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Major Professor

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A MATHEMATICAL SIMULATION MODEL OF ECOSYSTEM RESPONSE TO NATURAL STRESSES

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

James Donald Berg

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ABSTRACT

A mathematical model is presented which simulates structural and functional relationships in an annual herb ecosystem characteristic of the granitic outcrops of the Southeastern Piedmont. The model simulates ecological responses to environmental stresses, primarily in terms of demographic changes in dominant plant species and alterations in ecosystem processes such as nutrient cycling.

Previous experimental research on these ecosystems, and the ecological significance of environmental stress are reviewed in detail. Nutrient cycles are depicted deterministically, water cycles are stochastic, and simulated productivity is a product of the two.

The model itself is written in Fortran-10, and is easily adapted to most fortran utilities. Equations are written in linear difference as opposed to integrated differential form. For this reason, the model is constructed in an extended rather than subprogram form. All 2190 "day" steps of the model occur within a single, major loop. While only five years of daily estimated data are possible as output in the extended mode, the annual cycles of the biota are well represented in this time frame. Stress implementation is achieved through manipulation of simulated rainfall and soil depth constants.

Heuristic value of this model and others is developed, and further studies are suggested.

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CHAPTER I

INTRODUCTION

A. Ecosystem Analysis

Modern ecosystem analysis has its beginning with the definition of ecosystems as the fundamental ecological unit (Tansley, 1935, as cited by Lindeman, 1942). Lindeman clarified the definition by describing an ecosystem as the ". . . system composed of physical-chemical-biological processes within a space-time unit of any magnitude. . ." (Lindeman, 1942; p. 400). Lindeman firmly established the concept that quantification of interactive processes are the means of analyzing ecosystem functions.

Another definition of ecosystems is found in Kormondy: "The abiotic physico-chemical environment and the biotic assemblage of plants, animals, and microbes comprise an ecological system . . ." (1969, p. 1). Kormondy stated further that it is the interactive processes which make an ecosystem a unique entity rather than an assemblage of component parts.

The ecological concept of holism is the idea that the system as a whole is greater than the sum of its component parts because of interactions between the parts. This concept directly implies that systems are dynamic, and change through time. Therefore, it is necessary to understand some of the history of a system before accurate analysis of that system can be made. Johnson (1977) developed a modern paradigm of what ecosystem analysis ought to be. Developing concepts from several earlier workers (C.F.: Janitch, 1972; Maruyama, 1974), Johnson defined an ecological paradigm which includes the concept that:

> Ecological systems form an interacting, interconnected network of biotic and abiotic components. . . . The subjects of study are ecosystems and their components. Four primary features of ecosystems, as well as their relationships with other systems, are investigated by ecologists: structure, function, behavior, and history.

The development of this concept had fruition prior to the direct statement. Lindeman's concept of quantifying processes as a means of ecosystem analysis was well exemplified by H. T. Odum in 1957. Odum (1957) quantified energy transfers within a well-defined ecosystem, Silver Springs, Florida. His work opened the door to mathematical simulation models of ecosystems beyond the two-species interactions described by Lotka (1925), Volterra (1926), and others.

In the 1920's and 1930's ecologists began to assimilate information about ecosystem dynamics into very simple mathematical models (Kolling, 1968). As development of theory proceeded and mathematics advanced, models were oriented toward management problems in agricultural and parks systems (C.F.: Dyksterhuis, 1958; Cole, 1958; Leopold et al., 1963). As a result, these models were scarcely realistic of large-scale, natural ecosystems, but were oriented toward smaller, specific problems. Most recently, assimilation of large masses of quantified data into computer simulation models has provided additional insights into the functional processes of ecosystems (C.F.: Abramsky and Van Dyne, 1980; Shugart et al., 1973; Shugart et al., 1980; Van Dyne, 1978; Van Dyne, 1981; Shugart and West, 1980; West et al., 1980). It has become possible to simulate the processes of an ecosystem through linked mathematical equations.

Early in their development, mathematical simulation models of ecosystems were simple and primarily descriptive of ecosystem structure. Real world events were interpreted through understanding strengths and weaknesses of the models themselves. As technological advances made more (and more accurate) data available, mathematical simulation models imitated ecosystem functional processes.

When ecologists began attempts to incorporate large-scale dynamics and sufficient functional complexity into models to simulate natural ecosystems, the mathematics often became too cumbersome to prove practical. In the middle 1960's, with the increased availability of computers to ecologists, Eugene Odum declared that the "new ecology" must be a "systems ecology"; one in which sufficiently complex mathematical simulations of ecosystem components and functional processes is truly representative of ecosystems (Odum, 1964).

As data, processes, and computers have become more complex and sophisticated, models have become correspondingly more complex and precise. Now it is possible to utilize complex models to test ideas instead of simply to explain these ideas.

During the mid to late 1960's, the United States International Biological Program biome studies gathered enormous quantities of data. One series of models to come directly from the IBP biome studies has been the series of management models, designated ELM, from the Grassland Biome studies. The data base initially gathered from the IBP study has been augmented in numerous ways since the initial ELM models were designed.

Van Dyne (1971) published an overview of the many earlier models of the Grassland Biome study. Building advanced models upon improved and increased data bases continues. The ELM models are perhaps the best example of models where the dominant vegetation is herbaceous, and major biomass productivity follows annual cycles (Van Dyne, 1978).

Mathematical models of ecological changes and relationships has come to be the modern definition of system ecology (Patten, 1971). Two basic logical processes are utilized in the development of models, and may be used singly or together. Stochastic models are based upon probabilities. For example, assume the probability of a variable changing from state A to state B is 0.40 for conditions established, and from state A to state C is 0.60. The use of a switching function (such as a random number generator) determines which of the two states variable A will become. Assuming the random number generator produces numbers from 0.000 to 0.999, a switch utilizing random number "R" might read:

If "R" is less than or equal to 0.40, A becomes B.

If "R" is greater than 0.40, A becomes C.

Deterministic models are based upon changes in state in a set pattern. For example, state A becomes B under specific conditions of time and physical parameters. When conditions change again, B becomes C, and so on. Both stochastic and deterministic models are based upon changes in state with respect to time (Patten, 1971).

In order for a model to be a successful hypothesis, its predictions must be tested against "real-world" phenomena. This means that the

variables, while essentially abstract concepts, must be connected to the real world through accurate, specific physical measurements. The model is thus a meld of data, statistics, quantifications, and concepts (Patten, 1971).

Patten (1971) produced several guidelines for selecting the mathematical structure of a model. The five of these most pertinent to this study are:

1. Naturalness with which the mathematical theory represents the real-world phenomena. For example, are the functional processes discrete or continuous? Is there more than one type of interactive variable?

2. Ability to generate realistic predictions based upon changes in input variables.

3. Comprehensiveness and aesthetics of the model structure, keeping in mind that simplicity is essential.

4. Tractability of mathematics, or ease of functional extrapolation.

5. Consistency with other existing models of similar ecosystems.

B. The Ecosystem Selected for Study

B.1. Physical Description and History

Granite outcrop ecosystems of the Southeastern Piedmont, U.S.A., are characteristically contained upon granitic gneiss outcroppings ranging from 0.5 to 100 or more hectares. These outcroppings have gently sloping to rolling surfaces and are often steep-sides monadnocks. Plant communities found in depressions and along faults in the surface have an unusually large number of endemic species which reach their greatest

densities in and around DeKalb County, Georgia (Murdy, 1968). Soils of these depressions have been described as "an Entisol, sandy skeletal mixed lithic udorthent of an undesignated series" (Dyer and Lietzke, pers. comm.) which approaches the characteristics for a Lithic Quartzypsamment as described in the U.S. Department of Agriculture's Soil Taxonomy text (Agriculture Handbook No. 436, 1975). These soils are somewhat variable by texture, structure, organic and nutrient content, but are primarily sandy, with generally less than 5% organic content, and characteristically less than 5% clay, and 10% or less silt (Meyer, 1972). Exchangeable aluminum is low (generally less than 1 meq/100 g) and the pH is acidic, ranging between 4.5 and 5.0. Bulk density averages 1.33 g/cm^3, and the cation exchange capacity is usually fairly low at a mean of 4.3 (±0.7) meq/100 g (Meyer, 1972).

Soil filled depressions on the granite surface are often roughly circular, and have a wide range of diameters and maximum soil depths. Depressions range from less than one to several (8-10) meters in diameter, the average being about 2.5 meters. Soil depth maxima range from a few centimeters to 50 (and rarely, a meter deep), and the average maximum soil depth is about 25 centimeters (Burbanck and Platt, 1964).

Isolated depressions with very shallow soils (2-3 centimeters maximum) can be found which contain pure populations of Sedum smallii (Britton) Ahles. Shallow depressions with somewhat deeper soils (5-10 cm.) contain nearly pure populations of Minuartia uniflora (Walt.) Mattfield with peripheral populations of Sedum smallii. Most depressions,

however, contain a wide gradient of soil depths, ranging from one or two centimeters near the edges to approximately 20-25 centimeters near the center. In shallow soils of herbaceous annual ecosystems, S. smallii and M. uniflora compete, with M. uniflora succeeding in the deeper soils (Sharitz and McCormick, 1973). Interior to this zone is a zone of lichens, mosses, and annual herbs, Burbanck and Platt's (1964) Lichen-annual herb community. The vascular species which occupy this zone (8 to 15 cm. depth) include populations of Crotonopsis elliptica,[1] Hypericum gentianoides, M. uniflora, Viguiera porteri (A. Gray) Blake, and other species of lesser importance. The clear dominant species of the deeper soil communities is Viguiera porteri. During peak growth, V. porteri may produce 40 percent or more of the biomass in this zone. Deeper soils are occupied by a community of annual and perennial herbs. Polytrichum mosses and grasses form a fairly complete cover interrupted by Senecio tomentosus, Viguiera porteri, and Crotonopsis elliptica. If soil is deep enough, or a deep crack underlies the depression, Pinus virginiana or Juniperus virginiana occur.

Dominant annual plant species of granite outcrop ecosystems occur in discrete zones. Zones of vegetation are greatly influenced by soil depth and moisture. Primary succession proceeds according to direction and rate of soil accumulation in depressions on the rock surface (Lugo and McCormick, 1981). Community zonation is shown in Figure 1.

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[1]Except where authorities are listed, nomenclature follows that of Radford, Ahles, and Bell (1968).

Figure 1. Annual Plant Community Silhouette by Soil Depth.

A. 0.0 to 4.0 cm. soil depth—Sedum smallii dominated.

B. 4.0 to 12.0 cm. soil depth—Minuartia uniflora and lichen dominated.

C. 12.0 to 50.0 cm. soil depth—Viguiera porteri and moss dominated.

Shaded area represents granite substrate, white area between granite and plants represents soil.

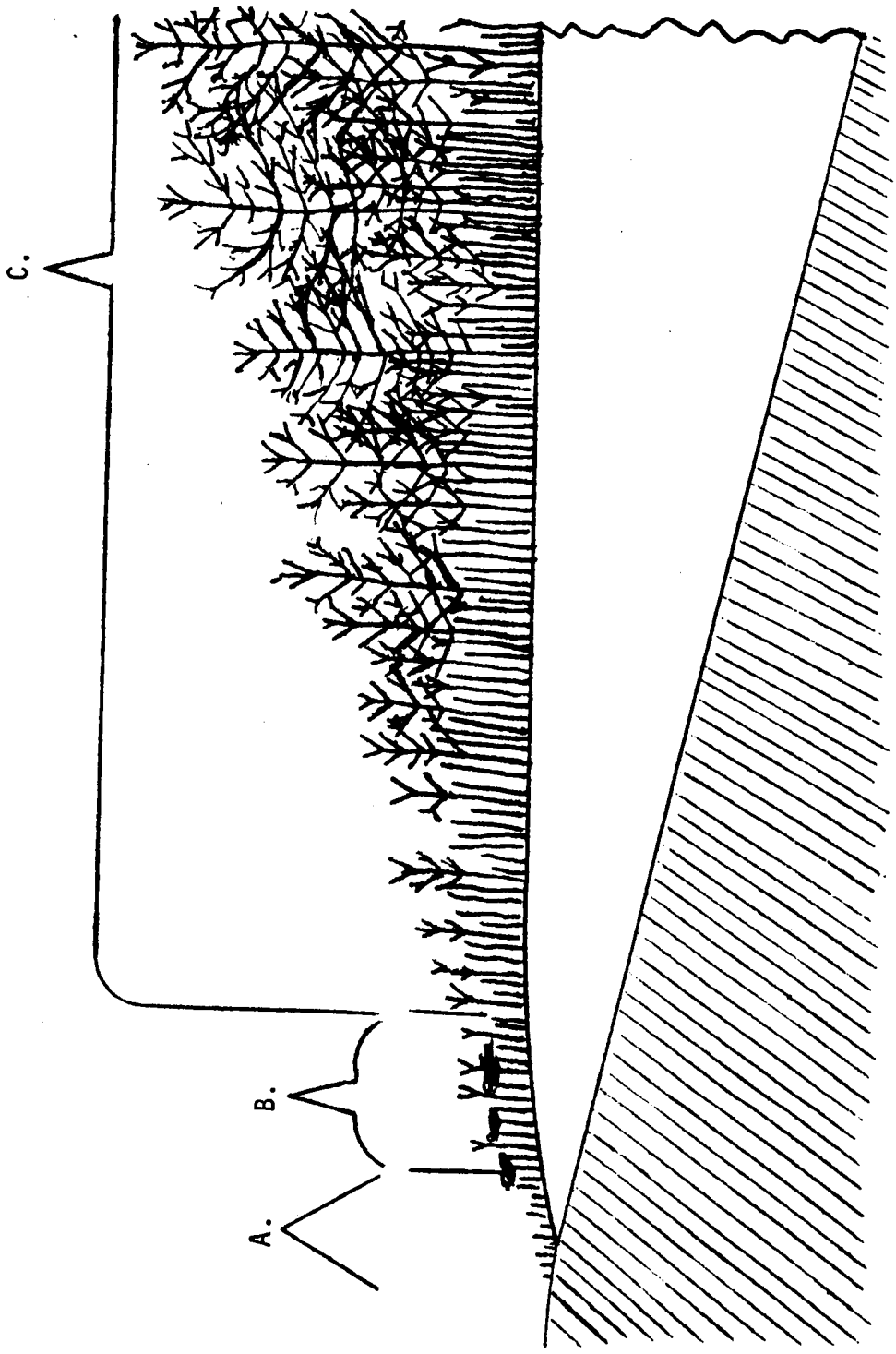


Figure 1

An excellent review of the components, functional dynamics, and other attributes which make granite outcrop ecosystems suitable for experimental manipulation can be found in McCormick et al., 1974. Among the characteristics described are:

1. Plant communities are small and isolated.
2. Animal dynamics are minimal.
3. The flora consists of endemic or highly characteristic annual and perennial species.
4. Nutrient and energy dynamics are well understood.
5. Population interactions are defined.
6. Stress effects of limited moisture are well understood.

Development of experimental and analytical procedures utilizing representative segments of the granite outcrop ecosystem began with McCormick and Platt (1962). They developed techniques for transplanting segments of the ecosystem to artificial substrates where they could be monitored for response to induced stresses and for response to the alleviation of naturally occurring stresses. Employing these techniques, numerous workers have developed a formidable collection of data from the outcrop ecosystem and its components. Nutrient cycles, energy transfers, interactive processes, and population dynamics have all been examined under natural and laboratory conditions.

Climatic conditions in the Piedmont region of Northern Georgia, U.S.A., are roughly similar to those in Knoxville, Tennessee. Transplanted granitic outcrop ecosystems underwent normal recovery from transplanting stresses, and continued to be essentially self-maintaining with periodic infusions of a few seeds from endemic annual species. Reseeding assured

maintenance of sufficiently large populations of the endemic species, and at no time did resowing exceed expected transfer among ecosystems in natural substrata. Relative self-maintenance of the endemic communities is assumed to result from successful duplication of environmental parameters found in their native habitats, including edaphic and climatic conditions.

Population dynamics have been examined for many of the major annual species and for most of the endemics. Shallow soil populations of Sedum smallii and Minuartia uniflora have been examined in depth (Sharitz and McCormick, 1973). Interactions such as competition among populations are ecosystem properties. Knowledge of the effects of external influences upon these interactions are an indication of the disruptive potential of natural stresses. One indication of the effects of ecosystem stress may be obtained by monitoring competitive interactions of S. smallii and M. uniflora.

Viguiera porteri is an important species in deeper soils of the outcrop ecosystem. At times, it may comprise the vast majority of vascular biomass in the deep soil communities. Studies by Mellinger (1971), Lugo (1969), and Meyer (1972) have delineated the environmental and ecosystem properties which govern population dynamics of V. porteri. By monitoring V. porteri populations, changes within these ecosystem properties are indicated.

Lugo (1969) described the energy budget and water dynamics of the ecosystem, and Meyer (1972) described the nutrient budget. Nutrient, energy, and water budgets are critical processes of any ecosystem.

Together with population dynamics and interactive processes they can be utilized to describe ecosystem function.

Numerous studies have been conducted which examine the effects of man-induced stressors upon granite outcrop ecosystem components, processes, and functions. McCormick and Platt (1962) examined the effects of ionizing radiation upon the ecosystem. They showed that gamma irradiation had profound effects upon the population dynamics of many species, especially M. uniflora and S. smallii. Murphy and McCormick (1970) tested the effects of enhanced beta radiation upon the ecosystem. The initial changes in ecosystem structure due to the effects of the simulated fallout were rapidly reversed, and original dynamics were reattained within just a few years.

Olson (1975) examined the effects of acid precipitation upon the ecosystem. He discerned marked alteration of some nutrient cycles critical for all species. Nabholz (1978) examined the effects of two differing organic toxins upon the ecosystem. While the nutrient and energy budgets discerned differed somewhat from those determined by other workers, many comparisons can be drawn to those ecosystem properties affected by the stressors applied and the effects of other stressors upon the ecosystem.

The data base for comparative studies upon granite outcrop ecosystems is very large and varied. The data of Meyer (1972), Lugo (1969) and Sharitz (1970) was used for much of the development of this project because their data is most consistent with data collected from The University of Tennessee's Simulated Granite Outcrop Ecosystem.

B.2. Description of the Biota

Five taxonomic groups were selected. Selection was based upon criteria which included dominance, productivity, availability of environmentally related data, and representativeness to granitic outcrop systems.

Sedum smallii (Britton) Ahles (Crassulaceae) is a small (up to 10.0 centimeters height) succulent characterized by its brilliant blood-red foliage. S. smallii dominates very shallow residual soil communities of granitic and acidic sandstone outcrops of the Southeastern Piedmont, U.S.A. The form of the plant varies from tiny, unbranched plants less than 1.5 centimeters tall at flowering to spreading, branched individuals with numerous flowers.

Taxonomists have had difficulty classifying this species. Variability of form is perhaps one reason, but the closely related species, S. pusillum, has added to the difficulties. The two species have very similar form, and both are restricted to acidic soils on outcrops. Several synonyms for S. smallii appear in literature with the most common being: Diamorpha cymosa (Nuttall) Britton, D. smallii Britton, and Sedum cymosum (Nuttall) Fröderström (Wilbur, 1964; Radford et al., 1968).

S. smallii flowers are typically four-merous, white, and 7.0 to 8.0 millimeters across. A red midrib may occur on petals. Stamens are prominent, pollen is bright yellow, and pollination is apparently achieved through the activities of small insects (Murdy, 1964). Flowering is completed by mid to late spring, and plants enter scenescence with

seed encapsulated. The dessicated plants remain with seed in place until abundant moisture, sufficiently cool temperatures, and the physical action of heavy autumn rains partially rehydrate the seed capsules (Wiggs and Platt, 1962). Seeds drop to the soil and germinate soon after the first frost. Young plants overwinter as small, red rosettes and bolt in early spring. Flower buds may appear as early as the last week of February, and by mid-April, most flowering is complete.

S. smallii is apparently a poor competitor in both deeper soils and areas where water is more abundant. Transplants made of a Georgia population continued to flower distinctly earlier in the spring than others in North Carolina (McCormick and Platt, 1964). Survival and persistence is a result of physiological tolerance to severe drought (Sharitz and McCormick, 1973).

Minuartia uniflora (Michaux) Mattfield (Caryophyllaceae) is a winter annual with a life cycle similar in most respects to that of Sedum smallii. The major difference lies in the fact that M. uniflora seeds drop from the capsule as soon as scenescent dehydration is complete in the spring. Flowering begins in early spring and some flowering may persist until late May, with the most intense flowering period occurring in mid-April.

M. uniflora stems range from 2.0 to 12.0 centimeters high and may be many-branched or unbranched. Cauline leaves are few in number, appearing mainly at nodes. Flowers are 7.0 to 12.0 millimeters across with most being about 10.0 millimeters.

This species has also been taxonomically revised numerous times. Nomenclature has varied from Arenaria groenlandica var. glabra (Michaux) Small, and Arenaria uniflora (Walt.) Muhl. (Wilbur, 1970; Radford et al., 1968) with the usage M. uniflora here being the name best accepted by McCormick et al. (1977).

M. uniflora is most abundant in shallow, residual soils on granitic outcroppings. The zone it occupies is slightly deeper than the zone populated by S. smallii, that is to a depth of 10.0 centimeters (Sharitz and McCormick, 1973). M. uniflora and S. smallii were shown to compete in the small area intermediate to the soil depths where each is most abundant (Sharitz and McCormick, 1973). Effects of environmental disturbance upon competing species may be examined through inclusion of these two species.

The third species selected for this study was Viguiera porteri (A. Gray) Blake (Asteraceae). V. porteri, or Confederate Daisy, is endemic to granitic outcrops of the Piedmont fall line. V. porteri is found in a narrow region centered in DeKalb County, Georgia (Murdy, 1964). While V. porteri populations usually make up a majority of the biomass in soil pockets reaching 15.0 to 50.0 centimeters deep, transplanted populations outside the narrow zone of endemism or apart from the residual soils of their usual habitat must be artificially maintained (Mellinger, 1968; Meyer, 1972). V. porteri is included because of its high productivity and annual cycle.

This species has no close relatives in the southeastern U.S.A. (McVaugh, 1943; Mellinger, 1968). V. porteri is an erect annual species

with opposite, spreading branches and opposite, dark olive linear lanceolate leaves. Flower heads are composed of several conspicuous toothed rays, bright yellow, and a cone of disc flowers the same color. Superficially, the flower heads resemble those of Rudbeckia species (coneflowers), with which it was initially classified. However, more careful examination of such characters as branching and leafing pattern, phenology, life cycle events, and reproductive structures clearly distinguish it as a separate genus (McVaugh, 1943; Radford et al., 1968).

V. porteri germinates in early spring and by mid-summer, plants may be 15 to 30 centimeters tall, and dominate soil pockets where it occurs. Flower buds are present by the end of August, and flower heads begin to open by mid-September. Flowering continues until frost kills the plants. Seeds drop from flower heads as flowers dessicate in the late fall, and require vernalization prior to germination. V. porteri can recover from brief periods of drought, but seed reserves in the soil insure population continuation in the event severe drought decreases reproduction for a season (Mellinger, 1968).

The fourth taxonomic group are the bryophytes. Species which comprise the common bryophyte populations are diverse. Grimmia laevigata (Brid.) Brid. is found on bare stone and the shallowest accumulations of sand and sandy residual soils. G. laevigata invades bare rock in a process where dessication of rootlets plays an important role in adhesion of plants (Keever, 1957). Accumulation of soil and rock fines in small mats of G. laevigata may permit germination of drought-tolerant annuals such as Sedum smallii. This phenomenon

probably gave rise to the untested hypothesis that these small moss mats are a first step in primary succession on granitic rocks (Whitehouse, 1933; Oosting and Anderson, 1937; Oosting and Anderson, 1939). Polytrichum species, usually P. ohioense Ren. and Card., form dense mats on deeper soils of most granitic outcrop ecosystems. Polytrichum is responsible for much of the primary production of deeper soil communities. Species of the Bryum, Hedwigia, Philonatus, and Campylopus genera may be present in lesser amounts.

Bryophytes were aggregated into a single group in this study. Principal modes of nutrient absorption and moisture retention are very similar among all species. This, coupled with their properties of erosion control, make their functional roles nearly identical.

The final biotic category is that of the lichens. Again, due to functional similarities, foliose lichens were aggregated into a single primary production group in this study. Most lichen biomass contains one or several species of Cladonia. C. caroliniana Tuckerman and C. rangiferina (L.) Web. are the two most abundant species, though at times, C. leporina E. Fries or C. sylvatica (L.) Hoffman may produce fairly large quantities of biomass (McVaugh, 1943).

Numerous additional species may be found in varying abundance in granitic outcrop communities. While none of these species has been included in this study, several of them merit mention by virtue of the unique aspect they lend the vegetation of the ecosystems. Many of these species are endemic to granitic outcrops or granitic and sandstone outcrops. All of them are indicative of xeric, shallow soil communities of the southeastern U.S.A.

Annual-perennial herbaceous communities in shallow soils may contain Phacelia maculata Wood (Hydrophyllaceae), Portulaca smallii P. Wilson (Portulacaceae), Talinum teretifolium Pursh (Portulacaceae), and Crotonopsis elliptica Willd. (Euphorbiaceae). Hypericum gentianoides (L.) PSB (Hypericaceae), Schoenolirion croceum (Michx.) Gray (Liliaceae), Linaria canadensis (L.) Dumont and Lindernia monticola Muhl. ex Nuttall (Scrophulariaceae), Senecio tomentosus Michaux and Krigia virginica (L.) Willd. (Asteraceae), and Opuntia compressa (Salisbury) MacBride (Cactaceae) may inhabit deeper soils. Classifications follow Radford, Ahles, and Bell's Flora of the Carolinas (1968) whenever possible. If a species has been subjected to taxonomic revision, other classification determinations have been presented. The following brief descriptions of these species are derived from Radford et al. (1968), and other literature as presented.

Phacelia maculata is an erect or spreading annual 5.0 to 35.0 centimeters tall. The corolla is blue to white, campanulate, and 6.0 to 9.0 millimeters broad. Murdy (1968) names P. dubia var. georgiana as a close relative, and both P. dubia var. georgiana and P. maculata are treated as endemic to granitic outcrops. No common name was found.

Ecological life history (Cotter and Platt, 1969) and taxonomic placement (Murdy, 1968; Radford et al., 1968) of Portulaca smallii have been thoroughly examined. P. smallii is a succulent summer-flowering annual with spreading stems 5.0 to 18.0 centimeters long. Flowers are small (5.0 to 6.0 millimeters wide), and when seed begins

to ripen, tufts of cotton-like fibers cover the fruits. Stems, leaves, and flowers are all deep pink to red. One common name, Rock Moss, was given (Cotter and Platt, 1969) in one paper, but no other references to any common name were found.

Talinum teretifolium has also been examined extensively. T. teretifolium (Eastern Sunbright) arises from a perenniating rhizome which rests on the surface of the soil. Leaves are 2.0 to 3.0 centimeters long, terete, and succulent. Leafy stems, leaves, and flower stems are all deciduous. Flowers are blue to pale pink, 1.2 to 2.0 centimeters across, and open in mid-afternoon during late July and August. The very specific phenology of flowering events is one trait distinguishing T. teretifolium from other closely related species like T. mengesii (Ware, 1972). The various species of Talinum apparently have a unique cytophyletic history. Several species are obviously closely related to each other, yet interspecific hybridization is limited or nonexistant and habitat differentiation is clearly defined (Murdy, 1968; Murdy et al., 1970; Ware, 1972; Black and Murdy, 1972).

Crotonopsis elliptica is a monoecious annual with erect habit, opposite branching, and elliptic to linear-lanceolate leaves. Inflorescences are inconspicuous terminal or axial spikelets rarely more than 5.0 millimeters long. C. elliptica appears to be restricted to granitic and sandstone outcrops along the fall line of the Piedmont. No common names were found.

Hypericum gentianoides (Pineweed) is an erect annual to 40.0 centimeters tall. Branches ascend and leaves are tightly appressed

and ascending. Flowers are conspicuous, yellow or yellow and red, and small, rarely more than 3.5 millimeters long. Radford et al. (1968) give Sarothra gentianoides L. as an archaic name.

Schoenolirion croceum is a monotypic, endemic genus. Leaves and flower stems arise from a perennial bulb. Leaves are linear, 20.0 to 40.0 centimeters long, and 2.0 to 4.0 millimeters wide. Flowers appear in spring on a 20.0 to 35.0 centimeter tall stem. They are bright yellow and arise in a terminal raceme. Sunnybell is the only common name found.

Two species of Schophulariaceae may often be found near one another in outcrop communities. Linaria canadense, or Toad-flax, is a biennial or winter annual with an erect stem 20.0 to 60.0 centimeters tall. Flowers appear in an open terminal raceme and vary in color from blue to purple. Flowers have typical zygomorphic schophularian shape and vary from 5.0 to 15.0 millimeters long, including the spur.

Lindernia monicola has blue to lavender flowers. It is a perennial with essentially leafless stems 10.0 to 20.0 centimeters tall. Flowers are 8.0 to 11.0 millimeters long and occur in terminal racemes. No common name was found.

Senecio tomentosus is a herbaceous perennial with an erect stem and a rosette of basal leaves. Flowers occur as a corymb of bright yellow heads in late spring. Basal rosettes of leaves may spread to 25.0 centimeters, and stems may reach heights of 30.0 centimeters but usually range from 15.0 to 20.0 centimeters. No common name was found.

Krigia virginica, one of the "dwarf dandelion" (Radford et al., 1968) species, is another yellow flowered composite. K. virginica is a diminutive winter annual with a basal rosette of leaves 4.0 to 10.0 centimeters across. Flower stems commonly reach only 5.0 to 10.0 centimeters height.

Opuntis compressa has been variously called O. humifusa Raf., O. macrocartha Gibbes, O. tunoidea Gibbes, O. cantabrigiensis Lynch and O. pollardii Britton and Rose. Evidently, there has been some uncertainty over appropriate taxonomy for Opuntia in the southeastern U.S.A. Radford et al. rely upon the expertise of K. E. Ahles, who describes the family in a sensu latu, which places all the above-mentioned taxa into the single species, O. compressa (1968). Considerable variation in general form is apparent between small populations in different locations.

C. Environmental Stress

Levitt (1980) defined a biological stress as any environmental factor capable of producing a potentially injurious strain upon living organisms. Lugo and McCormick (1979) described stressors as any situation, condition, quality, or intensity of environmental factors which can cause a biological system to mobilize resources and increase energy expenditures. The response of a biological system to stressors is stress. The change in biological equilibrium due to the actions of stress is strain. Thus we have a pathway: stressors (environmental factors) generate stresses (forces) upon biota resulting in strain (physiological responses).

Levitt further defined strain by equating biological stress with Newton's Laws of Motion governing forces upon bodies. If the intensity, mode of action, or length of time force is applied by a stressor upon a biological system is sufficiently injurious to the system, a portion of the resultant strain is plastic, and the biological system attains a new equilibrium. The portion of the strain from which the system recovers is elastic strain. Equally, a stress of insufficient magnitude or duration to produce permanent injury produces only elastic strain, and the system will eventually regain its former equilibrium.

In order to incorporate stress in a simulation model of an ecosystem, specific actions of stressors upon ecosystem components must be determined. Different biota react differently to a single stress of a given magnitude. It is, therefore, necessary to determine the type and degree of strain exhibited by each biological component to each stress exacted upon it. Since the strain upon biological systems must be measured in terms of energy rather than of force (Levitt, 1980), an accurate measure of biological energy units, such as biomass or grams of carbon fixed per unit area should be employed.

In order to utilize stress within a model, a mathematical description of the stress itself must be generated. For example, drought stress for a given terrestrial ecosystem might be expressed in terms of rainfall, temperature, evapotranspiration, and other factors which influence available moisture. Since each of the species comprising the biotic components of the ecosystem react differently to a level of drought stress, a functional relationship between available moisture

and resultant strain on the biological system must be ascertained for each of the biotic components. Moisture stress for a single species might be diagrammed as in Figure 2.

Obviously, this is an oversimplification. When a stress has been sufficiently intense to generate damage by plastic strain, the resultant changed equilibrium point may well result in an altered degree of stress susceptibility. Only when the ecosystem represented in the model has been examined sufficiently can realistic functions representing defineable stresses be developed.

Drought stress is the primary influence upon the structure and function of granite outcrop ecosystems. These systems are exposed to extremes of moisture and rapidly fluctuating temperatures due to their exposed position on large expanses of rock outcroppings and due to characteristics of their light, sandy soils (McCormick et al., 1974). This stress and its relationship to the species which persist in that habitat have been examined experimentally by several workers over a period of many years. A brief review of these studies in relation to specific stresses examined is appropriate here.

In 1973, Sharitz and McCormick published a study which clearly delineated the relationship of soil depth and moisture to the population dynamics of Sedum smallii and Minuartia uniflora, two dominant species found in granite outcrop ecosystems. Moisture relationships of Viguiera porteri, another dominant endemic species of the granite outcrops, are described in a study by Mellinger (1972). In both of these publications, as well as in Cummings (1969), and McCormick et al. (1974), the overriding stress was defined as moisture limitation at given soil depths.

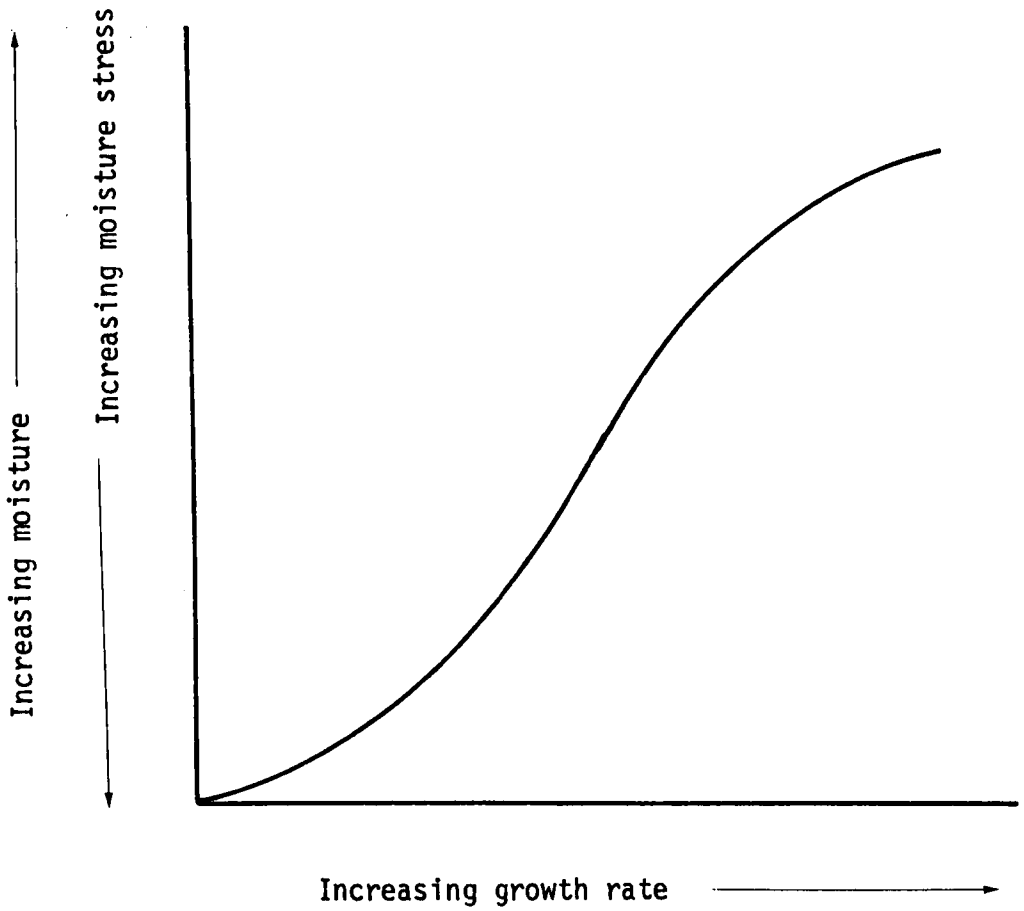


Figure 2. Moisture Stress versus Biotic Growth.

The second most influential stress upon these ecosystems results from the fragile character of their nutrient cycles. Through a careful series of nutrient analyses and nutrient addition studies, Meyer (1972) developed a complete series of nutrient cycles for the ecosystem and for many of its components. Meyer also noted that except for the ability to retain nutrients in biotic components during flood periods, the small volumes of soil which the ecosystems inhabit would quickly be depleted of essential nutrients. Because of the closed natural nutrient cycles in these ecosystems, the limiting effects of nutrients such as calcium and nitrogen, and the important role of plant species in retaining nutrients, disturbance of the life cycles of the biotic components, even for a short time, should be expected to result in significant nutrient losses from the system. This results in a potential long-term impact (centuries perhaps) of short-term stress (days perhaps).

In modelling, stress is usually defined in terms of resultant strain in ecosystem components. The effective way of describing strain for each component is in terms of measurable energy cost. Recovery of components subjected to elastic strain must be provided for, and altered equilibria resulting from plastic strain must be realistic and proportional to the initiating stress.

An additional property of strain is that it is proportional to the energy applied in stress. The stresses described by Lugo and McCormick are themselves components of the granitic outcrop ecosystem. The stresses determine the structure of the community in which they operate (Lugo and McCormick, 1981). We can therefore estimate the relative

biological "energy" of a stress by the strain it produces. Lugo and McCormick (1981) present a graph of the relationship of stress to primary production in granite outcrop ecosystems. This figure is reproduced here as Figure 3.

Through further manipulation of values assigned to the components in the figure, interrelationships of naturally occurring environmental stresses with biomass were calculated. Tables 1 through 3 and Figures 4 through 6 illustrate the case in point. By assigning numerical estimates of values for "Stress Index," "Soil Depth," and "Biomass," regression analysis shows that the relationship between soil depth and stress is logarithmic. In this instance, the stress index is a function based on the logarithm of soil depth.

At the same time, community biomass is an exponential function of soil depth, and a logarithmic function of the stress index. Once the relationships between biomass and soil depth are understood, changes in biomass which result from an additional stress can be calculated. Values based upon the naturally occurring stress index for this ecosystem can then be determined. The proportional differences in strain, resulting from the normal stress of soil depth and an applied stress such as a toxic substance, yield an estimate of cost of an anthropogenic stress to the ecosystem through loss of productivity.

