A Equation Notation

The equations as printed in Chapter 3 and Appendix B are written in the notation for the DYNAMO compiler. For complete information see the *DYNAMO User's Manual* by Alexander L. Pugh, III, third edition, M.I.T. Press, Cambridge, Massachusetts, 1970.

The letters J, K, and L following a decimal point that separates the letters from the symbol groups representing variables are time-step indicators. The "present" time at which the equation is being evaluated is called time K. The previous point in time was J, the next is L. In rate equations, the JK notation indicates the rate that existed over the preceding time interval, and KL indicates the rate of flow that is being computed for the following time interval.

Variables and constants are designated by letter groups as defined in Appendix C.

Before the equation in Appendix B and after the equation number in Chapter 3 is a letter indicating the kind of concept that is defined by the equation. The letter L indicates a level equation, N an initial value for a level, R a rate equation, A an auxiliary variable that is part of the rate equation it feeds, C a constant, T a table, and X indicates a continuation from the preceding line.

In several equations, for example Equation 2, will be found the CLIP function. It is used here as a switch to change the value of a constant at a specified point in time. In Equation 2, the value BRN is used until TIME reaches the value specified by SWT1 after which the value is changed to that given by BRN1. The several CLIP functions are used in producing the computer runs in this book.

TABLE and TABHL are table look-up functions as for example in Equation 3. In that equation the format indicates that a table by the name of BRMMT will be entered with the variable MSL. The table extends from a value of MSL of 0 to a value of 5 in steps of 1 unit in MSL. The following line gives the required six values for the table as graphically portrayed in Figure 3-1.

