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CELSS Scenario Analysis: Breakeven Calculations

Robert M. Mason
Metrics Research Corporation

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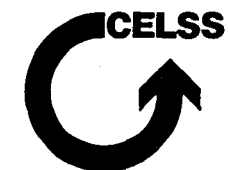
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Prepared for
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under Purchase Order (P.O.) A70035 B

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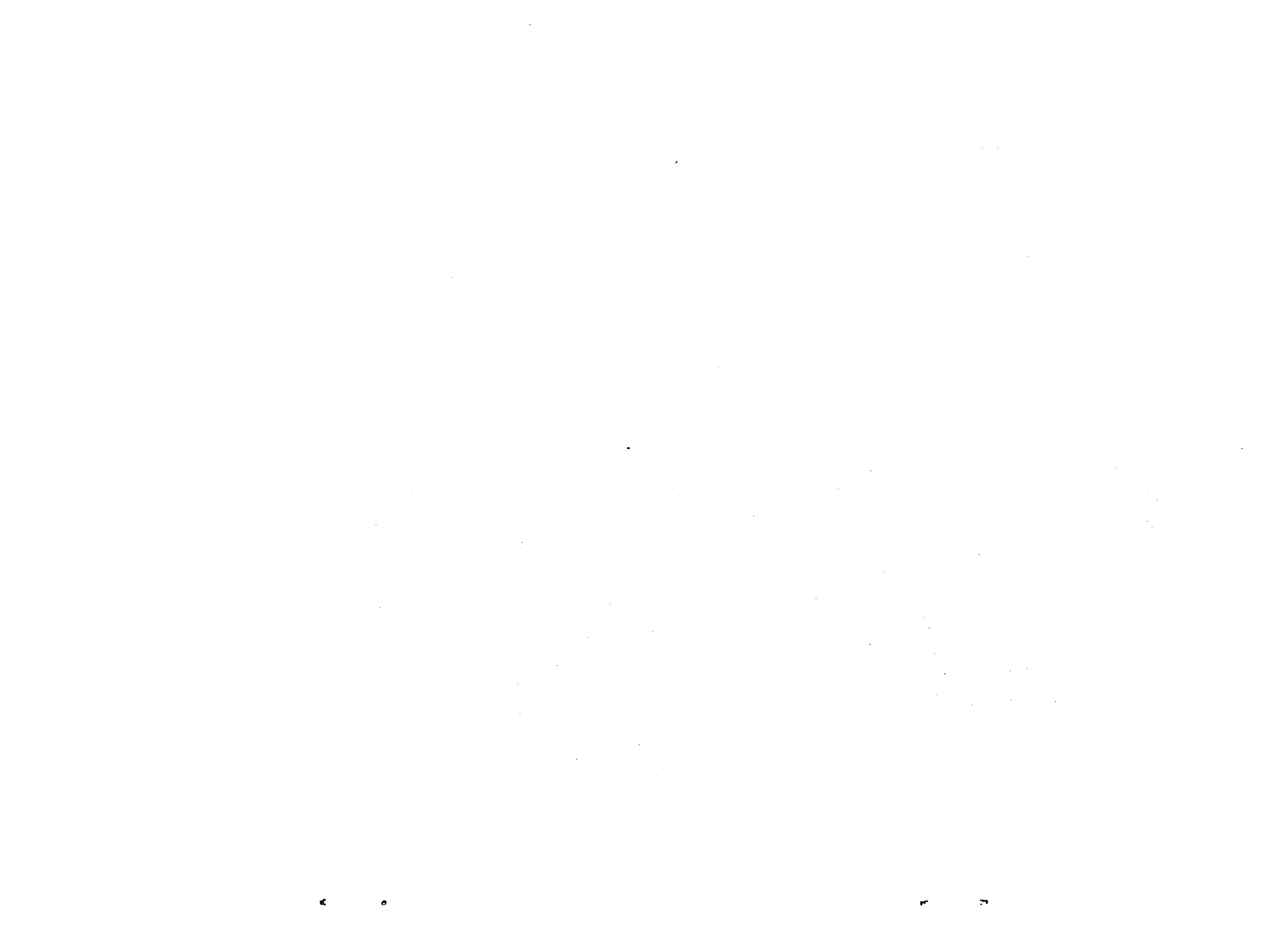
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TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION	1
Purpose	1
Background	1
MODEL SCOPE AND STRUCTURE	2
Scope	2
Assumptions	2
Focus and Limitations	2
Model Structure	3
Baseline Scenario (Resupply)	3
Alternative Scenario	3
EXAMPLE CALCULATIONS	7
Diet and Plant Growth Assumptions	7
Diet Basis	7
Plant Growth Rates	7
Storage and Resupply Assumptions	7
Breakeven Calculation Procedure and Results	10
DISCUSSION	13
Issues for Further Study	13
Plant Productivity Measures	13
Functional Components	13
Conclusions	13
NOTES AND REFERENCES	14
APPENDIX A. CONTROLLED ENVIRONMENT WEIGHT ESTIMATES	17
APPENDIX B. NOMENCLATURE AND CONVENTIONS	18
APPENDIX C. HP-67 PROGRAM FOR CULTIVAR CALCULATIONS	20
APPENDIX D. HP-67 PROGRAM FOR BREAKEVEN CALCULATION	24
APPENDIX E. FORTRAN PROGRAM FOR BREAKEVEN CALCULATION	27



INTRODUCTION

PURPOSE

This report summarizes the results of effort aimed toward the development of a rudimentary model that illustrates the relative mass requirements of food production components in a controlled ecology life support system (CELSS) based on regenerative concepts. The report is intended as a working paper which can provide a basis for further model development and analysis.

The model and analytic results can be useful for developing an understanding of the mass requirements for food production in a CELSS and how these requirements compare with food resupply requirements. Such an understanding aids in making knowledgeable decisions about research investment options in regenerative life support. More importantly, the documentation of the model and results reveals gaps in knowledge and thereby provides guidance for improving the model and the analysis procedures.

BACKGROUND

The need for life support options based on regenerative methods becomes increasingly important from a logistics standpoint for long duration missions. This need has been recognized and discussed in several workshops and reports (1,2,3,4,5).

Other studies, reports, and papers have proposed using scenario analyses to help evaluate research progress and to help program managers assess technology options for regenerative systems (6,7,8,9,10,11,12). The scenario analysis approach, although utilized in these prior studies, has heretofore not been documented in the detail necessary for comparative studies by other researchers. This report provides documentation of the initial model and illustrates its use and its sensitivity to changes in assumptions and parameter values. In addition to documenting the overall scenario model, this report also updates the diet assumed for the 1977 summer study (e.g., see 9).

MODEL SCOPE AND STRUCTURE

SCOPE

Assumptions

The model is a simple deterministic formulation that equates the mass required for food supply under two different scenarios: A) complete resupply of diet materials (baseline scenario) and B) part of the diet supplied by food grown in the space habitat by regenerative methods (alternative scenario). The model thus uses time as the dependent variable, permitting the calculation of a "breakeven time," which may be considered as the mission duration for which the total mass required for supplying dietary requirements under the baseline scenario equals the mass required under the alternative scenario.

Several simplifying general assumptions are implicit in the resulting formulation:

1. Mass requirements for the baseline food supply scenario are linear with time.
2. Total mass requirement for each scenario may be represented by a simple summation of component masses. Each component represents a particular necessary function and may further be subdivided into expressions representing subcomponents or macrocategories of design factors.
3. Several functional requirements which may be substantially different in the two scenarios are included from the model:
 - energy collection, power generation, energy storage, and waste energy rejection;
 - human and food supply waste processing requirements; and
 - food and waste storage requirements.
4. Food production by conventional biological growth (plant photosynthesis) is a viable candidate food production process. (See also reference 13.)

Focus and Limitations

The above assumptions indicate the model's focus on the food production function itself and not on components and functions which may

be heavily dependent on the choice of food supply. The model, at this stage of development, therefore is useful primarily for comparing conventional food supply alternatives which are judged not to have a substantial difference in requirements for (or impacts on) energy and waste processing functions. The results of model calculations also can indicate orders of magnitudes of mass requirements on an absolute scale, providing a starting point for assessing alternative food supply scenarios and for determining the relative mass of food supply components.