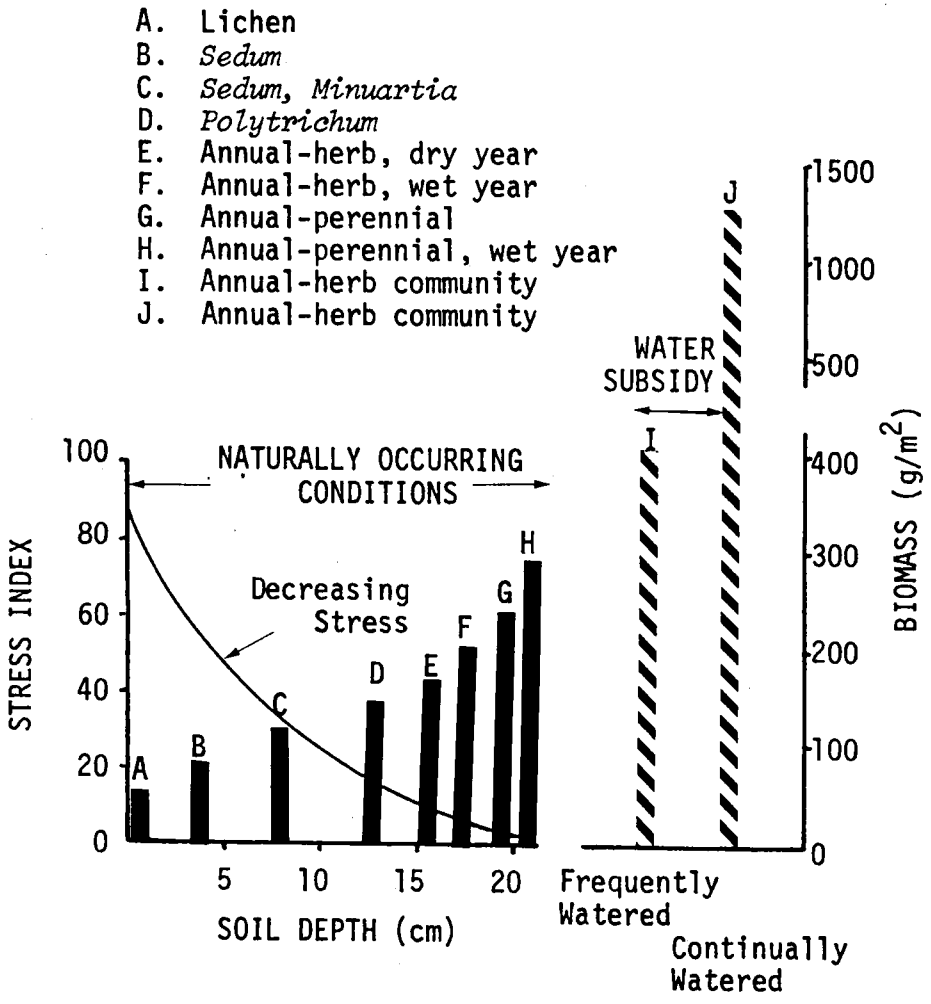


Figure 3. Relationship of Stress to Primary Production.

The stress index is the mean of summed values of three stressors: temperature, water, and nutrients. For each stressor the range and optima of conditions or intensities were determined. Optima were based upon responses of populations of dominant species of each habitat or sere. Stress is expressed as the percentage of deviation from optimal conditions experienced in the field.

From Lugo and McCormick, 1981.

Table 1

Interrelationships of Environmental Stress,
Soil Depth, and Primary Production

Stress Index (Y)	Soil Depth (Y) (cm.)
85.0	1.0
52.0	3.0
34.0	7.6
10.0	15.0
1.0	22.0

Equation (1)

Stress Index = 84.383 - (26.879 * (Log Soil Depth))

Source/Degrees Freedom		Sum Squares	Mean Square
TOTAL	4	4561.2	
Regression	1	4533.0	4533.0
Residual	3	28.2	9.4

F = 481.9, R square = 0.994

Table 2

Biomass of Granite Outcrop Communities by Soil Depth

Community	Biomass (grams/meter square)	Soil Depth (cm.)
A	58	1.00
B	100	3.00
C	125	8.00
D	167	12.50
E	200	16.00
F	233	18.00
G	300	19.50
H	358	21.23

Equation (2)

Biomass = 64.364 * (EXP (0.077 * Soil Depth))

Source/Degrees Freedom		Sum Squares	Mean Square
TOTAL	7	2.5	2.4
Regression	1	2.4	2.0
Residual	6	0.1	

F = 136.8, R square = 0.958

Table 3

Calculation of Biomass Using Stress Index Values

Community	(New Y) Biomass (grams/meter square) (From Equation (2))	Soil Depth (cm.)	(New X) Corresponding Stress Index (From Equation (1))
A	69.51	1.00	84.38
B	81.06	3.00	54.85
C	119.04	8.00	28.49
D	168.24	12.50	16.49
E	220.18	16.00	9.86
F	256.77	18.00	6.69
G	288.15	19.50	4.54
H	329.64	21.25	2.23

Equation (3)

Biomass = 395.631 - (77.382 * (Log Stress Index))

Source/Degrees Freedom		Sum Squares	Mean Square
TOTAL	7	66376.6	
Regression	1	65471.8	65471.8
Residual	6	904.8	150.8

F = 434.2, R square = 0.986

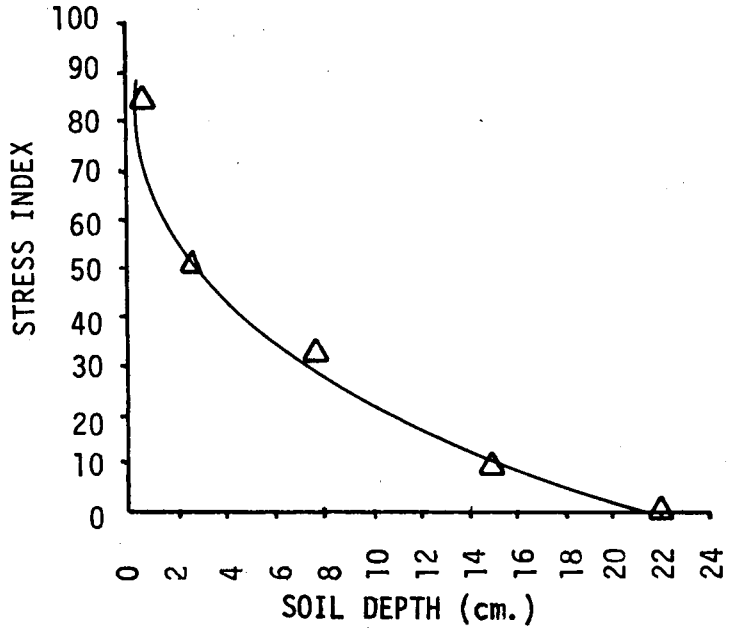


Figure 4. Stress Index versus Soil Depth in Granite Outcrop Ecosystems.

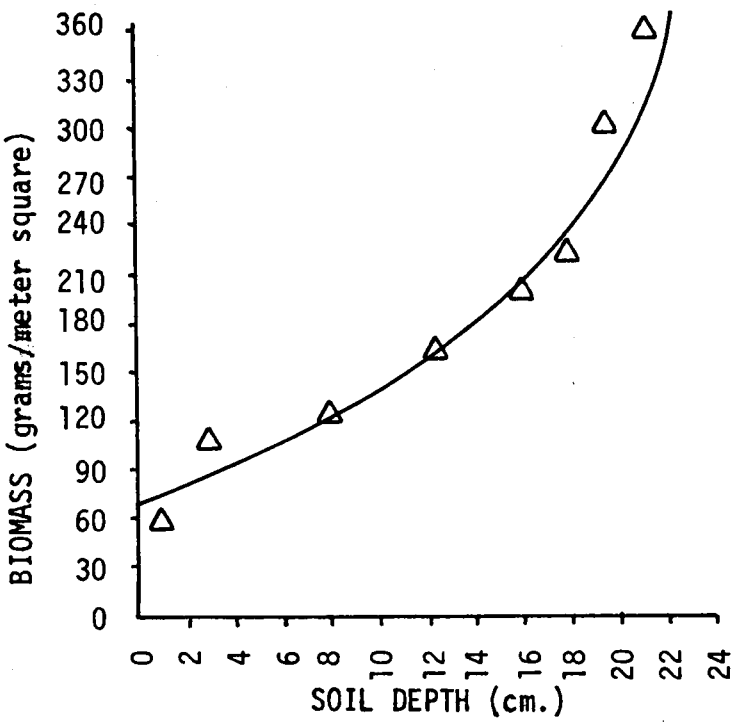


Figure 5. Ecosystem Biomass versus Soil Depth in Granite Outcrop Ecosystems.

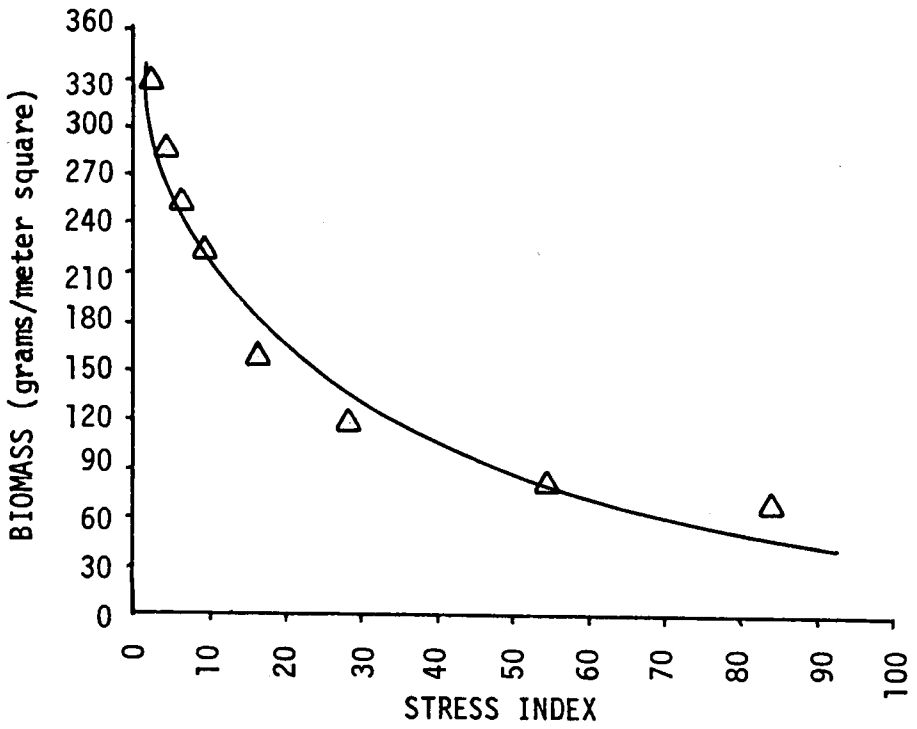


Figure 6. Ecosystem Biomass versus Stress Index on Granite Outcrop Ecosystems.

CHAPTER II

JUSTIFICATION AND OBJECTIVES OF THE STUDY AND SELECTION OF THE SYSTEM

Preceding sections describe the rationale and need for developing ecosystem stress-response models, as well as the suitability of granite outcrop ecosystems for this type of analysis. This study is based upon three bodies of information: (1) stress/production relationships within the ecosystem, such as those described by Lugo and McCormick (1981); (2) thorough understanding of functional relationships in the ecosystem to be modelled; and (3) contemporary methods of ecosystem analysis and modelling processes.

The primary objective of this study has been generation of a comprehensive model of an ecosystem where the major biota are annual species. Energy (as biomass), nutrient, population, and stress parameters have all been included in the model. Secondarily, this model was designed to coalesce and extend the use of a large data base. Segregation of stressers into effects upon ecosystem functions was an additional objective.

Specific objectives of a mathematical simulation model were considered when determining which physical and environmental parameters should be incorporated. If specific parameters could not be perceived as playing significant roles in the goals of the model, they were eliminated to reduce complexity. Additionally, parameters occasionally

occurred which would have contributed to the success of the model, but which were too poorly understood to be incorporated. Thus, the model is a compromise, developed from components and processes which were believed necessary to accomplish stated goals, and for which sufficient data and understanding exist.

The model developed herein incorporates energy dynamics, nutrient cycles, and population dynamics as major components of the granite outcrop ecosystems. Models of energy flow and nutrient dynamics have been developed for many ecosystems. Models of species population dynamics have been developed for a number of others. This model[2] is unusual in that it simulates and interconnects these major components of a single ecosystem as well as the stresses which control system dynamics.

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[2]The model acronym, BMAS14.FOR, stands for Biomass model, fourteenth variation, fortran language.

CHAPTER III

METHODS

A. Model Description

Most models are concerned with changes in variables through time and in space. This model deals with an isolated, restricted ecosystem, and the space-related variables are concerned with soil depth as a dimension. This model deals only with changes through time for an ecosystem where soil depth is specified as an input constant for each model run.

Ecosystem energetics is expressed as biomass accumulation and loss throughout annual cycles. Dominant stresses which control energy and nutrient dynamics are factors which partially or wholly control biomass of individual species populations. These stresses are coupled in such a fashion as to permit discernment of their individual roles in controlling population dynamics.

The model presented is mathematically similar to the Grassland Biome ELM models in that it utilizes finite difference equations to simulate ecosystem dynamics (Van Dyne et al., 1978; Van Dyne, 1979). The series of models developed during U.S. IBP Grassland Biome studies focuses upon plant production required to support domestic and nondomestic herbivores in managed ecosystems. The Granite Outcrop simulation model is based upon demographic fluctuations in major living components of the ecosystem, that is, dominant plant species. Fluctuations in energy flow and nutrient cycling are related to

quantitative and qualitative alterations in environmental stress. Virtually all other models which simulate population dynamics or growth utilize differential forms of logistic equations. Biotic growth functions utilized are developed from actual biomass data collected by numerous workers over the past twenty years. Growth and decay of each species population is represented by a series of equations which describe the real-life growth and decay of the organisms.

By utilizing the three dominant annual plant species and two aggregated categories which comprise the majority of the biomass, daily fluctuations in the distribution of five nutrients is estimated. Dynamics of the five biotic components have been estimated by a specific series of multipliers based upon their annual cycles. At the beginning of their cycles, initial growth of annual species is estimated on the basis of peak production during the previous growing season. Dynamics of growth and decay of perennial biota have been estimated through cosine wave functions.

Water is the single most limiting factor in granite outcrop ecosystems. In the granite outcrop ecosystem model, water stress was developed as a complex function correlating soil depth, temperature, rainfall, and a variable derived from seasonal evapotranspiration rates. Fortunately, the permanent wilting point for all three dominant vascular components examined is a constant 2.0% (25 bars extraction) (Sharitz and McCormick, 1973). As long as soil moisture levels remain above 2.0%, the water stress variable ranges from 1.0 to 2.0. When the available moisture drops below the wilting point, the water stress variable

becomes an increasingly smaller fraction. The daily rate of growth of each species was multiplied by the water stress variable, resulting in less (or no) increase in biomass for the days in question.

Primary connectance in granite outcrop ecosystems is due to nutrient retention. As the vegegation of one season begins to senesce, new generations of other plant species are beginning to grow. Destruction of a major plant component or decreased growth of one or more plant species can result in significant loss of an essential nutrient through leaching. Thus, a stress which affects either a nutrient cycle, growth of a major species, or phenology of growth events can result in a long-term perturbation to the system.

Nutrient cycles have been estimated by functions which are specific for each biotic compartment and specific for rates of transfer which change through time within those biotic compartments. Nutrient limitation of growth has been estimated by proportional reduction of increased biomass in each compartment whenever any nutrient has become reduced below a predetermined minimum.

Figure 7 is a schematic drawing of model operation. The schematic shows only one soil nutrient reservoir. Functional multipliers for incorporation of each nutrient into each biomass compartment vary, but pathways are all essentially the same. Figure 8 is a schematic diagram of nutrient relationships with a single biomass compartment. Specific interactions, multipliers, and functions are discussed in detail in Appendix A.

Figure 7. Schematic Diagram of the Annual Plant Community Model of the Granitic Outcrop Ecosystem.

A. Inputs and driving forces for the model system.

B. Biomass compartment; 1. represents time-variable multiplier; 2. represents a nutrient storage component of the biomass; 3. represents primary productivity as biomass.

C. Passive storage compartment.

D. Functional multiplier; a × b = c, arrows show direction of flow.

E. Condition switch; a condition of b. determines whether a. proceeds to c.

F. Heat sink.

G. Single function timer switch.

Nutrients are lumped to simplify this overview of the model system.

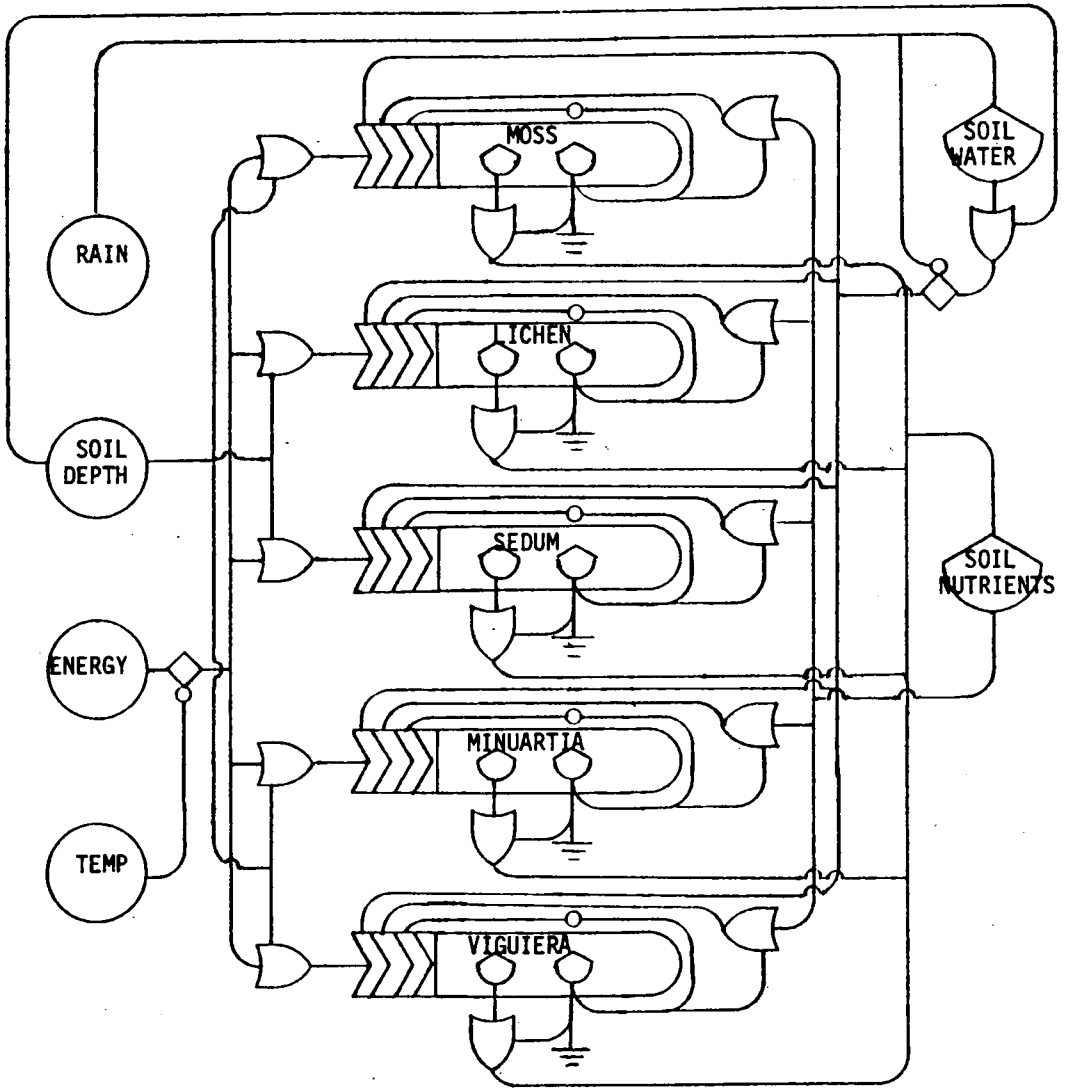

MOSS
LICHEN
SEDUM
MINUARTIA
VIGUIERA
RAIN
SOIL DEPTH
ENERGY
TEMP
SOIL WATER
SOIL NUTRIENTS

Figure 7

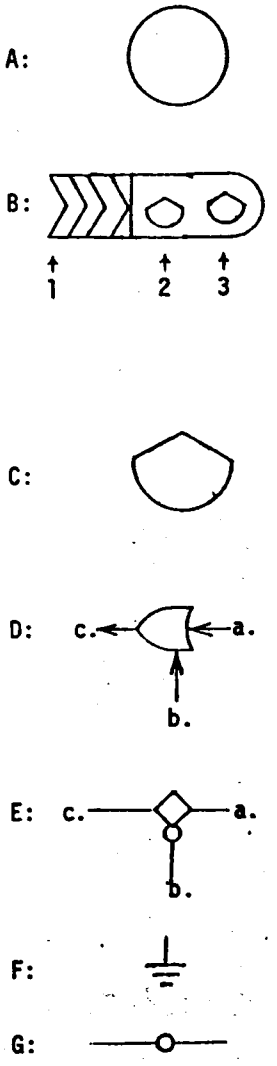

A:
B:
1
2
3
C:
D:
c.
a.
b.
E:
c.
a.
b.
F:
G:

Figure 8. Detail of the Biomass/Nutrient Transfers of the Model System. Nutrients represented are N—nitrogen, P—phosphorus, K—potassium, Mg—magnesium, and Ca—calcium. Elements of the diagram are:

A. Passive storage.

B. Functional multiplier.

C. Operational switch; condition of a. determines whether b. proceeds to c. or to d.

D. Production compartment; enclosed storage represents each nutrient plus B, biomass.

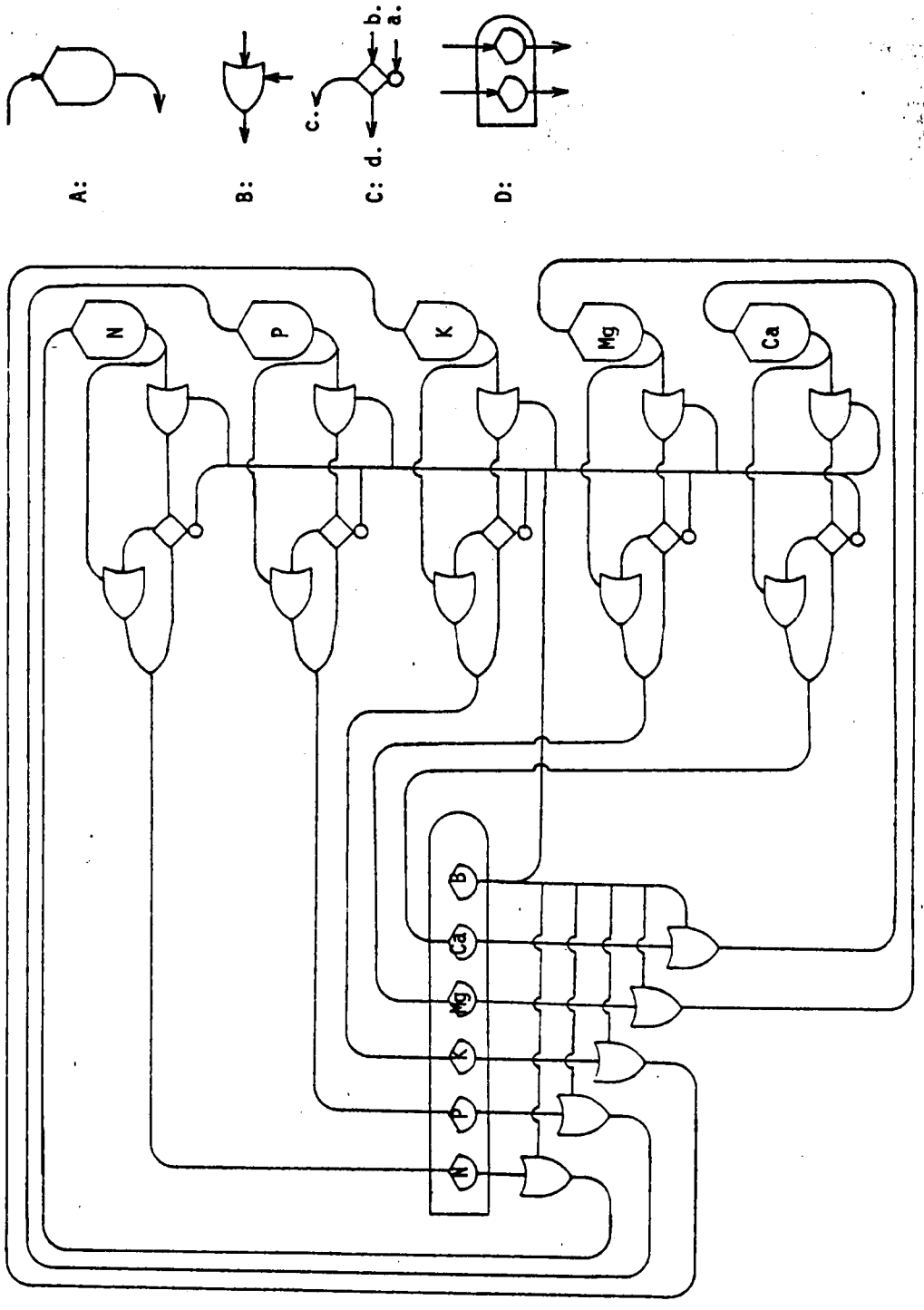


Figure 8

The magnitude of biomass variables increase as a result of multiples based upon regression of actual biomass data through time. In this model, these equations are therefore algebraic analogs of known or specifically postulated biological phenomena. They have a finite difference form based upon a time step of unity representative of days. Lassiter and Hayne (in Patten, 1971) utilized a similar series of finite difference equations to test whether such equations could accurately represent changes in variables in systems as complex as ecosystems. Many of the Grassland Biome study models utilize finite difference equations. The ELM-grassland models have been tested repeatedly, and new uses of model techniques and strategies developed in the IBP grassland biome studies are used frequently (C.F.: Wright and Van Dyne, 1981; Van Dyne, 1981; Kantz et al., 1982).

Lassiter and Hayne (1971) utilized a scaled sine wave to simulate annual climatic change. Sufficient precipitation and temperature data have been available in Knoxville (Fribourg et al., 1973, and Fribourg, pers. comm.) to develop functions which generate daily precipitation and daily mean temperature. These functions were based upon weekly precipitation probabilities and mean temperature over a twenty year period.

Bledsoe and Van Dyne (in Patten, 1971) utilize functions which generate cosine curves to represent biomass and some additional fluxes. Moss and lichen biomass in granite outcrop ecosystems follow similar patterns, and the functions which represent their growth and decay are delayed cosine functions, stepped to a daily incremental (difference)

time scale to match other difference equations for biomass growth in this model.

Patten (1972) pointed out that linearity within a model which uses differential equations is necessary to avoid problems involving complex pattern interactions. The algebraic functions (difference equations) of this model have sufficed to overcome potential problems of linearity.

The model developed here was written in Fortran-10. It is site-specific and utilizes linear difference equations to represent growth and transfer functions. It was developed from a mechanistic viewpoint; that is, all effects represented were quantified by physical and/or chemical actions. Connectivity in the granite outcrop ecosystems is primarily related to nutrient retention and soil moisture/plant competition interactions. Development proceeded from the premise that all variables were known at each point in time. This premise establishes that the driving variables were completely determined.

However, stochastic manipulation was required to compensate for unexplained variation in control. Thus, the growth functions were based on best-fit of "normal," real data. Rainfall and temperature functions are probabilistic, based upon a twenty year data base. Therefore, this model contains some functionally stochastic predictions in order to compute changes in state variables which would otherwise be totally deterministic.

B. Model Components and Functions

Model functions and components are described below. Relationships of these functions and components to specific stresses are defined, and specific types of information required to develop anthropogenic stress functions within the model system are described.

B.1. Soil Depth Relative to Ecosystem Structure and Functional Components

Among the inputs required by the model is the specification of a soil depth. Relationships of species distribution, abundance, and community structure to soil depth has been well documented (Whitehouse, 1933; Oosting and Anderson, 1939; Burbank and Platt, 1964; Sharitz and McCormick, 1973; Meyer, 1972). The property of soil depth is a required model input to determine the proportion of normal, expected growth each biotic component attains.

In addition, soil depth has a functional role in determining a water stress factor. Shallower soils are depleted of moisture at a much more rapid rate than are deeper soils.

Calcium availability in granite outcrop systems and rate of mineralization of nitrogen and phosphorus is also related to soil depth. Availability of other soil nutrients is highly variable and soil depth seems to have little effect on total availability.

B.2. Rainfall, Temperature, and Evaporation Factors

To provide realistic data, rainfall was generated in the model according to daily probabilities of events of specified amounts. Twenty

years of rainfall data were analyzed by Fribourg (1973) to provide the basis for developing rainfall approximations. Rainfall figures which are generated play an essential role in calculating the water stress coefficient.

In the current form of the model, temperature was utilized directly only to produce zero growth, which occurs below freezing. The equation which generates a temperature value utilizes a cosine function around a mean and bounded by the average difference between mean minimum and average, and mean maximum and average. Accuracy of this generator is limited because of seasonal differences in the range of mean high and mean low temperatures from the average. For this reason, the calculated daily mean temperature was not utilized directly in determining factors such as water stress and loss of biota due to forst-heave or extreme cold.

Both the rainfall and temperature functions depend upon a random number generator. This generator selected at random from the range of possibilities for a given day as described by a 20-year data base for mean daily precipitation and temperature. This provided a basis for a realistically random pattern of rainfall events and mean daily temperatures. A note of explanation concerning the DECSYSTEM-10 random number generator is in order.

First, the random number generating function itself requires a "seed," or numerical starting point from which to begin operation. In this case, any integer will suffice. However, the generator currently in operation produces a sequence of random fractions at precisely the same starting point, regardless of differences in

initiating "seeds." For this reason, the model calls for: "a pair of pseudorandom integers, four digits each . . . ." One of these integers acts as the random number generator seed. The other causes the generator to perform that number of operations before the fractions produced are used in the model. This permits 9999 potential starting points for the generator, and sequencing is randomized.

One specific benefit of this type of random number generating operation has been that use of the same pair of pseudorandom integers in subsequent model runs produce identical rainfall and temperature conditions within the model. This permitted other factors to be altered, and comparisons to be made of the subsequent influence of these factors.

The evaporation factor EVAP(I) should more properly be called a mean water loss factor. Lugo (1969) provided data showing water lost from an ecosystem on a monthly basis. By extrapolating this data into a series of functions, daily estimates of water loss were determined. These estimates (with a conversion factor) were used in determinations of daily estimates of water stress.

B.3. Soil Nutrients

Many of the variables in the model required initializing values. These values had to be of a form to fit the dimensioned data array. The array provided for 2191 values for each variable. This permitted the counting index, "I," to be used to set initial values, where "I" equals 1. Throughout the major portion of the model, the "I" value is one digit

higher than the number of "days" or iterations of the major loop. When some process began on "day" 44, the "I" counter read 45.

Critical among the initial values were five nutrients selected for inclusion in the model. Initial values for calcium, magnesium, potassium, phosphorus, and nitrogen were sufficiently large to permit normal maximum biomass values to be generated when all other conditions were favorable. However, they were also small enough to permit the development of stresses should any of them become depleted due to the direct or indirect action of stressors. Initial soil nutrient values may be adjusted if required.

Uptake and loss of nutrients in each of the five taxa were derived from Meyer's (1972) data and rechecked with data from our own systems. Equations within the model which determine nutrient contents of the species were based upon seasonal changes in rate of uptake (or loss) on a per-gram of biomass basis. Figure 9 is an illustration of the data employed to develop the equations used to determine the calcium content of a one meter square population of Viguiera porteri. An example of data derived from Meyer's work is found in Table 4.

Because of very low biomass on day 59, and because at very early stages of growth the total calcium content in even an ideal population of V. porteri would be minimal, regression analysis was performed upon only the last seven data points. This resulted in an F-value of 22.5 for 1/5 degrees of freedom, or a very high ($p > 0.001$) significance level. The resulting estimate of calcium in V. porteri is a single equation:

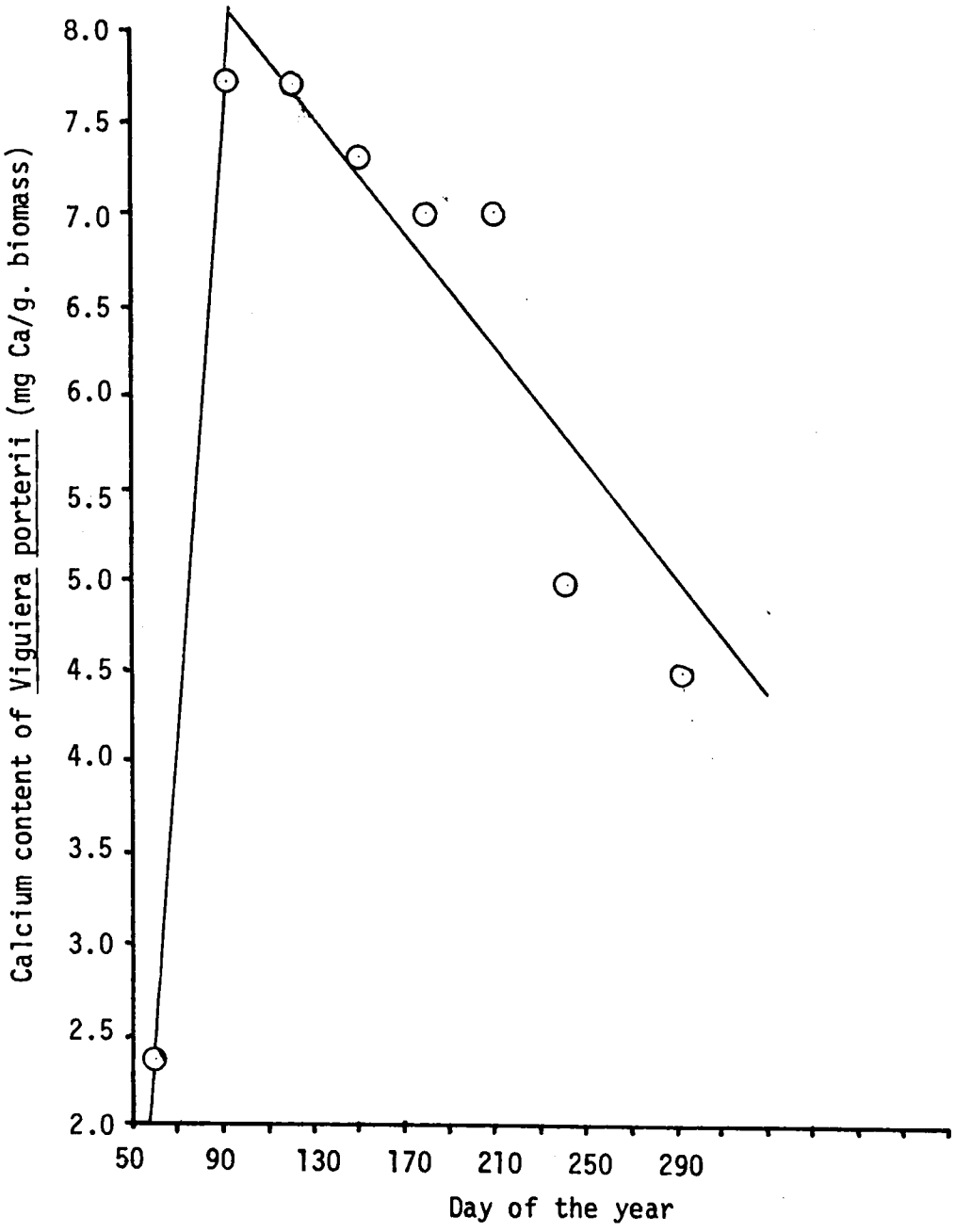


Figure 9. Calcium per Gram Biomass of Viguiera, by Time.

Table 4

Determination of Calcium Content in *Viguiera* Biomass on a Seasonal Basis

Day	Biomass (grams/meter square)	mg. Ca, ttl.	mg. Ca/g. biomass
59	6	14	2.333
90	22	169	7.6818
120	40	306	7.65
151	58	427	7.3621
181	98	687	7.0102
212	150	1046	6.9733
243	214	1061	4.9579
273	261	1175	4.5019

VPCA(I)=VPBM(I)*(9.918-(.0192*(X)))

where VPCA(I) is the total calcium content of V. porteri at "day" I, VPBM(I) is the biomass of V. porteri at "day" I, 9.918 is the intercept point, -.0192 is the slope of the regression line, and X is a real number equivalent to "day" I.

This equation was used throughout the life cycle of V. porteri. Note that the slope multiplier, (X), has become (X-365.) at the onset of germination in the second "year" of model functioning (more precisely, at "day" 411). For each subsequent "year," the value was altered by -365.

This same procedure was utilized to determine functions controlling nutrient content of each biotic component. At the end of each iteration of the model ("day"), soil nutrient contents were adjusted by subtracting total daily change in nutrient content of all biota.

Any time a soil nutrient value fell to a point where 1% of total soil nutrient is less than the amount of that nutrient required by a biotic component, biomass of that taxon is reduced. The reducing factor was 1% of total soil nutrient divided by the amount required by the species. This factor was therefore a fraction, which was then multiplied by the calculated biomass of the species to produce a new, lower biomass figure for the species for that "day."

B.4. Description of the X Variable and Its Initial Value

The "X" variable in the equation for calcium content of V. porteri has been mentioned. This variable is simply a real number equivalent of

the integer "I" which may be interpreted as an iteration or "day" counter. In mathematics, "mixed-mode" operations (integers acting mathematically with real, or decimal numbers) are often unacceptable, as they do not indicate whether the result is real or should be truncated at the decimal point to form an integer. The model avoids the question by using a real number equivalent of "I," and sets the preiteration value of X at 0.0.

B.5. Growth Factors and Soil Depth

The need to relate growth functions of biota to the mean soil depth of the ecosystem has been explained. While all five dominant taxa are distributed differently along soil depth gradients in the granite outcrop ecosystem, this model was designed to examine a one-meter square area of that system at a single, specific soil depth. Using biomass/soil depth figures from Sharitz (1970), regression equations for biomass of a species at a given soil depth were developed. An example of this is data used to develop the relationship of lichen growth to soil depth. Table 5 presents the data used to generate regression equations, where the maximum attainable biomass has been observed to be 196 g. per meter square. A regression curve was calculated for data from 1 through 9 centimeters of soil depth (based on percent of possible maximum). This resulted in the equation:

```
GFL01=(2.853*(EXP(.37*SDPTH)))/100
```

where GFL01 is the proportion of maximum growth, EXP is the base of

Table 5

Lichen Biomass per Meter Square and Proportion of Maximum Lichen Biomass by Soil Depth Category

Soil Depth (cm.)	g. Biomass/Meter Square Lichens	Percent of Possible Maximum: (2/196.*)x100
1	8.	4.13
3	20.	8.65
5	56.	18.145
7	84.	38.03
9	172.	79.708
11	184.	84.01
13	132.	60.834
15	82.	37.658

*A mean maximum value of 196 g. lichen per meter square has been observed (Berg, unpublished).

Data from Sharitz, 1970.

natural logarithms (e) to the (0.37*SDPTH) power, and SDPTH, is the entered soil depth. The soil depth at which 100% of maximum biomass was attained is approximately 9.619 cm.

A regression line for lichen biomass percentage at soil depths 11 through 15 proved to be a straight line:

GFL01=211.478-(11.588*SDPTH))/100

Once again, 100% of maximum biomass was attained at approximately 9.62 cm. of soil depth.

Through the use of a "conditional IF" clause, the equation actually used to generate the GFL01 value was determined by the entered soil depth (SDPTH). Adding the appropriate clause to the beginning of each equation produces functions in the form:

IF (SDPTH.LT.9.62) GFL01=(2.853*(EXP(.37*SDPTH)))/100

IF (SDPTH.GE.9.62) GFL01=(211.478-(11.588*SDPTH))/100

Clauses should be read as: "If soil depth is less than 9.62," and "If soil depth is greater than or equal to 9.62," respectively.

Through the use of these equations, calculated biomass for each of the soil depths in Table 5 are found in Table 6. Using GFL01 values for the indicated soil depth, reduced proportions of maximum lichen biomass are calculated. By plotting calculated values and actual values on the same graph, the closeness with which these equations apportion lichen biomass by soil depth (Figure 10) becomes apparent.

