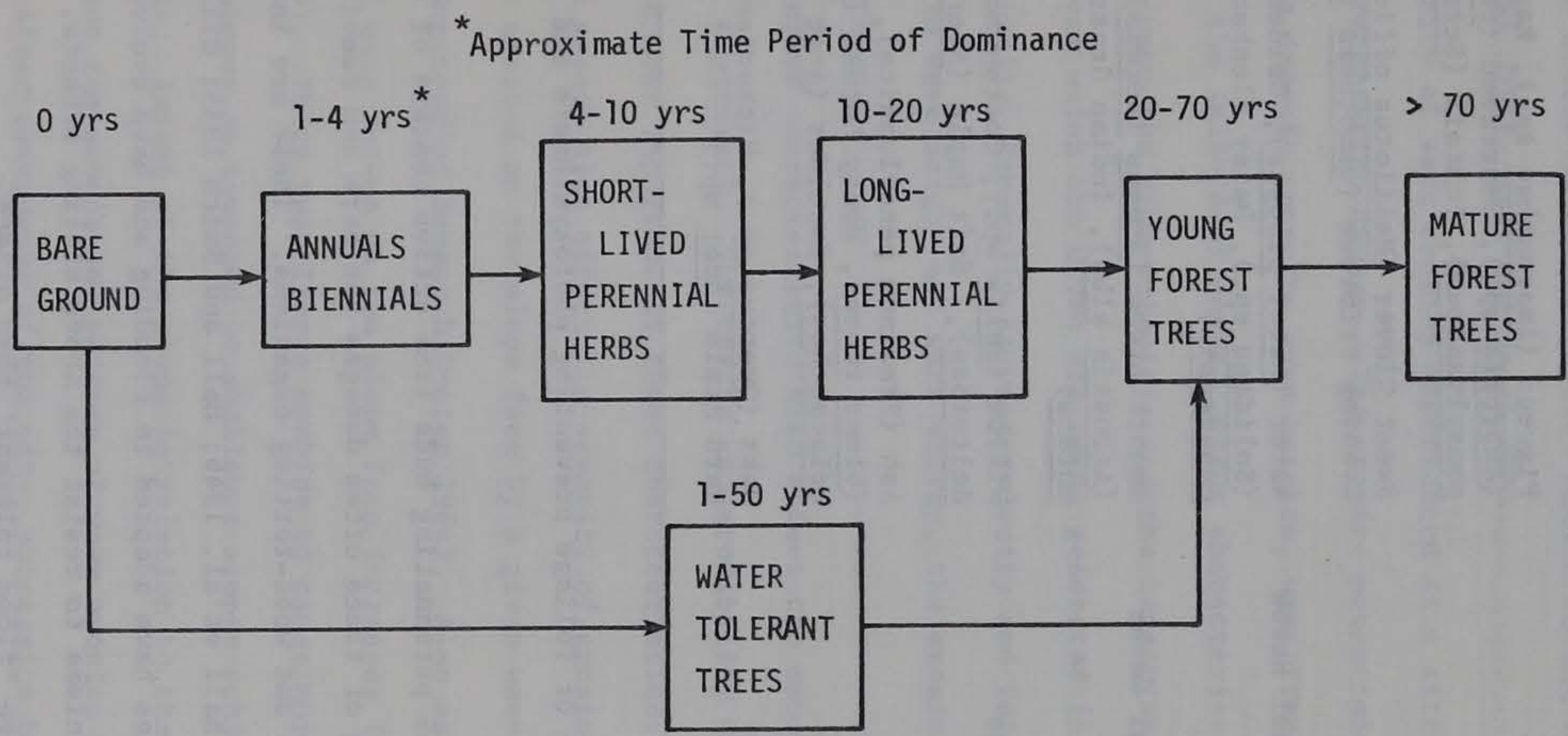


Fig. 16. Vegetative succession model for Iowa reservoirs.

Table 2. Common successional species.

Annuals	Pigweed (Amaranthus sp.), Ragweed (Ambrosia sp.), Smartweed (Polygonum pensylvanicum), Foxtail (Setaria sp.)
Biennials	Sweet Clover (Melilotus officinalis), Evening Primrose (Oenothera biennis)
Short-lived Perennial Herbs	Aster (Aster pilosus), Goldenrod (Solidago sp.), Daisy Fleabane (Erigeron canadensis)
Long-lived Perennial Herbs	Smooth Brome (Bromus inermis), Redtop (Agrostis alba), Indian Grass (Sorghastrum nutans)
Water Tolerant Trees	Willow (Salix sp.), Cottonwood (Populus deltoides), Soft Maple (Acer saccharinum)
Young Forest Trees	Ash (Fraxinum pensylvanica), Red Elm (Ulmus rubra), Honey Locust (Gleditsia triacanthos), Boxelder (Acer negundo)
Mature Forest Trees	Oaks (Quercus sp.), Hickories (Carya sp.) Hard Maple (Acer sp.)

2. Submersion of foliage preventing photosynthesis and gaseous exchange;
3. Kill of the perennating buds (the active centers of cell division).

Also, flooding of trees often damages the bark and cambium, opening the tree to disease and wood-rotting organisms. These are indirect causes of tree mortality (Hall et al. 1946; Hall and Smith 1955; Gill 1970). However, some species have adapted to flooding and have evolved various physiological mechanisms to resist the above killing effects. As a result some species are more "flood tolerant" than others.

Thus, it appears that flood tolerance, depth, and duration of flooding are all important in determining flood induced tree mortality. However, time of year when inundation occurs is also important. Damage appears to be less severe if the inundation occurs during the dormant season (Hall et al. 1946; Hall and Smith 1955).

Severity of wave erosion experienced at a site also affects the amount of vegetation damage. The erosive potential of a wind generated wave train depends upon the wave heights, wave frequency, and total energy of the individual waves. These characteristics of waves are dependent upon the wind velocity, and the length and width of the water surface over which the waves are being generated (i.e., the fetch) (Bhowmic 1975). Generally as wind velocity and fetch length cause an increase in wave height and wave energy, the erosive potential of the waves increases.

Shoreline characteristics also affect the amount of wave erosion a site will experience. The nature and erodability of the shoreline material may be the most important of these characteristics. However, shoreline slope and aspect also affect the severity of erosion. As slope increases the force exerted on the slope face by a given wave increases (U.S. Coastal Engineering Research Center 1966). Also as slope increases the height of wave run-up on the slope face increases (Thorn and Simmons 1971; Wood 1969). These two effects combine to cause more severe erosion on steeper slopes as compared to shallower slopes subjected to the same wave conditions. Aspect of the slope in relation to the prevailing wind will also affect the amount and pattern of wave erosion (Bhowmic 1975).

3. After reexposure of the site, succession begins again.

The exact rate and pattern of the successional development is dependent upon a complex of factors. Among these are: survivorship of the previous vegetation, time of year the site is reexposed, the suitability of the site substrate for plant growth, the amount of wave erosion the site has experienced, and the character of the seed sources impinging upon the site.

Time of year of exposure and slope of site combine to influence the relative importance of annual herbaceous species vs the water tolerant trees. In general, exposure in the spring favors the water tolerant trees while exposure in the summer favors annual herbaceous species. A shallow slope (less wave action, greater moisture availability) would favor the water tolerant trees, while a steeper slope (more wave action, less moisture availability) would favor the annual herbaceous species.

This observed pattern can be explained in the following way. Seeds of the water tolerant trees are produced by the billions and are widely disseminated by wind transportation mechanisms. These seeds are shed for about two to three weeks in May. However, they remain viable only for a few days and require moist bare soil to germinate. Thus, in a reservoir situation strong establishment of these species is observed at whatever elevation the water surface happens to be from mid to late May (Hall et al. 1946).

As wave action and wave erosion increase, more and more of the germinating seeds are washed out of the site. Thus, as site slope increases the number of successfully establishing individuals decreases.

The seeds of the annual herbaceous species, although still produced in great numbers, are produced in the fall. Also, these seeds have a viable period of several years. Therefore, it is seeds from previous seasons that produce the current year's crop. In a reservoir situation these seeds are either present at the site buried in the soil or are floated in with the flood water. They generally can germinate at any time during the period from early June to late July, and require much less moisture than the seeds of the water tolerant trees. Thus, if the site is exposed later than the first part of June the annual herbaceous species will establish but the water tolerant trees cannot (Hall et al. 1946).

Again, as wave action increases the rate of successful establishment and survivorship decreases. Severe wave action will prevent any establishment at all until the water level has receded well below the site.

Annual herbaceous and water tolerant tree species are competing for establishment on the bare soil exposed after inundation. If conditions favor the establishment of the water tolerant trees, their shading effect somewhat inhibits the invasion of herbaceous species. If conditions favor the establishment of annual herbaceous species, subsequent invasion of the water tolerant trees is inhibited as the seedlings of these species compete poorly with established vegetation.

Suitability of the site substrate primarily controls the rate at which succession proceeds. Suitability includes such factors as availability of nutrients, moisture holding capacity, pH, etc., and is roughly related to the soil organic matter content.

Any well-developed soil has a high suitability for plant growth. Succession will proceed fairly rapidly on sites having this type of substrate. However, in reservoirs, wave erosion removes the upper layers of the soil profile, exposing substrates with decreasing suitability as erosion becomes more severe. If wave erosion is severe enough to remove all of the soil, exposing the "subsoil" as a medium for plant growth, succession will proceed much more slowly. In this case the annual and biennial stages of succession persist years longer than what would be observed under favorable conditions.

When the subsoil is exposed the exact rate of succession is again dependent upon the suitability of the material exposed. Glacial till is fairly common as an underlying material in reservoir shorelines in the Midwest. This type of substrate would have a moderate level of suitability. However, some of the shale and sandstone substrates exposed at Red Rock Reservoir and the limestone bedrock exposed at Coralville Reservoir are so unsuitable for plant growth that the rate of succession on these sites is effectively zero. It is probable that no significant vegetation development would be observed at these sites for the remainder of the century.

The model presented in the remainder of this paper makes no attempt to accurately depict the situation where all of the previous soil has been removed by wave erosion. Sufficient information in this area simply wasn't available.

Finally, the types of plants that will be found during succession on a given site are influenced by the nature of the seed sources available to the site. It is a common tenet in plant ecology that seeds of early successional species are produced in large numbers, are small and light, and have well developed dispersal mechanisms. The seeds of these invading species are adapted for dispersal rather than competition.

Therefore, the character of the seed source for early successional species tends to be uniform over an area the size of a reservoir, and the seeds of invading species are present in large numbers at all sites.

However, the seeds of the longer-lived species found in the later stages of succession are produced in smaller numbers, are larger and heavier (more stored food), and have little or no transportation mechanism. The seeds of these species are adapted for competition rather than dispersal. In fact, it is common for species found in the later stages of succession to reproduce primarily through vegetative means. Thus, the later stages of succession will be most strongly influenced by the vegetation immediately surrounding the site. A once forested site will tend to undergo a forest succession after damage by inundation due to the influence of the undamaged forest upslope. A site previously in grassland or pasture will tend to undergo a herbaceous succession due to the undamaged herbaceous vegetation upslope.

4. MATHEMATICAL MODELS

One of the major objectives of this research is to develop a series of mathematical models for the operation of a multipurpose reservoir that is subject to severe fluctuating water levels. These models form a management and planning tool that allows an improved evaluation of trade-offs between the environmental impacts in the flood pool upstream of the dam and the economic benefits downstream of the dam. These models allow the engineer and planner to evaluate the effects of changing reservoir operating criteria on both the upstream vegetation and the downstream flood control benefits.

Because of the local interest in the Saylorville Reservoir and the possible impacts of reservoir flooding on the Ledges State Park, it was decided early in the project that the Saylorville Reservoir should be the principal test case. However, the study indicated that operation of Red Rock Reservoir, downstream from Saylorville Reservoir on the Des Moines River, has significant impact on how Saylorville is operated. Thus, the combined Saylorville and Red Rock Reservoir system was chosen for the final analysis.

4.1. Reservoir Operations Models

Red Rock and Saylorville Reservoirs are operated as reservoirs in series for local flood control along the Des Moines River and as part of the flood control reservoir system in the Upper Mississippi River Basin. The operating policy currently being used at Red Rock is guided by several factors, including the water surface elevation in the reservoir, inflow to the reservoir, season of the year, and flow forecasts on the Mississippi River (U.S. Army 1968). Saylorville Reservoir is operated on a fixed release schedule depending on the elevation of the water surface in the reservoir, the inflow to the reservoir, and the available storage at Red Rock Reservoir downstream. Thus, the storage in Red Rock Reservoir can be treated as a feedback loop in determining the releases from Saylorville Reservoir. A model concerned primarily with the optimum operation of Saylorville Reservoir considering both flood damage downstream of the reservoir and the environmental impact at the Ledges State Park was developed. The feedback from Red Rock Reservoir was included in order to predict the water levels in Saylorville Reservoir more accurately. The environmental impacts on the vegetation at the Ledges State Park is a function of the depth of flooding, the length of time flooding occurred and the time of year that flooding occurred. A conflict between environmental impacts in the Ledges and economic benefits from flood damage reduction downstream exists, since minimizing the environmental impacts would require that flood waters be released as rapidly as possible which would increase the flood damage downstream. The optimization model developed in this research is capable of determining the reservoir release rates that will minimize downstream flood damages subject to various levels of environmental concern.

4.1.1. Optimization Model Formulation

The objective of the model is to determine the changes in the flood damages associated with varying the flood operations of the Red Rock - Saylorville Reservoir system in order to gain certain environmentally desirable goals. In this specific case, the environmental objective was to reduce damage to vegetation and areas of recreational value in the flood pool area behind the Saylorville Dam. The associated costs are the cost of additional damage downstream of Saylorville Reservoir that may be incurred as a result of attempts to reduce the depth and duration of inundation in certain parts of the flood pool.

A dynamic programming optimization model that selects an optimal operating policy for the Saylorville Reservoir was developed for this project (Glanville 1976). For a given set of weekly average inflows, the model will search the feasible policy space outlined by the constraints and select a weekly operating policy which is optimal.

A forward-looking dynamic programming model was selected as the solution procedure because of the savings in computer memory space that are afforded by this approach over the conventional dynamic programming procedure. The model has only a single decision variable, release rate from Saylorville Reservoir, and the number of discrete states that are used is not excessive so there was no real need to use the state incremental or discrete differential solution algorithms.

The stages represent weekly operating periods in the Red Rock - Saylorville model. Daily operation was not used because of the substantial increase in the number of computations that would be needed and the fact that the additional information gained would be of limited usefulness. Monthly stages were rejected because the flood events would only be several months long at best and a monthly operating policy would not provide adequate information to be of use in analyzing the flood period operation.

The amount of water released from Saylorville in each stage (week) was used as the decision variable and the amount of water stored at Saylorville at the end of a week was used as the state variable. The state variable, storage at Saylorville Reservoir, could assume any positive value from 74,000 acre-feet at conservation pool level up to 865,000 acre-feet at maximum flood storage.

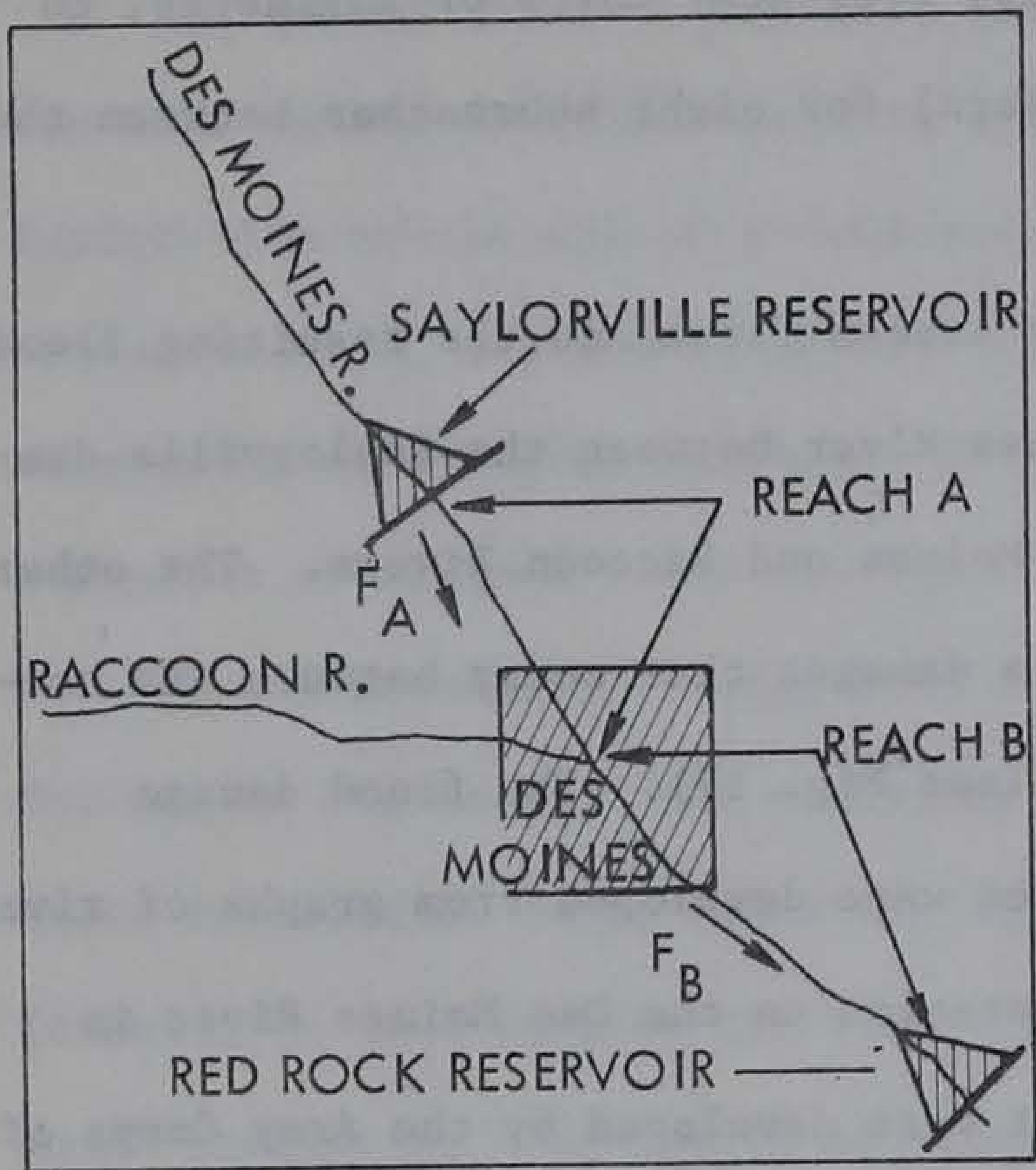
It was necessary to partition the storage in Saylorville Reservoir for use in the model. The number of discrete states to use in a discrete state formulation is an important consideration. Too few states in the formulation tend to give the resulting reservoir operation policy a spasmodic character, thus losing accuracy. At the opposite extreme, a large number of discrete states will allow a very smooth operating scheme but will greatly increase the number of calculations that must be made at each stage. A compromise can generally be arrived at by simply trying different numbers of discrete states until reasonable results are obtained. Twenty-five discrete states are used in the Red Rock - Saylorville model, dividing the flood storage into 24 equal volume increments, with each state representing 33,000 acre-feet.

The continuity equation serves as the transition function at each stage of the model. The continuity equation that is used does not contain terms to represent all of the natural processes, since evaporation, seepage, and rainfall directly on the reservoir were neglected.

The single stage returns for this flood operation study consisted of the flood damage that occurs between the Saylorville and Red Rock damsites as the result of the operating policy at Saylorville. The return function was composed of a set of eight discontinuous linear equations, supplied by the Rock Island District, U.S. Army Corps of Engineers, to describe the flood damages (in dollars) for eight subreaches between the two reservoirs (U.S. Army 1976).

Four of these equations relate stream flows and the resulting flood damage in the reach of the Des Moines River between the Saylorville damsite and the confluence of the Des Moines and Raccoon Rivers. The other four equations are used to calculate damages that occur between the confluence and the Red Rock Reservoir (see Fig. 17). The flood damage equations used as the return function were developed from graphs of river stage (at the Second Avenue gaging station on the Des Moines River in Des Moines) versus flood damage that were developed by the Army Corps of Engineers (Rock Island District) in 1959. Stage-discharge information for the gaging station at Des Moines was used to convert the flood damage information into a function of streamflow in ft^3/sec. It is recognized that inflation and further development in the flood plain since the curves were developed have made the present damage figures significantly different than those indicated in 1959. Therefore, the policy costs returned by the model will not be representative of current flood damages. The purpose of this model, however, is to compare the returns from various operating schemes, and it is felt that the 1959 cost information will provide an adequate indication of differences in the cost of various operating policies for comparative purposes.

The objective of the model is to find the operating policy (release rates) which minimizes the sum of all the single stage returns for each flood event. Inputs to the model consisted of weekly average historical flood flows representing the largest volume floods recorded at the U. S.



F_A = STREAM FLOW (cfs) IN REACH A

F_B = STREAM FLOW (cfs) IN REACH B

D = DAMAGE IN DOLLARS

REACH A

FLOW RANGE	DAMAGE
$0 \le F_A < 11,500$	$D = 0$
$11,500 \le F_A < 32,700$	$D = (F_A - 11,500) * 9.906$
$32,700 \le F_A < 58,200$	$D = (F_A - 32,700) * 344.627 + 1,300,000$
$58,200 \le F_A < 91,600$	$D = (F_A - 58,200) * 287.635 + 10,088,000$

REACH B

$0 \le F_B < 25,200$	$D = 0$
$25,200 \le F_B < 58,000$	$D = (F_B - 25,200) * 0.762$
$58,000 \le F_B < 84,500$	$D = (F_B - 58,000) * 34.718 + 380,000$
$84,500 \le F_B \le 100,000$	$D = (F_B - 84,500) * 23.871 + 2,460,000$

Fig. 17. Return function for the Red Rock-Saylorville model.

Geological Survey stream gaging station upstream of Saylorville Reservoir. Because of the positive feedback between the available storage in Red Rock Reservoir and the release rates from Saylorville Reservoir, a model of operations of Red Rock Reservoir had to be included. This required flows from the Raccoon River, the largest tributary entering the Des Moines River between the two reservoirs, to be included in the calculations of storage at Red Rock Reservoir.

The complete model can be described in mathematical terms as follows. The objective of the optimization model is:

$$\text{Minimize } C = \text{Min} \sum_{i=1}^{N} r_i(d_i) \qquad (1)$$

where C is the total policy cost for an N stage flood event; i is the stage index number (stages numbered in chronological order); N is the total number of stages in a flood event; and $r_i(d_i)$ is the single stage return from a policy decision d_i made in stage i.

The rate of outflow from the Saylorville Reservoir in stage n, designated by O_n, is the decision variable. The single stage return, $r_n(O_n)$, is the amount of flood damage incurred between the Saylorville and Red Rock sites as a result of O_n. The set of discontinuous linear equations that comprise the return function are shown in Fig. 17.

The constraints on the operating decision are:

$$S_n = S_{n-1} + I_n - O_n \qquad (2)$$

$$S_{min} \leq S_n \leq S_{max} \qquad (3)$$

$$O_n \leq O_{max}(H) \qquad (4)$$

where S_{n-1} and S_n are the storages in Saylorville Reservoir at the beginning and end of the nth week, I_n is the inflow during the nth week, 0_n is the outflow during the nth week (decision variable), S_{min} is the minimum storage in the reservoir (conservation pool storage), S_{max} is the maximum storage (full flood pool storage), and $0_{max}(H)$ is the maximum amount of water which can be released from the reservoir with a given head, H, available.

In addition to those constraints indicated above, two additional fundamental constraints were placed on the operation of both reservoirs. On the rising side of the inflow flood hydrograph, it was necessary to limit reservoir releases rates to no more than the rate at which water is entering the reservoir in order to avoid the possibility of causing downstream damages in excess of those that would occur if the reservoir were not present. On the falling side of the flood hydrograph, the rate of decline in the lake level in either reservoir was limited to no more than one foot per day. This was done in order to reduce the amount of bank sloughing that can occur along the edge of the flood pool if the lake level is lowered too rapidly. Mathematically, the constraints are on the rising side of the inflow hydrograph:

$$0_n \leq I_n \tag{5}$$

and on the recession side of the inflow hydrograph:

$$0_n \leq 0_7 \tag{6}$$

where I_n is the inflow to the reservoir in stage n; 0_7 is the outflow that would cause the reservoir water surface level to drop 7 ft in one week; and 0_n is the outflow from the reservoir during stage n.

The recursive equation expressing Bellman's Principle of Optimality (Bellman 1957) for this forward dynamic programming model is:

$$R_{n+1}(S_{n+1}) = \text{Min}[r_{n+1}(0_{n+1}) + R_n(S_n)] \quad (7)$$

where n is the stage number (stages numbered in chronological order); $R_n(S_n)$ is the return from the optimal policy which carries the system through the first n stages and leaves it in state S_n; and $r_{n+1}(0_{n+1})$ is the single stage return resulting from decision 0_{n+1}.

At every stage (week) the model defines the possible end of week states (water in storage) by solving the transformation function for the end of week storage with the outflow first set equal to the minimum release rate and then outflow set equal to the maximum release rate. Minimum outflow is equal to zero and maximum outflow is equal to either inflow on the rising side of the hydrograph or $0_{max}(H)$ on the recession side of the inflow hydrograph. The outflow rates required to move to all the discrete storage states enclosed by the maximum and minimum feasible storage, as defined above, are then calculated. The single stage return for each policy (calculated outflow rate) is determined and added to the optimal policy return from the previous stages. This process is continued until all pathways from the initial states (the possible beginning of week storages) to all possible end of week storages are searched. The optimum total policy is selected and stored for later use. The procedure is repeated until all weeks in the flood are analyzed and the total optimum policy is selected (Glanville 1976).

The above formulation can be used to find the minimum flood damage operating schedule for a given flood event. Additional constraints could be introduced in order to consider the environmental impacts in the analysis. However, there are advantages to introducing a "penalty function" which would make the states that are environmentally undesirable less attractive to the model. Unlike constraining parameters or equations that simply make certain policy decisions impossible, the penalty function permits the model to acknowledge that while certain policy decisions may not be desirable they are realistic, and may well be part of the optimal overall policy despite being penalized. Penalty functions play an important part in this model as a means to create and measure the effects of operating policies on environmental benefits which cannot be easily measured in economic terms.

In the absence of a penalty function, the dynamic programming algorithm chooses policy decisions that store water during high flow periods, since the objective is to minimize downstream flood damage. This results in frequent long periods of inundation which have severe impacts on shoreline vegetation. In this model a penalty function was introduced in an attempt to minimize the time that the flood pool is above some critical (target) elevation. To obtain such a policy, it is necessary to penalize the single stage returns resulting from decisions that do not adhere to the "desired policy." The exact amount of the penalty that is required varies with the state that the reservoir is in and the rate of inflow to the reservoir. This penalty system begins by identifying the most desirable feasible final state, as illustrated in Fig. 18. The lowest end of week state is the most desirable if all the final states are above the target, as in Situation 1 in Fig. 18. The final state, which is at or immediately below the target level, is considered the

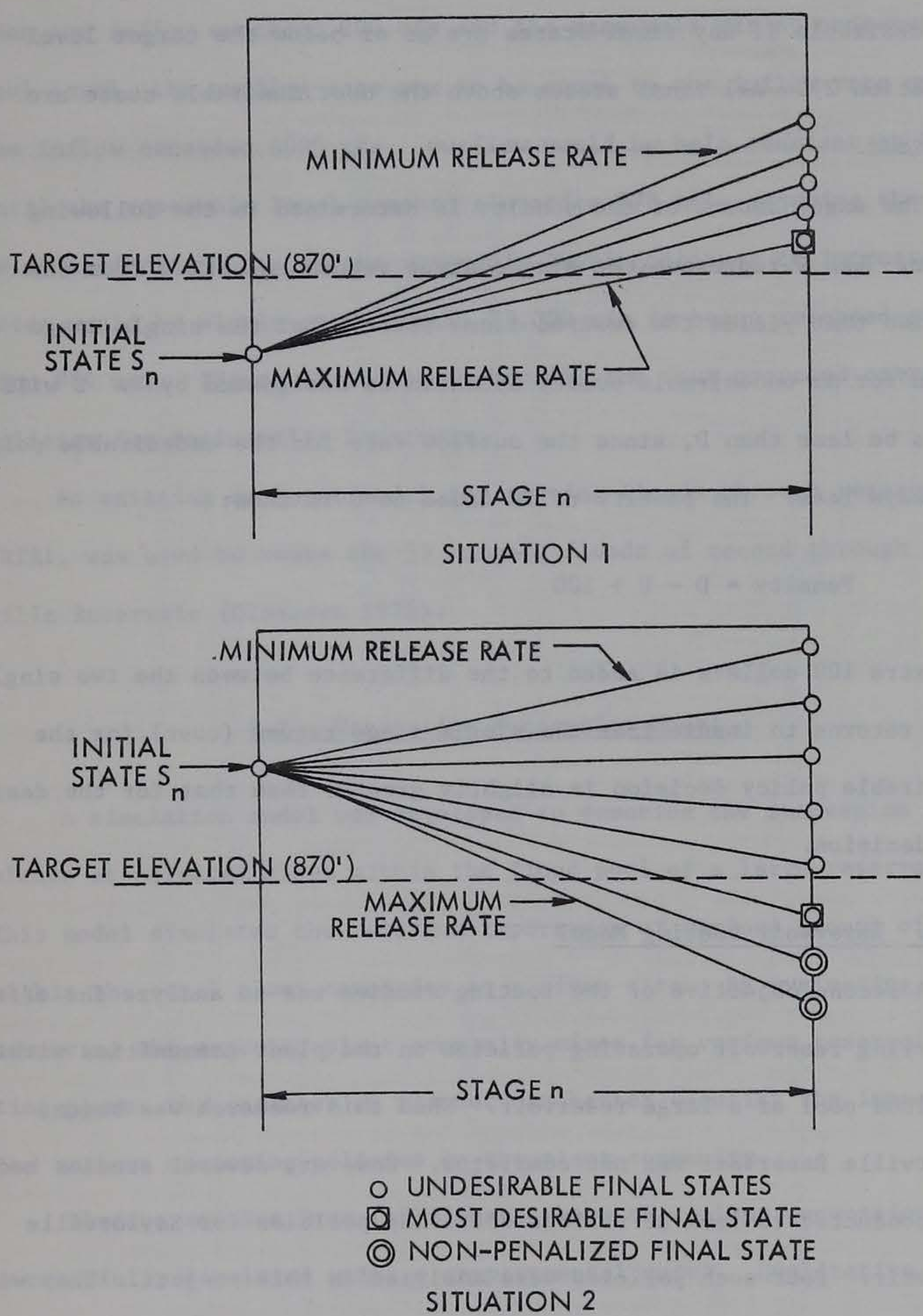


Fig. 18. Operation of penalty system 2.

most desirable if any final states are at or below the target level (Situation 2). All final states above the most desirable state are penalized.

The exact amount of the penalty is determined in the following manner. Let D represent the single stage return resulting from the decision that yields the desired final state. Let the single stage return for an undesirable policy decision be designated by U. U will always be less than D, since the outflow rate for the undesirable policy is always less. The penalty to be added to U is then:

$$\text{Penalty} = D - U + 100$$

The extra 100 dollars is added to the difference between the two single stage returns to insure that the single stage return (cost) for the undesirable policy decision is slightly greater than that for the desirable decision.

4.1.2. Reservoir Routing Model

A second objective of the routing studies was to analyze the effects of varying reservoir operating policies on the plant communities within the flood pool of a large reservoir. When this research was begun, Saylorville Reservoir was not completed. However, several studies had been conducted to look at various operating policies for Saylorville Reservoir. Four such policies were analyzed in this project. They will be referred to as the 8,000 cfs, 12,000 cfs, 16,000 cfs, and open conduit policies, respectively.

The original operating schedule proposed by the Corps of Engineers for Saylorville Reservoir called for the low flow release of 200 cfs.

When the inflow exceeded 200 cfs and the reservoir was at conservation pool level, the outflow rate was to be equal to the inflow rate until the inflow exceeded 8000 cfs. Outflow would be held constant at 8000 cfs until the reservoir level reached elevation 878 msl, assuming the inflow is still increasing. If the reservoir level continues to increase, the gates would be slowly opened until 21,000 cfs is being released at elevation 884 msl. Figure 19 shows graphically the four proposed operating policies for Saylorville Reservoir.

An existing computer model for routing floods through reservoirs, FRTR1, was used to route the 55 largest floods of record through Saylorville Reservoir (Claassen 1976).

4.2. Vegetative Succession Model

A simulation model was developed to describe the succession of plants at selected sites within the flood pool of a large reservoir. This model simulated the relative importance of various groups of plants within the total plant community at a given site. By evaluating and comparing the expected plant community mixes for various reservoir operating plans, the engineer or planner can better quantify the impacts of the various operating policies on the plant community.

Bledsoe and Van Dyne (1971) have shown that plant succession can be successfully simulated using a compartmental model. Qualitative data from two classic studies of succession were used to develop a mathematical structure that would simulate the results of those earlier findings. Since reservoir shoreline vegetation development is basically a successional

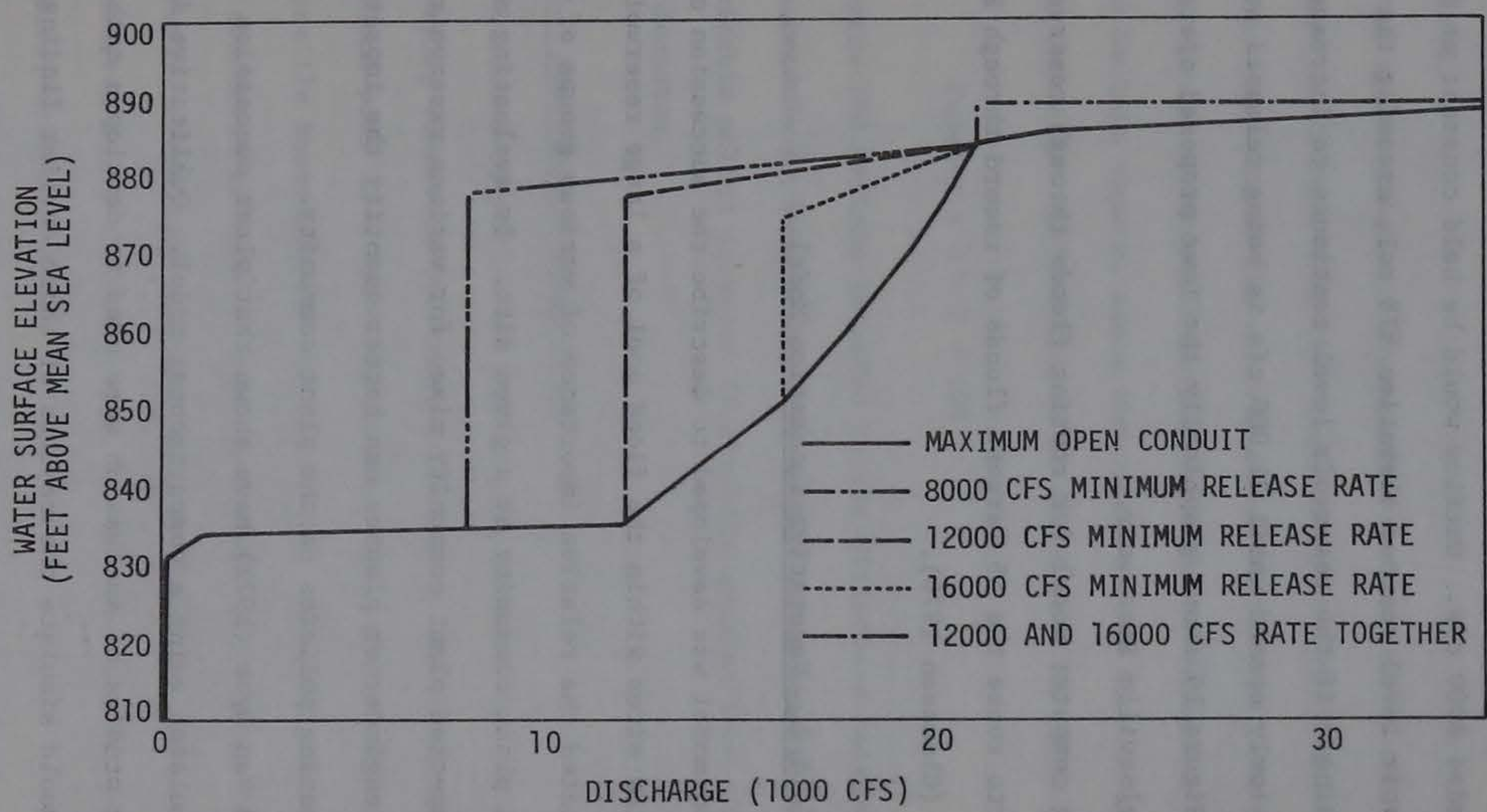


Fig. 19. Flood control policy alternatives for Saylorville Reservoir.

phenomenon, and since most of the data documenting this phenomenon are qualitative, the modeling problem in this research was directly analogous to the problem solved by Bledsoe and Van Dyne.

Because of the large number of plant species involved, it is impractical to develop a model that treats each species individually. Therefore, species are lumped together into ecologically similar groups, or compartments (Botkin 1974). For two species to be defined as ecologically similar they must have similar environmental requirements, similar life histories, similar physiognomy (appearance and growth form), appear together at similar times during the successional sequence, and have similar tolerances to flooding.

Section 11.1. in the Appendix lists all of the compartments used in the model and some common members of each. Vegetation in the model is referred to by compartment names which are understood to include all species within that compartment.

Note that three nonvegetative compartments are included. These are bare ground, shade caused by growth of trees, and soil organic matter. They are used in the model to represent some of the important environmental mechanisms controlling the successional process.

The compartments are interconnected, interacting elements of a system. The major interactions are:

1. Growth interactions. Growth in a later successional stage can be thought of as being dependent upon growth in a previous successional stage. This represents the successive modification of the environment by plant growth that results in species replacement.