MODEL STRUCTURE

Baseline Scenario (Resupply)

The baseline scenario is characterized by full resupply of necessary diet materials. The diet requirements are often given on a person-day or person-year basis. By letting \underline{M}_R be the resupply mass required for food (g/person-year), the food resupply mass for a population of N_p for a period of T years is given by

$$(\underline{M}_R)(N_p)(T). \quad (1)$$

To this mass should be added the mass required for air revitalization. Engineering considerations (14) suggest that this mass can be modeled by an expression representing a fixed mass and plus a mass which is linearly dependent on the number of persons:

$$M_o + (M_{ov})(N_p). \quad (2)$$

The mass required for the resupply is thus given by the sum of (1) plus (2).

Alternative Scenario

The alternative scenario is characterized by recycling of nutrients, utilizing plants for growing food. The mass required for growing and processing the food may be represented by the sum of five mass components: the food-producing biomass (M_p), the mass of the harvesting equipment (M_H), the food production system mass (system components for plant growth, excluding the plant biomass itself, M_{pS}), the mass of the food processing equipment (M_{FP}), and the mass of the water of transpiration (M_{WT}) required in the plant growth environment (including the atmospheric/vapor phase and the nutrient reservoir but excluding the water contained in the plant biomass). Each mass would be given in grams (or kilograms) unless

other dimensions are specified. The total mass for the alternative scenario is given by

$$M_B + M_H + M_{PS} + M_{FP} + M_{WT}. \quad (3)$$

Calculations for each of the components are given in the following paragraphs.

Food Producing Biomass. The total biomass required for the food production function is given by the sum of the biomass required for each of the individual foods in the diet. Letting M_{Bj} be the biomass required to produce the daily dietary requirement of one person for food j , the total productive biomass is given by

$$\sum_j (M_{Bj})(N_p). \quad (4)$$

M_{Bj} is calculated from the dietary requirements which are met by the food produced by the plants. If the daily diet amount of food j is R_{ej} , this is equal to the production rate of fresh edible food (g/person-day) and thus the total biomass harvest rate, B_{oj} (g/person-day) is given by

$$B_{oj} = (R_{ej}) / (e_{Bj}), \quad (5)$$

where e_{Bj} is the edible fraction (fresh). Assuming a simplified model of linear biomass growth over time, with t_{Hj} as the total growing period (time to harvest), then

$$M_{Bj} = (B_{oj})(t_{Hj}/2). \quad (6)$$

Harvesting Equipment. Food harvesting equipment for a CELSS has not been designed, and much of the harvesting functions may be fulfilled manually. Grain products (e.g., wheat) may be an exception, and this model assumes a single grain harvester (plot harvester) with a mass of 800 kg (15). That is, the initial assumption for harvesting equipment requirements is:

$$M_H = 800. \quad (7)$$

Food Production System. The food production system consists of the components necessary to sustain productive plant growth in a controlled environment. These components include lighting, atmospheric control, plant support, and control components. Estimates for these components, based initially on a design for earth-based phytotron facilities, have been placed into three categories: (1) fixed mass components, whose mass is independent of the total growing area required (e.g., control

components), (2) an unscaled mass which is linearly related to the size of the growing area (e.g., lighting components), and (3) a scaled mass which increases with the size of the growing area by a power relationship (e.g., atmospheric control components). The last category uses the empirical engineering rule of 0.6 scaling, in which the mass requirement increases with the 0.6 power of the area. Such a scaling is consistent with components whose capacity would be related to volume rather than area, for example. (Appendix A gives the individual components of a ground-based controlled environment (phytotron-type) system, their mass, and the estimated masses for the three model categories.)

The model calculation for the food production system mass (M_{PS}) is therefore

$$M_{PS} = M_{PSC} + (M_a)(A) + (M_{as})(A_B)^{0.6}, \quad (8)$$

where M_{PSC} is the total fixed (control component) mass, A is the growing area (or total illuminated area), M_a is the factor for the unscaled (linearly related to area) mass, and M_{as} is the scaled area factor.

The biomass growing area required per person (A_B , in m^2 /person) is calculated from the dietary requirements for the diet components and the plant productivities. For food j , the required area is given by

$$A_{Bj} = (R_{ej}) / [(P_j)(e_{Bj})], \quad (9)$$

where R_{ej} is the dietary requirement (required fresh edible production rate), e_{Bj} is the edible fraction (fresh) of the total biomass harvested daily, and P_j is the biomass productivity, or total biomass growth rate (g/m^2 -day).

Food Processing Equipment. Food processing equipment mass is estimated from data on current food preparation system technology and assumed engineering developments (16). The mass assumed for this equipment is

$$M_{FP} = K(N_p)^x, \quad (10)$$

where the factor K and the power x are determined by fitting a curve to the data for populations of 10 and 100 persons, and these parameters are 302.7 and 0.415, respectively, for M_{FP} in kilograms.

Water Reservoir Mass. The final component of mass in the alternative scenario is the water of transpiration, M_{WT} (kg). This mass includes the atmospheric (vapor phase) moisture in the plant growth chamber and the mass of the nutrient reservoir, but excludes the water in the plant

biomass. Plants differ in the amount of water they transpire daily, but the amount can be modeled by a linear relationship to the dry biomass of the plant. Consequently, in order to compare different plants and different diets, the model incorporates a parameter which represents the number of days of transpired water assumed to be required in the system for the growing biomass. For plant j , the water of transpiration mass, M_{WTj} is given by

$$M_{WTj} = (10)(\underline{M}_{Bdj})(N_p)(T_r), \quad (11)$$

where \underline{M}_{Bdj} is the dry biomass (kg/person) of plant j , 10 is the empirical factor representing the ratio of water mass transpired (per day) to the plant's dry biomass, N_p is the population, and T_r is the design factor representing the number of days of transpiration water required by the system.

EXAMPLE CALCULATIONS

DIET AND PLANT GROWTH ASSUMPTIONS

Diet Basis

The diet requirements assumed for both the baseline and alternative scenarios are based on a "thrifty food plan." This diet is characterized by less consumption of animal tissue and somewhat more grain consumption than actual consumption patterns of food stamp recipients. The diet assumed for the model is the thrifty plan with small variations due to the assumed percentage of waste and to minor diet variations. Table 1 compares the actual food consumption pattern, the thrifty diet, and the diet assumed for the model. Note that the last column in the table also is equivalent to the required production rate of edible fresh food.

Plant Growth Rates

Plant growth data are taken from the literature on crop yield and plant productivity studies. The other model parameters related to ratios of fresh and dry weights, edible and total biomass, etc., are taken from the same literature. Table 2 presents these and the related calculated values for the major food plants in the assumed diet.

STORAGE AND RESUPPLY ASSUMPTIONS

For the baseline scenario, food must be stored or resupplied. The mass of this stored or resupplied food is assumed to be linearly related to the edible dry biomass, with the small residual moisture content and packaging mass being 53% of the dry mass. The daily resupply mass for food j is therefore

$$M_{Rj} = (1.53)EB_{dj}, \quad (12)$$

where EB_{dj} is the edible biomass, dry, of food j .

The mass required for air revitalization, a function assumed to be performed adequately by the plants in the alternative scenario, is given by expression 2 for the baseline scenario. From reference 14, the total mass for air revitalization has a small (90.4 kg) fixed component and a larger variable component. The parameters for expression 2 are

$$M_o = 90.4 \text{ and } M_{ov} = 415.8.$$

Table 1. Food Quantities - Comparison of Consumption Pattern, Thrifty Diet, and Model Assumptions¹
(fresh weight, grams/person-day)

	Food Consumption Pattern ²	Thrifty Food Plan ³	Diet Assumed for Model Calculations (R _{ej})
A. Milk,cheese,ice cream	548.4	404.5	399.8
B. Meat,poultry,fish	209.2	196.5	196.5
C. Eggs	41.1	34.3	30.2
D. Dry beans,peas,nuts	16.2	28.5	Beans 16.2 Peanut Butter 11.7
E. Potatoes	84.3	131	131
F. Dark green, deep yellow vegetables	24.3	25.3	Leaf Cabbage 13.6 Carrots 11.7
G. Citrus fruit,tomatoes	110.3	116.7	Tomatoes ⁴ 116.7
H. Other vegetables,fruit	230.2	239.3	Green Beans 44.8 Head Cabbage 12.3 Lettuce 20.1 Melons ⁵ 253 Peas 9.7
I. Grain products		Cereal 57.7 Flour 59.7 Bread 148.5 Other Bakery Products 86.3	Wheat Equiv. 352
J. Fats, oils	38.9	61.6	61.6
K. Sugar, sweets	55.1	55.8	55.8
L. Accessories	Not Given	Not Given	80.4

Notes:

¹Adapted from "The Thrifty Food Plan" (17) and "Report to J. Spurlock" (BSSG) from Marcus Karel (18).