B Equations of the World Model

The following equations and control information are in the exact format used by the DYNAMO compiler for producing the computer output used in this book.

```
        *           WORLD DYNAMICS W5
 1      L      P.K=P.J+(DT)(BR.JK-DR.JK)
 1.1    N      P=P1
 1.2    C      P1=1.65E9
 2      R      BR.KL=(P.K)(CLIP(BRN,BRN1,SWT1,TIME.K))(BRFM.K)(BRMM.K)(BRCM.K)(BR
        X      PM.K)
 2.2    C      BRN=.04
 2.3    C      BRN1=.04
.2.4    C      SWT1=1970
 3      A      BRMM.K=TABHL(BRMMT,MSL.K,0,5,1)
 3.1    T      BRMMT=1.2/1/.85/.75/.7/.7
 4      A      MSL.K=ECIR.K/(ECIRN)
 4.1    C      ECIRN=1
 5      A      ECIR.K=(CIR.K)(1-CIAF.K)(NREM.K)/(1-CIAFN)
 6      A      NREM.K=TABLE(NREMT,NRFR.K,0,1,.25)
 6.1    T      NREMT=0/.15/.5/.85/1
 7      A      NRFR.K=NR.K/NRI
 8      L      NR.K=NR.J+(DT)(-NRUR.JK)
 8.1    N      NR=NRI
 8.2    C      NRI=900E9
 9      R      NRUR.KL=(P.K)(CLIP(NRUN,NRUN1,SWT2,TIME.K))(NRMM.K)
 9.1    C      NRUN=1
 9.2    C      NRUN1=1
 9.3    C      SWT2=1970
        NOTE        EQUATION 42 CONNECTS HERE FROM EQ. 4 TO EQ. 9
10      R      DR.KL=(P.K)(CLIP(DRN,DRN1,SWT3,TIME.K))(DRMM.K)(DRPM.K)(DRFM.K)(DR
        X      CM.K)
10.2    C      DRN=.028
10.3    C      DRN1=.028
10.4    C      SWT3=1970
11      A      DRMM.K=TABHL(DRMMT,MSL.K,0,5,.5)
11.1    T      DRMMT=3/1.8/1/.8/.7/.6/.53/.5/.5/.5/.5
12      A      DRPM.K=TABLE(DRPMT,POLR.K,0,60,10)
12.1    T      DRPMT=.92/1.3/2/3.2/4.8/6.8/9.2
13      A      DRFM.K=TABHL(DRFMT,FR.K,0,2,.25)
13.1    T      DRFMT=30/3/2/1.4/1/.7/.6/.5/.5
14      A      DRCM.K=TABLE(DRCMT,CR.K,0,5,1)
14.1    T      DRCMT=.9/1/1.2/1.5/1.9/3
15      A      CR.K=(P.K)/(LA*PDN)
15.1    C      LA=135E6
15.2    C      PDN=26.5
16      A      BRCM.K=TABLE(BRCMT,CR.K,0,5,1)
16.1    T      BRCMT=1.05/1/.9/.7/.6/.55
17      A      BRFM.K=TABHL(BRFMT,FR.K,0,4,1)
17.1    T      BRFMT=0/1/1.6/1.9/2
```

```
18      A       BRPM.K=TABLE(BRPMT,POLR.K,0,60,10)
18.1    T       BRPMT=1.02/.9/.7/.4/.25/.15/.1
19      A       FR.K=(FPCI.K)(FCM.K)(FPM.K)(CLIP(FC,FC1,SWT7,TIME.K))/FN
19.1    C       FC=1
19.2    C       FC1=1
19.3    C       FN=1
19.4    C       SWT7=1970
20      A       FCM.K=TABLE(FCMT,CR.K,0,5,1)
20.1    T       FCMT=2.4/1/.6/.4/.3/.2
21      A       FPCI.K=TABHL(FPCIT,CIRA.K,0,6,1)
21.1    T       FPCIT=.5/1/1.4/1.7/1.9/2.05/2.2
22      A       CIRA.K=(CIR.K)(CIAF.K)/CIAFN
22.1    C       CIAFN=.3
23      A       CIR.K=CI.K/P.K
24      L       CI.K=CI.J+(DT)(CIG.JK-CID.JK)
24.1    N       CI=CII
24.2    C       CII=.4E9