2. Growth limiting interactions: negative feedback. Growth in some compartments can be thought of as being limited by growth in other compartments. This is used to represent the deleterious effects of shading, interspecies competition, changes in soil chemistry, accumulation of organic litter, and other factors on some compartments. These are all important mechanisms (environmental modifications) involved in the successional replacement process.
3. Thresholds. Growth in some compartments can be thought of as being inhibited until certain levels of shade or soil organic matter are reached. This is an attempt to model the special environmental requirements of some compartments.

Figure 20, a block diagram of the model, shows all compartments and pathways of interaction. System state can be described by a numerical importance value for each compartment. If quantitative data were available, importance value would be expressed as some physical measurement such as percent cover, biomass per unit area, or frequency of occurrence (Muller-Dombois and Ellenberg 1974). In this case, importance value simply represents an arbitrary numerical scale showing the relative dominance of the compartments.

A system of differential equations describes the changes in system state with time. The general form of the equation used, for any compartment i, is:

$$\frac{\partial x_i}{\partial t} = \sum_{j=1}^{n} a_{ij} x_j - \sum_{j=1}^{n} b_{ij} x_i x_j \tag{8}$$

This form is a generalization of the classic Lotka-Volterra model of biological growth (Odum 1971).

Each of the terms in Eq. (8) is a specific type of interaction as shown in the system diagram (Fig. 20).

The term:

$$a_{ii}x_i \tag{9}$$

represents the intrinsic growth of the compartment that would occur in an isolated environment with unlimited resources (Odum 1971). The term:

$$-b_{ii}x_i^2 \tag{10}$$

represents the growth limiting effects of intraspecific competition that would occur in an isolated environment with limited resources (Odum 1971). Obviously, the reservoir vegetative compartments are not isolated from one another, so terms having the form:

$$a_{ij}x_j \tag{11}$$

represent the growth forcing dependancy of Compartment i on Compartment j. Finally, terms having the form:

$$-b_{ij}x_ix_j \tag{12}$$

represent the growth limiting effects of interspecific competition, shade, and soil organic matter (Odum 1971; May 1973; Smith 1974).

Note that for a given compartment many of the coefficients in the generalized equation are zero. This can be seen by studying the compartment interactions shown in Fig. 20.

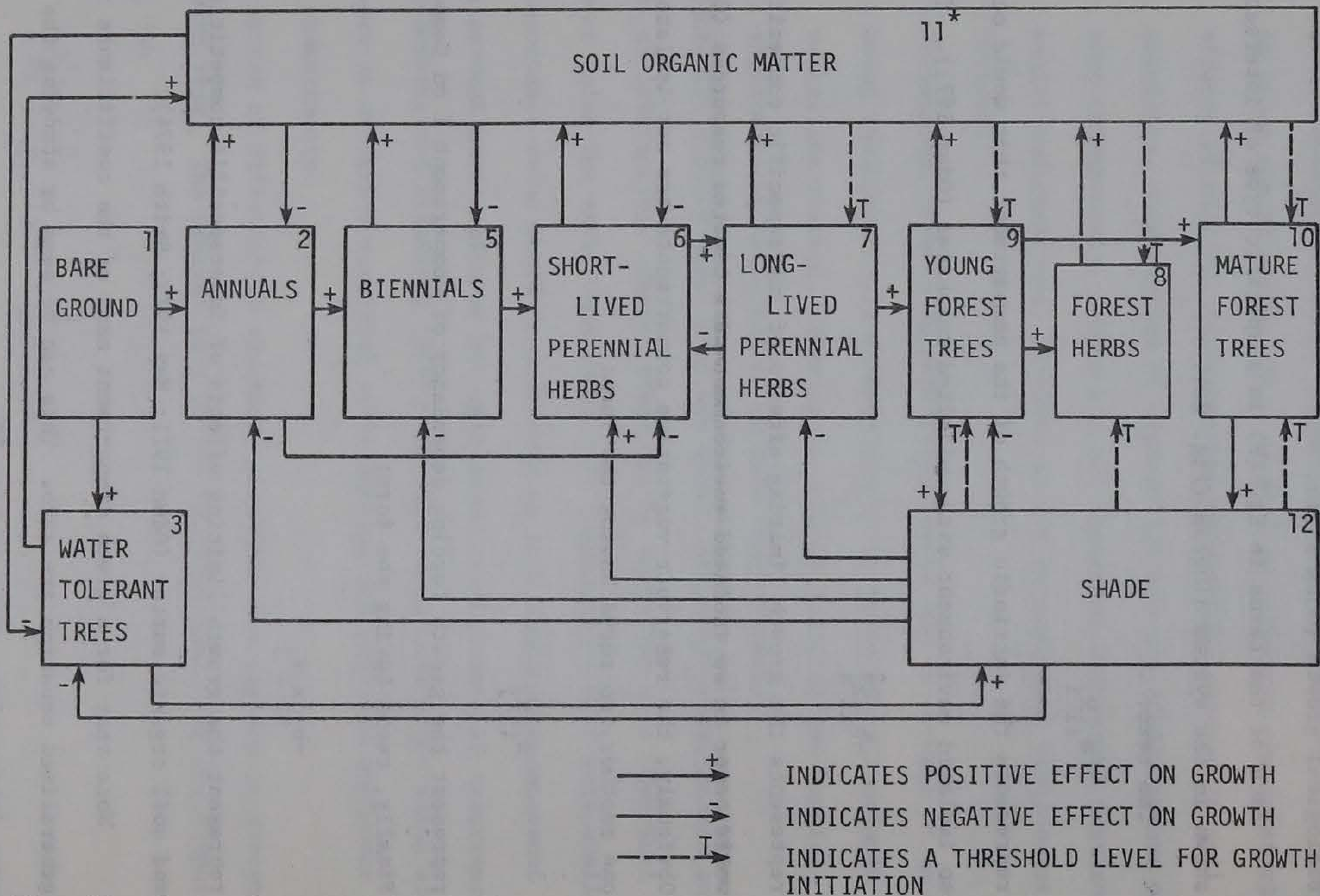


Fig. 20. Succession model block diagram.

A refinement to the basic equations permits threshold effects to be included in the model. Consider Compartment 7 (long-lived perennial herbs), for example, which might have the following terms incuded in its growth equation:

$$a_{77}x_7 - b_{7,12}x_7x_{12} \qquad (13)$$

Rewriting these terms gives:

$$a^*_{77}\ (1 - c_{7,12}x_{12})\ x_7 \qquad (14)$$

$$c_{7,12} = b_{7,12}/a_{77}$$

Growth can be delayed in this compartment until a threshold level is reached in Compartment 11 (soil organic matter) by substituting $f(x_{11})$ for a^*_{77} such that:

$$f(x_{11}) = \begin{cases} o & \text{if } x_{11} < T \\ a_{77} & \text{if } x_{11} \geq T \end{cases} \qquad (15)$$

In other words the intrinsic growth coefficient for Compartment 7 is a step function of Compartment 11. To be more realistic the modified coefficient $f(x_{11})$ should not be a step function but rather some unknown continuous function. A discussion of this concept is presented by Wiegert (1974). However, the amount of data available at this time is not sufficient to define a more exact formulation, and step functions are used in this model.

4.2.1. Modeling Flood Impacts

The severity of flood events was modeled using an artificial index, called the Flood Severity Index (SOF for Severity of Flooding), based upon the depth and duration of flood events. A SOF of 10 represents a combination of depth and duration of flooding severe enough to cause 100% kill of all vegetation.

A plot of the flood severity index is shown in Fig. 21. The severity of any flood is obtained by computing the average of the SOF determined from depth of flooding and the SOF determined from duration of flooding.

In order to model flood damage to the compartments, it was necessary to identify some relationship between the depth and duration of flooding and impact on the various compartments. Qualitative observations by Landers (1977) as well as other published data on vegetative response to flooding were used to develop the relationship between the SOF and the percent reduction in the various compartments in the model (Fig. 22).

Wave erosion was modeled by reducing the level of soil organic matter. This crude attempt to simulate the removal of soil proved adequate at most sites simulated in the study. In the present model, reduction of soil organic matter due to wave action is dependent only on site slope. The length and width of site fetch and the orientation of the site are not included.

Reduction in the shade compartment due to flooding is modeled by computing the percent reduction in the sum of importance values of the three woody compartments. The importance value of the shade compartment is then reduced by the same percentage.

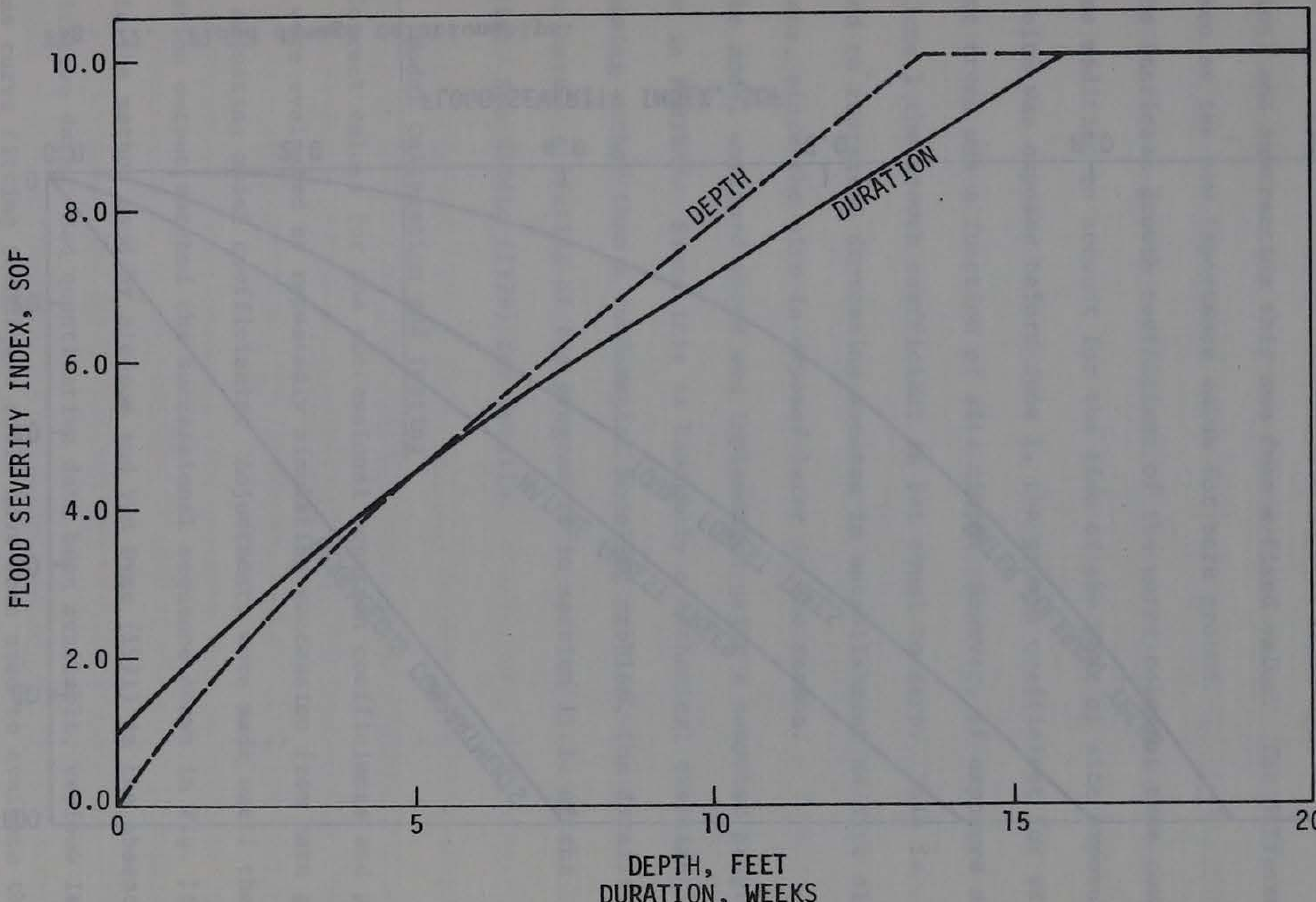


Fig. 21. Relationship of flood severity to depth and duration of flooding.

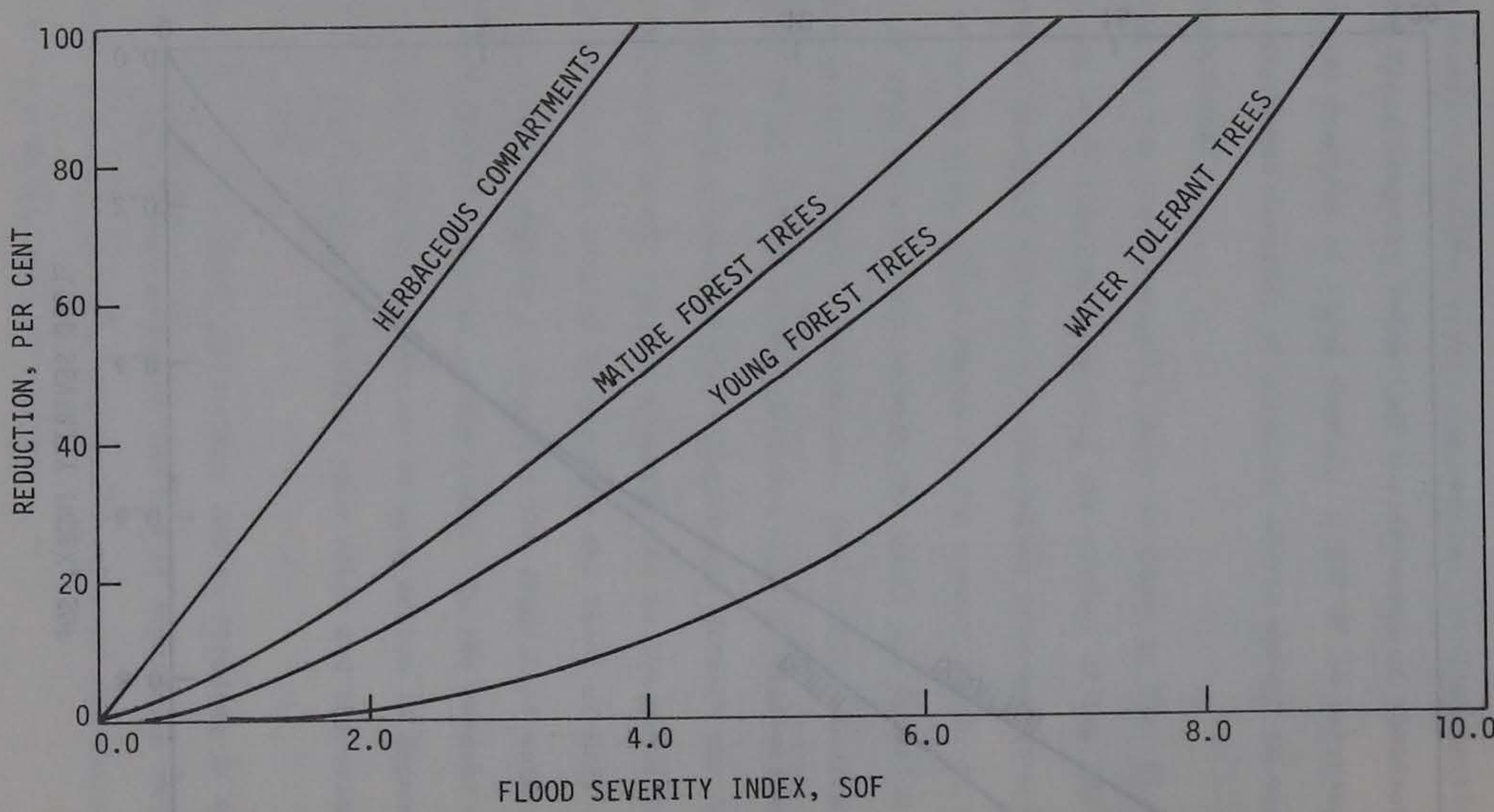


Fig. 22. Flood damage relationships.

The amount of bare ground exposed after a flood was modeled by summing the importance values of all vegetative compartments (after flood reduction) and subtracting this sum from a fixed value. The difference was taken as the new importance value for bare ground.

The intrinsic growth coefficient of the water tolerant tree compartment was modified to account for the time of the year of site exposure. If the site was exposed before June 1, the growth coefficient for water tolerant trees was a function of site slope. However, if exposure occurs after June 1 the growth coefficient is set equal to zero. This is intended to represent decreasing success in establishment as site slope increases, since the site is exposed later in the season.

The model outlined above was implemented using a computer program written in FORTRAN. Since this is basically a mechanical exercise in programming rather than a fundamental modeling problem, the details are omitted here. A listing of the program is in section 11.1. of the Appendix. See Riddle (1978) for details.

4.2.2. Model Calibration and Testing

Correct values for the successional equation coefficients and parameters were evaluated by repeatedly simulating succession from bare ground while adjusting model coefficients. Adjustments were made until the simulation output matched the successional sequence shown in Fig. 16. This is the method used by Bledsoe and Van Dyne (1971) in the absence of quantitative data. Had quantitative data been available, various least-squares curve fitting techniques could have been used to evaluate the coefficients (Bledsoe and Van Dyne 1971).

After evaluation of the equation coefficients and parameters the flood model was tested. Simulations were performed using several hypothetical combinations of vegetation, slope, and flood sequences. The results of these simulations were observed and minor changes were made in the flood model to force the model output to match a qualitative conception of the proper results.

The entire model was tested by simulating the vegetative succession at several sites in Coralville Reservoir, where flooding had occurred several times, to see how well the simulation results approximated the existing vegetation. Coralville Reservoir is the oldest of Iowa's large reservoirs, and it was hoped that its eighteen years of operation were long enough for the shoreline vegetation to have reached a "stable" condition.

Existing shoreline vegetation was surveyed in August 1976. Data collected included a slope profile survey, boundary elevations of all distinquishable vegetation zones, elevations of driftwood lines, and elevations of wave erosion benches. Within the vegetation zones all species observed were recorded and given a subjective importance rating based upon approximate cover (Muller-Dombois and Ellenberg 1974). In addition, notes were made concerning the general condition of the vegetation, severity of wave erosion, site substrate, and any other pertinent information.

A continuous record of the Coralville Reservoir pool elevations, obtained from the Corps of Engineers, Rock Island District, provided all necessary flood data. Aerial photographs of the Iowa River Basin taken in 1951 were used to estimate the preimpoundment vegetation present at each of the sites. Initial values of compartment importance were derived from these estimates.

The model was used to simulate vegetation response for three elevations (698, 705 and 709 ft msl) at each of the transects. Using the information obtained above, the simulations were run for the twenty-year period, April 1959 to April 1979. Model output for the year 1976 was compared to the observed vegetation at those sites.

After observing the results of these simulations, a few final adjustments were made in the model. However, no attempt was made to force all simulations to match observed vegetation exactly. Instead the model was made to fit the general pattern of vegetation development. Riddle (1978) presents the results of additional verification runs for several sites at Coralville Reservoir.

The simulation results using the final version of the model provide reasonably good approximations of the actual vegetation observed for most sites. However, the simulation results for a few sites that were unique in having very steep slopes, exposed limestone bedrock, or protection from wave action, are less representative. The present version of the model does not adequately account for such factors as the degree of wave erosion, the effects of site substrate, and the influence of surrounding vegetation.

Unfortunately, it is not possible to show the results of each site simulation alongside the field observations of site vegetation. Simulation results for one site are shown in Figs. 23 and 24. These results show flooding of transect 1, originally a pasture, at elevations 698 msl. Complete kill of the original pasture grasses is seen with replacement

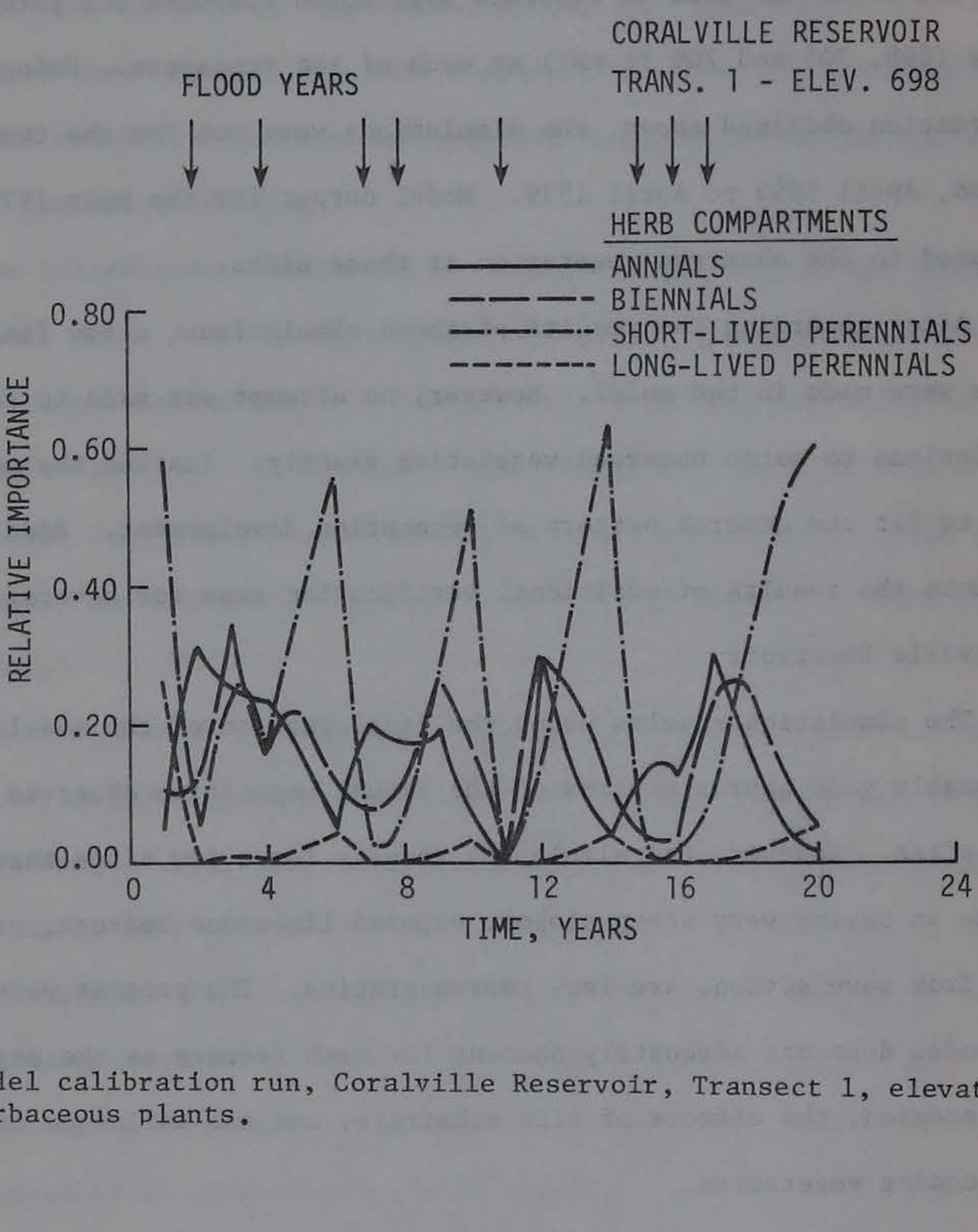


Fig. 23. Model calibration run, Coralville Reservoir, Transect 1, elevation 698, herbaceous plants.

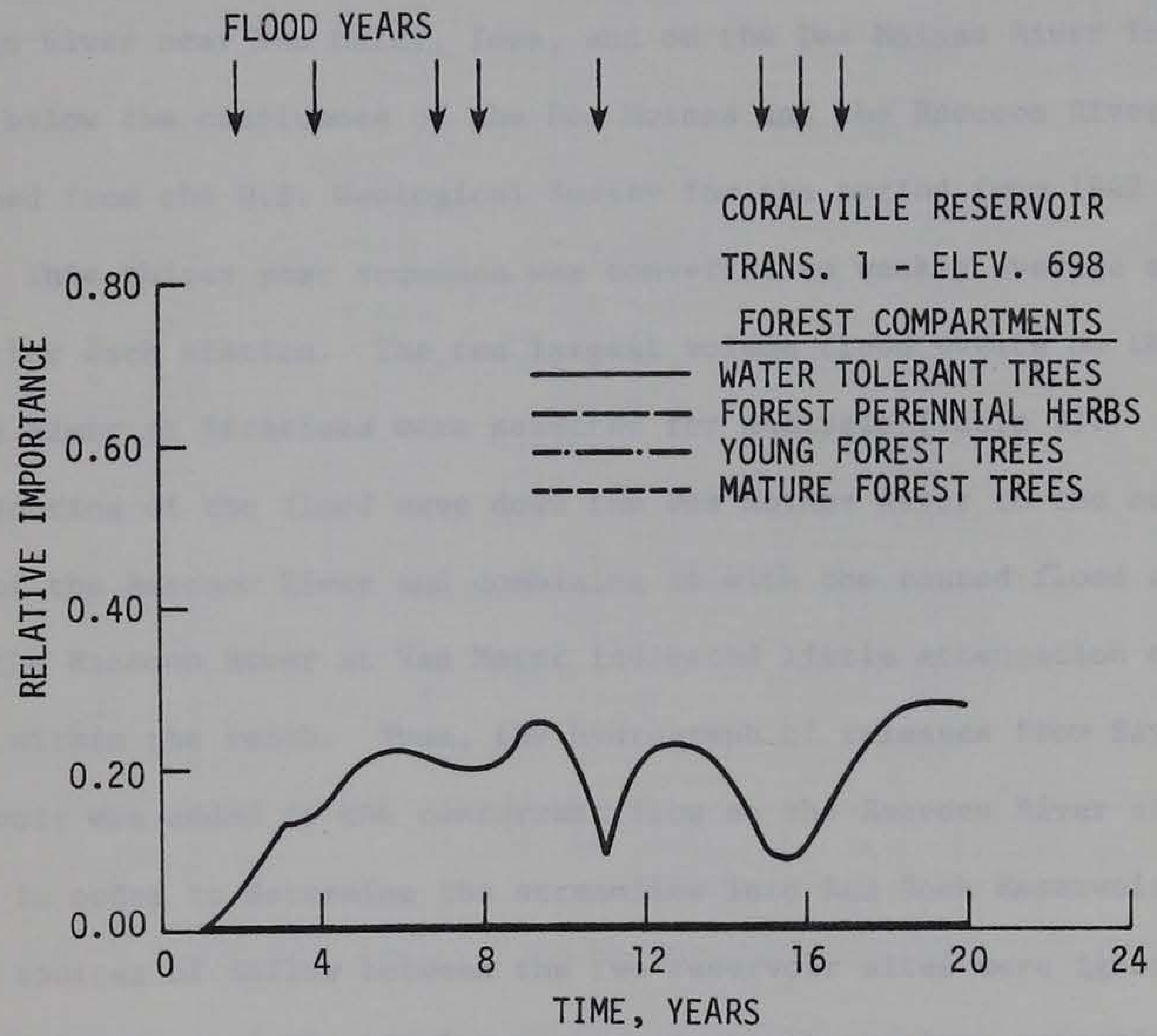


Fig. 24. Model calibration run, Coralville Reservoir, Transect 1, elevation 698, forest compartments.

by a fairly stable population of young, water tolerant trees and a cyclic pattern of weedy herbaceous succession occurring under the influence of frequent flooding. These simulation results are considered to be fairly good representations of the actual vegetation response observed at this site.

5. IMPACTS AT SAYLORVILLE RESERVOIR

5.1. Reservoir Operation

Daily streamflow records from the gaging stations on the Des Moines River at Stratford, Iowa (upstream from Saylorville Reservoir), on the Raccoon River near Van Meter, Iowa, and on the Des Moines River immediately below the confluence of the Des Moines and the Raccoon Rivers were obtained from the U.S. Geological Survey for the period from 1942 to 1972. This thirty year sequence was converted to weekly average streamflows for each station. The ten largest volume flood events on the Des Moines River at Stratford were selected for analysis (Table 3).

Routing of the flood wave down the Des Moines River to the confluence of the Raccoon River and combining it with the routed flood wave from the Raccoon River at Van Meter indicated little attenuation of flood peaks within the reach. Thus, the hydrograph of releases from Saylorville Reservoir was added to the concurrent flow on the Raccoon River at Van Meter in order to determine the streamflow into Red Rock Reservoir. All other sources of inflow between the two reservoir sites were ignored.

The purpose of the model was to evaluate the optimum operating scheme for the Red Rock - Saylorville system both with and without environmental penalties. The ten largest volume historical floods were input into the model to determine the policy which minimizes the flood damages between Saylorville and Red Rock Reservoirs. A second computer analysis was made with the added environmental penalty which would minimize the flood damage while adding a penalty for any time the reservoir rises above elevation 870 msl. Elevation 870 msl was chosen because

Table 3. The date, volume, and peak flow of the ten largest flood events on the Des Moines River at Stratford, Iowa.

	Historical Events		Peak Avg
Number	Date of Occurrence	Volume (acre-feet[a])	Weekly Flow (ft^3/sec)
1	April 1944	1,685,383	18,229
2	March 1945	2,110,351	12,333
3	April 1947	1,757,760	21,171
4	March 1951	2,969,980	23,529
5	June 1954	1,004,640	27,514
6	April 1960	1,024,827	18,157
7	April 1961	754,931	17,426
8	May 1962	2,359,207	23,371
9	April 1965	2,289,705	43,157
10	April 1969	2,989,973	21,100

[a]Note: 1 acre-foot = 1,233 cubic meters
1 ft^3/sec = 0.028 m^3/sec

other studies (Environtology Council 1973) have shown that significant damage to the Ledges State Park will occur when the water level is maintained above 870 msl for extended periods of time. This penalty encourages the solution to minimize the length of time the reservoir level would be above the target level, 870 msl.

Table 4 shows the characteristics of the optimum policies developed for each flood analyzed. The policy cost represents the flood damages incurred downstream of Saylorville Reservoir, with the zeroes indicating no flood damage occurred. In all cases good flood wave attenuation was realized.

Table 4. Summary of optimal policies using no penalty.

Event Number	Peak Inflow (cfs)	Peak Outflow (cfs)	Maximum Water stored at Saylorville (acre-feet)	Time Target is Exceeded (weeks[a])	Policy Cost ($)
1	18,229	13,310	238,790	0	18,485
2	12,333	11,063	106,958	0	0
3	21,171	13,766	271,748	0	22,873
4	23,529	17,271	436,538	2	100,847
5	27,514	10,956	370,622	0	0
6	18,157	9,975	205,832	0	2,279
7	17,426	10,305	172,874	0	0
8	23,371	15,940	304,706	0	68,926
9	43,157	16,167	667,224	9	46,229
10	21,100	16,353	337,664	0	95,380

[a]Target level is at elevation 870 msl.

Table 5 summarizes the results of the analysis using the environmental penalty. Since the penalty was involved only when the reservoir level rose above the target level of 870 msl, only Events 4 and 9 should be influenced. This in fact results. The penalty function was able to reduce the time above the target level to zero and four weeks for events 4 and 9, respectively. This was not accomplished, however, without an increase of 26 and 285% in the flood damages downstream for Events 4 and 9, respectively.

Table 5. Summary of optimal policies under the environmental penalty.

Event Number	Peak Inflow (cfs)	Peak Outflow (cfs)	Maximum Water Stored at Saylorville (acre-feet)	Time Target is Exceeded (weeks[a])	Policy Cost ($)
Historical					
1	18,229	13,310	238,790	0	18,485
2	12,333	11,063	106,958	0	0
3	21,171	13,766	271,748	0	22,873
4	23,529	17,271	370,622	0	127,712
5	27,514	10,956	370,622	0	0
6	18,157	9,975	205,832	0	2,279
7	17,426	10,305	172,874	0	0
8	23,371	15,940	304,706	0	68,926
9	43,157	18,540	535,412	4	177,881
10	21,100	16,352	337,664	0	95,380

[a]Target level is at elevation 870 msl.

5.2. Vegetative Succession at Saylorville Reservoir

Claassen (1976) gives flood routings for three different reservoir operation policies (Fig. 25). These are the 12,000 cfs, the 16,000 cfs. and the maximum release policies. The 12,000 cfs policy is intended to represent one of the Corps of Engineers design proposals. The maximum release policy is intended to represent the policy advocated by environmental groups concerned with protection of the Ledges. The 16,000 cfs

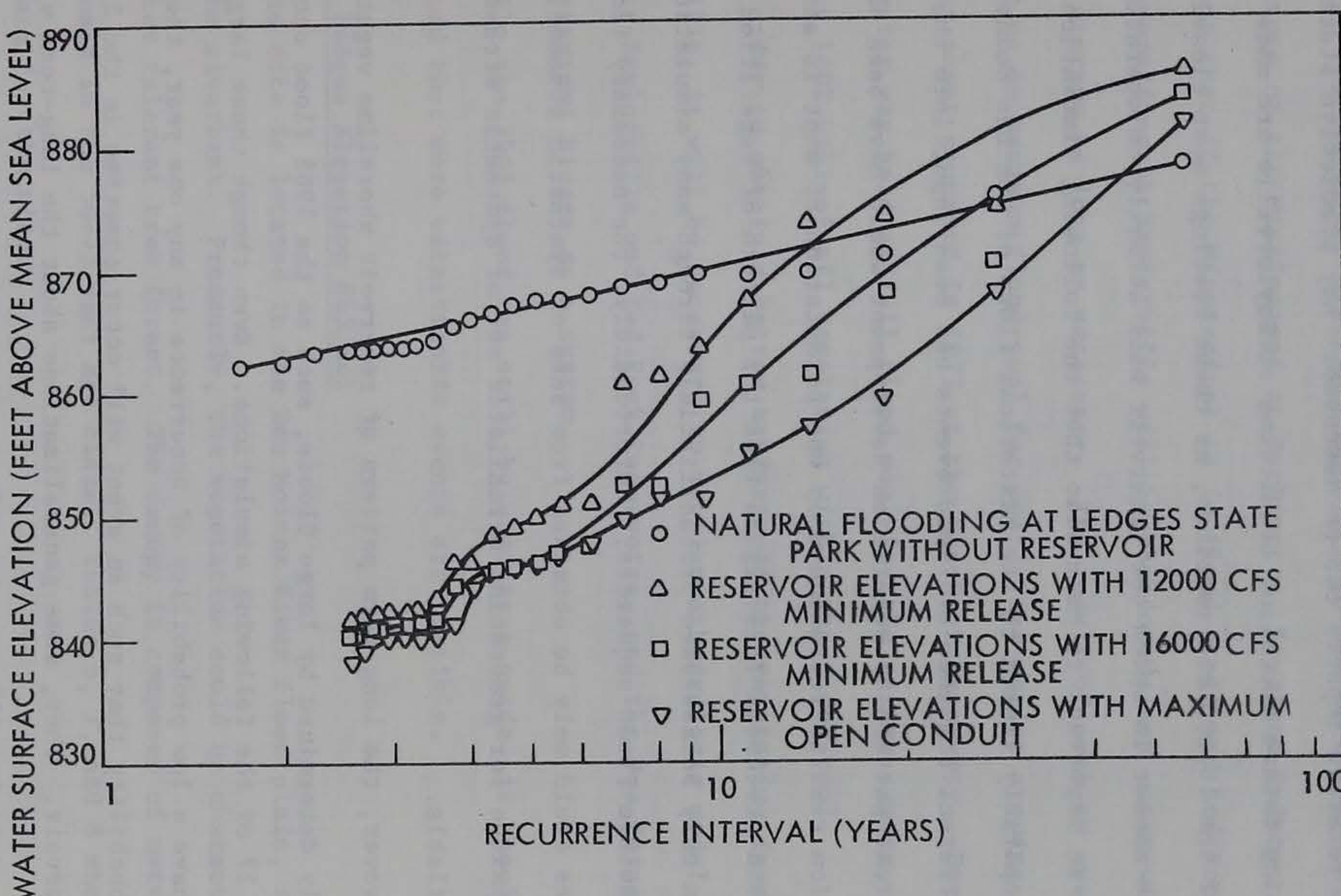


Fig. 25. Elevation frequency curve.

policy is intended to represent the compromise policy that was agreed upon.

Simulation results are presented for all three operational policies so that relative impacts can be assessed. Any predictive statements concerning future shoreline conditions at Saylorville are made on the basis of the 16,000 cfs routings, as these routings most closely approximate the manner in which the reservoir will actually be operated.

It is important to note also that the following simulation results are inseparably linked to the historical flows of the Des Moines River. If a different sequence of flood events had been input into the model a different pattern of vegetation development would have been shown. The simulation results represent only one permutation of what is actually a stochastic process. This argues that the pattern of vegetation development can only be assessed probabilisticly through many simulations with many possible flood sequences. Unfortunately, the necessary flood sequences could only be obtained from sets of synthetic streamflows, and the technique for generating a realistic set of synthetic streamflows is not available.

However, the long-term pattern of reservoir shoreline vegetation is primarily determined by large floods, such as the 1965 flood occurring in year 17 of the following simulations. Even though these large flood events have a low probability of occurrence in any one year, there is a high probability that such an event will occur sometime in the life of the reservoir. Thus, some generalizations about the long-term vegetative effects at Saylorville can be made on the basis of the 1965 (year 17) flood.

Claassen's (1976) hydrologic model of Saylorville considers the reservoir to be isolated, and outflows are determined only by the amount of water in storage. However, the actual operation of Saylorville will be tied to the amount of storage downstream in Red Rock Reservoir, and to the stage of the Mississippi at Burlington, Iowa and Quincy, Illinois. This means that if the Mississippi is in flood stage and Red Rock is full, normal operations at Saylorville will be abandoned, and water will be held in storage as long as necessary. The result of such an event could be water up to maximum flood pool for nearly the entire growing season. A similar event occurred in 1973 at the Red Rock Reservoir. During this event, water was held at full flood pool for the entire summer, resulting in nearly 100% kill of all vegetation within the flood pool.

