United States
Department of the Interior
Geological Survey

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Computer Program for a
Generic Western Coal Region Simulation Model
Developed to Investigate Potential Applications of
System Dynamics Modeling to the EIS Process

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Open File Report 78-321

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

Menlo Park, California
1978
This generic western coal region model (WCR) was prepared to investigate possible applications of system dynamics simulation modeling (Forrester, 1961; 1968) to the regional EIS process. It is intended as a tool for research and perhaps a starting point for further work. It is not intended for actual application in its present form.

The model is driven by user selected coal development scenarios and impacts are simulated in the mining, land, water, demographic, political, and environmental sectors. Interaction are based upon hypothesized causal relations. Provision is made for system delays and feedback effects among the sectors. All variables (such as electric generation capacity, industrial water use, number of miners, sulfur dioxide emission) are summed or averaged over the region. The model has a time horizon of 30 years (1970-2000).

Members of the Northern Powder River Basin EIS Task Force reviewed this model during our research effort. We believe that the task force benefited from exposure to this system dynamics model perspective, but the preliminary status of the modeling effort precluded formal application of it to this EIS. The EIS task force was not able to commit extensive staff time to this experimental effort. The time required for refinement and adjustment of a model, for the Northern Powder River region extended past the time by which the task force was required to
complete its assembly of analytical tools and information and proceed with its analysis and writing of the statement. Prospects for future use of system dynamics modeling in support of EIS preparation by the Geological Survey are uncertain. The collaborative effort between the modeling research team and those concerned with EIS preparation lasted one and a half years. No further exploratory efforts are active at this time, although they may be reinstituted after the professional community has had the opportunity to evaluate and critique the modeling effort.

The five county region of southeastern Montana (Bighorn, Custer, Powder River, Rosebud and Treasure Counties) was used as a source for much of the data. In many cases where data was not readily available, other sources or estimates were used. In addition, where specific information was not available we chose to hypothesize the nature of some causal relations rather than omit them from this experimental model.

The model source code was written for the Honeywell Multics system. The main program and most of the subroutines are in "old fortran"; one (wcrcat) is in PL/1. The overall structure of the model is shown in the figure on the following page.

References Cited


This is the "main" program for the western-coal regions model. Its major functions are to call the various sector subroutines as needed, store the proper calculation for the output, and to construct the output tables and graphs. It also includes a few data statements, but like all other constants, these can be altered by the set statements.

A detailed understanding of this master program is not needed in order to run the model.

To run the model: Type "ec wcr" (terminate all lines with a "return")

Program wcrcrd (subroutine output) prompts "n:2.
Type "0" to set new plot variables
"5" to retain plot variables from previous run (if any)
or "99" to stop

wcrcrd (subroutine wcrcat) then prompts "type show, set, or run"
"show" is used to examine constants and is terminated by ";"
for example:

  type show, set, or run: show
  show: c(10)
  c(10) = 5.0
  show: ;
  type show, set, or run:

"set" is used to change constants. Changes remain in effect until reset or the run is terminated. "set" is also terminated by ";".
for example:

  type show, set, or run: set
  set: c(10)=7.0,tc(c)=3.5,switch(99)=1;
  type show, set, or run:

"run" is used to begin execution.

************** start program statements *********************

common time
common/dt/dt
common /t/ tnam(75),tmxx(35),ttim(35),tcnt(35)
common/graph/put,max,min,flo,fup,opsym,ii,input
common/system/v(1000),c(1000),tc(1000),t1
common/energy/ctime
common/switch/switch(100)
integer switch
integer indgo, lnogo, wtrgo, demgo, polgo, envgo
integer opsym(10),ii(10)
real flo(10),fup(10)
real put(10),max(10),min(10)
c model termination date, iteration time interval, and
time between ordering decisions.
tstop=2000.0
dt=0.1
t1=1.0
c time after which development scenario is held constant
time=0.0
c data needed for plot routine
nprint=10
input=6
c default value for coal development scenario being simulated
ncdp=6

c switch array (0 is off, 1 is on)
c
do 5 i=1,10
   switch(i)=0
5 continue

c subroutine switches (0 is off, 1 is on)
c
   indgo=1
   wtrgo=1
   lndgo=1
demgo=1
   polgc=1
   envgo=1
   mingo=1

