Computer Science and Systems Analysis Technical Reports

Miami University *Year* 1987

A Simple System Dynamics Model For the Wildlife and Fish Resource

Raman Barlas
Miami University, commons-admin@lib.muohio.edu

MIAMI UNIVERSITY

DEPARTMENT OF COMPUTER SCIENCE & SYSTEMS ANALYSIS

TECHNICAL REPORT: MU-SEAS-CSA-1987-004

A Simple System Dynamics Model for the Wildlife and Fish Resource

Yaman Barlas

School of Engineering & Applied Science | Oxford, Ohio 45056 | 513-529-5928

A Simple System Dynamics Model
For the Wildlife and Fish Resource

by

Yaman Barlas
Systems Analysis Department
Miami University
Oxford, Ohio 45056

Working Paper #87-004 08/87

I. Introduction

I.1 Research Objectives

This research aims to build a dynamic model to describe the major relationships within the "Wildlife and Fish" element of the Forest Service. Our purpose is to capture the major relationships so that the model is capable of reproducing the dynamic behavior patterns exhibited by the important Wildlife and Fish variables. Such a model should include not only the "physical variables" (such as "acres prescribed burned" or "number of water developments") but also the management decision processes which influence those variables. Once the major "physical relationships" and "decision relationships" are appropriately described in the model, the latter should be able to exhibit the basic dynamic performance patterns observed in the Wildlife and Fish (W&F) sector. Then, such a model can be used as a "management laboratory". It is possible to explicate why and how particular performance patterns are exhibited by certain variables. If some of these performance patterns are undesirable, the model can help managers generate alternative policies to eliminate those undesired patterns. By using such dynamic models for Wildlife & Fish sector it is possible to investigate the medium-to-long-term implications of various alternative management policies.

I.2. Research Procedure

The first step towards building a dynamic model for the W&F sector was the identification of major variables to be included in such a model. A major variable is one which contributes significantly to the creation of the fundamental performance patterns observed for various W&F variables. Our main resources in this step have been the related Forest Service (FS) publications and our conversations with the FS managers and other staff. Valuable information about what the major variables are and how they are interrelated was obtained through these two main sources.

These variables and the interrelationships were displayed qualitatively by means of influence diagrams. The next stage was the actual construction of the model for the W&F sector. In System Dynamics (SD) methodology (a brief description of which was given in Barlas (1), modeling means writing mathematical equations to represent the relationships between the major system elements. The model equations were written under the light of our conversations with the FS managers and various FS publications. This phase also required the estimation of the parameters used in the model equations. Both quantitative and qualitative data from FS publications and from our conversations were used in order to estimate the model parameters. Once the parameters were estimated, the model equations were input as a DYNAMO computer program and then simulated on a digital computer to yield the "model performance patterns". The "model behavior" was then compared to the "observed behavior" of the W&F sector to see whether there was a significant discrepancy between the two. In such cases, the model equations and/or the associated parameter values were modified to remove any significant discrepancy. This procedure was repeated until the model behavior was judged to be reasonably close to the real behavior. Once this stage was reached, the model was accepted as a useful initial description of the W&F sector dynamics but by no means as the final and absolute model of it.

In the next section, we present this model of W&F sector. We start with our conceptual approach to the problem and then give the influence diagrams and the model equations. Finally, we present the behavior patterns exhibited by major W&F model variables.

II. The Model

II.1 Modeling Approach

Our conversations with FS managers and various FS publications seemed to suggest that an effective and useful approach to this modeling problem was to focus on major W&F activities. These activities-called direct habitat improvement-includes:

- Water Development
- Openings Development
- Thinning
- Prescribed Burning
- Seeding and Planting
- Wetland Improvements
- Fish Improvements
- Threatened and Endangered Species Improvement

Besides these activities, there is a group of activities called "coordination", including coordinating on the ground with other sectors such as Timber, Range etc., Training of the Coordination Personnel, Contributing to Land use Planning, Multiple Use Surveys, Environmental Statements, etc.

Thus, modeling consisted of writing equations to describe how decisions about the above activities were made and how these activities changed the physical condition of the land through time. Finally, since all activities depend on availability of funds, our model included a section called "Funds", to account for the fund request and fund acquisition processes.

II.2 Influence Diagrams and Model Equations

As stated in the previous section, the W&F system is modeled around nine major improvement activities and the fund generation process. the influence diagrams focusing on each one of these activities are shown in Figure 1 through 10. In the model these subsystems are not isolated but they are coupled to each other. The influence diagrams are presented separately for each subsystem simply because it was very impractical to try to draw the entire influence diagram in one figure. In the individual diagrams the points of major interaction between subsystems are represented symbolically by "Z-shaped" arrows. We now take each influence diagram and give the corresponding equations which describe the major relationships. A complete list of all model equations is provided in Appendix 1.

Water Development (WD)

Water development is the process of preparing waterholes for wildlife where the water is scarce. Waterholes deteriorate after a certain period of time. Though this "time to deteriorate" varies depending on many conditions, as a result of our conversations with FS managers, we learned that a well-maintained waterhole would last on the average for about 25 years. This process is described by:

WDDR.KL = DELAYP(WDR.JK, WDTD, WDN.K)

WDDR: water development deterioration rate

WDR: yearly water development rate

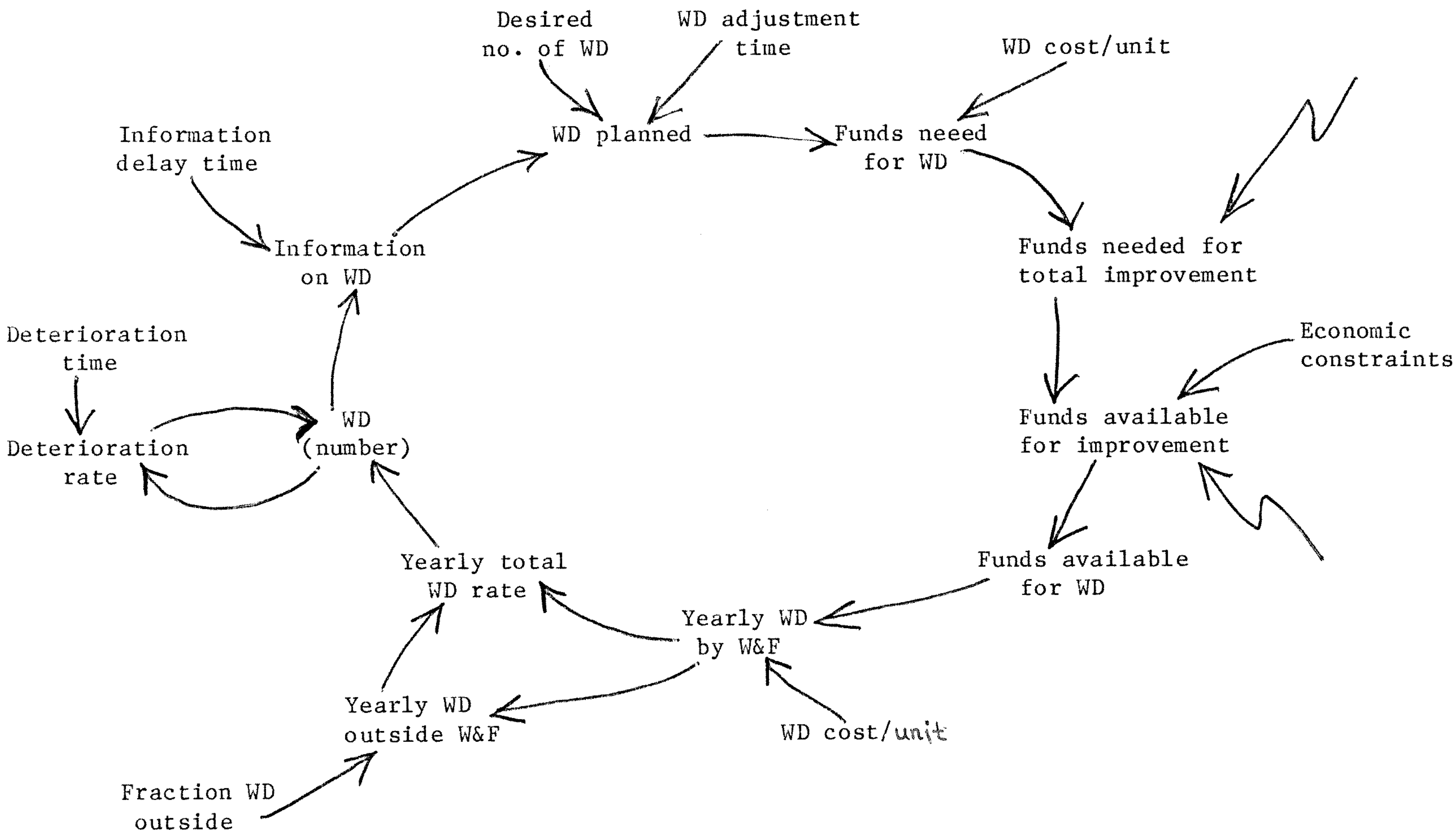


Figure 1. Water Development (WD)

WDTD: WD deterioration time (25 years)

WDN: number of water developments

DELAYP: A dynamo special purpose function used when a variable is caused by another variable after a third order time delay

The decision process by which WD activity is planned is described by the following equations:

WDRP.K = (WDDES.K - WDNI.K)/WDAT + WDNI.K/WDTD

WDRP: WD rate planned

WDDES.K = 15000*(1-0.8*EXP(-0.05*(TIME.K-TIMEN)))

WDDES: desired number of water developments

WDNI.K = SMOOTH(WDN.K, WDST)

WDNI: information on the number of water developments

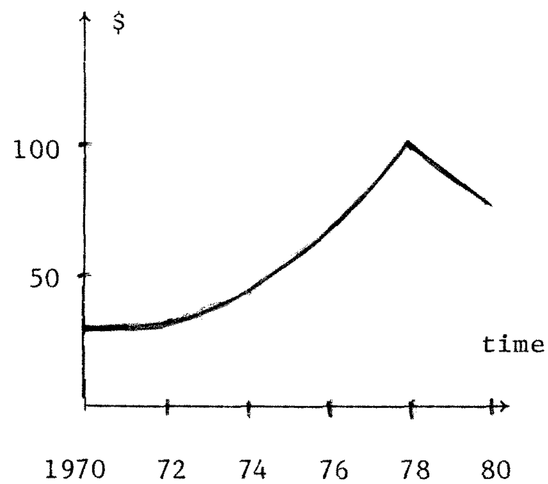
The first equation says that the WD plan depends on the difference between the desired number of water developments (WDDES) and the perceived number of water developments (WDNI). Every year, the WD activity is adjusted by a fraction of this difference ("error"). How much adjustment is made depends on the adjustment time WDAT. The larger the WDAT, the more patient is the planning decision. In the final model run, WDAT was chosen as 10 years.

The second equation says that the desired number of water developments starts from 3000 and increases with time and approaches asymptotically to 15,000. These numbers were estimated based on the best available information from wildlife reports. (The shape of the exponential function used in the WDDES equation is explained in Appendix 2.) The third equation represents the process by which information about the state of water developments is collected. With a WDST of 10 years, the equation states that the information about WD is obtained with an averaging period of 10 years.