²Based on National Survey of Food Stamp and Food Distribution Program Recipients, November, 1973 (Average 4-person Household); from "The Thrifty Food Plan" (17).

³Based on 20-54 year-old male nutritional requirements; amounts for some groups allow for approximately 5% discard and waste (e.g., egg shells).

⁴Tomatoes replace oranges on equal mass basis.

⁵Melons replace apples and bananas on 2.48 g per gram basis.

Table 2. Plant Productivity Parameters for Major Foods

Food	Column Parameter*	1 R_e	2 t_H	3 TB_d	4 P	5 EB_d	6 EB_f	7 e_B (6÷4)	8 $\frac{B}{O}$ (1÷7)	9 $\frac{A}{B}$ 1÷(4x7)	10 w_e 1-(5÷6)	Reference
Dry Beans		16.2	47	43.1	204.3	21.1	24.3	.119	136.1	.67	.132	19
Peanut Butter		12.3	110	49.5	355.0	8.2	9.4	.026	473.1	1.33	.126	20
Leaf, Head Cabbage		25.9	30	10.4	180.8	9.9	172.1	.952	27.2	.15	.942	21
Carrots		11.7	80	43.6	315.6	21.3	154.2	.489	23.9	.08	.862	21
Tomatoes		116.7	215	7.9	113.5	6.2	95.0	.84	138.9	1.22	.93	22
Potatoes		131.0	120	20.2	134.6	13.7	97.9	.727	180.2	1.34	.86	23
Green Beans		44.8	60	108.9	920.6	26.3	305.2	.332	134.9	.15	.914	24
Lettuce		20.1	28	11.6	221.1	8.5	161.3	.730	27.5	.12	.947	25
Melons		253.0	107	32.9	396.5	19.9	298.9	.754	335.5	.85	.933	26
Peas		9.7	50	15.6	99.9	0.6	3.7	.037	262.2	2.62	.838	27
Wheat		<u>352.2</u>	196	<u>148.4</u>	505.3	58.5	67.2	.133	<u>2648.1</u>	<u>5.24</u>	.129	24
Totals		993.6		486.1					4387.6	13.77		

* R_e = daily requirement (g-person⁻¹-day⁻¹, fresh); t_H = time to harvest (days); TB_d = total biomass, dry; P = productivity; EB_d = edible biomass, dry; EB_f = edible biomass, fresh (all g-m⁻²-day⁻¹); e_B = edible fraction, fresh; $\frac{B}{O}$ = biomass harvest rate (g-person⁻¹-day⁻¹); $\frac{A}{B}$ = growing area required (m²-person⁻¹); w_e = fraction moisture, edible.

BREAKEVEN CALCULATION PROCEDURE AND RESULTS

The calculation of times (years) for which the baseline and alternative scenario mass requirements are equal initially was performed using two programs for a programmable hand calculator (HP-67). These programs, described in Appendixes C and D, permit rapid evaluation of detailed scenarios and the evaluation of the model's sensitivity to changes in single parameter values. Appendix B summarizes the nomenclature conventions for both programs.

The first program (Appendix C) calculates the plant productivity, growing area requirements, and the other calculated plant parameters from the fresh and dry total and edible biomass productivity factors, the dietary requirements, and the growing period (time to harvest) for individual cultivars.

The second program uses the results of the first and design parameters (population and assumed parameter values for the growing environment and food processing component masses) to calculate the mission duration for which the mass requirements of the two scenarios are equal. This program is a preliminary, incomplete version of the model outlined in the text above. Specifically, the program in Appendix D does not include expression (2), the mass assumed to be required for air revitalization components in the baseline scenario. Therefore, the program is particularly useful for calculating breakeven times for individual food items/cultivars (scenario comparisons in which air revitalization is required both for the baseline case and an alternative that involves limited on-board food production).

Table 3 presents the results of calculations for the major plant-produced foods. Note that wheat has the earliest breakeven time, followed by beans (dry and green), melons, and potatoes, with peas having the longest breakeven time.

For the alternative scenario in which virtually all plant-derived food is grown, with the biomass providing both food production and air revitalization functions, the breakeven time is 12.4 years, as shown in Table 4. This table also shows the results of modifying the initial values of the parameters to generate additional alternative scenarios for comparison with the resupply case.

Table 3. Breakeven Analysis Results - Comparison of Resupply and Regenerative Scenarios

Assumptions: Resupply mass = 1.53 x dry mass of food required.

Initial alternative scenario parameter values:

$N_p = 10$ $M_{fp} = 0$ $M_{PSC} = 15.88$ $M_{as} = 122$

$T_r = 1$ $M_H = 0$ $M_a = 83.2$

Food	(Baseline)	(Alternative)			T_{BE} (yrs)
	Resupply Mass (kg-person ⁻¹ -yr ⁻¹)	Biomass Holdup (kg-person ⁻¹)	Growing Env. Equip. Mass (M _{PS}) (kg)	M_{WT} (kg)	
A. Dry Beans	7.87	3.22	955.3	69.9	13.1
B. Peanut Butter	6.00	25.6	1677	355.5	34.3
C. Cabbage	.84	.407	361.8	2.4	43.4
D. Carrots	.90	1.01	189.2	13.9	22.7
E. Tomatoes	4.56	14.9	1578	109	37.3
F. Potatoes	10.24	10.8	1710	162.3	18.4
G. Green Beans	2.15	4.14	296.3	46.6	16.1
H. Lettuce	.60	.402	266.8	2.1	44.9
I. Melons (for Apples)	4.00	7.64	578.5	63.4	16.2
(for Bananas)	2.33	4.46	381.0	37.0	18.3
(for Fresh Fruit)	3.13	5.94	475.1	49.3	16.9
J. Peas	.88	6.54	3061	102.1	360
K. Grain (Wheat)	171.3	259.5	5688	7629	7.9

Table 4. Breakeven Analysis, All Plants Combined

<u>Initial Values</u>	
$M_{TR} = 214.8 \text{ (kg person}^{-1}\text{-yr}^{-1}\text{)}$	$M_{PSC} = 15.9 \text{ (kg)}$
$N_p = 10 \text{ (persons)}$	$M_a = 83.2 \text{ (kg m}^{-2}\text{)}$
$T_r = 1$	$M_{as} = 122 \text{ (kg m}^{-2}\text{)}$
$M_{fp} = 787^*$	$A_B = 13.8 \text{ (m}^2\text{-person}^{-1}\text{)}$
$M_B = 344.6 \text{ (kg person}^{-1}\text{)}$	$M_o = 90.4$
$M_{Bd} = 86.4 \text{ (kg person}^{-1}\text{)}$	$M_{ov} = 415.8$
$M_H = 800 \text{ (kg)}$	

Other values given in Table 2.

*Corresponding to $K = 302.7$ and $x = 0.415$ in equation (10).

Results

<u>Scenario</u>	<u>Breakeven Time (T_{BE}, Years)</u>
A. Initial values, above	12.4
B. As A, with $M_o = M_{ov} = 0$	12.4
C. As A, with peas resupplied	9
D. As C, with $T_r = 1.1$	8.5
E. As C, with peanut butter resupplied	9.7
F. As C, with $N_p = 100$	8.5
G. As E, with $N_p = 100$	7.7

DISCUSSION

ISSUES FOR FURTHER STUDY

The results of applying the model thus far indicate several issues which should be considered further. These issues are outlined in the following paragraphs.

Plant Productivity Measures

The area of the growth chamber has a relatively large impact on the overall CELSS mass requirements. Consequently, plant productivity, as measured by the yield of edible (and digestible) biomass per unit area, is an important consideration.

Another contributor to total mass of the regenerative system is the standing biomass, or "biomass holdup." Plants which have low biomass holdup for a given edible production are thus desirable. (Note that time to harvest, or maturity period, is not directly, or solely, an adequate measure of productivity.)

Functional Components

The results indicate that the components associated with the growth chamber (scaled and unscaled components) are significant contributors to the total mass. Reductions in the mass required for these components (e.g., lighting) should be possible.

CONCLUSIONS

The model, although limited in scope, provides a useful starting point for analyzing alternative diet and plant growth scenarios. Further refinement is underway to improve the model's utility and to facilitate its application by other researchers.