In order to obtain a better estimate of the vegetative impacts at Saylorville, it will be necessary to develop a hydrologic model that considers Saylorville and Red Rock Reservoirs, and the Des Moines, Raccoon and Mississippi Rivers as a system.

While the 1965 flood can still be used as a guide, it should be understood that more catastrophic events are possible.

5.2.1. Ledges Elevation 865 msl

This site is located in the Des Moines River flood plain, right along the riverbank. Presently, the vegetation could be characterized as a water tolerant tree forest. The canopy is composed of mature individuals in the 50-75 year age class. Tables 6, 7, and 8 show the flood data for the site.

Table 6. Flood data, Ledges elevation 865 msl, 12,000 cfs release.

Years	Year	Date	Days	Avg Depth (ft)
3	1951	Apr 1-May 8	39	6.0
6	1954	Jun 21-Jul 9	18	6.0
12	1960	Apr 1-3	3	2.0
12	1961	Mar 28-31	4	1.5
13	1962	Mar 27-Apr 16	20	7.0
14	1962	Sep 1-2	2	0.5
17	1965	Apr 3-May 6	35	11.0
21	1969	Apr 13-May 7	25	5.0
21	1969	Jul 11-17	7	0.5

Table 7. Flood data, Ledges elevation 865 msl, 16,000 cfs release.

Years	Year	Date	Days	Avg Depth (ft)
3	1951	Apr 1-19	20	2.0
6	1954	Jun 21-Jul 3	13	5.0
12	1960	Apr 1-3	3	2.0
12	1961	Mar 28-31	4	1.5
13	1962	Mar 27-Apr 4	9	2.5
14	1962	Sep 1-2	2	0.5
17	1965	Apr 3-May 4	33	10.0
21	1969	Apr 13-22	10	1.5
21	1969	Jul 11-17	7	0.5

Table 8. Flood data, Ledges elevation 865 msl, maximum release.

Year	Year	Date	Days	Avg Depth (ft)
3	1951	Apr 1-13	13	2.0
6	1954	Jun 21-30	10	5.0
12	1960	Apr 1-3	3	2.0
12	1961	Mar 28-31	4	1.5
13	1962	Mar 27-Apr 4	9	2.5
14	1961	Sep 1-2	2	0.5
17	1965	Apr 3-May 1	29	9.0
21	1969	Apr 13-22	10	1.5
21	1969	Jul 11-17	7	0.5

5.2.1.1. 12,000 cfs Release. Figures 26 and 27 show the model simulation results for the 12,000 cfs alternative. They show a gradual decline in the integrity of the forest. Substantial tree kills are shown to occur, opening the canopy and allowing the invasion of weedy herbaceous species.

The importance of the water tolerant trees is shown to increase again toward the end of the simulation. This indicates the establishment and growth of new individuals. The character of this growth would be dense, low, and shrubby, a substantial change from the original flood plain forest.

5.2.1.2. 16,000 cfs Release. Figures 28 and 29 show the simulation results for the 16,000 cfs alternative. These results show damage, but

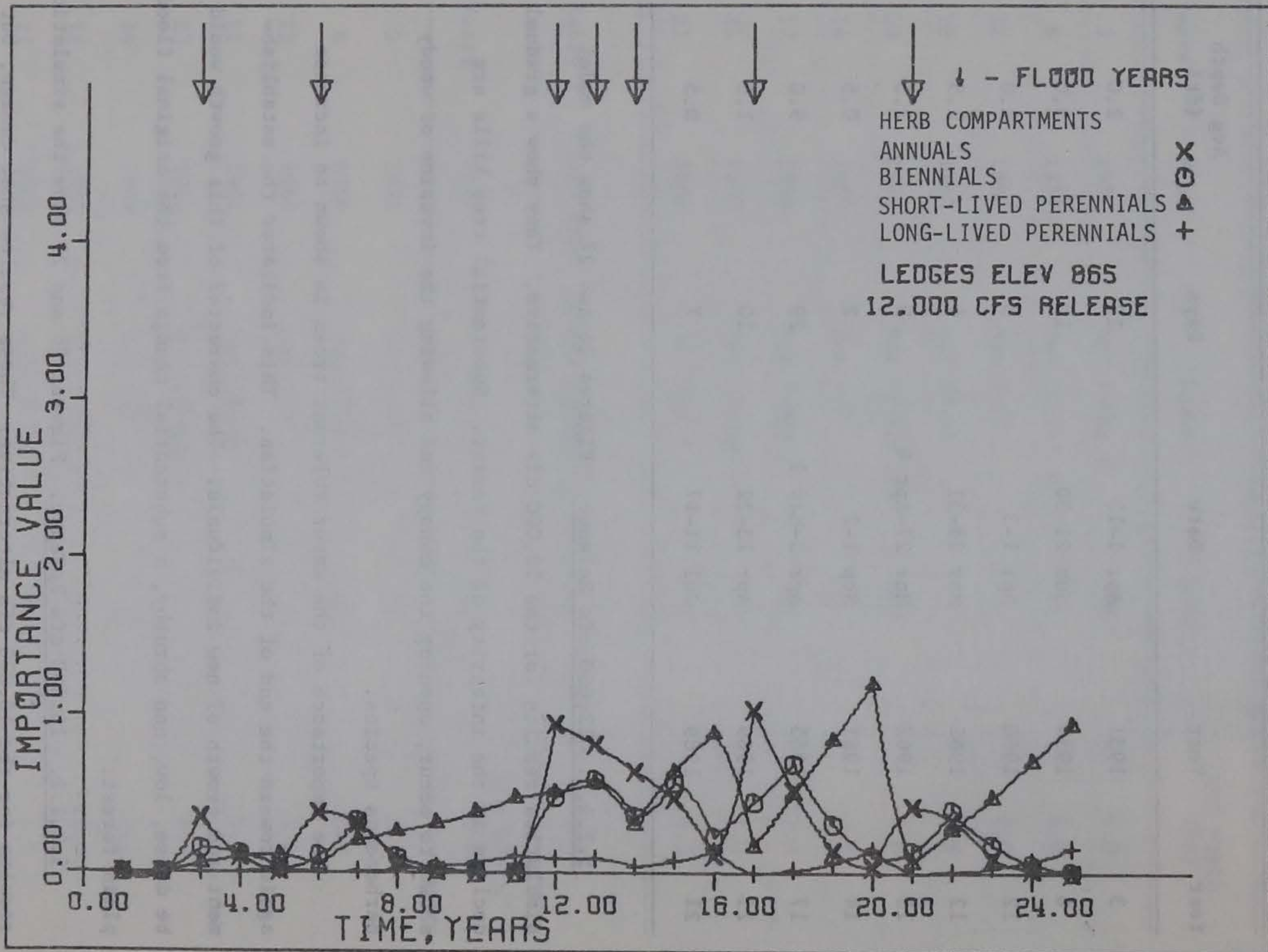


Fig. 26. Simulation results; Ledges elevation 865 msl, 12,000 cfs release, herbaceous compartments.

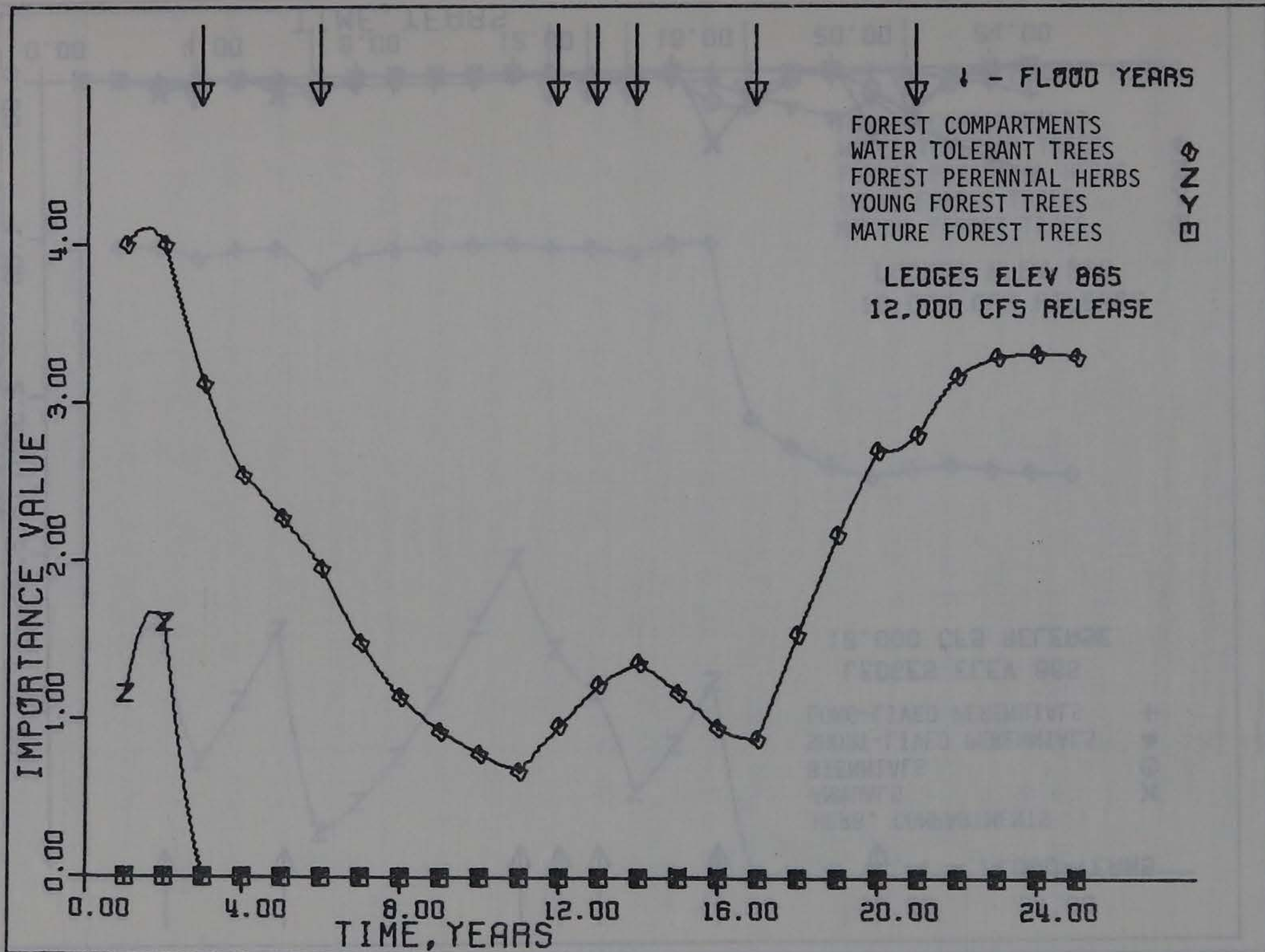


Fig. 27. Simulation results; Ledges elevation 865 msl, 12,000 cfs release, forest compartments.

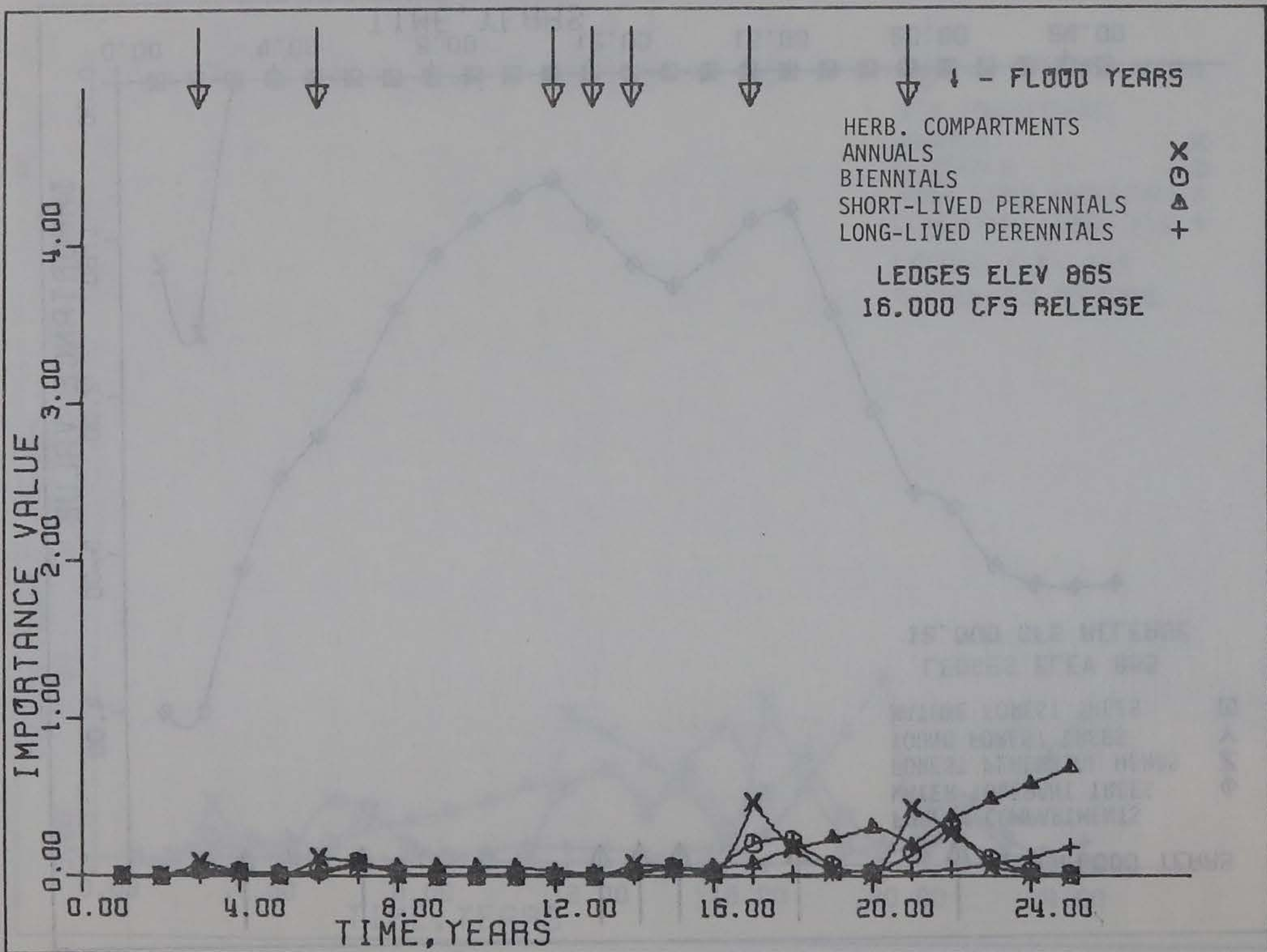


Fig. 28. Simulation results; Ledges elevation 865 msl, 16,000 cfs release, herbaceous compartments.

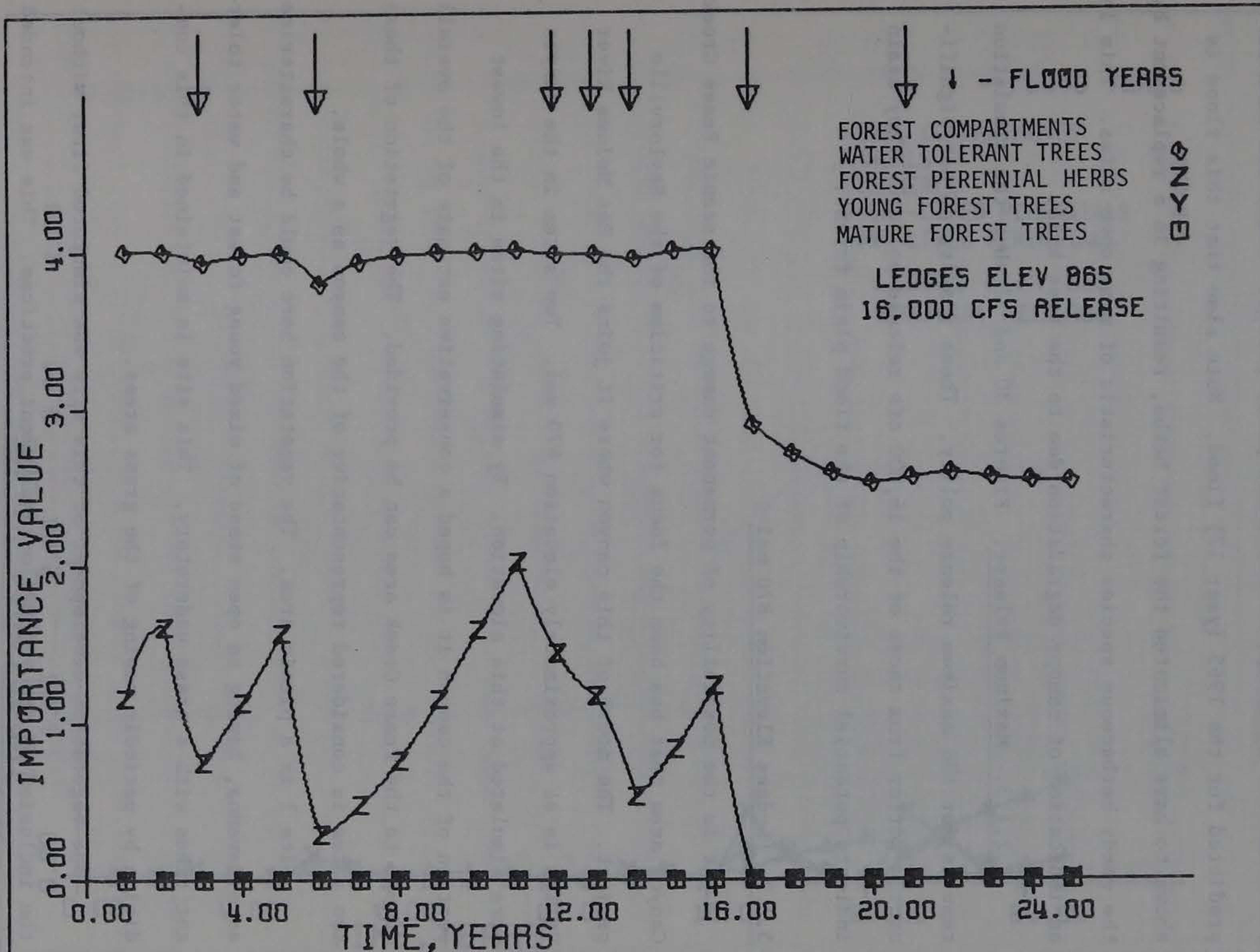


Fig. 29. Simulation results; Ledges elevation 865 msl, 16,000 cfs release, forest compartments.

potential survivorship, of the flood plain forest. About 25% kill is predicted for the 1965 (year 17) flood. Note also that this flood is shown to have eliminated the forest herbs, resulting in a replacement by the weedy herbaceous species characteristic of more open sites. This is an indication of canopy degradation due to the tree kill.

5.2.1.3. Maximum Release. Figures 30 and 31 show the simulation results for the maximum release policy. These results do not significantly differ from those of the 16,000 cfs release policy. They again indicate potential survivorship of the flood plain forest.

5.2.2. Ledges Elevation 870 msl

It is the possibility of permanent damage to the scenic Pease Creek Canyon area that has been the focus for criticism of the Saylorville project. The mouth of this canyon where it joins the Des Moines River Valley is at approximately elevation 870 msl. Two sites in the canyon were simulated at this elevation. By simulating sites in the lowest portion of the canyon it is hoped a conservative estimate of the overall damage to the Pease Creek area can be provided. The vegetation of these two sites is considered representative of the canyon as a whole.

Site 1 is a picnic area. The vegetation here could be characterized as a savanna, having an open stand of mixed young forest and water tolerant trees with a grass understory. This site is maintained in this condition by periodic mowing of the grass areas.

The vegetation development of this site was simulated first without the inclusion of any vegetation management practices. This was intended to represent the vegetation development after flooding if the area were

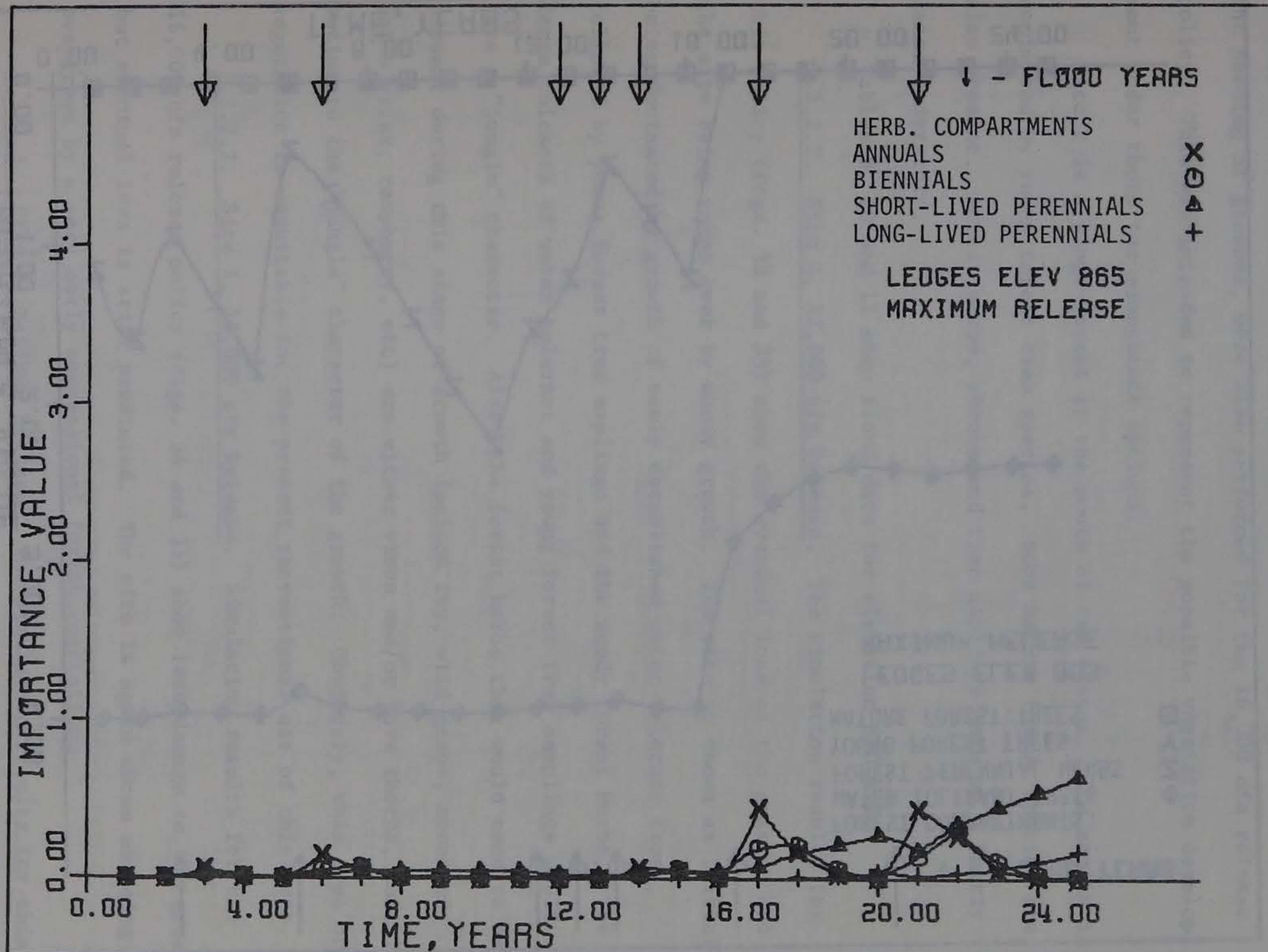


Fig. 30. Simulation results; Ledges elevation 865 msl, maximum release, herbaceous compartments.

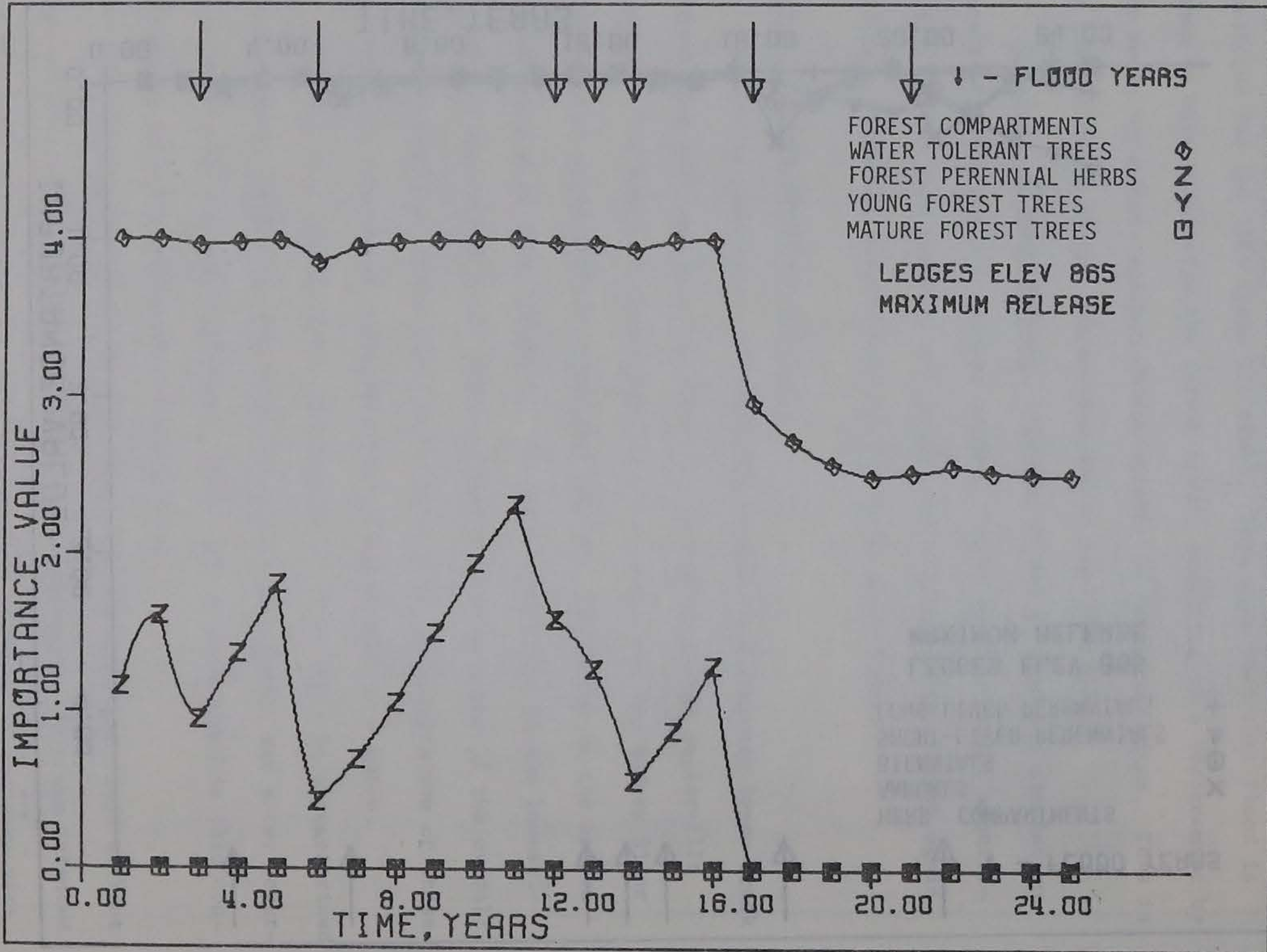


Fig. 31. Simulation results; Ledges elevation 865 msl, maximum release, forest compartments.

to be left alone. Additional simulations, including mowing and mowing and seeding of grasses, were also performed for the 16,000 cfs release policy. This was intended to represent the possible vegetation development under those two management options.

Site 2 is a slope forest at the mouth of the canyon. The canopy is dominated by young forest tree species. Some mature forest species are also present. Forest herbs, shrubs and tree saplings make up a fairly dense understory.

Tables 9, 10 and 11 show flood data for elevation 870 msl.

5.2.2.1. Site 1, 12,000 cfs Release. The simulation results for this policy (Figs. 32 and 33) show the eventual loss of the grasses and the site being taken over by woody growth. The site is shown as initially being dominated by growth of newly established water tolerant trees, followed by young forest tree saplings and the weedy forest herbs. The dense thickets of water tolerant and young forest tree samplings would have a "jungle" character. Also, the forest herbs that would tend to be present during this stage of growth (poison ivy, wild grape, moonseed, cat's briar, raspberry, etc) are either vines and/or have thorns, contributing to the "jungle" character of the growth. Obviously, this type of vegetation is unsuitable for the present recreational use of this area.

5.2.2.2. Site 1, 16,000 cfs Release. Simulation results for the 16,000 cfs release policy (Figs. 34 and 35) show less damage to the grasses, but eventual loss is still predicted. The site is again shown as being overgrown by a very early successional forest vegetation.

5.2.2.3. Site 1, Maximum Release. The simulation results for this alternative (Fig. 36 and 37) are very similar to those of the 16,000 cfs policy.

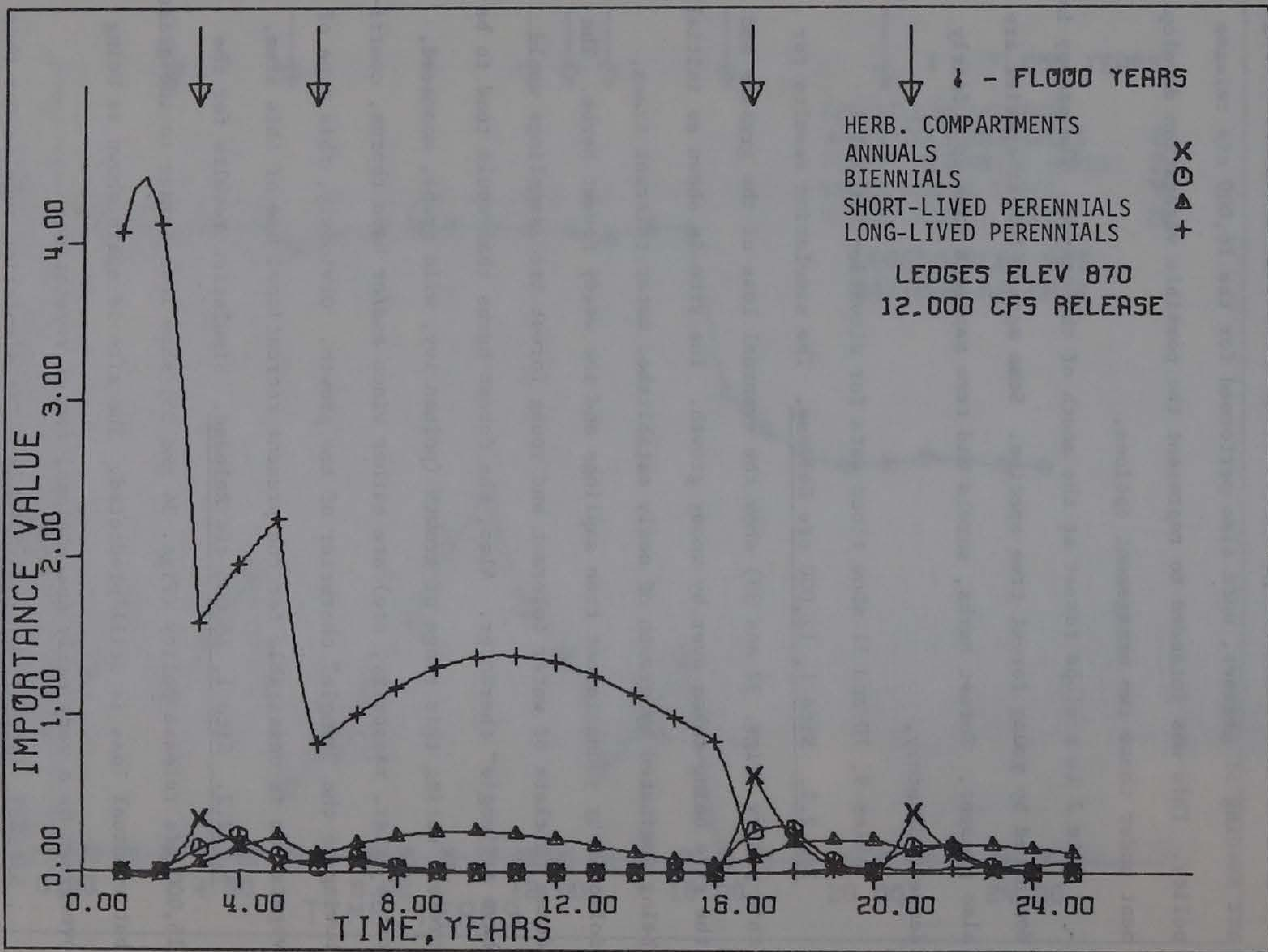


Fig. 32. Simulation results; Ledges elevation 870 msl, Site 1, 12,000 cfs release, herbaceous compartments.

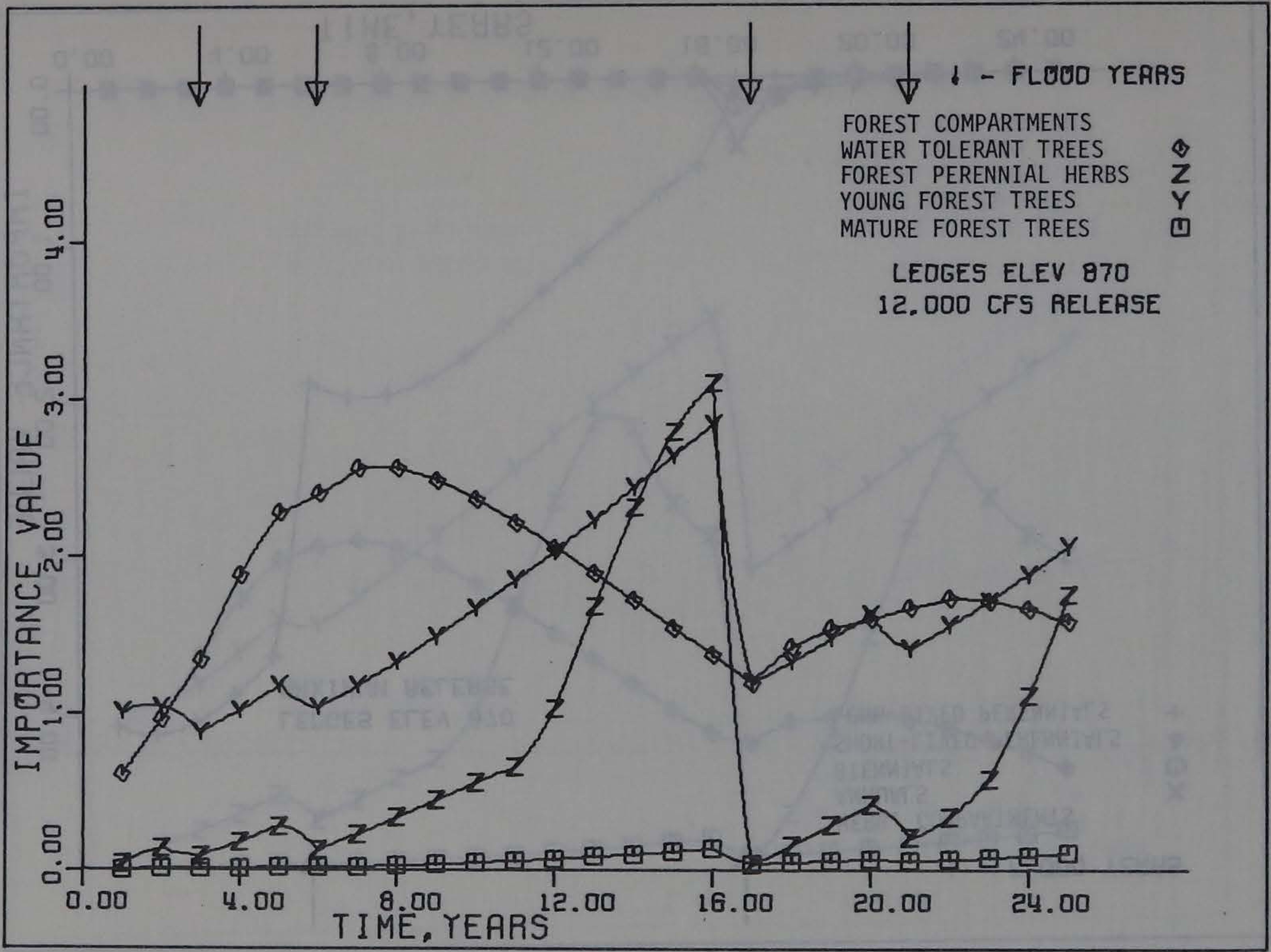


Fig. 33. Simulation results; Ledges elevation 870 msl, Site 1, 12,000 cfs release, forest compartments.