Once WD planned is computed, the the funds needed for WD is given by:

FRWD.K = WDC.K*WDRP.K

Where, WDC is the unit cost of WD which is a variable as shown in the following graph (WTAB):



(The effect of inflation is not included in these costs estimates so that all are measured in 1970 dollar value)

Then, the actual yearly WD by W&F sector is:

WDWR.K = FWD.K/WDC.K

Where FWD is the funds available for WD. Its equation will be given later in the "Funds" section. And finally, not all WD is carried by WDF sector:

WDX.K = WDXF*WDWR.K

WDX: WD outside Wildlife & Fish

WDXF = Outside WD fraction (0.10)

Thus, the total yearly WD becomes:

WDR.KL = WDWR.K + WDX.K.

Openings Development (OD):

Openings Development (OD) is the process of providing the wildlife with the necessary openings in the Forest Area. The structure of OD equations is exactly the same as the structure of WD equations explained above. The only change is in the unit of measurement (acres in the case of OD) and in some parameter values. The equations are given in the Appendix and can be easily understood once WD equations are understood.

Thinning (TH)

The structure of Thinning equations is also exactly the same as the previous ones. Therefore, the model listing for this subsytem must be self-explanatory.

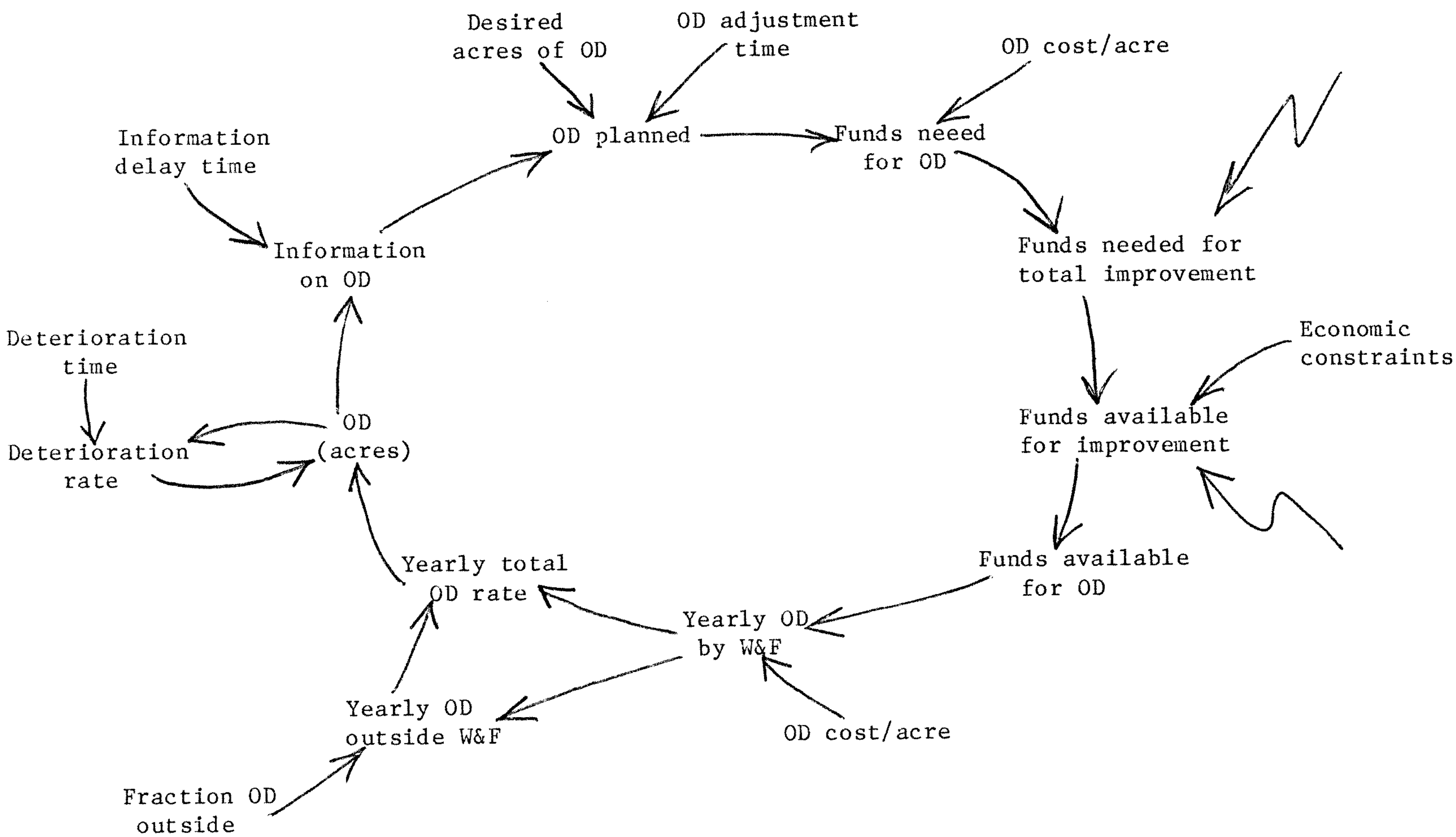


Figure 2. Openings Development (OD)

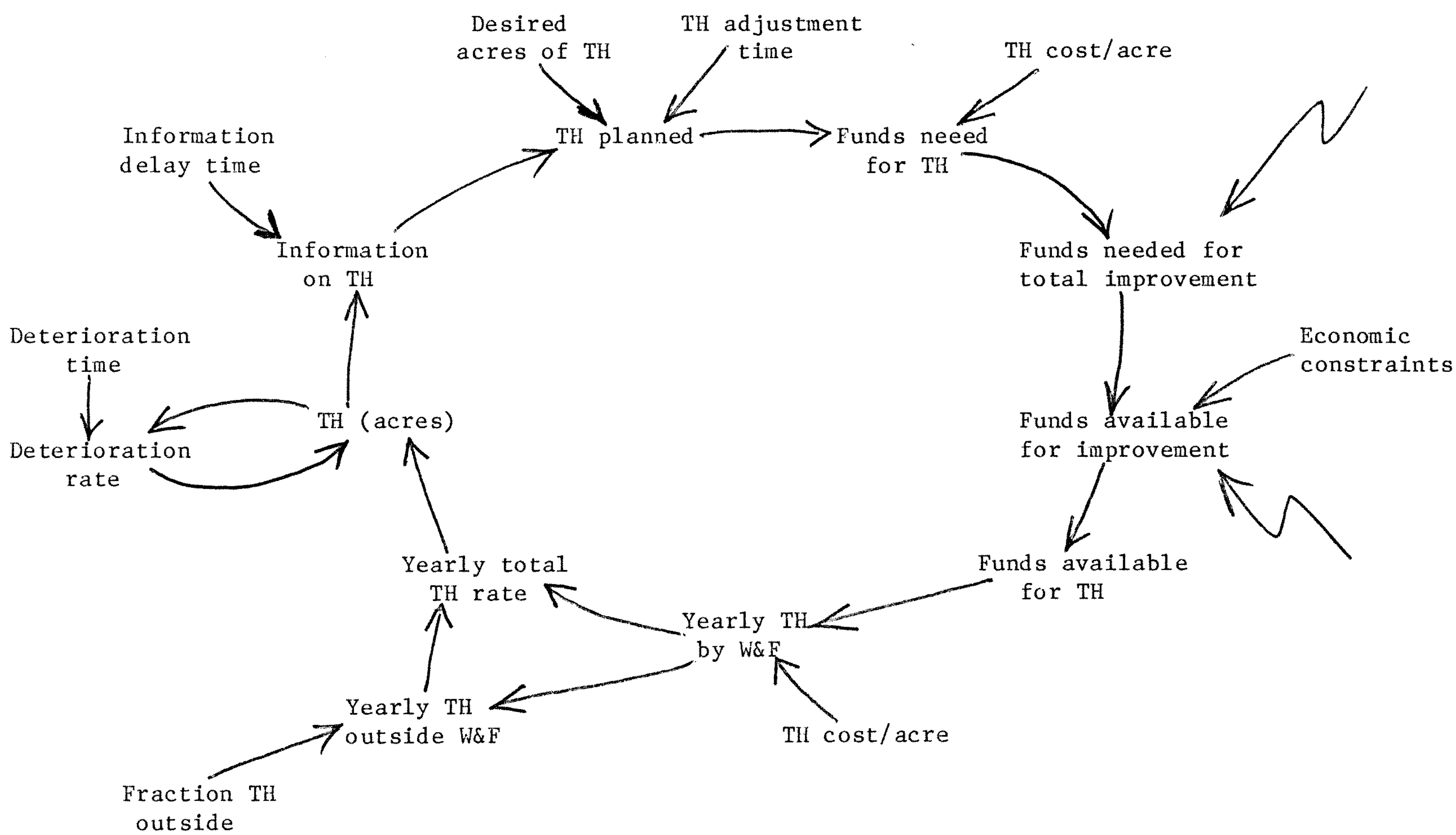


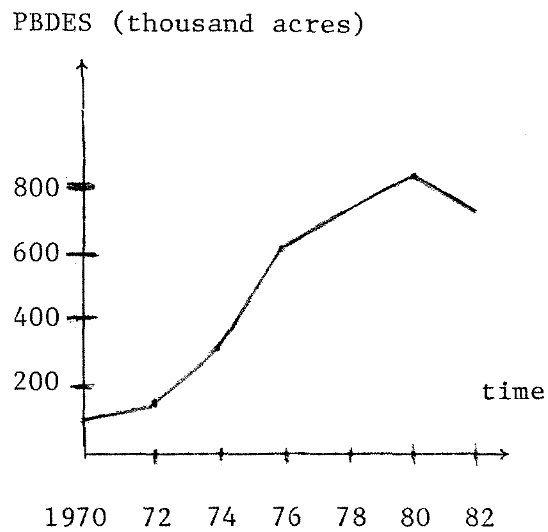
Figure 3. Thinning (TH)

Prescribed Burning (PB)

The structure of PB subsystem is similar to the previous ones. The only difference is in the "desired prescribed burning" (PBDES) equation which is not an asymptotic exponential but a TABLE function:

PBDES.K = TABHL (PBDEST, TIME.K, 1970, 1982,2)

The associated graph is chosen as:



Seeding and Planting (SP)

The equation which describes the planning process for Seeding & Planting has a form different than the previous ones. For this activity, it was more difficult to represent the physical characteristics of the process as third order delay process. It was more convenient to write the planning equation at a higher level of aggregation, without having to trace the acres in "seeded condition". This type of equation deals with "acres/yr" and not with "acres:"