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25. "Baseline Growth Studies of Grand Rapids Lettuce in Controlled Environments," P.A. Hammer, et al; Journal of the American Society of Horticultural Science 103:649-655, 1978.
26. "Nutrient Absorption and Growth of Four Muskmelon Varieties," K.B. Tyler and O.A. Lorenz; Proceedings of the American Society for Horticultural Science 84:364-371, 1964.
27. "Effect of High Temperature on Yield of Peas," R.G. Lambert and A.J. Linck; Plant Physiology 33:347-350, 1958.

Appendix A
CONTROLLED ENVIRONMENT WEIGHT ESTIMATES

System Component	Estimated Weights (lbs)			
	Initial ¹	Optimistic ²		
	Per .98m ²	(Net) Fixed	(Net) Per .98m ²	(For .6 scaling) Per .98m ²
1. Panels	612	0	0	0
2. Fan Coil Assembly	150	-	-	(Include in 6B)
3. Refrigeration Cond. Unit	185	-	(Include w/heat rejection)	-
4. Lighting	150	-	150*	-
5. Control Console	76	25	-	-
6A. Humidification	33			33
b. Dehumidification	205			200
7A. Exhaust & Make up Air Blower	76	-	-	-
B. CO ₂ Analyzer	-	10	-	-
8. Plant Support Structure	150		30	
9. Misc. Components (Wireways-50; Insulation-10; Piping-50; Vibration Links-5; Wires-30; Valves, etc.-15)	160		-	30
Total				
(lb)	1797	35	180	263
(kg)	812.12	15.88	81.65	119.30
(kg-m ⁻²)	827.6	NA	83.21	121.57

¹David Raper, personal communication (estimates from Environmental Specialties, Raleigh, North Carolina).

²Estimates by Mike Modell, Jack Spurlock, Dave Raper, and Bob Mason (79/06/26).

*Reduction should be possible.

Appendix B

NOMENCLATURE AND CONVENTIONS

Conventions

Subscript j refers to type of crop in cultivar.

Total biomass defined as edible and inedible.

Underbar: per person basis.

<u>Parameter or Variable</u>	<u>Symbol</u>
Growing area ($\text{m}^2\text{-person}^{-1}$)	\underline{A}_{Bj}
Total biomass harvest rate ($\text{g person}^{-1}\text{-day}^{-1}$)	\underline{B}_{Oj}
Edible fraction, fresh	e_{Bj}
Mass requirement for growing area, unscaled components (kg-m^{-2})	M_a
Mass requirement for growing area, scaled components (kg-m^{-2})	M_{as}
Dry biomass holdup (g-person^{-1})	\underline{M}_{Bdj}
Food processing equipment mass for 10 persons (kg)	M_{fp}
Mass of food harvesting equipment (kg)	M_H
Total growing area equipment mass (kg)	M_{PS}
Mass of control equipment for food production module (kg)	M_{PSC}
Additional mass required for alternative scenario above that required for baseline scenario	M_{TP}
Mass required for resupply/storage of food j ($\text{kg-person}^{-1}\text{-yr}^{-1}$)	\underline{M}_{TRj}
Mass of (transpiration) water required for adequate humidity and nutrient reservoir	M_{wt}

<u>Parameter or Variable (cont.)</u>	<u>Symbol</u>
Population	N_p
Total growth rate of fresh biomass ($\text{g m}^{-2}\text{-day}^{-1}$)	P_j
Production rate of fresh edible food ($\text{g person}^{-1}\text{-day}^{-1}$) (Set equal to daily requirement)	R_{ej}
Harvest waste, fresh ($\text{g person}^{-1}\text{-day}^{-1}$)	R_{wj}
Breakeven time (yrs); mission duration for which mass requirements of baseline and alternative scenarios are equal	T_{BE}
Total time to harvest (days)	t_{Hj}
Number of days of transpiration supply assumed	T_r
Fraction of water in total biomass	w_{Bj}
Fraction of water in edible portion	w_{ej}
Fraction of water in inedible portion	w_{wj}
Harvest waste water ($\text{g person}^{-1}\text{-day}^{-1}$)	W_{wj}

Appendix C

HP-67 PROGRAM FOR CULTIVAR CALCULATIONS

Storage

<p>0 \underline{R}_{ej}</p> <p>1 w_{ej}</p> <p>2 w_{wj}</p> <p>3 e_{Bj}</p> <p>4 t_{Hj}</p>	<p>5 $P_j = TB_{fj}$</p> <p>6 \underline{B}_{oj}</p> <p>7 (TB_{dj})</p> <p>8 (EB_{dj})</p> <p>9 (EB_{fj})</p>
--	--

Program Instructions

1. Key in TB_{dj} , press ENT
2. " " TB_{fj} , " "
3. " " EB_{dj} , " "
4. " " EB_{fj} , " A
5. " " t_{Hj} , " ENT
6. " " \underline{R}_{ej} , " B

7. Read out:
- | | |
|--|--|
| <p>1) \underline{R}_{ej}</p> <p>2) w_{ej}</p> <p>3) w_{wj}</p> <p>4) e_{Bj}</p> <p>5) t_{Hj}</p> <p>6) P_j</p> | <p>7) w_{ej}</p> <p>8) \underline{A}_{Bj}</p> <p>9) \underline{B}_{oj}</p> <p>10) \underline{M}_{Bj}</p> <p>11) \underline{R}_{wj}</p> <p>12) \underline{W}_{wj}</p> |
|--|--|

AGRICULTURAL DATA INPUT CONVERSIONS

Input Data Arrays

- TB_{dj} : Total biomass, dry ($g\ m^{-2}\ day^{-1}$)
 TB_{fj} : Total biomass, fresh ($g\ m^{-2}\ day^{-1}$)
 EB_{dj} : Edible biomass, dry ($g\ m^{-2}\ day^{-1}$)
 EB_{fj} : Edible biomass, fresh ($g\ m^{-2}\ day^{-1}$)

Derived Variable Arrays

- w_{ej} : Fraction of water in edible portion
 w_{wj} : Fraction of water in inedible portion
 e_{Bj} : Edible fraction, fresh
 P_j : Total growth rate of fresh biomass ($g\ m^{-2}\ day^{-1}$)

Sequence of Calculations

$$w_{ej} = \frac{EB_{fj} - EB_{dj}}{EB_{fj}} = 1 - EB_{dj}/EB_{fj}$$

$$w_{wj} = \frac{(TB_{fj} - EB_{fj}) - (TB_{dj} - EB_{dj})}{(TB_{fj} - EB_{fj})} = 1 - \frac{(TB_{dj} - EB_{dj})}{(TB_{fj} - EB_{fj})}$$

$$e_{Bj} = \frac{EB_{fj}}{TB_{fj}}$$

$$P_j = TB_{fj}$$

ALGORITHM FOR AGRICULTURAL PRODUCTION

Design Variables

N_p : Population

\underline{R}_{ej} : Production rate of fresh edible food ($\text{g person}^{-1} \text{ day}^{-1}$)

Data Arrays

w_{ej} : Fraction of water in edible portion

w_{wj} : Fraction of water in inedible portion

e_{Bj} : Edible fraction, fresh

t_{Hj} : Total time to harvest (days)

\underline{P}_j : Total growth rate of fresh biomass ($\text{g m}^{-2} \text{ day}^{-1}$)

Derived Variables

w_{Bj} : Fraction of water in total biomass

\underline{A}_{Bj} : Growing area ($\text{m}^2 \text{ person}^{-1}$)

\underline{B}_{oj} : Total biomass harvest rate ($\text{g person}^{-1} \text{ day}^{-1}$)

\underline{M}_{Bj} : Total biomass holdup (g person^{-1})

\underline{R}_{wj} : Harvest waste, fresh ($\text{g person}^{-1} \text{ day}^{-1}$)

\underline{W}_{wj} : Harvest waste water ($\text{g person}^{-1} \text{ day}^{-1}$)