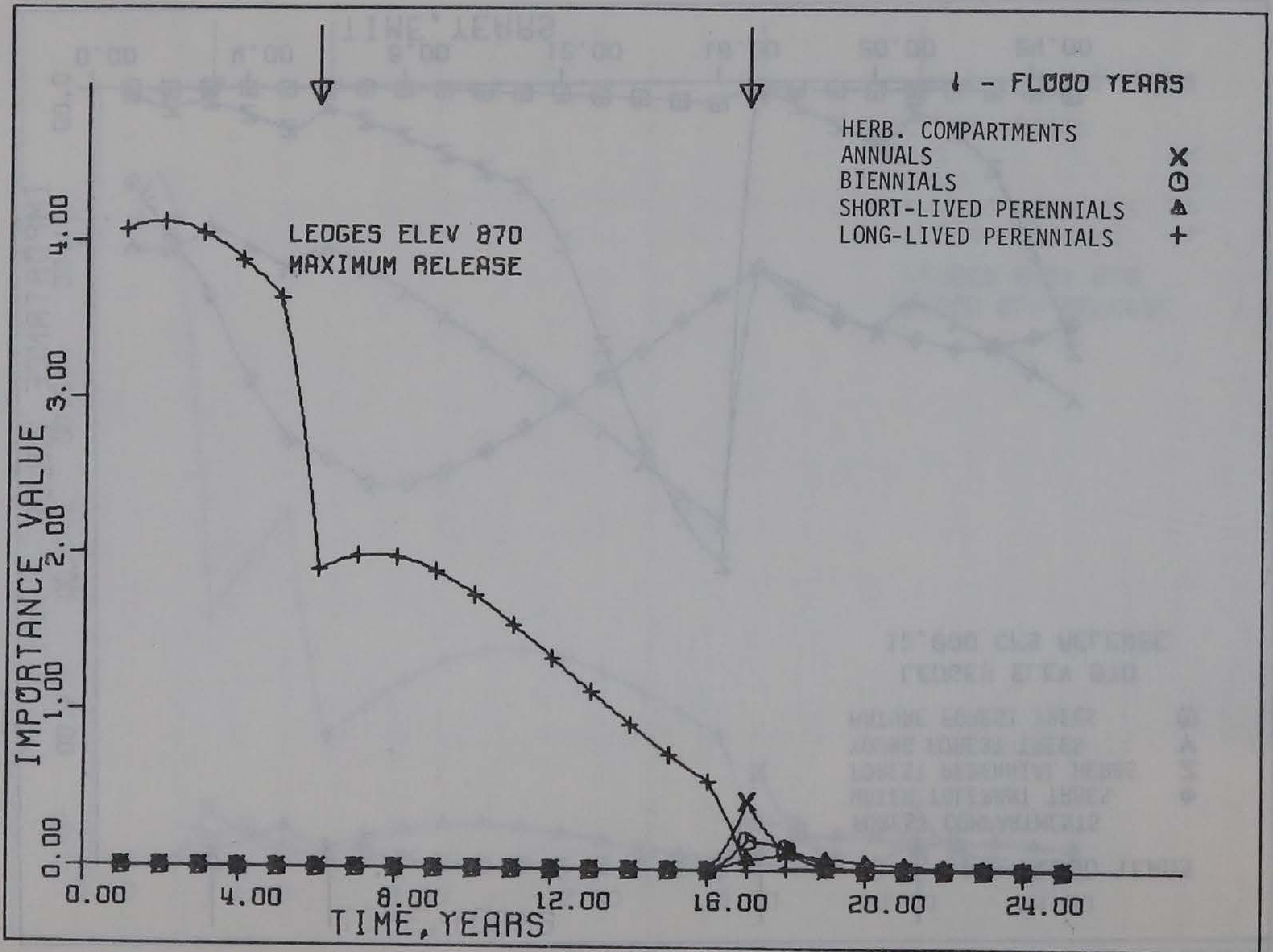


Fig. 34. Simulation results; Ledges elevation 870 msl, Site 1, 16,000 cfs release, herbaceous compartments.

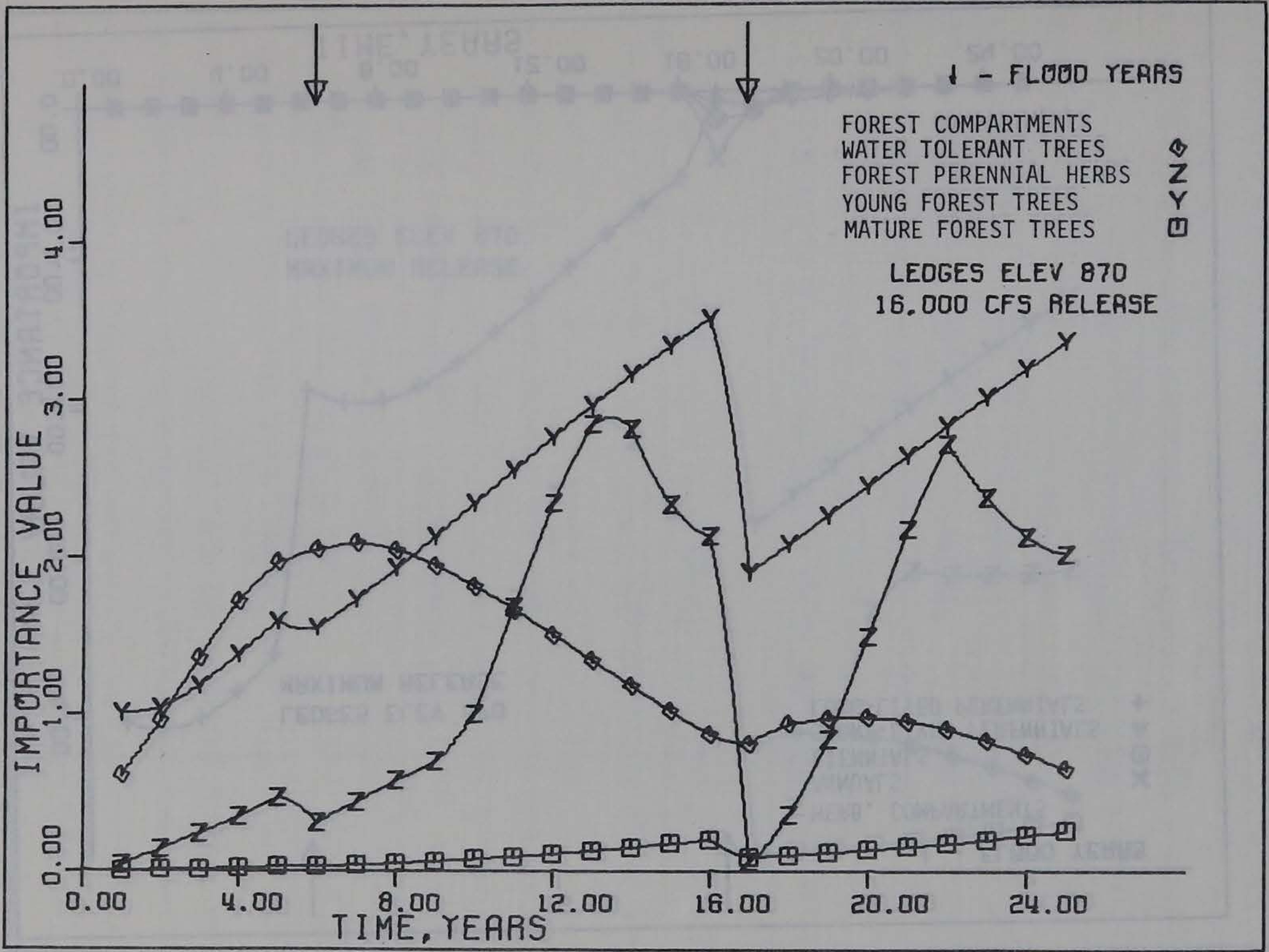


Fig. 35. Simulation results; Ledges elevation 870 msl, Site 1, 16,000 cfs release, forest compartments.

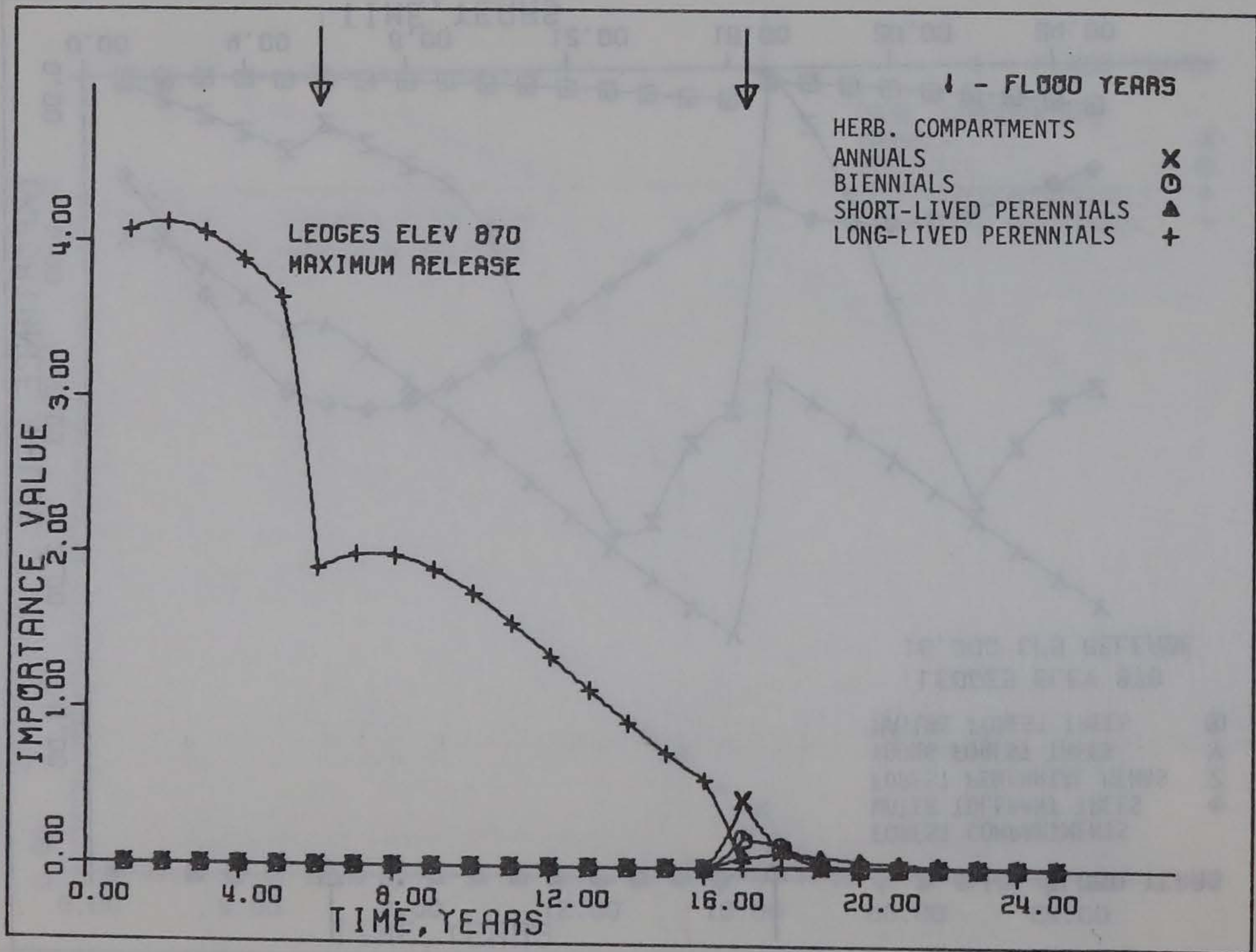


Fig. 36. Simulation results, Ledges elevation 870 msl, Site 1, maximum release, herbaceous compartments.

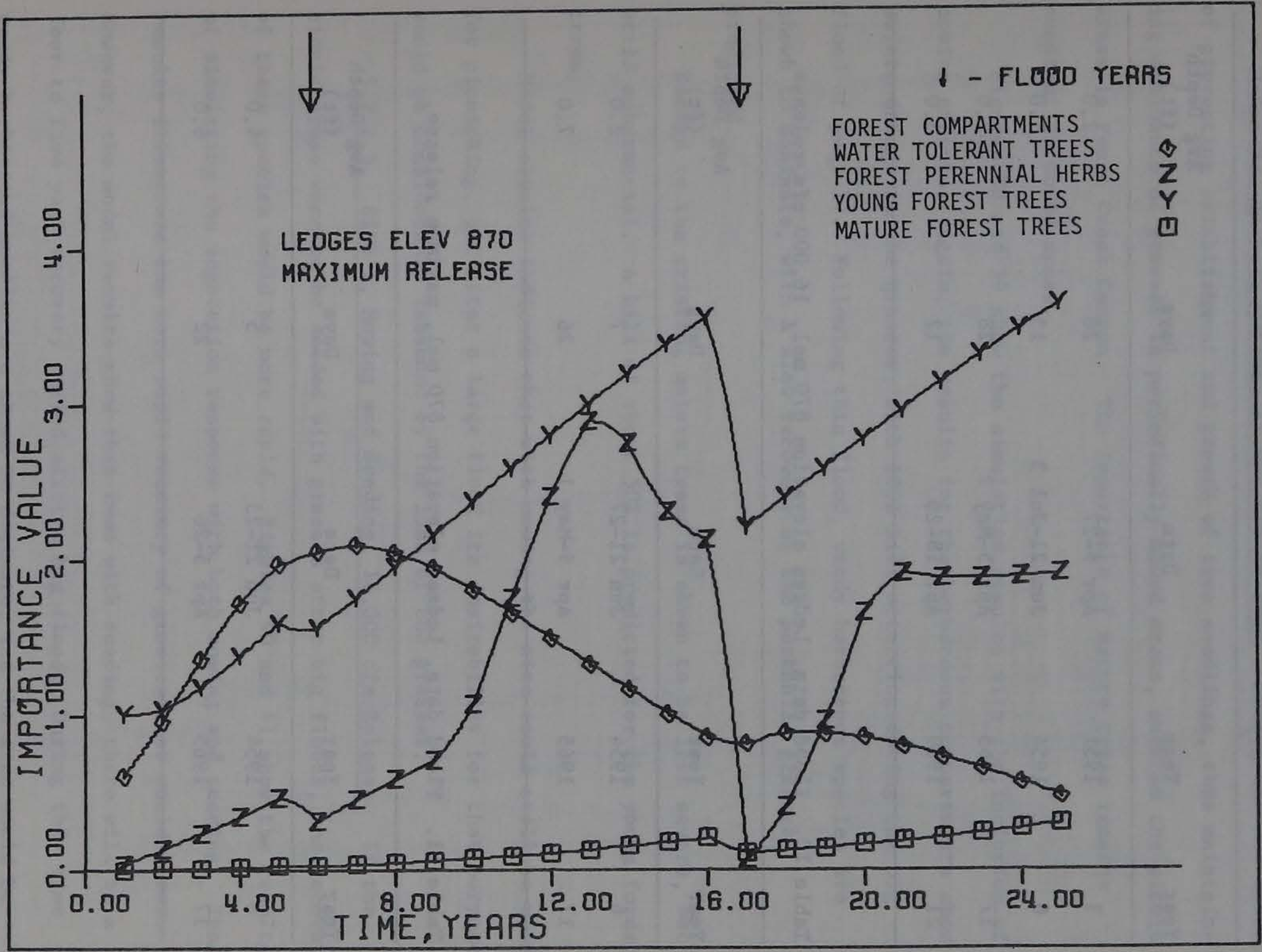


Fig. 37. Simulation results, Ledges elevation 870 msl, Site 1, maximum release, forest compartments.

Table 9. Flood data, Ledges elevation 870' msl, 12,000 cfs release.

Year	Year	Date	Days	Avg Depth (ft)
3	1951	Apr 8-27	20	2.0
6	1954	Jun 21-Jul 3	13	3.0
17	1965	Apr 5-May 2	28	9.0
21	1969	Apr 18-29	12	3.0

Table 10. Flood data, Ledges elevation 870 msl, 16,000 cfs release.

Year	Year	Date	Days	Avg Depth (ft)
6	1954	Jun 21-27	7	2.0
17	1965	Apr 5-May 1	26	7.0

Table 11. Flood data, Ledges elevation 870 msl, maximum release.

Year	Year	Date	Days	Avg Depth (ft)
6	1954	Jun 21-25	5	4.0
17	1965	Apr 5-26	22	6.0

5.2.2.4. Site 1, Mowing, 16,000 cfs Release. Mowing has the effect of preventing establishment and growth of tree seedlings, thus maintaining dominance of grasses in periodically mowed areas, such as the picnic areas in Pease Creek Canyon. The importance of mature trees remains constant in mowed areas.

Figures 38 and 39 show the simulation results with the inclusion of mowing effects. Again, the results for the herbaceous compartments show severe damage to the grasses, with 100% kill occurring during the big flood of year 17. Following this flood, weedy herbaceous species are shown to dominate, with a slow recovery of the perennial grasses predicted.

Damage to the existing mature trees is shown to be less severe, but still substantial. A kill of about 50% is predicted for the young forest trees.

Model results indicate that with mowing the site could still be used for picnicking, but after a large flood its desirability for that purpose would be considerably lessened by the loss of the grasses.

5.2.2.5. Site 1, Mowing and Seeding, 16,000 cfs Release. If the picnic areas were to be seeded with grasses after big floods, the recovery of these species would be more rapid. Figures 40 and 41 show the results of simulating the vegetation response with both mowing and seeding. These results illustrate the more rapid recovery of grasses that would occur. However, the model results show that even with seeding, there will be a four to five year recovery period after a big flood. During this time weedy herbaceous species are shown to dominate, and the area would be less suitable for picnicking.

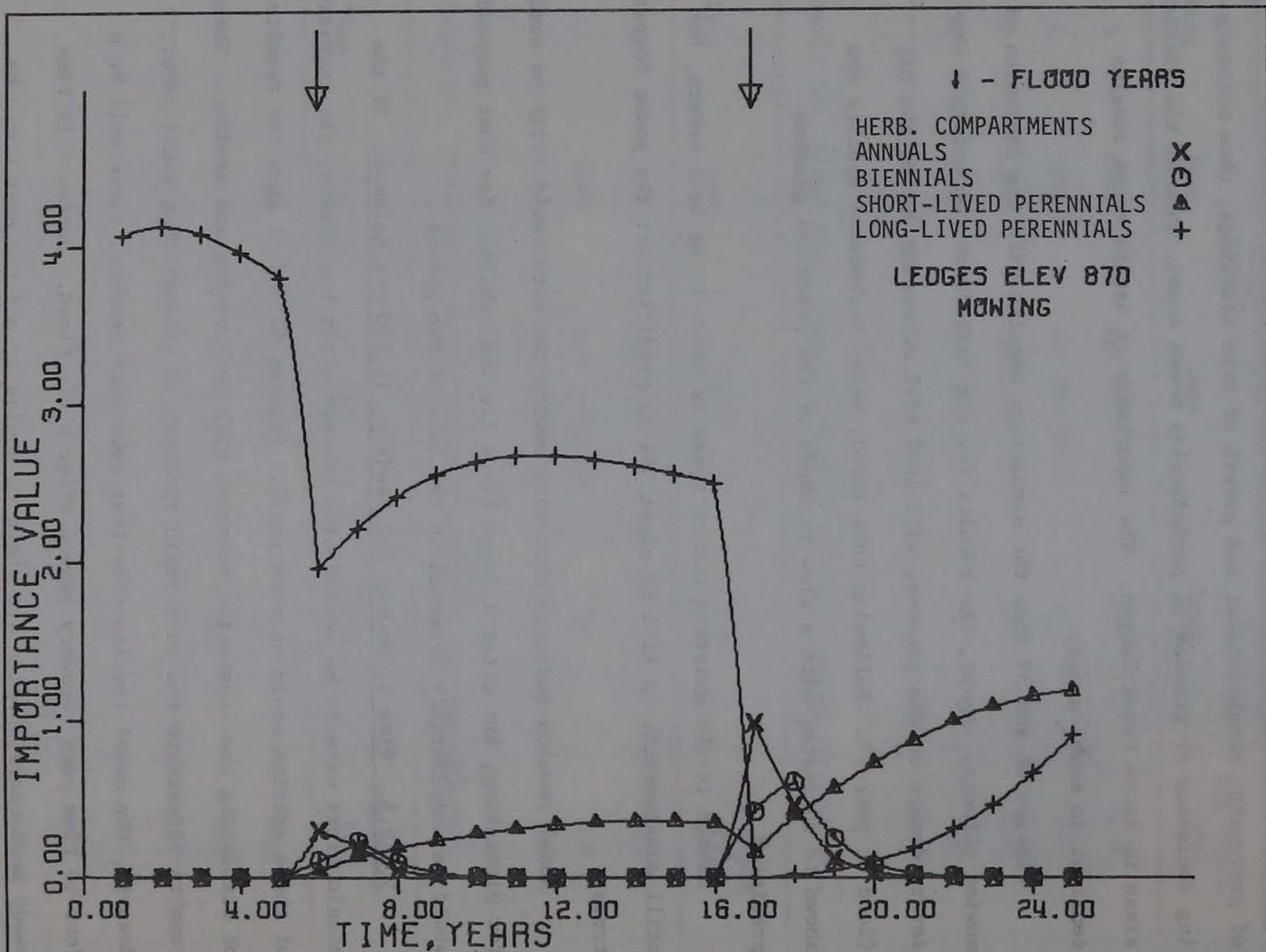


Fig. 38. Simulation results, Ledges elevation 870 msl, Site 1, 16,000 cfs release, mowing effects on herbaceous compartment.

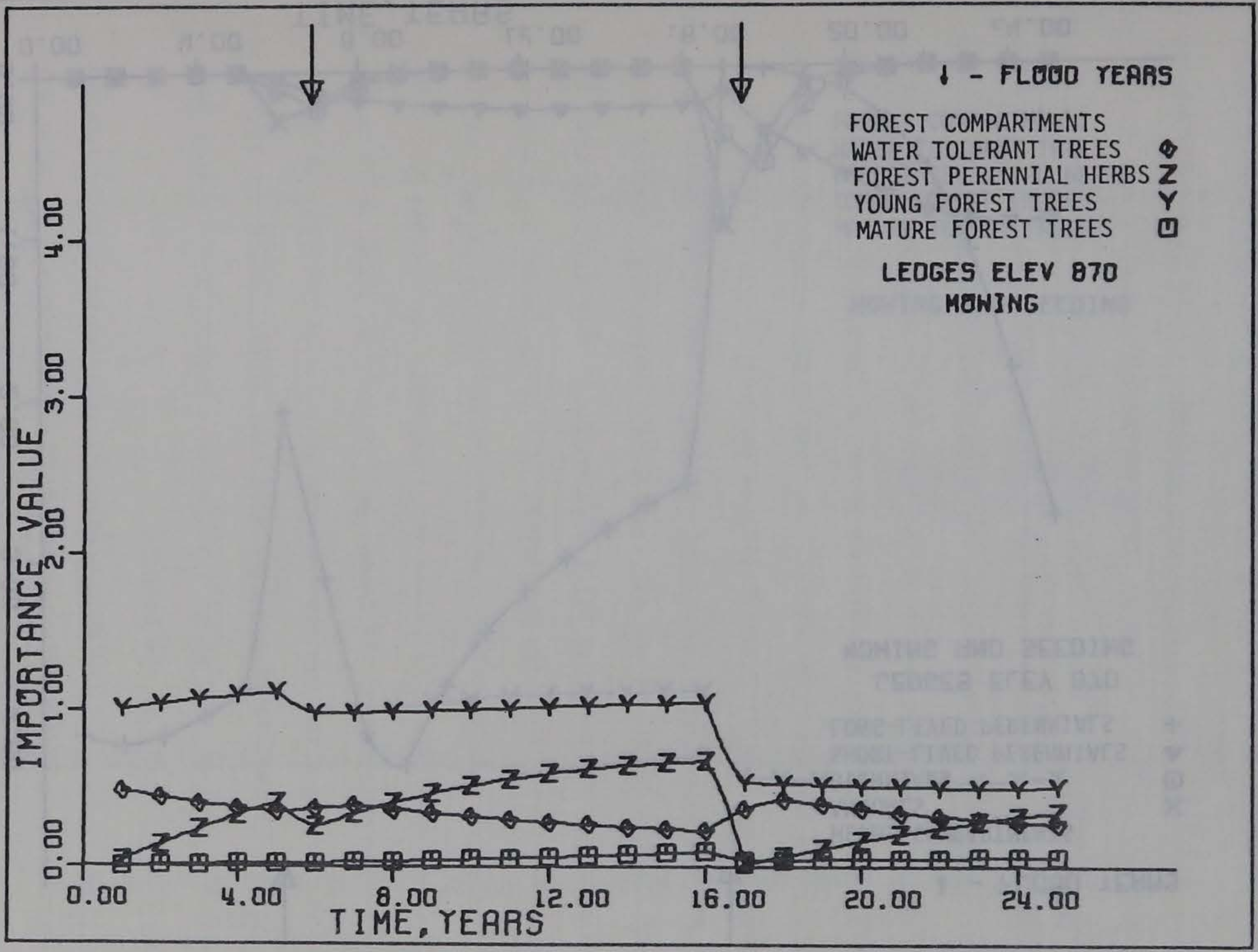


Fig. 39. Simulation results, Ledges elevation 870 msl, site with mowing, forest compartments.

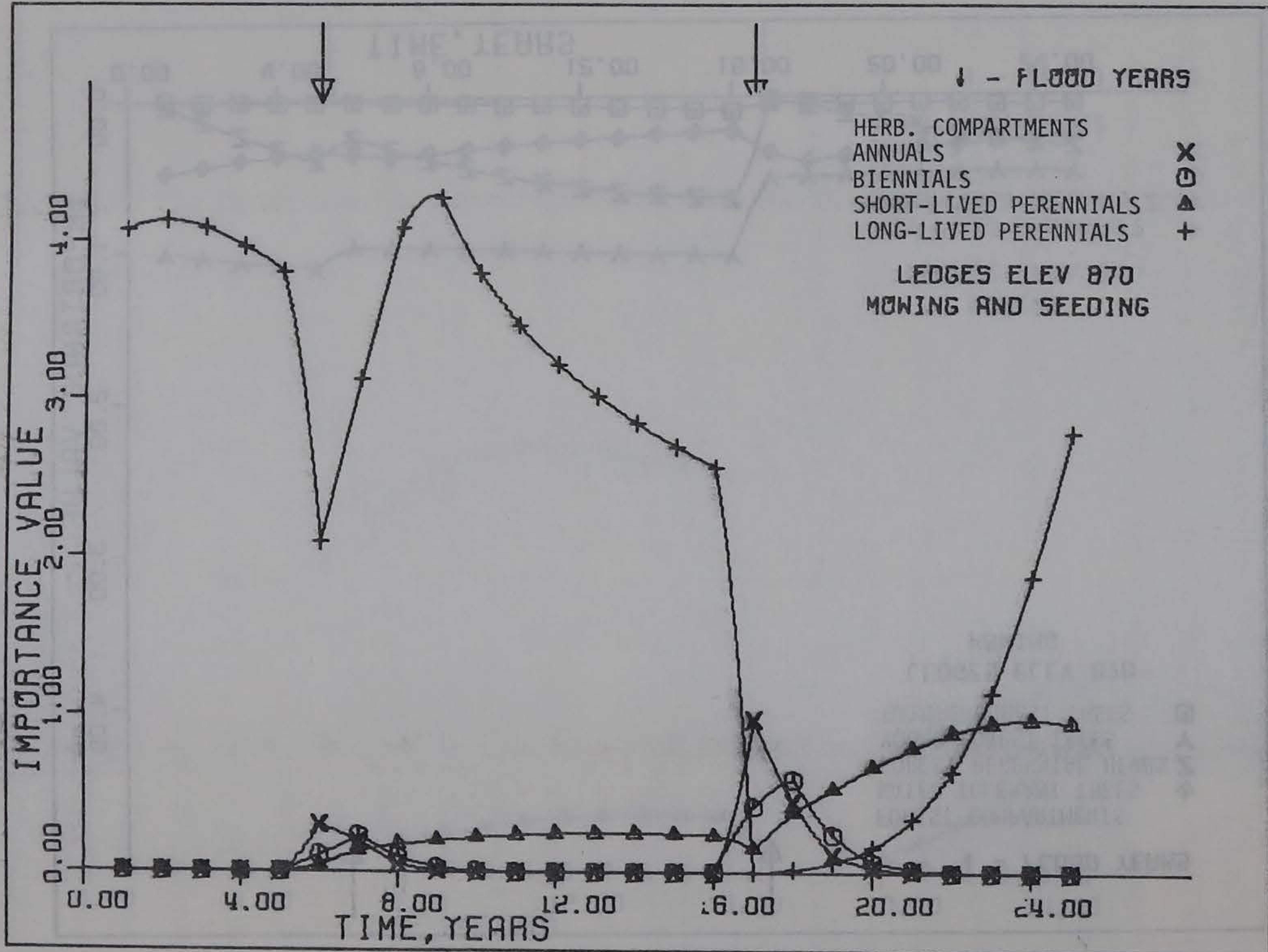


Fig. 40. Simulation results, Ledges elevation 870 msl with mowing and seeding, herbaceous compartments.

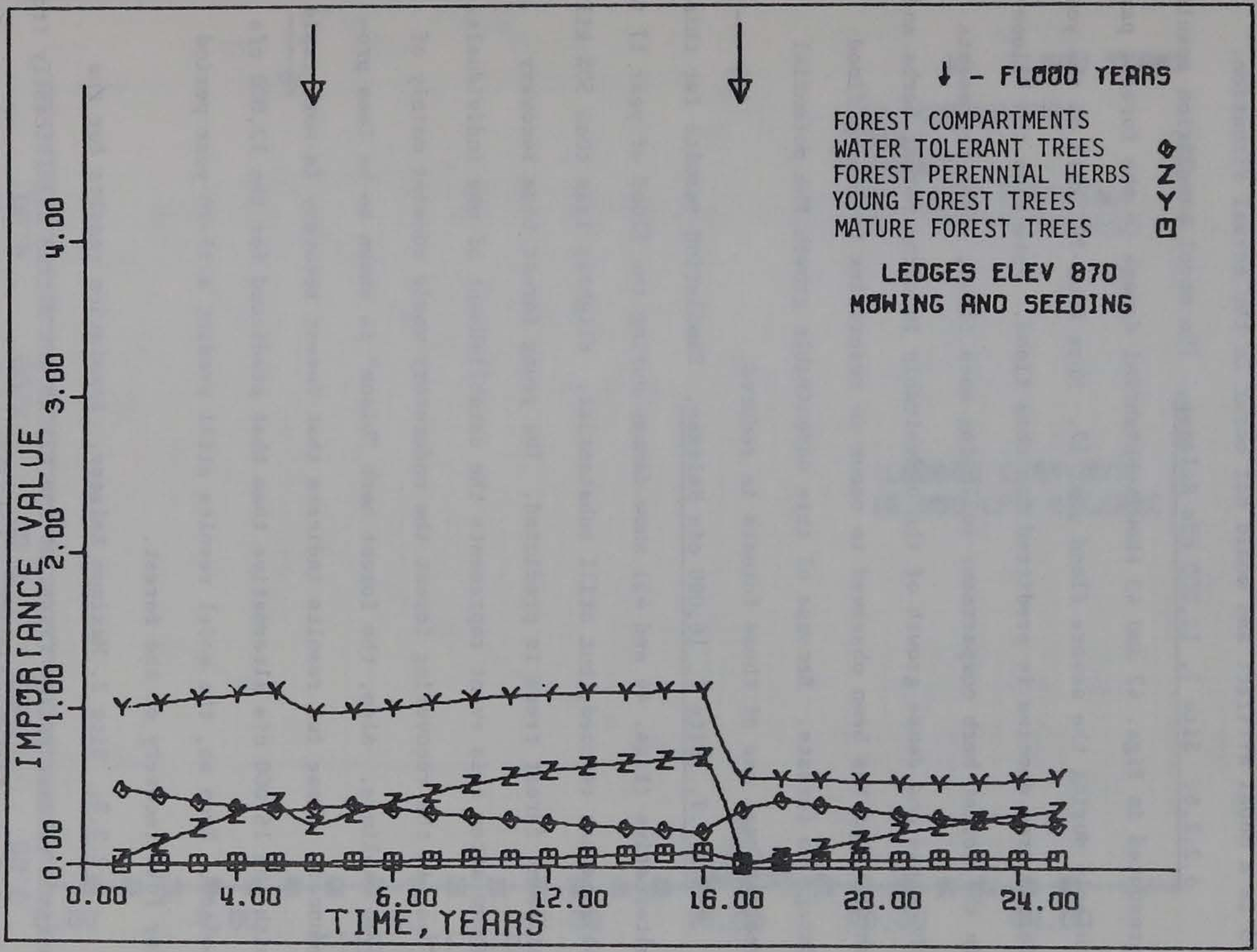


Fig. 41. Simulation results, Ledges elevation 870 msl, Site 1 with mowing and seeding, forest compartments.

The decline in the importance of grasses shown in years 10 through 15 is a model artifact and would not occur in the actual situation.

5.2.2.6. Site 2, 12,000 cfs Release. The model simulation results presented in Figs. 42 and 43 show substantial damage to the forest, particularly during the severe flood year 17. More than 50% kill of the young forest tree species is predicted for this flood. Note also the "blooms" in the forest herb compartment following each flood. This represents the rapid and dense growth of the undesirable invading forest herbs and shrubs that has been observed to occur in reservoirs following flood damage to forests. Because of this undesirable growth the potential recreational use of these forests is reduced.

5.2.2.7. Site 2, 16,000 cfs Release. Simulation results for this alternative (Figs. 44 and 45) show damage during the flood of year 17 to be somewhat reduced, but still substantial. Slightly less than 50% kill of young forest trees is predicted. The young forest tree recovery shown after this event represents the establishment of new individuals. Thus, in the recovering forest the understory would consist mainly of tree saplings. Also, the forest herb "bloom" is shown to be less pronounced. These two results indicate that forest recovery is more rapid with the 16,000 cfs alternative than that predicted for the 12,000 cfs policy. Even so, the model results still predict a 15-20 year period for full recovery of the forest.

5.2.2.8. Site 2, Maximum Release. Simulation results for the maximum release policy (Figs. 46 and 47) do not differ significantly from those of the 16,000 cfs release policy.

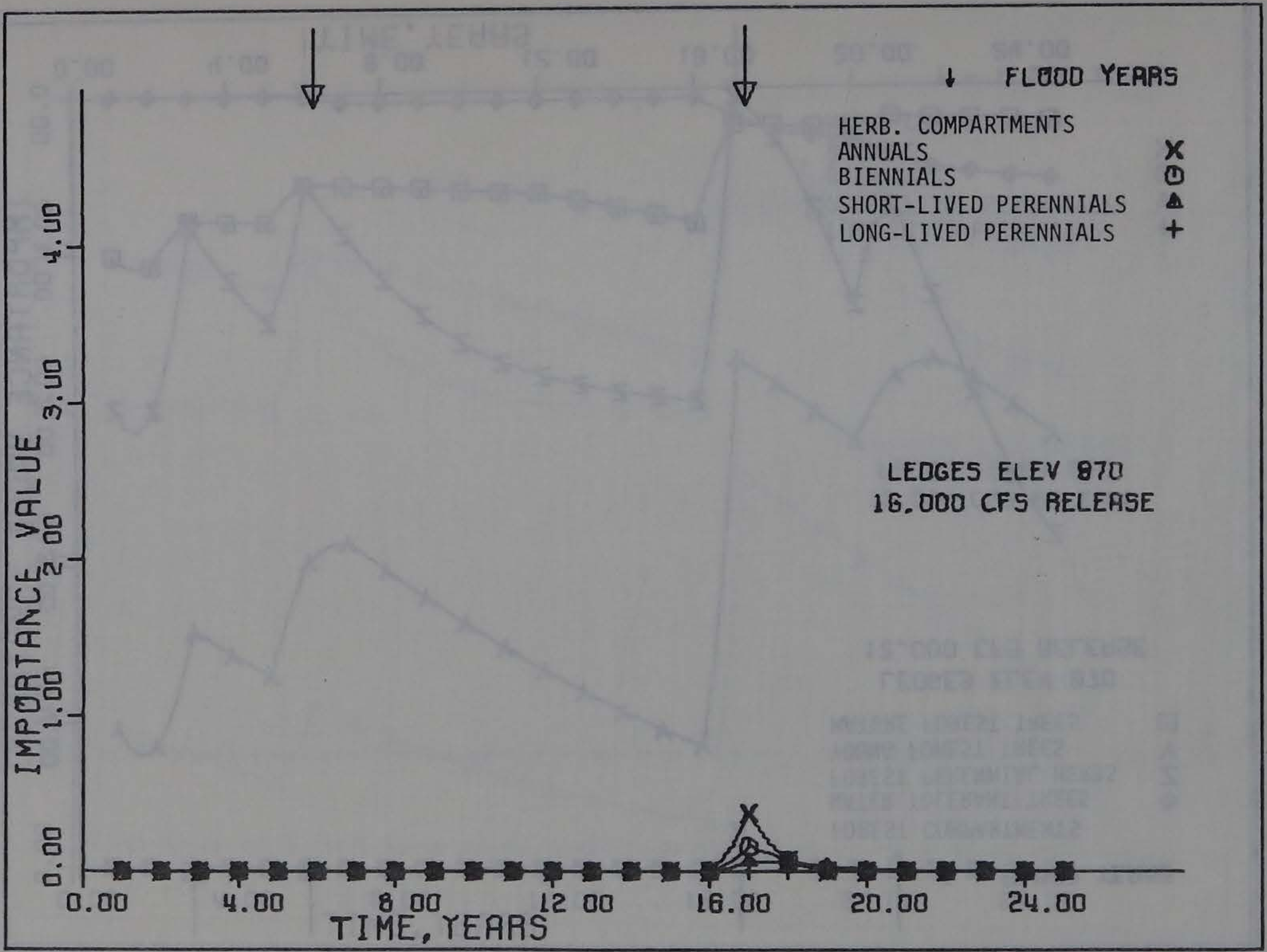


Fig. 42. Simulation results, Ledges elevation 870 msl, Site 2, 12,000 cfs release, herbaceous compartments.