25      R       CIG.KL=(P.K)(CIM.K)(CLIP(CIGN,CIGN1,SWT4,TIME.K))
25.1    C       CIGN=.05
25.2    C       CIGN1=.05
25.3    C       SWT4=1970
26      A       CIM.K=TABHL(CIMT,MSL.K,0,5,1)
26.1    T       CIMT=.1/1/1.8/2.4/2.8/3
27      R       CID.KL=(CI.K)(CLIP(CIDN,CIDN1,SWT5,TIME.K))
27.1    C       CIDN=.025
27.2    C       CIDN1=.025
27.3    C       SWT5=1970
28      A       FPM.K=TABLE(FPMT,POLR.K,0,60,10)
28.1    T       FPMT=1.02/.9/.65/.35/.2/.1/.05
29      A       POLR.K=POL.K/POLS
29.1    C       POLS=3.6E9
30      L       POL.K=POL.J+(DT)(POLG.JK-POLA.JK)
30.1    N       POL=POLI
30.2    C       POLI=.2E9
31      R       POLG.KL=(P.K)(CLIP(POLN,POLN1,SWT6,TIME.K))(POLCM.K)
31.1    C       POLN=1
31.2    C       POLN1=1
31.3    C       SWT6=1970
32      A       POLCM.K=TABHL(POLCMT,CIR.K,0,5,1)
32.1    T       POLCMT=.05/1/3/5.4/7.4/8
33      R       POLA.KL=POL.K/POLAT.K
34      A       POLAT.K=TABLE(POLATT,POLR.K,0,60,10)
34.1    T       POLATT=.6/2.5/5/8/11.5/15.5/20
35      L       CIAF.K=CIAF.J+(DT/CIAFT)(CFIFR.J*CIQR.J-CIAF.J)
35.1    N       CIAF=CIAFI
35.2    C       CIAFI=.2
35.3    C       CIAFT=15
36      A       CFIFR.K=TABHL(CFIFRT,FR.K,0,2,.5)
36.1    T       CFIFRT=1/.6/.3/.15/.1
37      S       QL.K=(QLS)(QLM.K)(QLC.K)(QLF.K)(QLP.K)
37.1    C       QLS=1
38      A       QLM.K=TABHL(QLMT,MSL.K,0,5,1)
38.1    T       QLMT=.2/1/1.7/2.3/2.7/2.9
39      A       QLC.K=TABLE(QLCT,CR.K,0,5,.5)
39.1    T       QLCT=2/1.3/1/.75/.55/.45/.38/.3/.25/.22/.2
40      A       QLF.K=TABHL(QLFT,FR.K,0,4,1)
40.1    T       QLFT=0/1/1.8/2.4/2.7
41      A       QLP.K=TABLE(QLPT,POLR.K,0,60,10)
41.1    T       QLPT=1.04/.85/.6/.3/.15/.05/.02
        NOTE        EQUATION 42 LOCATED BETWEEN EQ. 4 AND 9.
42      A       NRMM.K=TABHL(NRMMT,MSL.K,0,10,1)
42.1    T       NRMMT=0/1/1.8/2.4/2.9/3.3/3.6/3.8/3.9/3.95/4
        NOTE        INPUT FROM EQN. 38 AND 40 TO EQN. 35
43      A       CIQR.K=TABHL(CIQRT,QLM.K/QLF.K,0,2,.5)
43.1    T       CIQRT=.7/.8/1/1.5/2
        NOTE
        NOTE    CONTROL CARDS
        NOTE
43.5    C       DT=.2
43.6    C       LENGTH=2100
43.7    N       TIME=1900
44      A       PRTPER.K=CLIP(PRTP1,PRTP2,PRSWT,TIME.K)
44.1    C       PRTP1=0
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```
44.2    C       PRTP2=0
44.3    C       PRSWT=0
45      A       PLTPER.K=CLIP(PLTP1,PLTP2,PLSWT,TIME.K)
45.1    C       PLTP1=4
45.2    C       PLTP2=4
45.3    C       PLSWT=0
        PLOT    P=P(0,8E9)/POLR=2(0,40)/CI=C(0,20E9)/QL=Q(0,2)/NR=N(0,1000E9)
        PLOT    FR=F,MSL=M,QLC=4,QLP=5(0,2)/CIAF=A(.2,.6)
        RUN     ORIG
```