Similar manipulations of data from Sharitz (1970) and Meyer (1972) produced similar growth-limiting factors relative to soil depth for each of the remaining biota. These growth factors were then used as

Table 6

Lichen Biomass Predicted for a Range of Soil Depths
Using GFL01 Factors

Soil Depth (cm.)	g. Biomass (as 196*GFL01)
1	8.096
3	16.968
5	35.563
7	74.538
9	156.228
11	164.66
13	119.23
15	73.81

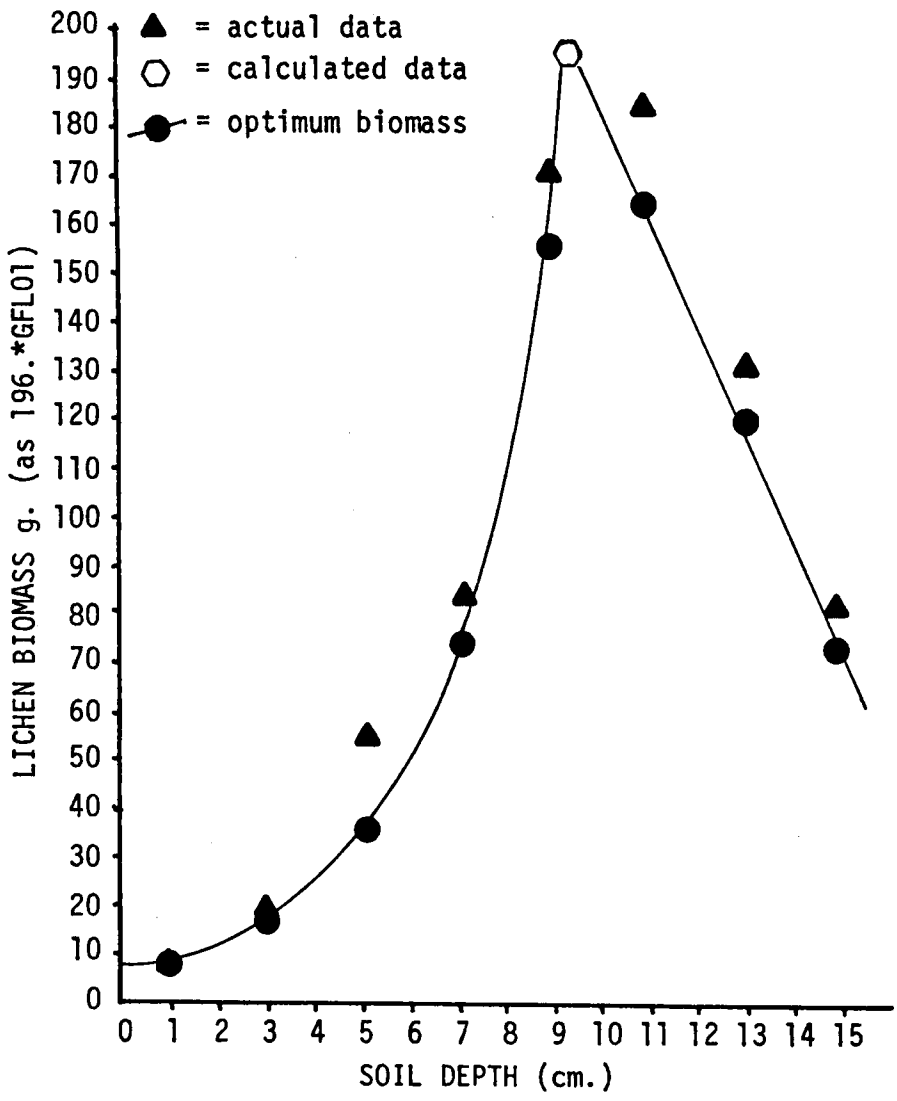


Figure 10. Lichen Biomass versus Soil Depth.

fractional multipliers within biomass generating equations. Because some of the growth factor equations produced values greater than 1.00 (100%) or less than 0.0 as a result of uncommon soil depth entries, each of the factors was provided with a limiting "conditional IF" statement. For example, soil depths greater than 18.24 cm. produced negative GFL01 factors for lichens. Since total lichen biomass could not be less than 0.0 grams per meter square, the expression:

```
IF (GFL01.LT.0.0) GFL01=0.0
```

was used to restrict values of GFL01 to positive values or zero. A full translation of the entire expression is: "If lichen growth factor one is less than zero, lichen growth factor one equals zero."

B.6. Initial Values of Lichen and Bryophyte Biomasses

A brief explanation of initial biomass values for bryophytes and lichens is needed. Both of the dominant nonvascular biotic components of this ecosystem follow a continuous, rhythmic growth cycle. An examination of their biomass on an annual basis showed clearly that they each attained maximum biomass after cooler, wetter times of year, and attained their lowest biomass after the summer drought. Since this model operates on a calendar year cycle, and both of these components began near the perogee of their annual biomasses, an estimate of their biomasses for the beginning date of the model was supplied. This provided each of these components with a realistic starting point from which to begin (or continue) their normal life cycle.

Using a cosine function which has a total period of 2x pi (values of -1 to +1 to -1) delayed by 15 days worth of (2pi/365) to attain the value for January 1 from the mid-December low, the equation:

ALBM(0)=(196.+(COS(3.39981)*22.5)*GFL01

was developed, where 196. is the mean maximum value, 22.5 is the span, and 3.39981 is the approximation, pi*(15*(2pi/365)). Since the function, (196.+(COS(3.39881)*22.5) is a constant equalling 174.2459, the initial value of ALBM(I), or ALBM(1) was set at 174.2459*GFL01. This same procedure was used to determine an initial value for bryophyte biomass, BBMD(I). The bryophyte constant is 400.2533, and BBMD(1)=400.2533*GFB01.

B.7. The Major Loop; Generation and Transformation of Variables

The major loop was performed cyclically a total number of times equal to the number of years entered times 365 plus 365. Each iteration of the loop corresponded to one "day." For example, if the user entered "5" in response to the request for "number of years simulation required," the major loop performed (5X365)+365, or 2190 iterations. The first 365 iterations were performed for the purpose of establishing and stabilizing the variables within the model, and were not written into the output file. The iteration or "day" counter is the variable "I."

The first major functions performed by the loop were the generation of that "day's" rainfall and mean temperature. In addition, the initial value of X, our real-number equivalent of I, is changed by adding 1.0 to it. From an initial value of 0.0, for iteration I+1, X=0.0 +1.0, or 1.0.

The next phase of the model contains the two groups of equations which generate biomass and nutrient content for the two nonvascular biotic components. Development of the basic equations for lichens and bryophytes was discussed earlier in section B.6. The basic equation was incorporated in the full growth function. Primarily only new (or current) growth of organisms was restricted or influenced by stresses. Only the increment of biomass produced that "day" was subjected to the stresses of that day. Using lichens again, the principal growth function:

ALBM(I)=(1.96+(COS(3.39981)*22.5))*GFL01,=174.2459*GFL01

which was used to determine the initial (I=1) biomass became:

ALBM(I)=ALBM(I-1)+((SIN(.25822+(X*.017214))*.387278)*GFL01*WSTRS(I))

when only daily changes in biomass were operated upon by stress factors. In this form, the SIN value (15*(2pi/365)) of the primary equation was multiplied by the constant .017214 which is the total annual period of the cosine function (2pi), divided by 365. This served to alter the value of the sine function from -1 to +1 to -1 during the annual cycle.

This equation, with additional considerations nullified, would generate a difference in biomass value for ALBM(I). This value was then multiplied by the soil depth controlled limiting growth factor (GFL01) discussed previously. Next, the quantity was multiplied by the water stress coefficient (WSTRS(I)), which has an annual mean of 1.0 and ranges from 0.0 during dry periods to 2.0 during wet, favorable periods. Finally, this modified amount of new biomass (which was positive or negative, for growth and decay, respectively) was added to the previous

day's lichen biomass. By utilizing a stepwise mathematical configuration for growth and decay rather than a continuous integral configuration, minute changes (1 day out of 5 years) can be analyzed in specific detail, and comprehension of these changes and the effects that caused them could be interpreted and understood with greater ease by large numbers of model users.

Following generation of a daily biomass figure, nutrient content of the species was calculated. In the case of lichen, calcium and magnesium are each constant concentrations throughout the annual cycle. To obtain total nutrient content of a species on a meter square population basis, biomass in grams was multiplied by nutrient content in milligrams per gram. This results in an estimate of nutrient partitioned into lichen biomass per meter square. In instances where nutrients were incorporated in constant concentrations per unit biomass, such as calcium, the equation was simply:

```
ALCA(I)=ALBM(I)*3.357
```

However, often the nutrient content of a species varied throughout an annual cycle, as seasonal climatic changes generated different physiological requirements.

For example, an examination of the changes in potassium content of lichens (Meyer, 1972) revealed that changes occurred in a cosine wave pattern, similar to the function for growth. By determining a mean concentration (0.620 mg./g.) and a span of mean-to-maximum (or mean to minimum; 0.323 mg./g.), the cosine function for concentration was multiplied by the biomass:

```
ALK(I)=ALBM(I)*(.620+(COS(3.39981*(X*.017214))*.323))
```

Note that the periodicity coincided with that of the growth function (3.39981, and 0.017214). Nutrient equations for phosphorus in lichens (ALP(I)) and nitrogen in lichens (ALN(I)) were found to be nearly identical to the equation for potassium in lichens. The only differences for ALP(I) and ALN(I) equations were their means (1.103 mg./g. and 12.0 mg./g. respectively) and their spans (0.63 and 5.38, respectively). Except for changes in means, spans and constants, the series of equations governing bryophyte biomass (BBMD(I)) and its nutrients (BBx(I)) were found to be the same in all respects to those of lichens.

In describing the equation series for lichens and bryophytes, careful consideration of the composition of the daily water stress factor (WSTRS(I)) was omitted. This is simply due to the order in which the developed variable equations and functions appear in the model.

As mentioned previously, the water stress coefficient is determined by three primary factors: water loss, rainfall, and soil depth. These factors have been discussed previously.

According to Sharitz (1970), only three days of warm, dry weather were required to deplete soil moisture of very shallow soils to the wilting point (2.0% or 25 bars). In order to calculate WSTRS (I), an intermediate variable (WP1(I)) was generated first. WP1 has a mean annual value of zero, and was varied according to soil depth, as exemplified by the following equation:

IF (SDPTH.LE.1.0) WP1(I)=((RN(I-2)+RN(I-1)+RN(I)))-((EVAP(I-2)+EVAP(I-1)+EVAP(I))/8.7422)

This is simply the sum of rainfall minus the corrected sum of water losses for three days (current I and the two I's immediately preceding). A correction factor for water loss coefficients was found necessary for the annual mean value of WP1(I) to equal 0.0.

For soil depths ranging from one through more than nine centimeters of soil depth, one additional rainfall and water loss factor were added for each centimeter of increased soil depth. For example, if the entered soil depth were 5.5, WP1(I) would be calculated by the following equation:

```
IF ((SDPTH.GT.5.).AND.(SDPTH.LE.6.)) WP1(I)=((RN(I-7)+RN(I-6)
+RN(I-5)+RN(I-4)+RN(I-3)+RN(I-2)+RN(I-1)+RN(I)))-((EVAP(I-7)+EVAP(I-6)
+EVAP(I-5)+EVAP(I-4)+EVAP(I-3)+EVAP(I-2)+EVAP(I-1)+EVAP(I))/8.7422)
```

which encompasses eight days' rainfall and water-loss factors.

As previously stated, it was necessary that the annual mean value of the water stress coefficient be 1.0. In order to obtain a reasonable range of values (from 0.0 during dry periods, which results in no growth to 2.0 during wet periods which results in a temporary doubling of the rate of growth) "conditional IF" statements were employed to restrict values of WSTRS(I) to this range:

```
IF (WP1(I).GE. 1.0) WSTRS(I)=2.0
IF (WP1(I).LE.-1.0) WSTRS (I)=0.0
IF ((WP1(I).GT.-1.0).AND.(WP1(I).LT.1.0)) WSTRS(I)=1.0+WP1(I)
```

One additional use of the WSTRS (I) variable was temperature related. If daily mean temperature (TEMP(I)) is 0.0 or negative, WSTRS (I) becomes 0.0, regardless of moisture content.

Equations which determined biomass and nutrient content of three dominant vascular species were grouped according to short time spans where individual functions were operational. Whenever one or more of the major biomass generating equations changed to allow for differential growth or decay patterns, any other functions of the series were altered as required, then placed into a new group. This was primarily due to the greater ease with which changes determining biomass generation could be followed and altered.

Annual cycles of Viguiera porterii are considered first because it is the first vascular plant to germinate in the calendar year time frame of this model. Table 7 contains a portion of biomass and nutrient information Meyer (1972) developed for V. porteri. A graph plotting actual data points through time, and lines representing results of regression analysis of portions of the data are presented in Figure 11.

The first portion of the decay curves were also developed from data presented by Meyer. It was necessary, however, to alter the decay in order to prevent duplicity of values. If the slope of the line of the first decay equation were continued, it would overlap the germination period and early growth phase of the subsequent year's biomass. Misleading values of VPBM(I) would be developed. This overlap of last season's dead biomass with this season's new growth does occur on the natural outcrop ecosystem but by the time germination occurs, nearly all the nutrient content has been leached out of the dead biomass. In order to more accurately reflect nutrient cycles, the decay curve for biomass of V. porteri was altered. Figure 12 presents the calculated biomass

Table 7

Seasonal Distribution of Nutrients in
Viguiera porteri Populations

	Biomass	Ca	Mg	K	P	N
Feb.	6.0	0.014	.003	.004	.003	-----
Mar.	22.0	0.169	.083	.242	.039	-----
Apr.	40.0	0.306	.150	.440	.070	1.510
May	58.0	0.427	.212	.696	.144	1.708
June	98.0	0.687	.231	1.277	.196	2.594
July	150.0	1.046	.239	1.042	.197	2.461
Aug.	214.0	1.061	.222	1.230	.205	2.231
Sept.	261.0	1.175	.259	1.83	.244	2.771

From Meyer, 1972 (this is Meyer's Table 20).

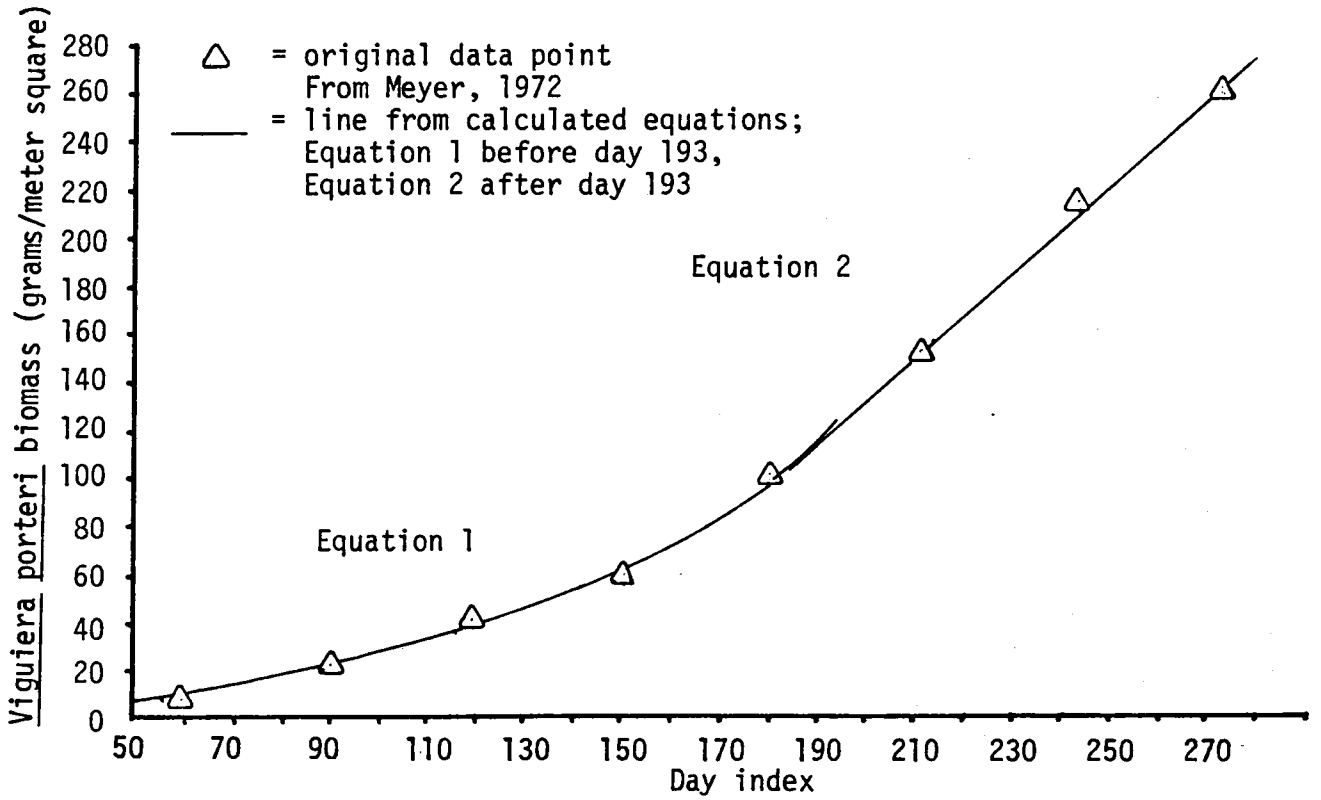


Figure 11. Viguiera Biomass, as Grams per Meter Square: Optimum Production by Date.

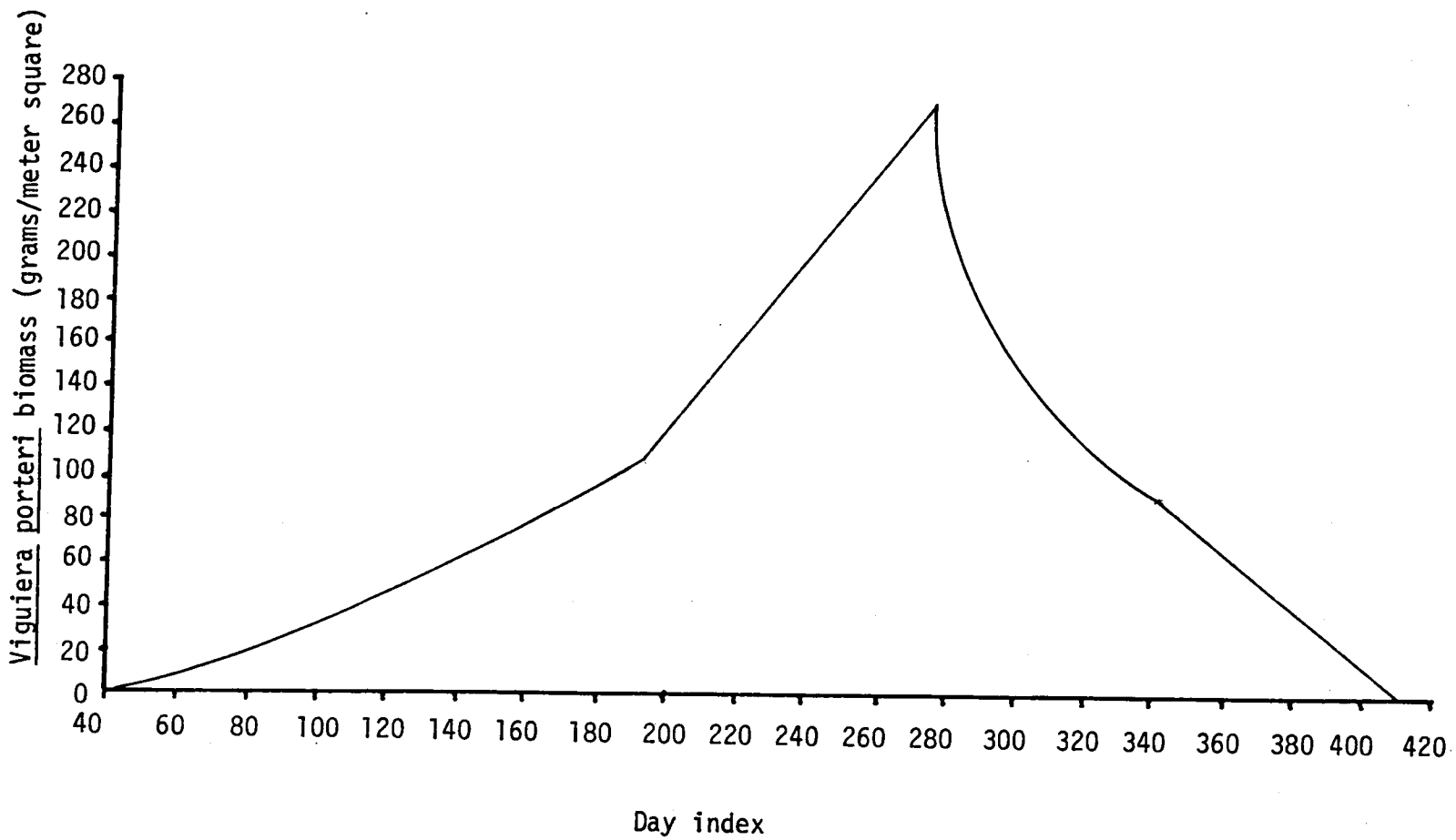


Figure 12. Viguiera Annual Optimal Biomass Production, Grams per Meter Square by Day.

attainable by Viguiera porteri for an entire annual cycle. The equations for this annual cycle and their appropriate "conditional IF" switching functions are:

```
     IF ((I.GT.45).AND.(I.LE.194)) GO TO 50
50   IF (I.EQ.46)VPBM(I)=.077*GFV01
     IF (I.GT.46) VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFV01*
                  WSTRS(I))
```

This equation operates from day 45, where I=46 (the best-estimate of germination date), through day 193, where I=194. It is an exponentially increasing function similar to many other early growth representations:

```
     IF ((I.GT.194).AND.(I.LE.278)) GO TO 60
60   VPBM(I)=VPBM(I-1)+((1.8745)*GFV01*WSTRS(I))
```

The equation operates from day 194 through day 277 (I's of 194 and 278, respectively). This is basically a linear increasing function with its constant (intercept) value equal to the Viguiera biomass figure generated on the last day the previous equation was operative:

```
     IF ((I.GT.277).AND.(I.LE.338)) GO TO 70
70   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
```

This represents the first phase of decay of Viguiera. Losses were found to be extremely rapid during this phase. Once again, the constant was the Viguiera biomass generated in the last iteration of the previous equation. Water stress (WSTRS(I)) was assumed to play no role (or an insignificant role) in decomposition, so is omitted:

```
     IF ((I.GT.339).AND.(I.LE.410)) GO TO 100
100  VPBM(I)=VPBM(I-1)-(1.2214*GFV01)
```

This final phase of decay was determined to be linear. Once again, the intercept was the last figure generated by the previous equation.

At this point in the model, a new generation of V. porteri was germinating. This occurred on day 410 (I=411), of the model operation (45+365). In order to incorporate the effects of stress upon the population during the previous growth cycle, the content for the new season's first equation was derived from the maximum biomass produced the previous year. Since the constant given in the primary growth equation was 0.077, and the optimum attainable biomass was 273.47 (a mean of twenty years of operation without stress), the VPBM(278) was divided by 3551.5584 (273.47/0.077). However, recovery of a population from the effects of stress often takes place in the germination and establishment phase the following season. A rough estimate of the recovery of V. porteri by enhanced establishment of new seedlings due to a reduction in competition was contained in a slight power-curve shaped alteration to the equation. The factor 2.719 times 273.47 to the 0.882 power equals 273.47. Any increase above 273.47 as a value of VPBM (278) generated a proportional decrease in success of the seedlings. At the same time, enhanced establishment occurred at values less than 273.47. For example, if only half the optimal biomass was attained, a 13% enhancement of reproductive success was produced. (2.719*(136.735**.822)= 154.91) and the biomass produced would be as though VPBM (278) were 154.91 grams instead of 136.735 grams. The equation used to determine the initial biomass for day 410, the beginning of the second growth cycle of V. porteri, is thus:

```
VPBM(411)=((2.715*(VPBM(278)**.822)/3551.5584)*((X-409.)**1.447)
*GFV01)
```

The value generated here was used in subsequent iterations which require the first phase of V. porteri growth during the second year (days 410 through 558). Note that X has become X-409. The form of this equation is the same as the first growth function:

```
VPBM(I)=VPBM(I-1)+(.26145*(VPBM(I-1)**.2804))*GFV01*WSTRS(I))
```

This same process was used on Meyer's data for V. porteri nutrient concentrations and the sets of equations for Sedum smallii and Minuartia uniflora and their nutrient concentrations.

Each series of equations was repeated the required number of times to produce up to 6 years of iterations by altering X factors and by changing the biomass values used to generate new growth by adding 365 to the index (I value) each year. At the end of the biomass and nutrient uptake phase of each iteration, recalculations were made of soil nutrients and biomasses. It was at this point that soil nutrient values were adjusted. At this time, all values calculated during an iteration of the major loop were written into the output file.

CHAPTER IV

IMPLEMENTATION OF THE MODEL

In its current form, the model BMAS14.FOR (Appendix B) requires an interactive computer system whereby the user enters data as requested by the model program. At The University of Tennessee, Knoxville, the Decsystem-10 computer has such an interactive capability.

The model program was written into a single file of ASCII characters on a random-access magnetic storage disc. Decsystem-10 Fortran was the language of choice because of its developmental and editing simplicity (copyright held by Digital Equipment Corporation, Maynard, Massachusetts, 1977, part number AA-0944E-TB).

Prior to execution, the program is compiled into a binary equivalent of the ASCII characters. The binary file, designated with the extension ".REL" is a machine language file, and program operation translates back and forth from binary to ASCII to binary during interactive operation.

Information required for successful use of the program includes random numbers for initiation of the random number generator in the computer system. In addition, the user must enter values for proportional precipitation, soil depth, and the number of years of output data desired (maximum number of years is five).

The program output is written into a magnetic disk file, and may be examined or printed as the user wishes. Care must be taken to be certain sufficient space is available for the output file, which may

exceed 1300 blocks. When utilizing the model, output file names and extensions (maximum length of six characters and three characters, respectively) should reflect the content and entered variables. For example, output file BMAS3D.110 contains data from 3.0 centimeters simulated soil depth, and a precipitation proportion of 1.10, or a 10% increase above normal. Note that file name and extension are separated by a period.

Twenty-two executions of the model were made to accumulate sufficient data for testing purposes. Each execution contains four years of data. The input variables utilized in the executions are summarized in Table 8. The first five 4-year runs were made to determine a twenty-year mean and standard deviation for normal precipitation. The next seventeen runs, 4 years each, all utilized the same pair of pseudorandom integers as input. This permitted repetition of identical basic precipitation and temperature patterns for several soil depths. In addition, effects of rainfall proportionally altered from the norm were assessed. The results of the generated data are presented in Chapter VII.

Table 8

Summary of Entered Constants for Twenty-Two Test Runs of Model BMAS14.FOR

Random Numbers Entered	Precipitation Proportion	Soil Depth (cm.)	Years Output	Output File Name
8361,2070	1.00	3.0	4	BMAS3B.OUT
5443,4723	1.00	3.0	4	BMAS3C.OUT
4930,0883	1.00	3.0	4	BMAS3D.OUT
2823,1670	1.00	3.0	4	BMAS3E.OUT
1658,6818	1.00	3.0	4	BMAS3F.OUT
4930,0883	1.10	3.0	4	BMAS3D.110
4930,0883	0.90	3.0	4	BMAS3D.090
4930,0883	1.00	5.0	4	BMAS5D.100
4930,0883	1.10	5.0	4	BMAS5D.110
4930,0883	0.90	5.0	4	BMAS5D.090
4930,0883	1.00	7.0	4	BMAS7D.100
4930,0883	1.10	7.0	4	BMAS7D.110
4930,0883	0.90	7.0	4	BMAS7D.090
4930,0883	1.00	10.0	4	BMS10D.100
4930,0883	1.10	10.0	4	BMS10D.110
4930,0883	0.90	10.0	4	BMS10D.090
4930,0883	1.00	17.0	4	BMS17D.100
4930,0883	1.10	17.0	4	BMS17D.110
4930,0883	0.90	17.0	4	BMS17D.090
4930,0883	1.00	24.0	4	BMS24D.100
4930,0883	1.10	24.0	4	BMS24D.110
4930,0883	0.90	24.0	4	BMS24D.090

CHAPTER V

RESULTS OF TEST EXECUTIONS OF MODEL BMAS14.FOR

The first five operations of the model varied only by random number initiator input. The values selected were from a table of random digits in Statistical Tables (Rohlf and Sokal, 1969). Each execution produced four years of data, and each month of each year's precipitation was summed. This data is summarized in Table 9.

The mean annual precipitation generated in the model is 129.9 (±21.5) centimeters for a precipitation proportional value (RNPROP) entry of 1.00. The end of Table 9 contains mean monthly precipitation values for the same twenty-year period.

One set of random number inputs (4930, 0993) was selected for repeated use to determine the effects of altered precipitation levels and soil depths upon biomass of the three vascular model components. A summary of the mean monthly precipitations for all four years and each of three levels of proportional precipitation is found in Table 10.

Maximum biomass produced in each year of each model iteration at each of six soil depth levels for each level of precipitation are shown in Table 11. Regression analysis of this data shows that soil depth is the primary factor responsible for varying productivity. Indications are that varying precipitation amounts by ±10% has a limited effect on productivity of Sedum smallii or of Minuartia uniflora (Table 11). However, utilizing the stepwise regression procedures in SAS-79 (SAS Institute, 1979) V. porteri biomass varies at a 0.128 level of

Table 9

Precipitation Summaries from Five 4-Year Runs of the Model

Random Number Input	8361,2070		5443,4723		4930,0883		2823,1670		1658,6818	
JAN	7.66	23.03	11.16	4.95	13.52	12.02	22.54	8.03	18.86	21.27
FEB	8.38	5.75	11.13	10.83	7.47	11.85	11.88	8.40	17.58	11.36
MAR	33.78	5.52	18.76	10.22	24.70	8.74	8.14	10.27	22.86	12.86
APR	6.78	5.39	14.87	8.62	14.77	5.73	3.37	24.59	2.55	13.30
MAY	5.35	2.73	10.25	12.36	7.40	7.69	29.85	9.71	8.54	6.11
JUN	8.83	19.15	14.15	5.24	4.65	16.31	10.21	5.89	7.66	5.04
JUL	11.06	32.61	3.80	5.97	10.96	17.29	6.79	5.33	8.50	5.23
AUG	10.15	18.39	19.04	15.99	2.47	11.30	2.95	14.01	17.44	11.49
SEP	19.88	7.87	12.42	11.92	3.37	6.48	9.19	9.27	0.99	5.41
OCT	14.04	11.84	2.80	13.48	16.72	7.19	21.75	7.35	13.55	8.73
NOV	1.23	9.47	8.87	5.96	0.48	2.31	10.65	21.69	12.91	13.50
DEC	13.66	10.69	11.92	20.14	5.18	1.56	14.25	3.80	8.14	11.89
TOTAL	140.80	152.44	139.17	125.68	111.69	108.47	151.57	128.34	139.58	126.19
JAN	17.73	4.55	35.55	4.92	6.84	15.44	15.93	12.21	2.49	23.81
FEB	6.56	4.13	17.83	15.64	16.10	17.77	15.56	21.83	14.93	12.24
MAR	8.09	13.81	10.33	24.69	24.38	10.05	17.80	6.55	16.25	6.66
APR	7.85	7.77	2.42	12.59	12.85	7.22	3.26	6.53	1.26	4.98
MAY	9.77	5.86	2.02	15.30	3.13	5.68	2.31	5.84	19.02	0.39
JUN	4.82	4.69	3.66	4.66	2.61	27.32	3.07	5.39	26.33	2.01
JUL	11.76	20.78	10.69	0.25	36.20	6.43	19.19	7.48	19.05	13.69
AUG	0.81	3.39	5.26	14.78	8.76	6.12	34.26	18.82	7.58	10.22
SEP	4.71	4.56	22.41	13.94	5.90	4.86	17.18	0.20	0.72	4.04
OCT	13.53	13.33	14.75	9.07	2.15	6.48	8.46	6.32	11.18	13.70

Table 9 (Continued)

Random Number Input	8361,2070		5443,4723		4930,0883		2823,1670		1658,6818	
NOV	3.98	5.50	3.22	15.92	8.09	8.47	10.00	14.15	16.83	1.84
DEC	4.21	0.55	21.97	13.42	22.84	24.39	15.42	4.04	1.69	3.69
TOTAL	93.82	88.92	150.11	145.18	149.85	140.23	162.44	109.36	137.33	97.22

Mean Annual Precipitation: 129.9(21.5) cm.

Mean Monthly Precipitations:

JAN	14.1(8.4) cm.
FEB	12.4(4.8) cm.
MAR	14.7(7.9) cm.
APR	8.3(5.7) cm.
MAY	8.5(6.7) cm.
JUN	9.1(7.6) cm.
JUL	12.7(9.3) cm.
AUG	11.7(7.9) cm.
SEP	8.3(6.3) cm.
OCT	10.8(4.8) cm.
NOV	8.8(5.8) cm.
DEC	10.7(7.6) cm.

(N=20)

Values are centimeters of precipitation.

Table 10

Monthly Precipitation Means of Four-Year Test Runs Compared to Twenty-Year Means

	Twenty-Year Monthly Mean	Four-Year Means RNPROP=1.00	RNPROP=1.10	RNPROP=0.90
JAN	1.41(±8.4)	12.0(±3.7)	13.1(±4.1)	10.8(±3.3)
FEB	12.4(±4.75)	13.3(±4.6)	14.6(±5.1)	12.0(±4.2)
MAR	14.7(±7.9)	17.0(±8.8)	18.6(±9.6)	15.3(±7.9)
APR	8.3(±5.7)	10.1(±4.3)	11.1(±4.8)	9.1(±3.9)
MAY	8.5(±6.7)	6.0(±2.1)	6.6(±2.3)	5.3(±1.9)
JUN	9.1(±7.6)	12.7(±11.45)	14.0(±12.6)	11.4(±10.3)
JUL	12.7(±9.3)	17.7(±13.1)	19.5(±14.4)	16.0(±12.1)
AUG	11.7(±7.9)	7.2(±3.8)	7.9(±4.1)	6.5(±3.4)
SEP	8.3(±6.3)	5.2(±1.4)	5.9(±1.5)	4.8(±1.2)
OCT	10.8(±4.8)	8.1(±6.1)	9.0(±6.8)	7.3(±5.5)
NOV	8.8(±5.8)	4.8(±4.0)	5.3(±4.5)	4.4(±3.6)
DEC	10.7(±7.6)	13.5(±11.8)	14.8(±13.0)	12.2(±10.6)

Annual Means:

Number of Years	Proportion of Normal Precipitation	Mean (±Standard Deviation)
20	1.00	129.9(±21.5)
4	1.00	127.6(±20.6)
4	1.10	140.5(±22.8)
4	0.90	114.9(±18.6)

Values are centimeters of precipitation.

Table 11

Maximum Biomass Generated for Each Vascular Species by Soil Depth, RNPROP, and Precipitation, for Four Years of Data

Soil Depth	RNPROP	Rainfall (cm.)	Sedum Biomass	Minuartia Biomass	Viguiera Biomass
3.0	1.00	111.7	36.50	10.85	0.04
3.0	1.00	108.5	23.01	7.94	0.06
3.0	1.00	149.8	28.25	9.54	0.02
3.0	1.00	140.2	37.21	11.05	0.04
3.0	1.10	122.9	36.12	10.79	0.04
3.0	1.10	119.3	23.15	8.02	0.07
3.0	1.10	164.8	28.58	9.74	0.02
3.0	1.10	155.1	37.68	11.18	0.04
3.0	0.90	100.5	33.94	10.01	0.04
3.0	0.90	97.6	21.40	7.44	0.06
3.0	0.90	134.8	25.87	8.70	0.02
3.0	0.90	126.6	34.89	10.38	0.03
5.0	1.00	111.7	22.90	30.56	0.26
5.0	1.00	108.5	13.74	23.50	0.58
5.0	1.00	149.8	16.00	23.84	0.17
5.0	1.00	140.2	22.86	30.74	0.23
5.0	1.10	122.9	23.60	31.86	0.29
5.0	1.10	119.3	14.41	24.46	0.64
5.0	1.10	164.8	16.94	25.18	0.18
5.0	1.10	155.1	23.56	31.51	0.30
5.0	0.90	100.5	22.17	29.24	0.23
5.0	0.90	97.6	13.05	22.52	0.51
5.0	0.90	134.8	15.11	22.53	0.17
5.0	0.90	126.6	22.20	30.01	0.16
7.0	1.00	111.7	14.12	58.33	0.95
7.0	1.00	108.5	8.39	47.80	2.16
7.0	1.00	149.8	9.33	43.44	0.93
7.0	1.00	140.2	13.79	57.08	0.57
7.0	1.10	122.9	14.55	60.79	1.08
7.0	1.10	119.3	8.88	49.99	2.50
7.0	1.10	164.8	9.85	45.82	0.94
7.0	1.10	155.1	14.13	58.34	0.85
7.0	0.90	100.5	13.71	55.66	0.81
7.0	0.90	97.6	7.76	44.88	1.69
7.0	0.90	134.8	8.75	40.08	0.91
7.0	0.90	126.6	13.45	55.80	0.37
10.0	1.00	111.7	4.95	97.87	4.31
10.0	1.00	108.5	3.07	83.68	7.04

Table 11 (Continued)

Soil Depth	RNPROP	Rainfall (cm.)	Sedum Biomass	Minuartia Biomass	Viguiera Biomass
10.0	1.00	149.8	3.21	67.80	5.10
10.0	1.00	140.2	5.19	98.96	2.38
10.0	1.10	122.9	5.07	100.68	4.84
10.0	1.10	119.3	3.30	89.16	8.99
10.0	1.10	164.8	3.36	72.24	5.49
10.0	1.10	155.1	5.33	101.05	2.53
10.0	0.90	100.5	4.84	94.96	3.94
10.0	0.90	97.6	2.84	76.65	5.66
10.0	0.90	134.8	3.07	62.76	4.10
10.0	0.90	126.6	5.01	96.46	2.16
17.0	1.00	111.7	0.00	0.00	49.95
17.0	1.00	108.5	0.00	0.00	66.26
17.0	1.00	149.8	0.00	0.00	66.26
17.0	1.00	140.2	0.00	0.00	42.13
17.0	1.10	122.9	0.00	0.00	55.01
17.0	1.10	119.3	0.00	0.00	83.64
17.0	1.10	164.8	0.00	0.00	73.33
17.0	1.10	155.1	0.00	0.00	44.48
17.0	0.90	100.5	0.00	0.00	46.62
17.0	0.90	97.6	0.00	0.00	53.84
17.0	0.90	134.8	0.00	0.00	56.77
17.0	0.90	126.6	0.00	0.00	38.14
24.0	1.00	111.7	0.00	0.00	113.98
24.0	1.00	108.5	0.00	0.00	140.41
24.0	1.00	149.8	0.00	0.00	155.91
24.0	1.00	140.2	0.00	0.00	106.07
24.0	1.10	122.9	0.00	0.00	124.66
24.0	1.10	119.3	0.00	0.00	176.45
24.0	1.10	164.8	0.00	0.00	171.72
24.0	1.10	155.1	0.00	0.00	111.86
24.0	0.90	100.5	0.00	0.00	106.97
24.0	0.90	97.6	0.00	0.00	114.62
24.0	0.90	134.8	0.00	0.00	135.76
24.0	0.90	126.6	0.00	0.00	96.05

significance with RNPROP, rainfall proportion. While this is not highly significant, the level of significance is indicative of the role precipitation proportion plays.

Unless precipitation varies considerably from normal amounts, there would seem to be little effect upon the growth rate of plants. Periodicity of precipitation plays a much greater role in the accumulation of biomass.

S. smallii and M. uniflora germinate at about the same time in the autumn. They break dormancy of rosettes (or "bolt") in early spring. Rainfall during the spring of the year and autumn the preceding year have a much greater effect upon S. smallii and M. uniflora growth than precipitation during any other times of the annual cycle. This can be seen in Tables 12-15.