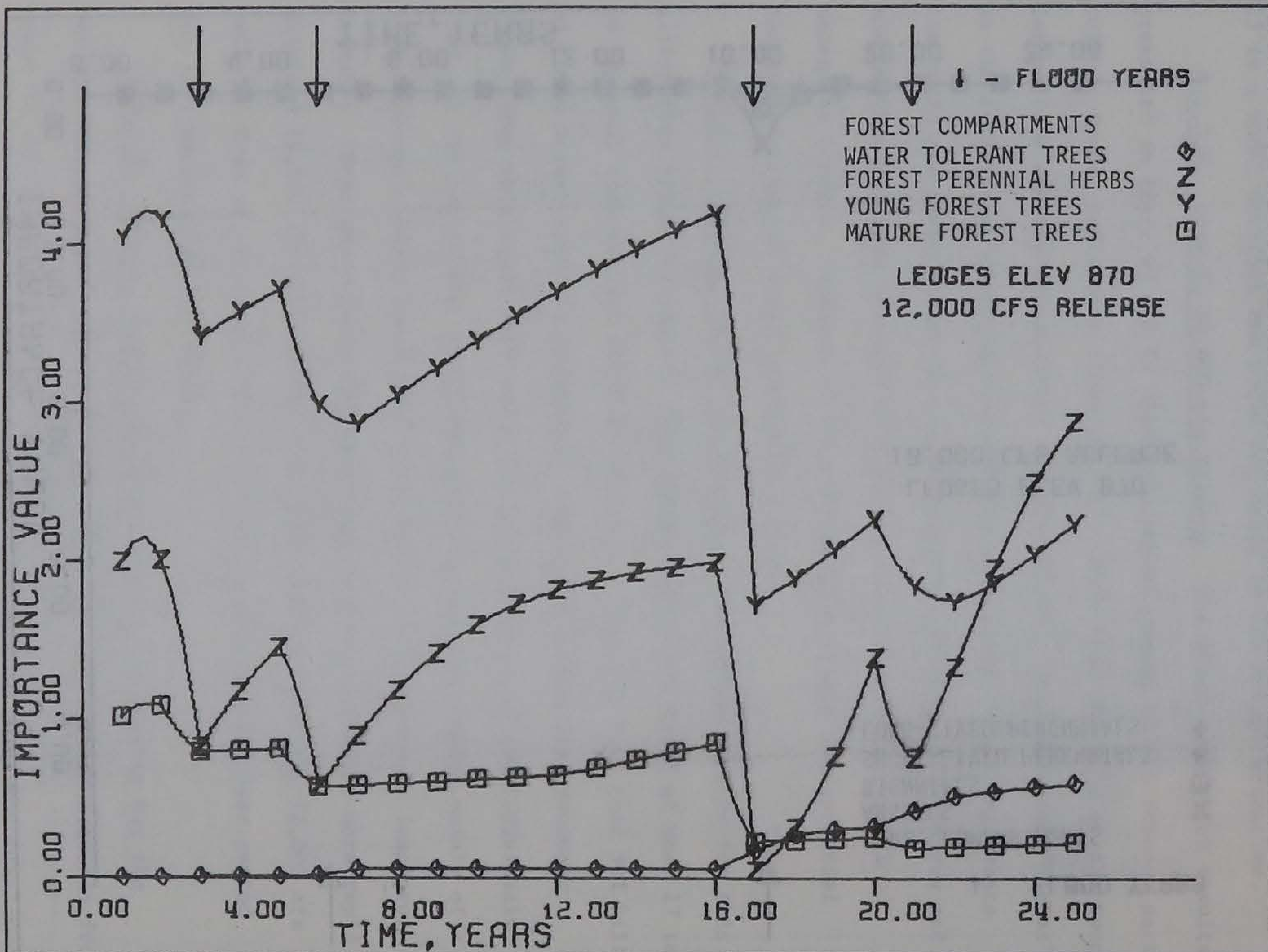


Fig. 43. Simulation results, Ledges elevation 870 msl, Site 2, 12,000 cfs release, forest compartments.

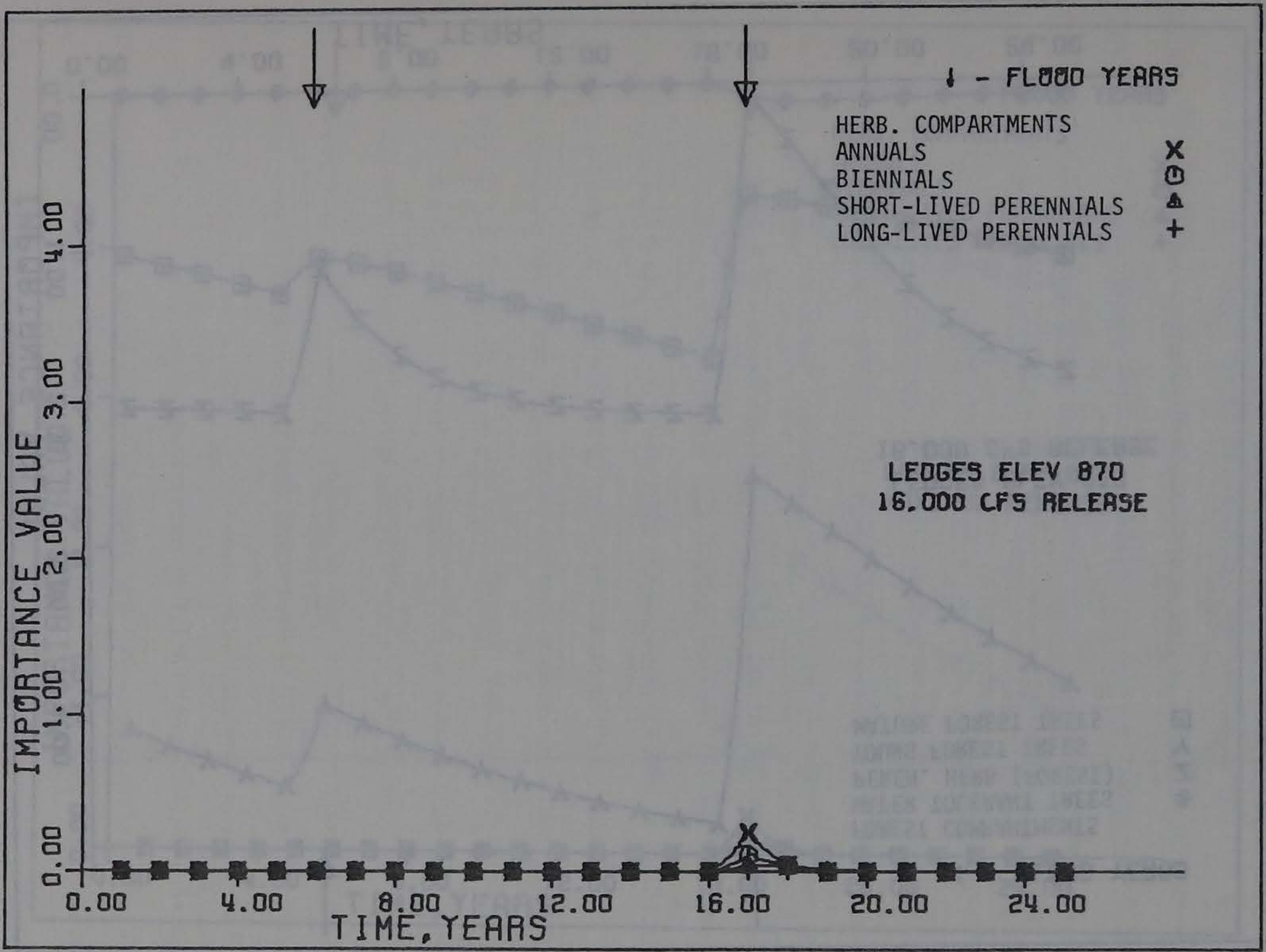


Fig. 44. Simulation results, Ledges elevation 870 msl, Site 2, 16,000 cfs release, herbaceous compartments.

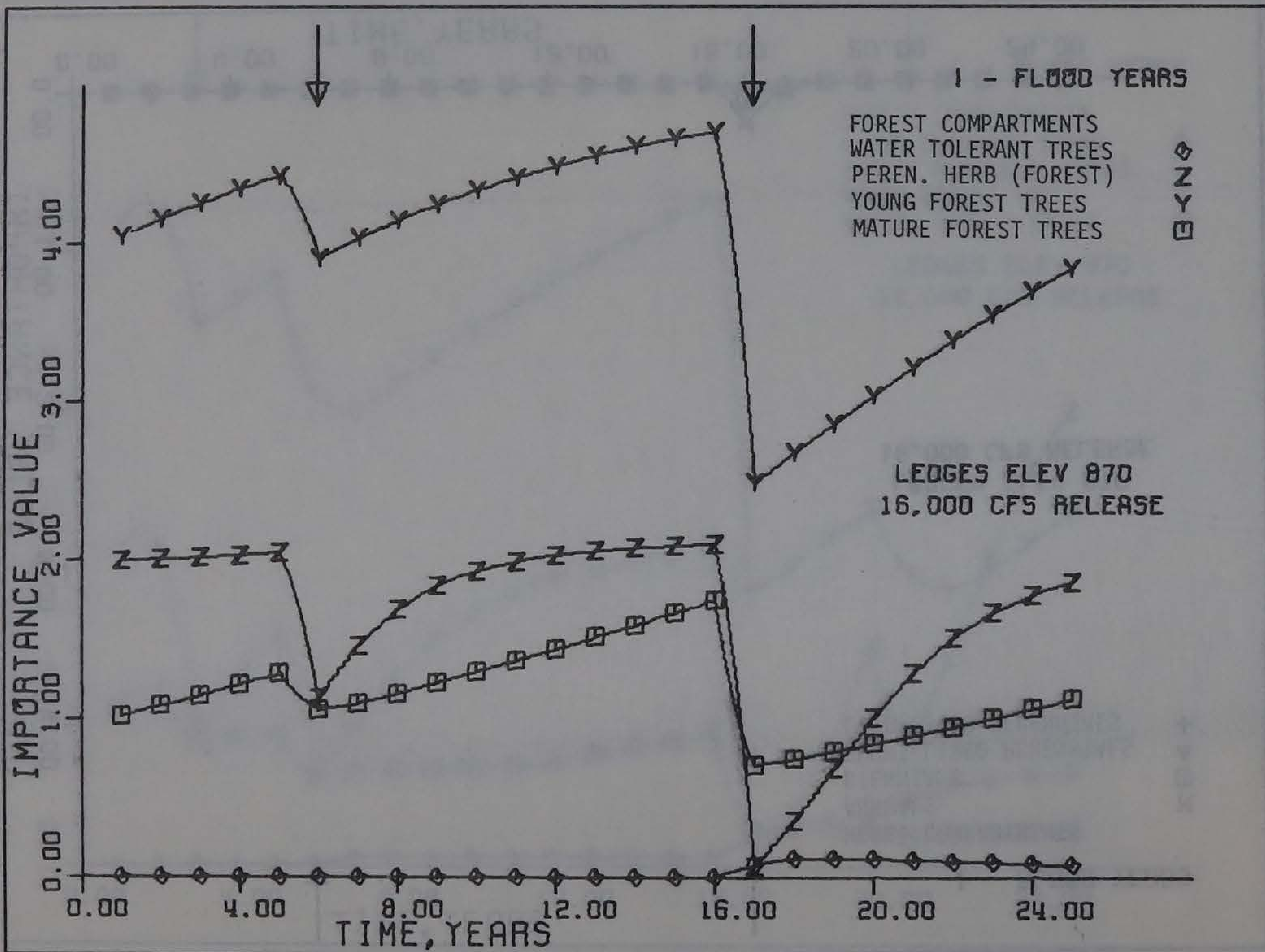


Fig. 45. Simulation results, Ledges elevation 870 msl, Site 2, 16,000 cfs release, forest compartments.

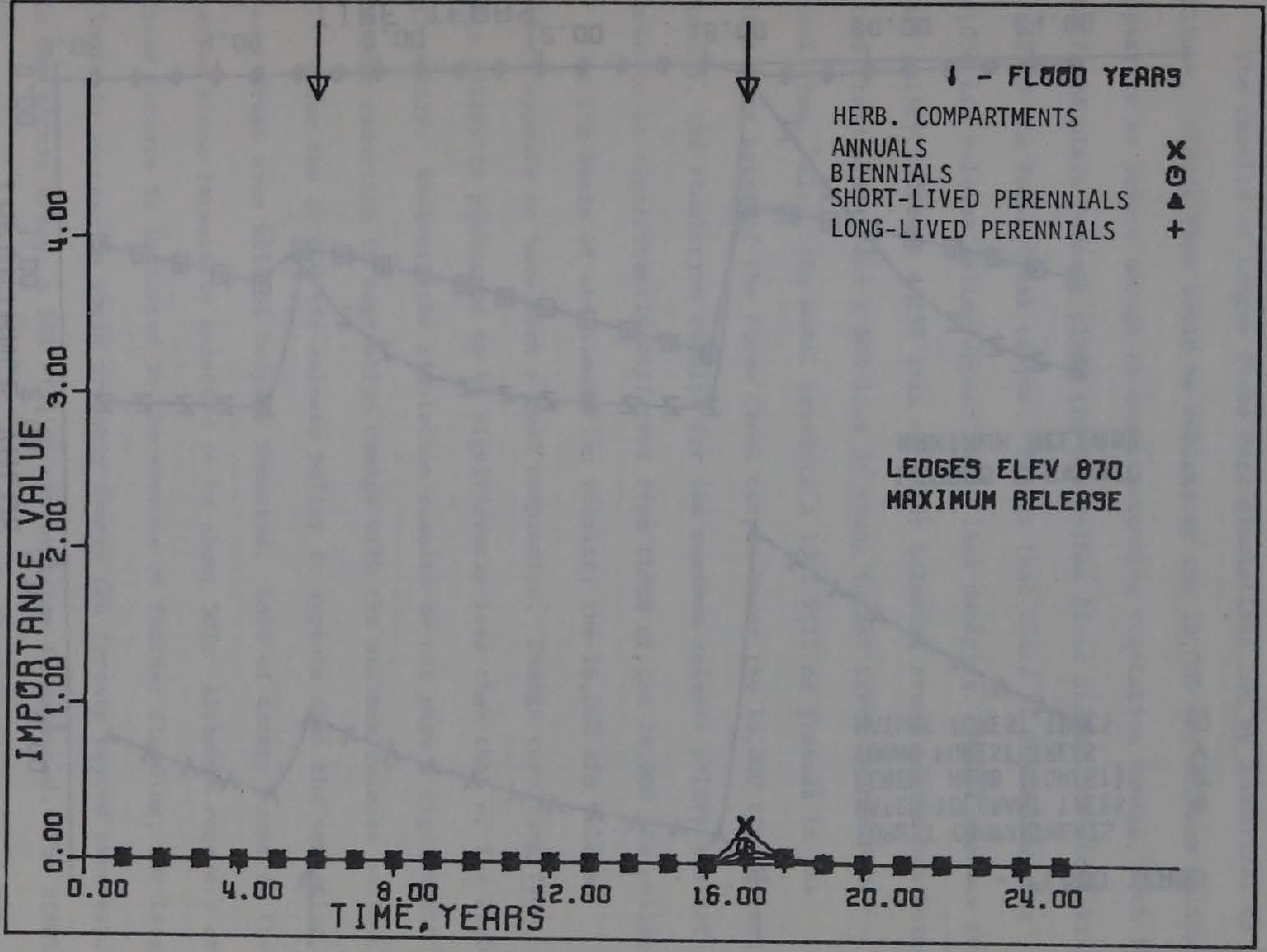


Fig. 46. Simulation results, Ledges elevation 870 msl, Site 2, maximum release, herbaceous compartments.

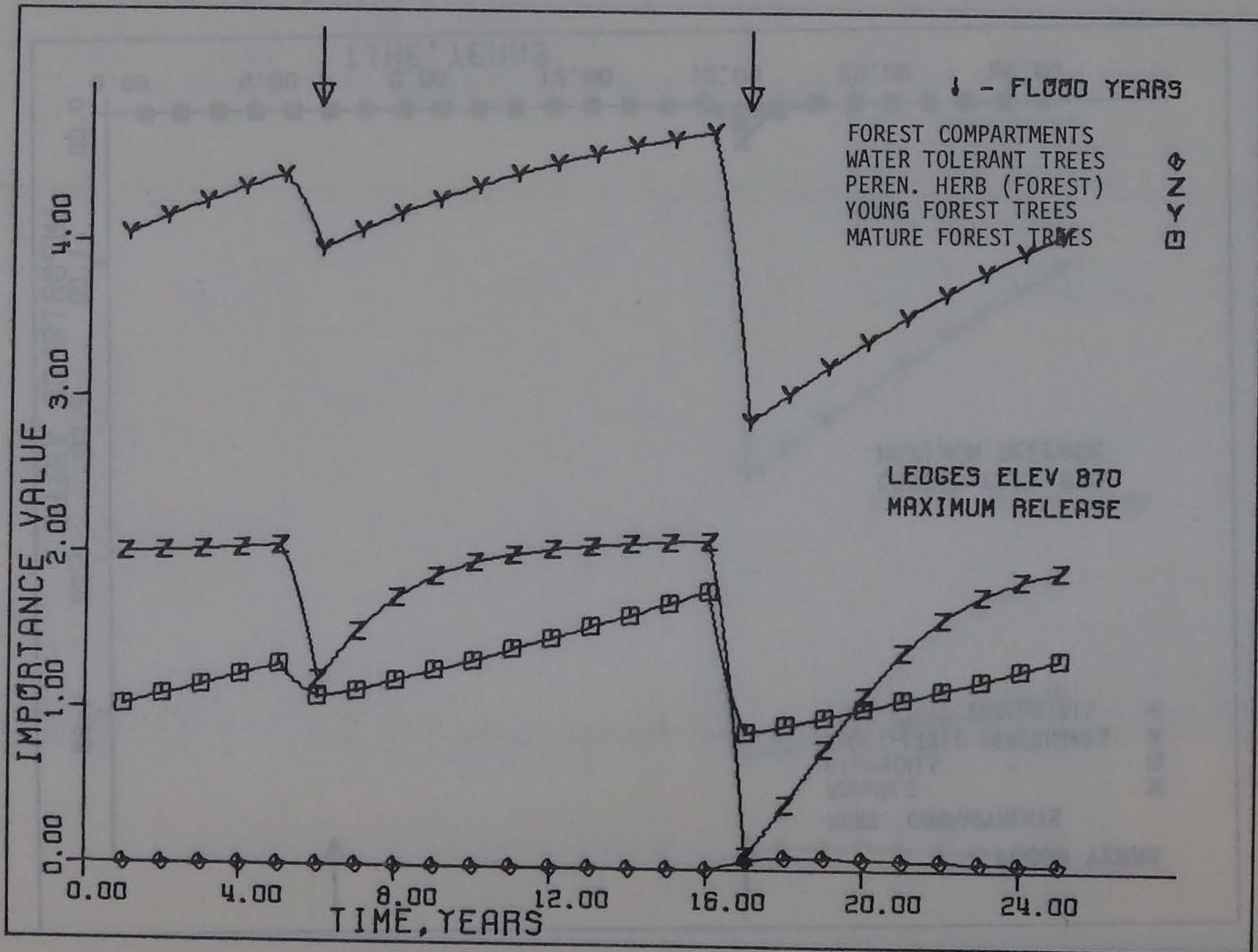


Fig. 47. Simulation results, Ledges elevation 870 msl, Site 2, maximum release, forest compartments.

5.2.3. Summary of Ledges State Park Simulations

The results of Ledges State Park simulations can be summarized as follows. Floods that would be imposed by the 12,000 cfs release policy appear to be severe enough to cause extensive vegetation damage, both in the flood plain forests along the Des Moines River and in the picnicking areas of the Pease Creek canyon. Floods that would be imposed by the 16,000 cfs release policy appear to be less damaging. Model results for this policy indicate a 25% loss of water tolerant trees in the Des Moines River flood plain, and a 50% loss of young forest trees in the Pease Creek area. Also, the model predicts a 100% kill of grasses in the picnicking areas of the Pease Creek canyon under the 16,000 cfs policy. Finally, the simulation results for the maximum release policy are not shown to be significantly different from those of the 16,000 cfs policy.

On the basis of the simulation results, the 16,000 cfs release policy appears to have been a good compromise. Damage resulting from this policy is predicted to be significantly less than that of the 12,000 cfs policy. However, the simulation results do not show a significant further reduction in vegetation damage with the maximum release policy.

Under the 16,000 cfs release policy it appears that the sensitive Pease Creek area will be heavily impacted. Loss of canopy trees in the canyon slope forests is expected to be about 50%. Although recovery of these forests is indicated in the absence of further flooding, two large floods in succession would probably damage the forests beyond recovery. In the picnic areas, a 50% kill of canopy trees is expected. The simulation results predict 100% kill of grasses in these areas.

The above impacts could be somewhat alleviated with proper vegetation management. Picnic areas will proabably have to be reseeded after every inundation exceeding 20 days. Events of this magnitude have a return interval of about 20 years. The loss of young forest trees could be replaced by plantings of water tolerant species (15-20% kill at this elevation) as existing trees die. This change in species composition would not significantly affect the present recreational use of the area, at least not in the long-term. However, short-term recreational use might be somewhat impaired until the plantings could mature.

Two factors not adequately represented in the model might act to cause damages more severe than those predicted in the above simulations. The first is silt deposition. Extensive deposition of suspended soil particles has been found to occur in the upper reaches of Iowa's flood control reservoirs. This deposition is assumed to have a negative effect on vegetation, but the exact nature of these effects is unexplored. The second factor is wave erosion. Erosion of foot trails is already a problem in the park, indicating that the material composing some of the bluffs is easily erodable. The additional stress imposed on these bluffs by water and waves might cause severe erosion and slumping. Plant colonization of these bluffs, once denuded of vegetation and topsoil, would be extremely slow.

One factor, which also was not adequately represented in the model and which can reduce the expected damage, became evident in the 1979 snow-melt-rainfall flood event leading to the 883.7 ft inundation level. This is the effect of a very late arrival of the spring growing season. The dormant season in 1979 extended through the early part of the flood storage period--into early May, and reservoir levels were reduced to the 870 msl level before many of the forest trees were leafing out. The grasses in the canyon area did emerge and survive, as did the forest and herbaceous vegetation. Sediment depths, although 1 to 2 in. in depth, were not sufficient in combination with above average spring rainfall to prevent almost full recovery. However, nature may not be so gracious in future flood events.

5.3. Summary of Simulation Results

Based upon the simulation results from both Coralville and Saylorville it is possible to define five vegetative zones present in fluctuating-pool reservoirs (see Fig. 48).

- Zone 1. Inundation in this zone is severe enough to cause 100% kill of all vegetation. The vegetation most likely to be found in this zone consists of the annual, biennial, and short-lived perennial, weedy, herbaceous species.
- Zone 2. Inundation in this zone is severe enough to kill all vegetation except the water tolerant trees. The predominant vegetation in this zone consists of varying (with site conditions) mixtures of water tolerant tree saplings and herbaceous weeds.
- Zone 3. Survivorship of the young and mature forest tree species begins in this zone. However, flood water inundation is still severe enough to kill all of the long-lived perennials. Thus, the vegetation of originally forested sites in this zone will be heavily disturbed, having a fairly open canopy of young forest

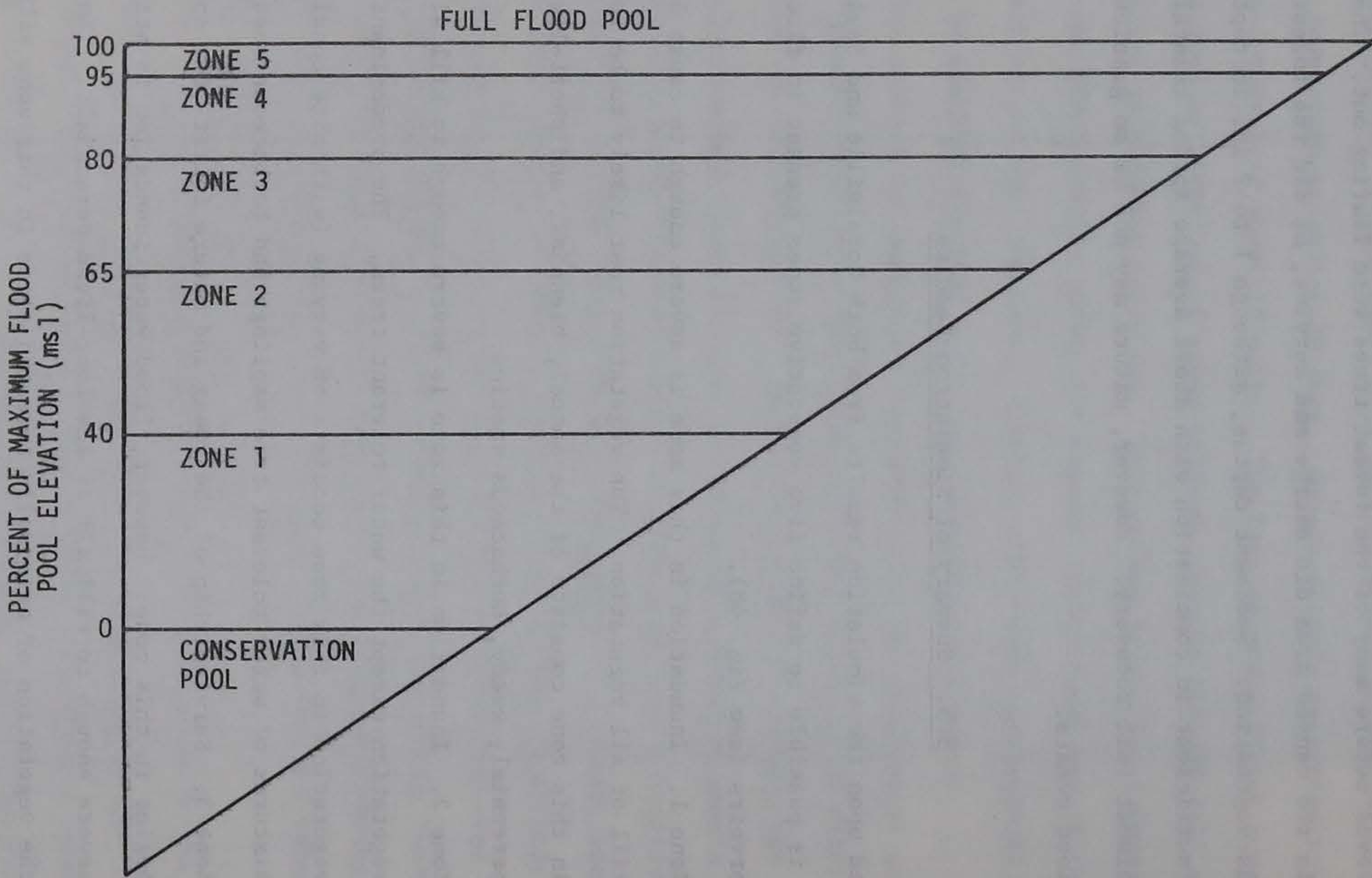


Fig. 48. Zone classification for vegetative impact in fluctuating flood control pools.

Table 12. Comparison of estimated vegetation zone elevations in Coralville and Saylorville reservoirs.

Zone	Coralville Elevation (msl)	Coralville Return Intervals[a] (yr)	Saylorville Elevation (msl)	Saylorville Return Intervals[b] (yr)
1	< 695	< 1.7	< 850	< 6
2	695-700	1.7-2.5	850-870	6-20
3	700-705	2.5-3.3	870-880	20-30
4	705-710	3.3-10	880-885	30-40
5	> 710	> 10	> 885	> 40

[a] See the Appendix, section 11.2.

[b] See Claassen (1976).

tree species and a dense tangled understory of the early successional forest herbs and shrubs. An originally pastured site in this zone will be dominated primarily by short-lived perennial herbs.

- Zone 4. In this zone inundation is mild enough to allow good survivorship of trees and some survivorship of the long-lived perennial herbs. The vegetation of sites in this zone will be similar in character to the original vegetation, but the effects of flooding will be evident by the invasion of weedy species.
- Zone 5. In this zone inundation is mild enough that the original vegetation is essentially undamaged.

Table 12 shows the approximate elevations of these zones for both Coralville and Saylorville. The zone elevations shown for Coralville were determined primarily from field observations while those shown for Saylorville were determined from simulation results. Table 12 also compares the return interval (1/frequency) of flooding at the various zone elevations.

The return intervals of flooding at the zone elevations do not compare well. This reflects the differences in size, operation, and hydrologic regimes between the two reservoirs. This also reflects the fact that frequency of flooding is only one of the major variables affecting vegetation response.

The zone elevations in Coralville and Saylorville can also be compared by expressing zone elevation as percent full flood pool. This expression is obtained by taking the following ratio:

% Full Flood Pool Elevation =

$$\frac{\text{Zone Elevation} - \text{Conservation Pool Elevation}}{\text{Full Flood Pool Elevation} - \text{Conservation Pool Elevation}} \times 100$$

Zone elevations expressed in this manner are compared in Table 13. A fairly good agreement between the two reservoirs is shown. It might be possible to set forth some rules-of-thumb concerning the long-term vegetation development in Iowa flood control reservoirs using percent of full flood pool to define the vegetation zones.

It should be noted that at the present time the vegetation zones at Red Rock Reservoir do not conform to the percent full flood pool ranges shown in Table 13. The unusually severe flood of 1973 left essentially only two zones at Red Rock, 100% kill and no kill. Any shoreline vegetation presently existing within the flood pool is a result of succession from bare ground, particularly on the sloping valley walls. The only exception is the flood plain area in the vicinity of the Runnells' high bridge crossing and between this location and the upstream part of the flood pool at Des Moines. Within this reach there is a transition of complete to partial to good survival of the more flood-tolerant species of forest habitat in that part of the reservoir where inundation was less severe and the large trees are only partially submerged.

Table 13. Comparison of zone elevations at Coralville and Saylorville expressed as percent full flood pool.

Zone	Percent Full Flood Pool	
	Coralville	Saylorville
1	< 41	< 30
2	41-59	30-65
3	59-81	65-82
4	81-93	82-91
5	> 93	> 91

6. MANAGEMENT OF RESERVOIR FLOOD POOL FLOOD PLAINS FOR WILDLIFE THROUGH CROP PRODUCTION

6.1. Background

A problem cited earlier and one of the problems addressed by this study, which is also one of the major criticisms of flood control reservoirs, is the severe impact of the fluctuating pool on the terrestrial habitat as it affects animals and vegetation. Many of these effects are unavoidable in the reasonable operation of such a reservoir. However, part of the environmental stress and aesthetic displeasure can be alleviated by the implementation of mitigation measures, these are often operating measures which can affect the ability to use such a reservoir for floodwater storage by altering release rates. Another method that is currently practiced at Red Rock Reservoir along the Des Moines River, southeast of Des Moines, Iowa, is a land management program.

As a part of the mitigation process, land in the reservoir flood pool flood plain is selectively being cultivated to produce food for wildlife, with an emphasis on waterfowl. Red Rock Reservoir is a federal reservoir built and operated by the Rock Island District of the U. S. Army Corps of Engineers. As such, all operations and management are subject to legislative rules and guidelines regulating such reservoirs. Congressional authorization allows such a program as long as it is carried out with the primary emphasis on management for wildlife. However, additional benefits are achieved, in that otherwise unused reservoir lands are returned to production, areas that would likely be aesthetically displeasing are improved, and more areas are available for recreational use.

6.2. Red Rock Reservoir Program

The game management program is being run by the Iowa Conservation Commission according to agreements with the Corps of Engineers. Many of the stipulations of the agreement have been established by federal regulations stemming from congressional authorization for this program. A total of 25,542 acres is under Commission management. Of this, 10,000 acres are being planted annually, depending on actual spring and early summer pool elevations.

According to the terms of the agreement between the Commission and the Corps, the Commission has the right to manage this land primarily for the benefit of wildlife. Management includes the decision as to which crops are planted in which fields, maintenance of cover, and many other factors that will be discussed later in this report. The right to plant a crop in a given field is contracted to a specific farmer, usually the individual from whom the land was purchased in the land acquisition process for the reservoir. Such a farmer is renting the land for agricultural cropping purposes only and must not prevent the public from legally using this land.

All costs of administering the program are the responsibility of the Commission. Each farmer (cooperator) pays all costs of crop production and harvesting. As part of the land rental agreement, five percent of the crops (by rows) are left in the fields. Of the remaining 95%, all is harvested, with farmers receiving 70 to 90% of the crop and 5 to 25% going to the Commission. The portion going to the Commission is either sold at grain elevators or purchased by the farmers who raised and harvested the crop. However the crop is sold, weigh slips must accompany all payments. The weigh slips must be for the total crop as the basis for calculating the Commission's portion of the crop.

At first glance, this type of a system depends greatly and perhaps unduly on the honesty of the farmer, potentially to the detriment of the state. However, the desirability of contracting with the Commission for this land is great enough that there is a continuing waiting list of individuals who would like to farm this land. Because of this demand for the land, the Commission does not hesitate to terminate any contract with a farmer who does not live up to the agreements. This serves as a self-policing measure, as many of those on the waiting list are already farming adjacent parcels of land. Thus, farmers are unwilling to jeopardize their right to continued use of reservoir land, since neighbors may be watching over their shoulders. The Commission can also make yield comparisons between fields to get an idea if the harvests are being properly reported.

The share of money from the crop that goes to the Commission must be placed in a Corps of Engineer's trust fund. At the present time, this money can be spent only for specified uses. These include the financing of aerial seeding of the flood plain areas with a grain crop for wildlife during years that the pool levels inundate the fields late enough in the growing season to prevent regular planting and harvesting of crops as well as the purchasing of grain for feeding wildlife in years that pool elevations are high late enough in the year such that even aerial seeding does not yield sufficient food for migrating waterfowl. However, there has been limited use of these funds and most of the income received by the Commission remains in the trust fund. This in part results from the fact that Corps officials are not sure of other ways in which these funds can be legally spent. It is hoped that the possible uses will soon be clarified so that these funds might be optimally used for reservoir management.

In addition to the audit and field checks on the farmers, there is also a check on the Commission. Federal auditors review the Commission's records once every year. There has been no problem with the Commission records throughout Red Rock's operation.

The Commission budgets \$70,000 from their own funds for staff and other expenses to administer the program. From this program, the Commission benefits in several basic areas. First, the Commission gets to manage the flood plain for the benefit of waterfowl and upland game. Second, food is left in the fields for the wildlife as a result of the 5% intentionally left in the fields and that lost due to usual equipment inefficiencies in harvesting the crops. This program also allows the Commission to open additional land for public hunting in the fall.

6.3. Land Management

The ability to manage this land essentially involves all aspects of the farming practices used. Various size fields are set up. Cover for wildlife is maintained throughout the area and the Commission determines what crop is planted in each field. Crops include corn, soybeans, oats hay, wheat, milo and sorghum. Although the following date restrictions may vary from year to year, the general time frame applies. Fields cannot be entered to begin spring field preparation until the end of March.

At this time, the fields require full tillage practices to be used since no fall tillage is permitted after the harvest. Problems do arise in the spring because the greatest potential for inundation of the field exists with higher reservoir pool levels which usually begin with excessive snowmelt runoff. As a result of the frequent inundation and sediment deposition, the addition of phosphorus to the fields is not necessary. However, nitrogen is added to the fields at approximately the same levels as in upland areas. Insecticides are restricted to the organophosphates; and herbicides used are not to interfere with the established crop rotation. In future years, all corn that is planted will be restricted to varieties that mature in 105 days or less. This is to assure that harvesting is completed and that equipment is out of the fields by the time of the fall migration of the waterfowl.

Crops can usually be planted using standard field equipment if farmers can get into the fields. If high water prevents this, the Commission may seed aerially in July for the waterfowl if the pool level has lowered sufficiently by then. Further obligations on the part of the farmers include the mowing of roadsides the weeks before Memorial Day, July 4th and Labor Day. The only exception is the Memorial Day period. If a farmer is still involved in planting crops on tracts rented from the State, the mowing need not be done at this time.

Several stipulations apply to the harvesting of crops. Fields planted in hay may only be cut between August 1 and August 15 with the farmer receiving 100% of that cutting. This gives time for the maturing of young fowl and other wildlife that may be nested in the fields while allowing time for further growth to provide food and cover for wildlife during the coming winter. When harvesting crops, the 5% of the crop left in the fields for wildlife is the 5% of the crop area, by rows, that is nearest to cover. Although these rows are generally less productive than center rows, they provide the best combination of food and cover for the wildlife. The harvesting of all crops must be completed and farm equipment must be out of the fields by the end of September. The only fall tillage that is permitted is planting selected fields with winter wheat following a crop of soybeans. Crop stubble and residues must remain in all fields.

Of the 25,542 acres under Commission management, 2,462 acres serve as a waterfowl refuge, with hunting prohibited during migration periods in spring and fall. This was reduced from 8,047 acres because heavy siltation in the lower portion of the area made this land unmanageable. The reduced area appears to be satisfactory for the numbers of waterfowl passing through the area each year. The management area is shown in Fig. 49 with the original and present refuge areas defined. The refuge area serves as a refuge during waterfowl migration periods only. At these times, the refuge area is posted and no one is allowed to enter. At other times of the year, it is open to public hunting.