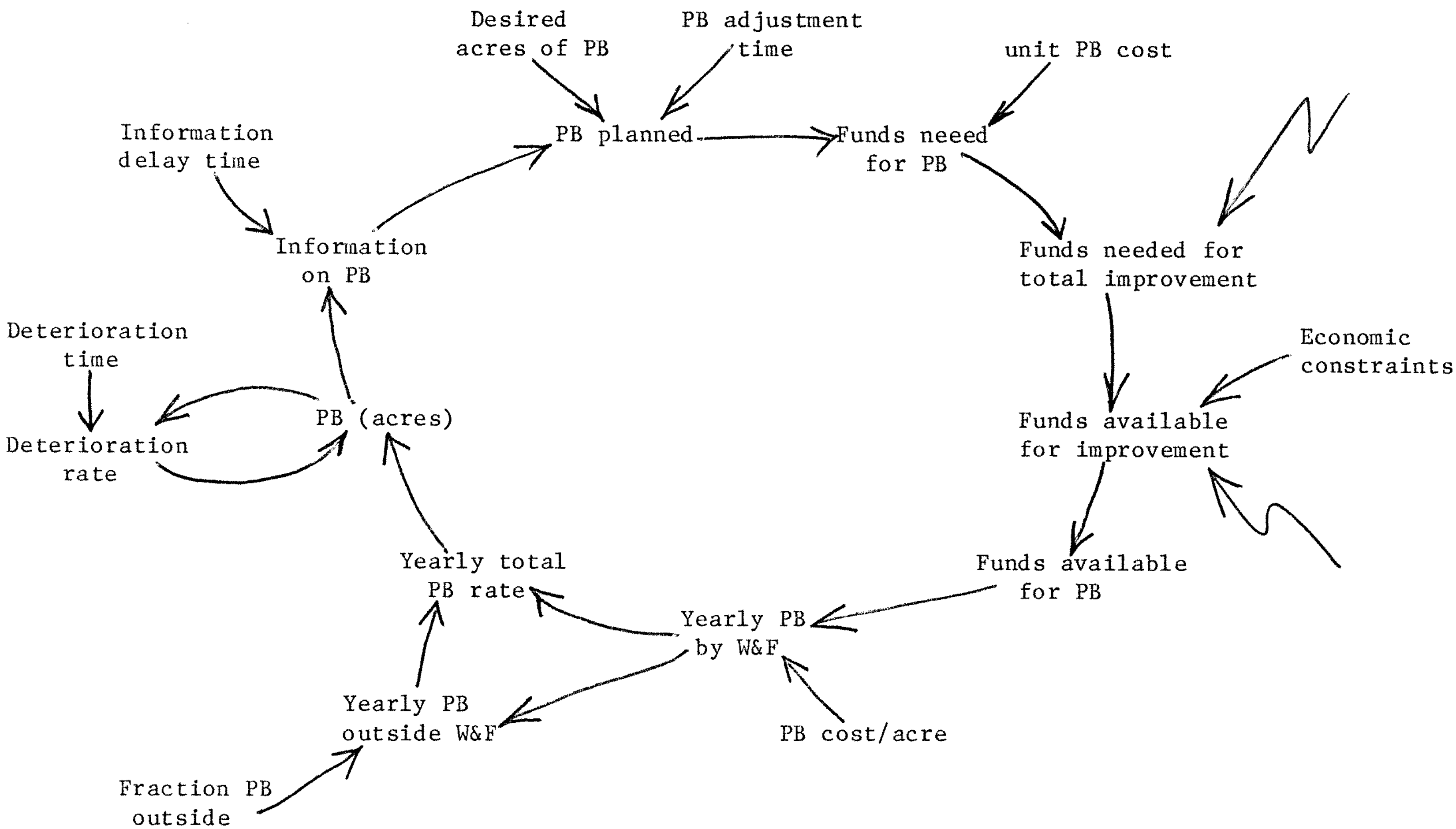


Figure 4. Prescribed Burning (PB)

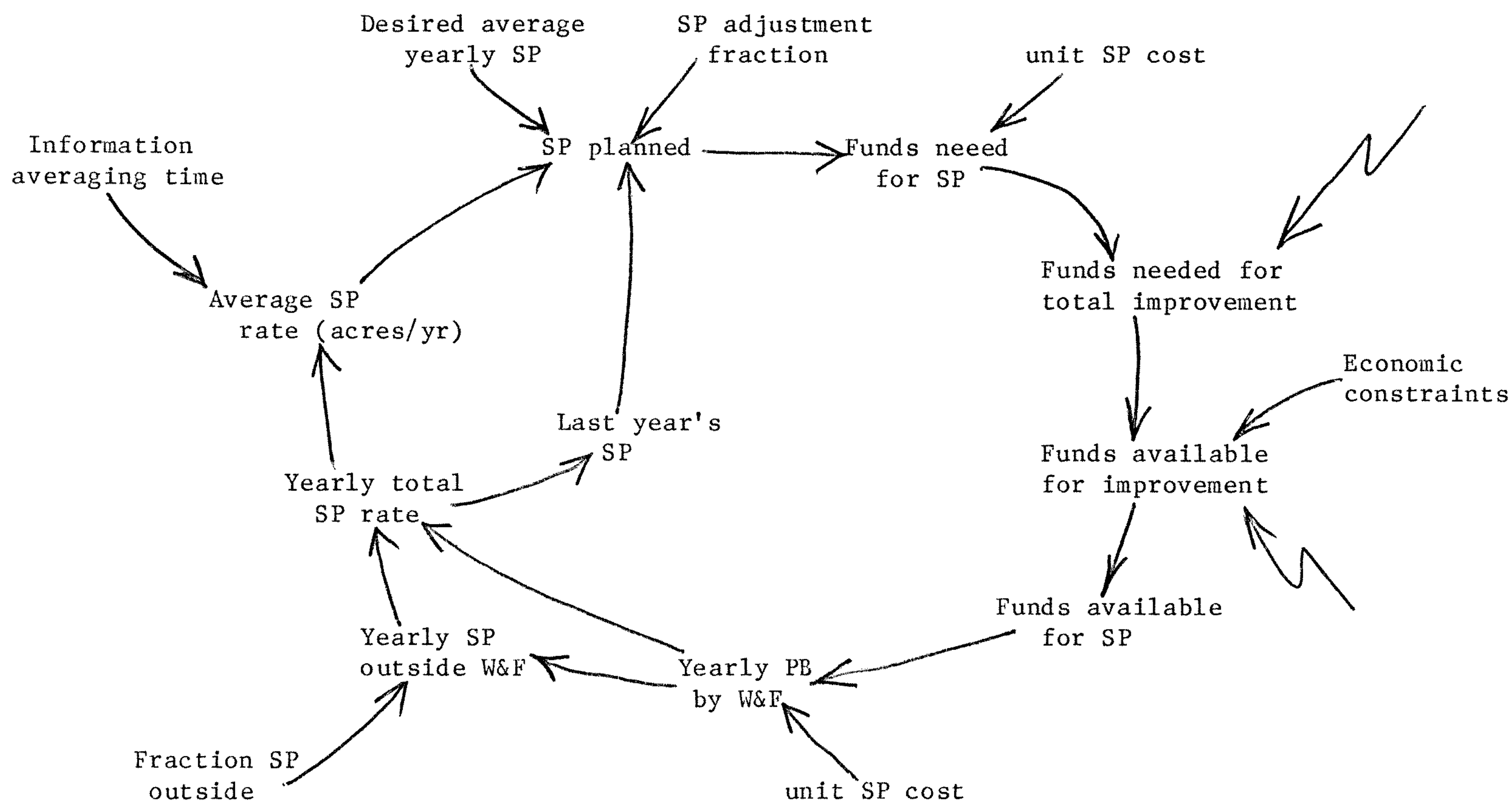


Figure 5. Seeding and Planting (SP)

SPRP.K = (SPDES.K-SMOOTH(SPR.JK SPST))*SPAF + SPLY.lK

SPRP : SP planned (acres/yr.)

SPLY.KL : SPWR.K Last years SP by W&F sector

SPDES.K : 10000 acres/year

SPAF : 0.20 SP adjustments fraction.

Thus, last years SP activity is adjusted depending on the difference between the desired SP per year and the last couple of year's average (SPST = 5 years in the final runs) SP rate. How much adjustment is made depends on the adjustment fraction SPAF. Once SPRP is computed, the rest of the equations for SP subsystem is the same as the previous subsystems.

Wetland Improvements (WI)

The equations for this section is exactly the same as the SP section except the values of constants and table functions.

Fish Improvement (FI)

The equations for this section is almost the same as the SP section except numerical values of parameters. The only other difference is that in this section all FI activities are carried out by W&F sector. There is no significant FI activity within Forest Service carried out by a sector other than W&F.

Threatened & Endangered Species Improvements (TE)

The structure of this section is exactly the same as that of Fish Improvement sector.

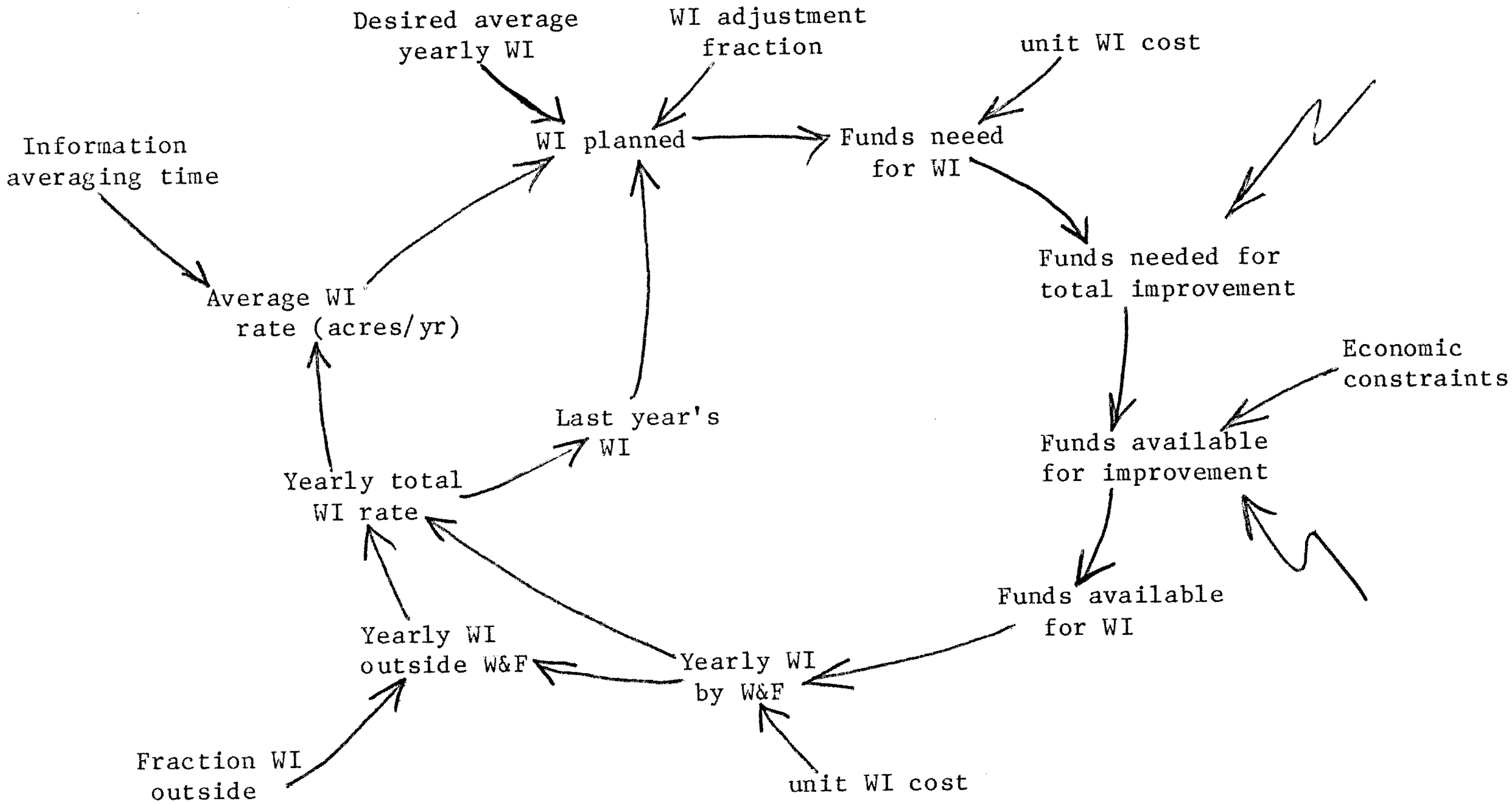


Figure 6. Wetland Improvement (WI)