The greatest growth of V. porteri is in mid- to late summer. A wet spring and summer generate the greatest growth for any single year.

Table 12

Precipitation Periodicity versus Maximum Growth, Year 1

Month	Precipitation (cm.)	Periods of Maximum Growth		
		Sedum	Minuartia	Viguiera
JAN	13.52	*	*	
FEB	7.47	*	*	
MAR	24.40	*	*	
APR	14.77	*	*	
MAY	7.40			
JUN	4.65			*
JUL	10.96			*
AUG	2.47			*
SEP	3.37			*
OCT	16.72	*	*	
NOV	0.48	*	*	
DEC	5.18	*	*	
		Maximum Biomass Produced		
Soil Depth = 3.0 Centimeters		36.504	10.846	0.037
Soil Depth = 7.0 Centimeters		14.120	58.328	0.949

Table 13

Precipitation Periodicity versus Maximum Growth, Year 2

Month	Precipitation (cm.)	Periods of Maximum Growth		
		Sedum	Minuartia	Viguiera
JAN	12.02	*	*	
FEB	11.85	*	*	
MAR	8.74	*	*	
APR	5.73	*	*	
MAY	7.69			
JUN	16.31			*
JUL	17.29			*
AUG	11.30			*
SEP	6.48			*
OCT	7.19	*	*	
NOV	2.31	*	*	
DEC	1.56	*	*	
		Maximum Biomass Produced		
Soil Depth = 3.0 Centimeters		23.007	7.939	0.065
Soil Depth = 7.0 Centimeters		8.389	47.797	2.157

Table 14

Precipitation Periodicity versus Maximum Growth, Year 3

Month	Precipitation (cm.)	Periods of Maximum Growth		
		Sedum	Minuartia	Viguiera
JAN	6.84	*	*	
FEB	16.10	*	*	
MAR	24.38	*	*	
APR	12.85	*	*	
MAY	3.13			
JUN	2.61			*
JUL	36.20			*
AUG	8.76			*
SEP	5.90			*
OCT	2.15	*	*	
NOV	8.09	*	*	
DEC	22.84	*	*	
		Maximum Biomass Produced		
Soil Depth = 3.0 Centimeters		28.250	9.536	0.015
Soil Depth = 7.0 Centimeters		9.326	43,439	0.927

Table 15

Precipitation Periodicity versus Maximum Growth, Year 4

Month	Precipitation (cm.)	Periods of Maximum Growth		
		Sedum	Minuartia	Viguiera
JAN	15.44	*	*	
FEB	17.77	*	*	
MAR	10.05	*	*	
APR	7.22	*	*	
MAY	5.68			
JUN	27.32			*
JUL	6.43			*
AUG	6.12			*
SEP	4.86			*
OCT	6.48	*	*	
NOV	8.47	*	*	
DEC	24.39	*	*	
		Maximum Biomass Produced		
Soil Depth = 3.0 Centimeters		37.208	11.048	0.038
Soil Depth = 7.0 Centimeters		13.794	57.082	0.568

CHAPTER VI

VALIDATION

Validation is essential for hypothetical models. The validation process usually awaits collection of experimental data after model development and implementation. By contrast, model BMAS14.FOR was developed from field and experimental data which had been collected as baseline information and as control data in previous experimental work. In this case, requirements for validation are partially satisfied.

Full validation can only be accomplished by comparison of data generated by the model with independent field data. Biomass data for Sedum smallii, Minuartia uniflora, and Viguiera porteri were collected in April and June 1982. The data were collected from experimental outcrop communities on The University of Tennessee campus. Standing biomass at defined soil depths was compared with equivalent data generated by the model. Information from 10 cm. x 10 cm. sample sizes was multiplied by 100 to obtain estimates of biomass per meter square. Means and standard deviations of experimental community data are compared to means and standard deviations of model generated data data in Table 16.

Without exception, means of field data and model data compare favorably. In all cases, deviations from the mean were much lower in model generated data than field collected data. While comparison of model generated data with a single season's field data hardly

Table 16

Comparison of Model and Field Biomass Data*

Species	Date/ Day No.	Soil Depth (cm)	Sample Size (n)	Biomass (S.D.)	Data Type
Viguiera porteri	6-15-82	22.14±3.13	n = 9	70.66±112.45	F
Viguiera porteri	166	24.0	n = 8	65.70±10.43	M
Sedum smallii	4-2-82	2.77±0.56	n = 6	35.33±29.99	F
Sedum smallii	4-2-82	2.43±0.76	n = 7	32.43±32.93	F
Sedum smallii	92	3.0	n = 8	26.87±5.26	M
Minuartia uniflora	4-2-82	2.77±0.56	n = 1	3.0	F
Minuartia uniflora	4-2-82	2.43±0.76	n = 8	26.87±5.26	M
Minuartia uniflora	92	3.0	n = 8	8.80±1.18	M

*Model biomass is compared with biomass from one season's field data for the vascular components of the model. "F" indicates field data, "M" indicates model data.

constitutes a full validation, the partial validation provided by model development procedures lend validity to the results.

Because most available field data were used to develop this model, few samples remained available for validation. Low sample numbers ($n = 6$ to 9) are primarily responsible for high variance in the field data used to test validity. As additional field data are gathered, comparisons with model generated data will be more meaningful as variance is reduced. Sufficient validity has been demonstrated to advocate continued use of the model.

CHAPTER VII

DISCUSSION AND CONCLUSIONS

This mathematical simulation model of annual communities found on Granite Outcrop Ecosystems is useful in interpreting qualitative and quantitative influences of natural stresses upon populations which dominate the system. Analysis of these stresses also help explain the persistence of endemic flora capable of tolerating extended periods of drought and the lack of successful intrusion by more common old-field species.

Numerous models simulate patterns of annual biomass production and appropriate nutrient transfers among biota (C.F.: Van Dyne et al., 1978; Francis et al., 1979; Van Dyne, 1981). Most of these, however, ignore dynamics of specific populations of organisms. Primary production compartments are lumped according to their utilization. In addition, many models of ecosystems emphasize successful aspects of population dynamics over long periods of time (C.F.: Shugart and West, 1980; Shugart et al., 1978). A very few models have incorporated plant population dynamics, energy transfers, and nutrient cycles in linear difference equation form; the majority utilize long-range studies and incorporate differential functions (Van Hook et al., 1982).

Lugo and McCormick (1981) developed a stress index based upon the naturally occurring stresses which limit plant community development. Models incorporating stress have lumped the effects of natural stresses

with anthropogenic stresses (C.F.: Kautz et al., 1982; Van Dyne, 1981; Van Hook et al., 1982). Evaluation of naturally occurring stresses permits effects of anthropogenic stresses to be proportionally evaluated, and compared to the effects of naturally occurring stresses.

Some measures of stress effects have been suggested by Ivanovici and Wiebe (1981). Net primary production as accumulation of biomass is a viable measure of ecosystem health, but is a time consuming effort. In an ecosystem whose biota are mostly comprised of annual plants and plants with annual growth cycles, a few seasons growth suffice to permit analysis of the effects of stress on productivity. Variability of measurable components of granite outcrop ecosystems is high; however, ease of measurement of such components as biomass has allowed sufficient data to be collected to minimize the effects of that variability.

Evaluation of the separate effects of differing soil depths and levels of precipitation show their proportional stress relationships, though the two stressors are closely correlated. Other, similar stress relationships could also be developed within the framework of the model.

In view of the results presented, it can be concluded that complex, interactive mathematical simulation models can be successfully designed utilizing difference rather than differential equations. This overcomes many of the problems nonlinear progressions cause when utilizing differential mathematics. In addition, models can be generated in such a way as to permit non-systems oriented individuals to utilize them, and to comprehend results with minimal difficulty..

The majority of workers seem to be concerned with the stepped results generated by difference equations. Hall and Day (1977) point out that time step relative to total time involved in a model operation can be critical to accuracy of results. Integration of data through the use of differential equations simply assumes an infinitely small time step. By using daily incremental steps through a full 365 day annual cycle, the predictive accuracy of the model BMAS14.FOR appears sufficiently close to be representative of the granite outcrop ecosystem. Preliminary results of data from granite outcrop ecosystems constructed on artificial substrata at The University of Tennessee show comparable biomass at equivalent times. Comparisons to Meyer's (1972), Sharitz (1970), and Lugo's (1969) biomass data are predictably close, but these data were utilized in formulation of the growth equations, and cannot serve for further validation.

As with all models of natural ecosystems, this one is a compromise: further implementation would be enhanced by incorporation of the non-endemic ephemeral vegetation. These biota doubtless help retain nutrients during spring rains, but their specific functional role is insufficiently defined for incorporation at this time. In addition, functional processes of micro-arthropods are inadequately defined for inclusion in the model. Addition of these functional groups to the model would enhance accuracy of nutrient and energy cycles.

A comparison of model BMAS14.FOR with the guidelines suggested on page 5 (Patten, 1971) shows that three of the characteristics of the model fit closely with the guidelines. Firstly, functional

processes within the model are accurately described by the mathematics of the model. Secondly, output from the model appears to be realistic, though at this time, insufficient independent data are available for full validation of results. Thirdly, the mathematics are tractable. Alteration of a few constants or mathematical functions make the equation series flexible enough to accommodate most processes.

While the model is comprehensive relative to the few species and limited processes represented, it is not aesthetically pleasing in its current, extended format. Perhaps alteration of form to incorporate separate nested loops for functional processes would make a printout of the model look neater, but the ease of affecting change within the model structure would be lost.

No measure of consistency with equivalent models of similar systems exists at this time. This is primarily due to the extended differential functional format of many successional population models, or the lumping of producers into large compartments in difference formatted models. In addition, while functional processes within the granite outcrop ecosystem are similar to those of most other terrestrial ecosystems, the biota are unique. The uniqueness of the organisms, especially in their adaptation to high moisture and heat stress, makes comparison to other ecosystems generally difficult. At the same time, these attributes permit description of functional relationships beyond that of most other models.

After examining the model, model output, results and analysis of data, the following five conclusions are drawn:

1. Model BMAS14.FOR accurately depicts the effects stress and soil depth upon primary production of annual communities of the granitic outcrop ecosystems.

2. Model BMAS14.FOR accurately depicts the effects of moisture stress, soil depth, and reduced primary production upon population dynamics of annual plants of the granitic outcrop ecosystems.

3. Model BMAS14.FOR demonstrates that linear difference algebraic equations can be sufficiently complex to accurately represent nutrient transfers, primary productivity, population dynamics, and stress relationships in an annual plant dominated natural terrestrial ecosystem.

4. Model BMAS14.FOR simulates the normal development of secondary nutrient stresses when the primary stress of limited moisture is removed from annual plant communities of the granitic outcrop ecosystems.

5. Model BMAS14.FOR is designed in such a fashion as to readily accomodate additional, anthropogenic stressors to annual plant communities of the granitic outcrop ecosystems.

The primary objective set forth in Chapter II was generation of a comprehensive model of granite outcrop ecosystems. Conclusions 1, 2, and 4 show that this objective has been satisfied as well as current information regarding the ecosystem permits. As information about ephemeral species and other system components is collected, the model may be readily amended to accomodate the information.

A secondary objective was utilization and extension of an already existing large data base, especially regarding naturally occurring stressors to the ecosystem. Conclusions 3, 4, and 5 address this objective well. In addition, as suggested by conclusion 5, the model provides a basis of comparison between natural and anthropogenic stressors.

Model BMAS14.FOR can be used to incorporate information suggested by short term experiments to provide predictive information useful for long term experiments. The heuristic value of this model is great when used in such a fashion. Small, annual plant dominated, readily defined and bounded ecosystems such as the granite outcrop ecosystems provide a ready basis for experiments upon ecosystem-level effects of anthropogenic stressors. Model BMAS14.FOR should prove an invaluable aid to such experiments.

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LITERATURE CITED

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APPENDICES

APPENDIX A

DEFINITIONS AND DESCRIPTIONS OF MODEL COMPONENTS AND MECHANICS OF THE MODEL

APPENDIX A

The first step in understanding and utilizing this model is to proceed stepwise through a printed copy of the basic model. Note first that in fortran, a single process, description, or function which requires more than one card of space (ie. more than about 62 characters) requires a "continuation mark" on each line subsequent to the first line. In Decsystem-10 Fortran, this is a single digit following a spacing tabulation. A good example may be found in the first statement of this program, the DIMENSION statement.

Part I: The "Dimension" Variables

The list of definitions and descriptions proceeds in sequential (rather than alphabetical) form throughout the basic model. This permits the reader to directly follow the course of the model. This section of the program is found on page 165, Appendix B.

DIMENSION statement. This statement is required for allocation of space in an interactive array. It permits each variable to be recalculated the required number of times (in this case, 2191), and to be used in calculation of other values. This particular array is a matrix of 49 variables x 2191 iterations. A complete list of the variable acronyms follows:[1]

---

[1] "I" is the number which designates which iteration the value represents. It ranges from 1 to 2191.

1. VPBM(I). This is the variable name for Viguiera porteri biomass. At the end of the program (if allowed to run the full 5 years) there will be 2190 of these values generated, and 1825 of them will be written into the output file; 2191 less 366 days for initializing). The units for this and all biomass figures is grams/meter square.
2. AMUBM(I). This is the variable name for Minuartia uniflora biomass. The "A" is simply a way to convert the name into a "real" number configuration. (Note: In Decsystem-10 Fortran, variable names beginning with the letters I, J, K, L, M, or N are reserved for integer variables).
3. SSBM(I). This is the variable name for Sedum smallii biomass.
4. BBMD(I). This is the variable name for bryophyte biomass. The "D" is simply to give the name four characters, allowing it to match the length of most other biomass variables, and to help distinguish it from BBMG(I), the magnesium content of the bryophyte population.
5. ALBM(I). This is the variable name for lichen biomass, with the preceding "A" to convert the name into a "real" number configuration.

The preceding five biomass variables are the major biomass components of the ecosystem. They have been thoroughly examined by many workers for life cycle events, nutrient content, and growth patterns (C.F. Sharitz and McCormick, 1973; Lugo, 1969; Meyer 1972; Meyer, McCormick, and Wells, 1975; McCormick, Lugo and Sharitz, 1974). The values represent grams of biomass per meter square.

6. RN(I). This is the rainfall variable. A thorough discussion of the generation process occurs later in this appendix. Rainfall events are generated as centimeters of rain per day.
7. RANDL(I). This variable is simply 10 ** (RAND), where RAND is a random number between zero and 1.0. It is used in the temperature generator. (Double asterisks denote exponentiation.)
8. TEMP(I). This is the temperature variable. A complete discussion of its generation occurs later in this appendix. Temperature is generated as °C, mean, daily.
9. EVAP(I). This variable is an index of mean water loss from the system. It follows a complex curve, described later in this appendix.
10. RNI(I). This variable is an intermediate, utilized to generate the RN(I) rainfall variable.
11. WP1(I). This variable is used in determining a water stress coefficient. A thorough description of its calculation is described later in this appendix.
12. WSTRS(I). This variable is the water stress coefficient. It is based upon rainfall and evaporation for a variable period of days, and depends directly upon soil depth. It is a multiplier of the basic biomass equations and ranges from 0.0 to 2.0 with a mean of 1.0.
13. VPCA(I). This variable is the calcium content of the meter square of Viguiera porteri biomass. The units are mg./meter square of biomass.

14. VPMG(I). This is the magnesium content of Viguiera porteri. The units are mg./meter square of biomass.

15. VPK(I). This is the potassium content of the meter square of Viguiera biomass.

16. VPP(I). This is the phosphate content of the meter square of Viguiera biomass.

17. VPN(I). This is the nitrogen content of the meter square of Viguiera biomass.

18/22. AMUCA(I), AMUMG(I), AMUK(I), AMUP(I), AMUN(I). These represent the nutrient content of the Minuartia uniflora biomass. The _ CA, _ MG, _ K, _ P, and _ N are the same five nutrients just described for Viguiera. Units are mg./meter square of Minuartia biomass.

23/27. SSCA(I), SSMG(I), SSK(I), SSP(I), SSN(I). These represent the nutrient content of the Sedum smallii biomass. The same five nutrient designations pertain.

28/32. BBCA(I), BBMG(I), BBK(I), BBP(I), BBN(I). These represent the nutrient content of the bryophyte biomass.

33/37. ALCA(I), ALMG(I), ALK(I), ALP(I), ALN(I). These represent the nutrient content of the lichen biomass.

38. SOILCA(I). This is the estimated calcium content of the soil under the biomass. It varies with uptake by plants and losses through decay from a value entered in the initial portion of the model. Its derivation is described in detail later in this appendix.

39/42. SOILMG(I), SOILK(I), SOILP(I), SOILN(I). These represent the estimated soil content of magnesium, potassium, phosphate, and nitrogen, respectively. While the rates and amounts of exchange vary, these are initiated and re-evaluated in the same manner as calcium, previously described in brief. Details of soil nutrient value changes are described later in this appendix.

43. TTLBMS(I). This value is simply the daily sum of all five biomass values (or total biomass).

44. LDAY(I). This is the "day" index for the model output. Since the first 365 iterations of the model serve as a stabilizer, they are not printed in the output. Thus, "I" iterations of the model cause I-365 days of output. The number of "LDAY(I)'s" which the model shows is equal to the number of days represented by the years of operation indicated by the user. This is explained in detail later in this appendix.

45/49. ZSCA(I), ZSMG(I), ZSK(I), ZSP(I), ZSN(I). These are variables used in the process of reducing biomass values due to depleted soil nutrients. They are simply 1% of each of the soil nutrients available at that time.

Note that the above descriptions/definitions are very brief. The mechanisms for calculating them, as well as additional variables, are detailed in other areas of this chapter.

Part II: The "Open" Statements

This portion of the program is found on page 165, Appendix B. Three files are "opened" (or accessed) for use by the model. The first

of these, "ABBR.1", is a file of slopes and constants used in the RN(I) (rainfall) generator. Since probabilities of rainfall events of a given magnitude vary through time, there are slopes and constants of probability equations given for a six-year (2190 day) period, the maximum number of iterations of the model. These variables, SLOPE and CONST, are read one at a time, sequentially, by the model. The "UNIT=20" designation tells the computer where this file has been stored for access. More information about the data in this file is provided in the description of the RN(I) generating functions.

The file "TEMPS".PAN" is a file containing 2190 values of temperature means (TMEAN) and ranges (SPAN) used in the generation of a daily mean temperature in the model (TEMP(I)). It is designated as "UNIT=21" and read, sequentially, at the appropriate time in model iteration.

The third file opened is "BMASxx.nnn". This is an output file, and the results of the model procedures are written into this file sequentially. This allows the output information to be printed or accessed at will. The small x's and n's in the file name are numbers from 0-9, or letters, and can be changed to permit different names to be shown for different runs of the model. This file is designated "UNIT=22".

Page 166, Appendix B contains four "TYPE" statements. These cause the information in numbered format statements to be typed on the user's terminal. For example, the first "TYPE" statement:

Type 800

types the information in the indicated format statement (line index 800, page 226, Appendix B) on the terminal. This is:

"INPUT TWO PSEUDORANDOM INTEGERS, FOUR DIGITS EACH,
SEPARATED BY A COMMA:"

When the user enters these numbers, the program assigns the values to the variable names "IDUMMY" and "JRDUM" respectively. This is accomplished by way of the ACCEPT statement immediately following the TYPE 800 statement. These integers are the "seed" or originating value for the random number generator, and a number of iterations through the generator prior to using generated values.

A word of explanation is required. The random number generator for the Decsystem-10 Computer requires an initiating value, a "seed", to begin the process. While on most other computers, the value of the seed causes different series of random numbers to be generated, this is not so in the Dec-10. Regardless of the value of the seed, the same sequence of random variables (values between 0 and 1.0) are produced. The second integer entered, therefore, causes the random number generator to go through that number of iterations before the values are used in other parts of the model.

While this seems to be a drawback to the random number generating system, it has one distinct advantage. By entering the same pair of pseudorandom integers, the same rainfall and temperature variables can be repeated, allowing for "control" and "experimental" runs, or runs where soil depth or precipitation and temperature are different.

The random numbers generated after the "dummy" iterations are used in the rainfall and mean temperature formulae.

The computer then asks the user to enter "THE PROPORTION OF NORMAL RAINFALL TO BE SIMULATED:". A few lines of explaination are printed before the user replies. Floods of up to twice optimal precipitation, and droughts of no precipitation at all are the extreme replies. However, a 10% increase in precipitation can be produced by entering 1.10, a 15% increase produced by entering 1.15, and so on. This entered constant is termed "RNPROP" and is simply a multiplier of the "RNI(I)" variable produced.

The next entry called for is "NYRS," the number of years of simulation required as output. While a maximum of five years data are written into the output file, the model goes through six years of iterations to produce the output. The first 365 iterations are simply to allow the model to stabilize. The input is any integer from 1 to 5. The value "IDAYS" is then generated by the formula:

IDAYS=(365*(NYRS+1))+1

IDAYS is then used as a maximum value for the counter which limits the number of iterations of the main loop of the model.

The fourth entry called for is "SDPTH", the operating soil depth of the model. This can be any real number from 1.0 to perhaps 25.0, and represents the mean soil depth, in centimeters, of the meter-square plot under consideration.

This value permits changes in dominance and biomass produced by the five major biotic components, which vary according to soil depth in the natural ecosystem. SDPTH is also used in the calculation of the water stress (WSTRS(I)) variable, and in soil nutrient concentrations, specifically soil calcium (SOILCA(I)).

The next seven lines establish some initial conditions used in the model, as well as generating a value for the number of iterations displayed in the output file. These are found on page 167, Appendix B.

The value "JDAYS" is simply calculated by IDAYS-366, and appears in the output as the number of "days" represented in the output.

The initial value, "X=0.0" serves as a real number index. Many operations in the loop require a time-variable multiplication in real-number mode. Since it is sometimes mathematically incorrect to multiply integers by real numbers, "X" is used, and increases in value as "X=X+1.0" inside the major loop. Thus, X is a real-number equal in value to the time variable, I+1 (since I at 1 sets initial conditions).

Here also, the initial values for the five soil nutrients are established. While at this point in the model development, SOILCA(1) is the only nutrient not a constant, there may be some changes in these values as additional data on the soil nutrients is developed.

The "WRITE" statement found here represents the first information written into the output file. We will discuss the mechanisms of writing sequential output here. First, the "WRITE" statement requires some analysis:

```
WRITE (22,840) IDUMMY,JRDUM,NYRS,JDAYS,SDPTH,RNPROP
```

This tells the computer <u>what</u> is to happen next (WRITE), <u>where</u> it is to happen (unit 22, the output file), its configuration (840, the line number of the "FORMAT" statement), and what variables are involved (IDUMMY, etc.).

Next, the format or configuration in which these variables appear must be <u>exactly</u> described. Traditionally, format statements are listed

at the end of the program. This format is found on page 226, Appendix B. We will consider these one line at a time.

840 FORMAT (1X,'RANDOM NUMBER GENERATOR SEEDS ARE:',2X,I4,',',

"840" is the line number for the format currently being used. "FORMAT" is the designation of what is being written. The formatted material must be enclosed in parentheses, thus the "(". "1X,'RANDOM NUMBER GENERATOR SEEDS ARE:', "is simply a space (1X) followed by the alphabetically written phrase "RANDOM...". Commas are used to separate the segments of formatted material. In Decsystem-10 Fortran, Hollerith character segments (that is, alphabetically written phrases and the like which are to be transcribed directly as written) can be indicated by setting them off by single quotes.

The "2X,I4" segment indicates two spaces followed by a 4-digit integer, the first variable named in the "WRITE" statement. In this instance, this is the first of the pseudorandom integers entered in section 3, "IDUMMY". Then ", ', '," which is a Hollerith character segment of one character, a comma. The output file now has the following printed in it:

RANDOM NUMBER GENERATOR SEEDS ARE: 1234,

The next line is as follows:

1X,I4/1X,'THE NUMBER OF YEARS EQUALS',1X,I1,1X,'OR',1X,I4,

The first "1" is a continuation mark. The "1X," is again, one space. The "I4" is the second variable indicated in the "WRITE" statement. In this case, it is the second of the random number generator seeds, "JRDUM".

The slash ("/") which follows is a sign to the computer indicating "carriage return", or go to the beginning of the next line. So far our "FORMAT" statement has printed one line:

THE RANDOM NUMBER GENERATOR SEEDS ARE: 1234,1234

The next line begins after the slash, with one space ("1X") and the Hollerith phrase: "'THE NUMBER OF YEARS EQUALS'". This is followed by another space and the third variable ("1X,I1,"), in this case, the number of years entered ("YRS"). Then another space, the Hollerith phrase "'OR'", another space, and the fourth variable from the "WRITE" statement (1X,'OR',1X,I4,) are written.

The third line of format begins with a continuation mark ("2"), a space, and the Hollerith phrase "DAYS" (21X,'DAYS.':,): The second line written in the output is thus:

THE NUMBER OF YEARS EQUALS 5 or 1825 DAYS.

The complete third line of this format statement is:

21X,'DAYS.'/1X,'AND THE MEAN SOIL DEPTH EQUALS',1X,F4.1

We have already taken care of the "21X,'DAYS.'". The slash is once again, a "carriage return", and by passing the Hollerith phrase and the single space we have a new indicator for the fifth variable. The first four variables in the "WRITE" statement were all integers. They are formatted by the "In" designation, where n is the expected maximum number of digits in the number. For example, ",I4," indicates an integer of no more than four digits, such as 1234. The fifth variable in the "WRITE" statement, "SDPTH", is soil depth, a real (decimal) number. Real numbers are formatted with the "Fn.m" designation, where

n is the total number of spaces required for the number (including a space for the decimal), and m is the number of spaces following the decimal. For example "F4.1," indicates a real number of three spaces with a fraction, such as "16.2." The next line of the format statement permits the proportion of normal rainfall variable to be written. Once again, a real number format is utilized.

The fifth through the thirteenth line of this format statement are extended Hollerith phrases, resulting in four lines of written output which extend through much or all of the 132 spaces (1/10 inch per space) available on standard "greenbar" computer paper. The spacing is such that the columns of data printed in the output fall in order under the headings, with "DAY#" offset to the left to delineate each "day's" data.

The purpose of this "WRITE" statement is to provide a heading of information. This enables the reader to check on the pseudorandom "seeds" used, the total "time" represented in the results, the soil depth employed in that specific run of the model and the proportion of optimal precipitation used. It also provides column headings to assist in data interpretation.

Next, five new variables are calculated which are not included in the "DIMENSION" statement. They are calculated only once for each run of the model. These variables are growth factors associated with each of the five biotic components relative to soil depth (page 168, Appendix B).

They represent the proportion of each component's maximum attainable biomass which actually occurs at the entered soil depth. Since each biomass component is affected differently by the variable soil depth, each will be considered singly.

The first growth factor considered is that for Sedum smallii ("GFSO1"). Sedum reaches its maximum growth potential (in the Knoxville area) at about 1 cm. soil depth. In deeper soils, competition from other biota reduce its productivity in a logarythmic fashion. Analysis of data from other workers tends to substantiate the logarythmic decrease in biomass toward deeper soils (Sharitz & McCormick, 1973; Meyer, 1972). The equation for determining the percentage of maximum Sedum biomass produced at a given soil depth is:

```
GFSO1=(100-(38.76*(ALOG(SDPTH))))/100
```

where "ALOG" is the Decsystem-10 function for deriving natural logarythms, and "SDPTH" is the entered soil depth. The curve for this function is illustrated in Figure A-1.

Two conditions must be enforced for this equation. Since it is possible for the equation to produce values greater than 1.0 (or 100%), it is necessary to limit the value to a maximum of 1.0. This is accomplished by the next line in the program:

```
IF (GFSO1.GT.1.00) GFSO1=1.00
```

This is a "conditional If statement" and may be read as: "IF GFSO1 is greater than 1.00, GFSO1 equals 1.00". The implication is that if GFSO1 is less than or equal to 1.00, GFSO1 equals the calculated value.

The second condition which must be enforced is because the equation is capable of producing negative values at deeper soil depths. The third line in this series establishes a lower limit of zero for GFSO1:

```
IF (GFSO1.LT.0.00) GFSO1=0.00
```

This "conditional If statement" can be read as: "IF GFSO1 is less than 0.00, GFSO1 equals 0.00". Once again, the converse is implied.

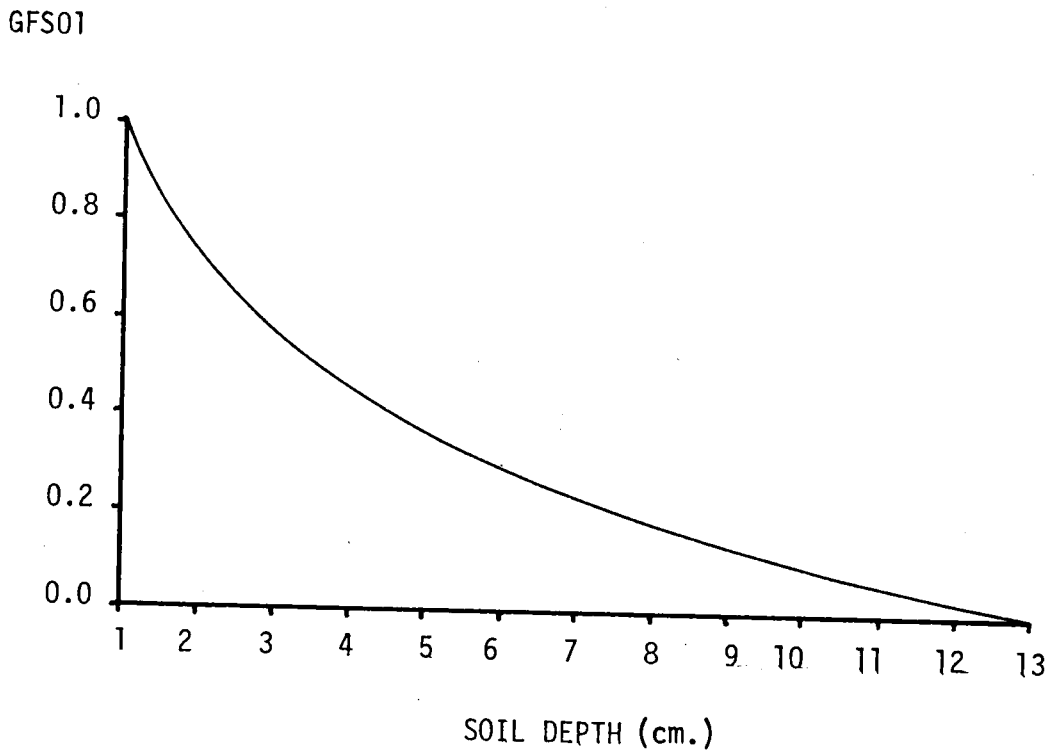


Figure A-1. Sedum Growth Potential at Different Soil Depths. GFSOI=(100-(38.76*(ALOG(SDPTH))))/100, where GFSOI is the Sedum soil depth determined growth factor, ALOG is the logarythm (base e) function, and SDPTH is soil depth in centimeters.

That is, if GFSOl is not less than 0.00, GFSOl equals the calculated value. Thus, we have set limits of 0.00 and 1.00 for GFSOl, and it must be equal to one or the other, or lie between these values.

The equation for Minuartia's growth limiting factor begin with conditional phrases. We will consider these in order, with a word of explanation. Minuartia uniflora attains its maximum biomass productivity (in Knoxville) at 9.0 cm. of soil depth. For soil depths less than 9.0 cm., the reduction in growth is a linear function, and is represented in the combined "conditional If statement" and equation:

IF (SDPTH.LE.9.) GFMOl=(-11.375+(12.375*SDPTH))/100

The condition to be met is that: "If soil depth is less than or equal to 9.0 cm.". Provided that the statement is true, we have the equation:

GFMOl=(-11.375+(12.375*SDPTH))/100

which determines the value of GFMOl. This portion of the growth limiting factor for Minuartia is illustrated in Figure A-2.

The second line of the program which deals with GFMOl is the "paired conditional If statement" which sets GFMOl to 1.0 for soil depths ranging from 9.0 to 11.0 cm. It is:

IF ((SDPTH.GT.9.).AND.(SDPTH.LE.11.)) GFMOl=1.00

which can be read as "If soil depth is greater than 9.0 and less than or equal to 11.0, GFMOl equals 1.00". This is the range of soil depths at which Minuartia attains its maximum productivity.

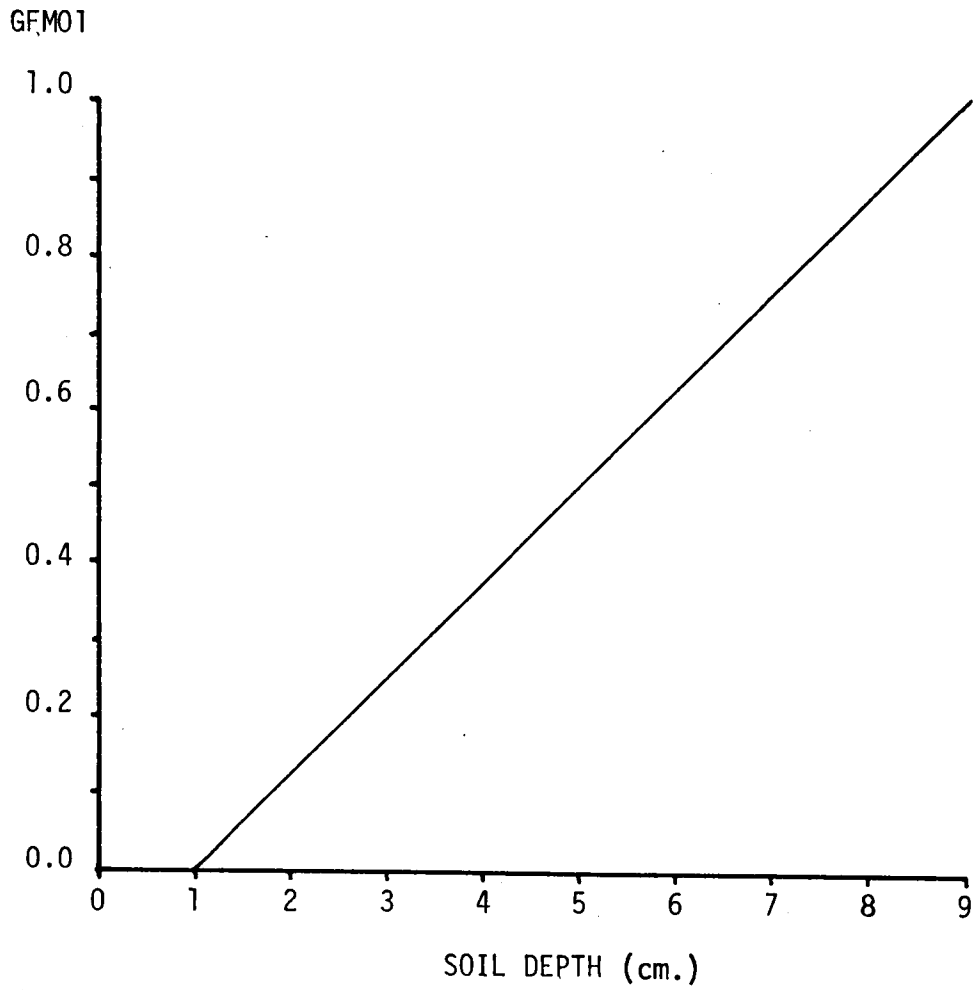


Figure A-2. Minuartia Growth Potential in Shallow Soils. GFMOI=(-11.375+(12.375*SDPTH))/100, where GFMOI is the soil depth limited growth factor for Minuartia and SDPTH is soil depth in centimeters.

The third program line dealing with GFMO1 deals with soil depths greater than 11.0 cm. This, like the others, is a "conditional if statement" which is followed by the equation for calculating GFMO1 when its condition is met:

```
IF (SDPTH.GT.11.) GFMO1=(444.6667-(31.333*SDPTH))/100
```

"If soil depth is greater than 11.0", is the condition, and once again, the equation is of linear form:

```
GFMO1=(444.6667-(31.333*SDPTH))/100
```

The shape of the curve is illustrated in Figure A-3.

Once again, "conditional If statements", like the two used to limit GFSO1, are used to limit GFMO1 to the range of 0.00 to 1.00. They are the next two lines of the program:

```
IF (GFMO1.LT.0.00) GFMO1=0.00
IF (GFMO1.GT.1.00) GFMO1=1.00
```

The equation which determines the growth factor for Viguiera porteri is:

```
GFVO1=(.001*(SDPTH**3.833))/100
```

(Note that a pair of asterisks together signify exponentiation).
Thus, we see that there is an exponential decrease in Viguiera production with decreased soil depth. The curve for this equation is illustrated in Figure A-4.

Once again, a "conditional If statement" is required to restrict values of GFVO1 to the range 0.00 through 1.00. This is the next line in the program:

```
IF (GFVO1.GT.1.00) GFVO1=1.00
```

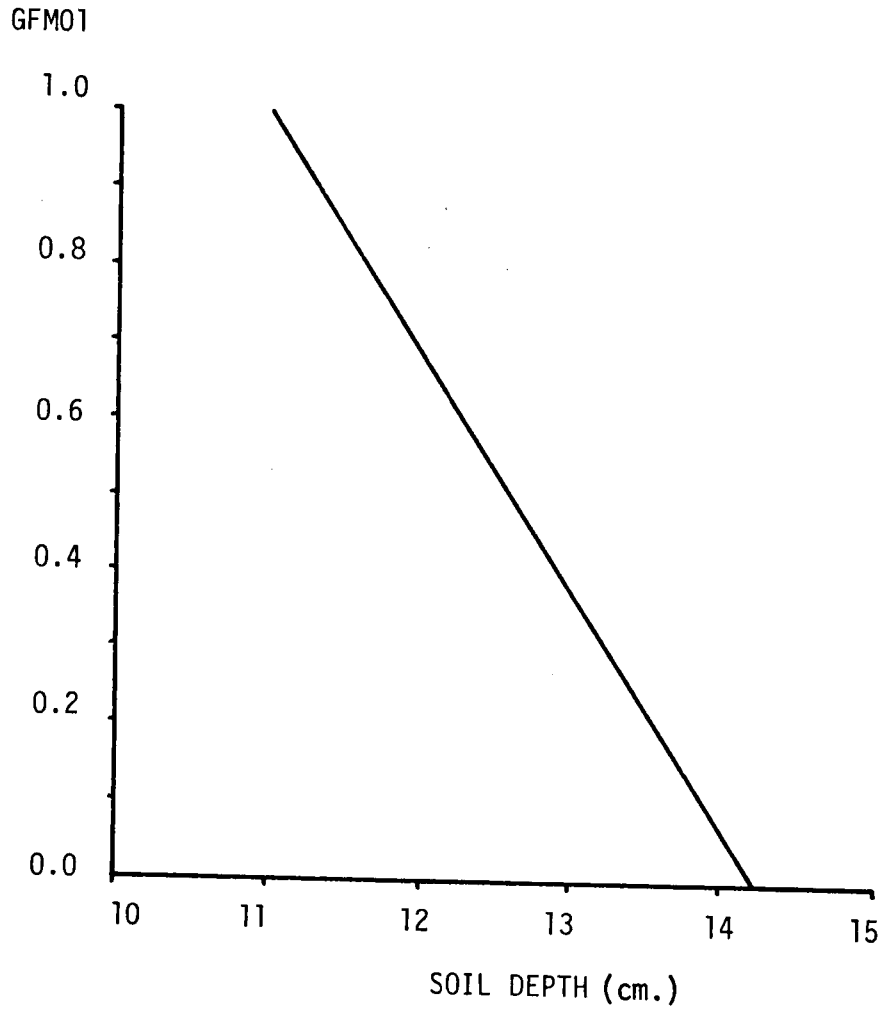


Figure A-3. Minuartia Growth Potential in Deeper Soils. GFMO1=(444.6667-(31.333*SDPTH))/100, where GFMO1 is the soil depth limited growth factor for Minuartia and SDPTH is soil depth in centimeters.