The remaining 23,080 acres are open to the public on a year-round basis, and is extensively used for hunting. Fishing areas along the Des Moines River and dog trail areas have also been developed to help add to the usefulness of the area. In addition to these activities, the area serves very well as an area for observation of waterfowl (including shorebirds), song birds and predatory birds and upland game. The area is used for low intensity activities and is being maintained that way

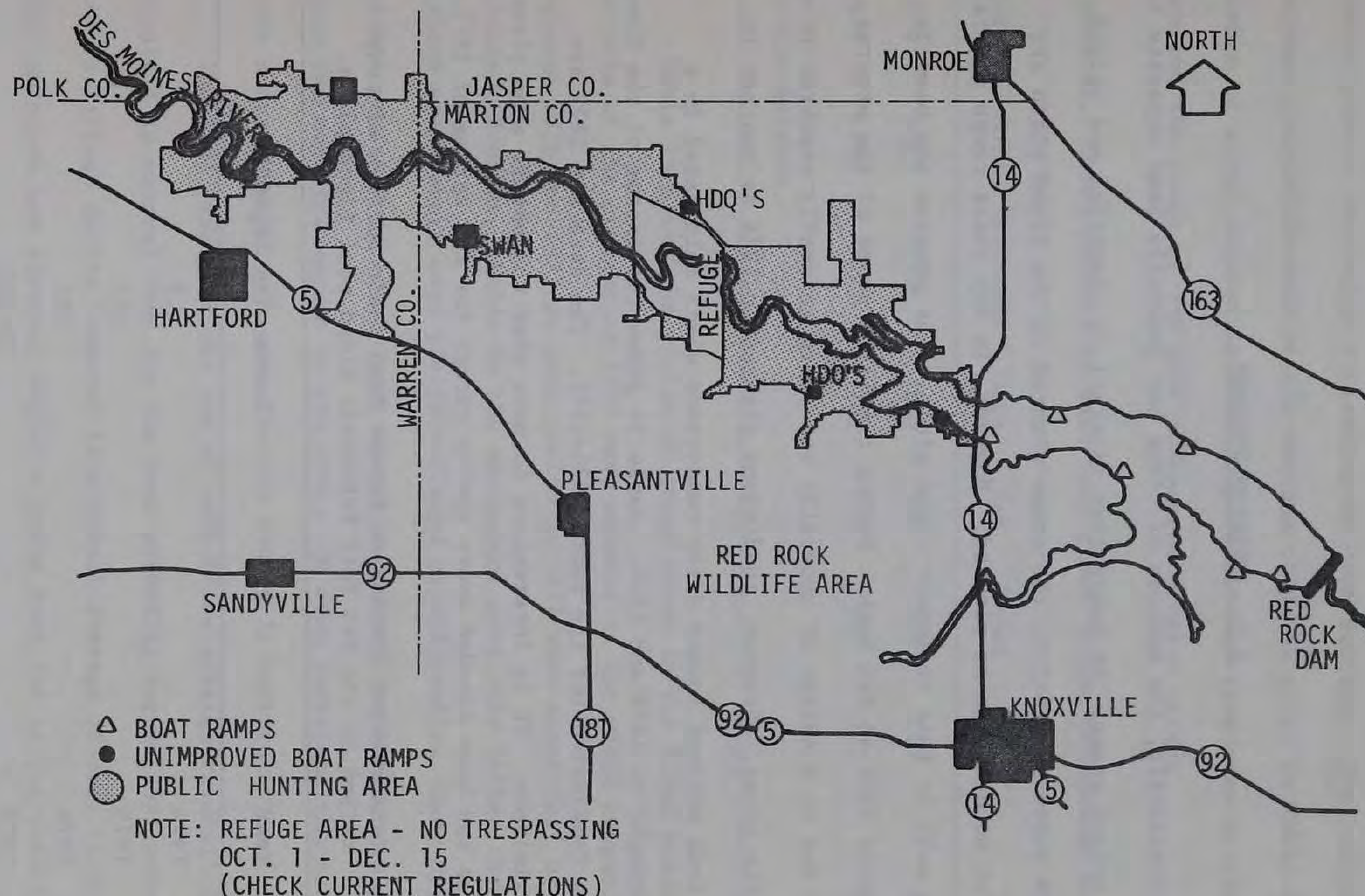


Fig. 49. Crop management areas in Red Rock Reservoir under the supervision of the Iowa Conservation Commission.

with the farming practices designed to enhance such development of the area.

6.4. Program Success

Interestingly, the success of crops has generally been opposite to that of upland areas. In years that rainfall is plentiful and upland crops are quite successful, the crops planted in the flood plain are flooded or no crop can be planted. However, in dry years crops generally do quite well in this reservoir flood plain. The program has been in effect since 1968 at Red Rock. During the first years of the program, flooding due to a series of unusually wet years generally resulted in no appreciable crops. However, conditions changed in 1974 as weather in central Iowa shifted toward drier conditions which culminated in a severe drought in 1976 and 1977. Table 14 shows the income of the Conservation Commission for the years 1974-1977. The data for 1977 are only preliminary. It is interesting to note that the entire area planted with crops has been flooded every spring except for the spring of 1977.

Table 14. Conservation Commission income from their portion of crops raised in the Red Rock Reservoir flood pool flood plain.

Year	Income (in $1,000)
1974	9
1975	135
1976	195
1977	70-100

Although grain prices have varied during this period, these figures should give a reasonable indication of crop success. The breakdown of acreage planted in each of the various crops is given in Table 15. The number of acres planted in each crop is altered from year to year to achieve the goals of the game management program better.

Table 15. Acres planted in each crop grown in the management area.

Year	Corn	Soybeans	Oats	Hay	Wheat	Milo[a]	Total
1975	3685	1996	243	388	105	147	6,564
1976	4980	3772	261	207	544	227	9,991

[a]Grain Sorghum.

Table 16 gives the yields of crops grown in the flood plain. The effects of the drought of 1977 were evident in the yield comparison between 1975 and 1977 as corn yields in 1977 were about half of the 1975 yields. However, yields in the management area were better than in the upland areas where corn yields suffered significantly. Many upland fields produced so little corn that the cost of harvesting was greater than the expected return on the crop. In some instances the corn yields were under a bushel per acre (Marion County in particular).

The 1977 crop year was one of well below average rainfall in Iowa. Rainfall in central Iowa for the year preceding August 1977 averaged ten to fifteen inches compared to a normal average of over thirty inches. Soil moisture was severely depleted going into the spring with little rainfall in the spring. Thus, corn plants were becoming stressed by the

Table 16. Yields of several crops grown in the flood pool flood plain of Red Rock Reservoir.

Year	Crop Yields, bushels/acre		
	Corn	Soybeans	Sorghum
1975	100-120	30 (weed problem)	90-110
1977	50-60		

end of June. This continued until August when the drought was relieved as Iowa experienced the heaviest rainfall of any month on record. However, this was too late to significantly improve crop yields. These heavy August rains resulted in sufficient runoff toward the end of the month so that the Red Rock Reservoir pool elevation raised from the normal conservation pool elevation of 725 msl to a high for the year of 733 msl on August 30, 1977. This was high enough to flood the lowest 400 to 500 acres of the 10,000 acres under cultivation. However, the pool level decreased with little resultant effect on the crops which were later harvested. As pointed out earlier, the entire area under cultivation has been flooded every spring except for the spring of 1977. Thus, if pool elevations decrease early enough in the season, farming these lands can prove quite profitable, and becomes a part of total reservoir management.

In addition to the agricultural success of the area, the game management aspect has also been quite successful. During migration periods, from 25,000 to 35,000 ducks and geese have stopped in the area before continuing their flight. Many remain for the winter. In years that unsuccessful crop production results in insufficient food, the birds pass by. The management program has also helped other wildlife. There have been much larger numbers of various game animals than in surrounding areas. This is especially true of quail, pheasants and deer. As a result, this area has become a very popular public hunting area.

7. CONCLUSIONS AND RECOMMENDATIONS

Results of the computer simulations of vegetative impacts at Coralville Reservoir indicate that the present vegetation model will realistically simulate vegetative responses to flooding in a general sense, but cannot be expected to give precise results for any specific site. It does provide temporal impact results which are important in a comparative analysis of alternative flood control operational procedures and reservoir regulation. Modeling of specific sites could be improved with improved modeling of 1) wave erosion and its effect on vegetation, 2) the effect of differing site substrates, 3) the influence of surrounding vegetation, and 4) the effect of siltation. Additional research into all of these areas is needed.

The model results could also be improved simply by input of better baseline data. Permanent vegetative-impact study areas should be established in new reservoirs such as Saylorville, preferably before impoundment. Repeated observations over a number of years would then provide the kind of baseline data needed.

Results of the Saylorville Reservoir simulations for the lower Ledges State Park indicate that the area will be heavily impacted. For continued recreational use of the area, intensive clean up of flood debris and removal of silt will be necessary following each inundation, and fairly intensive vegetation management practices will be needed. These include periodic replanting of the lowest areas to desirable grass cover, mowing of weedy mudflat areas, planting fast growing trees in areas where trees are killed, and removal of dead trees. Relocation of intensively used recreation facilities and programs in the lower Ledges State Park needs to be completed. The recent acquisition of timbered tracts upstream on Pease and Davis Creeks, above the maximum flood pool level, will assist in reaching the general environmental mitigation goals and objectives. An opportunity also exists to transfer the recreation fields, concession building, and lodge facility now existing south of the mouth of Pease Creek at the Des Moines River to a nearby terrace, a few hunderd yards farther south of the existing flood plain area. This would be above maximum flood levels on well drained terrace, and would be sufficiently close to the Pease Creek Canyon area to permit constructing new, higher-level trails to connect the two areas. Completion and implementation of the new Iowa Conservation Commission master plan for the Ledges State Park is urgently needed if a favorable public attitude is to be achieved regarding environmental mitigation.

The Ledges State Park area also presents the opportunity to experiment with alternative vegetation management plans. Various water tolerant species of grasses and shrubs could be established and observed in experimental plots. Results of such studies might provide information that would lead to a practical and effective vegetation management program for flood control reservoirs.

In general the results of this study indicate the following rules-of-thumb for long-term development of shoreline vegetation in Iowa's flood control reservoirs.

1. Below the elevation of 40% of the maximum flood pool rise, no vegetation can withstand the periodic flooding which occurs. Weedy herbaceous species temporarily dominate this zone.

2. Between elevations in the range 40%-65% of the maximum rise in the flood pool, only the water tolerant trees can survive flooding. Mixed water tolerant trees and weedy herbaceous species dominate this zone.
3. Between elevations in the range of 65-80% of the maximum rise in the flood pool, survivorship of young and mature forest trees begins. No survival of long-lived perennial herbaceous species is expected. Vegetation in this zone will consist of very disturbed forests or short-lived perennial communities, depending upon site conditions and original vegetation.
4. Between elevations of about 80-95% of the rise in the maximum flood pool, tree survivorship is good and survival of long-lived perennial herbs begins. Vegetation in this zone is similar in character to the original vegetation, but is disturbed and weedy. Above elevations of about 95 of the full rise of the flood pool, vegetation is essentially undamaged unless it is on steep slopes where sloughing occurs due to wave action. (See Fig. 48 for visual aspects of this zone classification.)

In order to develop a model that will have the accuracy and realism needed to provide simulations usable as input into the design of reservoirs and optimization of reservoir operation plans, additional research is needed. This will probably entail large-scale reservoir shoreline studies collecting information on site geological conditions (parent material, slope, aspect, and general topographic position), vegetation, and wave erosion. The methods of Jaakson (1970) might be adapted for this purpose. It is hoped that these kinds of studies will be undertaken at Saylorville Reservoir, as a coordinated project among the Corps of Engineers, the Iowa Conservation Commission, other affected or interested state resource agencies, and the state universities.

The management of flood plains within the flood control pool through regulated agricultural use, for wildlife and waterfowl sustenance, appears to have considerable merit and probability of success. This is a very desirable alternative to allowing the natural vegetative succession to occur after inundation kills existing vegetation. Such a management program can be an important program for the mitigation of the effects of such flood control reservoirs, and retains a good measure of agricultural production capability on these lands.

Although success of raising crops and providing a resting area for migrating waterfowl cannot be guaranteed every year, the years of success are quite beneficial. Such a program returns land to production that would otherwise be of little use. This can result in retaining an important economic stimulus to the region encompassing the reservoir. In addition, habitat and food are provided for wildlife to help increase their numbers. Such an area can be used as a public hunting area, a wildlife refuge, or a combination of the two, thereby resulting in increased beneficial use of a flood pool area.

The success of the farming of portions of the flood pool at Red Rock Reservoir indicates that agricultural production should be one management alternative to be considered in these areas. The appearance of a corn or soybean field is often more aesthetically pleasing than a field of ragweed, smartweed or goldenrod. However, for better management of these areas there needs to be a reevaluation of the use of funds derived from the crops. The program could be self-supporting if the additional funds were used in the management program. To increase wildlife habitat, it may be desirable to construct several small subimpoundments and levees to create artificial marsh areas. These management alternatives are not possible under existing funding and management agreements between the Iowa Conservation Commission and the Corps of Engineers. It is the recommendation of this study that a reanalysis of this joint agreement be made in order to improve management of the upper end of Red Rock Lake for wildlife habitat. Similar agreements should be investigated at the other large reservoirs in Iowa.

The final report recommendation is an appeal for increased funds for reservoir operation and management. Comprehensive environmental mitigation requires a commitment of personnel and funds far above past efforts, when the operation of physical facilities was the primary responsibility. The $6,000,000 environmental mitigation plan for Saylorville Reservoir is a key example of what can be accomplished, and a start for a better future. Reservoir land and resource management is comparable to farming or forest management. Neglect of any reservoir area compares with a farmer neglecting to plant a field, or a forester neglecting to reforest after timber harvest. Future returns from the initial investment are thereby sacrificed. Reservoir management must include the management of the lands within the flood pool as well as those above maximum flood pool elevation. The ability to use the trust funds collected by the Corps of Engineers for any and all environmental mitigation measures is important. This would enhance debris cleanup, slope and shoreline renovation and protection, periodic replanting of selected herbaceous and forest cover, improving forest and herbaceous cover in all reservoir lands, and other improvements of a real or aesthetic nature. Revision of present policies and limitations on expenditures is recommended.

The study well illustrates the importance of reservoir management. The results and recommendations, if carried out fully and effectively, will do much to regain public confidence in a resource area where public support has waned or disappeared. Multipurpose reservoir development, which includes a greater proportion of water supply (such as Rathbun Reservoir) and thereby limits the amount of vertical fluctuation, is another alternative worthy of consideration. This has measurably reduced the visual impact along the shoreline of the conservation pool, where most water-borne outdoor recreation takes place. It thereby minimizes the cost of environmental mitigation as well. Such additional alternative program and cost evaluation should be made for any new proposed reservoirs, particularly in the midwest where fluctuating pools have been so accessible and visible to the public.

8. ACKNOWLEDGMENTS

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The following graduate students were employed on the project and contributed with their theses: William J. Claassen, Thomas D. Glanville, and William F. Riddle. Barry L. Butterfield, an undergraduate civil engineering student and later a water resources graduate student, assisted in early studies of alternative Saylorville Reservoir operation.

The entire research project has contributed measurably to achieving a state-federal environmental mitigation plan acceptable to the Governor's office and Iowa congressional delegation. A $6,000,000 federal authorization and appropriation has now been made by congress to accomplish this goal.

Sincere thanks goes to the U.S. Army Corps of Engineers, Rock Island District, for their cooperation in obtaining the necessary data for Coralville, Red Rock and Saylorville Reservoirs. The assistance of the personnel from the Iowa Conservation Commission is also acknowledged.

9. PROJECT PUBLICATIONS

The following reports, theses and papers have been published as a result of this project.

1. DOUGAL, M. D. (1974), "Comments on Saylorville Reservoir, Regarding Findings and Final Environmental Study of the Corps of Engineers." Mimeographed Report, Iowa State University, Ames, Iowa. Report includes as an appendix, "Effects of Operating Saylorville Lake Under Alternative Schemes," by Barry L. Butterfield, 1974.
2. GLANVILLE, T. D. (1976), "Optimal Operation of a Flood Control Reservoir," M.S. Thesis, Iowa State University, Ames, Iowa.
3. CLAASSEN, W. J. (1976), "Analysis of Alternative Flood Control Policies at Saylorville Reservoir," M.S. Thesis, Iowa State University, Ames, Iowa.
4. RIDDLE, W. F. (1978), "Modeling Shoreline Vegetation in Iowa's Flood Control Reservoir," M.S. Thesis, Iowa State University, Ames, Iowa.
5. AUSTIN, T. A. and T. D. Glanville (1979), "Flood Control Reservoir Operations Under Environmental Restraints." Water Resources Bulletin, American Water Resources Assoc. 15(3):766-778.
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11. APPENDIX

11.1 Vegetative Simulation Model

Program Listing

```
C........... VEGSIM, VERSION1, JAN 1977, W.F. RIDDLE ......
C
C     PROGRAM DESCRIPTION-
C
C       VEGSIM IS A COMPARTMENTAL SIMULATION MODEL OF THE
C       VEGETATION DEVELOPMENT ALONG THE SHORES OF FLOOD
C       CONTROL RESERVOIRS IN IOWA.
C
C     DEFINITION OF VARIABLES.
C
C       DATA BLOCK VALS-
C         C(I)- COMPARTMENT IMPORTANCE VALUES
C         DERC(I)- TIME DERIVATIVE OF C(I)
C         COEF(I)- COEFFICIENTS OF THE SYSTEM OF DIFFERENTIAL
C         EQUATIONS DESCRIBING C(I) AND DERC(I)
C
C       DATA BLOCK YRVAL
C         CYR(I,Y)- YEARLY STORED VALUES OF C(I)
C         DERYR(I,Y)- YEARLY STORED VALUES OF DERC(I)
C         COFYR(I,J,Y)- YEARLY STORED VALUES OF COEF(I,J)
C
C       DATA BLOCK PRAMS-
C         A(I)- VALUES OF A SUBSCRIPT II IN EQUATIOJS
C         RED(I,J)- VALUES OF C SUBSCRIPT IJ IN EQUATIONS
C         TO(I)- SOIL ORGANIC MATTER THRESHOLDS
C         TS(I)- SHADE THRESHOLDS
C
C       DATA BLOCK FLD-
C         IYOF- YEAR A FLOOD OCCURS
C         ISF- COMPUTATION STEP A FLOOD STARTS
C         IEF- COMPUTATION STEP A FLOOD ENDS
C         DPTH- AVERAGE DEPTH OF FLOODING
C         DUR- DURATION OF FLOODING IN WEEKS
C         TSF- TIME A FLOOD STARTS IN WEEKS FROM APR. 1
C         TEF- TIME A FLOOD ENDS IN WEEKS FROM APR. 1
```

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C
C      CONTROL VARIABLES-
C        T- VALUE OF TIME IN YEARS
C        L- STEP COUNTER SHOWING THE NUMBER OF COMPUTATION
C        STEPS SINCE THE BEGINNING OF THE YEAR
C        NSTEP- THE NUMBER OF COMPUTATION STEPS PER YEAR
C        DELT- TIME INCREMENT OF EACH COMPUTATION STEP
C        Y- YEAR COUNTER
C        N- STEP ON WHICH VALUES OF C, DERC, AND COEF ARE
C           TO BE SAVED
C        STPWK- NUMBER OF COMPUTATION STEPS PER WEEK
C
C      MISCELLANEOUS VARIABLES-
C        SLOP- SITE SLOPE
C        LABEL- COMPARTMENT LABELS
C
C****************** PROGRAM LISTING **************************
C
      DIMENSION C(12),DERC(12),COEF(12,13),CYR(12,50),DERYR(12,50),COFYR
     *(12,13,50),LABEL(12,5),A(12),RED(12,12),TO(12),TS(12)
      INTEGER Y
      COMMON Y,T
      COMMON/VALS/ C,DERC,COEF
      COMMON/YRVAL/ CYR,DERYR,COFYR
      COMMON/PRAMS/ A,RED,TO,TS
      COMMON/NAMES/ LABEL
      COMMON/FLD/ IYOF,ISF,IEF,DPTH,DUR,TSF,TEF
      COMMON/FLOD/ DELT,L,SLOP,STPWK
      COMMON/NSTP/ NSTEP,N
C
C                 - READ IN INITIAL VALUES OF C,DERC, AND COEF
C                 - READ IN PRAMS
C                 - READ IN CONTROL VARIABLES
C                 - READ IN LABELS
C                 - READ IN SITE SLOPE
```

```
C                  - READ IN DATA FOR FIRST FLOOD
C
      READ(5,1) (C(I),I=1,12)
    1 FORMAT(12F5.2)
      READ(5,2) ((COEF(I,J),J=1,13),I=1,12)
    2 FORMAT(13F6.3)
      READ(5,2) (A(I),(RED(I,J),J=1,12),I=1,12)
      READ(5,400) (TO(I),I=1,12)
      READ(5,400) (TS(I),I=1,12)
  400 FORMAT(12F6.3)
      READ(5,3) DELT,TMAX,N,NSTEP
    3 FORMAT(F6.4,5X,F8.3,5X,I3,5X,I4)
      READ(5,5) ((LABEL(I,J),J=1,5),I=1,12)
    5 FORMAT(5A4)
      READ(5,6) SLOP
    6 FORMAT(F4.2)
      READ(5,7) IYOF,TSF,TEF,DPTH,DUR
    7 FORMAT(I2,5X,F4.1,5X,F4.1,5X,F4.1,5X,F4.1)
C
C                  - WRITE THE ABOVE DATA AS A CHECK
C
      WRITE(6,8)
    8 FORMAT('0',2X,'YEAR',10X,'COMPARTMENT',10X,'VALUES',39X,'MATRIX VA
     *LUES')
      WRITE(6,9)
    9 FORMAT('0',4X,'0')
      DO 11 I=1,12
        WRITE(6,10) I,(LABEL(I,L),L=1,5),C(I),(COEF(I,J),J=1,13)
   10   FORMAT(' ',10X,I2,1X,5A4,4X,F5.1,9X,13(F5.2,1X))
   11 CONTINUE
      DO 600 I=1,12
        WRITE(6,500) I,A(I),(RED(I,J),J=1,12)
  500   FORMAT('0','COMPARTMENT',I2,'PARAMETERS ARE',13(1X,F6.3))
  600 CONTINUE
      WRITE(6,700) (TO(I),I=1,12)
```

```
  700 FORMAT('0','ORGANIC MATTER THRESHOLDS ARE',5X,12(F5.2))
      WRITE(6,800) (TS(I),I=1,12)
  800 FORMAT('0','SHADE THRESHOLDS ARE',5X,12(F5.2))
      WRITE(6,12)  DELT,TMAX,N,NSTEP
   12 FORMAT('0','DELT=',F5.3,3X,'TMAX=',F5.2,3X,'N=',I2,3X,'NSTEP=',I2)
      WRITE(6,14) SLOP
   14 FORMAT('0','SLOP= ',F4.2)
      WRITE(6,15) IYOF,TSF,TEF,DPTH,DUR
   15 FORMAT('0','FIRST FLOOD PRAMS ARE  IYOF=',I2,3X,'TSF=',F4.1,3X,'TE
     *F=',F4.1,3X,'DPTH=',F4.1,3X,'DUR=',F4.1)
C
C                 - INITIALIZE THE VALUES OF T, Y AND L
C
      T=0.0
      Y=1
      L=0
C
C                - COMPUTE ISF AND IEF
C
      STPWK=FLOAT(NSTEP)/52.0
      ISF=TSF*STPWK+0.5
      IEF=TEF*STPWK+0.5
      IF(ISF.NE.NSTEP) GO TO 16
      ISF=0
      IYOF=IYOF+1
C
C                 - WRITE STPWK, ISF, AND IEF AS A CHECK
C
   16 WRITE(6,200) STPWK,ISF,IEF
  200 FORMAT('0','COMPUTATION OF FLOOD STEPS',5X,'STPWK=',F4.2,3X,'ISF='
     *,I2,3X,'IEF=',I2)
C
C                 - CALL SUBROUTINE MATIX TO COMPUTE THE
C                   NECESSARY CHANGES IN COEF
C
```

```
   20 CALL MATIX
C
C                     - USING THE SYTEM OF DIFFERENTIAL EQ-
C                       ATIONS, COMPUTE DERC(I)
C
      DO 30 I=1,12
        DERC(I)=0.0
        DO 25 J=1,12
          DERC(I)=DERC(I)+COEF(I,J)*C(J)
   25   CONTINUE
        DERC(I)=DERC(I)+COEF(I,13)*C(I)*C(I)
   30 CONTINUE
C
C                     - ONCE A YEAR AT L EQUAL TO N SAVE THE VALUES
C                       OF C(I),DERC(I), COEF(I,J).
C
      IF(L.EQ.N)CALL SAVE
C
C                     - INCREMENT TIME AND CHECK TO SEE IF SIM-
C                       ULATION TIME HAS RUN OUT
C
      T=T+DELT
      ISTOP=(TMAX-T)*FLOAT(NSTEP)
      IF(ISTOP.EQ.0) GO TO 50
C
C                     - INCREMENT STEP COUNTER AND CHECK TO SEE IF
C                       A YEAR HAS ELAPSED. IF SO, INCREMENT YEAR
C                       COUNTER AND RESET L.
C
   33 L=L+1
      IF(L.EQ.NSTEP) GO TO 34
      GO TO 35
   34 Y=Y+1
      L=0
C                     - CHECK TO SEE IF A FLOOD EVENT OCCURS
```

```
C                    IN THIS TIME STEP.
C
   35 IF(Y.NE.IYOF) GO TO 36
      IF(L.NE.ISF) GO TO 36
      WRITE(6,100) T,L,Y
  100 FORMAT('0',' TIMES  - MAIN PROGRAM',5X,F5.2,5X,I2,5X,I2)
      CALL FLOOD
      WRITE(6,100) T,L,Y
      GO TO 20
C
C                  - COMPUTE THE NEW VALUES OF C
C
   36 DO 40 I=1,12
        C(I)=C(I)+DERC(I)*DELT
   40 CONTINUE
      GO TO 20
C
C                  - WHEN T EXCEEDS TMAX CALL THE SUBROUTINES
C                    PLOUT AND PROUT TO PRODUCE AN OUTPUT
C
   50 WRITE(6,300) Y,T
  300 FORMAT('0','SIMULATION ENDING',5X,I2,5X,F6.3)
      CALL PROUT
      CALL PLOUT
      STOP
      END
C............... SUBROUTINE SAVE ..........................
C
C     JOB DESCRIPTION -
C
C        SAVE TAKES THE VALUE OF C(I), DERC(I), COEF(I,J) ONCE
C        A YEAR AND STORES THESE VALUES IN A SEPARATE ARRAY.
C
C**************** SUBROUTINE LISTING ***********
C
```

```
      SUBROUTINE SAVE
      DIMENSION C(12),DERC(12),COEF(12,13),CYR(12,50),DERYR(12,50),COFYR
     *(12,13,50)
      INTEGER Y
      COMMON/VALS/ C,DERC,COEF
      COMMON/YRVAL/ CYR,DERYR,COFYR
      COMMON Y,T
C
C                   - TRANSFER THE VALUES OF C, DERC, AND
C                     COEF TO CYR, DERYR, AND COFYR.
C
      DO 20 I=1,12
        CYR(I,Y)=C(I)
        DERYR(I,Y)=DERC(I)
        DO 10 J=1,13
          COFYR(I,J,Y)=COEF(I,J)
   10   CONTINUE
   20 CONTINUE
      RETURN
      END
C
C............... SUBROUTINE MATIX ...........................
C
C     JOB DESCRIPTION-
C
C       MATIX TAKES THE VALUES IN COEF AND MODIFIES THEM AC-
C       CORDING TO THE SYSTEM EQUATIONS
C
C*************** SUBROUTINE LISTING ***************************
C
      SUBROUTINE MATIX
      DIMENSION C(12),DERC(12),COEF(12,13),A(12),RED(12,12),TO(12),TS(12
     $)
      INTEGER Y
      COMMON Y,T
```

```
      COMMON/VALS/ C,DERC,COEF
      COMMON/PRAMS/ A,RED,TO,TS
C
C                 - BEGIN MODIFICATION OF COEFFICIENT VALUES
      COEF(1,1)=A(1)
      COEF(2,2)=A(2)*(1.0+RED(2,12)*C(12))
      IF(C(3).GT.3.5) GO TO 10
      COEF(3,3)=A(3)*(1.0-RED(3,11)*C(11)-RED(3,12)*C(12))
      GO TO 20
   10 COEF(3,3)=A(3)
   20 COEF(4,4)=A(4)
      COEF(5,5)=A(5)*(1.0+RED(5,12)*C(12))
      COEF(6,6)=A(6)*(1.0-RED(6,7)*C(7)-RED(6,11)*C(11)-RED(6,12)*C(12))
      IF(C(11).GT.TO(7)) GO TO 30
      COEF(7,7)=0.0
      GO TO 40
   30 COEF(7,7)=A(7)*(1.0-RED(7,12)*C(12))
   40 IF(C(12).GT.TS(8)) GO TO 50
      COEF(8,8)=0.0
      GO TO 60
   50 Z=TS(8)*1.5
      IF(C(12).GT.Z) GO TO 55
      COEF(8,8)=A(8)
      GO TO 60
   55 COEF(8,8)=A(8)/3.0
   60 IF(C(11).LT.TO(9)) GO TO 90
      IF(C(12).LT.TS(9)) GO TO 90
      IF(C(9).LT.C(3)) GO TO 70
      IF(C(9).LT.C(10)) GO TO 70
      COEF(9,9)=A(9)
      GO TO 100
   70 COEF(9,9)=A(9)*(1.0-RED(9,12)*C(12))
      GO TO 100
   90 COEF(9,9)=0.0
  100 IF(C(11).LT.TO(10)) GO TO 130
```

```
      IF(C(12).LT.TS(10)) GO TO 130
      COEF(10,10)=A(10)
      GO TO 140
  130 COEF(10,10)=0.0
  140 COEF(11,11)=A(11)
      COEF(12,12)=A(12)
      RETURN
      END
C
C.............. SUBROUTINE FLOOD ...........................
C
C     JOB DESCRIPTION
C
C        FLOOD SIMULATES VEGETATION KILL BY REDUCING COMPARTMENT
C        IMPORTANCE ACCORDING TO THE FLOOD SEVERITY INDEX AND
C        THE COMPARTMENT DAMAGE FUNCTION.
C
C     PREVIOUSLY UNDEFINED VARIABLES
C
C        SOF- VALUE OF THE FLOOD SEVERITY INDEX
C        R- AMOUNT OF COMPARTMENT REDUCTION
C
C************* SUBROUTINE LISTING ***************************
      SUBROUTINE FLOOD
      DIMENSION C(12),DERC(12),COEF(12,13),A(12),RED(12,12),TO(12),TS(12
     *),CYR(12,50),DERYR(12,50),COFYR(12,13,50)
      INTEGER Y
      COMMON/FLD/ IYOF,ISF,IEF,DPTH,DUR,TSF,TEF
      COMMON/VALS/ C,DERC,COEF
      COMMON/PRAMS/ A,RED,TO,TS
      COMMON Y,T
      COMMON/FLOD/ DELT,L,SLOP,STPWK
      COMMON/NSTP/ NSTEP,N
      COMMON/YRVAL/ CYR,DERYR,COFYR
C
```

```
C                  - INDICATE FLOOD ROUTINE BEGINNING
C
      WRITE(6,100)
  100 FORMAT('0','CALL FLOOD')
C
C                - COMPUTE FLOOD SEVERITY INDEX USING BOTH
C                  DEPTH AND DURATION. AVERAGE THE RESULTS.
C
      SOF=0.5*((1.0+0.82*DUR**0.87)+1.16*DPTH**0.83)
      IF(SOF.GT.10.0)SOF=10.0
C
C                  - WRITE SOF
C
      WRITE(6,300) SOF
  300 FORMAT('0','SOF=',F5.2)
C
C                - COMPUTE THE PER CENT REDUCTION OF EACH
C                  COMPARTMENT. REDUCE CPMPARTMENT VALUES.
C
C         HERBACEOUS COMPARTMENTS
C
      R=0.25*SOF
      IF(R.GT.1.0)R=1.0
    2 Z=1.0-R
      C(2)=C(2)*Z
      C(5)=C(5)*Z
      C(6)=C(6)*Z
      C(7)=C(7)*Z
      C(8)=C(8)*Z
C
C                  - WRITE  R
C
      WRITE(6,101) R
  101 FORMAT('0','HERBACEOUS REDUCTION =',F4.2)
C
```

```
C
      SB=C(3)+C(9)+C(10)
C
C          WATER TOLERANT TREES
C
      R=0.002*SOF**2.76
      IF(R.GT.1.0)R=1.0
    4 C(3)=C(3)*(1.0-R)
C
C                    - WRITE R
C
      WRITE(6,102) R
  102 FORMAT('0','WATER TOLERANT TREE REDUCTION =',F4.2)
C
C          YOUNG FOREST TREES
C
      R=0.05*SOF**1.47
      IF(R.GT.1.0)R=1.0
    6 C(9)=C(9)*(1.0-R)
C
C                    - WRITE R
C
      WRITE(6,103) R
  103 FORMAT('0','YOUNG FOREST TREE REDUCTION =',F4.2)
C
C          MATURE FOREST TREES
C
      R=0.09*SOF**1.24
      IF(R.GT.1.0)R=1.0
    8 C(10)=C(10)*(1.0-R)
C
C                    - WRITE R
C
      WRITE(6,104) R
  104 FORMAT('0','MATURE FOREST TREE REDUCTION =',F4.2)
```

```
C
C
      SA=C(3)+C(9)+C(10)
C
C        MARSH PERENNIALS
C
      R=0.02*SOF**2.06
      IF(R.GT.1.0)R=1.0
   10 C(4)=C(4)*(1.0-R)
C
C                    - WRITE R
C
      WRITE(6,105) R
  105 FORMAT('0','MARSH PERENNIAL REDUCTION =',F4.2)
C
C        SHADE
C
      Z=SA/SB
      C(12)=C(12)*Z
C
C                    - WRITE Z
C
      WRITE(6,106)Z
  106 FORMAT('0','SHADE REDUCTION =',F4.2)
C
C        SOIL ORGANIC MATTER
C
      R=5.0*SLOP**2.3
      IF(R.GT.1.0)R=1.0
      C(11)=C(11)*(1.0-R)
C
C                    - WRITE R
C
      WRITE(6,107) R
  107 FORMAT('0','ORGANIC MATTER REDUCTION =',F4.2)
```

```
C
C               - INITIALIZE BARE GROUND
C
      SUM=0.0
      DO 11 I=2,10
        SUM=SUM+C(I)
   11 CONTINUE
C
C                 - WRITE SUM
C
      WRITE(6,108) SUM
  108 FORMAT('0','SUM =',F5.2)
C
      C(1)=5.0-SUM
      IF(C(1).LT.0.0)C(1)=0.0
C
C               - MODIFICATION OF MODEL PARAMETERS
C
      IF(C(3).GT.2.0) GO TO 13
      A(3)=1.0-2.0*SLOP
      IF(A(3).LT.0.0) A(3)=0.0
      IF(TEF.GT.8.6) A(3)=0.0
C
C                 - WRITE NEW PRAMS
C
   13 WRITE(6,400) A(3)
  400 FORMAT('0','NEW PRAMS ARE',6(5X,F5.2))
C
C               - INITIALIZE TIME AND THE STEP COUNTER TO
C                 THE APPROPRIATE VALUES.
C
      IF(IEF.GT.N) GO TO 14
      GO TO 17
   14 IF(ISF.GT.N) GO TO 17
      DO 16 I=1,12
```

```
      CYR(I,Y)=0.1
      DERYR(I,Y)=0.0
      DO 15 J=1,13
        COFYR(I,J,Y)=0.0
15    CONTINUE
16   CONTINUE
17   IF(IEF.LT.ISF) GO TO 18
     T=T+DELT*(IEF-ISF)
     GO TO 19
18   T=T+DELT*((NSTEP-ISF)+IEF)
     Y=Y+1
19   IF(IEF.EQ.NSTEP) GO TO 20
     L=IEF
     GO TO 21
20   L=0
     Y=Y+1
C
C             - READ IN THE INFORMATION ABOUT THE NEXT
C               FLOOD.
C
21   READ(5,22) IYOF,TSF,TEF,DPTH,DUR
22   FORMAT(I2,5X,F4.1,5X,F4.1,5X,F4.1,5X,F4.1)
C
C               - COMPUTE NEW ISF AND IEF
C
     ISF=TSF*STPWK+0.5
     IEF=TEF*STPWK+0.5
     IF(ISF.NE.NSTEP) GO TO 23
     ISF=0
     IF(IEF.EQ.NSTEP) IEF=0
     IYOF=IYOF+1
C
C               - WRITE NEXT FLOOD PRAMS
C
23   WRITE(6,500) IYOF,TSF,TEF,DPTH,DUR,ISF,IEF
```

```
500 FORMAT('0','NEXT FLOOD PRAMS ARE IYOF=',I2,3X,'TSF=',F4.1,3X,'TEF=
   *',F4.1,3X,'DPTH=',F4.1,3X,'DUR=',F4.1,3X,'ISF=',I2,3X,'IEF=',I2)
    RETURN
    END
C
C............. SUBROUTINE PROUT ..........................
C
C      JOB DESCRIPTION
C
C        THIS SUBROUTINE TAKES THE YEARLY STORED VALUES OF
C        C,DERC, AND COEF AND PRODUCES A PRINTED OUTPUT
C
C************** SUBROUTIN LISTING ***************************
C
      SUBROUTINE PROUT
      DIMENSION CYR(12,50),DERYR(12,50),COFYR(12,13,50),LABEL(12,5)
      INTEGER Y
      COMMON Y,T
      COMMON/YRVAL/ CYR,DERYR,COFYR
      COMMON/NAMES/ LABEL
C
C              - PRINT HEADINGS
C
      WRITE(6,1)
    1 FORMAT('0',2X,'YEAR',10X,'COMPARTMENT',10X,'VALUES',39X,'MATRIX VA
     *LUES')
C
C              - PRINT THE OUTPUT
C
      DO 30 K=1,Y
        WRITE(6,5) K
    5   FORMAT('0',3X,I2)
        DO 25 I=1,12
          WRITE(6,10) I,(LABEL(I,L),L=1,5),CYR(I,K),(COFYR(I,J,K),J=1,13
     *)
```

```
10      FORMAT(' ',10X,I2,1X,5A4,4X,F5.1,9X,13(F5.2,1X))
25    CONTINUE
30  CONTINUE
    RETURN
    END
C
C.............. SUBROUTINE PLOUT ...........................
C
C     JOB DESCRIPTION
C
C        THIS SUBROUTINE TAKES THE YEARLY STORED VALUES OF
C        C AND COEF AND PRODUCES A PLOTTED OUTPUT
C
C     PREVIOUSLY UNDEFINED VARIABLES
C
C       SIMPLOTTER PARAMETERS
C         MODE- GRAPHING STYLE
C         XSIZE- LENGTH OF X AXIS
C         YSIZE- LENGTH OF Y AXIS
C         XSF- X AXIS SCALE FACTOR
C         XMIN- MINIMUM X VALUE
C         YS1- Y AXIS SCALE FACTOR 1
C         YS2 Y AXIS SCALE FACTOR 2
C         YMIN- MININUM Y VALUE
C         XLAB- X AXIS LABEL
C         YLAB- Y AXIS LABEL
C         GLAB- GRAPH LABEL
C         ISYM- SYMBOL CODE
C
C       OTHER VARIABLES
C         NFLDS- NUMBER OF FLOODS
C         FLDS(I)- YEARS THAT FLOODS OCCUR
C         STRING AND STR2- A SITE LABEL PRINTED ON GRAPH
C         XDATA AND YDATA- COORDINATES OF POINTS TO BE PLOTTED
C         SUM(K)- SUM OF IMPORTANCE VALUES IN ANY YEAR K
```