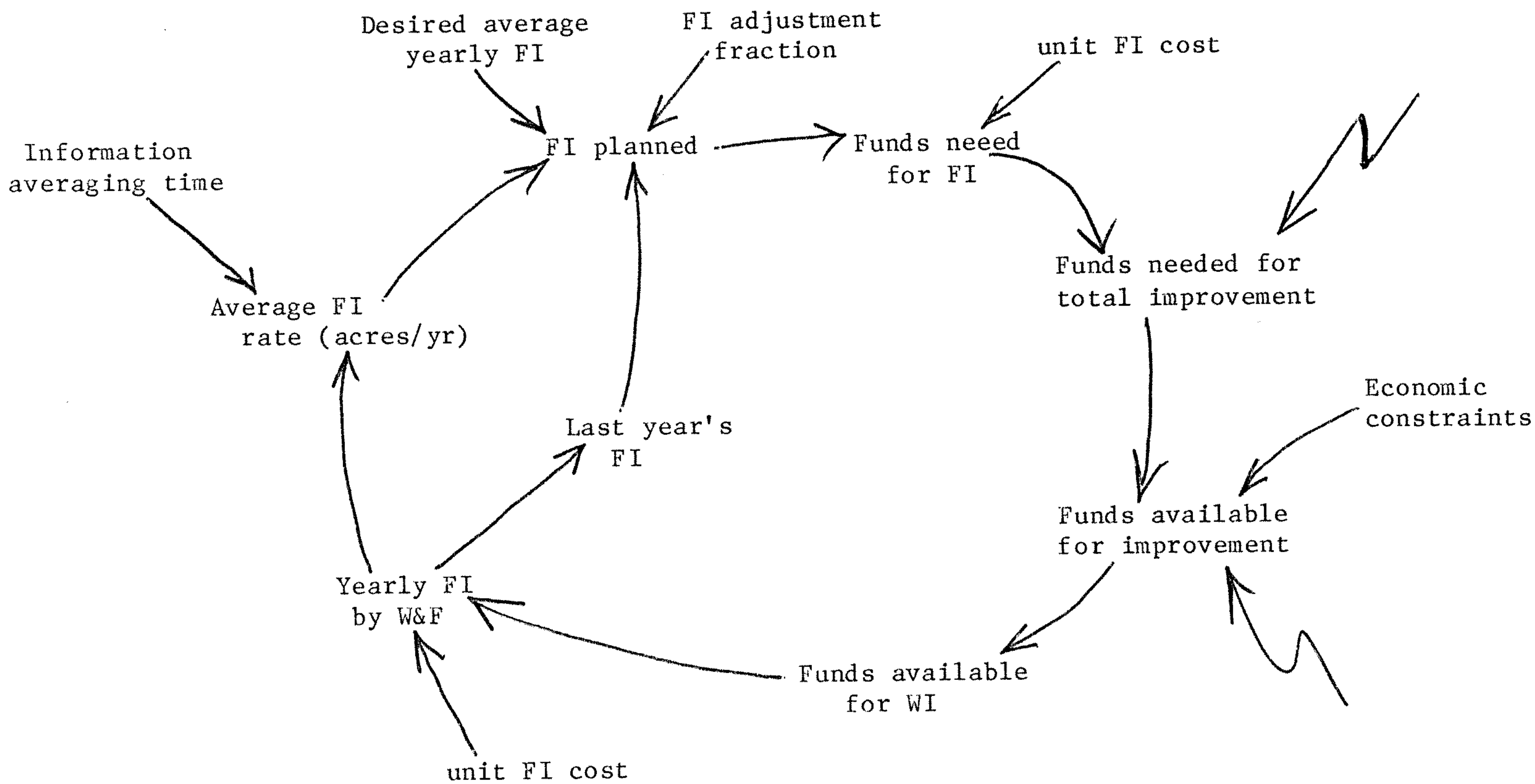


Figure 7. Fish Improvement (FI)

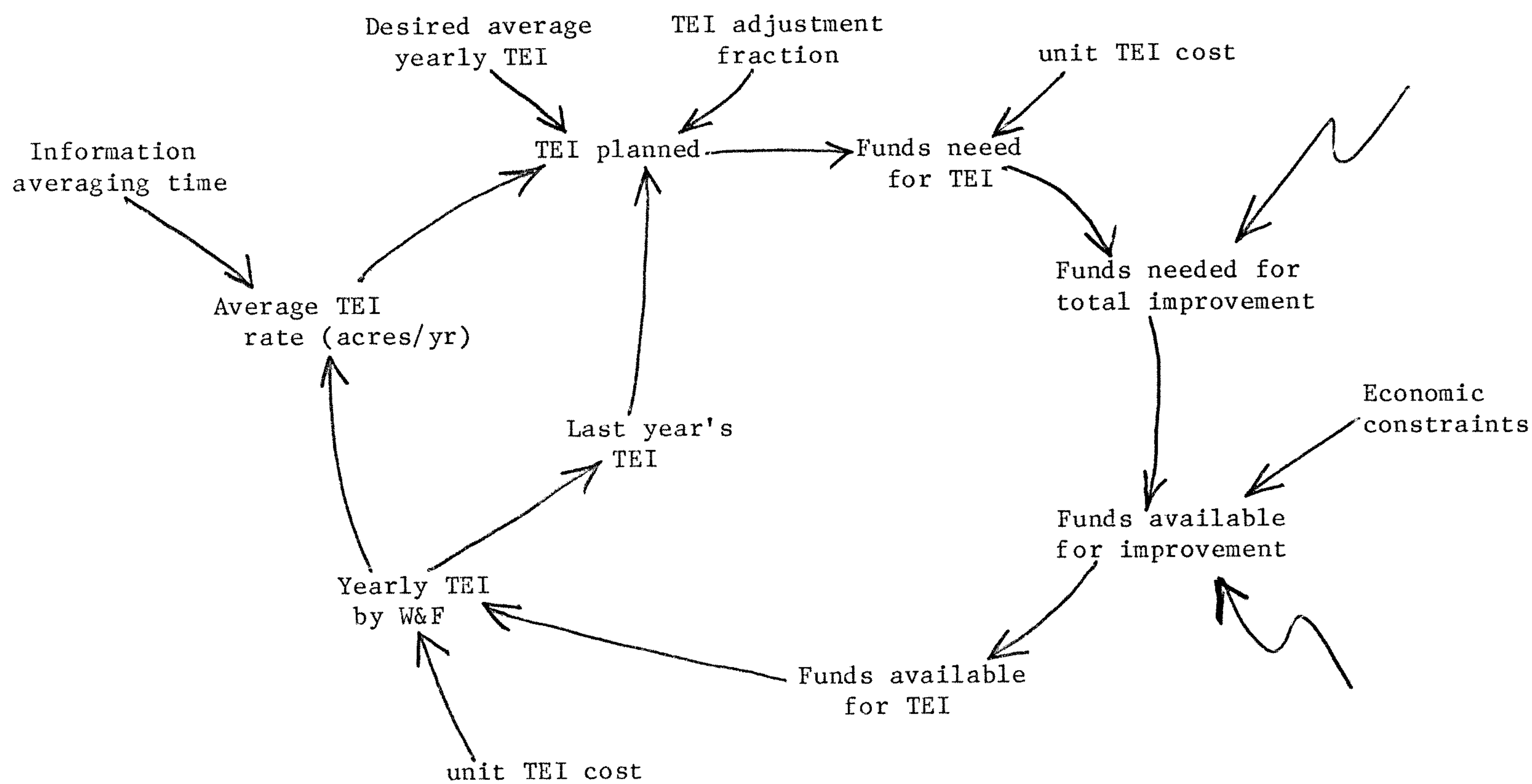


Figure 8. Threatened and Endangered Species Improvement (TEI)

Coordination (CO)

Coordination is the name given to many different activities of different nature (activities carried out together with other sectors like Timber or Range, participation in Land Use Planning, Multiple use surveys, environmental statements, training of coordination personnel). Probably due to its nature, it was not possible to find accurate information about how exactly various wildlife coordination decisions and plans are made. By taking a more empirical approach, we were able to find from the Wildlife reports that the coordination funds constitute about a third of the total improvement budget. To yield approximately such a ratio, the following equation was used:

COFE.KL = COF.K*SMOOTH(FOI.K,COST)

COF.K = Coordination fraction

COST = Coordination smoothing time (3 years).

This means that CO Funds equal a fraction of the average of the improvement funds of the last 3 years. Because of this averaging effect, COF was not chosen as a constant of about 1/3, but it is taken as a variable starting from 0.60 and approaching gradually 0.33. (Since the W&F funds show a sharp increase between 1974 and 1980, this variable COF in effect resulted in a CO fund of about 1/3 of the same year's improvement funds).

Funds (F)

This section computes how much funds are needed for the planned activities and how much funds are actually obtained. The needed funds

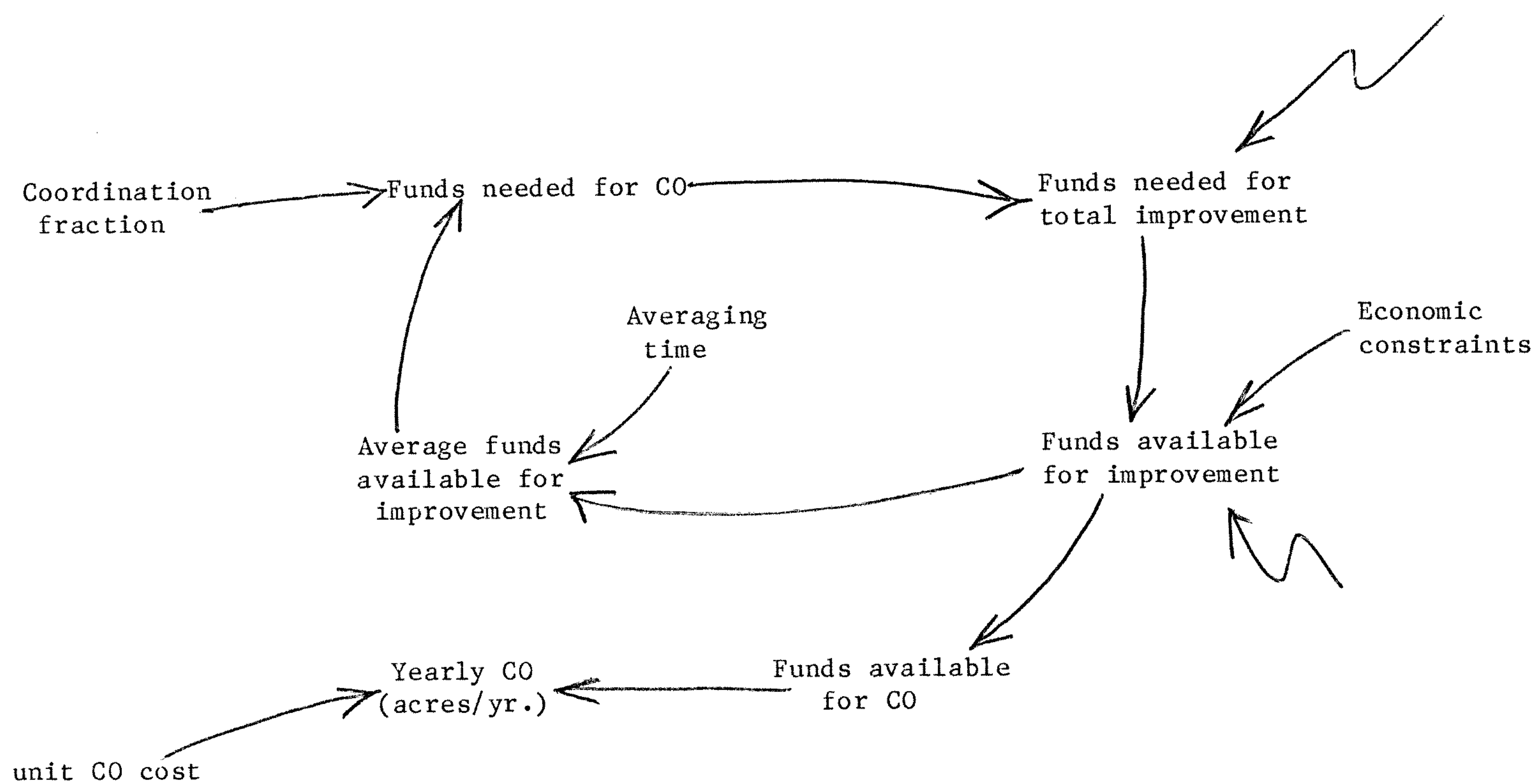


Figure 9. Coordination (CO)

equal planned activities times the unit cost. For example, for the water development:

FRWD.K = WDC.K*WDRP.K

The funds needed are computed the same way for all other improvement activities.