Sequence of Calculations

1. $w_{Bj} = w_{ej} e_{Bj} + w_{wj} (1 - e_{Bj})$

2. $\underline{A}_{Bj} = \underline{R}_{ej} / \underline{P}_j e_{Bj}$

3. $\underline{B}_{oj} = \underline{R}_{ej} / e_{Bj}$

4. $\underline{M}_{Bj} = \underline{B}_{oj} t_{Hj} / 2$

5. $\underline{R}_{wj} = \underline{B}_{oj} (1 - e_{Bj})$

6. $\underline{W}_{wj} = \underline{R}_{wj} w_{wj}$

CULTIVAR CALCULATIONS PROGRAM LISTING

1. * LBL A	28. ÷	55. - X - (w_{Bj})
2. STO 9	29. STO 3	56. RCL 0
3. +	30. R/S	57. RCL 5
4. STO 8	31. * LBL B	58. ÷
5. +	32. STO 0	59. RCL 3
6. STO 5	33. - X - (R_{ej})	60. ÷
7. +	34. +	61. - X - (A_{Bj})
8. STO 7	35. STO 4	62. RCL 0
9. 1	36. RCL 1	63. RCL 3
10. RCL 8	37. - X - (w_{ej})	64. ÷
11. RCL 9	38. RCL 2	65. - X - (B_{oj})
12. ÷	39. - X - (w_{wj})	66. STO 6
13. -	40. RCL 3	67. RCL 4
14. STO 1	41. - X - (e_{Bj})	68. X
15. RCL 7	42. RCL 4	69. 2
16. RCL 8	43. - X - (t_{Hj})	70. ÷
17. -	44. RCL 5	71. - X - (M_{Bj})
18. RCL 5	45. - X - (P_j)	72. 1
19. RCL 9	46. RCL 1	73. RCL 3
20. -	47. RCL 3	74. -
21. ÷	48. X	75. RCL 6
22. CHS	49. 1	76. X
23. 1	50. RCL 3	77. - X - (R_{wj})
24. +	51. -	78. RCL 2
25. STO 2	52. RCL 2	79. X
26. RCL 9	53. X	80. - X - (w_{wj})
27. RCL 5	54. +	81. R/S

Appendix D

HP-67 PROGRAM FOR BREAKEVEN CALCULATION

Storage

Register	Parameter	Register	Parameter	Register	Parameter
1	N_p	6	M_{PSC}	2	$\frac{A}{B}$
9	M_{fp}	5	M_H	1	M_{as}
8	T_r	4	$\frac{M}{Bd}$	0	M_a
7	M_{TR}	3	$\frac{M}{B}$		

Operating Instructions

Notes

1. Key in N_p Press
2. " " M_{TR} " " (kg)
3. " " T_r " "
4. " " M_{fp} "
5. " " $\frac{M}{B} \cdot 10^{-3}$ " ($\frac{M}{B} \cdot 10^{-3}$) = kg-person⁻¹
6. " " $\frac{M}{Bd} \cdot 10^{-3}$ " " ($\frac{M}{Bd} \cdot 10^{-3}$) = kg-person⁻¹
7. " " M_H " "
8. " " M_{PSC} "
9. " " M_a "
10. " " M_{as} " "
11. " " $\frac{A}{B}$ "
12. Read out: T_{BE} Breakeven time (years)
 M_{TP} Total PCELSS mass requirement (above resupply component mass)
 M_{wt} Water mass - transpiration reservoir
 M_{PS} Total growing environment equipment mass

To run again changing only a few parameter values:

key in new value, press STO X, where X is from above table.
Repeat for each changed value

Press

CELSS BREAKEVEN ANALYSIS PROGRAM LISTING

1. * LBL A	29. ENT	57. 1
2. STO 9	30. RCL 0	58. 5
3. +	31. X	59. Y^X
4. STO 8	32. $X \rightarrow Y$	60. RCL 9
5. +	33. .	61. X
6. STO 7	34. 6	62. STO C
7. +	35. Y^X	63. RCL 3
8. STO I	36. RCL 1	63a. RCL I
9. R/S	37. X	63b. X
10. * LBL B	38. +	64. +
11. STO 6	39. RCL 6	65. RCL 5
12. +	40. +	66. +
13. STO 5	41. STO A	67. RCL A
14. +	42. RCL I	68. +
15. STO 4	43. RCL 8	69. RCL B
16. +	44. X	70. +
17. STO 3	45. RCL 4	71. STO D (M_{TP})
18. R/S	46. X	72. RCL 7
19. * LBL C	47. 1	73. RCL I
20. STO 2	48. 0	74. X
21. +	49. X	75. ÷
22. STO 1	50. STO B	76. - X - (T_{BE})
23. +	51. RCL I	77. RCL D
24. STO 0	52. 1	78. - X - (M_{TP})
25. RCL I	53. 0	79. RCL B
26. RCL 2	54. ÷	80. - X - (M_{wt})
27. X	55. .	81. RCL A
28. ENT	56. 4	82. - X - (M_{PS})
		83. RTN

Calculations

1. $M_{PSS} = M_{as} \left(\frac{A}{B} N_p \right) \cdot 6$
2. $M_{PSU} = M_{a-B} \frac{A}{B} N_p$
3. $M_{PS} = M_{PSS} + M_{PSU} + M_{PSC}$ (STO A)
4. $M_{wt} = 10 \cdot \frac{M_{Bd}}{B} \cdot N_p \cdot T_r$ (STO B)
5. $M_{fp} = M_{fp} \left(\frac{N_p}{10} \right) \cdot 415$ (STO C)
6. $M_B = N_p \cdot \frac{M_B}{B}$
7. $M_{TP} = M_B + M_H + M_{FP} + M_{PS} + M_{wt}$ (STO D)
8. $T_{BE} = M_{TP} \div \left(\frac{M_{TR}}{B} \cdot N_p \right)$

APPENDIX E

FORTRAN Program for Breakeven Calculation

Purpose: This program is based on the PRELIMINARY SCENARIO ANALYSIS MODEL by Robert M. Mason.

Author: Martha Sadler, New View, Sept 1980

Environment:

DEC VAX-11/780 VAX/VMS VAX-11 FORTRAN IV-PLUS

Non-Standard Code:

VAX-11 FORTRAN IV-PLUS extensions of ANS FORTRAN 1966:

Data types: CHARACTER, LOGICAL*1,
Block IF logical structure: IF THEN, ELSE, ELSE IF, ENDIF
statements
END= and ERR= in READ or WRITE statements
OPEN, CLOSE, DEFINE FILE file control specifications

Commons Used:

<name>	<description>
REAL1	Real variables
CHAR2	Character variables
INT3	Integer variables
LOG4	Logical variables

Subroutines Called:

<name>	<description>
BLOCK DATA	COMMON DATA
PRODUC	This subroutine performs cultivar calculations.
BREAK	This subroutine performs breakeven calculations.
DESCRT	Gives description of variables when '?' input.
MFREIN	Modified version of FREEIN.FOR written by Walton
MDECDE	Modified version of DECODE.FOR written by Walton

Limitations

Exit Points
Constraints and Cautions

VARIABLE DESCRIPTIONS

TR NUMBER OF DAYS OF TRANSPIRATION
 MCONST RATIO OF PLANT THAT IS DRY WEIGHT
 TBJD TOTAL DRY BIOMASS (G PER SQ M PER DAY)
 TBD TOTAL DRY BIOMASS (G PER SQ M PER DAY)
 TBFJ TOTAL FRESH BIOMASS (G PER SQ M PER DAY)
 TBF TOTAL FRESH BIOMASS (G PER SQ M PER DAY)
 EBDJ EDIBLE DRY BIOMASS (G PER SQ M PER DAY)
 EBD EDIBLE DRY BIOMASS (G PER SQ M PER DAY)
 EBFJ EDIBLE FRESH BIOMASS (G PER SQ M PER DAY)
 EBF EDIBLE FRESH BIOMASS (G PER SQ M PER DAY)
 WEJ FRACTION OF WATER IN EDIBLE PORTION
 MBD DRY BIOMASS HOLDUP (G PER PERSON)
 MPSC MASS OF CONTROL EQUIPMENT FOR FOOD PRODUCTION MODULE (KG)
 MA MASS REQUIREMENT FOR GROWING AREA, UNSCALED COMPONENTS
 (KG PER SQ M)
 MAS MASS REQUIREMENT FOR GROWING AREA, SCALED COMPONENTS
 (KG PER SQ M)
 MFP FOOD PROCESSING EQUIPMENT MASS FOR 10 PERSONS (KG)
 MH MASS OF FOOD HARVESTING EQUIPMENT (KG)
 WWJ FRACTION OF WATER IN INEDIBLE PORTION
 EBJ EDIBLE FRACTION FRESH
 PJ TOTAL GROWTH RATE OF FRESH BIOMASS (G PER SQ M PER DAY)
 WBJ FRACTION OF WATER IN TOTAL BIOMASS
 ABJ GROWING AREA (SQ M PER PERSON)
 REJ PRODUCTION RATE OF FRESH EDIBLE FOOD
 (G PER PERSON PER DAY)
 BOJ TOTAL BIOMASS HARVEST RATE (G PER PERSON PER DAY)
 THJ TOTAL TIME TO HARVEST (DAYS)
 TH TOTAL TIME TO HARVEST (DAYS)
 RWJ HARVEST WASTE, FRESH (G PER PERSON PER DAY)
 MBJ TOTAL BIOMASS HOLDUP (G PER PERSON)
 MB TOTAL BIOMASS HOLDUP (G PER PERSON)
 TOTMBJ BIOMASS HOLDUP FOR TOTAL POPULATION
 TOTMFP FOOD PROCESSING EQUIPMENT MASS FOR TOTAL POPULATION (KG)
 MTRJ MASS REQUIRED FOR RESUPPLY/STORAGE OF FOOD J
 (KG PER PERSON PER YR)
 MTP ADDITIONAL MASS REQUIRED FOR ALTERNATIVE SCENARIO ABOVE
 THAT REQUIRED FOR BASELINE SCENARIO
 MWT MASS OF WATER REQUIRED FOR ADEQUATE HUMIDITY AND
 NUTRIENT RESERVOIR
 MPS TOTAL GROWING AREA EQUIPMENT MASS (KG)
 NP POPULATION
 TBE BREAKEVEN TIME (YEARS)