```
C
C************** SUBROUTINE LISTING *************************
C
      SUBROUTINE PLOUT
      DIMENSION CYR(12,50),DERYR(12,50),COFYR(12,13,50),LABEL(12,5),ILAB
     *(5),XLAB(5),YLAB1(5),YLAB2(5),GLAB1(5),GLAB2(5),XDATA(50),YDATA(50
     *),SUM(50),FLDS(50),STRING(5),STR2(5)
      INTEGER Y
      COMMON Y,T
      COMMON/YRVAL/ CYR,DERYR,COFYR
      COMMON/NAMES/ LABEL
C                - READ THE PARAMETERS NEEDED FOR THE
C                  SIMPLOTTER
C
      READ(5,1) MODE,XSIZE,YSIZE,XSF,XMIN,YS1,YMIN,YS2
    1 FORMAT(I4,7(F7.3))
      READ(5,2) (XLAB(I),I=1,5),(YLAB1(I),I=1,5),(YLAB2(I),I=1,5),(GLAB1
     $(I),I=1,5),(GLAB2(I),I=1,5)
    2 FORMAT(20A4)
      READ(5,3) NFLDS
    3 FORMAT(I2)
      READ(5,4) (FLDS(I),I=1,NFLDS)
    4 FORMAT(20(F4.1))
      READ(5,6) (STRING(I),I=1,5)
      READ(5,6) (STR2(I),I=1,5)
    6 FORMAT(5A4)
C
C               - BEGIN FORMING THE REST OF THE PARAMETERS
C                 TO PLOT THE FIRST COMPARTMENT
C
      ISYM=2
      NPTS=Y
      X=0.0
      DO 5 K=1,Y
        X=X+1.0
```

```
      XDATA(K)=X
    5 CONTINUE
      DO 10 K=1,Y
       YDATA(K)=CYR(2,K)
   10 CONTINUE
      DO 15 L=1,5
       ILAB(L)=LABEL(2,L)
   15 CONTINUE
C
C              - PLOT THE FIRST COMPARTMENT
C
      CALL GRAPH(NPTS,XDATA,YDATA,4,MODE,XSIZE,YSIZE,XSF,XMIN,YS1,YMIN,X
     *LAB,YLAB1,GLAB1,ILAB)
      MODD=MODE
C
C              - PLOT THE HERBACEOUS COMPARTMENTS
C
      DO 25 I=5,7
       ISYM=I-4
       DO 21 L=1,5
        ILAB(L)=LABEL(I,L)
   21  CONTINUE
       DO 22 K=1,Y
        YDATA(K)=CYR(I,K)
   22  CONTINUE
       CALL GRAPHS(NPTS,XDATA,YDATA,ISYM,MODD,ILAB)
   25 CONTINUE
C
C              - PLOT A MARK SHOWING FLOOD YEARS
C
      DO 250 I=1,NFLDS
       X0=FLDS(I)/XSF-0.16
       CALL LETTRS (X0,4.88,0.5,'"',0.0,1)
  250 CONTINUE
      CALL LETTRS (5.5,5.0,0.1,'" - FLOOD YEARS;',0.0,15)
```

```
C
C                 - WRITE A SITE LABEL
C
      CALL LETTRS (4.85,3.75,0.10,STRING,0.0,20)
      CALL LETTRS (4.85,3.55,0.1,STR2,0.0,20)
C
C                 - PLOT THE FOREST COMPARTMENTS
C
      DO 26 L=1,5
        ILAB(L)=LABEL(3,L)
   26 CONTINUE
      DO 27 K=1,Y
        YDATA(K)=CYR(3,K)
   27 CONTINUE
      CALL GRAPH(NPTS,XDATA,YDATA,5,MODE,XSIZE,YSIZE,XSF,XMIN,YS1,YMIN,X
     *LAB,YLAB1,GLAB2,ILAB)
      DO 35 I=8,10
        ISYM=I
        DO 30 L=1,5
          ILAB(L)=LABEL(I,L)
   30   CONTINUE
        DO 31 K=1,Y
          YDATA(K)=CYR(I,K)
   31   CONTINUE
        CALL GRAPHS(NPTS,XDATA,YDATA,ISYM,MODD,ILAB)
   35 CONTINUE
C
C                 - PLOT A MARK SHOWING FLOOD YEARS
C
      DO 350 I=1,NFLDS
        X0=FLDS(I)/XSF-0.16
        CALL LETTRS (X0,4.88,0.5,'"',0.0,1)
  350 CONTINUE
      CALL LETTRS (5.5,5.0,0.1,'" - FLOOD YEARS;',0.0,15)
C
```

```
C               - WRITE A SITE LABEL
C
      CALL LETTRS (4.85,3.75,0.10,STRING,0.0,20)
      CALL LETTRS (4.85,3.55,0.1,STR2,0.0,20)
C
C               - FORM THE VECTOR SUM.
C
      DO 40 J=1,Y
        SUM(J)=0.0
   40 CONTINUE
      DO 60 J=1,Y
        DO 50 M=1,10
          SUM(J)=SUM(J)+CYR(M,J)
   50   CONTINUE
   60 CONTINUE
C
C               -PLOT GRAPHS OF BOTH  THE HERBACEOUS AND
C                 FOREST COMPARTMENTS SHOWING RELATIVE IM-
C                 PORTANCE.
C               - PLOT THE HERBACEOUS COMPARTMENTS
C
      DO 70 K=1,Y
        YDATA(K)=CYR(2,K)/SUM(K)
   70 CONTINUE
      DO 80 L=1,5
        ILAB(L)=LABEL(2,L)
   80 CONTINUE
      CALL  GRAPH(NPTS,XDATA,YDATA,4,MODE,XSIZE,YSIZE,XSF,XMIN,YS2,YMIN,X
     *LAB,YLAB2,GLAB1,ILAB)
      DO 100 I=5,7
        ISYM=I-4
        DO 85 L=1,5
          ILAB(L)=LABEL(I,L)
   85   CONTINUE
        DO 90 K=1,Y
```

```
        YDATA(K)=CYR(I,K)/SUM(K)
 90   CONTINUE
      CALL GRAPHS(NPTS,XDATA,YDATA,ISYM,MODD,ILAB)
100 CONTINUE
C
C             - PLOT A MARK SHOWING FLOOD YEARS
C
    DO 450 I=1,NFLDS
      X0=FLDS(I)/XSF-0.16
      CALL LETTRS (X0,4.88,0.5,'"',0.0,1)
450 CONTINUE
    CALL LETTRS (5.5,5.0,0.1,'" - FLOOD YEARS;',0.0,15)
C
C             - WRITE A SITE LABEL
C
    CALL LETTRS (4.85,3.75,0.10,STRING,0.0,20)
    CALL LETTRS (4.85,3.55,0.1,STR2,0.0,20)
C
C             - PLOT THE FOREST COMPARTMENTS
C
    DO 101 L=1,5
      ILAB(L)=LABEL(3,L)
101 CONTINUE
    DO 102 K=1,Y
      YDATA(K)=CYR(3,K)/SUM(K)
102 CONTINUE
    CALL GRAPH(NPTS,XDATA,YDATA,5,MODE,XSIZE,YSIZE,XSF,XMIN,YS2,YMIN,X
   *LAB,YLAB2,GLAB2,ILAB)
    DO 110 I=8,10
      ISYM=I
      DO 103 L=1,5
        ILAB(L)=LABEL(I,L)
103   CONTINUE
      DO 104 K=1,Y
        YDATA(K)=CYR(I,K)/SUM(K)
```

```
  104   CONTINUE
        CALL GRAPHS(NPTS,XDATA,YDATA,ISYM,MODD,ILAB)
  110 CONTINUE
C
C                - PLOT A MARK SHOWING FLOOD YEARS
C
      DO 550 I=1,NFLDS
        X0=FLDS(I)/XSF-0.16
        CALL LETTRS (X0,4.88,0.5,'"',0.0,1)
  550 CONTINUE
      CALL LETTRS (5.5,5.0,0.1,'" - FLOOD YEARS;',0.0,15)
C
C                - WRITE A SITE LABEL
C
      CALL LETTRS (4.85,3.75,0.10,STRING,0.0,20)
      CALL LETTRS (4.85,3.55,0.1,STR2,0.0,20)
      RETURN
      END
```

Table A-1. Input data description.[1]

Data Block	Variable Names	Format	Number of Cards
Initial compartment values	C(I)	12(F5.2)	1
Coefficient matrix	COEF(I,J)	13(F6.3)	12
Growth coefficient modification parameters[2]	A(I), RED(I,J)	13(F6.3)	12
Organic matter thresholds	(TO(I))	12(F6.3)	1
Shade thresholds	TS(I)	12(F6.3)	1
Time control parameters	DELT, TMAX, N, NSTEP	(F6.4, 5X, F8.3, 5X, 13, 5X, 14)	1
Compartment labels	LABEL(I,J)	5A4	12

[1]Listed in order of appearence in the deck.

[2]See equation 7.

Table A-2. Input data description, continued.

Data Block	Variable Names	Format	Number of Cards
Site slope	Slop	F4.2	1
Flood data	1YOF, TSF, TEF, DPTH, DUR	(I2, 4(5X,F4.1))	Varies
Simplotter parameters	XLAB(I), YLAB1(I) YLAB2(I), GLAB1(I) GLAB2(I)	20A4	2
Flood mark control	NFLDS	12	1
Data	FLDS(I)	20(F4.1)	1
Additional labels to be	STRING(I)	5A4	1
plotted on the graphs	STR2(I)	5A4	1

11.2 Statistical Analysis of Coralville Pool Elevations

Table A-3. Coralville Reservoir, maximum pool elevations.

Rank	Plotting Positions %	Plotting Positions T_r	Elevation	Year
1	5.3	19.0	711	1969
2	10.5	9.5	710	1973
3	15.8	6.3	709	1974
4	21.0	4.8	708	1965
5	26.3	3.8	707	1965
6	31.6	3.2	702	1962
7	36.8	2.7	701	1975
8	42.1	2.4	699	1969
9	47.4	2.1	698	1959
10	52.6	1.90	695	1972
11	57.9	1.73	695	1976
12	63.2	1.58	693	1970
13	68.4	1.46	691	1961
14	73.7	1.36	685	1964
15	79.0	1.27	685	1967
16	84.2	1.19	683	1963
17	89.5	1.12	683	1968
18	94.7	1.06	683	1971

$\bar{x} = 697$ $N = 18$

$S = 10.0$

$G = -0.03$

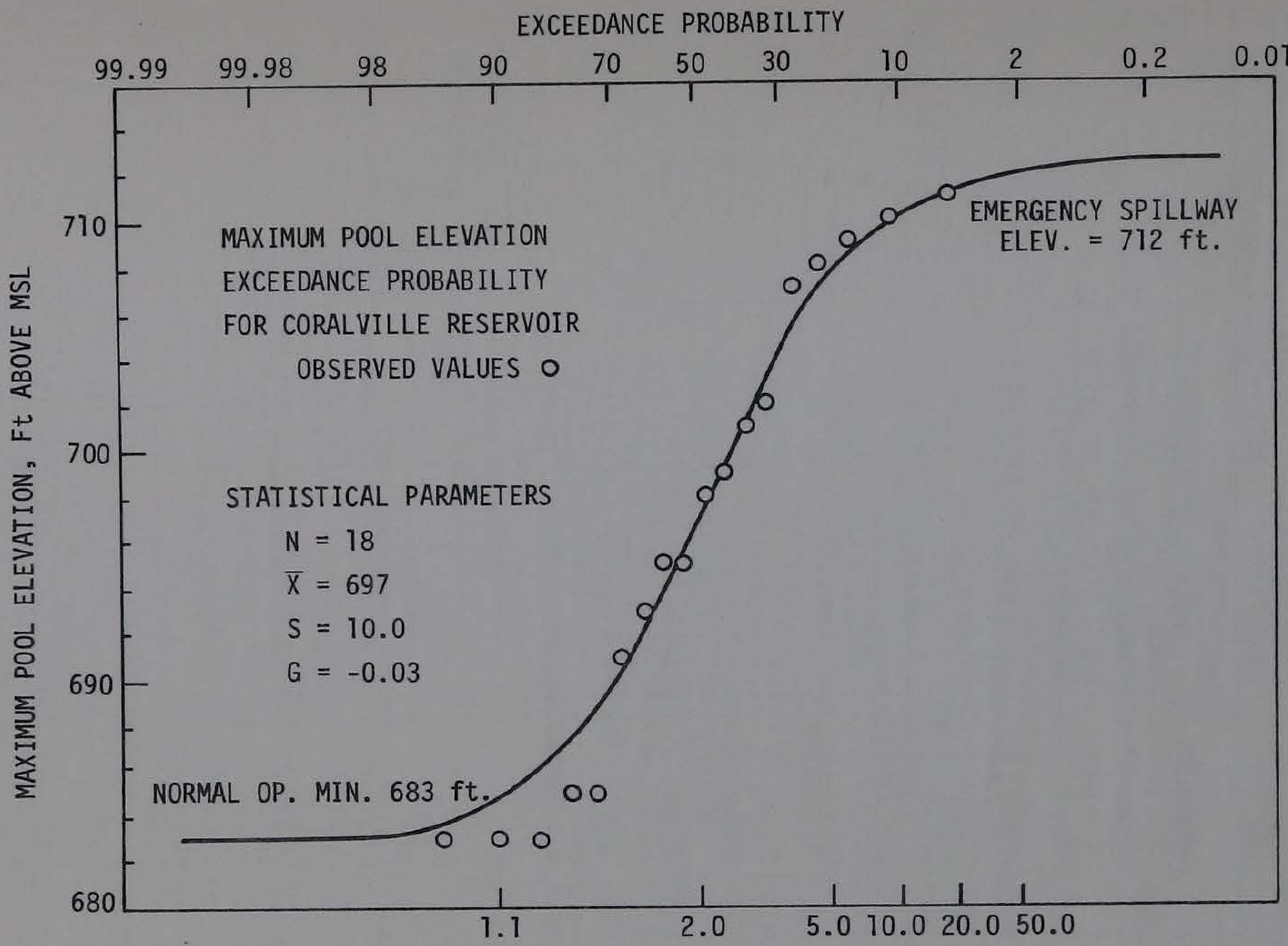

Fig. A-1. Elevation frequency curve for Coralville Reservoir.

11.3. Coralville Field Data

Braun - Blanquet Rating Symbols

Species Quantity

5 - Any number > 75% cover

4 - Any number 50-75% cover

3 - Any number 25-50% cover

2 - Any number 5-25% cover

1 - Numerous < 5% cover

+ - Few, small cover

r - Solitary, small cover

Stratum

T - Tree layer. Plants > 5 m

S - Shrub layer. Plants 50 m - 5 m

H - Herb layer. Plants < 30 m - 1 m

M - Moss and lichen layer. Plants < 10 m

Table A-4. Transect 1 elevation 698 msl.

Compartment	Species	Braun-Blanquet Rating
Annual	Gerardia tenuifolia	2 H
	Ambrosia artemisiifolia	1 H
	Erigeron annuus	1 H
	Cassia fasciculata	+ H
Biennial	Oenothera biennis	1 H
	Melilotus officinalis	+ H
Short-lived perennial	Aster pilosus	2 H
	Erigeron canadensis	2 H
	Solidago sp.	1 H-S
	Trifolium repens	r H
Long-lived perennial	Phalaris arundinacea	1 H
Water tolerant tree	Populus deltoides	1 S
	Salix sp.	1 H-S

Table A-5. Transect 4 elevation 698 msl.

Compartment	Species	Braun-Blanquet Rating
Annual	Cassia fasciculata	1-2 H
Forest herb	Anemone sp.	2 H
	Vitis riparia	1 H
Water tolerant tree	Acer saccharinum	5 S

Table A-6. Transect 5 elevation 698 msl.

Compartment	Species	Braun-Blanquet Rating
Annual	Gerardia tenuifolia	2 H
	Cassia fasciculata	1 H
Biennial	Oenothera biennis	+ H
Forest herb	Toxicodendron radicans	1 H
	Vitis riparia	1 H
	Lobelia puberula	r H
Water tolerant tree	Acer saccharinum	4-5 S-T
Young forest tree	Gleditsia triancanthos	2 S-T
	Ulmus rubra	2 H-S
Long-lived perennial	Unidentified grass	2 H

Table A-7. Transect 1 elevation 705 and 709 msl.

Compartment	Species	Braun-Blanquet Rating
Annual	Mentha longifolia	1 H
	Lactuca canadensis	+ H
Biennial	Oenothera biennis	+ H
	Rudbeckia hirta	+ H
Short-lived perennial	Aster pilosus	2 H
	Carex sp.	2 H
	Solidago sp.	2 H
	Asclepias sp.	+ H
Long-lived perennial[a]	Agrostis alba	3 H
	Bromus inermis	2 H
	Phlaris arundinacea	2 H
Young forest tree	Acer negundo	r S
	Fraxinus sp.	r S
	Gleditsia triacanthos	+ S
	Ulmus americana	+ S

[a]Long-lived perennials were present only in the upper portion of this zone.

Table A-8. Transect 5 elevation 705 msl.

Compartment	Species	Braun-Blanquet Rating
Annual	Erigeron annuus	1-2 H
	Ambrosia artemisiifolia	1 H
	Cassia fasciculata	1 H
Biennial	Oenothera biennis	+ H
Forest herb	Toxicodendron radicans	2-3 H
	Anemone sp.	1 H
	Lobelia puberula	r H
Young forest tree	Gleditsia triacanthos	2 S-T
	Fraxinus pennsylvanica	2 S-T
	Ulmus rubra	2 S-T
Mature forest tree	Quercus sp. (seedling)	+ H

Table A-9. Transect 6 elevation 705 msl.

Compartment	Species	Braun-Blanquet Rating
Annual	Ambrosia artimisifolia	1 H
Biennial	Verbascum thapsus	1 H
	Melilotus officinalis	+ H
Short-lived perennial	Aster pilosus	1 H
Forest herb	Toxicodendron radicans	2 H
	Anemone sp.	1 H
	Galium triflorum	1 H
	Vitis riparia	1 H
	Eupatorium serotinum	+ H
Young forest tree	Ulmus rubra	2 S-T
	Fraxinus pennsylvanica	1 S
Water tolerant tree	Acer saccharinum	1 S
Mature forest tree	Quercus alba	4 T

Table A-10. Transect 2 elevation 705 msl.

Compartment	Species	Braun-Blanquet Rating
Biennial	Melilotus officinalis	+ H
	Verbascum thapsus	+ H
Short-lived perennial	Asclepias verticillata	+ H
	Solidago sp.	r H
Forest herb	Menispermum canadense	2 H
	Toxicodendron radicans	2 H
	Vitis riparia	2 H
	Anemone sp.	1-2 H
	Oxalis sp.	+ H
	Urticia diocia	+ H
Young forest tree	Cornus sp.	1 S

Table A-11. Transect 5 elevation 709 msl.

Compartment	Species	Braun-Blanquet Rating[a]
Short-lived perennial	*Solidago* sp.	--
Long-lived perennial	*Bromus inermis*	--
Forest herb	*Toxicodendron radicans*	--
Young forest tree	*Fraxinus pennsylvanica*	--
	Gleditsia triacanthos	--
	Juglans nigra	--
	Rhus typhina	--
	Ulmus rubra	--
Mature forest tree	*Quercus* sp. (seedling)	--
	Carya sp. (seedling)	--

[a]Ratings were not recorded for this zone.

Table A-12. Transect 6 elevation 709 msl.

Compartment	Species	Braun-Blanquet Rating[a]
Short-lived perennial	Solidago sp.	--
Forest herbs	Toxicodendron radicans	--
	Parthenocissus quinquefolia	--
Young forest tree	Cornus sp.	--
	Fraxinus pennsylvanica	--
	Ulmus rubra	--
Mature forest tree	Quercus alba	(dominant)

[a]Ratings were not recorded for this zone.

11.4. Reservoir Optimization Model

Program Listing

```
$JOB     'GLANVILLE',TIME=80,PAGES=50
         DIMENSION INST(25),STORR(25,2),FSTAR(25,40),STORED(25,40),C(25,25)
         DIMENSION STATES(25),O(25,25),ELSTAT(25),IXSTAR(25,40)
         REAL INFLOW(40,2)
         INTEGER FINSTS(25),XXSTAR(25),ISTEP(41)
         DIMENSION OFLOW(25,40),OUTBAC(40)
         REAL IFRR(25,2)
         DIMENSION FLOW(40)
         INTEGER FINSTW(25)
         DIMENSION NNUM(10)
         INTEGER PENCOD
C
C
C*****STATES IS A VECTOR CONTAINING THE 25 DISCRETE STORAGE VOLUMES (AC-FT)
C        USED AS THE STATE VARIABLE IN THE DYNAMIC PROGRAMMING FORMULATION
C
C
         DATA STATES/865000.,832034.,799076.,766118.,733160.,700202.,667244
        *.,634286.,601328.,568370.,535412.,502454.,469496.,436538.,403580.,
        *370622.,337664.,304706.,271748.,238790.,205832.,172874.,139916.,10
        *6958.,74000./
C
C
C*****ELSTAT(X) IS THE ELEMENT OF ELSTAT THAT CONTAINS THE ELEVATION
C        (FT. ABOVE SEA LEVEL) OF THE WATER SURFACE IN SAYLORVILLE WHEN IT IS
C        IN STATE(X)
C
C
         DATA ELSTAT/898.80,897.45,896.05,894.58,893.06,891.46,889.78,888.0
        *2,886.17,884.21,882.14,879.93,877.57,875.04,872.31,869.35,866.12,8
        *62.55,858.91,855.39,851.35,847.87,844.31,839.78,833.58/
         NSTS=25
C
C
C*****NNUM(X) IS THE DURATION, IN WEEKS, OF EVENT NUMBER X
C
         NNUM(1)=20
         NNUM(2)=26
         NNUM(3)=24
         NNUM(4)=26
         NNUM(5)=12
         NNUM(6)=13
         NNUM(7)=9
         NNUM(8)=30
         NNUM(9)=27
         NNUM(10)=26
C
C        PENALTY CODE*****   PENCOD=NEGATIVE VALUE IMPLIES NO PENALTY
C                            PENCOD=0 IMPLIES STRAIGHT LINE SEMI-LOG PENALTY
C                            PENCOD= POSITIVE VALUE IMPLIES PENALTY IS FUNCTION OF
C                            LOWEST FEASIBLE FINAL STATE
         PENCOD=-1
         NUMDIM=40
         DO 600 IEVNT=9,9
         NOISTS=1
         NN=1
         N=1
         DO 5 MJ=2,25
       5 INST(MJ)=0
         INST(1)=25
         DO 7 NJ=1,2
         DO 6 MJ=1,25
       6 STORR(MJ,NJ)=0.0
       7 CONTINUE
         STORR(25,1)=90000.
         NUM=NNUM(IEVNT)
         NSTGS=NNUM(IEVNT)
         NSTEPS=NSTGS+1
         DO 12 J=1,2
         READ(5,11) (INFLOW(I,J),I=1,NUM)
```

```
   11 FORMAT(8(F10.0))
   12 CONTINUE
   60 CALL  STAGE(NN,N,INST,STATES,NOISTS,FSTAR,INFLOW,STORR,C,FINSTS,NOF
     *S,NSTGS,XXSTAR,NUM,0.650,NSTS,STORED,FINSTW,IFRR,IXSTAR,ELSTAT,OFL
     *OW,NUMDIM)
   39 DO 40 I=1,NSTS
   40 INST(I)=FINSTS(I)
      NOISTS=NOFS
      NN=NN+1
      N=N+1
      IF(NN .GT. NSTGS) GO TO 70
      GO TO 60
   70 CALL POLICY(IXSTAR,NSTS,NSTGS,FSTAR,FINSTS, ISTEP,NSTEPS,NOFS,UFLO
     *W,OUTBAC,BEST)
      WRITE(6,71)
   71 FORMAT('0',1X,'WEEK',5X,'INFLOW(CFS)',5X,'OUTFLOW(CFS)',5X,'BEST S
     *TATE',5X,'ELEVATION(FT)',5X,'INFLOW TO RED ROCK(CFS)',5X,'STORAGE
     *AT RED ROCK(AC-FT)')
      INDEX=NSTEPS
      DO 72 I=1,NSTGS
      FLOROC=OUTBAC(I)+INFLOW(I,2)
      INDEX=INDEX-1
      IELEV=ISTEP(INDEX)
   72 WRITE(6,73)I,INFLOW(I,1),OUTBAC(I),ISTEP(INDEX),ELSTAT(IELEV),FLOR
     *OC,STORED(IELEV,I)
   73 FORMAT(' ',1X,I3,9X,F6.C, 9X,F9.2,11X,I3,12X,F6.2,18X,F9.2,22X,F8.
     *0)
      DO 500 I=1,NUM
  500 FLOW(I)=INFLOW(I,1)
      VOL=0.0
      DO 501 I=1,NSTGS
  501 VOL=VOL+FLOW(I)*13.8843
      WRITE(6,502) IEVNT,VOL
  502 FORMAT('0',48X,'EVENT #',2X,I3,/' ',45X,'VOLUME (AC-FT)=',F10.0)
      WRITE(6,503) BEST
  503 FORMAT('0',45X,'POLICY COST ($) =',F10.0)
      IF(IEVNT .EQ. 1) GO TO 587
      IF(IEVNT .EQ. 2) GO TO 588
      IF(IEVNT .EQ. 3) GO TO 589
      IF(IEVNT .EQ. 4) GO TO 590
      IF(IEVNT .EQ. 5) GO TO 591
      IF(IEVNT .EQ. 6) GO TO 592
      IF(IEVNT .EQ. 7) GO TC 593
      IF(IEVNT .EQ. 8) GO TO 594
      IF(IEVNT .EQ. 9) GO TO 595
      WRITE(6,601)
  601 FORMAT('0',45X,'APRIL, 1969')
      GO TO 599
  587 WRITE(6,608)
  608 FORMAT('0',45X,'APRIL, 1944')
      GO TO 599
  588 WRITE(6,609)
  609 FORMAT('0',45X,'MARCH, 1945')
      GO TO 599
  589 WRITE(6,610)
  610 FORMAT('0',45X,'APRIL, 1947')
      GO TO 599
  590 WRITE(6,602)
  602 FORMAT('0',45X,'MARCH, 1951')
      GO TO 599
  591 WRITE(6,603)
  603 FORMAT('0',45X,'JUNE, 1954')
      GO TO 599
  592 WRITE(6,604)
  604 FORMAT('0',45X,'APRIL, 1960')
      GO TO 599
  593 WRITE(6,605)
  605 FORMAT('0',45X,'APRIL, 1961')
      GO TO 599
  594 WRITE(6,606)
```

```
      606 FORMAT('0',45X,'MAY, 1962')
          GO TO 599
      595 WRITE(6,607)
      607 FORMAT('0',45X,'APRIL, 1965')
      599 CONTINUE
          IF(PENCOD)1000,1001,1002
     1000 WRITE(6,1003)
     1003 FORMAT('0',45X,'NO PENALTY')
          GO TO  5990
     1001 WRITE(6,1004)
     1004 FORMAT('0',45X,'STRAIGHT LINE SEMI-LOG PENALTY')
          GO TO 5990
     1002 WRITE(6,1005)
     1005 FORMAT('0',45X,'PENALTY=FUNCTION OF LOWEST FEASIBLE FINAL STATE')
     5990 CALL PLOT(IEVNT,FLOW,OUTBAC,NSTGS)
      600 CONTINUE
       50 STOP
          END

          SUBROUTINE STAGE(NN,N,INST,STATES,NOISTS,FSTAR,INFLOW,STORR,C,FINS
         *TS,NOFS,NSTGS,XXSTAR,NUM,O,*,NSTS,STORED,FINSTW,IFRR,IXSTAR,ELSTAT
         *,OFLOW,NUMDIM)
C
C*****ARGUMENT LISTING*****  SUBROUTINE STAGE  **********************************
C
C
C       ***** NOTE ***** SUBROUTINE STAGE IS THE CONTROLLING SUBPROGRAM FOR THIS
C       DYNAMIC PROGRAMMING RESERVOIR OPERATION MODEL. GIVEN THE PROPER INPUT AS
C       LISTED IN THE ARGUMENT LISTING, SUBROUTINE STAGE WILL PERFORM ALL
C       NECESSARY OPERATIONS REQUIRED IN A SINGLE STAGE AND IS THE ONLY
C       SUBROUTINE THAT NEED BE CALLED BY THE MAIN PROGRAM.
C
C
C       XX-DESIGNATES OUTPUT NECESSARY TO CONSTRUCT THE OPTIMAL POLICY
C
C       *- DESIGNATES INPUT TO SUBROUTINE STAGE PROVIDED BY THE MAIN PROGRAM
C
C       **- DESIGNATES INPUT PROVIDED INITIALLY IN STAGE # 1 BY THE MAIN PROGRAM
C       AND IS SUBSEQUENTLY RE-EVALUATED INTERNALLY IN EACH STAGE TO PROVIDE NEW
C       INPUT FOR THE FOLLOWING STAGE
C
C       ***- DESIGNATES VALUES GENERATED AND USED INTERNALLY WHICH ARE MADE
C       AVAILABLE IN THE CALL LIST TO AID IN TESTING THE PROGRAM
C
C
C    * NN= STAGE NUMBER
C
C    * N= WEEK NUMBER (USED AS A SUBSCRIPT TO INDEX THE WEEKLY INFLOW DATA)
C
C   ** INST=VECTOR CONTAINING ALL INITIAL STATES FOR A GIVEN STAGE
C
C    * STATES=VECTOR CONTAINING THE DISCRETE STORAGE STATES (IN ACRE-FT.) THAT
C      SAYLORVILLE MAY OCCUPY
C
C   ** NOISTS= NUMBER OF INITIAL STATES (IE  STATES THAT MAY BE OCCUPIED AT
C      THE BEGINNING OF A GIVEN STAGE)
C
C   XX FSTAR(X,Y)= LEAST COST POSSIBLE IN TRAVERSING FROM STATE X IN STAGE
C      Y TO THE INITIAL STATE IN STAGE 1
C
C    * INFLOW(X,Y)= STREAM FLOW IN STAGE X AT  Y=1--STRATFORD, D.M. RIVER
C      Y=2  VAN METER, RACCOON RIVER
C
C   ** STORR(X)= TOTAL STORED WATER IN REDROCK RESERVOIR WHEN SAYLORVILLE
C      IS AT STATE X
C
C  *** C(X,Y) = COST OF TRAVERSING FROM STATE Y TO STATE X IN A GIVEN STAGE
C
C  *** FINSTS= VECTOR CONTAINING ALL POSSIBLE FINAL STATES FOR A GIVEN STAGE
C
```

```
C *** NOFS= NUMBER OF FINAL STATES
C
C   * NSTGS= NUMBER OF STAGES IN THE EVENT
C
C  XX XXSTAR(X,N)= INDICATES  THE  OPTIMAL STATE  TO  PROCEED TO WHEN AT
C       STATE X IN STAGE N  (WHEN PROCEEDING BACKWARDS IN TIME FROM STAGE N
C
C   * NUM= NUMBER OF WEEKS OF INFOW IN THE STREAMFLOW INPUT ARRAY
C
C *** O(X,Y)= THE OUTFLOW NECESSARY FROM SAYLORVILLE RESERVOIR IN ORDER TO
C       TO TRAVERSE FROM STATE Y TO STATE X
C
C
      DIMENSION STORR(NSTS,2),O(NSTS,NSTS),STORED(NSTS,NSTGS)
      DIMENSION OFLOW(NSTS,NSTGS)
      DIMENSION INST(NSTS),STATES(NSTS),FSTAR(NSTS,NSTGS)
      DIMENSION C(NSTS,NSTS)
      REAL IFRR(NSTS,2)
      INTEGER FINSTW(NSTS),FINSTS(NSTS),XXSTAR(NSTS)
      DIMENSION IXSTAR(NSTS,NSTGS)
      REAL INFLOW(NUMDIM,2)
      DIMENSION ELSTAT(NSTS)
C
C     SET FINAL STATES AND OUTFLOW ARRAYS TO ZERO
C
      DO 100 JJ=1,NSTS
  100 FINSTS(JJ)=0
      DO 200 KK=1,NSTS
      DO 300 LL=1,NSTS
      O(KK,LL)=0.0
C
C     INITIALIZE ALL ELEMENTS OF COST ARRAY TO 1.0E70
C
  300 C(LL,KK)=1.0E70
  200 CONTINUE
      LL=0
      NOFS=0
      L=1
   60 CONTINUE
      CALL ELEVV(L,ELEV,STORAG,INST,STATES,NSTS)
      PERS=((STORAG - 74000.)/791000.) *100.
      LEVEL=INST(L)
      PERR=((STORR(LEVEL,1)-90000.)/1740000.)*100.
      CALL FEAST(LL,N,INFLOW,STATES,PERR,PERS,ELEV,STORAG,FINSTS,FINSTW,
     *NOFS,O,K,OMAX,OMIN,FMAX,FMIN,NN,L,NUM,INST,&51,NSTS,ELSTAT,NUMDIM,
     *NOISTS)
      CALL COSTS(L,NN,N,K,O,LL,FSTAR,C,NSTGS,INFLOW,NUM,INST,NSTS,NUMDIM
     *,ELSTAT)
      IF(L .EQ. NOISTS) GO TO 50
      L=L+1
      GO TO 60
   50 CONTINUE
      CALL PICOPT(NSTGS,N,NOFS,FINSTS,C,FSTAR,XXSTAR,NN,NSTS,IXSTAR,OFLO
     *W,O)
      CALL REDROC(N,NN,NOFS,FINSTS,O,XXSTAR,STORR,NSTGS,INFLOW,NUM,NSTS,
     *STORED,IFRR,NUMDIM)
      RETURN
   51 RETURN1
      END

      SUBROUTINE ELEVV(L,ELEV,STORAG,INST,STATES,NSTS)
      DIMENSION STATES(NSTS)
      INTEGER INST(NSTS)
      LEVEL=INST(L)
      STORAG=STATES(LEVEL)
      IF(STORAG .LE. 196000.) GO TO 10
      IF (STORAG .GT. 196000. .AND. STORAG .LE. 283000.) GO TO 20
      IF(STORAG .GT. 283000.) GO TO 30
   10 ELEV=(ALOG10(STORAG)-4.519)/0.02579 +820.
      RETURN
```

```
      20 ELEV=(ALOG10(STORAG)-5.292)/0.01595 +850.
         RETURN
      30 ELEV=(ALOG10(STORAG) -5.452)/0.01250 +860.
         RETURN
         END

         SUBROUTINE FEAST(LL,N,INFLOW,STATES,PERR,PERS,ELEV,STORAG,FINSTS,F
        *INSTW,NOFS,O,K,OMAX,OMIN,FMAX,FMIN,NN,L,NUM,INST,*,NSTS,ELSTAT,NUM
        *DIM,NOISTS)
C
C
C        SUBROUTINE FEAST ACCEPTS AN INITIAL STATE AND LOCATES ALL FEASIBLE FINAL
C        STATES FOR THE INITIAL STATE. SUBROUTINE FEAST ALSO DETERMINES THE
C        OUTFLOWS FROM SAYLORVILLE THAT ARE NECESSARY TO TRAVERSE FROM THE INITIAL
C        STATE TO ITS FEASIBLE FINAL STATES. SUBROUTINE STAGE CALLS SUBROUTINE
C        FEAST ONCE FOR EACH INITIAL STATE IN THE STAGE AND THE OUTFLOWS ARE
C        STORED FOR LATER USE BY SUBROUTINE COSTS IN AN ARRAY O(X,Y), WHICH GIVES
C        THE OUTFLOWS REQUIRED TO TRAVERSE FROM INITIAL STATE Y TO FINAL STATE X.
C
C
         DIMENSION STATES(NSTS),O(NSTS,NSTS),INST(NSTS)
         INTEGER FINSTS(NSTS),FINSTW(NSTS)
         REAL INFLOW(NUMDIM,2)
         DIMENSION ELSTAT(NSTS)
         DO 200 JJ=1,NSTS
     200 FINSTW(JJ)=0.0
         NSTOP=NSTS+1
         SMAX=865000.
         SMIN=74000.
         EL=ELEV
         ELPLUS= EL -7. +0.1
         ELMNUS=EL-0.1
         IFLAG=0
         LL=0
         IF(NN .EQ. 1 ) GO TO 10
         DIFFLO=INFLOW(N,1)-INFLOW(N-1,1)
         PERCNT=(DIFFLO/INFLOW(N-1,1))*100.
         IF(PERCNT .GE. 20.) GO TO 10
      12 ELEV7=ELEV-7.
         ELOWER =ELEV7
         EUPPER=ELEV
         ITRIAL=1
C
C
C*****CONSTRAINT*** ON THE FALLING SIDE OF THE HYDROGRAPH THE MAXIMUM OUTFLOW
C        IS LIMITED SO THAT THE WATER SURFACE WILL DROP NO MORE THAN 1 FT. PER DAY
C        ( 7 FT./WEEK). THIS IS DONE TO REDUCE BANK SLOUGHING ALONG THE EDGE OF THE
C        FLOOD POOL.
C
C
C*****CHECK TO SEE IF A 7 FT. DROP IN THE WATER SURFACE, IN ONE WEEK, EXCEEDS
C        THE RESERVOIR RATING CURVE.
C
C
C*****IF THE RATING CURVE IS EXCEEDED, SEARCH ITERATIVELY TO FIND THE AMOUNT
C        OF DROP THAT IS ACCEPTABLE.
C
C
      19 IF(ELEV7 .LT. 833.0) GO TO 23
         IF(ELEV7 .LE. 850.) GO TO 20
         IF(ELEV7 .GT. 850.  .AND. ELEV7 .LE. 860.) GO TO 21
         IF(ELEV7 .GT. 860.) GO TO 22
      20 STOR7=10**(0.02579*(ELEV7-820.)+4.519)
         GO TO 30
      21 STOR7=10**(0.01595*(ELEV7-850.) +5.292)
         GO TO 30
      22 STOR7=10**(0.01250*(ELEV7-860.)+5.452)
         GO TO 30
      23 ELEV7=833.58
         STOR7=STATES(NSTS)
```