In addition to the improvement activities, a certain amount of funds is needed for maintenance of certain activities (WD, OD, TH, PB, SP, WI, FI). How much money is needed for maintenance depends on how much money was spent on such activities on the last couple of years (3 years):

FRIM.K + FIMF.K*SMOOTH(FORIM.JK,IMST)

FRIM: Funds needed for improvement maintenance

FORIM.KL = FWD.K + FOD.K + FTH.K + FPB.K + FSP.K +FWI.K + FFI.K

IMST: Averaging time for improvement maintenance (3 years)

and

FIMF.K = TABHL(IMTAB,TIME.K, 1970, 1980, 2)

Thus, improvement funds fraction FIMF is variable. Data from wildlife reports suggest that in early seventies this fraction was extremely high (around 1.0) and dies down gradually to about 0.10 in 1980.

The total funds needed for improvement is then:

FRI.K = FRWD.K + FROD.K + FRTH.K + FRPB.K + FRSP.K + FRWI.K + FRFI.K + FRTEI.K + FRCO.K + FRIM.K

The funds obtained for improvement is generated by the equation:

FOI.K = MIN(INDX.K*FRI.K,LIMIT.K)

This equation first says that the funds obtained is equal to the funds requested times an economic index. Secondly, it says that the funds obtained cannot be above a maximum LIMIT (taken as a maximum increase of 40% from the last 3 years average funds). The general economic index INDX intends to reflect the impact of the general economic condition on the process of fund generation. This index must be chosen as a time function to reflect the economic condition. For example:

INDX.K = A.K*SIN(2*PI*TIME.K/PRD+PHS) + B.K

states that the index goes up and down as a sine wave with an amplitude A, an average B a period PRD and a phase angle PHS. In the base run, the average B is chosen as 1 and the amplitude A as 0 so that INDX was always 1. This assumes no drastic economic change occurs throughout the simulation run period. In other runs, the INDX can be chosen in a realistic way, with a possible addition of a random term. Again, it should be noted that the inflation factor is not taken into account so that all funds are in 1970 dollars.

Finally, once the improvement funds (FOI) are available, a simple equation generates the funds for regional office (R8) as a function of FOI:

FRR.K = 0.15*FOI.K

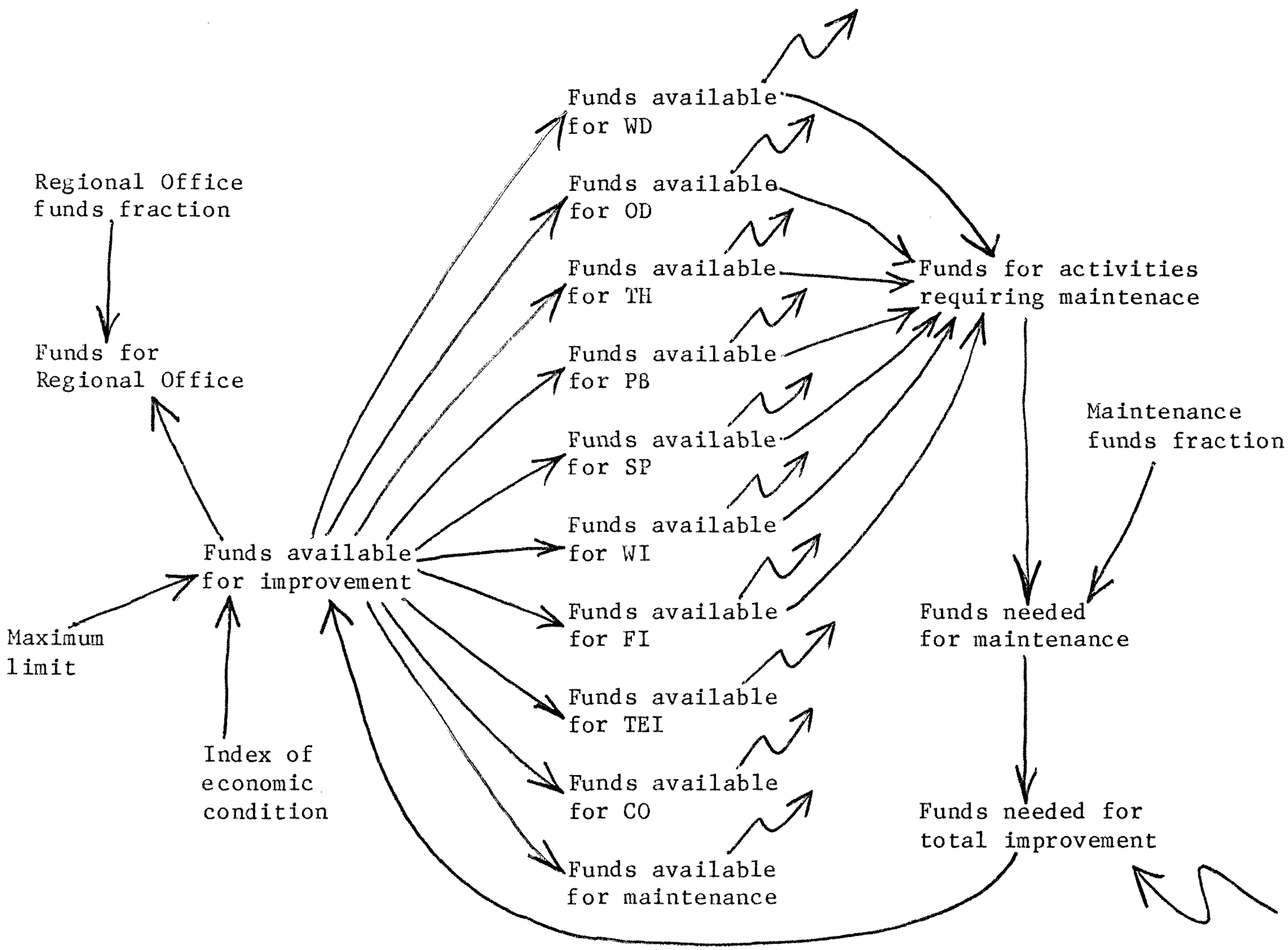


Figure 10. Funds

The obtained improvement funds are distributed among the different activities according to their proportion in the total funds requested. For example, for water development:

$$FWD.K = FOI.K*(FRWD.K/FRI.K)$$

The same rule is used for all activities.

These generated funds are used in turn in their respective subsystems to fund the respective improvement activities.

In this section, we gave a brief description of the important model equations. For a complete list of equations, the reader is referred to the appendix. In the next section, we present the behavior patterns of the major model variables.

II.3 Model Behavior

After all model parameters were estimated, the DYNAMO equations were run on a digital computer to yield the time histories for important model variables. The simulation was started in 1970 and spanned a 50 year period ending in 2020. The resulting time histories are shown on the following pages. Thus, the simulation did not only give a historical reproduction (1970-1982) but also future projections (1982-2020) for the important Wildlife and Fish variables. The first two graphs show the time histories of the major activities (in acres or number per year), and the last two graphs show the time histories for the dollars spent for those activities (in 1970 dollars). In general,