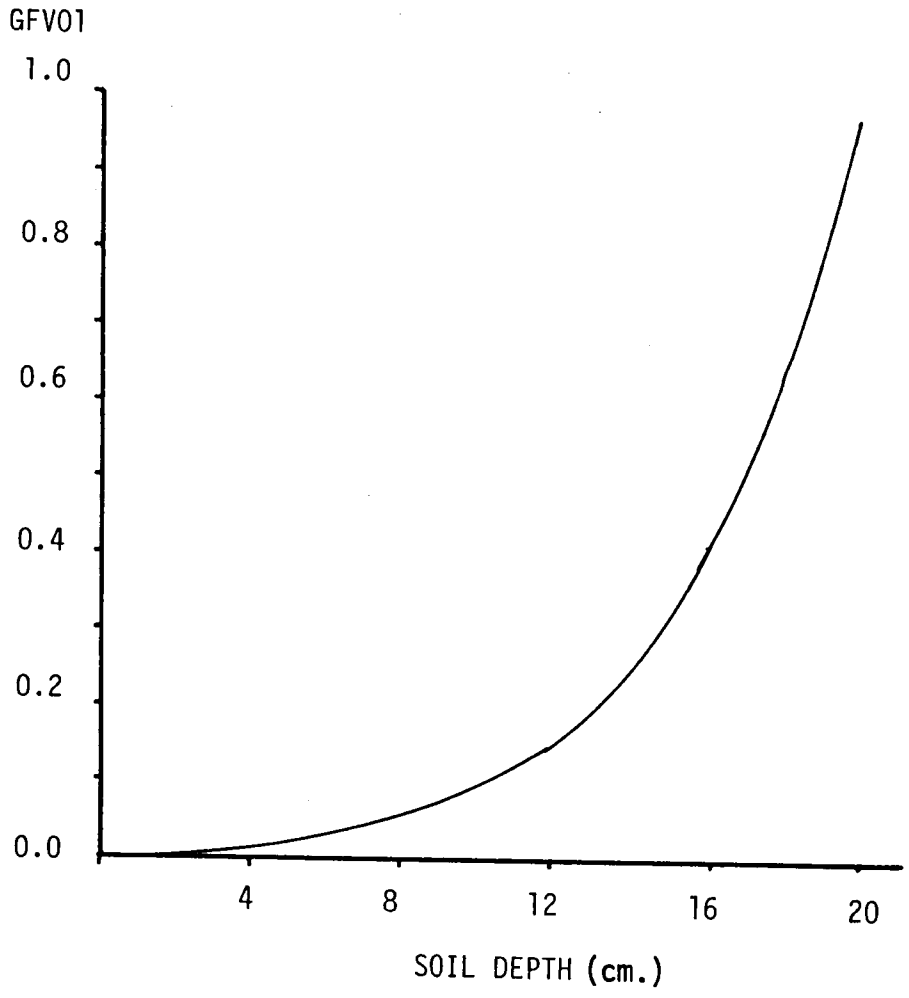


Figure A-4. Viguiera Growth Potential in Outcrop Soils. GFV01=(.001*(SDPTH**3.833))/100, where GFV01 is the soil depth limited growth factor for Viguiera and SDPTH is soil depth in centimeters.

Note that a lower bounding equation is not required, as the equation itself limits GFV01 to positive values.

The equations which determine values for the bryophyte growth limiter begin with "conditional If statements" similar in form to those for GFM01. Bryophyte biomass production is a complex curve, with a change in shape at 11.1 cm. (in Knoxville), and this is reflected in the conditions for determining the equation used to calculate GFB01:

```
IF (SDPTH.LT.11.1) GFB01=(6.68+(38.771*(ALOG(SDPTH))))/100
```

"If soil depth is less than 11.1 cm." sets the conditions for using the first equation for calculating GFB01. The term "ALOG" is a Decsystem function which generates the natural logarythm of the number which follows. The form of the curve is illustrated in Figure A-5.

At depths greater than 11.1 cm., the "conditional If statement" of the second equation causes the second equation to be used in calculating GFB01:

```
IF (SDPTH.GE.11.1) GFB01=(22.173*(EXP(.1*SDPTH)))/100
```

Once again, a pair of "conditional IF statements" are required to set the limits of the GFB01 range of values at 0.00 and 1.00. These follow the two program lines which establish the calculated value of GFB01:

```
IF (GFB01.GT.1.00) GFB01=1.00
IF (GFB01.LT.0.00) GFB01=0.00
```

The function which limits lichen production by soil depth is again determined by using "conditional IF statements". In this case, lichens attain maximum productivity at 9.62 cm. of soil depth. The first probability, that of soil depth less than 9.62 cm., is found as:

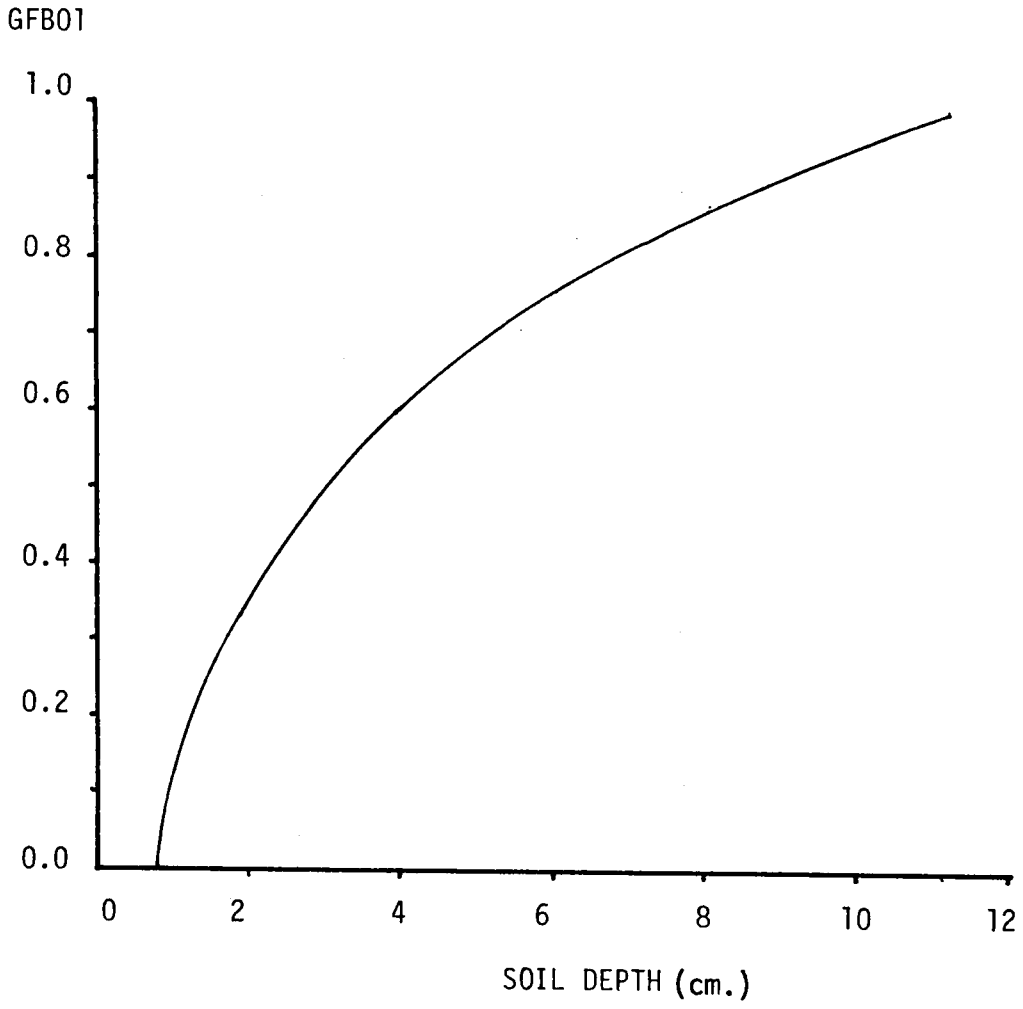


Figure A-5. Bryophyte Growth Potential in Shallow Soils. GFBO1=(6.68+(38.771*(ALOG(SDPTH))))/100, where GFBO1 is the soil depth limited growth factor for bryophytes, ALOG is the function which produces natural logarythms, and SDPTH is soil depth in centimeters.

```
IF (SDPTH.LT.9.62) GFLO1=(2.853*(EXP(.37*SDPTH)))/100
```

The curve produced by this equation is illustrated in Figure A-6. When soil depth is greater than or equal to 9.62, the second option is exercised:

```
IF (SDPTH.GE.9.62) GFLO1=(211.478-(11.588*SDPTH))/100
```

The shape of this curve is a straight line as illustrated in Figure A-7. Since the equations calculating GFLO1 preclude any values greater than 1.00, it is only necessary to establish the lower limit at 0.00:

```
IF (GFLO1.LT.0.00) GFLO1=0.00
```

Once the limiting growth factors for lichens and bryophytes have been established, it is necessary to set initial values for these biomass components. This is required because their growth cycles resemble a 2 pi cosine wave function, delayed so the peak of productivity is near summer solstice. A more thorough discussion of the growth functions is found in Chapter V of the main body of this dissertation. The equations for establishing these initial parameters are:

```
ALBM(1)=174.2459*GFLO1
BBMD(1)=400.2533*GFBO1
```

The constants 174.2479 (lichens) and 400.2533 (bryophytes) are derived using their respective growth functions.

Page 169, Appendix B, begins with an explanation, and the standard form of a "Do Loop." There are five elements indicated or implied in this statement:

```
30 DO 40   J=1,JRDUM
```

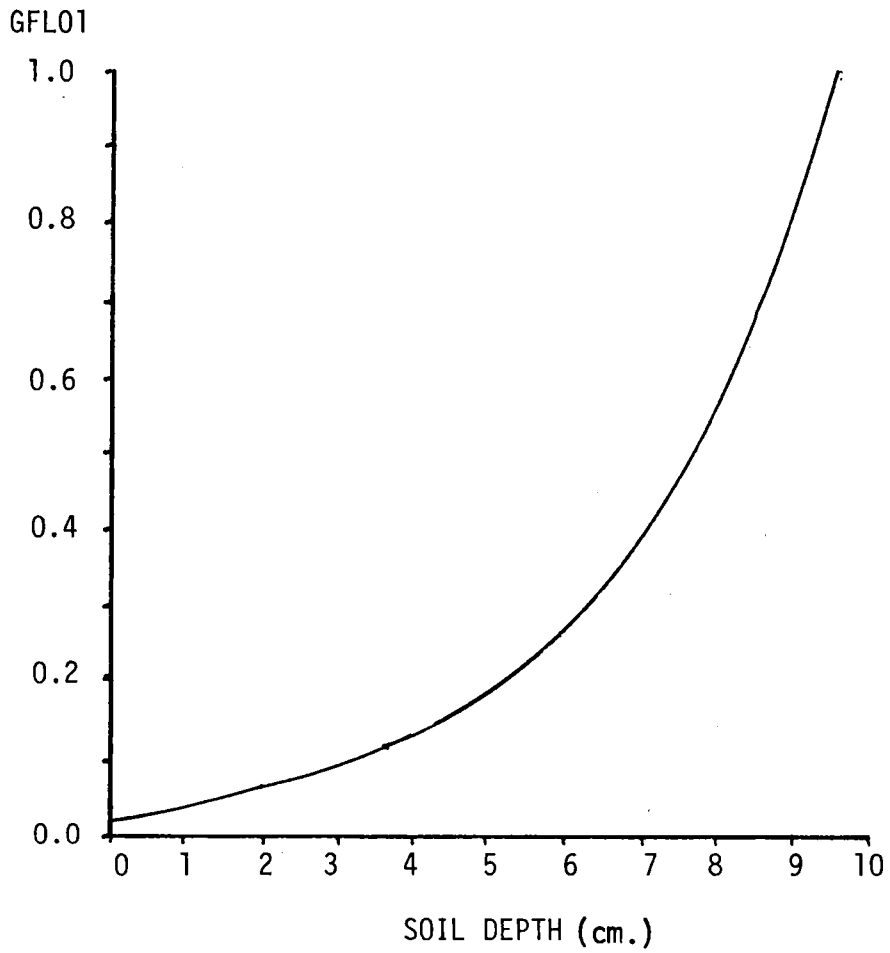


Figure A-6. Lichen Growth Potential in Shallow Soils. GFLO1=(2.853*(EXP(.37*SDPTH)))/100, where GFLO1 is the soil depth in centimeters, and EXP (.37*SDPTH) is the base of natural logarythms to the (.37*SDPTH) power.

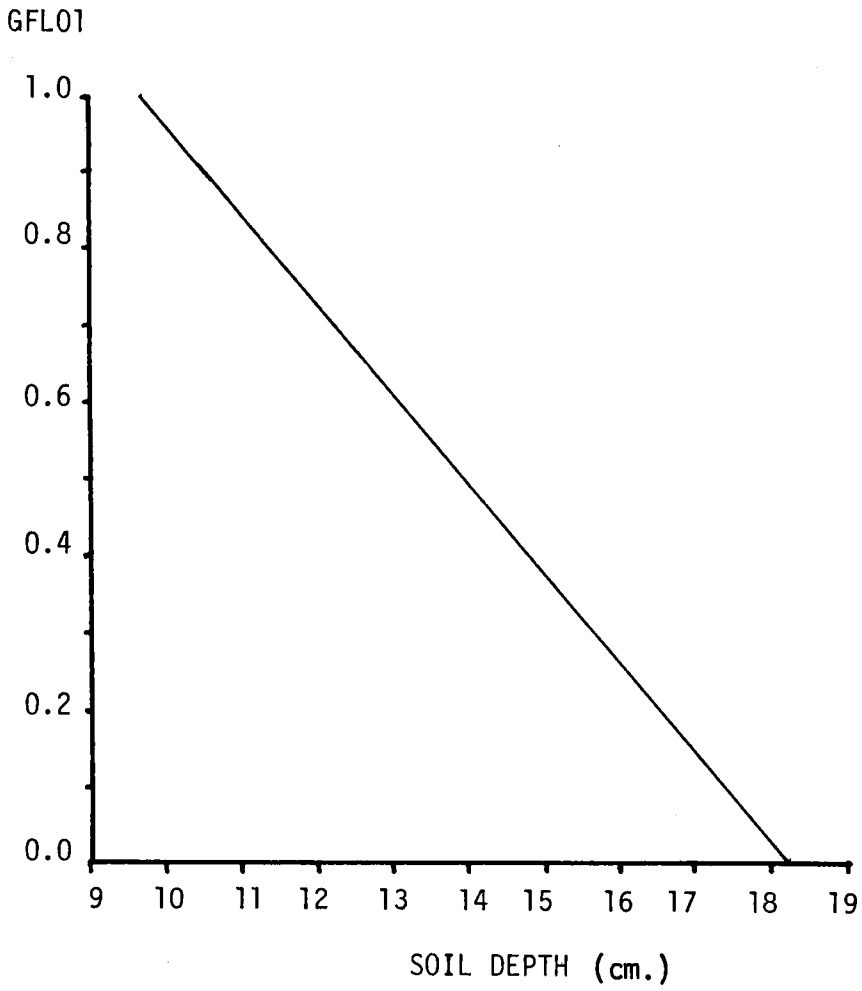


Figure A-7. Lichen Growth Potential in Deeper Soils. GFLO1=(211.478-(11.588*$\overline{\text{SDPTH}}$))/100, where GFLO1 is the soil depth limited growth factor for lichens and SDPTH is soil depth in centimeters.

First, the phrase "DO 40" tells the computer that a loop begins at that point and operates through line 40 (a "CONTINUE" statement). The phrase "J=1, JRDUM" tells the computer the number of iterations of the loop which are to be run. In this case, there will be "JRDUM" iterations made (the second of our entered pseudorandom integers) beginning at point "1". Thus, "J" is the index variable whose initial parameter is "1" and whose terminal parameter is "JRDUM". It is sometimes necessary to use an increment other than one for a "DO" statement. In this case, a third value would be attached to the end of the statement as: "J-1,JRDUM,2". This would result in values of J being 1,3,5,...,JRDUM. The increment parameter is omitted in this model, and thus understood to be 1. Values of J are 1,2,3,...,JRDUM are produced.

In this small loop, a single function is performed "JRDUM" times. It is represented by the equation:

RAND=RAN(IDUMMY)

"RAND" is a dummy variable name for the random number generated by "RAN(IDUMMY)" and has values ranging from 0.0 to 1.0 "RAN" is the Decsystem-10 function for generating these random numbers, and "IDUMMY" is the first pseudorandom integer entered by the user, the "seed".

As noted previously, the value of "IDUMMY" does not influence the series of values generated by the "RAN" function. Thus, to obtain a unique starting point for "RAND" (used later but in this loop, generated and ignored) it is necessary to generate and discard a random number of values before using the next ones.

The next section, beginning on page 170, Appendix B, is the entire main loop of the program. Each subsection will be discussed separately.

The first subsection has three components which must be considered. The first program line in this subsection is the "DO statement" for the major loop:

```
DO 730 I=2,IDAYS
```

Note that some values already occupy the first space allotted in the DIMENSION array. Since there are several values "initialized" in their respective first spaces (of 2191 each) allotted, we must use a starting point other than 1 for the major "DO" loop of the program.

This statement says that the beginning of the loop is here, the end is the "CONTINUE" statement at line 730. The counting index, "I", runs from an initial parameter of "2" to a terminal parameter of "IDAYS" (calculated from the number of years, "NYRS", entered by the user). Once again, since no increment is stated, the computer assumes the default of 1.

The second statement in this subsection is the command to the computer to "READ" the information in unit "20" which is file "ABBR.1":

```
READ (20,850) SLOPE,CONST
```

The "850" is an index line number for the "FORMAT" statement which describes the structure of the information in unit 20. The variables "SLOPE," and "CONST" are the names applied to the pairs of variables which are to be read sequentially, one pair at a time.

In this case, the format of the data, found on page 226, Appendix B, allows for 7 characters in the first variable, "SLOPE," the fourth of

which is the decimal point (F7.3). Following a space (",1X,") the second variable occupies 5 character spaces, the second of which is the decimal point (F5.3). Thus, "SLOPE" and "CONST" may each have 3 characters following the decimal point. [Note that the minus sign must be allowed for in the format phrase for the variable.] The file "ABBR.1" (unit 20) has as its first sixteen lines the data in Table A-1.

Note that there are groups of seven pairs of the same numbers. The data was derived from grouped weekly probabilities (Fribourg et al., 1973; Fribourg, pers. comm.). Using a 1/7 approximation and a correction factor (explained on page 46), the approximations are each repeated seven times, except for the last of each "year," where eight repetitions are used.

The next calculation must begin with input from file "TEMPS.PAN." In this case, the "READ" command:

```
READ (21,860) TMEAN,SPAN
```

refers the computer to unit "21" (file "TEMPS.PAN"), and format "860". The variables to be read are "TMEAN," and "SPAN." They are to be read according to the format:

```
860 FORMAT (1X,F6.3,2X,F6.3)
```

where each variable is allocated a total space of six characters, three of them following the decimal point in the third space. The first sixteen lines of file "TEMPS.PAN" (unit 21) are listed in Table A-2. Notice that the repeating pattern of seven appears again. Once again, this is due to the use of 1/7 approximations derived from weekly data (Fribourg et al., op. cit., Fribourg, pers. comm.).

Table A-1

The First Sixteen Pairs of Values Found in File ABBR.1, Used in Precipitation Simulation

Slope	Const.
-11.622	0.491
-11.622	0.491
-11.622	0.491
-11.622	0.491
-11.622	0.491
-11.622	0.491
-11.622	0.491
-9.502	0.575
-9.502	0.575
-9.502	0.575
-9.502	0.575
-9.502	0.575
-9.502	0.575
-9.502	0.575
-11.337	0.564
-11.337	0.564

Table A-2

The First Sixteen Pairs of Values from File TEMPS.PAN, Used in Temperature Simulation

TMEAN	SPAN
6.717	6.267
6.717	6.267
6.717	6.267
6.717	6.267
6.717	6.267
6.717	6.267
6.717	6.267
5.345	5.928
5.345	5.928
5.345	5.928
5.345	5.928
5.345	5.928
5.345	5.928
5.345	5.928
5.289	5.628
5.289	5.628

The next line in this subsection is the same equation as appeared in the small "DO" loop described on page 169. In this case, the "RAND" of:

```
RAND=RAND(IDUMMY)
```

is actually used. Remember that the first "JRDUM" iterations were discarded.

The fifth line on page 170, Appendix B, calculates a new variable based on the random variable "RAND" generated in the preceding line.

```
RANDL(I)=10**RAND
```

This simply creates a variable between 1.0 and 10.0 to be used in the cosine function which calculates the daily mean temperature.

The sixth line is the basic formula which calculates the daily rainfall. Random number values lower than slope intercept values are 0.00, or negative. These values are disregarded and constitute days of no rainfall:

```
RNI(I)=2.79*(10**((SLOPE*RAND)+CONST))
```

The value 2.79 is a combined conversion × correction factor for the data in file "ABBR.1." This is 2.54 times 1.1 truncated to 2 decimal places. The correction factor of 2.54 is necessary because the original data is generated in inches of rainfall rather than centimeters. The 1.1 is necessary because numerous test runs of the equation generated mean annual rainfalls consistently 10% low. This is probably due to the use of the 1/7 approximation of weekly data. The exponent to which 10 is taken, "((SLOPE*RAND)+CONST)," will result in a zero (or negative) value unless "(SLOPE*RAND)" is less than "CONST." By using this exponential

format, only a very small "RAND" value will result in a large rainfall event. Precipitation amounts can be altered to produce simulated flooding or drought, or they may remain "normal." The next equation multiplies the RNI(I) variable by the proportion entered in section two (RNPROP) to generate the precipitation value used in the program functions:

RN(I)=RNI(I)*RNPROP

The eighth line is the equation which calculates daily mean temperature:

TEMP(I)=((TMEAN+(COS(3.1416+RANDL(I)*SPAN))-1.1112)

"TMEAN" is the mean of twenty years of temperature data (for that week) and is read from file "TEMPS.PAN." The use of a cosine function means that a range of values from +1 to -1 times the "SPAN" (or range above and below the mean) is produced. The value "3.1416" (an approximation of Pi) is used to cause the value to begin at a maximum point of -1. This causes selection for the middle of the available temperature range. By way of example, let us assume values for "RAND" of 0.042, 0.851, 0.289, and 0.615. The corresponding values of RANDL(I) are 1.1015, 7.0958, 1.9454, and 4.1210. By using these values in the equation with the first four values of "TMEAN" and "SPAN," the daily mean temperatures (TEMP(I) for I=1 through 4 are:

TEMP(1)=((6.717+(COS(3.1416+1.1015)*6.267))-1.1112)=2.77°C

TEMP(2)=((6.717+(COS(3.1416+7.0958)*6.267))-1.1112 =1.30°C

TEMP(3)=((6.717+(COS(3.1416+1.9454)*6.267))-1.1112)=7.90°C

TEMP(4)=((6.717+(COS(3.1416+4.1210)*6.267))-1.1112)=9.10°C

Once again, the correction factor of "-1.1112" is required as the mean value difference between the high and low limits of the mean plus the span. The last equation in this subsection is the real number "counter" or day-equivalent discussed on page 51.

The development of a series of equations describing the annual cycle of evaporation occupies the large section beginning on page 171, Appendix B. A series of five equations, keyed by "conditional If statements," is required for each year the model operates. Figure A-8 shows the approximation of a 1-year evaporation cycle. We will discuss the first seven equations singly, and the others as a group.

The equation and attendant "conditional IF" phrase for the first 32 model iterations ("days") is:

```
IF (I.LE.32) EVAP(I)=.968-(.006258*X)
```

Remembering that "X" is a real number equivalent of counting index, "I" (representing DAYS), we see that this is a linear equation. Values for the first 31 iterations (the month of January) range from 0.968 to 0.774 (see Figure A-8).

The equation for the next 89 days (I=33 through 121) is an exponential one. The pair of "conditional If" phrases and the equation are:

```
IF ((I.GT.32).AND.(I.LE.121)) EVAP(I)=.402*(EXP(.0211329*X))
```

The values of EVAP(I) calculated by this equation range from 0.791 through 5.077.

The next 123 days (1=122 through 244) are again of linear decline form. The "conditional If" statements and equation are:

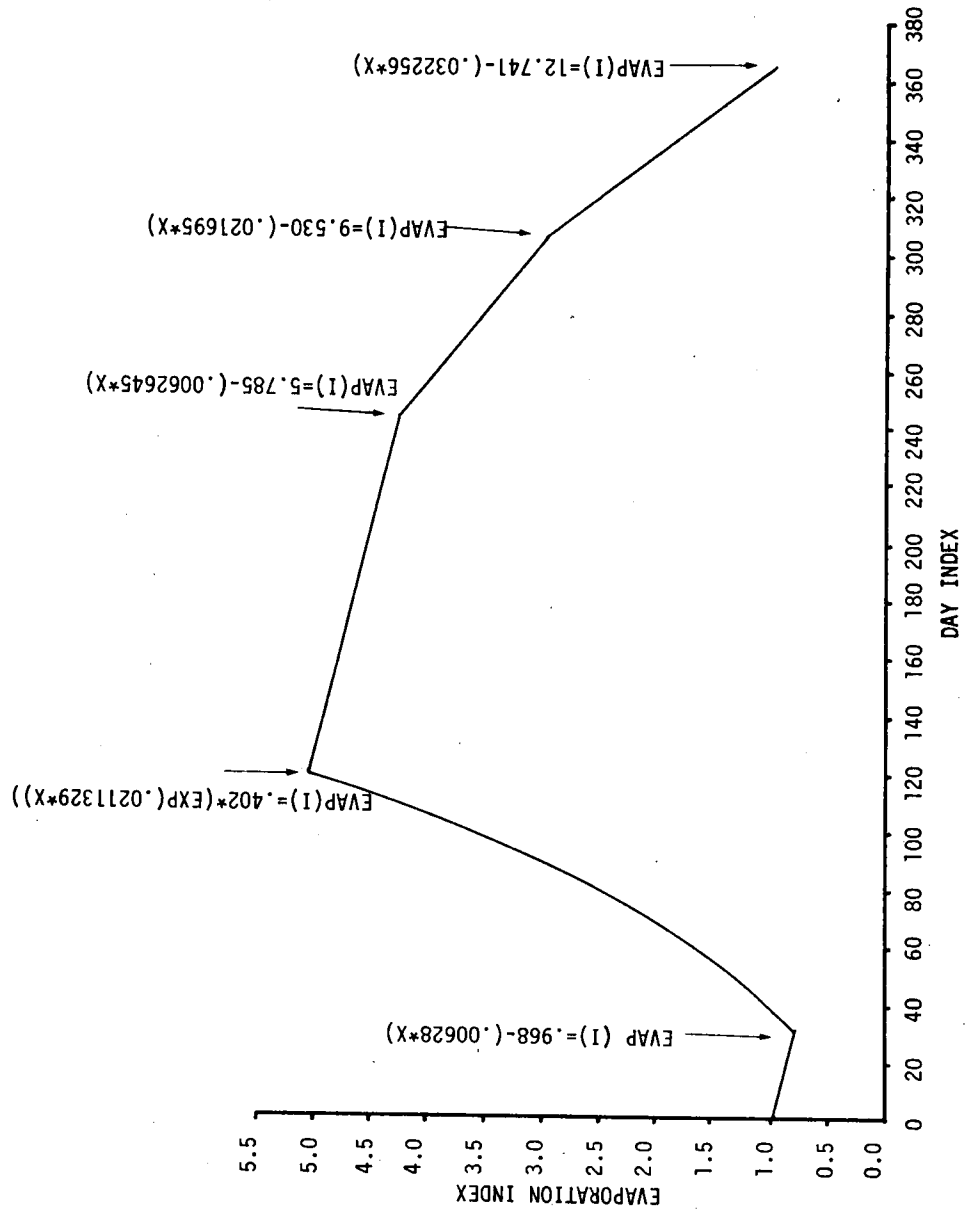


Figure A-8. Approximation of an Annual Evaporation Curve from Granite Outcrop Soils. Change points from one equation to the next are marked with arrows. Eq. 1 is: EVAP(I)=.968-(.00628**); Eq. 2 is: EVAP(I)=.402*(EXP(.0211329**)); Eq. 3 is: EVAP (I)= 5.785-(.0062645**); Eq. 4 is: EVAP(I)=9.530-(.021695**); Eq. 5 is: EVAP(I)=12.741-(.032256**).

```
IF ((I.GT.121).AND.(I.LE.244)) EVAP(I)=5.785-(.0062635*X)
```

The values of EVAP(I) calculated by this equation range from 5.027 downward through 4.263. (See Figure A-8).

The next 61 days (I=245 through 305) are of the same linear form, but the slope steepens. The "conditional If" statement and attendant equation are:

```
IF ((I.GT.244).AND.(I.LE.305))EVAP(I)=9.530-(.021695*X)
```

The values of EVAP(*) calculated by this equation range from 4.236 down through 2.935 (See Figure 6X).

For the last 61 days of the year (I=306 through 366), the change in slope is even more marked. The "conditional If statement" and attendant equation are:

```
IF ((I.GT.305).AND.(I.LE.366))EVAP(I)=12.741-(.032256*X)
```

The EVAP(I) values generated by this equation range from 2.903 through .968, our starting point.

An examination will show the same five basic equations repeated in sequence. Changes are made in the "conditional If" statements to match the same period in subsequent years. For example, in the second "year" of operation:

```
IF (I.LE.32)  EVAP(I)=.968-(.006258*X)
```

becomes

```
IF ((I.GT.366).AND.(I.LE.397))  EVAP(I)=.968-(.006258*(X-365.))
```

The first 31 EVAP(I)'s of the year are calculated, and (X-365.) of the second year equals X of the first year. This pattern of change is repeated sequentially through 2190 iterations.

The use of combined rainfall and evaporation figures is used in the development of a water stress factor. Since only about three days is required to dry the shallowest soils to below wilting point during the drier part of the year (Sharitz, 1973; Lugo, 1969), and since deeper soils retain moisture above a wilting point for as long as twelve days, the "wilting point factor" (WP1(I)) is developed on a soil depth x number of days basis. The easiest way to explain its development is to give examples:

IF (SDPTH.LE.I.) WP1(I)=((RN(I-2)+RN(I-1)+RN(I)))-((EVAP(I-2)+EVAP(I-1)+EVAP(I))/8.7472)

The "conditional If statement" for this particular example means that this equation for WP1(I) is used only for soils of 1.0 cm. depth or less. It is simply the sum of rainfall for the day (I) in question plus the rainfall of the preceding two days (three days in all), minus a corrected sum of evaporation indices for the same time period. The correction factor is required to scale evaporation into units equivalent to the rainfall units. The greater soil depths simply ameliorate the effects of drying by extending the time period for both rainfall and evaporation estimates. For example, the maximum figure pertains to soil depths greater than 9.0 cm.:

IF (SDPTH.GT.9.) WPI(1)=((RN(I-11)+RN(I-10)+RN(I-9)+RN(I-8)+RN(I-7)+RN(I-6)+RN(I-5)+RN(I-4)+RN(I-3)+RN(I-2)+RN(I-1)+RN(I)))-EVAP(I-9)+EVAP(I-8)+EVAP(I-7)+EVAP(I-6)+EVAP(I-5)+EVAP(I-4)+EVAP(I-3)+EVAP(I-2)+EVAP(I-1)+EVAP(I))/8.7472)

This equation calculates WP1(I) on the basis of twelve days of rainfall and twelve days of evaporation.

By itself, the WP1 value can range from plus 36 to minus 36 (or so; depending upon soil depth, rainfall, and time of year), but the mean of WP1(I) for numerous "years" of model operation is 0.0. The water stress factor itself was designed as a multiplier for biomass generating equations, similar to the design of the growth limiting factors developed for soil depth as a limiting factor. The mean value of the multiplier needed to be 1.000, however. Values less than 0.0 were meaningless, and certainly growths greater than twice "normal" (during a wet period) were infeasible. Using this basis, WP1 was limited in effect to producing water stress factors (WSTRS(I)) ranging from 0.0 to 2.0 with a mean of 1.0. To accomplish this, WP1(I) (mean of 0.0) is added to 1.0 to produce the daily water stress factor. Thus we see the need for the two "conditional If" statement contains upon WP1(I):

```
IF (WP1(I).GE.1.0) WSTRS(I)=2.0
IF (WP1(I).LE.-1.0) WSTRS(I)=0.0
```

The only "converse" which holds true for both conditions is the major equation for determining WSTRS(I):

```
IF ((WP1(I).LT.1.0).AND.(WP-(IP.GT.-1.0)) WSTRS(I)=1.0+WP1(I)
```

One additional constraint is that imposed by temperature. Since growth of plants essentially ceases at freezing temperatures, WSTRS(I) is set to equal 0.0 when TEMP(I) is less than or equal to 0.0:

```
IF (TEMP(I).LE.0.0) WSTRS(I)=0.0
```

Next, beginning of page 174, Appendix B, we come to the first of the biomass generation and nutrient partitioning equations. We will consider these one at a time, as with other new sections.

Analysis of previous data of the productivity of both major nonvascular biomass components, lichens and bryophytes, shows that their biomass tends to follow an annual cycle which approximates a cosine wave function peaking near the end of the cooler, wetter months of the year (data developed from Meyer, 1972). As noted previously, lichens attain maximum productivity at 9.62 cm. soil depth. Using differences as a basis, the equation for

ALBM(I)=ALBM(I-1)+(SIN(.25822+(X*.017214))*.387278)*GFL01*WSTRS(I))

It is necessary to add the change in biomass to the previous day's biomass figure in order to retain differences in stress effects. The primary function is (196.+(COS(3.39981+(X*.017214))*22.5)). Note that the initial biomass parameter for lichens is this primary function where X=0.0, multiplied by the soil depth limited growth factor GFL01. The cosine function is delayed by pi to drop the value of the cosine to a low of -1. Since the total period involved per year is 2 Pi (for a complete -1 to +1 to -1 cycle), and the low occurs in mid-December, we add 15 days worth of the total period (or 15*(2 pi/365, or approximately .017214. We multiply this figure by X, our real number equivalent of 1 (or "day") and add it to the delay factor. We use the cosine of this sum, multiplied by the span[2] of the function to produce the range of annual changes

---

[2]In cosine or sine wave functions, span is defined as the absolute change from the mean value to either the maximum value or minimum value produced. With a mean of 196., a span of 22.5 indicates that a maximum value of 218.5 (196.+22.5) and a minimum value of 173.5 (196.-22.5) are produced.

in values for lichen biomass (remember, cosines range from +1 to -1). When this is multiplied by the span, values ranging from 12.5 to -12.5 are attained. These changes are added to the mean biomass to produce the "ideal" cycle of biomass values for lichens. The daily value is then altered by multiplying by the limiting factor caused by soil depth (GFL01) difference from ideal and by the daily water stress factor (WSTRS(I)).

In order to allow stresses to operate more effectively, the data from this primary fuction were used to generate a function based upon differences in biomass. This is a sine function with a (2pi/365)*15 day delay. The constant is dropped, and the span becomes 0.387278. The primary function then becomes:

(SIN(.25822+(X*.017214))*.387278)

The next equation pertains to the partitioning of available soil calcium to lichens. Soil calcium is apportioned to lichen through splash and periodic flooding. Lichens also act as accumulators of blowing dust during dry periods. Since calcium content in rainfall reaches a maximum of only 0.5 mg./L of precipitation (Meyer, 1972), it is assumed that most calcium incorporated into lichen comes from underlying soil. The number of milligrams of calcium per gram biomass of lichen remains essentially constant all year. Thus:

ALCA(I)=ALBM(I)*3.357

shows that (grams lichen biomass per meter square)*(3.357 mg. calcium per gram biomass) yields (mg. calcium per meter square of lichen biomass). The linear data has 0.0 as an intercept. This second equation precludes the necessity of conditional switches.

Except that the value of the constant has changed, the same relationship holds true for magnesium in lichens:

ALMG(I)=ALBM(I)*0.356

The concentration of potassium in lichens changes on an annual cycle of the same period (2 pi) as the changes in biomass. In fact, except for scalar differences, the cosine waves of lichen biomass and potassium concentration match. Thus, we represent the sum of potassium in lichens as:

ALK(I)=(ALBM(I)*(.620+(COS(3.39981+(X*.017214))*.323)))

In this case, the lichen biomass is multiplied by a calculated concentration coefficient. This concentration coefficient has the same basic structure as preceding cosine functions. The mean value in this instance if 0.620 the cosine value is the same; 3.39981+(X*.017214), and the span is 0.323.

An examination of the equations for determining lichen phosphate and nitrogen contents show the same kind of cosine functional relationship:

ALP(I)=(ALBM(I)*(1.103+(COS(3.39981+(X*.017214))*.630)))

ALN(I)=(ALBM(I)*(12.000+(COS(3.39981+(X*.017214))*5.380)))

In these cases, the mean for phosphate is 1.103 and the span is 0.630, For nitrogen, the mean is 12.000 and the span is 5.380.

Bryophyte productivity follows the same annual pattern displayed by lichens; that is, a 2 pi cosine wave function reaching a low during mid-December. The primary differences between lichen productivity and bryophyte productivity are the means and spans of their primary equations, and in the growth factors determined by soil depth. The productivity function for bryophytes is:

BBMD(I)=BBMD(I-1)+((SIN(.25822+(X*.017214))*6.60215)*GFBO1*WSTRS(I)

The primary determining function is (SIN(.25822+X*.017214))*6.60215). The equation is essentially the same as the lichen function.

The partitioning of soil nutrients for bryophytes also follows the same patterns as the series for nutrient partitioning for lichens. Calcium and magnesium concentrations per unit biomass remain constant, and potassium, phosphorus, and nitrogen follow cosine wave structure. Only the values of the constants, means, and spans are changed:

BBCA(I)=BBMD(I)*4.45

BBMG(I)=BBMD(I)*0.577

BBK(I)=BBMD(I)*(.950+(COS(3.39981+(X*.017214)*.389)))

BBP(I)=(BBMD(I)*(1.462+(COS(3.39981+(X*.017214))*.905)))

BBN(I)=(BBMD(I)*(15.240+(COS(3.39981+(X*.017214))*6.557)))

The entire subsection beginning on page 175, Appendix B, is comprised of switches in the form of "conditional If statements". While lichens and bryophytes have continuous productive cycles, biomass for annual plants begin their life cycles near zero. Also, different phases in growth cycles of annual plants produce biomass at different rates than other phases in their growth cycles. It becomes necessary to change the basic functions which control the amount of annual plant tissue produced (or lost) during different times of the year. For example, in the first annual cycle (the one where results aren't written into the output), prior to the 45th day (Feb. 14), only lichens and bryophytes are considered to have any biomass at all. On the 45th day, germination of Viguiera porterii

begins[3], and the variable VPBM(I) is no longer equal to 0.000.

The first "conditional If statement" switch causes the program to proceed to the end of the loop, where values are finally recalculated prior to returning to the first step in the DO loop:

```
IF (I.LT.46) GO TO 710
```

There, the values for lichen and bryophyte biomass, their respective nutrients, the changes in available soil nutrients, rainfall estimates, temperature means, attendant water stress factors, and total biomass are recalculated as required for the first 44 iterations of the loop.