```
   30 OMAX=((STORAG-STOR7)*43560.)/604800. + INFLOW(N,1)
      IF(INST(L) .EQ. NSTS) GO TO 32
      ELMID=(EL + ELEV7)/2.
      ELEV=ELMID
      GO TO 34
   32 ELEV=ELSTAT(NSTS)
   34 IF(ELEV .GE. 833. .AND. ELEV .LT. 860.) GO TO 1
      IF(ELEV .GE. 860. .AND. ELEV .LT. 884.) GO TO 2
      IF(ELEV .GE. 884. .AND. ELEV .LT. 896.) GO TO 3
      IF(ELEV .GE. 896. .AND. ELEV .LE. 900.) GO TO 4
    1 FLOMAX=214.81*(ELEV -833.) +11800.
      GO TO 31
    2 FLOMAX=141.67*(ELEV-860.) +17600.
      GO TO 31
    3 FLOMAX=10**(0.05060*(ELEV-884.)+4.32222)
      GO TO 31
    4 FLOMAX=10**(0.03923*(ELEV-896.)+4.92942)
   31 DIFFX=OMAX-FLOMAX
      IF(DIFFX .GE. -50. .AND. DIFFX .LE. 50.) GO TO 35
      IF(DIFFX)33,37,37
   33 IF(ITRIAL .EQ. 1) GO TO 35
      EUPPER=ELEV7
      ELEV7=(EUPPER+ELOWER)/2.
      IF(ELEV7 .LE. ELPLUS) GO TO 35
      ITRIAL=ITRIAL+1
      GO TO 19
   37 ELOWER=ELEV7
      ELEV7=(ELOWER+EUPPER)/2.
      IF(ELEV7 .GE. ELMNUS) GO TO 38
      ITRIAL=ITRIAL+1
      GO TO 19
   10 CONTINUE
C
C
C*****CONSTRAINT*** ON THE RISING SIDE OF THE HYDROGRAPH THE MAXIMUM OUTFLOW
C     IS LIMITED TO THE INFLOW.
C
C
C*****NO COSTS ARE INCURRED AT OUTFLOWS LESS THAN 11500 CFS MAKING IT ACCEPTABLE
C     TO RELAX THE CONSTRAINT THAT LIMITS THE MAXIMUM OUTFLOW TO THE INFLOW.
C     IN THIS CASE, THE SITUATION WILL BE HANDLED AS IF ON THE FALLING SIDE
C     OF THE HYDROGRAPH.
      IF(INFLOW(N,1) .GE. 11500.) GO TO 11
      GO TO 12
   11 OMAX=INFLOW(N,1)
      IFLAG=1
      FMIN=STORAG
      GO TO 36
   38 OMAX=FLOMAX
   35 FMIN= STORAG+ (INFLOW(N,1) - OMAX)*13.8843
      IF (FMIN .LT. SMIN)  FMIN=SMIN
      IF(FMIN .GT. SMAX) FMIN=SMAX
   36 IF(EL .LT. 870.) GO TO 40
      DIF= PERS-PERR
      IF (DIF .LE. 15.) GO TO 40
      IF(INFLOW(N,1) .LT. 16000.) GO TO 39
      OMIN=16000
      FLODIF=INFLOW(N,1) - OMIN
      IF(FLODIF .GT. 2375.) GO TO 45
      OMIN=INFLOW(N,1) -2375.
      GO TO 45
   39 OMIN=INFLOW(N,1)
      GO TO 45
   40 IF(IFLAG .EQ. 0) GO TO 43
      IF(INFLOW(N,1) .LT. 8000.) GO TO 44
      OMIN=8000.
      FLODIF= INFLOW(N,1) -OMIN
      IF(FLODIF .GT. 2375.) GO TO 45
      OMIN=INFLOW(N,1)-2375.
```

```
      GO TO 45
   43 IF(OMAX - INFLOW(N,1) - 2376.) 46,44,44
   44 OMIN=INFLOW(N,1)
      GO TO 45
   46 OMIN=OMAX-2376.
   45 FMAX=STORAG +((INFLOW(N,1) - OMIN)*604800.)/43560.
      IF(FMAX .GT. SMAX) FMAX=SMAX
      IF(FMAX .LT. SMIN) FMAX=SMIN
      K=0
      J=1
   80 IF(STATES(J) .LE. FMAX .AND. STATES(J) .GE. FMIN) GO TO 50
      IF(K .GE. 1) GO TO 70
      GO TO 60
   50 M=INST(L)
      O(J,M)=INFLOW(N,1)+(STORAG-STATES(J))*0.07202
      ELMID=(ELSTAT(J)+ELSTAT(M))/2.
      ELEV=ELMID
      IF(ELEV .GE. 833. .AND. ELEV .LT. 860.) GO TO 51
      IF(ELEV .GE. 860. .AND. ELEV .LT. 884.) GO TO 52
      IF(ELEV .GE. 884. .AND. ELEV .LT. 896.) GO TO 53
      IF(ELEV .GE. 896. .AND. ELEV .LE. 900.) GO TO 54
   51 FLOMAX=214.81*(ELEV -833.) +11800.
      GO TO 57
   52 FLOMAX=141.67*(ELEV-860.) +17600.
      GO TO 57
   53 FLOMAX=10**(0.05060*(ELEV-884.)+4.32222)
      GO TO 57
   54 FLOMAX=10**(0.03923*(ELEV-896.)+4.92942)
   57 IF(O(J,M) .GT. FLOMAX) GO TO 59
      K=K+1
      LL=J
      FINSTW(K)=J
      IF(NOFS .EQ. 0) GO TO 58
      IF(J .LE. FINSTS(NOFS)) GO TO 60
   58 NOFS=NOFS+1
      FINSTS(NOFS)=J
       GO TO 60
   59 CONTINUE
      O(J,M)=0.0
      GO TO 70
   60 J=J+1
      IF(J .EQ. NSTOP) GO TO 70
      GO TO 80
   70 IF(K .EQ. 0) GO TO 101
      GO TO 90
  101 WRITE(6,102) NN,INST(L)
  102 FORMAT('0',10X,'NO FINAL STATES FEASIBLE IN STAGE',I3,2X,'FOR INIT
     *IAL STATE LEVEL #',I3)
      K=100
      IF(L .EQ. NOISTS .AND. NOFS .EQ. 0) GO TO 5000
      GO TO 90
 5000 WRITE(6,103) NN
  103 FORMAT('0',10X,'NO FEASIBLE FINAL STATES FOR ANY INITIAL STATE OF
     *STAGE #',I4)
      RETURN1
   90 RETURN
      END

      SUBROUTINE COSTS(L,NN,N,K,O,LL,FSTAR,C,NSTGS,INFLOW,NUM,INST,NSTS,
     *NUMDIM,ELSTAT)
C
C
C     SUBROUTINE COSTS ACCEPTS THE ARRAY O(X,Y) SUPPLIED BY SUBROUTINE FEAST
C     AND INFLOW(N,2), WHICH IS FLOW ON THE RACCOON RIVER, AND CALCULATES THE
C     TOTAL COSTS ACCUMULATED IN TRAVERSING FROM STAGE # 1 TO THE PRESENT
C     STATE IN THE PRESENT STAGE. COSTS ARE STORED FOR SUBSEQUENT USE IN AN
C     ARRAY C(X,Y) WHICH REPRESENTS THE TOTAL COST OF TRAVERSING FROM STATE X
C     IN THE PRESENT STAGE THROUGH STATE Y IN THE PREVIOUS STAGE BACK TO STAGE
C     # 1
C
```

```
C
      DIMENSION O(NSTS,NSTS),FSTAR(NSTS,NSTGS),INST(NSTS)
      DIMENSION C(NSTS,NSTS)
      REAL INFLOW(NUMDIM,2)
      DIMENSION ELSTAT(NSTS)
      IF(K .EQ. 100) GO TO 10
      LJ=LL
      M=INST(L)
      KOUNT=0
   20 CONTINUE
      IF(O(LJ,M) .LT. 11500.) GO TO 30
      IF(O(LJ,M) .GE. 11500. .AND. O(LJ,M) .LT. 32700.) GO TO 40
      IF(O(LJ,M).GE. 32700. .AND. O(LJ,M) .LT. 58200.) GO TO 50
      IF(O(LJ,M) .GE. 58200. .AND. O(LJ,M) .LE. 91600.) GO TO 60
   30 C1=0.
      GO TO 70
   40 C1=(O(LJ,M) -11500.)*9.906
      GO TO 70
   50 C1=(O(LJ,M)-32700.)*344.627+1300000.
      GO TO 70
   60 C1=(O(LJ,M)-58200.)*287.635+ 1C088000.
   70 O2=O(LJ,M) + INFLOW(N,2)
      IF(O2 .LT. 25200.) GO TO 80
      IF(O2 .GE. 25200. .AND. O2 .LT. 58000.) GO TO 90
      IF(O2 .GE. 58000. .AND. O2  .LT. 84500.) GO TO 100
      IF(O2  .GE. 84500. .AND. O2  .LE. 100000.) GO TO 110
   80 C2=0.
      GO TO 120
   90 C2=(O2-25200.) *0.762
      GO TO 120
  100 C2=(O2-58000.) *34.718 + 380000.
      GO TO 120
  110 C2=(O2-84500.) * 23.871 + 2460000.
  120 IF(NN .EQ. 1) GO TO 130
      C(LJ,M)=C1+C2+FSTAR(L,NN-1)
      GO TO 140
  130 C(LJ,M)=C1+C2
  140 CONTINUE
  141 KOUNT=KOUNT+1
      IF (KOUNT .EQ. K) GO TO 10
      LJ=LJ-1
      GO TO 20
   10 RETURN
      END

      SUBROUTINE PICOPT(NSTGS,N,NOFS,FINSTS,C,FSTAR,XXSTAR,NN,NSTS,IXSTA
     *R,OFLOW,O)
C
C
C     SUBROUTINE PICOPT ACCEPTS THE ARRAY C(X,Y) FROM SUBROUTINE COSTS AND
C     SEARCHES EACH ROW TO FIND THE COLUMN CCNTAINING THE MINIMUM (OPTIMUM)
C     COST. PICOPT RETURNS XXSTAR(X,NN) AND FSTAR(X,NN) WHICH IS INFORMATION
C     NECESSARY TO CONSTRUCT THE OPTIMAL POLICY FOR AN EVENT.  FSTAR(X,NN)
C     CONTAINS THE MINIMUM (OPTIMAL) COST POSSIBLE IN TRAVERSING FROM THE
C     INITIAL STATE AT THE BEGINNING OF THE EVENT TO STATE X IN STAGE # NN.
C     XXSTAR(X,NN) TELLS WHICH STATE IN STAGE # (NN-1) WAS PASSED THROUGH IN
C     OBTAINING THE MINIMUM COST FOR STATE X IN STAGE # NN.
C
C
      DIMENSION O(NSTS,NSTS)
      DIMENSION OFLOW(NSTS,NSTGS)
      INTEGER XXSTAR(NSTS),FINSTS(NSTS)
      DIMENSICN IXSTAR(NSTS,NSTGS)
      DIMENSION FSTAR(NSTS,NSTGS)
      DIMENSION C(NSTS,NSTS)
      NSTOP=NSTS-1
      J=1
      LL=FINSTS(J)
   70 L=1
      FSTAR(J,NN)=C(LL,1)
```

```
      XXSTAR(J)=L
      IXSTAR(LL,NN)=L
      OFLOW(LL,NN)=O(LL,L)
   40 IF(FSTAR(J,NN)-(C(LL,L+1)+1.))25,30,30
   25 IF(FSTAR(J,NN)-(C(LL,L+1)-1.))10,10,30
   30 FSTAR(J,NN)=C(LL,L+1)
      XXSTAR(J)=L+1
      IXSTAR(LL,NN)=L+1
      OFLOW(LL,NN)=O(LL,L+1)
   10 L=L+1
      IF(L .GT. NSTOP) GO TO 50
      GO TO 40
   50 LL=LL+1
      J=J+1
      IF(LL .GT. FINSTS(NOFS)) GO TO 90
      GO TO 70
   90 RETURN
      END

      SUBROUTINE REDROC(N,NN,NOFS,FINSTS,O,XXSTAR,STORR,NSTGS,INFLOW,NUM
     *,NSTS,STORED,IFRR,NUMDIM)
C
C
C     SUBROUTINE REDROC MODELS THE OPERATION OF RED ROCK RESERVOIR. OPERATION
C     OF THE MODEL APPROXIMATES A PORTION OF THE OPERATING SCHEDULE DEVELOPED
C     BY THE CORPS OF ENGINEERS. SUBROUTINE REDROC RETURNS THE TOTAL STORAGE
C     IN RED ROCK RESERVOIR IN A VECTOR STORR(X,NN) WHICH IS INTERPRETED AS
C     THE STORAGE (AC-FT) IN RED ROCK AT THE END OF STAGE NN IF SAYLORVILLE
C     GOES TO STATE X IN THE SAME STAGE.
C
C
      REAL INFLOW(NUMDIM,2)
      REAL IFRR(NSTS,2)
      DIMENSION STORR(NSTS,2),O(NSTS,NSTS),STORED(NSTS,NSTGS)
      INTEGER FINSTS(NSTS),XXSTAR(NSTS),X,Y
C
C     SUM OUTFLOW FROM SAYLORVILLE + RACCOON RIVER TO FIND INFLOW TO RED ROCK
C
      DO 9 I=1,NSTS
    9 STORR(I,2)=0.0
      LL=1
   10 X=FINSTS(LL)
      Y=XXSTAR(LL)
      IFRR(X,2)=O(X,Y) + INFLOW(N,2)
      LL=LL+1
      IF(LL .GT. NOFS) GO TC 20
      GO TO 10
   20 LL=1
   30 X=FINSTS(LL)
      Y=XXSTAR(LL)
C
C     STORR(Y,1)= TOTAL STORAGE IN RED ROCK WHEN SAYLORVILLE IS AT STATE Y
C
      IF(STORR(Y,1).GE.89900..AND. STORR(Y,1) .LT. 290000.)GO TO 40
      IF(STORR(Y,1).GE.290000..AND. STORR(Y,1) .LT.820000 .) GO TO 50
      IF(STORR(Y,1).GF.820000..AND. STORR(Y,1) .LE. 2630000.) GO TO 60
C
C     STATEMENTS 40,50 AND 60 CONVERT TOTAL STORAGE (AC-FT) TO ELEVATION (FT)
C
   40 RELEV=((ALOG10(STORR(Y,1))-4.95424)/0.03388)+725.
      GO TO 70
   50 RELEV=((ALOG10(STORR(Y,1))-5.46240)/0.02257)+740.
      GO TO 70
   60 RELEV=((ALOG10(STORR(Y,1))-5.91381)/0.01687)+760.
   70 CONTINUE
      IF(RELEV .GE. 775) GO TO 80
      IF(NN .EQ. 1) GO TO 90
      GO TO 100
   80 IF(RELEV .GE. 775. .AND. RELEV .LT. 779.8) GO TO 110
      IF(RELEV .GE. 779.8 .AND. RELEV .LE. 782.) GO TO 120
```

```
      IF(RELEV .GT. 782.) GO TO 130
  110 OUT=5000.*(RELEV-775.) + 30000.
      GO TO 139
  120 OUT=34545.4546*(RELEV-779.8)+54000.
      GO TO 139
  130 OUT=130000.
      GO TO 139
   90 IF (IFRR(X,2) .LT. 18000) GO TO 150
      OUT=18000.
      GO TO 140
  150 OUT=IFRR(X,2)
      STORR(LL,2)=STORR(Y,1)
      LL=LL+1
      IF(LL .GT. NOFS) GO TO 220
      GO TO 30
  100 IF(IFRR(X,2) .GT. IFRR(Y,1)) GO TO 90
      RELEV7=RELEV-7.
      IF(RELEV7 .LT. 725.) GO TO 169
      IF(RELEV7 .GE. 725. .AND. RELEV7 .LT. 740.) GO TO 170
      IF(RELEV7 .GE. 740. .AND. RELEV7 .LT. 760.) GO TO 180
      IF(RELEV7 .GE. 760. .AND. RELEV7 .LE. 790.)GO TO 190
  169 RELEV7=725.
  170 STORR7=10**(0.03388*(RELEV7-725.) +4.95424)
      GO TO 200
  180 STORR7=10**(0.02257 *(RELEV7-740.)+ 5.46240)
      GO TO 200
  190 STORR7=10**(0.01687*(RELEV7-760.)+5.91381)
  200 OUT7=(((STORR(Y,1)-STORR7)*43560.)/604800.) + IFRR(X,2)
      IF(OUT7 .GT. 18000.) GO TO 210
      OUT=OUT7
      GO TO 140
  210 OUT=18000.
      GO TO 140
  139 CONTINUE
  140 CONTINUE
      STORR(LL,2)=STORR(Y,1)+((IFRR(X,2)-OUT)*604800.)/43560.
      IF(STORR(LL,2).GT.1783200. .AND.STORR(LL,2) .LT.2630000.) GO TO 26
     *0
      GO TO 271
  260 WRITE(6,250) Y,X,NN
  250 FORMAT('0',10X,'***** REDROCK EXCEEDS ELEVATION 780  IF SAYLORVILL
     *E GOES FROM STATE # ',I2,1X,'TO STATE #',I2,1X,'IN STAGE # ',I3)
      GO TO 270
  271 IF(STORR(LL,2) .GT. 2630000.) GO TO 201
      GO TO 270
  201 WRITE(6,202) X,NN
  202 FORMAT('0',10X,'RED ROCK EXCEEDS ELEV. 790 IF SAYLORVILLE GOES TO
     *STATE#',I2,1X,'IN STAGE #',I3,2X,'THE ELEVATION AT RED'//' ',10X,'
     *ROCK HAS BEEN ARTIFICIALLY RESET TO 775 SO THAT PROGRAM OPERATION
     *MAY CONTINUE')
      STORR(LL,2)=1468000.
  270 LL=LL+1
      IF(LL .GT. NOFS) GO  TO 220
      GO TO 30
  220 J=1
  240 K=FINSTS(J)
      IFRR(K,1)=IFRR(K,2)
      J=J+1
      IF(J .GT. NOFS) GO TO 230
      GO TO 240
  230 DO 300 I=1,NSTS
      IF(I .GT. NOFS) RETURN
      NJ=FINSTS(I)
      STORR(NJ,1)=STORR(I,2)
      STORED(NJ,NN)=STORR(I,2)
  300 CONTINUE
      RETURN
      END

      SUBROUTINE POLICY(IXSTAR,NSTS,NSTGS,FSTAR,FINSTS,ISTEP,NSTEPS,NOFS
     *,OFLOW,OUTBAC,BEST)
```

```
C
C
C     SUBROUTINE POLICY RECONSTRUCTS THE TOTAL OPTIMAL POLICY. POLICY SEARCHES
C     THE COLUMN OF THE FSTAR MATRIX THAT CONTAINS THE FSTAR VALUES FOR THE
C     FINAL STAGE OF THE PROBLEM. IT LOCATES THE STATE IN THE LAST STAGE THAT
C     HAS THE LOWEST TOTAL POLICY COST. THE OPTIMAL POLICY IS RECONSTRUCTED
C     FROM THIS POINT BY USING THE INFORMATION IN THE IXSTAR MATRIX. THE
C     OPTIMAL STATE TO BE IN AT THE END OF STAGE N WILL BE STORED IN ISTEP
C     (NSTGS + 1 - N). THE OPTIMAL OUTFLOW FROM SAYLORVILLE IN STAGE N WILL BE
C     STORED IN OUTBAC(N).
C
C
C
      DIMENSION OFLOW(NSTS,NSTGS),OUTBAC(NSTGS)
      DIMENSION FSTAR(NSTS,NSTGS)
      INTEGER IXSTAR(NSTS,NSTGS),FINSTS(NSTS),ISTEP(NSTEPS)
      L=1
      BEST=FSTAR(L,NSTGS)
      NUM=1
   30 IF(BEST .LT.FSTAR(L+1,NSTGS))GO TO 10
      IF(BEST .EQ. FSTAR(L+1,NSTGS)) GO TO 20
      GO TO 40
   10 L=L+1
      IF(L .EQ.NOFS) GO TO 50
      GO TO 30
   20 NUM=NUM+1
      GO TO 10
   40 BEST=FSTAR(L+1,NSTGS)
      NUM=NUM+1
      GO TO 10
   50 LAST=FINSTS(NUM)
      ISTEP(1)=LAST
      KOUNT=NSTGS+1
      DO 100 I=1,NSTGS
      KOUNT=KOUNT-1
      J=I+1
      K=ISTEP(I)
      OUTBAC(KOUNT)=OFLOW(K,KOUNT)
  100 ISTEP(J)=IXSTAR(K,KOUNT)
      RETURN
      END

      SUBROUTINE PLOT(NU,XFLO,OFLO,NOBS)
      DIMENSION JOUT(101),XFLO(NOBS),OFLO(NOBS),KOUT(101)
      DATA K/1H*/,NOTH/1H /,IHEAD/1H+/,IX/1HX/,KK/1HO/
      WRITE(6,4) NU
    4 FORMAT('1',48X,'EVENT # ',I3)
      DO 12 I=1,101
   12 JOUT(I)=IHEAD
      WRITE(6,100)
  100 FORMAT('0',47X,'FLOW(CFS)'/'0',35X,'EACH * INDICATES 700  CFS (INF
     *LOW)'/' ',35X,'EACH O INDICATES 700 CFS (OUTFLOW)'/' ',35X,'* OR O
     * IN ''WEEK'' AXIS INDICATES FLOW LESS THAN 700 CFS')
      WRITE(6,8) (JOUT(I),I=1,101)
    8 FORMAT('0','WEEK',1X,101(A1),1X,'INFLOW',5X,'OUTFLOW')
      DO 80 J=1,NOBS
      DO 50 I=1,101
      JOUT(I)=NOTH
   50 KOUT(I)=NOTH
      JOUT(1)=IHEAD
      NUM1=(XFLO(J)/700 )+1
      IF(NUM1.EQ. 1) GO TO 41
      DO 200 II=2,NUM1
  200 JOUT(II)=K
      WRITE(6,9) J,(JOUT(L),L=1,101),XFLO(J),OFLO(J)
    9 FORMAT('0',I3,2X,101(A1),1X,F7.0,4X,F7.0)
   44 NUM2=(OFLO(J)/700 )+1
      IF(NUM2 .EQ. 1) GO TO 45
      KOUT(1)=IHEAD
      DO 201 II=2,NUM2
```

```
  201 KOUT(II)=KK
      WRITE(6,10) (KOUT(L),L=1,101)
   10 FORMAT(' ',5X,101(A1))
      GO TO 80
   41 JOUT(1)=K
      WRITE(6,9)J,(JCUT(L),L=1,101),XFLO(J),OFLO(J)
      GO TO 44
   45 KOUT(1)=KK
      WRITE(6,10) (KOUT(L),L=1,101)
   80 CONTINUE
      WRITE(6,1000)
 1000 FORMAT('1','       ')
      RETURN
      END

$ENTRY
```

WEEK	INFLOW(CFS)	OUTFLOW(CFS)	BEST STATE	ELEVATION(FT)	INFLOW TO RED ROCK(CFS)	STORAGE AT RED ROCK(AC-FT)
1	4006.	4006.00	25	833.58	7527.00	90000.
2	1669.	1669.00	25	833.58	5255.00	89999.
3	2060.	2060.00	25	833.58	8631.00	89999.
4	749.	749.00	25	833.58	2212.00	89999.
5	14944.	10196.73	23	844.31	23367.73	164527.
6	43157.	9926.11	9	886.17	23903.11	246487.
7	20914.	16166.73	7	889.78	20496.73	281152.
8	10513.	10513.00	7	889.78	12960.00	211176.
9	7914.	10287.63	8	888.02	12630.63	136626.
10	5699.	10446.27	10	884.21	11769.27	89999.
11	5780.	10527.27	12	879.93	11808.27	89999.
12	5871.	10618.27	14	875.04	12227.27	89999.
13	10554.	10554.00	14	875.04	17251.00	89999.
14	10461.	10461.00	14	875.04	13968.00	89999.
15	6639.	11386.27	16	869.35	14236.27	89999.
16	3583.	8330.27	18	862.55	9529.27	89999.
17	2631.	5004.63	19	858.91	6240.63	89999.
18	2019.	4392.63	20	855.39	5640.63	89999.
19	1521.	3894.63	21	851.35	4462.63	89999.
20	1237.	3610.63	22	847.87	4006.63	89999.
21	752.	3125.63	23	844.31	3424.63	89999.
22	499.	2872.63	24	839.78	3086.63	89999.
23	432.	2805.63	25	833.58	2995.63	89999.
24	354.	354.00	25	833.58	512.00	89999.
25	292.	292.00	25	833.58	437.00	89999.
26	300.	300.00	25	833.58	457.00	89999.
27	364.	364.00	25	833.58	583.00	89999.

EVENT # 9
VOLUME (AC-FT)= 2289705.

POLICY COST ($) = 46229.

APRIL, 1965

NC PENALTY

```
                                   EVENT #   9

                                   FLOW(CFS)

                          EACH * INDICATES 700  CFS (INFLOW)
                          EACH O INDICATES 700 CFS (OUTFLOW)
                          * OR O IN 'WEEK' AXIS INDICATES FLOW LESS THAN 700 CFS

WEEK ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++INFLOW    OUTFLOW

  1  +*****                                                               4006.     4006.
     +00000

  2  +**                                                                  1669.     1669.
     +00

  3  +**                                                                  2060.     2060.
     +00

  4  +*                                                                    749.      749.
     +0

  5  +*********************                                              14944.    10197.
     +00000000000000

  6  +*************************************************************      43157.     9926.
     +00000000000000

  7  +*****************************                                      20914.    16167.
     +00000000000000000000000

  8  +***************                                                    10513.    10513.
     +000000000000000

  9  +***********                                                         7914.    10288.
     +00000000000000

 10  +********                                                            5699.    10446.
     +00000000000000

 11  +********                                                            5780.    10527.
     +000000000000000

 12  +********                                                            5871.    10618.
     +000000000000000

 13  +***************                                                    10554.    10554.
     +000000000000000

 14  +**************                                                     10461.    10461.
     +00000000000000

 15  +*********                                                           6639.    11386.
     +0000000000000000

 16  +*****                                                               3583.     8330.
     +00000000000

 17  +***                                                                 2631.     5005.
     +0000000

 18  +**                                                                  2019.     4393.
     +000000

 19  +**                                                                  1521.     3895.
     +00000

 20  +*                                                                   1237.     3611.
     +00000

 21  +*                                                                    752.     3126.
     +0000

 22  *                                                                     499.     2873.
     +0000

 23  *                                                                     432.     2806.
     +0000

 24  *                                                                     354.      354.
     0

 25  *                                                                     292.      292.
     0

 26  *                                                                     300.      300.
     0

 27  *                                                                     364.      364.
     0
```

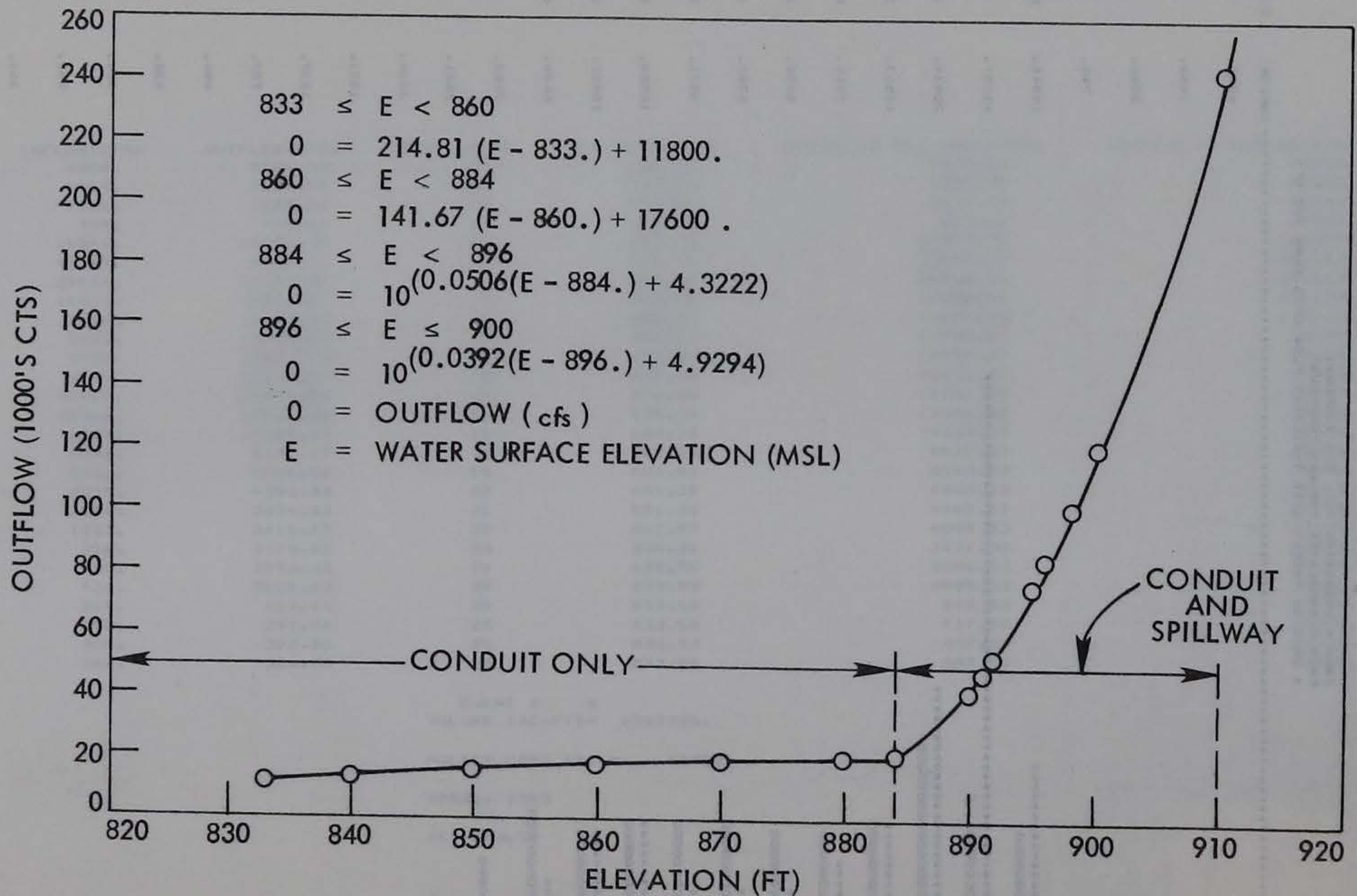

Fig. A-2. Maximum outflow vs. elevation for Saylorville Dam conduit and spillway.

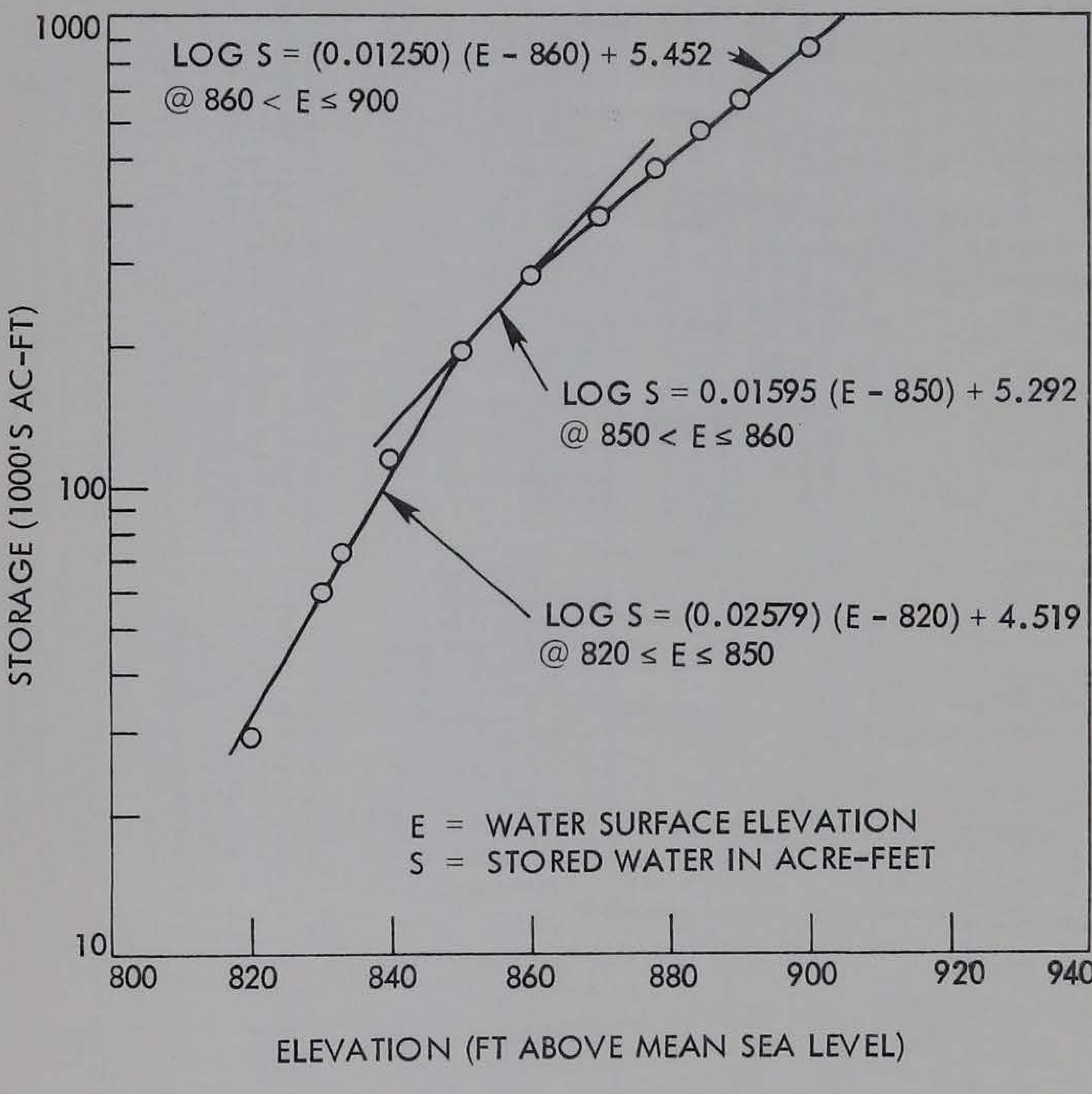

Fig. A-3. Elevation vs. storage at Saylorville Reservoir.

11.5. Flood Control Regulation Schedule

Table A-13. Red Rock Reservoir flood control regulation schedule (U. S. Army Corps of Engineers, 1968).

Regulation Schedule	Reservoir Stage		Condition	Operation
A. Normal flood control operation	Rising	I.	16 December thru 20 April.	Maintain permanent pool level 725 by releasing inflow up to 22,000 cfs, then, permit pool level to rise with uncontrolled outlet discharge until elevation 750 is reached (corresponds to uncontrolled outlet discharge of 30,000 cfs) then continue to release 30,000 cfs as pool continues to rise, except as limited by Conditions A-II, and Schedule B.
	Rising	II.	16 December thru 20 April. Discharge at Ottumwa or Keosauqua above, or forecast to exceed 30,000 cfs (corresponds to stage 10.9) or 35,000 cfs (corresponds to stage 10.8) respectively.	Release not less than 5,000 cfs to control flow to those discharges at respective stations insofar as possible except as limited by Schedule B.
	Falling, steady or rising	III.	21 April thru 15 December. Reservoir at or above permanent pool elevation 725 but lower than elevation 775.	Release 18,000 cfs until reservoir recedes to permanent pool level, after which it shall be held at that level insofar as possible without exceeding release of 18,000 cfs, except as limited by Conditions A-IV, and Schedule B.
	Rising	IV.	21 April thru 15 December. Discharge at Ottumwa or Keosauqua above or forecast to exceed 18,000 cfs (corresponds to stage 7.5) or 22,000 cfs (corresponds to stage 7.5) respectively including release in Condition A-III.	Release not less than 5,000 cfs to control flow to those discharges at respective stations insofar as possible except as limited by Schedule B.

- Continued -

Table A-13. Continued.

Regulation Schedule	Reservoir Stage	Condition	Operation
	Rising	V. Any date, stage at, above, or forecast to exceed 17.0 feet on Mississippi River gage at Burlington, Iowa, or 18.0 feet on Mississippi River gage at Quincy, Illinois.	During period corresponding to time Mississippi River is above forecast stages, provided reservoir inflow is greater than 5,000 cfs, release not less than 5,000 cfs until reservoir elevation 755.5 is reached; then provided (a) reservoir inflow is greater than 15,000 cfs release not less than 15,000 cfs until reservoir elevation 763.5 is reached, or, (b) if reservoir inflow is between 5,000 cfs and 15,000 cfs release the inflow; then, if operation (a) was followed and at elevation 763.5, provided (c) reservoir inflow is greater than 25,000 cfs release not less than 25,000 cfs until reservoir elevation 755 is reached, or (d) if reservoir inflow is between 15,000 cfs and 25,000 cfs release the inflow; then if operation (c) was followed release not less than 30,000 cfs, except as limited by Schedule B.
B. Large magnitude flood operation.	Rising	I. Any date, reservoir elevation is rising and above or forecast to exceed elevation 775.	When predictions indicate that anticipated runoff from a storm will appreciably exceed the storage capacity remaining in the reservoir when operated under Schedule A, release rates will be made in accordance with the following schedule·

Pool Elev.	Outflow cfs
775	30,000
776	35.000
777	40,000
778	45,000
779	50,000
780	60,000
780.5	80,000
781	100,000
781.5	115,000
782	130,000
783	130,000
784	130,000
785	130,000
785	*

*Open spillway tainter gates as necessary to maintain reservoir elevation 785 until uncontrolled spillway and outlet conduit discharge prevails, then allow reservoir to continue rising with uncontrolled spillway and outlet conduit discharge.