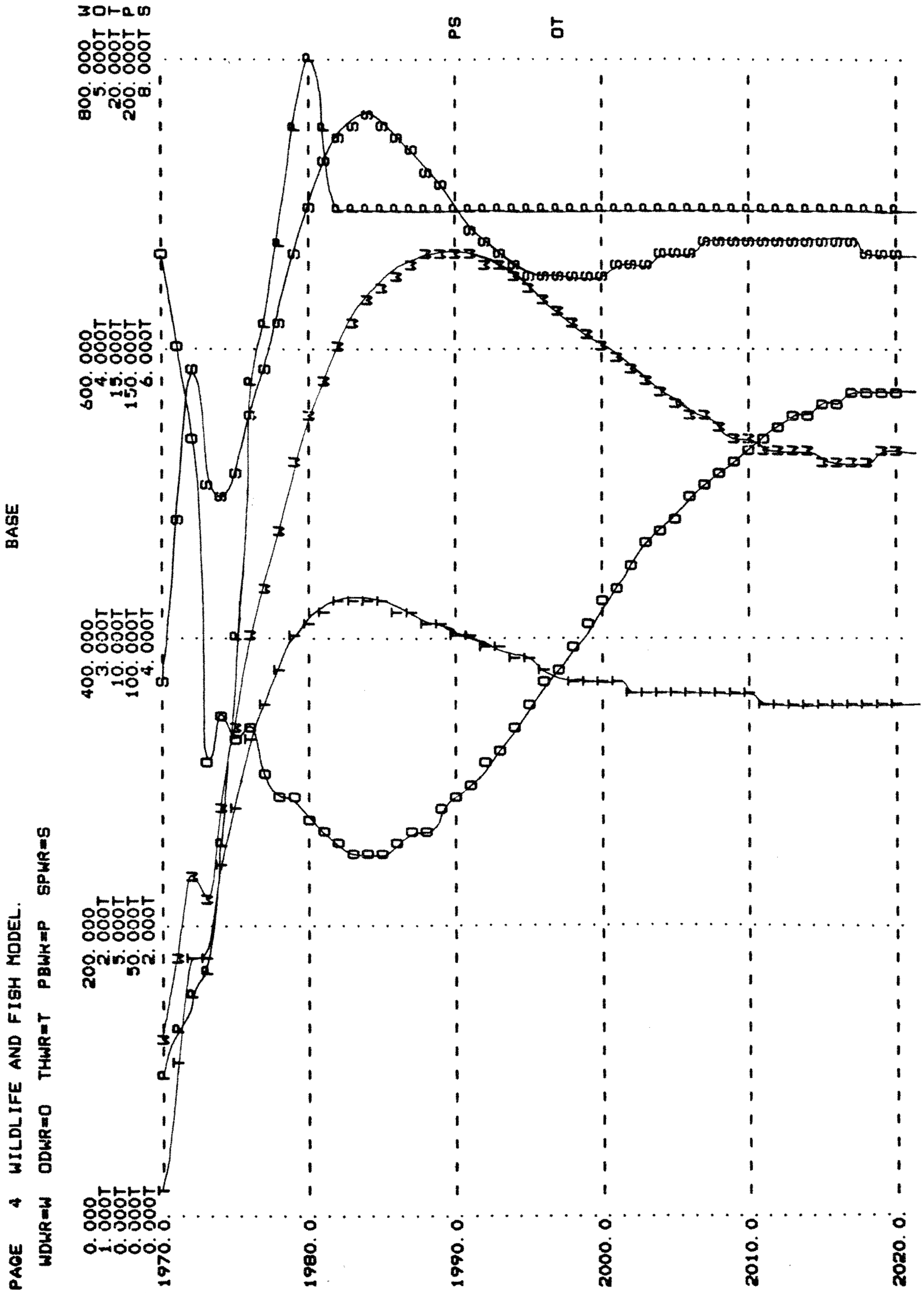
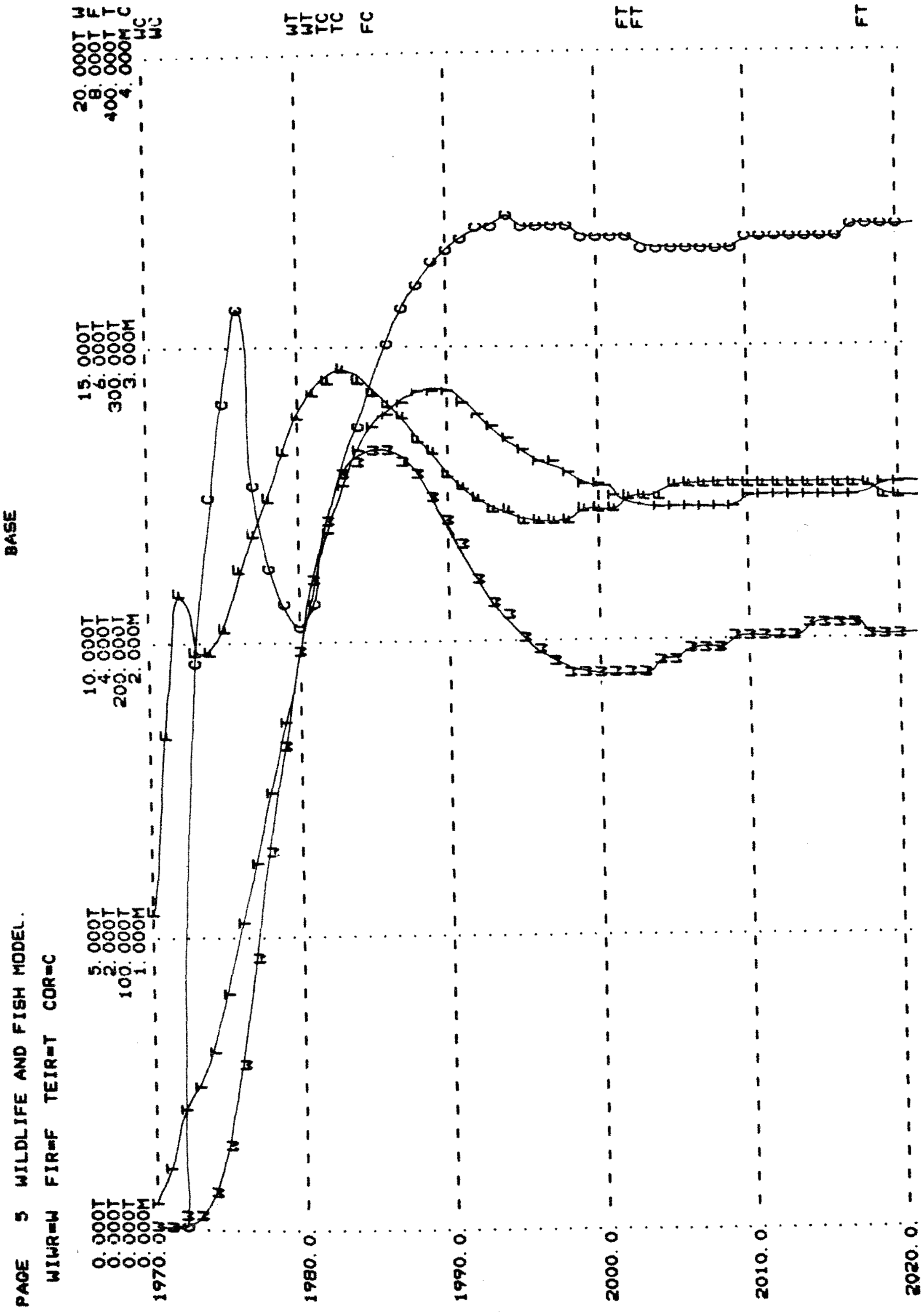
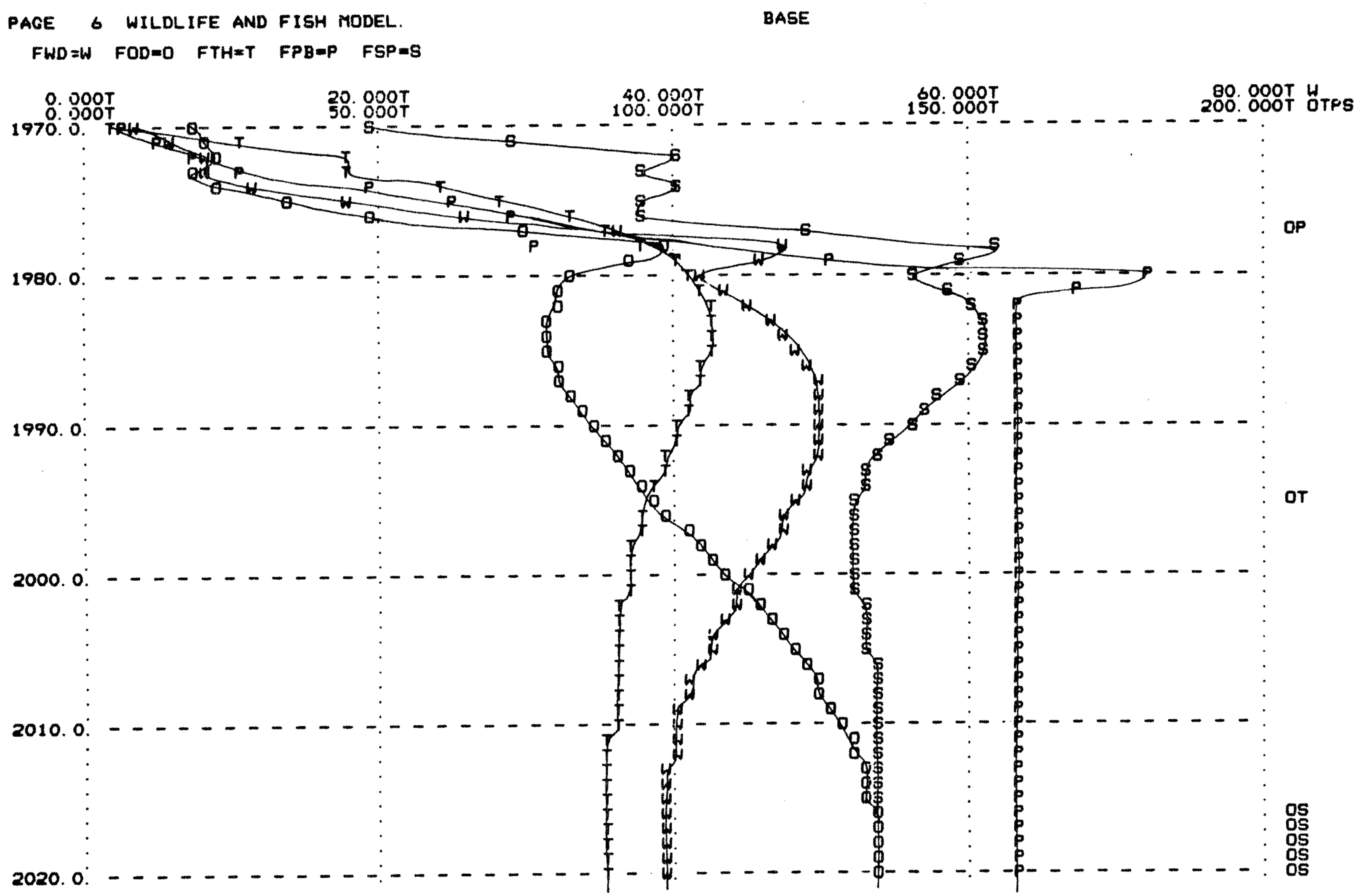


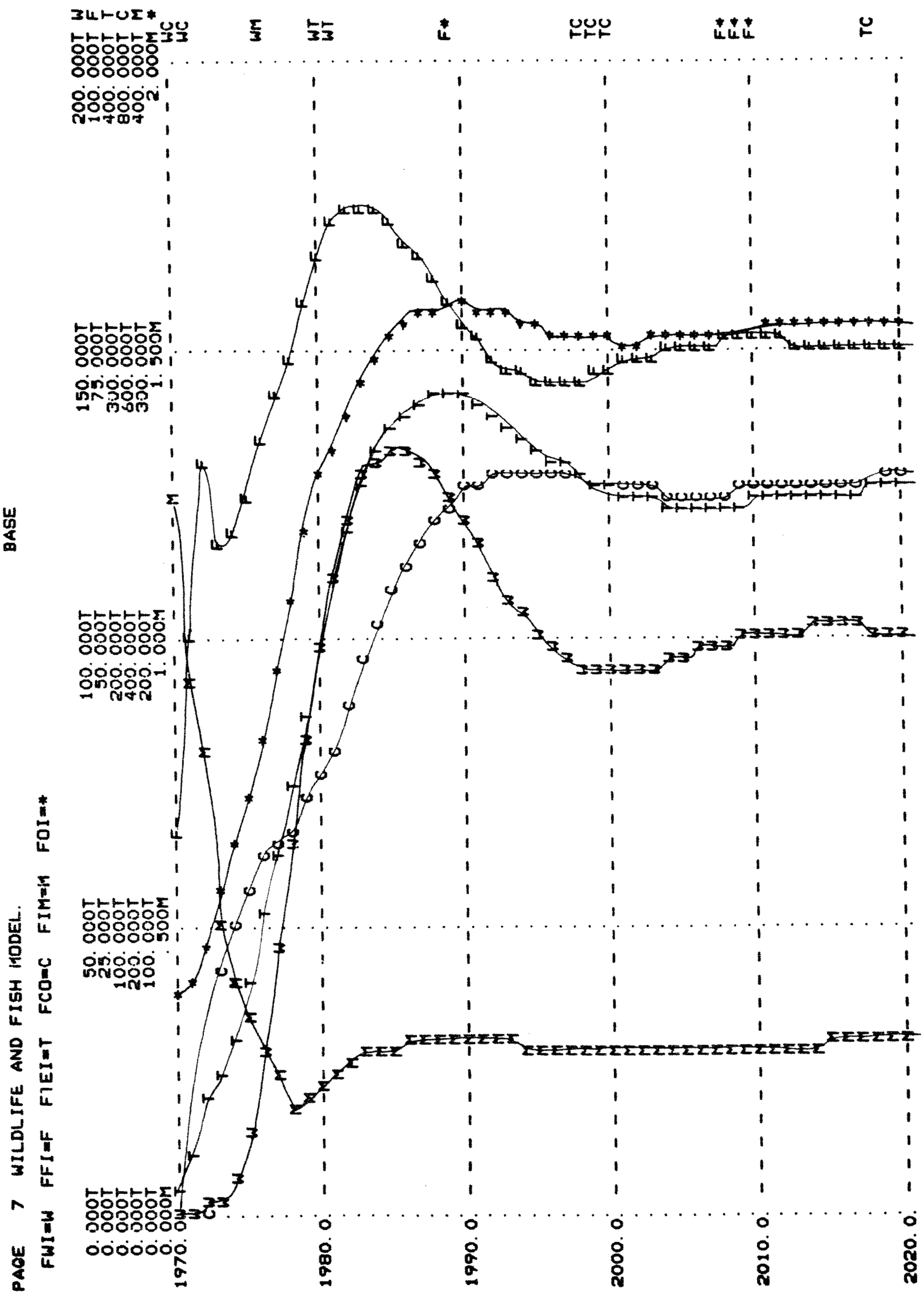
Figure 11. Behavior Patterns of the Major Wildlife and Fish Variables Generated by Computer Simulation.