However, as the second switch states, when the counting index I reaches 46, a new portion of the program is included:

```
IF ((I.GE.46).AND.(I.LE.194)) GO TO 50
```

The line index 50 is the first line of a brief segment which begins the generation of Viguiera biomass and the nutrient partitioning which accompanies its growth. We will examine the processes following line 50 in detail in the following subsection.

Each iteration through the loop sends operation to the appropriately numbered line, dependant upon the value of I. This model contains sufficient switches and function groups for six full years of operations, the last five of which are written as output.

---

[3]While it is clearly somewhat unrealistic to consider germination of an annual plant population to begin at exactly the same time each year, consideration of the multitude of environmental triggers which do control germination would greatly increase the complexity of this model. In order to keep the model as simple as possible, annual species are considered to begin germination the same day, each year.

The subsection beginning on page 178, Appendix B, is the largest segment of the model. Fortunately, it is also one of the simplest. For the sake of brevity, we will discuss representative samples of the segments in this subsection, and summarize at the end of the discussion.

Line 50

This segment is reached when I is 46 or greater, but less than (or equal to) 194. The first function initializes VPBM(I) by multiplying an initial value (0.0FF) by the growth limiter, GFV01.

```
IF (I.EQ.46) VPBM(I)=0.077*GFV01
```

The next growth function here uses this value to continue production:

```
VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFV01*WSTRS(I))
```

Perhaps the easiest way to interpret this complex function is to show its functioning in some examples. First, prior to day 46, VPBM(I)=0.000, and on day 46, VPBM(I)=.077*GFV01.

By omitting consideration of GFV01 (a constant in any given run of the model), and WSTRS(I) (a mean of 1.00), we continue thusly:

```
VPBM(47)=VPBM(46)+(.26145**(VPBM(46)**0.2904))
        =.077+(.26145*(.077**.2904))
        =.077+.124
        =.201
```

Again:

```
VPBM(48)=VPBM(4F)+(.261145*(VPBM(47)**.2904))
        =.201+(.26145*(.201**.2904))
        =.201+.164
        =.365
```

The calculated biomass values for the first three days of optimum Viguiera growth are thus:

VPBM(46)=.077

VPBM(4F)=.201

VPBM(48)=.365

This growth phase of Viguiera is exponential. These values would not be realistic for exceptional years when Viguiera populations are totally destroyed early in the life cycle. However, the studies of Mellinger (1971) demonstrate that anything short of annual extinction has little effect on population production and reproductive potential. Even annual extinction of a given population has no lasting impact due to reserves in the soil.

The equation is:

VPCA(I)=VPBM(I)8(9.918-(.0192*(X)))

This expresses in milligrams the total calcium in Viguiera. The equations for the nutrient content of the species were developed from best-fit curves of data presented by Meyer (1972). By using the calculated Viguiera biomasses from the preceding example we estimate the calcium content of the Viguiera population for the first three days of growth as:

VPCA(46)=.077*(9.918-(.0192*(45)))

=.69716 mg. Ca.

VPCA(47)=.201*(9.918-(.0192*(46)))

=1.81

VPCA(48)=.365(9.918-(.0192*(47)))

=.3.2907

By examining the calcium data with respect to biomass, as the population ages the Calcium content per gram Viguiera biomass is decreasing in a linear fashion.

The estimate of magnesium content follows a very similar equation to that of calcium:

```
VPMG(I)=VPBM(I)*(5.537-(.01765*(X)))
```

Note that the constant (5.537) is lower, and the slope of the line (.01765) is shallower.

The magnesium content of the first three days of Viguiera growth, as milligrams magnesium, are:

```
VPMG(46)=.077*(5.537-(.01765*(45)))
        =.36519 mg. Mg.
VPMG(4F)=.201*(5.537-(-.1765*(46)))
        =.9497
VPMG(48)=.365*(5.537-(.01765*(47)))
        =1.7182
```

The equations for potassium content must contain "conditional If" switches. This is because at day 90 and at day 181, the relationship between potassium content and Viguiera biomass is altered:

```
IF (I.LE.90) VPK(I)=VPBM(I)*((5.4252*(EXP(-34.538776)))*((X)**
6.2784)*1000
```

This complex relationship represents a logarithmic increase in the relative potassium content for the first 44 days post-germination. Logarythmic increase in potassium content per gram of biomass during early growth of Viguiera was determined over a three year period of

study (Meyer, 1972). We can only speculate that this increase is related to the unusual drought stress tolerance of Viguiera.

The potassium content estimates, as milligrams of K, for the first three days of Viguiera growth are:

VPK(46)=.077*((5.4252*(EXP(-34.538776)))*((45)**6.2784))*1000=.01001 mg. K

VPK(47)=.201*((5.4252*(EXP(-.34.538776)))*((46)**6.27884))*1000=.0300

VPK(48)=.365*((5.4252*(EXP(.34.538776)))*((47)**6.2784))*1000=.0545

After day 90 and until day 181, the relationship of potassium content in Viguiera biomass assumes an increasing linear relationship:

IF ((I.GT.90).AND.(I.LE.181)) VPK(I)=VPBM(I)*(7.04+(.03297*(X)))

Using an estimate of Viguiera biomass for day 91, the potassium content is:

VPK(91)=20.23095*(7.04+(.03297*(91)))=203.124 mg. K

The second change in the relationship of potassium content in Viguiera biomass occurs at day 181. The equation which fits best is a linear decreasing proportion:

IF ((I.GT.181).AND.(I.LE.212)) VPK(I)=VPBM(I)*(50.5-(.20719*(X)))

Using an estimate of Viguiera biomass at day 190, the potassium content is:

VPK(190)=104.306*(50.5-(.20719*(190)))=1161.333 mg. K

As with potassium, phosphorus content in Viguiera biomass requires a "conditional If" switch. For the first 151 days of the year, the relationship is best expressed by:

IF (I.LE.151) VPP(I)=VPBM(I)*((.02094*(X))-.692)

Phosphorus content for the first day of Viguiera growth is thus:

VPP(46)=.077*((.02094*(45))-.692=.01927 mg. P (as Phosphate)

The relationship of phosphorus content to Viguiera biomass for this time period is an increasing linear one.

However, after day 151, the equation for phosphorus content of Viguiera is:

IF ((I.GT.151).AND.(I.LE.409) VPP(I)=VPBM(I)*(24509*((X)**(-1.8284)))

which is a slowly increasing logarythmic function.

Using an estimate of Viguiera biomass for day 152, we obtain the phosphorus content as:

VPP(152)=67.430*(24509*((152)**(-1.8284)))=169.3932 mg P

The next equation estimates nitrogen content of the Viguiera population. No switch is required because the relationship remains constant throughout the life cycle:

VPN(I)=VPBM(I)*(59.028-(.17732*(X)))

This is a decreasing linear function, and the nitrogen content for the first days growth is estimated:

VPN(46)=.077*(59.028-(.17732*(45)))=3.9307 mg N (as Kjeldahl Nitrogen)

The last line in the segment is completed for that particular trip through the main loop ("I"). The remainder of this subsection is skipped over and the operation is transferred to line 710. We will discuss this section in detail later.

When the model has performed 193 iterations of the major loop, the operation is transferred to line 60 instead of line 50. Each iteration from I=195 through I=278 is transferred to line 60. Transfer is required

because the growth of Viguiera assumes a new pattern; biomass is now increasing linearly rather than exponentially. The equation for this new growth pattern is:

VPBM(I)=VPBM(I-1)+(1.8745*GFV)1*WSTRS(I))

Here, the equation is similar in many aspects to the growth function described above. The use of the soil depth controlled growth factor, and the daily water stress function are the same as before. However, the function which calculates the new biomass becomes a straight line. The slope of the equation is 1.8745:

VPBM(I)=VPBM(I-1)+(1.8745*GFV01*WSTRS(I))

Following the primary growth function of Viguiera, the calcium, magnesium, potassium, phosphorous, and nitrogen content of Viguiera are calculated. The segment ends, as before, with the "unconditional GO TO" statement which transfers the model operation to line 710.

For iteration numbers 279 and 280, model operation moves to line 70. This is the last of the segments which deal exclusively with Viguiera biomass, as Minuartia begins its cycle at day 281.

Here, once again, there is a change in the life cycle of Viguiera. Scenesence begins at day 279, and the loss of biomass takes the form:

VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1)))GFV01)

The decrease in biomass is exponential at this stage. Note also, that water stress plays no part in the decrease in biomass. While loss of nutrients implies decomposition by microbes, and that process requires water, the water stress coefficients we used for growth have no significant effect upon the rate of decomposition in this model.

Using a calculated value for Viguiera biomass at day 278 with the same growth factor from soil depth and water stress conditions as before (ie. both=1.0), we can calculate the biomass for day 279 as:

VPBM(279)=264.8795-((.1084*(EXP(.0214*264.8795)))=233.4894

The five nutrient contents in Viguiera at that time are calculated as before, and once again model operation is transferred to line 710.

In iteration number 281, model operation is transferred to line 80. At this point, Minuartia germinates and its biomass component is calculated. The first seven lines are identical to those in 70 above and calculate data for Viguiera as before. The eighth line is simply a "CONTINUE" statement. This statement does nothing but move the operation to the next line. It is employed here as an aid to the user, and simply makes the division between species equation sets more distinct.

Again, an initial value for AMUBM(I) is established by multiplying an initial constant (0.045) by the soil depth limited growth function, GFMO1:

```
IF (I.EQ.281) AMUBM(I)=0.045*GFMO1
AMUBM(281)=.045+(.172*(AMUBM(280)**.277))
          +.1179
AMUBM(282)=.1179+(.172*(AMUBM(281)**.277))
          =.1908
```

The next five lines calculate the five nutrients being considered for the Minuartia biomass generated. The first of these, the equation for determining the calcium content of Minuartia, is:

AMUCA(I)=AMUBM(I)*(.345*(EXP(.0103*(X-279.))))

This shows that calcium increases exponentially with Minuartia during this phase of its life cycle. The calcium content in the first day's biomass is thus:

```
AMUCA(281)=.045*(.345*(EXP(.0103*(280.-279.))))
          =.015686 mg. of Ca.
```

The equation for determining magnesium content of Minuartia for this phase is found next:

```
AMUMG(I)=.045*(3.154-(01256*(X-279.)))
         =.14136 mg. of Mg.
```

This equation shows that magnesium content of Minuartia follows a decreasing linear proportion for this phase of growth.

During this phase of growth, potassium concentration in Minuartia follows a very peculiar logarythmically decreasing function:

```
AMUK(I)=AMUBM(I)*((11.462438**10)*((X)**(-4.721)))
```

For the first day's growth, potassium content is calculated as:

```
AMUK(281)=.045*((11.462438**10)*((280.)**(-4.721)))
         =.00493 mg. of K
```

The equation which best describes the relationship of phosphorus content of Minuartia is an increasing linear function:

```
AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-365.)))
```

The phosphorus content of the Minuartia biomass on day 281 is:

```
AMUP(281)=.045*(2.353+(.01147*(280-365)))
         =.06201 mg. of P
```

In this growth phase, the nitrogen content of Minuartia is a constant 25.176 milligrams per gram biomass. The equation is simply:

```
AMUN(I)=AMUBM(I)*25.176
```

This equation is followed by the "unconditional GO TO" statement which sends model operation to line 710.

Iteration 306 is the first in which Sedum smallii biomass is produced. Line 90 begins with the same series of calculations for Viguiera and Minuartia as the previous segment. The equations are identical except for a pair of functions for the calculation of magnesium in Viguiera. Each of these begins with a "conditional If" switch which operates from day 311 to day 312. For I less than 313, VPMG(I) is:

VPMG(I)=VPBM(I)*(5.537-(.01765*(X)))

a decreasing linear relationship. For I greater than 313, VPMG(I) is a constant, 0.0655 mg./g. biomass.

The 18th line in this segment contains the initial growth function for Sedum biomass generation.[4] Once initialized, growth in this early phase of the life cycle is exponential, and represented by the equation:

SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1**.289))*GFSO1*WSTRS(I))

Considering GFSO1 and WSTRS(I) each to be 1.0, the first three days of biomass for Sedum are:

SSBM(306)=0.045 g./meter square

SSSBM(307)=0.12283 g./meter square

SSBM(308)=0.22101 g./meter square

The early growth phase of Sedum has three nutrients in constant proportion to biomass. These are calcium, phosphorus, and nitrogen.

---

[4]Once again, the initial value for SSBM(I) is a constant (0.045) multiplied by the growth factor, GFSO1.

The equations which determine the nutrient content of one meter square of Sedum biomass are:

```
SSCA(I)=SSBM(I)*3.7242
SSMG(I)=SSBM(I)*(1.61-(.004025*(X-204.)))
SSK(I)=SSBM(I)*(7.194-(.02095*(X-304.)))
SSP(I)=SSBM(I)*2.18
SSN(I)=SSBM(I)*12.2726
```

All these relationships are types examined previously.

At line reference 110, page 181, Appendix B, we find the next equation series which bears explanation. In this statement, which represents only iteration for day 410 (I=411), we are at the point of germination for the second growth cycle of Viguiera. At this time, the maximum amount of biomass accumulated for Viguiera the previous cycle (occurring on day 278) provides a basis for the germination biomass of the second year. The equation is based upon examination of numerous runs for optimum productivity and a best-estimate of the initial biomass of the species.

A power code function of the maximum biomass provides the basis for germination. A less-than-optimal biomass will produce fewer seeds. Fewer seeds will increase the proportion of established seedlings by reduced competition. The result is a tendancy toward re-establishment of optimum biomass production. The equation is:

```
VPBM(I)=((2.715*(VPBM(277)**.822)/3551.5584)
```

It is, however, those periods when biomass has been very reduced the previous year that the need for close approximation by a power curve becomes necessary. By looking at the values for low biomass we can see

the curve which generates a larger-than-linear proportion of new biomass. This is illustrated in Figure A-9. The value generated for VPBM(I) here is used in place of the constant (.077) used for the first cycle of Viguiera biomass.

At line reference 180, page 186, Appendix B, the germination of Minuartia begins its second cycle. Here, the previous maximum Minuartia biomass is divided by the optimal maximum (78.5316) to generate a proportional variable, AMX1.

AMX1=(AMUBM(468)/78.5316)

This proportion is then used as a switch to determine which of two growth functions are used to produce the new biomass constant for Minuartia. The first of these "conditional If" switches and it's attendant equation is:

IF (AMX1.GE.0.20) AMUBM(I)=((-82.809+(36.887*(ALOG1(AMUBM(467)))))/1711.1333333333)*GFMO1

Once again, by examination of theoretical examples, we can see the result of this logarythmic function. Consider some results (If GFMO1=1.0) of this application, Figure A-10. Note that any value less than approximately 15.7 grams of AMUBM (468) causes the second equation to be used.

The curve in Figure A-10 shows that as maximum biomass decreases from optimum, a greater proportion of the Minuartia biomass is relegated to reproduction. This occurs to a hypothetical point where insufficient maximum biomass is attained to permit the kind of recovery implied in the above equation. This has been estimated as 20% of optimum biomass, hence the AMX1 switching constant of 0.20.

VPBM(278)	New Biomass(411)
45	.018111
30	.012977
15	.007341
10	.00526
5	.00297

These data provide a plot like this:

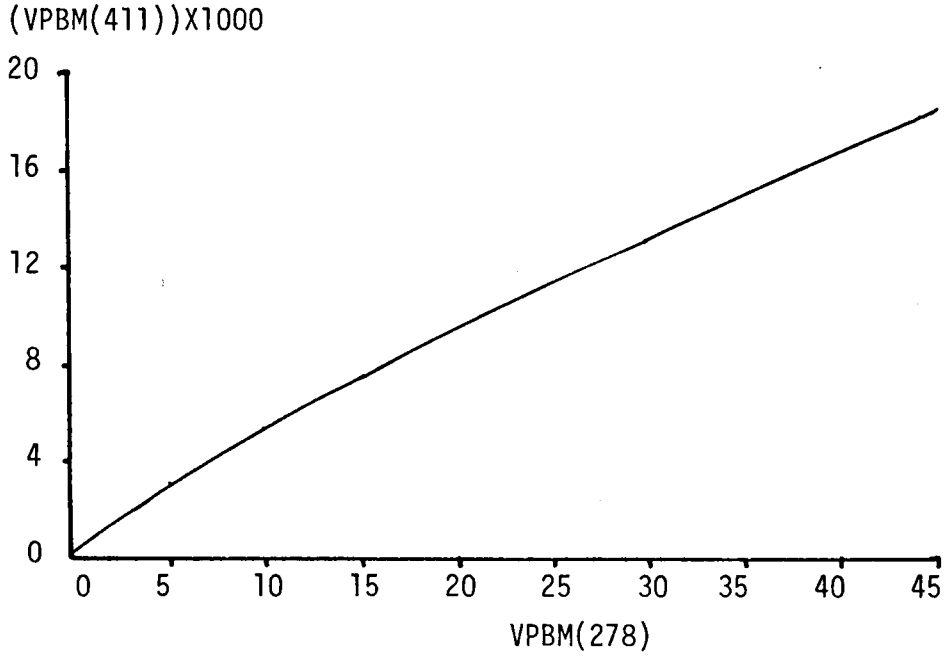


Figure A-9. Germination Level of Viguiera, I=411 Relative to Maximum Growth the Previous Year (278).

AMUBM(468)	AMX1	New Biomass Constant
80.0	1.0187	.046069
70.0	.8936	.043191
60.0	.7640	.039868
50.0	.6367	.035937
40.0	.5093	.031127
30.0	.3820	.024926
20.0	.2547	.016185
16.0	.2037	.0113746

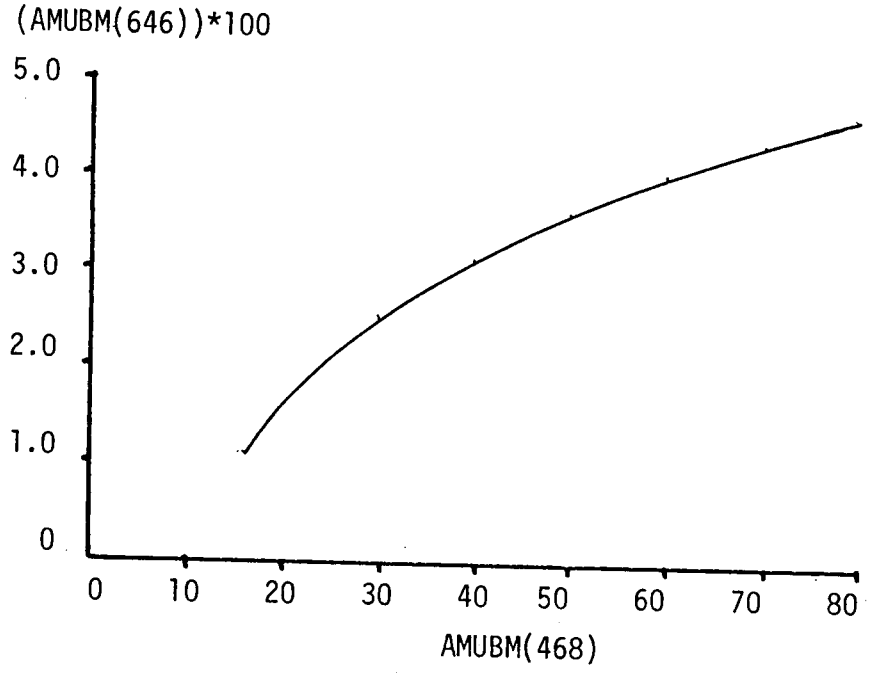


Figure A-10. Minuartia Germination, I=646, Relative to the Previous Season's Maximum Biomass When AMX1 Is Greater Than or Equal to 0.20. AMX1=(AMUBM(468)/78.5316).

Where less than 20% of optimum biomass has been attained at day 467, a linear proportion of AMUBM(467) is used to generate the new biomass constant. The equation is:

```
IF (AMX1.LT.0.20) AMUBM(I)=(((AMUBM(468)/1711.1333333333)*
I((X-644.)**1.423))*GFM01
```

Some hypothetical data for low AMUBM*468) are presented in Figure A-11.

The equations which generate a new biomass constant for Sedum are found at line reference 200, page 188, Appendix B. Maximum biomass of the previous growth season is utilized (we assume seed production occurs at the time biomass is at it's peak). In some respects it is very similar to the equations for Minuartia in the previous segment. Once again, a proportional constant, SX1, is generated by dividing actual SSBM data by the optimal production figure. For SSBM, this occurs on iteration 477 in the first full year of production. The optimal biomass figure for this day is 79.0384 grams, thus in the equation:

```
SX1=(SSBM(477)/79.0384)
```

SX1 acts as the determining value in the "conditional If" switches for the SSMB(I) equations. The first of these, where 40% or more of optimal SSBM(477) was attained, is an increasing function with an exponential form:

```
IF (SX1.GE.0.40) SSBM(I)=(((59.279+(.25*SSBM(476)))/
11720.3333333333)*((X-669.)**1.4487))*GFS01
```

Some hypothetical data for calculating a new biomass constant for Sedum are presented in Figure A-12.

AMUBM(468)	AMX1	New Biomass Constant
15	.1910	.00877
13	.1655	.00760
11	.1401	.00643
9	.1146	.00526
7	.0891	.00409
5	.0637	.00292
3	.0382	.00175
1	.0127	.00058

This data forms a straight line plot with its intercept 0.0.

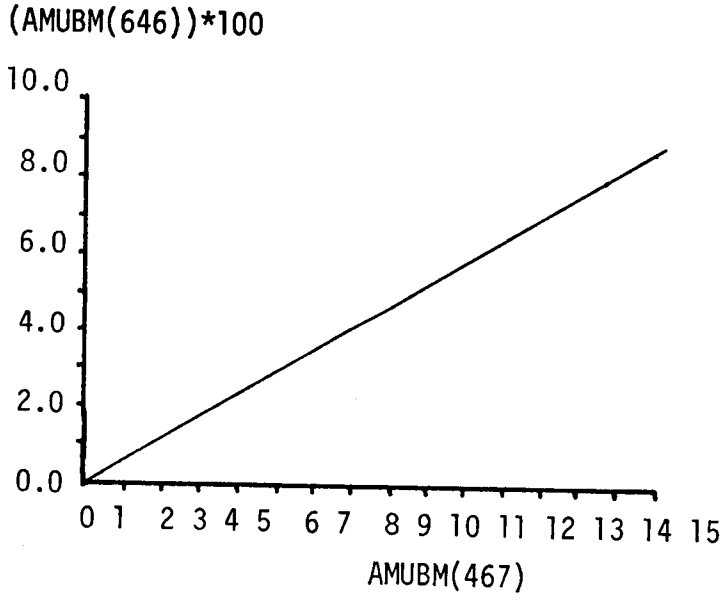


Figure A-11. Minuartia Germination, I=646, Relative to the Previous Year's Maximum Biomass When AMX1 Is Less Than 0.20. AMX1= (AMUBM(468)/78.5316).

SSM(477)	SX1	New Biomass Constant
85	1.0754	.046810
75	.9489	.045356
65	.8224	.043904
55	.6959	.042450
45	.5693	.040997
35	.4428	.039544
32	.4049	.039108

The following graph shows the slope of the plotted data to be nearly linear.

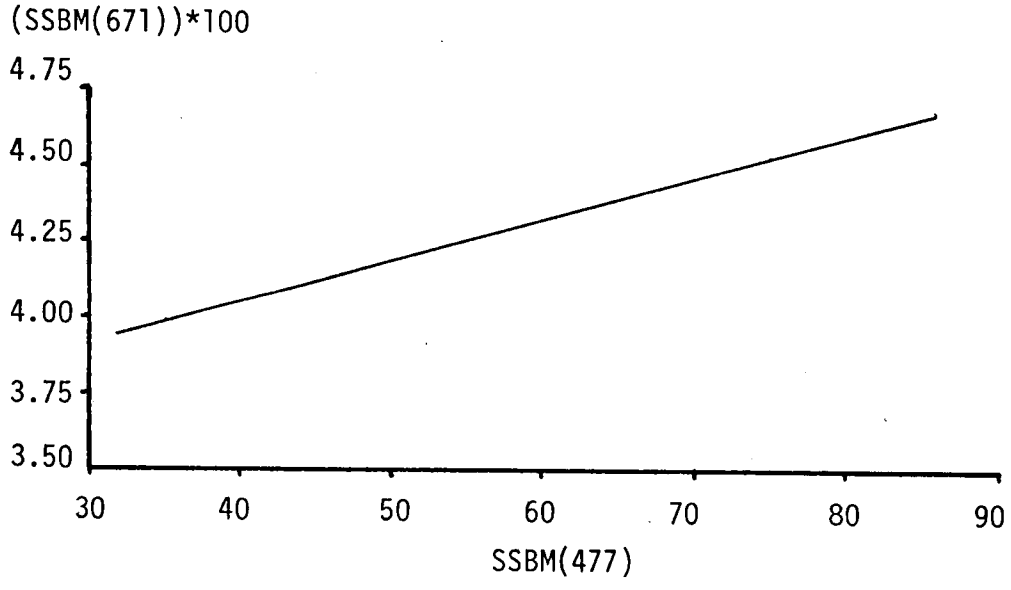


Figure A-12. Sedum Germination, I=671, Relative to the Previous Season's Maximum Biomass, When SX1 Is Greater Than or Equal to 0.40. SX1=(SSBM(477)/79.0384)

Note that 40% of optimum biomass at SSBM(477) is required to attain this proportionally high establishment of seedlings. Let us consider a hypothesized case where less than 40% of optimum Sedum biomass was attained (Figure A-13). When this occurs, the equation for SSBM(I) becomes:

```
IF (SX1.LT.0.40) SSBM(I)=((SSBM(477)/1720.3333333333)*
1((X-669.)**1.4487))*GFS01
```

Each of the dominant species have exhibited the ability to compensate for high mortality by greatly increasing biomass or seed production of survivors. For example, Mellinger (1972) demonstrated that reproductive potential of Viguiera is relatively constant regardless of any degree of mortality short of extinction. At the required intervals throughout the main loop of the model, Viguiera, Minuartia, and Sedum repeat this pattern of germination and establishment based upon the previous season's maximum biomass figures.

After each day's preliminary calculations, the "unconditional GO TO" statement:

```
GO TO 710
```

sends the program to line 710, where final calculations are carried out, and the data is written into the output file.

This subsection, page 224, Appendix B, is the last phase of the loop. Here, final calculations are made before writing the results into the output file.

SSBM(477)	SX1	New Biomass Constant
30	.3796	.01744
25	.3163	.01453
20	.2530	.01163
15	.1898	.00872
10	.1265	.00581
5	.0633	.00291

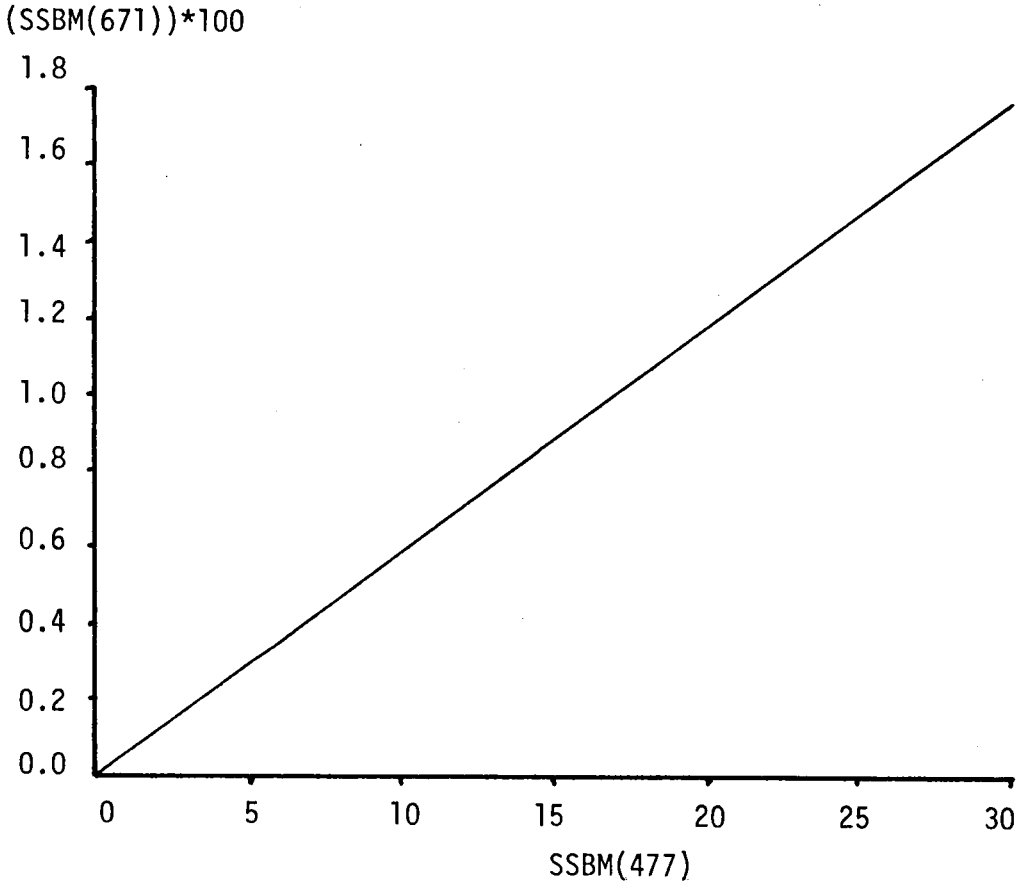


Figure A-13. Sedum Germination, I=671, Relative to the Previous Season's Maximum Biomass, with SX1 Less Than 0.40. SX1=(SSBM (477/79.0384)

The first step is the establishment of 0.0 as the minimum value for any real number in the model operation. Negative biomass values may be mathematically possible, but infeasible in reality.

The next calculation, page 225, Appendix B, is simply the establishment of a "day" counter which permits the index days printed into the output file to correspond with the days counted. We can thus eliminate the first 365 "days" of operation as the model stabilizes. It takes the form:

```
LDAY(I)=I-366
```

The next equation requires three lines. It is the point at which soil calcium (SOILCA(I)) content is altered by biotic activity. Considering the equation one line at a time, the first line is:

```
SOILCA(I)=SOILCA(I-1)-((VPCA(I)+AMUCA(I)+SSCA(I)
```

This portion of the equation tells us that the new iteration's soil calcium (SOILCA(I) is equal to the previous "day's" soil calcium minus the calcium content of Viguiera, Minuartia, and Sedum for the present iteration. Continuing:

```
     1 BBCA(I)+ALCA(I))-(BBCA(I-1)+ALCA(I-1)+
     2 VPCA(I-1)+AMUCA(I-1)+SSCA(I-1)))
```

The remainder of the calcium content of our biomass groups is added together for that iteration, and the content from the previous day's iterations are subtracted. Thus, we subtract differences in biotically held calcium from the previous soil calcium.

This same procedure is followed for each of the other four nutrients we are monitoring.

After determining the new soil nutrient contents, a recalculation of biomass occurs relative to the new soil content. This is made on the basis of "ZSnut". figures; simply, 1% of the total soil nutrient. The expression:

```
ZSCA(I)=SOILCA(I)*.01
```

produces ZSCA(I), 1% of soil calcium. Making the assumption that 1% of the total nutrient is available for the growth of any single plant group, we use "conditional If" statements to determine the need to recalculate biomass due to a limited nutrient factor. Consider, for example, the first equation under the one determining ZSCA(I):

```
IF (ZSCA(I).LT.VPCA(I)) VPBM(I)=VPBM(I)*(ZSCA(I)/VPCA(I))
```

This calculates a new VPBM(I) whenever the calcium required for Viguiera growth is more than 1% of the total soil calcium. Growth is reduced by the proportion available relative to the amount required (ZSCA(I)/VPCA(I)).

This process is followed for each of the five nutrients and each of the three vascular populations. It is assumed that lichens and mosses do not become nutrient limited by soil nutrient reductions.

In order to provide an indicator of the daily biomass content of our meter square of granite outcrop, TTLBM(I) is calculated:

```
TTLBMS(I)=VPBM(I)+AMUBM(I)+SSBM(I)+ALBM(I)+BBMD(I)
```

This gives a general indicator of whole-system "health".

Following this calculation, one final "conditional If" statement is required to allow the program to begin writing the data at iteration 367:

```
IF (I.LE.366) GO TO 730
```

This simply bypasses the "WRITE" statement, and sends the program to the point where the loop recommences.

The final "WRITE" statement contains all the variables we require in the output, listed sequentially. Naturally, we can omit the writing of such variables as "RAND" and "RANDL" as they would be meaningless outside the context of the operations where they are used.

After the list of variables to be written into the output file, we encounter the final line of this massive loop:

```
740 CONTINUE
```

which sends the operation back to our "DO" statement. If all iterations have been completed, the program moves to the next step; STOP. Format statements for all the "TYPE", "WRITE", and "READ" statements in the program follow the "STOP" command.