C Definitions of Terms

Following are the definitions of the letter groups used to identify variables and constants in the model equations.

```
BR        BIRTH RATE (PEOPLE/YEAR)
BRCM      BIRTH-RATE-FROM-CROWDING MULTIPLIER (DIMENSIONLESS)
BRCMT     BIRTH-RATE-FROM-CROWDING-MULTIPLIER TABLE
BRFM      BIRTH-RATE-FROM-FOOD MULTIPLIER (DIMENSIONLESS)
BRFMT     BIRTH-RATE-FROM-FOOD-MULTIPLIER TABLE
BRMM      BIRTH-RATE-FROM-MATERIAL MULTIPLIER (DIMENSIONLESS)
BRMMT     BIRTH-RATE-FROM-MATERIAL-MULTIPLIER TABLE
BRN       BIRTH RATE NORMAL (FRACTION/YEAR)
BRN1      BIRTH RATE NORMAL NO. 1 (FRACTION/YEAR)
BRPM      BIRTH-RATE-FROM-POLLUTION MULTIPLIER (DIMENSIONLESS)
BRPMT     BIRTH-RATE-FROM-POLLUTION-MULTIPLIER TABLE
CFIFR     CAPITAL FRACTION INDICATED BY FOOD RATIO (DIMENSIONLESS)
CFIFRT    CAPITAL-FRACTION-INDICATED-BY-FOOD-RATIO TABLE
CI        CAPITAL INVESTMENT (CAPITAL UNITS)
CIAF      CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION (DIMENSIONLESS)
CIAFI     CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION, INITIAL
               (DIMENSIONLESS)
CIAFN     CAPITAL-INVESTMENT-IN-AGRICULTURE FRACTION NORMAL
               (DIMENSIONLESS)
CIAFT     CAPITAL-INVESTMENT-IN-AGRICULTURE-FRACTION ADJUSTMENT TIME
               (YEARS)
CID       CAPITAL-INVESTMENT DISCARD (CAPITAL UNITS/YEAR)
CIDN      CAPITAL-INVESTMENT DISCARD NORMAL (FRACTION/YEAR)
CIDN1     CAPITAL-INVESTMENT DISCARD NORMAL NO. 1 (FRACTION/YEAR)
CIG       CAPITAL-INVESTMENT GENERATION (CAPITAL UNITS/YEAR)
CIGN      CAPITAL-INVESTMENT GENERATION NORMAL
               (CAPITAL UNITS/PERSON/YEAR)
CIGN1     CAPITAL-INVESTMENT GENERATION NORMAL NO. 1
               (CAPITAL UNITS/PERSON/YEAR)
CII       CAPITAL INVESTMENT, INITIAL (CAPITAL UNITS)
CIM       CAPITAL-INVESTMENT MULTIPLIER (DIMENSIONLESS)
CIMT      CAPITAL-INVESTMENT-MULTIPLIER TABLE
CIQR      CAPITAL-INVESTMENT-FROM-QUALITY RATIO (DIMENSIONLESS)
CIQRT     CAPITAL-INVESTMENT-FROM-QUALITY-RATIO TABLE
CIR       CAPITAL-INVESTMENT RATIO (CAPITAL UNITS/PERSON)
CIRA      CAPITAL-INVESTMENT RATIO IN AGRICULTURE
               (CAPITAL UNITS/PERSON)
CLIP      LOGICAL FUNCTION USED AS A TIME SWITCH TO CHANGE
               PARAMETER VALUE
CR        CROWDING RATIO (DIMENSIONLESS)
DR        DEATH RATE (PEOPLE/YEAR)
DRCM      DEATH-RATE-FROM-CROWDING MULTIPLIER (DIMENSIONLESS)
DRCMT     DEATH-RATE-FROM-CROWDING-MULTIPLIER TABLE
DRFM      DEATH-RATE-FROM-FOOD MULTIPLIER (DIMENSIONLESS)
DRFMT     DEATH-RATE-FROM-FOOD-MULTIPLIER TABLE
```

```
DRMM      DEATH-RATE-FROM-MATERIAL MULTIPLIER (DIMENSIONLESS)
DRMMT     DEATH-RATE-FROM-MATERIAL-MULTIPLIER TABLE
DRN       DEATH RATE NORMAL (FRACTION/YEAR)
DRN1      DEATH RATE NORMAL NO. 1 (FRACTION/YEAR)
DRPM      DEATH-RATE-FROM-POLLUTION MULTIPLIER (DIMENSIONLESS)
DRPMT     DEATH-RATE-FROM-POLLUTION-MULTIPLIER TABLE
ECIR      EFFECTIVE-CAPITAL-INVESTMENT RATIO (CAPITAL UNITS/PERSON)
ECIRN     EFFECTIVE-CAPITAL-INVESTMENT RATIO NORMAL
               (CAPITAL UNITS/PERSON)
FC        FOOD COEFFICIENT (DIMENSIONLESS)
FC1       FOOD COEFFICIENT NO. 1 (DIMENSIONLESS)
FCM       FOOD-FROM-CROWDING MULTIPLIER (DIMENSIONLESS)