(Figure 11. continued)



(Figure 11. continued)



(Figure 11. continued)

the behavior patterns of all major variables for the historical reproduction period were in reasonable agreement with the time histories available (if any) for those variables. The basic behavior mode is a sharp growth - with differing slopes - for all major activities, except for openings development which shows a gradual decline during this period and coordination activities which exhibits an oscillatory behavior in the same period. All of these major behavior patterns are greatly verified by the available historical data (USDA (2), USDA (3)). In the projection period (1982-2020) the fundamental pattern for all activities is one of transition to steady state.

All activities, except openings development, reach a maximum between the yars 1980 and 1990 and then show a gradual decline pattern until they reach their steady-state values by the year 2010. Openings development shows a reverse trend, reaching a minimum between 1980 and 1990 and then exhibiting - gradual growth towards its steady-state value. Since these are all future projections, it was not possible to make any comparison with available data. Yet, these projection patterns were compared to several different Forest Service projections such as the ones in the "Recommended Renewable Resources Program" book. The model projections and FS projections in general looked in agreement with each other. As a result, it was concluded that the model was an acceptable one to reproduce and predict the basic behavior patterns of the important W&F variables.

III. OBSERVATIONS AND CONCLUSIONS

An examination of the major time histories suggests that in general they can be characterized by three modes: 1-A period of sharp growth between 1970 and 1980, 2-A period of transition to steady-state between 1980 and 1990 and 3 - the steady-state period after 1990. This growth-transition-steady state characteristic of the time histories is relatively independent of the exact values of various model parameters. This dominant mode of behavior is primarily determined by the shape of the goal curves (desired values) and by the physical limitations imposed by Forests. This means that changing the values of most model parameters does not drastically alter the dominant mode of behavior. The exact values of parameters do have an impact on the exact values assumed by system variables and on exactly for how long these variables exhibit growth, when the transition period starts, how long it lasts etc. But the general mode of behavior is not an outcome of some specific set of parameter values. On the other hand, changing the desired value curve for a certain variables may change the corresponding mode of behavior drastically. Similarly, a significant modification of an equation describing how Forests respond to an improvement activitiy, would result in a significant change in the corresponding behavior mode.

Finally, the basic behavior mode naturally depends on the availability of funds required for improvement activities. The base run assumes that funds are essentially obtained as they are necessitated. This assumption can be changed by making use of INDX equation to account for a budget cutback due to an economic recession.

To conclude, if there are no significant errors in the shapes of goal curves and in the forms of major system equations, the major W&F activities should exhibit the performance patterns suggested by the simulation runs. We must finally add that this model should be accepted only as an initial candidate and not as a final model of W&F sector.

This is true especially because the dynamics of W&F sector is in reality influenced by the dynamics of other FS sectors such as Range, Timber, Recreation etc. These interrelationships were incorporated in the present model by means of some equations with a great degree of oversimplification mainly because the focus of this research was the W&F sector rather than the entire Forest Service. If in the future, similar models are built for the other sectors, then consolidation of these models into one total model should result in more credible time histories for the major W&F activities.

REFERENCES

1. Barlas, Yaman, Report on System Dynamics Approach to Forest Systems Management, School of Industrial And Systems Engineering, Georgia Institute of Technology, Atlanta, GA, 1984.

2. U.S.D.A. Forest Service, Wildlife Reports, 1971-1980.

3. U.S.D.A. Forest Service, Region 8 Allotment Sheets, 1971-1980.

Appendix 1

The complete list of model equations.

```
   WILDLIFE AND FISH MODEL.
PT D
OTE
OTE   WATER DEVELOPMENT (WD)
OTE
   WDDR.KL=DELAYP(WDR.JK,WDTD,WDN.K)  WATER DEVELOPM. DETERIOR. RATE
   WDTD=25      YEARS                 WATER DEVELOP. DETERIORATION TIME
   WDN=WDNN                      INITIAL VALUE
   WDNN=3000          NUMBER
   WDNI.K=SMOOTH(WDN.K,WDST)    INFORMATION ON WATER DEVELOPMENTS
   WDST=10     YEARS             INFORMATION AVERAGING TIME
   WDRP.K=(WDDES.K-WDNI.K)/WDAT+WDNI.K/WDTD    WD PLANNED
   WDDES.K=15000*(1-0.8*EXP(-0.05*(TIME.K-TIMEN)))  DESIRED NO. OF WD
   WDAT=10    YEARS                WD ADJUSTMENT TIME
   WDWR.K=FWD.K/WDC.K            YEARLY WATER DEVEL. BY WILDLIFE SECTOR
   WDC.K=TABHL(WTAB,TIME.K,1970,1980,2)     WATER DEVELOPM. COST/UNIT
   WDX.K=WDXF*WDWR.K          WATER DEVELOPM. OUTSIDE WILDLIFE SECTOR
   WDXF=0.10                 FRACTION WD OUTSIDE WILDLIFE SECTOR
   WDR.KL=WDWR.K+WDX.K       TOTAL YEARLY WATER DEVELOPMENT ACTUAL
OTE
OTE   OPENINGS DEVELOPMENT (OD)
OTE
   ODDR.KL=DELAYP(ODR.JK,ODTD,ODA.K)    OPENINGS DEVELOP. DETERIOR. RATE
   ODTD=50         YEARS        OPENINGS DEVEL. TIME TO DETERIORATE
   ODA=ODAN                  INITIAL VALUE
   ODAN=50000          ACRES
   ODAI.K=SMOOTH(ODA.K,ODST)    INFORMATION ON OPENING DEVELOPMENTS
   ODST=10   YEARS              INFORMATION AVERAGING TIME
   ODRP.K=(ODDES.K-ODAI.K)/ODAT+ODAI.K/ODTD    OD PLANNED
   ODDES.K=200000*(1-0.5*EXP(-0.1*(TIME.K-TIMEN)))  DESIRED ACRES OF OD
   ODAT=15     YEARS           OPENING DEVELOPM. ADJUSTMENT TIME
   ODWR.K=FOD.K/ODC.K           YEARLY OPENING DEVELOPMENTS BY WIDLIFE SECTOR
   ODC.K=TABHL(OTAB,TIME.K,1970,1980,2)    COST OF OPENING DEVEL./ACRE
   ODX.K=ODXF*ODWR.K          OPENINGS DEVELOPMENT OUTSIDE WILDLIFE SECTOR
   ODXF=0.20          FRACTION OPENINGS DEVELOP. OUTSIDE WILDLIFE SECTOR
R  ODR.KL=ODWR.K+ODX.K      TOTAL YEARLY OPENINGS DEVELOPMENT ACTUAL
NOTE
NOTE   THINNING (TH)
NOTE
R  THEDR.KL=DELAYP(THR.JK,THTD,THA.K)  THINNING EFFECT DETERIORATION RATE
C  THTD=12   YEARS                THINNING EFFECT DETERIORATION TIME
N  THA=THAN                       THINNED ACRES INITIAL
C  THAN=10000          ACRES
A  THAI.K=SMOOTH(THA.K,THST)  INFORMATION ON THINNED ACRES
C  THST=10    YEARS               INFORMATION AVERAGING TIME
A  THRP.K=(THDES.K-THAI.K)/THAT+THAI.K/THTD    THINNING PLANNED
A  THDES.K=125000*(1-0.95*EXP(-0.2*(TIME.K-TIMEN)))  THINN. ACRES DESIRED
C  THAT=10   YEARS                THINNING ADJUSTMENT TIME
A  THWR.K=FTH.K/THC.K              YEARLY THINNING BY WILDLIFE SECTOR
A  THC.K=10.0        $/ACRE            COST OF THINNING PER ACRE
A  THX.K=THXF*THWR.K             THINNING FROM OUTSIDE WILDLIFE SECTOR
C  THXF=1.00              FRACTION THINNING OUTSIDE WILDLIFE
R  THR.KL=THWR.K+THX.K      TOTAL YEARLY THINNING RATE
NOTE
NOTE   PRESCRIBED BURNING (PB)
NOTE
R  PBEDR.KL=DELAYP(PBR.JK,PBTD,PBA.K)  PB EFFECT DETERIORATION RATE
C  PBTD=4    YEARS           PRESCRIBED BURN EFFECT TIME TO DETERIORATE
N  PBA=PBAN                  INITIAL PRESCRIBED BURN ACRES
C  PBAN=150000          ACRES
A  PBAI.K=SMOOTH(PBA.K,PBST)  INFORMATION ON PRESCRIBED BURN ACRES
C  PBST=10  YEARS             AVERAGING TIME FOR PB INFORMATION
```