FORTRAN PROGRAM

```

C SEE 'PRELIMINARY SCENARIO ANALYSIS MODEL', CELSS WORKING PAPER,
C WP754-1 BY ROBERT MASON, APRIL, 1980
  REAL DEFVAL(6,11),NUMBER,AMOUNT,GENVAR(6,2),USRVAL(6,11),TR,
  X MCONST,TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,
  XWWJ,EBJ,PJ,WBJ,ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,
  X MTRJ,MTP,MWT,MPS,NP,TBE,ALLMBD,ALLMTR,ALLMBJ,ALLABJ
  CHARACTER*13 FDNAME(11),WHICH
  CHARACTER*80 LINE
  CHARACTER*6 VRNAME(6),GENAME(6),THIS
  LOGICAL*1 FINISH,COMBND,POPULN
  INTEGER OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFAULT,USER,SAVE
  COMMON/REAL1/DEFVAL,NUMBER,AMOUNT,GENVAR,USRVAL,TR,MCONST,
  *TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,WWJ,EBJ,PJ,WBJ,
  *ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,MTRJ,MTP,MWT,MPS,NP,TBE
  COMMON/CHAR2/FDNAME,WHICH,LINE,VRNAME,GENAME,THIS
  COMMON/LOG4/FINISH,COMBND,POPULN
  COMMON/INT3/OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFAULT,USER
C
  LAST =6
  SAVE = 12
  OMEGA = 11
  USER = 2
  DEFAULT = 1
  TERMOT=6
  TERMIN=5
  FINISH = .FALSE.
  COMBND = .FALSE.
  POPULN = .FALSE.
C
  WRITE (TERMOT,5)
  5  FORMAT (' ','THIS PROGRAM IS BASED
  X ON THE PRELIMINARY SCENARIO',/,
  X' ANALYSIS MODEL BY ROBERT M. MASON',/,/,
  X' TO OBTAIN A DESCRIPTION OF A VARIABLE, TYPE IN--?VARIABLE',/,
  X' NAME--WHEN INPUT IS ASKED FOR')
  OPEN (UNIT=10,NAME='MASON.DAT',TYPE='OLD')
  9  WRITE (TERMOT,10)
  10 FORMAT (' ','DO YOU WISH TO RUN A COMBINATION OF FOODS FOR',/,
  * ' BREAKEVEN ANALYSIS,1=YES,0=NO')
C
  READ (TERMIN,15) LINE
  15 FORMAT (A80)
C
  IF (LINE(1:1).EQ.'?') THEN
    CALL DESCRT (LINE,9)
  ELSE
    MODE = 1
    CALL MFREIN (LINE,MODE,ANSR,NVAR,9)
  END IF
C
  IF (ANSR.EQ.1) THEN

```

```

C RUN COMBINATION
  COMBND = .TRUE.
  OPEN (UNIT=12,NAME='COMB.DAT',TYPE='NEW')
  END IF
C
20  CALL PRODUC
C
C IF A COMBINATION IS RUN, BREAKEVEN CALCULATIONS ARE MANDATORY
  IF (COMBND) THEN
    ANSR = 1
    GO TO 167
  END IF
C
159 WRITE (TERMOT,160)
160 FORMAT (' ','DO YOU WISH BREAKEVEN CALCULATIONS,1=YES,2=NO')
  READ (TERMIN,165) LINE
165 FORMAT (A80)
C
  IF (LINE(1:1).EQ.'?') THEN
    CALL DESCRT (LINE,159)
  ELSE
    MODE = 1
    CALL MFREIN (LINE,MODE,ANSR,NVAR,159)
  END IF
C
167 IF (ANSR.EQ.1) THEN
  WRITE (TERMOT,168)
168 FORMAT (' ','BREAKEVEN CALCULATIONS')
  IF (.NOT.POPULN) THEN
169 WRITE (TERMOT,170)
170 FORMAT (' ','ENTER POPULATION')
  READ (TERMIN,172) LINE
172 FORMAT (A80)
C
  IF (LINE(1:1).EQ.'?') THEN
    CALL DESCRT (LINE,169)
  ELSE
    MODE = 0
    CALL MFREIN (LINE,MODE,NP,NVAR,169)
  END IF
  END IF
C
  CALL BREAK
  WRITE (SAVE,200) FDNAME(FOOD),MTRJ,MBJ,MBD,ABJ
200 FORMAT (A11,F6.2,F7.3,F7.3,F6.2)
  END IF
C
  IF (.NOT.COMBND) THEN
C
599 WRITE (TERMOT,600)
600 FORMAT (' ','DO YOU WISH TO RUN THE PROGRAM AGAIN,1=YES,0=NO')
  READ (TERMIN,602) LINE
602 FORMAT (A80)
C
  IF (LINE(1:1).EQ.'?') THEN
    CALL DESCRT (LINE,599)
  ELSE

```

```

        MODE = 1
        CALL MFREIN (LINE,MODE,ANSR,NVAR,599)
        END IF
C
        IF (ANSR.EQ.1) THEN
            GO TO 20
        END IF
    ELSE
        POPULN = .TRUE.
605     WRITE (TERMOT,610)
610     FORMAT (' ','ANOTHER FOOD?,1=YES,0=NO')
        READ (TERMOT,615) LINE
615     FORMAT (A80)
C
        IF (LINE(1:1).EQ.'?') THEN
            CALL DESCRT (LINE,605)
        ELSE
            MODE = 1
            CALL MFREIN (LINE,MODE,ANSR,NVAR,605)
        END IF
C
625     IF (ANSR.EQ.0) THEN
            FINISH = .TRUE.
            ENDFILE SAVE
            CLOSE (UNIT=12)
            OPEN (UNIT=12,NAME='COMB.DAT',TYPE='OLD')
            ALLMBD = 0
            ALLMTR = 0
            ALLMBJ = 0
            ALLABJ = 0
690     READ (SAVE,700,END=710) MTRJ,MBJ,MBD,ABJ
700     FORMAT (11X,F6.2,F7.3,F7.3,F6.2)
            ALLMTR = ALLMTR + MTRJ
            ALLMBJ = ALLMBJ + MBJ
            ALLMBD = ALLMBD + MBD
            ALLABJ = ALLABJ + ABJ
            GO TO 690
C
710     FDNAME(FOOD) = 'DIET'
            MBD = ALLMBD
            MTRJ = ALLMTR
            MBJ = ALLMBJ
            ABJ = ALLABJ
C
            WRITE (TERMOT,720)
720     FORMAT (' ','BREAKEVEN CALCULATIONS FOR DIET')
            CALL BREAK
C
            ELSE
                GO TO 20
            END IF
        END IF
        CLOSE (UNIT=10)
        CLOSE (UNIT=12)
        STOP
        END
C