APPENDIX B

FORTRAN-10 MODEL

```
      DIMENSION VPBM(2191),AMUBM(2191),SSBM(2191),BBMD(2191),
     1ALBM(2191),RN(2191),RANDL(2191),TEMP(2191),EVAP(2191),
     2RNI(2191),WP1(2191),WSTRS(2191),VPCA(2191),VPMG(2191),
     3VPK(2191),VPP(2191),VPN(2191),AMUCA(2191),AMUMG(2191),
     4AMUK(2191),AMUP(2191),AMUN(2191),SSCA(2191),
     5SSMG(2191),SSK(2191),SSP(2191),SSN(2191),BBCA(2191),
     6BBMG(2191),BBK(2191),BBP(2191),BBN(2191),ALCA(2191),
     7ALMG(2191),ALK(2191),ALP(2191),ALN(2191),
     8SOILCA(2191),SOILMG(2191),SOILK(2191),SOILP(2191),
     9SOILN(2191),TTLBMS(2191),LDAY(2191),ZSCA(2191),ZSMG(2191),
     1ZSK(2191),ZSP(2191),ZSN(2191)
      OPEN(UNIT=20,FILE='ABBR.1',ACCESS='SEQIN',MODE='ASCII')
      OPEN(UNIT=21,FILE='TEMPS.PAN',ACCESS='SEQIN',MODE='ASCII')
      OPEN(UNIT=22,FILE='BMAS7D.090',ACCESS='SEQOUT',MODE='ASCII')
```

```
C       ****************************************************************
C       * THE NEXT FOUR QUESTIONS REQUIRE THE USER TO ENTER THE        *
C       * INITIATING PARAMETERS FOR THE MODEL.  THESE ARE PRINTED      *
C       * IN THE FIRST THREE LINES OF THE OUTPUT, AND THEY MAY BE      *
C       * USED IN SUBSEQUENT RUNS OF THE MODEL TO ENABLE USERS TO      *
C       * CHANGE ONLY PORTIONS OF OTHER ENTERED DATA.  THIS ALLOWS     *
C       * THE DUPLICATION OF PHYSICAL PARAMETERS, INCLUDING THE        *
C       * PSEUDORANDOMLY GENERATED RAINFALL AND TEMPERATURE DATA.      *
C       ****************************************************************
        TYPE 800
        ACCEPT *,IDUMMY,JRDUM
10      TYPE 810
        ACCEPT *,RNPROP
        IF (RNPROP.LE.0.0)  GO TO 10
        IF (RNPROP.GT.2.0)  GO TO 10
20      TYPE 820
        ACCEPT *,NYRS
        IDAYS=(365*(NYRS+1))+1
        IF (IDAYS.GT.2191)     IDAYS=0
        IF (IDAYS.EQ.0)     GO TO 20
        TYPE 830
        ACCEPT *,SDPTH
```

```
C       ****************************************************************
C       * THE "X" INITIATOR IS SIMPLY A REAL NUMBER EQUIVALENT TC *
C       * THE "I" INDEX OF THE MASTER LOOP.  THIS PERMITS USE OF  *
C       * A "DAY" CCUNTER IN FUNCTIONS WHERE MIXED-MODE MATH IS   *
C       * NOT PROPER.  INCLUDED IN THE FCRMAT STATEMENT BELCw IS A*
C       * GUIDE, OUTLINING THE OUTPUT DATA FORMAT.  THIS IS       *
C       * PRINTED BELCW THE INITIATING PARAMETERS AND ABOVE THE   *
C       * FIXED-FORMAT CATA OUTPUT.                               *
C       ****************************************************************
        JDAYS=IDAYS-366
        X=0.0
        SOILCA(1)=(110+(89.124*SDPTH))*100
        SOILMG(1)=20200.0
        SOILK(1)=6420C.C
        SOILP(1)=8664C.0
        SOILN(1)=2532C0.0
        WRITE (22,840) IDUMMY,JRDUM,NYRS,JDAYS,SDPTH,RNPROP
```

```
C       ************************************************************
C       * THE "GF_01" FUNCTIONS BELOW ARE GENERATED AS SWITCHED    *
C       * PARTIAL REGRESSIONS DRAWN FROM DATA RELATIVE TO SPECIES  *
C       * GROWTH AS A FUNCTION OF SOIL DEPTH.  THEY ARE USED AS    *
C       * PROPORTIONAL MULTIPLIERS OF OPTIMAL BIOMASS GENERATORS,  *
C       * AND THEIR VALUE IS DETERMINED IN PART BY THE SOIL DEPTH  *
C       * MEAN ENTERED AS AN INITIAL PARAMETER.                    *
C       ************************************************************
        GFS01=(100-(38.76*(ALOG(SDPTH))))/100
        IF (GFS01.GT.1.00)     GFS01=1.00
        IF (GFS01.LT.0.00)     GFS01=0.00
        IF (SDPTH.LE.9.)     GFM01=(-11.375+(12.375*SDPTH))/100
        IF ((SDPTH.GT.9.).AND.(SDPTH.LE.11.))     GFM01=1.00
        IF (SDPTH.GT.11.)     GFM01=(444.6667-(31.3333*SDPTH))/100
        IF (GFM01.LT.0.00)     GFM01=0.00
        IF (GFM01.GT.1.00)     GFM01=1.00
        GFV01=(.001*(SDPTH**3.833))/100
        IF (GFV01.GT.1.00)     GFV01=1.00
        IF (SDPTH.LT.11.1)     GFB01=(6.68+(38.771*(ALOG(SDPTH))))/100
        IF (SDPTH.GE.11.1)     GFB01=(22.173*(EXP(.1*SDPTH)))/100
        IF (GFB01.GT.1.00)     GFB01=1.00
        IF (GFB01.LT.0.00)     GFB01=0.0
        IF (SDPTH.LT.9.62)     GFL01=(2.853*(EXP(.37*SDPTH)))/100
        IF (SDPTH.GE.9.62)     GFL01=(211.478-(11.588*SDPTH))/100
        IF (GFL01.LT.0.00)     GFL01=0.00
        ALBM(1)=174.2459*GFL01
        BBMD(1)=400.2533*GFB01
```

```
C       ************************************************************
C       * THE NEXT SMALL LOOP USES THE SECOND PSEUDORANDOM SEED    *
C       * AS A RANDOMIZER FOR THE RAINFALL AND TEMPERATURE FUNC-   *
C       * TIONS.  IN THE MAJOR PROGRAM LOOP OF THE MODEL, THE      *
C       * RAINFALL AND TEMPERATURE GENERATORS BECOME OPERATIVE.    *
C       * INSIDE THIS LOOP, CONSTANTS ARE READ FROM DATA FILES     *
C       * OUTSIDE THE PROGRAM PROPER.  IN THE RAINFALL GENERATOR,  *
C       * THE LINE SLOPE AND INTERCEPT (OR CONST) ARE  INPUT       *
C       * VARIABLES READ FROM A FILE OF SUCH, DERIVED FROM DATA    *
C       * ENCOMPASSING TWENTY YEARS OF EAST TENNESSEE RAINFALL     *
C       * AND THE PROBABILITY EQUATIONS DEVELOPED FROM THAT DATA.  *
C       * THE TMEAN AND SPAN CONSTANTS ARE USED IN A COSINE BASED  *
C       * FUNCTION WHICH DETERMINES A DAILY MEAN TEMPERATURE.      *
C       * THE CONSTANTS ARE DERIVED FROM TEMPERATURE MEANS AND     *
C       * EXTREEMS ACCUMULATED OVER THE SAME TWENTY-YEAR PERIOD    *
C       * AS THE RAINFALL DATA.                                    *
C       *(THE BASIC INFORMATION IS COURTESY OF DR. HENRY FRIEDURG  *
C       *  INSTITUTE OF AGRICULTURE, PLANT AND SOIL SCIENCES,      *
C       *  UNIVERSITY OF TENNESSEE, KNOXVILLE, 37916.)             *
C       ************************************************************
30      DO 40  J=1,JROUM
        RAND=RAN(IDUMMY)
40      CONTINUE
```

```
DO 730 I=2,IDAYS
 READ (20,850) SLOPE,CONST
 READ (21,860) TMEAN,SPAN
 RAND=RAN(IDUMMY)
 RANDL(I)=10**RAND
 RNI(I)=2.79*(10**((SLOPE*RAND)+CONST))
 RN(I)=RNI(I)*RNPROP
 TEMP(I)=((TMEAN+(COS(3.1416+RANDL(I))*SPAN))-1.1112)
 X=X+1.0
```

```
C       ****************************************************************
C       * THE EVAP FUNCTIONS ARE PRIMARILY A PRODUCT OF A TIME-        *
C       * VARIABLE RELATIONSHIP ORIGINALLY DEVELOPED FOR THE           *
C       * GRANITE OUTCROP ECOSYSTEM BY DR. KEN MEYER.  THE UNITS       *
C       * ARE DIFFERENT FROM THOSE OF THE GENERATED RAINFALL DATA      *
C       * AND ARE USED WITH A DIVISOR TO GENERATE WATER POTENTIAL      *
C       * AND WATER STRESS FACTORS.                                    *
C       ****************************************************************
        IF (X.LE.0.0)     EVAP(I)=.968
        IF (X.LE.0.0)     RN(I)=.1107
        IF (I.LE.32)     EVAP(I)=.968-(.006258*X)
        IF ((I.GT.32).AND.(I.LE.121))     EVAP(I)=.402*(EXP(.0211329*X))
        IF ((I.GT.121).AND.(I.LE.244))     EVAP(I)=5.785-(.0062645*X)
        IF ((I.GT.244).AND.(I.LE.305))     EVAP(I)=9.530-(.021695*X)
        IF ((I.GT.305).AND.(I.LE.366))     EVAP(I)=12.741-(.032256*X)
        IF ((I.GT.366).AND.(I.LE.397))     EVAP(I)=.968-(.006258*(X-365.))
        IF ((I.GT.397).AND.(I.LE.486))     EVAP(I)=.402*(EXP(.0211329*(X-
       1365.)))
        IF ((I.GT.486).AND.(I.LE.609))     EVAP(I)=5.785-(.0062645*(X-
       1365.))
        IF ((I.GT.609).AND.(I.LE.670))     EVAP(I)=9.530-(.021695*(X-365.)
       1)
        IF ((I.GT.670).AND.(I.LE.731))     EVAP(I)=12.741-(.032256*(X-
       1365.))
        IF ((I.GT.731).AND.(I.LE.762))     EVAP(I)=.968-(.006258*(X-730.))
        IF ((I.GT.762).AND.(I.LE.851))     EVAP(I)=.402*(EXP(.0211329*(X-
       1730.)))
        IF ((I.GT.851).AND.(I.LE.974))     EVAP(I)=5.785-(.0062645*(X-
       1730.))
        IF ((I.GT.974).AND.(I.LE.1035))     EVAP(I)=9.530-(.021695*(X-
       1730.))
        IF ((I.GT.1035).AND.(I.LE.1096))     EVAP(I)=12.741-(.032256*(X-
       1730.))
        IF ((I.GT.1096).AND.(I.LE.1127))     EVAP(I)=.968-(.006258*(X-
       11095.))
        IF ((I.GT.1127).AND.(I.LE.1216))     EVAP(I)=.402*(EXP(.0211329*
```

```
1(X-1095.)))
 IF ((I.GT.1216).AND.(I.LE.1339))    EVAP(I)=5.785-(.0062645*(X-
11095.))
 IF ((I.GT.1339).AND.(I.LE.1400))    EVAP(I)=9.530-(.021695*(X-
11095.))
 IF ((I.GT.1400).AND.(I.LE.1461))    EVAP(I)=12.741-(.032256*(X-
11095.))
 IF ((I.GT.1461).AND.(I.LE.1492))    EVAP(I)=.968-(.006258*(X-
11460.))
 IF ((I.GT.1492).AND.(I.LE.1581))    EVAP(I)=.402*(EXP(.0211329*
1(X-1460.)))
 IF ((I.GT.1581).AND.(I.LE.1704))    EVAP(I)=5.785-(.0062645*(X-
11460.))
 IF ((I.GT.1704).AND.(I.LE.1765))    EVAP(I)=9.530-(.021695*(X-
11460.))
 IF ((I.GT.1765).AND.(I.LE.1826))    EVAP(I)=12.741-(.032256*(X-
11460.))
 IF ((I.GT.1826).AND.(I.LE.1857))    EVAP(I)=.968-(.006258*(X-
11825.))
 IF ((I.GT.1857).AND.(I.LE.1946))    EVAP(I)=.402*(EXP(.0211329*
1(X-1825.)))
 IF ((I.GT.1946).AND.(I.LE.2069))    EVAP(I)=5.785-(.0062645*(X-
11925.))
 IF ((I.GT.2069).AND.(I.LE.2130))    EVAP(I)=9.530-(.021695*(X-
11825.))
 IF (I.GT.2130)     EVAP(I)=12.741-(.032256*(X-1825.))
 IF (SDPTH.LE.1.)    WP1(I)=((RN(I-2)+RN(I-1)+RN(I)))-((EVAP(I-2)+
1EVAP(I-1)+EVAP(I))/8.7422)
 IF ((SDPTH.GT.1.).AND.(SDPTH.LE.2.))    WP1(I)=((RN(I-3)+RN(I-2)+
1RN(I-1)+RN(I)))-((EVAP(I-3)+EVAP(I-2)+EVAP(I-1)+EVAP(I))/8.7422)
 IF ((SDPTH.GT.2.).AND.(SDPTH.LE.3.))    WP1(I)=((RN(I-4)+RN(I-3)+
1RN(I-2)+RN(I-1)+RN(I)))-((EVAP(I-4)+EVAP(I-3)+EVAP(I-2)+EVAP(I-1)+
2EVAP(I))/8.7422)
 IF ((SDPTH.GT.3.).AND.(SDPTH.LE.4.))    WP1(I)=((RN(I-5)+RN(I-4)+
1RN(I-3)+RN(I-2)+RN(I-1)+RN(I)))-((EVAP(I-5)+EVAP(I-4)+EVAP(I-3)+
2EVAP(I-2)+EVAP(I-1)+EVAP(I))/8.7422)
```

```
 IF ((SDPTH.GT.4.).AND.(SDPTH.LE.5))     WP1(I)=((RN(I-6)+RN(I-5)+
1RN(I-4)+RN(I-3)+RN(I-2)+RN(I-1)+RN(I)))-((EVAP(I-6)+EVAP(I-5)+
2EVAP(I-4)+EVAP(I-3)+EVAP(I-2)+EVAP(I-1)+EVAP(I))/8.7422)
 IF ((SDPTH.GT.5.).AND.(SDPTH.LE.6.))     WP1(I)=((RN(I-7)+RN(I-6)+
1RN(I-5)+RN(I-4)+RN(I-3)+RN(I-2)+RN(I-1)+RN(I)))-((EVAP(I-7)+
2EVAP(I-6)+EVAP(I-5)+EVAP(I-4)+EVAP(I-3)+EVAP(I-2)+EVAP(I-1)+
3EVAP(I))/8.7422)
 IF ((SDPTH.GT.6.).AND.(SDPTH.LE.7.))     WP1(I)=((RN(I-8)+RN(I-7)+
1RN(I-6)+RN(I-5)+RN(I-4)+RN(I-3)+RN(I-2)+RN(I-1)+RN(I)))-((EVAP(I-
28)+EVAP(I-7)+EVAP(I-6)+EVAP(I-5)+EVAP(I-4)+EVAP(I-3)+EVAP(I-2)+
3EVAP(I-1)+EVAP(I))/8.7422)
 IF ((SDPTH.GT.7.).AND.(SDPTH.LE.8.))     WP1(I)=((RN(I-9)+RN(I-8)+
1RN(I-7)+RN(I-6)+RN(I-5)+RN(I-4)+RN(I-3)+RN(I-2)+RN(I-1)+RN(I)))-
2((EVAP(I-9)+EVAP(I-8)+EVAP(I-7)+EVAP(I-6)+EVAP(I-5)+EVAP(I-4)+
3EVAP(I-3)+EVAP(I-2)+EVAP(I-1)+EVAP(I))/8.7422)
 IF ((SDPTH.GT.8.).AND.(SDPTH.LE.9.))     WP1(I)=((RN(I-10)+RN(I-9)
1+RN(I-8)+RN(I-7)+RN(I-6)+RN(I-5)+RN(I-4)+RN(I-3)+RN(I-2)+RN(I-1)+
2RN(I)))-((EVAP(I-10)+EVAP(I-9)+EVAP(I-8)+EVAP(I-7)+EVAP(I-6)+
3EVAP(I-5)+EVAP(I-4)+EVAP(I-3)+EVAP(I-2)+EVAP(I-1)+EVAP(I))/8.7422)
 IF (SDPTH.GT.9.)     WP1(I)=((RN(I-11)+RN(I-10)+RN(I-9)+RN(I-8)+
1RN(I-7)+RN(I-6)+RN(I-5)+RN(I-4)+RN(I-3)+RN(I-2)+RN(I-1)+RN(I)))-
2((EVAP(I-11)+EVAP(I-10)+EVAP(I-9)+EVAP(I-8)+EVAP(I-7)+EVAP(I-6)+
3EVAP(I-5)+EVAP(I-4)+EVAP(I-3)+EVAP(I-2)+EVAP(I-1)+EVAP(I))/8.7422)
 IF (WP1(I).GE.1.0)     WSTRS(I)=2.0
 IF (WP1(I).LE.-1.0)     WSTRS(I)=0.0
 IF ((WP1(I).LT.1.0).AND.(WP1(I).GT.-1.0))     WSTRS(I)=1.0+WP1(I)
 IF (TEMP(I).LE.C.0) WSTRS(I)=0.0
```

```
C       ****************************************************************
C       * THE LICHEN BICMASS AND BRYOPHYTE BICMASS GENERATCRS ARE *
C       * BASED UPCN COSINE FUNCTION WHICH PEAK AT THE COOLER,    *
C       * WETTER PORTICN OF THE ANNUAL GRCWTH CYCLE.  THE NUTRIENT*
C       * BALANCES OFTEN FOLLOW A SIMILAR PATTERN OF ACCUMULATICN *
C       * AND LCSS (BASEC UPON CONCENTRATION/UNIT BIOMASS ) AND   *
C       * ARE ALSO COSINE FORM.  CALCIUM ANC MAGNESIUM REMAIN AT  *
C       * FAIRLY CONSTANT CONCENTRATICNS, ANC ARE SIMPLY MULTI-   *
C       * PLIERS.                                                 *
C       ****************************************************************
        ALBM(I)=ALBM(I-1)+((((SIN(.25822+(X*.017214))*.387278))
       1*GFLO1)*WSTRS(I))
        ALCA(I)=ALBM(I)*3.357
        ALMG(I)=ALBM(I)*0.356
        ALK(I)=(ALBM(I)*(.620+(COS(3.39981+(X*.017214))*.323)))
        ALP(I)=(ALBM(I)*(1.103+(COS(3.39981+(X*.017214))*.630)))
        ALN(I)=(ALBM(I)*(12.0+(COS(3.39981+(X*.017214))*5.380)))
        BBMD(I)=BBMD(I-1)+((((SIN(.25822+(X*.017214))*6.60215))
       1*GFBO1)*WSTRS(I))
        BBCA(I)=BBMD(I)*4.45
        BBMG(I)=BBMD(I)*0.577
        BBK(I)=(BBMD(I)*(.950+(COS(3.39981+(X*.017214))*.385)))
        BBP(I)=(BBMD(I)*(1.462+(COS(3.39981+(X*.017214))*.965)))
        BBN(I)=(BBMD(I)*(15.240+(COS(3.39981+(X*.017214))*6.557)))
```

```
C     ************************************************************
C     * THE BELOW SWITCHES ARE USED TO SEND THE OPERATION TC THE*
C     * PROPER SET CF EQUATIONS FOR THE ENCCMPASSED TIME PERICD.*
C     * IT WAS ELECTED TO DRAW THE PROGRAM CUT OVER THE FULL    *
C     * TIMESPAN CF FUNCTICNAL OPERATION RATHER THAN USE SUB-   *
C     * ROUTINES TO ALLOW THE USER MCRE FREEDOM CF ALTERATICN.  *
C     * THE EXTENDED FORM IS ALSO SIMPLER TO FOLLOW IN TIME     *
C     * SEQUENCE FOR UNEXPERIENCED USERS.                       *
C     ************************************************************
      IF (I.LT.46)     GO TO 710
      IF ((I.GE.46).AND.(I.LE.194))    GC TO 50
      IF ((I.GT.194).AND.(I.LE.278))    GC TO 60
      IF ((I.GT.278).AND.(I.LE.280))    GO TO 70
      IF ((I.GT.280).AND.(I.LE.305))    GO TO 80
      IF ((I.GT.305).AND.(I.LE.339))    GC TO 90
      IF ((I.GT.339).AND.(I.LE.410))    GO TO 100
      IF (I.EQ.411)     GC TO 110
      IF ((I.GT.411).AND.(I.LE.468))    GO TO 120
      IF ((I.GT.468).AND.(I.LE.477))    GO TO 130
      IF ((I.GT.477).AND.(I.LE.559))    GC TO 140
      IF ((I.GT.559).AND.(I.LE.631))    GO TO 150
      IF ((I.GT.631).AND.(I.LE.643))    GO TO 160
      IF ((I.GT.643).AND.(I.LE.645))    GC TO 170
      IF (I.EQ.646)     GO TO 180
      IF ((I.GT.646).AND.(I.LE.670))    GO TO 190
      IF (I.EQ.671)     GO TO 200
      IF ((I.GT.671).AND.(I.LE.704))    GO TO 210
      IF ((I.GT.704).AND.(I.LE.775))    GO TO 220
      IF (I.EQ.776)     GO TO 230
      IF ((I.GT.776).AND.(I.LE.833))    GO TO 240
      IF ((I.GT.833).AND.(I.LE.842))    GC TO 250
      IF ((I.GT.842).AND.(I.LE.924))    GC TO 260
      IF ((I.GT.924).AND.(I.LE.996))    GO TO 270
      IF ((I.GT.996).AND.(I.LE.1008))    GC TC 280
      IF ((I.GT.1008).AND.(I.LE.1010))    GO TO 290
      IF (I.EQ.1011)     GO TO 300
```

```
IF ((I.GT.1011).AND.(I.LE.1035))    GO TO 310
IF (I.EQ.1036)    GO TO 320
IF ((I.GT.1036).AND.(I.LE.1069))    GO TO 330
IF ((I.GT.1069).AND.(I.LE.1140))    GO TO 340
IF (I.EQ.1141)    GO TO 350
IF ((I.GT.1141).AND.(I.LE.1198))    GO TO 360
IF ((I.GT.1198).AND.(I.LE.1207))    GO TO 370
IF ((I.GT.1207).AND.(I.LE.1289))    GO TO 380
IF ((I.GT.1289).AND.(I.LE.1361))    GO TO 390
IF ((I.GT.1361).AND.(I.LE.1373))    GO TO 400
IF ((I.GT.1373).AND.(I.LE.1375))    GO TO 410
IF (I.EQ.1376)    GO TO 420
IF ((I.GT.1376).AND.(I.LE.1400))    GO TO 430
IF (I.EQ.1401)    GO TO 440
IF ((I.GT.1401).AND.(I.LE.1434))    GO TO 450
IF ((I.GT.1434).AND.(I.LE.1505))    GO TO 460
IF (I.EQ.1506)    GO TO 470
IF ((I.GT.1506).AND.(I.LE.1563))    GO TO 480
IF ((I.GT.1563).AND.(I.LE.1572))    GO TO 490
IF ((I.GT.1572).AND.(I.LE.1654))    GO TO 500
IF ((I.GT.1654).AND.(I.LE.1726))    GO TO 510
IF ((I.GT.1726).AND.(I.LE.1738))    GO TO 520
IF ((I.GT.1738).AND.(I.LE.1740))    GO TO 530
IF (I.EQ.1741)    GO TO 540
IF ((I.GT.1741).AND.(I.LE.1765))    GO TO 550
IF (I.EQ.1766)    GO TO 560
IF ((I.GT.1766).AND.(I.LE.1799))    GO TO 570
IF ((I.GT.1799).AND.(I.LE.1870))    GO TO 580
IF (I.EQ.1871)    GO TO 590
IF ((I.GT.1871).AND.(I.LE.1928))    GO TO 600
IF ((I.GT.1928).AND.(I.LE.1937))    GO TO 610
IF ((I.GT.1937).AND.(I.LE.2019))    GO TO 620
IF ((I.GT.2019).AND.(I.LE.2091))    GO TO 630
IF ((I.GT.2091).AND.(I.LE.2103))    GO TO 640
IF ((I.GT.2103).AND.(I.LE.2105))    GO TO 650
IF (I.EQ.2106)    GO TO 660
```

```
IF ((I.GT.2106).AND.(I.LE.2130))     GO TO 670
IF (I.EQ.2131)     GO TO 680
IF ((I.GT.2131).AND.(I.LE.2164))     GO TO 690
IF (I.GT.2164)     GO TO 700
```

```
C       ************************************************************
C       * THE FOLLOWING SERIES OF EQUATION GROUPS GENERATE DATA    *
C       * FOR BIOMASS AND NUTRIENTS FOR THE SPECIES IN THE MODEL.  *
C       ************************************************************
50      IF (I.EQ.46)     VPBM(I)=.077*GFV01
        IF (I.GT.46)     VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*
       1GFV01*WSTRS(I))
        VPCA(I)=VPBM(I)*(9.918-(.0192*(X)))
        VPMG(I)=VPBM(I)*(5.537-(.01765*(X)))
        IF (I.LE.90)     VPK(I)=VPBM(I)*((5.4252*(EXP(-34.538776)))*((X)**
       16.2784))*100C
        IF ((I.GT.90).AND.(I.LE.181))     VPK(I)=VPBM(I)*(7.04+(.03297*(X)
       1))
        IF ((I.GT.181).AND.(I.LE.212))     VPK(I)=VPBM(I)*(50.5-(.20719*
       1(X)))
        IF (I.LE.151)     VPP(I)=VPBM(I)*((.02094*(X))-.692)
        IF ((I.GT.151).AND.(I.LE.409))     VPP(I)=VPBM(I)*(24509*((X)**(-
       11.8284)))
        VPN(I)=VPBM(I)*(59.028-(.17732*(X)))
        GO TO 710
60      VPBM(I)=VPBM(I-1)+(1.8745*GFV01*WSTRS(I))
        VPCA(I)=VPBM(I)*(9.918-(.0192*(X)))
        VPMG(I)=VPBM(I)*(5.537-(.01765*(X)))
        IF ((I.GT.182).AND.(I.LE.213))     VPK(I)=VPBM(I)*(50.5-(.20719*
       1(X)))
        IF ((I.GT.213).AND.(I.LE.409))     VPK(I)=VPBM(I)*6.577
        VPP(I)=VPBM(I)*(24509*((X)**(-1.8284)))
        VPN(I)=VPBM(I)*(59.028-(.17732*(X)))
        GO TO 710
70      VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
        VPCA(I)=VPBM(I)*(9.918-(.0192*(X)))
        VPMG(I)=VPBM(I)*(5.537-(.01765*(X)))
        VPK(I)=VPBM(I)*6.577
        VPP(I)=VPBM(I)*(24509*((X)**(-1.8284)))
        VPN(I)=VPBM(I)*(59.028-(.17732*(X)))
        GO TO 710
```

```
80        VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
          VPCA(I)=VPBM(I)*(9.918-(.0192*(X)))
          VPMG(I)=VPBM(I)*(5.537-(.01765*(X)))
          VPK(I)=VPBM(I)*6.577
          VPP(I)=VPBM(I)*(24509*((X)**(-1.8284)))
          VPN(I)=VPBM(I)*(59.028-(.17732*(X)))
          CONTINUE
          IF (I.EQ.281)     AMUBM(I)=.045*GFM01
          IF (I.GT.281)     AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*
         1GFMC1*WSTRS(I))
          AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-279.))))
          AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-279.)))
          AMUK(I)=AMUBM(I)*((11.462438**10)*((X)**(-4.721)))
          AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-365.)))
          AMUN(I)=AMUBM(I)*25.176
          GO TO 710
90        VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
          VPCA(I)=VPBM(I)*(9.918-(.0192*(X)))
          IF ((I.GT.44).AND.(I.LE.310))     VPMG(I)=VPBM(I)*(5.537-(.01765*
         1(X)))
          IF ((I.GT.310).AND.(I.LE.409))     VPMG(I)=VPBM(I)*.0655
          VPK(I)=VPBM(I)*6.577
          VPP(I)=VPBM(I)*(24509*((X)**(-1.8284)))
          VPN(I)=VPBM(I)*(59.028-(.17732*(X)))
          CONTINUE
          AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
         1WSTRS(I))
          AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-279.))))
          AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-279.)))
          AMUK(I)=AMUBM(I)*((11.462438**10)*((X)**(-4.721)))
          AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-365.)))
          AMUN(I)=AMUBM(I)*25.176
          CONTINUE
          IF (I.EQ.306)     SSBM(I)=.045*GFS01
          IF (I.GT.306)     SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*
         1GFS01*WSTRS(I))
```

```
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-304.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-304.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
100   VPBM(I)=VPBM(I-1)-(1.2214*GFVC1)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X)))
      VPMG(I)=VPBM(I)*.0655
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      IF (I.LE.365)     AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-279.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-279.)))
      IF (I.LE.365)     AMUK(I)=AMUBM(I)*((11.462438**10)*((X)**(-4.721)
     1))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-365.)))
      AMUN(I)=AMUBM(I)*25.176
      IF (I.GT.365)     AMUCA(I)=AMUBM(I)*(.8504*(EXP(.0108*(X-365.))))
      IF (I.GT.365)     AMUK(I)=AMUBM(I)*(.05959+(.06579*(X-365.)))
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-304.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-304.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
```

```
110       VPBM(I)=((2.715*(VPBM(278)**.822)/3551.5584)
         1*((X-409.)**1.447)*GFV01)
          VPCA(I)=VPBM(I)*(9.918-(.0192*(X-365.)))
          VPMG(I)=VPBM(I)*(5.537-(.01765*(X-365.)))
          VPK(I)=VPBM(I)*((5.4252*(EXP(-34.538776)))*((X-365.)**6.2784))
         1*1000
          VPP(I)=VPBM(I)*((.02094*(X-365.))-.692)
          VPN(I)=VPBM(I)*(59.028-(.17732*(X-365.)))
          CONTINUE
          AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFMC1*
         1WSTRS(I))
          AMUCA(I)=AMUBM(I)*(.8504*(EXP(.0108*(X-365.))))
          AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-279.)))
          AMUK(I)=AMUBM(I)*(.05959+(.00579*(X-365.)))
          AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-365.)))
          AMUN(I)=AMUBM(I)*25.176
          CONTINUE
          SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
         1WSTRS(I))
          SSCA(I)=SSBM(I)*3.7242
          SSMG(I)=SSBM(I)*(1.61-(.004025*(X-304.)))
          SSK(I)=SSBM(I)*(7.194-(.02095*(X-304.)))
          SSP(I)=SSBM(I)*2.18
          SSN(I)=SSBM(I)*12.2726
          GO TO 710
120       VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFV01
         1*WSTRS(I))
          VPP(I)=VPBM(I)*((.02094*(X-365.))-.692)
          VPCA(I)=VPBM(I)*(9.918-(.0192*(X-365.)))
          VPMG(I)=VPBM(I)*(5.537-(.01765*(X-365.)))
          IF (I.LE.455)     VPK(I)=VPBM(I)*((5.4252*(EXP(-34.538776)))*((X-
         1365.)**6.2784))*1000
          IF ((I.GT.455).AND.(I.LE.546))     VPK(I)=VPBM(I)*(7.04+(.03297*
         1(X-365.)))
          VPN(I)=VPBM(I)*(59.028-(.17732*(X-365.)))
          CONTINUE
```

```
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      IF ((I.GT.365).AND.(I.LE.455))     AMUCA(I)=AMUBM(I)*(.8504*
     1(EXP(.0108*(X-365.))))
      IF ((I.GT.455).AND.(I.LE.608))     AMUCA(I)=AMUBM(I)*(3.1291-
     1(.00979*(X-365.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-365.)))
      IF ((I.GT.365).AND.(I.LE.454))     AMUK(I)=AMUBM(I)*(.05959+
     1(.06579*(X-365.)))
      IF ((I.GT.454).AND.(I.LE.485))     AMUK(I)=AMUBM(I)*5.9835
      IF ((I.GT.280).AND.(I.LE.454))     AMUP(I)=AMUBM(I)*(2.353+
     1(.01147*(X-365.)))
      IF ((I.GT.454).AND.(I.LE.644))     AMUP(I)=AMUBM(I)*(567607*((X-
     11365.)**(-2.685)))
      IF (I.LE.424)     AMUN(I)=AMUBM(I)*25.176
      IF ((I.GT.424).AND.(I.LE.645))     AMUN(I)=AMUBM(I)*(778.779*((X-
     11365.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-304.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-304.)))
      IF (I.LE.424)     SSP(I)=SSBM(I)*2.18
      IF ((I.GT.424).AND.(I.LE.669))     SSP(I)=SSBM(I)*(8.672-(1.355*
     1(ALOG(X-304.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
130   VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFVC1
     1*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-365.)))
      VPP(I)=VPBM(I)*((.02094*(X-365.))-.692)
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-365.)))
      VPK(I)=VPBM(I)*(7.04+(.03297*(X-365.)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-365.)))
      CONTINUE
```

```
      AMUBM(I)=AMUBM(I-1)-(.5875*GFM01)
      AMUCA(I)=AMUBM(I)*(3.1291-(.C0979*(X-365.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-365.)))
      AMUK(I)=AMUBM(I)*5.9835
      AMUP(I)=AMUBM(I)*(567607*((X-365.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-365.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-304.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-304.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-304.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
140   VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFV01
     1*WSTRS(I))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-365.)))
      IF (I.LE.516)     VPP(I)=VPBM(I)*((.02094*(X-365.))-.692)
      IF (I.GT.516)     VPP(I)=VPBM(I)*(24509*((X-365.)**(-1.8284)))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-365.)))
      IF ((I.GT.455).AND.(I.LE.546))     VPK(I)=VPBM(I)*(7.04+(.03297*
     1(X-365.)))
      IF ((I.GT.546).AND.(I.LE.577))     VPK(I)=VPBM(I)*(5C.5-(.20719*
     1(X-365.)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-365.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.5875*GFM01)
      AMUMG(I)=AMUBM(I)*(3.154-(.C1256*(X-365.)))
      AMUCA(I)=AMUBM(I)*(3.1291-(.C0979*(X-365.)))
      IF ((I.GT.454).AND.(I.LE.485))     AMUK(I)=AMUBM(I)*5.9835
      IF ((I.GT.485).AND.(I.LE.730))     AMUK(I)=AMUBM(I)*((11.462438**
     110)*((X-365.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-365.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-365.)**(-0.855)))
      CONTINUE
```

```
      SSBM(I)=SSBM(I-1)-(.203*GFS01)
      IF (I.LE.546)     SSCA(I)=SSBM(I)*3.7242
      IF (I.GT.546)     SSCA(I)=SSBM(I)*(10.4856-(.03715*(X-365.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-304.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-304.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-304.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
150   VPBM(I)=VPBM(I-1)+((1.8745)*GFV01*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-365.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-365.)))
      IF ((I.GT.546).AND.(I.LE.577))     VPK(I)=VPBM(I)*(50.5-(.20719*
     1(X-365.)))
      IF (I.GT.577)     VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-365.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-365.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.2891*GFM01)
      IF ((I.GT.455).AND.(I.LE.608))     AMUCA(I)=AMUBM(I)*(3.1291-
     1(.00979*(X-365.)))
      IF ((I.GT.608).AND.(I.LE.645))     AMUCA(I)=AMUBM(I)*(3.3705-
     1(.010784*(X-365.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-365.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-365.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-365.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-365.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(.203*GFS01)
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-304.)))
      IF ((I.GT.546).AND.(I.LE.608))     SSCA(I)=SSBM(I)*(10.4856-
     1(.03715*(X-365.)))
      IF ((I.GT.608).AND.(I.LE.669))     SSCA(I)=SSBM(I)*(2.17404-
     1(.0029467*(X-365.)))
      IF (I.LE.609)     SSK(I)=SSBM(I)*(7.194-(.02095*(X-304.)))
      IF ((I.GT.609).AND.(I.LE.669))     SSK(I)=SSBM(I)*(.797-(.000645*
     1(X-304.)))
```

```
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-304.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
160   VPBM(I)=VPBM(I-1)+((1.8745)*GFV01*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-365.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-365.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-365.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-365.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.2891*GFM01)
      AMUCA(I)=AMUBM(I)*(3.3705-(.C1C784*(X-365.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-365.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-365.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-365.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-365.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0C29467*(X-365.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-304.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-304.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-304.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
170   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-365.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-365.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-365.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-365.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.2891*GFM01)
      AMUCA(I)=AMUBM(I)*(3.3705-(.C10784*(X-365.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-365.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-365.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-365.)**(-2.685)))
```

```
      AMUN(I)=AMUBM(I)*(778.779*((X-365.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0C29467*(X-365.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-304.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-304.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-304.))))
      SSN(I)=SSBM(I)*12.2726
      GO TC 710
180   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-365.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-365.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-365.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-365.)))
      CONTINUE
      AMX1=(AMUBM(468)/78.5316)
      IF (AMX1.GE.C.20)     AMUBM(I)=((-82.809+(36.887*(ALOG(AMUBM(468))
     1)))/1711.1333333333)*GFMC1
      IF (AMX1.LT.0.20)     AMUBM(I)=(((AMUBM(468)/1711.1333333333)*((X-
     1644.)**1.423))*GFMC01)
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.C108*(X-644.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-644.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-365.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-730.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0C29467*(X-365.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-304.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-3C4.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-304.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
190   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-365.)))
```

```
 VPMG(I)=VPBM(I)*(5.537-(.01765*(X-365.)))
 VPK(I)=VPBM(I)*6.577
 VPP(I)=VPBM(I)*(24509*((X-365.)**(-1.8284)))
 VPN(I)=VPBM(I)*(59.028-(.17732*(X-365.)))
 CONTINUE
 AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
1WSTRS(I))
 AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-644.))))
 AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-644.)))
 AMUK(I)=AMUBM(I)*((11.462438**10)*((X-365.)**(-4.721)))
 AMUN(I)=AMUBM(I)*25.176
 AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-730.)))
 CONTINUE
 SSBM(I)=SSBM(I-1)-(1.22*GFS01)
 SSCA(I)=SSBM(I)*(2.17404-(.0029467*(X-365.)))
 SSMG(I)=SSBM(I)*(1.61-(.004025*(X-304.)))
 SSK(I)=SSBM(I)*(.797-(.000645*(X-304.)))
 SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-304.))))
 SSN(I)=SSBM(I)*12.2726
 GO TO 710
```

```
200      VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
         VPCA(I)=VPBM(I)*(9.918-(.0192*(X-365.)))
         VPMG(I)=VPBM(I)*(5.537-(.01765*(X-365.)))
         VPK(I)=VPBM(I)*6.577
         VPP(I)=VPBM(I)*(24509*((X-365.)**(-1.8284)))
         VPN(I)=VPBM(I)*(59.028-(.17732*(X-365.)))
         CONTINUE
         AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
        1WSTRS(I))
         AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-644.))))
         AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-644.)))
         AMUK(I)=AMUBM(I)*((11.462438**10)*((X-365.)**(-4.721)))
         AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-730.)))
         AMUN(I)=AMUBM(I)*25.176
         CONTINUE
         SX1=(SSBM(477)/79.0384)
         IF (SX1.GE.0.40)     SSBM(I)=(((59.279+(.25*SSBM(477)))/
        11720.3333333333)*((X-669.)**1.4487))*GFS01
         IF (SX1.LT.0.40)     SSBM(I)=((SSBM(477)/1720.3333333333)*((X-
        1669.)**1.4487))*GFS01
         SSCA(I)=SSBM(I)*3.7242
         SSMG(I)=SSBM(I)*(1.61-(.004025*(X-669.)))
         SSK(I)=SSBM(I)*(7.194-(.02095*(X-669.)))
         SSP(I)=SSBM(I)*2.18
         SSN(I)=SSBM(I)*12.2726
         GO TO 710
210      VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
         VPCA(I)=VPBM(I)*(9.918-(.0192*(X-365.)))
         IF (I.LE.675)     VPMG(I)=VPBM(I)*(5.537-(.01765*(X-365.)))
         IF (I.GT.675)     VPMG(I)=VPBM(I)*.0655
         VPK(I)=VPBM(I)*6.577
         VPP(I)=VPBM(I)*(24509*((X-365.)**(-1.8284)))
         VPN(I)=VPBM(I)*(59.028-(.17732*(X-365.)))
         CONTINUE
         AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
        1WSTRS(I))
```

```
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-644.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-644.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-365.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-730.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-669.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-669.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
220   VPBM(I)=VPBM(I-1)-(1.2214*GFV(1)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-365.)))
      VPMG(I)=VPBM(I)*.0655
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-365.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-365.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      IF (I.LE.730)     AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-644.))))
      IF (I.GT.730)     AMUCA(I)=AMUBM(I)*(.8504*(EXP(.0108*(X-730.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-365.)))
      IF (I.LE.730)     AMUK(I)=AMUBM(I)*((11.462438**10)*((X-365.)**(-
     14.721)))
      IF (I.GT.730)     AMUK(I)=AMUBM(I)*(.05959+(.06579*(X-730.)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-730.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-644.)))
```

```
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-644.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
230   VPBM(I)=((2.715*(VPBM(643)**.822)/3551.5584)*((X-774.)
     1**1.447)*GFVC1)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-730.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-730.)))
      VPK(I)=VPBM(I)*((5.4252*(EXP(-34.538776)))*((X-730.)
     1**6.2784))*1000
      VPP(I)=VPBM(I)*((.02094*(X-730.))-.692)
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-730.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      AMUCA(I)=AMUBM(I)*(.8504*(EXP(.0108*(X-730.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-730.)))
      AMUK(I)=AMUBM(I)*(.05959+(.06579*(X-730.)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-730.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-669.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-669.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
240   VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFVC1
     1*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-730.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-730.)))
      IF (I.LE.820)    VPK(I)=VPBM(I)*((5.4252*(EXP(-34.538776)))*((X-
     1730.)**6.2784))*1000
      IF (I.GT.820)    VPK(I)=VPBM(I)*(7.04+(.03297*(X-730.)))
```

```
      VPP(I)=VPBM(I)*((.02094*(X-730.))-.692)
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-730.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      IF (I.LE.819)     AMUCA(I)=AMUBM(I)*(.8504*(EXP(.01CE*(X-730.))))
      IF (I.GT.819)     AMUCA(I)=AMUBM(I)*(3.1291-(.00979*(X-730.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-730.)))
      IF (I.LE.819)     AMUK(I)=AMUBM(I)*(.05959+(.06579*(X-730.)))
      IF (I.GT.819)     AMUK(I)=AMUBM(I)*5.9835
      IF (I.LE.819)     AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-730.)))
      IF (I.GT.819)     AMUP(I)=AMUBM(I)*(5676C7*((X-730.)**(-2.685)))
      IF (I.LE.789)     AMUN(I)=AMUBM(I)*25.176
      IF (I.GT.789)     AMUN(I)=AMUBM(I)*(778.779*((X-730.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-669.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-669.)))
      IF (I.LE.789)     SSP(I)=SSBM(I)*2.18
      IF (I.GT.789)     SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-669.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
250   VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFVCI
     1*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-730.)))
      VPK(I)=VPBM(I)*(7.04+(.03297*(X-730.)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-730.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-730.)))
      VPP(I)=VPBM(I)*(24509*((X-730.)**(-1.8284)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.5875*GFM01)
      AMUCA(I)=AMUBM(I)*(3.1291-(.00979*(X-730.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-730.)))
      AMUK(I)=AMUBM(I)*5.9835
```

```
      AMUP(I)=AMUBM(I)*(567607*((X-730.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-730.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-669.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-669.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-669.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
260   VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFV01
     1*WSTRS(I))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-730.)))
      IF (I.LE.881)     VPP(I)=VPBM(I)*((.02094*(X-730))-.692)
      IF (I.GT.881)     VPP(I)=VPBM(I)*(24509*((X-730.)**(-1.8284)))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-730.)))
      IF (I.LE.911)     VPK(I)=VPBM(I)*(7.04+(.03297*(X-730.)))
      IF ((I.GT.911).AND.(I.LE.942))     VPK(I)=VPBM(I)*(50.5-(.20719*
     1(X-730.)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-730.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.5875*GFM01)
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-730.)))
      AMUCA(I)=AMUBM(I)*(3.1291-(.00979*(X-730.)))
      IF (I.LE.850)     AMUK(I)=AMUBM(I)*5.9835
      IF (I.GT.850)     AMUK(I)=AMUBM(I)*((11.462438**10)*((X-730.)**(-
     14.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-730.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-730.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(.203*GFS01)
      IF (I.LE.911)     SSCA(I)=SSBM(I)*3.7242
      IF (I.GT.911)     SSCA(I)=SSBM(I)*(10.4856-(.03715*(X-730.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-669.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-669.)))
```

```
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-669.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
270   VPBM(I)=VPBM(I-1)+((1.8745)*GFV01*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-730.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-730.)))
      IF ((I.GT.911).AND.(I.LE.942))    VPK(I)=VPBM(I)*(50.5-(.20719*
     1(X-730.)))
      IF (I.GT.942)    VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-730.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-730.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.2891*GFM01)
      IF ((I.GT.820).AND.(I.LE.973))    AMUCA(I)=AMUBM(I)*(3.1291-
     1(.00979*(X-730.)))
      IF ((I.GT.973).AND.(I.LE.1010))    AMUCA(I)=AMUBM(I)*(3.3705-
     1(.010784*(X-730.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-730.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-730.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-730.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-730.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(.203*GFS01)
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-669.)))
      IF ((I.GT.911).AND.(I.LE.973))    SSCA(I)=SSBM(I)*(10.4856-
     1(.03715*(X-730.)))
      IF ((I.GT.973).AND.(I.LE.1034))    SSCA(I)=SSBM(I)*(2.17404-
     1(.0029467*(X-730.)))
      IF (I.LE.973)    SSK(I)=SSBM(I)*(7.194-(.02095*(X-669.)))
      IF ((I.GT.973).AND.(I.LE.1034))    SSK(I)=SSBM(I)*(.797-(.000645*
     1(X-669.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-669.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
280   VPBM(I)=VPBM(I-1)+((1.8745)*GFV01*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-730.)))
```

```
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-730.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-730.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-730.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.2891*GFM01)
      AMUCA(I)=AMUBM(I)*(3.3705-(.C10784*(X-730.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-730.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-730.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-730.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-730.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0C29467*(X-730.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-669.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-669.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-669.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
290   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-730.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-730.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-730.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-730.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.2891*GFM01)
      AMUCA(I)=AMUBM(I)*(3.3705-(.C10784*(X-730.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-730.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-730.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-730.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-730.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0C29467*(X-730.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-669.)))
```

```
      SSK(I)=SSBM(I)*(.797-(.000645*(X-669.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-669.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
300   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-730.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-730.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-730.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-730.)))
      CONTINUE
      AMX2=(AMUBM(833)/78.5316)
      IF (AMX2.GE.0.20)     AMUBM(I)=((-82.809+(36.887*(ALOG(AMUBM(833))
     1)))/1711.1333333333)*GFM01
      IF (AMX2.LT.0.20)     AMUBM(I)=(((AMUBM(833)/1711.1333333333)*((X-
     11009.)**1.423))*GFM01)
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-1009.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1009.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-730.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1095.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0029467*(X-730.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-669.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-669.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-669.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
310   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-730.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-730.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-730.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-730.)))
      CONTINUE
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```
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFMC1*
     1WSTRS(I))
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-1009.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1009.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-730.)**(-4.721)))
      AMUN(I)=AMUBM(I)*25.176
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1095.)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0029467*(X-730.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-669.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-669.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-669.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
320   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-730.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-730.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-730.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-730.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-1009.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1009.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-730.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1095.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SX2=(SSBM(842)/79.0384)
      IF (SX2.GE.0.40)     SSBM(I)=(((59.279+(.25*SSBM(842)))/
     11720.3333333333)*((X-1034.)**1.4487))*GFS01
      IF (SX2.LT.0.40)     SSBM(I)=((SSBM(842)/1720.3333333333)*((X-
     11034.)**1.4487))*GFS01
      SSCA(I)=SSBM(I)*3.7242
```

```
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1034.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1034.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
330   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-730.)))
      IF (I.LE.1040)    VPMG(I)=VPBM(I)*(5.537-(.01765*(X-730.)))
      IF (I.GT.1040)    VPMG(I)=VPBM(I)*.0655
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-730.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-730.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-1009.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1009.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-730.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1095.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1034.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1034.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
340   VPBM(I)=VPBM(I-1)-(1.2214*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-730.)))
      VPMG(I)=VPBM(I)*.0655
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-730.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-730.)))
      CONTINUE
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```
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      IF (I.LE.1095)     AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-1009.))))
      IF (I.GT.1095)     AMUCA(I)=AMUBM(I)*(.8504*(EXP(.0108*(X-1095.)))
     1)
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-730.)))
      IF (I.LE.1095)     AMUK(I)=AMUBM(I)*((11.462438**10)*((X-730.)**(-
     14.721)))
      IF (I.GT.1095)     AMUK(I)=AMUBM(I)*(.05959+(.06579*(X-1095.)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1095.)))
      AMUN(I)=AMUBM(I)*25.176
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1009.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1009.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
350   VPBM(I)=((2.715*(VPBM(1008)**.822)/3551.5584)*((X-1139.
     1)**1.447)*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1095.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1095.)))
      VPK(I)=VPBM(I)*((5.4252*(EXP(-34.538776)))*((X-1095.)
     1**6.2784))*1000
      VPP(I)=VPBM(I)*((.02094*(X-1095.))-.692)
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1095.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      AMUCA(I)=AMUBM(I)*(.8504*(EXP(.0108*(X-1095.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1095.)))
      AMUK(I)=AMUBM(I)*(.05959+(.06579*(X-1095.)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1095.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
```

```
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1034.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1034.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
360   VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFV01
     1*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1095.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1095.)))
      IF (I.LE.1185)     VPK(I)=VPBM(I)*((5.4252*(EXP(-34.538776)))*((X-
     11095.)**6.2784))*1000
      IF (I.GT.1185)     VPK(I)=VPBM(I)*(7.C4+(.03297*(X-1095.)))
      VPP(I)=VPBM(I)*((.02094*(X-1095.))-.692)
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1095.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      IF (I.LE.1184)     AMUCA(I)=AMUBM(I)*(.8504*(EXP(.01C8*(X-1095.)))
     1)
      IF (I.GT.1184)     AMUCA(I)=AMUBM(I)*(3.1291-(.00979*(X-1095.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1095.)))
      IF (I.LE.1184)     AMUK(I)=AMUBM(I)*(.05959+(.06579*(X-1095.)))
      IF (I.GT.1184)     AMUK(I)=AMUBM(I)*5.9835
      IF (I.LE.1184)     AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1095.)))
      IF (I.GT.1184)     AMUP(I)=AMUBM(I)*(567607*((X-1095.)**(-2.685)))
      IF (I.LE.1154)     AMUN(I)=AMUBM(I)*25.176
      IF (I.GT.1154)     AMUN(I)=AMUBM(I)*(778.779*((X-1095.)**(-0.855))
     1)
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1034.)))
```

```
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1034.)))
      IF (I.LE.1154)     SSP(I)=SSBM(I)*2.18
      IF (I.GT.1154)     SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1034.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
370   VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFV01
     1*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1095.)))
      VPK(I)=VPBM(I)*(7.04+(.03297*(X-1095.)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1095.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1095.)))
      VPP(I)=VPBM(I)*(24509*((X-1095.)**(-1.8284)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.5875*GFM01)
      AMUCA(I)=AMUBM(I)*(3.1291-(.00979*(X-1095.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1095.)))
      AMUK(I)=AMUBM(I)*5.9835
      AMUP(I)=AMUBM(I)*(567607*((X-1095.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-1095.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1034.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1034.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1034.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
380   VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFV01
     1*WSTRS(I))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1095.)))
      IF (I.LE.1246)     VPP(I)=VPBM(I)*((.02094*(X-1095.))-.692)
      IF (I.GT.1246)     VPP(I)=VPBM(I)*(24509*((X-1095.)**(-1.8284)))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1095.)))
      IF (I.LE.1276)     VPK(I)=VPBM(I)*(7.04+(.03297*(X-1095.)))
      IF (I.GT.1276)     VPK(I)=VPBM(I)*(50.5-(.20719*(X-1095.)))
```

```
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1095.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.5875*GFM01)
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1095.)))
      AMUCA(I)=AMUBM(I)*(3.1291-(.00979*(X-1095.)))
      IF (I.LE.1215)     AMUK(I)=AMUBM(I)*5.9835
      IF (I.GT.1215)     AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1095.)**
     1(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-1095.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-1095.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(.203*GFS01)
      IF (I.LE.1276)     SSCA(I)=SSBM(I)*3.7242
      IF (I.GT.1276)     SSCA(I)=SSBM(I)*(10.4856-(.03715*(X-1095.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1034.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1034.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1034.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
390   VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFV01
     1*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1095.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1095.)))
      IF (I.LE.1307)     VPK(I)=VPBM(I)*(50.5-(.20719*(X-1095.)))
      IF (I.GT.1307)     VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1095.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1095.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.2891*GFM01)
      IF (I.LE.1338)     AMUCA(I)=AMUBM(I)*(3.1291-(.00979*(X-1095.)))
      IF (I.GT.1338)     AMUCA(I)=AMUBM(I)*(3.3705-(.010784*(X-1095.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1095.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1095.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-1095.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-1095.)**(-0.855)))
      CONTINUE
```