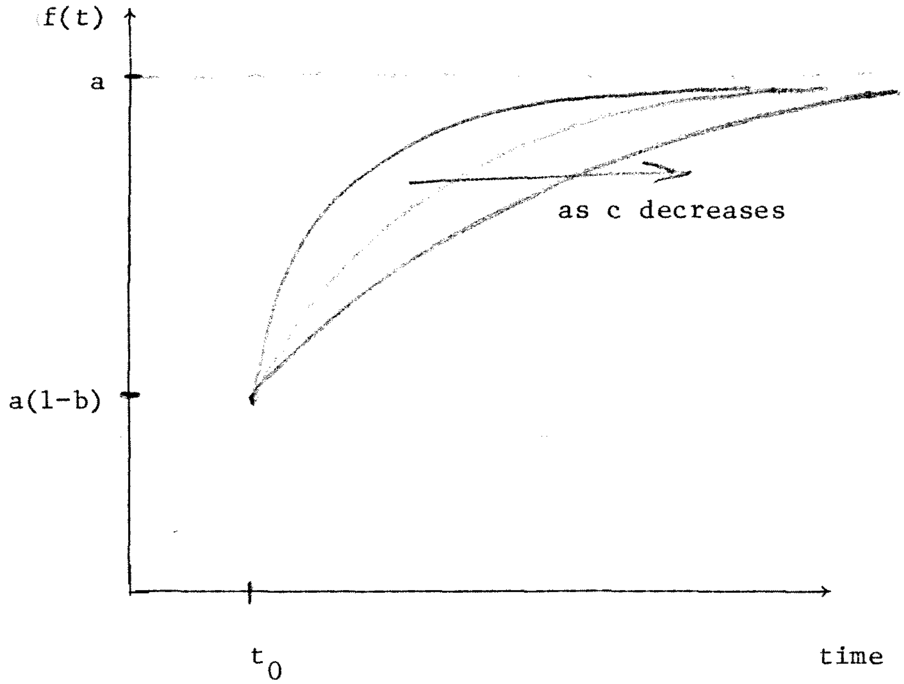
```
    PBRP.K=(PBDES.K-PBAI.K)/PBAT+PBAI.K/PBTD   PRESCRIBED BURN PLANNED
    PBDES.K=TABHL(PBDEST,TIME.K,1970,1982,2)  DESIRED PB ACRES
    PBAT=4   YEARS            PRESCRIBED BURN ADJUSTMENT TIME
    PBWR.K=FPB.K/PBC.K          PRESCRIBED BURN BY WILDLIFE SECTOR
    PBC.K=TABHL(PTAB,TIME.K,1970,1980,2)   PRESC. BURN COST PER ACRE
    PBX.K=PBXF*PBWR.K          PRESCRIBED BURN OUTSIDE WILDLIFE SECTOR
    PBXF=1.00                 FRACTION PB OUTSIDE WILDLIFE SECTOR
    PBR.KL=PBWR.K+PBX.K       TOTAL YEARLY PRESCRIBED BURNING ACTUAL
OTE
OTE   SEEDING AND PLANTING (SP)
OTE
    SPRP.K=(SPDES.K-SMOOTH(SPR.JK,SPST))*SPAF+SPLY.JK  SP PLANNED
    SPST=5   YEARS          SEEDING AND PLANTING INFO. AVERAGING TIME
    SPAF=0.20               SEEDING AND PLANTING ADJUSTMENT FRACTION
    SPDES.K=10000  ACRES/YEAR    DESIRED YEARLY SP ACRES
    SPLY.KL=SPWR.K          LAST YEARS SP BY WILDLIFE SECTOR
    SPLY=SPLYN
    SPLYN=2500
    SPWR.K=FSP.K/SPC.K         SEEDING AND PLANTING BY WILDLIFE SECTOR
    SPC.K=TABHL(STAB,TIME.K,1970,1980,2)  SEEDING & PLANTING COST/ACRE
    SPX.K=SPXF*SPWR.K       SEEDING AND PLANTING OUTSIDE WILDLIFE SECTOR
    SPXF=0.50               FRACTION SP OUTSIDE WILDLIFE SECTOR
    SPR.KL=SPWR.K+SPX.K     TOTAL YEARLY SEEDING AND PLANTING ACTUAL
    SPR=SPRN
    SPRN=4000
NOTE
NOTE   WETLAND IMPROVEMENTS (WI)
NOTE
A   WIRP.K=(WIDES.K-SMOOTH(WIR.JK,WIST))*WIAF+WILY.JK  WI PLANNED
A   WIDES.K=TABHL(WIDEST,TIME.K,1970,1980,2)
C   WIST=5   YEARS                 WETLAND IMPROV. INFO. AVERAGING TIME
C   WIAF=0.25               WETLAND IMPROVEMENT ADJUSTMENT FRACTION
R   WILY.KL=WIWR.K            LAST YEARS WETLAND IMPROVEMENT
N   WILY=WILYN
C   WILYN=30
A   WIWR.K=FWI.K/WIC.K         WETLAND IMPROVEMENT BY WILDLIFE SECTOR
A   WIC.K=10.0        $/ACRE        COST OF WETLAND IMPROVEMENT PER ACRE
A   WIX.K=WIXF*WIWR.K       WETLAND IMPROV. OUTSIDE WILDLIFE SECTOR
C   WIXF=0.0                FRACTION WI OUTSIDE WILDLIFE SECTOR
R   WIR.KL=WIWR.K+WIX.K       TOTAL YEARLY WETLAND IMPROVEMENT ACTUAL
N   WIR=WIRN
C   WIRN=30
NOTE
NOTE   FISH IMPROVEMENT (FI)
NOTE
A   FIRP.K=(FIDES.K-SMOOTH(FIR.JK,FIST))*FIAF+FIR.JK   FI PLANNED
A   FIDES.K=5000   ACRES   DESIRED ACRES OF YEARLY FISH IMPROVEMENT
C   FIST=5    YEARS        FI INFORMATION AVERAGING TIME
C   FIAF=0.30              FISH IMPROVEMENT ADJUSTMENT FRACTION
R   FIR.KL=FFI.K/FIC.K       FISH IMPROVEMENT RATE ACTUAL
N   FIR=FIRN
C   FIRN=1000
A   FIC.K=15.0        $/ACRE        FISH IMPROVEMENT COST PER ACRE
NOTE
NOTE   THREATENED AND ENDANGERED SPECIES IMPROVEMENT (TEI)
NOTE
A   TEIRP.K=(TEIDES.K-SMOOTH(TEIR.JK,TEIST))*TEIAF+TEIR.JK  TEI PLANN.
A   TEIDES.K=250000*(1-0.9*EXP(-0.2*(TIME.K-TIMEN)))  DESIRED YEARLY TEI
C   TEIST=5   YEARS      TEI INFORMATION AVERAGING TIME
C   TEIAF=0.20           TEI ADJUSTMENT FRACTION
R   TEIR.KL=FTEI.K/TEIC.K     YEARLY ACTUAL TEI ACRES
N   TEIR=TEIRN
C   TEIRN=5000
A   TEIC.K=1.0   $/ACRE    COST OF TEI PER ACRE
```

```
OTE
OTE    COORDINATION (CO)
OTE
    COFE.KL=COF.K*SMOOTH(FOI.K,COST)    EXPECTED COORDINATION FUNDS
    COFE=COFEN
    COFEN=0.0
    COST=3   YEARS     COORDINATION AVERAGING TIME
    COC.K=TABHL(COCT,TIME.K,1972,1980,2)    $/ACRE    CO COST PER ACRE
    COF.K=CLIP(TABHL(COFT,TIME.K,1972,1980,2),0.0,TIME.K,1972)  CO FRACTION
    COR.KL=FCO.K/COC.K           ACTUAL YEARLY COORDINATION ACRES
OTE
OTE    FUNDS (F)
OTE
    FRI.K=FRWD.K+FROD.K+FRTH.K+FRPB.K+FRSP.K+FRWI.K+FRFI.K
    +FRTEI.K+FRCO.K+FRIM.K              FUNDS NEEDED FOR IMPROVEMENT
A   FRWD.K=WDC.K*WDRP.K           FUNDS NEEDED FOR WATER DEVELOPMENT
A   FROD.K=ODC.K*ODRP.K             "       "       "  OPENINGS DEVELOP.
A   FRTH.K=THC.K*THRP.K             "       "       "  THINNING
A   FRPB.K=PBC.K*PBRP.K             "       "       "  PRESCRIBED BURN.
A   FRSP.K=SPC.K*SPRP.K             "       "       "  SEEDING & PLANTING
A   FRWI.K=WIC.K*WIRP.K             "       "       "  WETLAND IMPROVEMENT
A   FRFI.K=FIC.K*FIRP.K             "       "       "  FISH IMPROVEMENT
A   FRTEI.K=TEIC*TEIRP.K            "       "       "  THREATN.& ENDANG. IMP.
A   FRCO.K=COFE.JK                  "       "       "  COORDINATION
R   FORIM.KL=FWD.K+FOD.K+FTH.K+FPB.K+FSP.K+FWI.K+FFI.K
N   FORIM=FORIMN
C   FORIMN=250000
A   FRIM.K=FIMF.K*SMOOTH(FORIM.JK,IMST)    FUNDS REQUIRED FOR MAINTENANCE
A   FIMF.K=TABHL(IMTAB,TIME.K,1970,1980,2)         IM FUNDS FRACTION
C   IMST=3   YEARS               IMPROVEM. MAINTENANCE AVERAGING TIME
A   FOI.K=MIN(INDX.K*FRI.K,LIMIT.K)    FUNDS OBTAINED FOR IMPROVEMENT
A   INDX.K=A.K*SIN(2*PI*TIME.K/PRD+PHS)+B.K  A GENERAL ECONOMIC INDEX
A   A.K=0.0                        INDEX AMPLITUDE
A   B.K=1.0                        INDEX AVERAGE
C   PRD=10.0         YEARS            INDEX PERIOD
C   PHS=0.0          RADIANS         INDEX PHASE
A   LIMIT.K=MAXM.K*SMOOTH(FOI.K,LIMTM)    MAX. LIMIT ON WILDLIFE FUNDS
N   LIMIT=2000000
A   MAXM.K=1.4                      MAXIMUM CHANGE IN WILDLIFE FUNDS
C   LIMTM=3   YEARS                AVERAGING TIME FOR "LIMIT"
A   FRR.K=FRF.K*FOI.K              FUNDS FOR REGIONAL OFFICE
A   FRF.K=0.15                     FRACTION FUNDS FOR REGIONAL OFFICE
A   FWD.K=FOI.K*(FRWD.K/FRI.K)     FUNDS  NEEDED FOR WATER DEVELOPMENT
A   FOD.K=FOI.K*(FROD.K/FRI.K)       "       "       "  OPENINGS DEVELOPM.
A   FTH.K=FOI.K*(FRTH.K/FRI.K)       "       "       "  THINNING
A   FPB.K=FOI.K*(FRPB.K/FRI.K)       "       "       "  PRESCRIBED BURN.
A   FSP.K=FOI.K*(FRSP.K/FRI.K)       "       "       "  SEEDING & PLANTING
A   FWI.K=FOI.K*(FRWI.K/FRI.K)       "       "       "  WETLAND IMPROVEM.
A   FFI.K=FOI.K*(FRFI.K/FRI.K)       "       "       "  FISH IMPROVEMENT
A   FTEI.K=FOI.K*(FRTEI.K/FRI.K)     "       "       "  T&E IMPROVEMENT
A   FCO.K=FOI.K*(FRCO.K/FRI.K)       "       "       "  COORDINATION
A   FIM.K=FOI.K*(FRIM.K/FRI.K)       "       "       "  IMPROVEMENT MAIN.
NOTE
NOTE   PROGRAM SPECIFICATIONS
NOTE
C   PI=3.1416
N   TIME=TIMEN
C   TIMEN=1970
SPEC DT=1/LENGTH=2020/PRTPER=1/PLTPER=1     BASE SIMULATION
PRINT WDWR,ODWR,THWR,PBWR,SPWR,WIWR,FIR,TEIR,COR
PRINT FWD,FOD,FTH,FPB,FSP,FWI,FFI,FTEI,FCO,FIM,FOI
PLOT WDWR=W/ODWR=O/THWR=T/PBWR=P/SPWR=S
PLOT WIWR=W/FIR=F/TEIR=T/COR=C
PLOT FWD=W/FOD=O/FTH=T/FPB=P/FSP=S
```

```
LOT FWI=W/FFI=F/FTEI=1/FC3=C/F14=4/FC1=*
OTE
    IMTAB=1.0/0.80/0.40/0.20/0.10/0.08
    WTAB=30/33/40/65/100/75
    CTAB=4/6/8/18/40/35
    PTAB=0.25/0.50/0.75/0.50/0.45/0.90
    PBDEST=100000/150000/300000/600000/700000/800000/700000
    WIDEST=100/300/1500/7000/10000/10000
    STAB=13/17/20/17/25/20
    COCT=0.16/0.08/0.08/0.12/0.15
    COFT=0.60/0.55/0.45/0.35/0.33
UN BASE
```

Appendix 2

The behavior of the exponential function used in some "desired value" equations.



$f(t) = a(1-be^{-c(t-t0)})$

f(t) : the desired value at time t.

a(1-b): the initial value of the desired value

a: the final (steady-state) value of the desired value