```

```

C
BLOCK DATA
REAL DEFVAL (6,11),NUMBER,AMOUNT,GENVAR (6,2),USRVAL (6,11),TR,
X MCONST,TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,
XWWJ,EBJ,PJ,WBJ,ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,
X MTRJ,MTP,MWT,MPS,NP,TBE
CHARACTER*13 FDNAME(11),WHICH
CHARACTER*80 LINE
CHARACTER*6 VRNAME(6),GENAME(6),THIS
LOGICAL*1 FINISH,COMBND,POPULN
INTEGER OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFAULT,USER
COMMON/REAL1/DEFVAL,NUMBER,AMOUNT,GENVAR,USRVAL,TR,MCONST,
*TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,WWJ,EBJ,PJ,WBJ,
*ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,MTRJ,MTP,MWT,MPS,NP,TBE
COMMON/CHAR2/FDNAME,WHICH,LINE,VRNAME,GENAME,THIS
COMMON/LOG4/FINISH,COMBND,POPULN
COMMON/INT3/OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFAULT,USER
DATA FDNAME/'DRY BEANS','PEANUT BUTTER','CABBAGE',
X'CARROTS','TOMATOES','POTATOES','GREEN BEANS',
X'LETTUCE','MELONS','PEAS','WHEAT'
DATA GENVAR/1.,0,0,15.88,83.2,122.,0,0,0,0,0,0/
DATA GENAME/'TR','MFP','MH','MPSC',
X'MA','MAS'
DATA VRNAME/'TH','TBD','TBF','EBD',
X'EBF','MCONST'
DATA DEFVAL/47.0,43.1,204.3,21.1,24.3,.217,
X110.0,49.5,355.0,8.2,9.4,.139,30.0,10.4,180.8,9.9,172.1,.059,
X80.1,43.6,315.6,21.3,154.2,.138,215,7.9,113.5,6.2,95.0,.073,
X120.0,20.2,134.6,13.7,97.9,.150,60,108.9,920.6,26.3,305.2,.113,
X28.0,11.6,221.1,8.5,161.3,.052,107.0,39.9,396.5,19.9,298.9,.083,
X50.0,15.6,99.9,.6,3.7,.156,196.0,148.4,505.3,58.5,67.2,.294/
END

```

```

C
C
C SUBROUTINE PRODUC
C THIS SUBROUTINE PERFORMS CULTIVAR CALCULATIONS
C

```

```

REAL DEFVAL (6,11),NUMBER,AMOUNT,GENVAR (6,2),USRVAL (6,11),TR,
X MCONST,TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,
XWWJ,EBJ,PJ,WBJ,ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,
X MTRJ,MTP,MWT,MPS,NP,TBE
CHARACTER*13 FDNAME(11),WHICH
CHARACTER*80 LINE
CHARACTER*6 VRNAME(6),GENAME(6),THIS
LOGICAL*1 FINISH,COMBND,POPULN
INTEGER OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFAULT,USER
COMMON/REAL1/DEFVAL,NUMBER,AMOUNT,GENVAR,USRVAL,TR,MCONST,
*TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,WWJ,EBJ,PJ,WBJ,
*ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,MTRJ,MTP,MWT,MPS,NP,TBE
COMMON/CHAR2/FDNAME,WHICH,LINE,VRNAME,GENAME,THIS
COMMON/LOG4/FINISH,COMBND,POPULN
COMMON/INT3/OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFAULT,USER

```

```

C
9 WRITE(TERMOT,10)
10 FORMAT(' ','WOULD YOU LIKE A LIST OF FOODS STORED IN THE LIBRARY,
X1=YES,0=NO')
READ(TERMIN,20)LINE

```

```

20  FORMAT(A80)
    IF (LINE(1:1).EQ.'?') THEN
        CALL DESCRT (LINE,9)
    ELSE
        MODE = 1
        NVAR = 1
        CALL MFREIN(LINE,MODE,ANSR,NVAR,9)
    END IF
C
    IF (ANSR.EQ.1) THEN
        WRITE (TERMOT,30) (FDNAME(I),I=1,OMEGA)
30  FORMAT(' ',A13)
    ENDIF
C
49  WRITE (TERMOT,50)
50  FORMAT (' ',/, ' ENTER A SINGLE FOOD NAME')
    READ (TERMIN,55) LINE
55  FORMAT (A80)
C
    IF (LINE(1:1).EQ.'?') THEN
        CALL DESCRT (LINE,49)
    ELSE
        WHICH = LINE(1:13)
    END IF
C
    DO 57 I=1,OMEGA
        IF (WHICH.EQ.FDNAME(I)) THEN
            FOOD=I
            GO TO 35
        ENDIF
57  CONTINUE
C
    WRITE (TERMOT,60)
60  FORMAT (' ', 'FOOD NOT IN LIBRARY',/)
    GO TO 9
C
35  WRITE (TERMOT,40) WHICH
40  FORMAT (' ', 'WOULD YOU LIKE A LIST OF THE VARIABLES AND THEIR
XDEFAULT VALUES FOR',/, ' ',A13, ' IN THE LIBRARY, ENTER 1 FOR YES,
X0 FOR NO')
    READ (TERMIN,45) LINE
45  FORMAT (A80)
C
C IF ? THEN GETS DESCRIPTION OF VARIABLE
    IF (LINE(1:1).EQ.'?') THEN
        CALL DESCRT (LINE,35)
    ELSE
        MODE = 1
        NVAR = 1
C RETURNS ANSR
        CALL MFREIN (LINE,MODE,ANSR,NVAR,35)
    END IF
C
C
    IF (ANSR.EQ.1) THEN
C
70  DO 74 I=1, LAST

```

```

71         WRITE (TERMOT,71)VRNAME(I),DEFVAL(I,FOOD)
74         FORMAT (' ',A6,4X,F5.1)
C         CONTINUE
C
C         ENDIF
C
C         DO 75 VAL = 1, LAST
75         USRVAL (VAL,FOOD) = DEFVAL (VAL,FOOD)
C         CONTINUE
C
77         WRITE (TERMOT,80)
80         FORMAT (' ','WOULD YOU LIKE TO CHANGE A DEFAULT VALUE,1=YES,0
X=NO')
85         READ (TERMIN,85) LINE
C         FORMAT (A80)
C
C         IF (LINE(1:1).EQ.'?') THEN
C             CALL DESCRT (LINE,77)
C         ELSE
C             MODE = 1
C             NVAR = 1
C             CALL MFREIN (LINE,MODE,ANSR,NVAR,77)
C         END IF
C
C
C
C         IF (ANSR.EQ.1) THEN
89         WRITE (TERMOT,90)
90         FORMAT (' ','WHICH VARIABLE?')
95         READ (TERMIN,95) LINE
C         FORMAT (A80)
C
C         IF (LINE(1:1).EQ.'?') THEN
C             CALL DESCRT (LINE,89)
C         ELSE
C             THIS = LINE(1:6)
C         END IF
C
C
C
98         WRITE (TERMOT,100)
100        FORMAT (' ','ENTER VALUE')
101        READ (TERMIN,101) LINE
C         FORMAT (A80)
C
C         IF (LINE(1:1).EQ.'?') THEN
C             CALL DESCRT (LINE,98)
C         ELSE
C             MODE = 0
C             CALL MFREIN (LINE,MODE,NUMBER,NVAR,98)
C         END IF
C
C
C         DO 110 I=1,OMEGA
C             IF (THIS.EQ.VRNAME(I)) THEN
C                 USRVAL (I,FOOD)=NUMBER
C                 GO TO 77
C             ENDIF
C
C
110        CONTINUE
C