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      SSBM(I)=SSBM(I-1)-(.203*GFS01)
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1034.)))
      IF (I.LE.1338)     SSCA(I)=SSBM(I)*(10.4856-(.03715*(X-1095.)))
      IF (I.GT.1338)     SSCA(I)=SSBM(I)*(2.17404-(.0029467*(X-1095.)))
      IF (I.LE.1338)     SSK(I)=SSBM(I)*(7.194-(.02095*(X-1034.)))
      IF (I.GT.1338)     SSK(I)=SSBM(I)*(.797-(.000645*(X-1034.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1034.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
400   VPBM(I)=VPBM(I-1)+((1.8745)*GFV01*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1095.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1095.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1095.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1095.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.2891*GFMC1)
      AMUCA(I)=AMUBM(I)*(3.3705-(.010784*(X-1095.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1095.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1095.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-1095.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-1095.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0029467*(X-1095.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1034.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-1034.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1034.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
410   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1095)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1095.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1095.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1095.)))
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      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.2891*GFM01)
      AMUCA(I)=AMUBM(I)*(3.3705-(.C10784*(X-1095.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.C1256*(X-1095.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1095.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-1095.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-1095.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0C29467*(X-1095.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1034.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-1034.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1034.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 71C
420   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1095.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1095.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1095.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1095.)))
      CONTINUE
      AMX3=(AMUBM(1198)/78.5316)
      IF (AMX3.GE.0.20)     AMUBM(I)=((-82.809+(36.887*(ALOG(AMUBM(1198)
     1))))/1711.1333333333)*GFM01
      IF (AMX3.LT.C.2C)     AMUBM(I)=(((AMUBM(1198)/1711.1333333333)*
     1((X-1374.)**1.423))*GFM01)
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-1374.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1374.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1095.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1460.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0C29467*(X-1095.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1034.)))
```

```
      SSK(I)=SSBM(I)*(.797-(.000645*(X-1034.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1034.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
430   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1095.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1095.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1095.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1095.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-1374.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1374.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1095.)**(-4.721)))
      AMUN(I)=AMUBM(I)*25.176
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1460.)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0029467*(X-1095.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1034.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-1034.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1034.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
440   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1095.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1095.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1095.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1095.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-1374.))))
```

```
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1374.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1095.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1460.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SX3=(SSBM(1207)/79.0384)
      IF (SX3.GE.0.40)     SSBM(I)=(((59.279+(.25*SSBM(1207)))/
     11720.3333333333)*((X-1399.)**1.4487))*GFS01
      IF (SX3.LT.0.40)     SSBM(I)=((SSBM(1207)/1720.3333333333)*((X-
     11399.)**1.4487))*GFS01
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1399.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1399.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
450   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFVC1)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1095.)))
      IF (I.LE.1405)     VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1095.)))
      IF (I.GT.1405)     VPMG(I)=VPBM(I)*.0655
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1095.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1095.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-1374.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1374.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1095.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1460.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1399.)))
```

```
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1399.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
  460 VPBM(I)=VPBM(I-1)-(1.2214*GFVC1)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1095.)))
      VPMG(I)=VPBM(I)*.0655
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1095.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1095.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      IF (I.LE.1460)     AMUCA(I)=AMUBM(I)*(.345*(EXP(.01CE*(X-1374.))))
      IF (I.GT.146C)     AMUCA(I)=AMUBM(I)*(.8504*(EXP(.01C8*(X-1460.)))
     1)
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1095.)))
      IF (I.LE.146C)     AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1095.)**
     1(-4.721)))
      IF (I.GT.146C)     AMUK(I)=AMUBM(I)*(.05959+(.06579*(X-1460.)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1460.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1399.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1399.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
  470 VPBM(I)=((2.715*(VPBM(1373)**.822)/3551.5584)*
     1((X-1504.)**1.447)*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-146C.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1460.)))
      VPK(I)=VPBM(I)*((5.4252*(EXP(-34.538776)))*((X-1460.)
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1**6.2784))*1000
 VPP(I)=VPBM(I)*((.02094*(X-1460.))-.692)
 VPN(I)=VPBM(I)*(59.028-(.17732*(X-1460.)))
 CONTINUE
 AMUBM(I)=AMUEM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
1WSTRS(I))
 AMUCA(I)=AMUBM(I)*(.8504*(EXP(.0108*(X-1460.))))
 AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1460.)))
 AMUK(I)=AMUBM(I)*(.05959+(.06579*(X-1460.)))
 AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1460.)))
 AMUN(I)=AMUBM(I)*25.176
 CONTINUE
 SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
1WSTRS(I))
 SSCA(I)=SSBM(I)*3.7242
 SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1399.)))
 SSK(I)=SSBM(I)*(7.194-(.02095*(X-1399.)))
 SSP(I)=SSBM(I)*2.18
 SSN(I)=SSBM(I)*12.2726
 GO TO 710
480  VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFV01
1*WSTRS(I))
 VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1460.)))
 VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1460.)))
 IF (I.LE.1550)    VPK(I)=VPBM(I)*((5.4252*(EXP(-34.538776)))*((X-
11460.)**6.2784))*1000
 IF (I.GT.1550)    VPK(I)=VPBM(I)*(7.04+(.03297*(X-1460.)))
 VPP(I)=VPBM(I)*((.02094*(X-1460.))-.692)
 VPN(I)=VPBM(I)*(59.028-(.17732*(X-1460.)))
 CONTINUE
 AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
1WSTRS(I))
 IF (I.LE.1549)    AMUCA(I)=AMUBM(I)*(.8504*(EXP(.0108*(X-1460.)))
1)
 IF (I.GT.1549)    AMUCA(I)=AMUBM(I)*(3.1291-(.00979*(X-1460.)))
 AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1460.)))
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```
      IF (I.LE.1549)     AMUK(I)=AMLBM(I)*(.05959+(.06579*(X-1460.)))
      IF (I.GT.1549)     AMUK(I)=AMLBM(I)*5.9835
      IF (I.LE.1549)     AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1460.)))
      IF (I.GT.1549)     AMUP(I)=AMLBM(I)*(567607*((X-1460.)**(-2.685)))
      IF (I.LE.1519)     AMUN(I)=AMLBM(I)*25.176
      IF (I.GT.1519)     AMUN(I)=AMLBM(I)*(778.779*((X-1460.)**(-0.855))
     1)
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1399.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1399.)))
      IF (I.LE.1519)     SSP(I)=SSBM(I)*2.18
      IF (I.GT.1519)     SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1399.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
490   VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFV01
     1*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1460.)))
      VPK(I)=VPBM(I)*(7.04+(.03297*(X-1460.)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1460.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1460.)))
      VPP(I)=VPBM(I)*(24509*((X-1460.)**(-1.8284)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.5875*GFM01)
      AMUCA(I)=AMUBM(I)*(3.1291-(.00979*(X-1460.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1460.)))
      AMUK(I)=AMUBM(I)*5.9835
      AMUP(I)=AMUBM(I)*(567607*((X-1460.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-1460.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1399.)))
```

```
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1399.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1399.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
500   VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFV01
     1*WSTRS(I))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1460.)))
      IF (I.LE.1611)     VPP(I)=VPBM(I)*((.02094*(X-1460.))-.692)
      IF (I.GT.1611)     VPP(I)=VPBM(I)*(24509*((X-1460.)**(-1.8284)))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1460.)))
      IF (I.LE.1641)     VPK(I)=VPBM(I)*(7.04+(.03297*(X-1460.)))
      IF (I.GT.1641)     VPK(I)=VPBM(I)*(50.5-(.20719*(X-1460.)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1460.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.5875*GFM01)
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1460.)))
      AMUCA(I)=AMUBM(I)*(3.1291-(.00979*(X-1460.)))
      IF (I.LE.1580)     AMUK(I)=AMUBM(I)*5.9835
      IF (I.GT.1580)     AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1460.)**
     1(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-1460.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-1460.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(.203*GFS01)
      IF (I.LE.1641)     SSCA(I)=SSBM(I)*3.7242
      IF (I.GT.1641)     SSCA(I)=SSBM(I)*(10.4856-(.03715*(X-1460.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1399.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1399.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1399.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
510   VPBM(I)=VPBM(I-1)+((1.8745)*GFV01*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1460.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1460.)))
      IF (I.LE.1672)     VPK(I)=VPBM(I)*(50.5-(.20719*(X-1460.)))
      IF (I.GT.1672)     VPK(I)=VPBM(I)*6.577
```

```
      VPP(I)=VPBM(I)*(24509*((X-1460.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1460.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.2891*GFM01)
      IF (I.LE.1703)     AMUCA(I)=AMUBM(I)*(3.1291-(.00979*(X-1460.)))
      IF (I.GT.1703)     AMUCA(I)=AMUBM(I)*(3.3705-(.010784*(X-1460.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1460.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1460.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-1460.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-1460.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(.203*GFS01)
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1399.)))
      IF (I.LE.1703)     SSCA(I)=SSBM(I)*(10.4856-(.03715*(X-1460.)))
      IF (I.GT.1703)     SSCA(I)=SSBM(I)*(2.17404-(.0029467*(X-1460.)))
      IF (I.LE.1703)     SSK(I)=SSBM(I)*(7.194-(.02095*(X-1399.)))
      IF (I.GT.1703)     SSK(I)=SSBM(I)*(.797-(.000645*(X-1399.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1399.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
520   VPBM(I)=VPBM(I-1)+((1.8745)*GFV01*hSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1460.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1460.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1460.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1460.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.2891*GFM01)
      AMUCA(I)=AMUBM(I)*(3.3705-(.010784*(X-1460.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1460.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1460.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-1460.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-1460.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0029467*(X-1460.)))
```

```
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1399.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-1399.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1399.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
530   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1460.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1460.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1460.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1460.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.2891*GFM01)
      AMUCA(I)=AMUBM(I)*(3.3705-(.010784*(X-1460.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1460.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1460.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-1460.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-1460.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0029467*(X-1460.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1399.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-1399.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1399.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
540   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1460.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1460.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1460.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1460.)))
      CONTINUE
     AMX4=(AMUBM(1563)/78.5316)
      IF (AMX4.GE.0.20)     AMUBM(I)=((-82.809+(36.887*(ALOG(AMUBM(1563)
     1))))/1711.1333333333)*GFM01
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```
      IF (AMX4.LT.C.2C)     AMUBM(I)=(((AMUBM(1563)/1711.1333333333)*
     1((X-1739.)**1.423))*GFM01)
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-1739.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1739.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1460.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1825.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0C29467*(X-1460.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1399.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-1399.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1399.))))
      SSN(I)=SSBM(I)*12.2726
      GO TC 710
550   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1460.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1460.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1460.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1460.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-1739.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1739.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1460.)**(-4.721)))
      AMUN(I)=AMUBM(I)*25.176
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1825.)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0C29467*(X-1460.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1399.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-1399.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1399.))))
      SSN(I)=SSBM(I)*12.2726
```

```
      GO TO 710
560   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1460.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1460.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1460.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1460.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFMC1*
     1WSTRS(I))
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-1739.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1739.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1460.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1825.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SX4=(SSBM(1572)/79.0384)
      IF (SX4.GE.0.40)     SSBM(I)=(((59.279+(.25*SSBM(1572)))/
     11720.3333333333)*((X-1764.)**1.4487))*GFS01
      IF (SX4.LT.0.40)     SSBM(I)=((SSBM(1572)/1720.3333333333)*((X-
     11764.)**1.4487))*GFS01
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1764.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1764.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
570   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1460.)))
      IF (I.LE.1770)     VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1460.)))
      IF (I.GT.1770)     VPMG(I)=VPBM(I)*.0655
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1460.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1460.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
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```
     1WSTRS(I))
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-1739.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1739.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1460.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1825.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1764.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1764.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
580   VPBM(I)=VPBM(I-1)-(1.2214*GFVC1)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1460.)))
      VPMG(I)=VPBM(I)*.0655
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1460.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1460.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFMC1*
     1WSTRS(I))
      IF (I.LE.1825)     AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-1739.))))
      IF (I.GT.1825)     AMUCA(I)=AMUBM(I)*(.8504*(EXP(.0108*(X-1825.)))
     1)
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1460.)))
      IF (I.LE.1825)     AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1460.)**
     1(-4.721)))
      IF (I.GT.1825)     AMUK(I)=AMUBM(I)*(.05959+(.06579*(X-1825.)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1825.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
```

```
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1764.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1764.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
590   VPBM(I)=((2.715*(VPBM(1738)**.822)/3551.5584)*((X-1869.)
     1**1.447)*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1825.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1825.)))
      VPK(I)=VPBM(I)*((5.4252*(EXP(-34.538776)))*((X-1825.)
     1**6.2784))*1COC
      VPP(I)=VPBM(I)*((.02094*(X-1825.))-.692)
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1825.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      AMUCA(I)=AMUBM(I)*(.8504*(EXP(.0108*(X-1825.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1825.)))
      AMUK(I)=AMUBM(I)*(.05959+(.06579*(X-1825.)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1825.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1764.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1764.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
600   VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFV01
     1*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1825.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1825.)))
      IF (I.LE.1915)     VPK(I)=VPBM(I)*((5.4252*(EXP(-34.538776)))*((X-
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     11825.)**6.2784))*1000
      IF (I.GT.1915)     VPK(I)=VPBM(I)*(7.04+(.03297*(X-1825.)))
      VPP(I)=VPBM(I)*((.02094*(X-1825.))-.692)
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1825.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFMC1*
     1WSTRS(I))
      IF (I.LE.1914)     AMUCA(I)=AMUBM(I)*(.8504*(EXP(.0108*(X-1825.)))
     1)
      IF (I.GT.1914)     AMUCA(I)=AMUBM(I)*(3.1291-(.00979*(X-1825.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1825.)))
      IF (I.LE.1914)     AMUK(I)=AMUBM(I)*(.05959+(.06579*(X-1825.)))
      IF (I.GT.1914)     AMUK(I)=AMUBM(I)*5.9835
      IF (I.LE.1914)     AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-1825.)))
      IF (I.GT.1914)     AMUP(I)=AMUBM(I)*(567607*((X-1825.)**(-2.685)))
      IF (I.LE.1884)     AMUN(I)=AMUBM(I)*25.176
      IF (I.GT.1884)     AMUN(I)=AMUBM(I)*(778.779*((X-1825.)**(-0.855))
     1)
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1764.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1764.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1764.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
610   VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFV01
     1*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1825.)))
      VPK(I)=VPBM(I)*(7.04+(.03297*(X-1825.)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1825.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1825.)))
      VPP(I)=VPBM(I)*(24509*((X-1825.)**(-1.8284)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.5875*GFM01)
```

```
      AMUCA(I)=AMUBM(I)*(3.1291-(.00979*(X-1825.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1825.)))
      AMUK(I)=AMUBM(I)*5.9835
      AMUP(I)=AMUBM(I)*(567607*((X-1825.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-1825.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1764.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1764.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1764.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
620   VPBM(I)=VPBM(I-1)+((.26145*(VPBM(I-1)**.2904))*GFV01
     1*WSTRS(I))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1825.)))
      IF (I.LE.1611)     VPP(I)=VPBM(I)*((.02094*(X-1825.))-.692)
      IF (I.GT.1611)     VPP(I)=VPBM(I)*(24509*((X-1825.)**(-1.8284)))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1825.)))
      IF (I.LE.2006)     VPK(I)=VPBM(I)*(7.04+(.03297*(X-1825.)))
      IF (I.GT.2006)     VPK(I)=VPBM(I)*(50.5-(.20719*(X-1825.)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1825.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.5875*GFMC1)
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1825.)))
      AMUCA(I)=AMUBM(I)*(3.1291-(.00979*(X-1825.)))
      IF (I.LE.1945)     AMUK(I)=AMUBM(I)*5.9835
      IF (I.GT.1945)     AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1825.)**
     1(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-1825.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-1825.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(.203*GFS01)
      IF (I.LE.2006)     SSCA(I)=SSBM(I)*3.7242
      IF (I.GT.2006)     SSCA(I)=SSBM(I)*(10.4856-(.03715*(X-1825.)))
```

```
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1764.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-1764.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1764.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
630   VPBM(I)=VPBM(I-1)+((1.8745)*CFV01*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1825.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1825.)))
      IF (I.LE.2C37)     VPK(I)=VPBM(I)*(50.5-(.20719*(X-1825.)))
      IF (I.GT.2C37)     VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1825.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1825.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.2891*CFM01)
      IF (I.LE.2C68)     AMUCA(I)=AMUBM(I)*(3.1291-(.00979*(X-1825.)))
      IF (I.GT.2068)     AMUCA(I)=AMUBM(I)*(3.3705-(.010784*(X-1825.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1825.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1825.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-1825.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-1825.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(.203*GFS01)
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1764.)))
      IF (I.LE.2C68)     SSCA(I)=SSBM(I)*(10.4856-(.03715*(X-1825.)))
      IF (I.GT.2C68)     SSCA(I)=SSBM(I)*(2.17404-(.0029467*(X-1825.)))
      IF (I.LE.2068)     SSK(I)=SSBM(I)*(7.194-(.02095*(X-1764.)))
      IF (I.GT.2C68)     SSK(I)=SSBM(I)*(.797-(.C00645*(X-1764.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1764.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
640   VPBM(I)=VPBM(I-1)+((1.8745)*CFV01*WSTRS(I))
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1825.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1825.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1825.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1825.)))
```

```
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.2891*GFM01)
      AMUCA(I)=AMUBM(I)*(3.3705-(.C1C784*(X-1825.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1825.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1825.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-1825.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-1825.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0C29467*(X-1825.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1764.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-1764.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1764.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
650   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1825.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1825.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1825.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1825.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)-(.2891*GFM01)
      AMUCA(I)=AMUBM(I)*(3.3705-(.C10784*(X-1825.)))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1825.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1825.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(567607*((X-1825.)**(-2.685)))
      AMUN(I)=AMUBM(I)*(778.779*((X-1825.)**(-0.855)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0C29467*(X-1825.)))
      SSMG(I)=SSBM(I)*(1.61-(.004C25*(X-1764.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-1764.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1764.))))
      SSN(I)=SSBM(I)*12.2726
      GO TC 71C
```

```
660       VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
          VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1825.)))
          VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1825.)))
          VPK(I)=VPBM(I)*6.577
          VPP(I)=VPBM(I)*(24509*((X-1825.)**(-1.8284)))
          VPN(I)=VPBM(I)*(59.028-(.17732*(X-1825.)))
          CONTINUE
          AMX5=(AMUBM(1928)/78.5316)
          IF (AMX5.GE.C.2C)     AMUBM(I)=((-82.809+(36.887*(ALCG(AMUBM(1928)
         1))))/1711.1333333333)*GFM01
          IF (AMX5.LT.C.2C)     AMUBM(I)=(((AMUBM(1928)/1711.1333333333)*
         1((X-2104.)**1.423))*GFMC1)
          AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-2104.))))
          AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-2104.)))
          AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1825.)**(-4.721)))
          AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-2190.)))
          AMUN(I)=AMUBM(I)*25.176
          CONTINUE
          SSBM(I)=SSBM(I-1)-(1.22*GFS01)
          SSCA(I)=SSBM(I)*(2.17404-(.0C29467*(X-1825.)))
          SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1764.)))
          SSK(I)=SSBM(I)*(.797-(.000645*(X-1764.)))
          SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1764.))))
          SSN(I)=SSBM(I)*12.2726
          GO TO 710
670       VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
          VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1825.)))
          VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1825.)))
          VPK(I)=VPBM(I)*6.577
          VPP(I)=VPBM(I)*(24509*((X-1825.)**(-1.8284)))
          VPN(I)=VPBM(I)*(59.028-(.17732*(X-1825.)))
          CONTINUE
          AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
         1WSTRS(I))
          AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-2104.))))
          AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-2104.)))
```

```
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1825.)**(-4.721)))
      AMUN(I)=AMUBM(I)*25.176
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-2190.)))
      CONTINUE
      SSBM(I)=SSBM(I-1)-(1.22*GFS01)
      SSCA(I)=SSBM(I)*(2.17404-(.0029467*(X-1825.)))
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-1764.)))
      SSK(I)=SSBM(I)*(.797-(.000645*(X-1764.)))
      SSP(I)=SSBM(I)*(8.672-(1.355*(ALOG(X-1764.))))
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
680   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1825.)))
      VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1825.)))
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1825.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1825.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-2104.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-2104.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1825.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-2190.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SX5=(SSBM(1937)/79.0384)
      IF (SX5.GE.0.40)     SSBM(I)=(((59.279+(.25*SSBM(1937)))/
     11720.3333333333)*((X-2129.)**1.4487))*GFS01
      IF (SX5.LT.0.40)     SSBM(I)=((SSBM(1937)/1720.3333333333)*((X-
     12129.)**1.4487))*GFS01
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-2129.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-2129.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
```

```
      GO TO 710
690   VPBM(I)=VPBM(I-1)-((.1084*(EXP(.0214*VPBM(I-1))))*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1825.)))
      IF (I.LE.2135)     VPMG(I)=VPBM(I)*(5.537-(.01765*(X-1825.)))
      IF (I.GT.2135)     VPMG(I)=VPBM(I)*.0655
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1825.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1825.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
      AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-2104.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-2104.)))
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1825.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-2190.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-2129.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-2129.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      GO TO 710
700   VPBM(I)=VPBM(I-1)-(1.2214*GFV01)
      VPCA(I)=VPBM(I)*(9.918-(.0192*(X-1825.)))
      VPMG(I)=VPBM(I)*.0655
      VPK(I)=VPBM(I)*6.577
      VPP(I)=VPBM(I)*(24509*((X-1825.)**(-1.8284)))
      VPN(I)=VPBM(I)*(59.028-(.17732*(X-1825.)))
      CONTINUE
      AMUBM(I)=AMUBM(I-1)+((.172*(AMUBM(I-1)**.277))*GFM01*
     1WSTRS(I))
        AMUCA(I)=AMUBM(I)*(.345*(EXP(.0108*(X-2104.))))
      AMUMG(I)=AMUBM(I)*(3.154-(.01256*(X-1825.)))
```

```
      AMUK(I)=AMUBM(I)*((11.462438**10)*((X-1825.)**(-4.721)))
      AMUP(I)=AMUBM(I)*(2.353+(.01147*(X-2190.)))
      AMUN(I)=AMUBM(I)*25.176
      CONTINUE
      SSBM(I)=SSBM(I-1)+((.182*(SSBM(I-1)**.289))*GFS01*
     1WSTRS(I))
      SSCA(I)=SSBM(I)*3.7242
      SSMG(I)=SSBM(I)*(1.61-(.004025*(X-2129.)))
      SSK(I)=SSBM(I)*(7.194-(.02095*(X-2129.)))
      SSP(I)=SSBM(I)*2.18
      SSN(I)=SSBM(I)*12.2726
      CONTINUE
```

```
710       IF (VPBM(I).LT.0.00)     VPBM(I)=0.00
          IF (VPCA(I).LT.C.00)     VPCA(I)=0.CO
          IF (VPMG(I).LT.0.00)     VPMG(I)=0.CO
          IF (VPK(I).LT.0.00)     VPK(I)=0.00
          IF (VPP(I).LT.C.00)     VPP(I)=0.00
          IF (VPN(I).LT.0.00)     VPN(I)=0.00
          IF (AMUBM(I).LT.0.00)     AMUBM(I)=C.CO
          IF (AMUCA(I).LT.0.00)     AMUCA(I)=0.0
          IF (AMUMG(I).LT.0.00)     AMUMG(I)=C.00
          IF (AMUK(I).LT.0.00)     AMUK(I)=0.CO
          IF (AMUP(I).LT.C.00)     AMUP(I)=0.00
          IF (AMUN(I).LT.C.00)     AMUN(I)=0.CO
          IF (SSBM(I).LT.C.00)     SSBM(I)=0.00
          IF (SSCA(I).LT.0.00)     SSCA(I)=0.CO
          IF (SSMG(I).LT.0.00)     SSMG(I)=0.00
          IF (SSK(I).LT.C.00)     SSK(I)=0.00
          IF (SSP(I).LT.0.00)     SSP(I)=0.00
          IF (SSN(I).LT.0.00)     SSN(I)=0.00
          IF (BBMD(I).LT.C.00)     BBMD(I)=0.CO
          IF (BBCA(I).LT.0.00)     BBCA(I)=0.00
          IF (BBMG(I).LT.C.00)     BBMG(I)=0.CO
          IF (BBK(I).LT.0.00)     BBK(I)=0.00
          IF (BBP(I).LT.C.00)     BBP(I)=0.00
          IF (BBN(I).LT.C.00)     BBN(I)=C.00
          IF (ALBM(I).LT.C.00)     ALBM(I)=0.00
          IF (ALCA(I).LT.C.00)     ALCA(I)=0.CC
          IF (ALMG(I).LT.0.00)     ALMG(I)=0.CC
          IF (ALK(I).LT.C.00)     ALK(I)=0.00
          IF (ALP(I).LT.0.00)     ALP(I)=0.00
          IF (ALN(I).LT.0.00)     ALN(I)=0.00
          CONTINUE
```

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C       ************************************************************
C       * THE FOLLOWING SERIES OF EQUATIONS: 1) SET THE "DAY"      *
C       * INDEX, 2) RE-ALLOCATE AND RECALCULATE SOIL NUTRIENTS,    *
C       * 3) ESTABLISH MULTIPLICATIVE FACTORS SIMULATING LIMITED   *
C       * GROWTH DUE TO NUTRIENT DEPLETION, AND 4) ELIMINATE ANY   *
C       * "NEGATIVE" BIOMASS OR NUTRIENT. (SET LIMITS TO 0.)       *
C       * THE FINAL PRINTOUT FORMAT IS ALSO INCLUDED, ELIMINATING  *
C       * THE FIRST 365 ITERATIONS, WHICH ARE PRIMARILY USEFUL AS  *
C       * A STABILIZER OF CONDITIONS IN THE MODEL.                 *
C       ************************************************************
720     LDAY(I)=I-366
        SOILCA(I)=SOILCA(I-1)-((VPCA(I)+AMLCA(I)+SSCA(I)+
       1BBCA(I)+ALCA(I))-(BBCA(I-1)+ALCA(I-1)+
       2VPCA(I-1)+AMLCA(I-1)+SSCA(I-1)))
        SOILMG(I)=SOILMG(I-1)-((VPMG(I)+AMUMG(I)+SSMG(I)+
       1BBMG(I)+ALMG(I))-(ALMG(I-1)+BBMG(I-1)+
       2VPMG(I-1)+AMUMG(I-1)+SSMG(I-1)))
        SOILK(I)=SOILK(I-1)-((VPK(I)+AMUK(I)+SSK(I)+
       1BBK(I)+ALK(I))-(BBK(I-1)+ALK(I-1)+
       2VPK(I-1)+AMUK(I-1)+SSK(I-1)))
        SOILP(I)=SOILP(I-1)-((VPP(I)+AMUP(I)+SSP(I)+
       1BBP(I)+ALP(I))-(BBP(I-1)+ALP(I-1)+
       2VPP(I-1)+AMUP(I-1)+SSP(I-1)))
        SOILN(I)=SOILN(I-1)-((VPN(I)+AMUN(I)+SSN(I)+
       1BBN(I)+ALN(I))-(BBN(I-1)+ALN(I-1)+
       2VPN(I-1)+AMUN(I-1)+SSN(I-1)))
        IF (SOILCA(I).LT.0.0)    SOILCA(I)=0.0
        IF (SOILMG(I).LT.0.0)    SOILMG(I)=0.0
        IF (SOILK(I).LT.0.0)     SOILK(I)=0.0
        IF (SOILP(I).LT.0.0)     SOILP(I)=0.0
        IF (SOILN(I).LT.0.0)     SOILN(I)=0.0
        TTLBMS(I)=VPBM(I)+AMUBM(I)+SSBM(I)+ALBM(I)+BBMD(I)
        IF (I.LE.366)    GO TO 730
        WRITE (22,870) LDAY(I),VPBM(I),VPCA(I),VPMG(I),VPK(I),VPP(I),VPN(I),
       1AMUBM(I),AMUCA(I),AMUMG(I),AMUK(I),AMUP(I),AMUN(I),SSBM(I),SSCA(I)
       2,SSMG(I),SSK(I),SSP(I),SSN(I),BBMD(I),BBCA(I),BBMG(I),BBK(I),
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     3BBP(I),BBN(I),ALBM(I),ALCA(I),ALMG(I),ALK(I),ALP(I),ALN(I),RN(I),
     4TEMP(I),EVAP(I),WSTRS(I),TTLBMS(I),SOILCA(I),SOILMG(I),SOILK(I),
     5SOILP(I),SOILN(I)
730   CONTINUE
     CONTINUE
740  CONTINUE
     STOP
800  FORMAT (1X,'INPUT TWO PSEUDORANDOM INTEGERS,
     1 FOUR DIGITS EACH, SEPARATED BY A COMMA:')
810  FORMAT (1X,'SIMULATED RAINFALL CAN DIFFER FROM
     1 NORMAL AMOUNTS.  ENTER'/1X,'THE PROPORTION
     2 OF NORMAL RAINFALL TO BE SIMULATED:'//1X,
     3'(NOTE THAT 1.00 SHOULD BE ENTERED FOR "NORMAL"
     4 AMOUNTS, 1.10 FOR A'/1X,'TEN PERCENT INCREASE,
     5  0.90 FOR A TEN PERCENT DROUGHT, ETC.)'//
     61X,'AN ANSWER LESS THAN 0.0 OR GREATER THAN
     7 2.0 CAUSES'/1X,'THE REQUEST TO BE REPEATED.')
820  FORMAT (1X,'ENTER NO. OF YEARS (MAX=5) OF SIMULATION:')
830  FORMAT (1X,'ENTER THE MEAN SOIL DEPTH IN CM.:')
840  FORMAT (1X,'RANDOM NUMBER GENERATOR SEEDS ARE:',2X,I4,',',
     11X,I4/1X,'THE NUMBER OF YEARS EQUALS',1X,I1,1X,'OR',1X,I4,
     21X,'DAYS.'/1X,'THE MEAN SOIL DEPTH EQUALS',1X,F4.1/
     31X,'AND THE PROPORTION OF NORMAL RAINFALL IS',1X,F4.2///
     41X,'DAY#   VPBM(I)  VPCA(I)   VPMG(I)   VPK(I)
     5    VPP(I)    VPN(I)    AMUBM(I) AMUCA(I)  AMUMG(I)
     6   AMUK(I)   AMUP(I)   AMUN(I)'/8X,'SSBM(I)  SSCA(I)
     7   SSMG(I)   SSK(I)    SSP(I)    SSN(I)     BBMD(I)
     8  BBCA(I)   BBMG(I)    BBK(I)    BBP(I)    BBN(I)'/8X,'
     9ALBM(I)  ALCA(I)   ALMG(I)   ALK(I)    ALP(I)    ALN(I)
     1  RN(I)  TEMP(I) EVAP(I)   WSTRS(I)  TTLBMS(I)'/8X,'
     2SOILCA(I)    SCILMG(I)    SCILK(I)     SOILP(I)
     3     SOILN(I)')
850   FORMAT (1X,F7.3,1X,F5.3)
860   FORMAT (1X,F6.3,2X,F6.3)
870  FORMAT (1X,I4,1X,F8.3,5(1X,F9.3),2X,F8.3,5(1X,F9.3)/6X,
     1F8.3,5(1X,F9.3),2X,F8.3,5(1X,F9.3)/6X,F8.3,5(1X,F9.3),
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22X,F5.2,2X,F6.3,2X,F8.5,2X,F7.4,2X,F10.3/4X,5(2X,F11.4))
END
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VITA

James Donald Berg was born in Cedar Rapids, Iowa, on July 13, 1946. As a young child, the family moved to Hillsboro, Illinois, where James attended elementary school. Following successive moves to Harrisburg, Pennsylvania, and to Charleston, West Virginia, he was graduated from Stonewall Jackson High School of Charleston in June 1964.

Following a three year tour of duty in the United States Marine Corps, he entered Morris Harvey College (now the University of Charleston) in Charleston, West Virginia. In June 1972 he received a Bachelor of Science degree in biology. In the fall of 1972, James accepted a teaching assistantship at the College of Williams and Mary in Williamsburg, Virginia, and worked toward a Master of Arts degree in biology. This degree was awarded in August 1974.

James entered the Graduate School of The University of Tennessee, Knoxville, in September 1974. He received the Doctor of Philosophy degree with a major in ecology in March 1983.

The author is a professional ecologist as certified by the Ecological Society of America, and a member of Chi Beta Phi Honorary Society.

He married the former Sarah M. Karnes of Charleston, West Virginia, in June 1970. They have a son, Christopher, born June 15, 1978.