FCMT      FOOD-FROM-CROWDING-MULTIPLIER TABLE
FN        FOOD NORMAL (FOOD UNITS/PERSON/YEAR)
FPCI      FOOD POTENTIAL FROM CAPITAL INVESTMENT
               (FOOD UNITS/PERSON/YEAR)
FPCIT     FOOD-POTENTIAL-FROM-CAPITAL-INVESTMENT TABLE
FPM       FOOD-FROM-POLLUTION MULTIPLIER (DIMENSIONLESS)
FPMT      FOOD-FROM-POLLUTION-MULTIPLIER TABLE
FR        FOOD RATIO (DIMENSIONLESS)
LA        LAND AREA (SQUARE KILOMETERS)
MSL       MATERIAL STANDARD OF LIVING (DIMENSIONLESS)
NR        NATURAL RESOURCES (NATURAL RESOURCE UNITS)
NREM      NATURAL-RESOURCE-EXTRACTION MULTIPLIER (DIMENSIONLESS)
NREMT     NATURAL-RESOURCE-EXTRACTION-MULTIPLIER TABLE
NRFR      NATURAL-RESOURCE FRACTION REMAINING (DIMENSIONLESS)
NRI       NATURAL RESOURCES, INITIAL (NATURAL-RESOURCE UNITS)
NRMM      NATURAL-RESOURCE-FROM-MATERIAL MULTIPLIER (DIMENSIONLESS)
NRMMT     NATURAL-RESOURCE-FROM-MATERIAL-MULTIPLIER TABLE
NRUN      NATURAL-RESOURCE USAGE NORMAL
               (NATURAL RESOURCE UNITS/PERSON/YEAR)
NRUN1     NATURAL-RESOURCE USAGE NORMAL NO. 1
               (NATURAL RESOURCE UNITS/PERSON/YEAR)
NRUR      NATURAL-RESOURCE-USAGE RATE (NATURAL RESOURCE UNITS/YEAR)
P         POPULATION (PEOPLE)
PDN       POPULATION DENSITY NORMAL (PEOPLE/SQUARE KILOMETER)
PI        POPULATION, INITIAL (PEOPLE)
PLSWT     PLOT SWITCH TIME (YEARS)
PLTP1     PLOT PERIOD NO. 1 (YEARS)
PLTP2     PLOT PERIOD NO. 2 (YEARS)
PLTPER    PLOT PERIOD (YEARS)
POL       POLLUTION (POLLUTION UNITS)
POLA      POLLUTION ABSORPTION (POLLUTION UNITS/YEAR)
POLAT     POLLUTION-ABSORPTION TIME (YEARS)
POLATT    POLLUTION-ABSORPTION-TIME TABLE
POLCM     POLLUTION-FROM-CAPITAL MULTIPLIER (DIMENSIONLESS)
POLCMT    POLLUTION-FROM-CAPITAL-MULTIPLIER TABLE
POLG      POLLUTION GENERATION (POLLUTION UNITS/YEAR)
POLI      POLLUTION, INITIAL (POLLUTION UNITS)
POLN      POLLUTION NORMAL (POLLUTION UNITS/PERSON/YEAR)
POLN1     POLLUTION NORMAL NO. 1 (POLLUTION UNITS/PERSON/YEAR)
POLR      POLLUTION RATIO (DIMENSIONLESS)
POLS      POLLUTION STANDARD (POLLUTION UNITS)
PRSWT     PRINT SWITCH TIME (YEARS)
PRTP1     PRINT PERIOD NO. 1 (YEARS)
PRTP2     PRINT PERIOD NO. 2 (YEARS)
PRTPER    PRINT PERIOD (YEARS)
QL        QUALITY OF LIFE (SATISFACTION UNITS)
QLC       QUALITY OF LIFE FROM CROWDING (DIMENSIONLESS)
QLCT      QUALITY-OF-LIFE-FROM-CROWDING TABLE
QLF       QUALITY OF LIFE FROM FOOD (DIMENSIONLESS)
QLFT      QUALITY-OF-LIFE-FROM-FOOD TABLE
QLM       QUALITY OF LIFE FROM MATERIAL (DIMENSIONLESS)
QLMT      QUALITY-OF-LIFE-FROM-MATERIAL TABLE
QLP       QUALITY OF LIFE FROM POLLUTION (DIMENSIONLESS)
QLPT      QUALITY-OF-LIFE-FROM-POLLUTION TABLE
QLS       QUALITY-OF-LIFE STANDARD (SATISFACTION UNITS)
SWT1      SWITCH TIME NO. 1 FOR BRN (YEARS)
SWT2      SWITCH TIME NO. 2 FOR NRUN (YEARS)
SWT3      SWITCH TIME NO. 3 FOR DRN (YEARS)
SWT4      SWITCH TIME NO. 4 FOR CIGN (YEARS)
SWT5      SWITCH TIME NO. 5 FOR CIDN (YEARS)
SWT6      SWITCH TIME NO. 6 FOR POLN (YEARS)
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SWT7       SWITCH TIME NO. 7 FOR FC (YEARS)
TABHL      LOGICAL FUNCTION, TABLE LOOK UP AND INTERPOLATION
TABLE      LOGICAL FUNCTION, TABLE LOOK UP AND INTERPOLATION
TIME       CALENDAR TIME (YEARS)
```