```



```

C ERROR ROUTINE
  WRITE (TERMOT,115)
115  FORMAT (' ', 'VARIABLE NOT IN FILE')
  GO TO 35
  ENDIF
C
C VARIABLES SET TO DEFAULT OR USER DEFINED VALUES
  THJ=USRVAL(1,FOOD)
  TBDJ=USRVAL(2,FOOD)
  TBFJ=USRVAL(3,FOOD)
  EBDJ=USRVAL(4,FOOD)
  EBFJ=USRVAL(5,FOOD)
  MCONST = USRVAL(6,FOOD)
C
139  WRITE (TERMOT,140),FDNAME(FOOD)
140  FORMAT (' ', 'TO RUN PROGRAM ENTER DAILY REQUIRMENT OF ',A13,/,
X' IN GRAMS')
  READ (TERMIN,141) LINE
141  FORMAT (A80)
C
  IF (LINE(1:1).EQ.'?') THEN
    CALL DESCRT(LINE,139)
  ELSE
    MODE = 0
    CALL MFREIN(LINE,MODE,AMOUNT,NVAR,139)
  ENDIF
C
C EQUASIONS FOR CALCULATIONS
  REJ = AMOUNT
  WEJ = 1 - EBDJ / EBFJ
  WWJ = 1 - ((TBDJ - EBDJ) / (TBFJ - EBFJ))
  EBJ = EBFJ / TBFJ
  PJ = TBFJ
  WBJ = WEJ * EBJ + WWJ * (1-EBJ)
  ABJ = REJ / (PJ * EBJ)
  BOJ = REJ / EBJ
  MBJ = (BOJ * THJ / 2) / 1000.
  RWJ = BOJ * (1-EBJ)
  HARWWJ = RWJ * WWJ
C
  WRITE (TERMOT,145)
145  FORMAT (' ', 'FOOD',10X,'REJ',5X,'TH',
X 4X,'TBDJ',3X,'TBFJ',3X,'EBDJ',
X3X,'EBFJ',3X,'EBJ',3X,'BOJ',5X,'ABJ',3X,'WEJ')
  WRITE(TERMOT,150) FDNAME(FOOD),REJ,THJ,TBDJ,
X TBFJ,EBDJ,EBFJ,EBJ,BOJ
X,ABJ,WEJ
150  FORMAT (' ',A13,F5.1,2X,F5.0,2X,4(F5.1,2X),F4.3,1X,F7.1,
X1X,F6.2,1X,F4.3)
C
  RETURN
  END
C
C
C
  SUBROUTINE BREAK
C THIS SUBROUTINE PERFORMS BREAKEVEN CALCULATIONS

```

C

```
REAL DEFVAL(6,11),NUMBER,AMOUNT,GENVAR(6,2),USRVAL(6,11),TR,  
X MCONST,TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,  
XWWJ,EBJ,PJ,WBJ,ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,  
X MTRJ,MTP,MWT,MPS,NP,TBE  
CHARACTER*13 FDNAME(11),WHICH  
CHARACTER*80 LINE  
CHARACTER*6 VRNAME(6),GENAME(6),THIS  
LOGICAL*1 FINISH,COMBND,POPULN  
INTEGER OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFAULT,USER  
COMMON/REAL1/DEFVAL,NUMBER,AMOUNT,GENVAR,USRVAL,TR,MCONST,  
*TBDJ,TBFJ,EBDJ,EBFJ,WEJ,MBD,MPSC,MA,MAS,MFP,MH,WWJ,EBJ,PJ,WBJ,  
*ABJ,REJ,BOJ,THJ,RWJ,MBJ,TOTMBJ,TOTMFP,MTRJ,MTP,MWT,MPS,NP,TBE  
COMMON/CHAR2/FDNAME,WHICH,LINE,VRNAME,GENAME,THIS  
COMMON/LOG4/FINISH,COMBND,POPULN  
COMMON/INT3/OMEGA,VAL,FOOD,TERMOT,TERMIN,ANSR,LAST,DEFAULT,USER
```

C

```
179 WRITE (TERMOT,180)  
180 FORMAT(' ','DO YOU WISH A LIST OF VARIABLES AND DEFAULT VALUES,  
X0=NO,1=YES')  
READ (TERMIN,185) LINE  
185 FORMAT(A80)
```

C

```
IF (LINE(1:1).EQ.'?') THEN  
CALL DESCRT (LINE,179)  
ELSE  
MODE = 1  
CALL MFREIN (LINE,MODE,ANSR,NVAR,179)  
END IF
```

C

```
IF (ANSR.EQ.1) THEN  
DO 210 I=1,LAST  
WRITE (TERMOT,195) GENAME(I),GENVAR(I,DEFAULT)  
195 FORMAT (' ',A6,3X,F6.2)  
210 CONTINUE  
ENDIF
```

C

```
C SETS DEFAULT VALUES TO USER VALUES  
DO 220 I=1,LAST  
GENVAR(I,USER)=GENVAR(I,DEFAULT)  
220 CONTINUE
```

C

```
225 WRITE (TERMOT,230)  
230 FORMAT(' ','DO YOU WISH TO CHANGE THE VALUE OF A VARIABLE,  
X1=YES,0=NO')  
READ (TERMOT,240) LINE  
240 FORMAT (A80)
```

C

```
IF (LINE(1:1).EQ.'?') THEN  
CALL DESCRT (LINE,225)  
ELSE  
MODE = 1  
CALL MFREIN (LINE,MODE,ANSR,NVAR,225)  
END IF
```

C

```
IF (ANSR.EQ.1) THEN  
249 WRITE (TERMOT,250)
```

```

250     FORMAT (' ','WHICH VARIABLE')
      READ (TERMIN,260) LINE
260     FORMAT (A80)
C
      IF (LINE(1:1).EQ.'?') THEN
        CALL DESCRT (LINE,249)
      ELSE
        THIS = LINE(1:6)
      END IF
C
269     WRITE (TERMOT,270)
270     FORMAT (' ','ENTER VALUE')
      READ (TERMIN,272) LINE
272     FORMAT (A80)
C
      IF (LINE(1:1).EQ.'?') THEN
        CALL DESCRT (LINE,269)
      ELSE
        MODE = 0
        CALL MFREIN (LINE,MODE,NUMBER,NVAR,269)
      END IF
C
      DO 280 I=1, LAST
        IF (THIS.EQ.GENNAME(I)) THEN
          GENVAR(I,USER)=NUMBER
          GO TO 225
        ENDIF
280     CONTINUE
C
      WRITE (TERMOT,285)
285     FORMAT (' ','VARIABLE NOT IN FILE')
      GO TO 179
      ENDIF
C
C SETS VARIABLES EQUAL TO USER VALUES
      TR = GENVAR(1,USER)
      MFP = GENVAR(2,USER)
      MH = GENVAR(3,USER)
      MPSC = GENVAR(4,USER)
      MA = GENVAR(5,USER)
      MAS = GENVAR(6,USER)
C
C IF THE PLANT COMBINATION IS NOT COMPLETED
      IF (.NOT.FINISH) THEN
        MBD = MBJ * MCONST
        MTRJ = (EBDJ * 365.25 * 1.53 * ABJ) /1000.
      END IF
C
C EQUASIONS FOR BREAKEVEN CALCULATIONS
      MPS = (MPSC) + (MAS * (ABJ * NP) ** .6) + (MA * ABJ * NP)
      MWT = 10. * MBD * NP * TR
      TOTMFP = MFP * (NP /10.) ** .415
      TOTMB = NP * MBJ
      MTP = TOTMB + MH + TOTMFP + MPS + MWT
      TBE = MTP / (MTRJ * NP)
C
      WRITE (TERMOT,290)

```

```

290  FORMAT (' ',3X,'FOOD',28X,'MTRJ',5X,'MB',8X,'MPS',8X,'MWT',6X,
      X'TBE',/)
      WRITE (TERMOT,200) FDNAME(FOOD),MTRJ,MBJ,MPS,MWT,TBE
200  FORMAT (' ',3X,A13,18X,F6.2,2X,F7.3,2X,F8.1,2X,F8.1,2X,F7.1,/)
C
      RETURN
      END
C
      SUBROUTINE DESCRT(LINE,*)
C THIS SUBROUTINE RETURNS THE DESCRIPTION OF ANY VARIABLE WHEN A '?'
C VARIABLE NAME IS ENTERED
C
      CHARACTER*80 LINE
      CHARACTER*90 RECORD
      CHARACTER*6 VARBLE
      CHARACTER*83 SCRIPT
      INTEGER FILE,TERMOT
C
      FILE = 10
      TERMOT = 6
C
C READS THE FILE THAT CONTAINS DESCRIPTIONS
5      READ (FILE,10,END=25) VARBLE,SCRIPT
10     FORMAT (A6,1X,A83)
C
C COMPARES WITH FILE TO FIND DESCRIPTION
      IF (LINE(2:7).EQ.VARBLE) THEN
15         WRITE (TERMOT,15) VARBLE,SCRIPT
            FORMAT (' ',A6,3X,A83)
            GO TO 40
C
C READS ANOTHER
      ELSE
            GO TO 5
C
      END IF
C
C ERROR ROUTINE
25     WRITE (TERMOT,30)
30     FORMAT (' ','DESCRIPTION OF VARIABLE NOT FOUND')
C
C SETS POINTER AT BEGINNING OF FILE
40     REWIND FILE
            RETURN
            END

```

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16. Abstract This report considers a model of the relative mass requirements of food production components in a controlled ecological life support system (CELSS) based on regenerative concepts. Included are a discussion of model scope, structure, and example calculations. The report is intended to serve as a working paper which can provide a basis for further model development and analysis. Computer programs for cultivar and breakeven calculations are included.					
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