data mingo/1/
c output arrays
c
do 6 i=1,10
   flo(i)=0.
   fup(i)=0.
6 continue

c set output symbols
c
data oopsym/0,'1','2','3','4','5','6','7','8','9','A','B','C','D','E','F'/
c initialize constants
c
call wcrco

c continue

c prompts for 5 variables to be plotted
call output(ii)
c

c initialize dictionaries
call indic
do 305 i=1,35
305  tnam(i)=0.0
   do 315 i=1,10
      max(i)=-1.0e10
      min(i)=+1.0e10
315  continue

  initialize variable array
  
   do 101 i=1,1000
      v(i)=0.0
101  continue

  initialize levels
  
   call wcrin
   time=1970.0

  following statement permits the use of set statements to
  alter constants, initial values, default values, etc.
  for any given simulation. (see instructions for making
  simulations). Subroutine wcrcat is written in pl1.
  
   call wcrcat(v,tc,switch,ncdp,flo,fup,tstop,time)

  tpy is an abbreviation for tons per year
  initial synthetic fuel capacity million tpy
   v(14)=energy(3,ncdp,1970.0)/c(3)
  initial electrical generation nominal capacity tpy
   v(55)=energy(1,ncdp,1970.0)/c(38)
  initial coal export capacity million tpy
   v(80)=energy(2,ncdp,1970.0)
  initial coal mine capacity million tpy
   v(825)=totccl(ncdp,1970.0)

  -----------------------------------------------
   krate=1
   go to 500

20  continue
   kput = 1
   go to 600

40  continue
   if(time.ge.tstop) goto 95
   krate = 2
   kput = 2
50  continue
   kpr=0
55  time=time+dt
   go to 500

70  continue
   kpr=kpr+1
   if(kpr.le.nprint-1) goto 55
   go to 600
c continue
if(time .lt. tstop-dt) go to 50
-----------------------------
95 continue
if (switch(99).eq.1) write(21,99)
98 format(* 014*)
rewind 20
c call graph
c go to 10
-----------------------------
c preliminary output subroutine
c 600 continue
c c put(*)=output var
 c put(1)=time
 do 700 i=1,nput-1
  put(i+1)=v(i)(i))
700 continue
do 620 i=2,nput
if(max(i).lt.put(i)) max(i)=put(i)
if(min(i).gt.put(i)) min(i)=put(i)
620 continue
write(20) (put(i),i=1,nput)
c for output table, set switch(99)=1
if(switch(99).eq.1)write(6,99),(put(i),i=1,nput)
if(switch(99).eq.1)write(21,90),(put(i),i=1,nput)
99 format(1h ,6f10.?)
c go to (40,90), kput
c -----------------------------
c 500 continue
c c sector subroutines
c call wcrint(ncdp,indgo)
call wcmin(ncdp,mingo)
call wcwtr(wtrgo)
call wcddem(demgo)
call wcrlnd(lmdgo)
call wcenv(envgo)
call wcrool(polgo,ncdp)
c go to (29,70), krate
end
This sector simulates the growth of the coal industries in the region so as to provide data for impacts of these industries in other model sectors, and to accept feedback which may influence the growth of the industries. The sector is divided into three subsectors: synthetic fuel production, electrical generation, and coal export. There are three principle exogenous inputs to the sector: these are the assumed scenarios for synthetic fuels, electricity, and for coal export capacity in the region. These exogenous variables are the primary "driving forces" of the model and thus determine the relative magnitude of development, impacts, etc.

The decisive process for each of the subsectors is the ordering and construction of new facilities. It is assumed that the scenarios represent economically and/or politically "desirable" developments which utility management will try to attain. However, the desired rates of acquiring new capacity may be modified by several other factors, such as "political climate" for industrial growth, labor shortages, water shortages, etc.

The basic unit of energy is one million tons of coal (at 9000 btu/lb). In addition, for the electrical generation subsector the model also calculates the number of "standard 1000 megawatt electrical generation (mwe) plants", and for the synthetic fuel subsector the number of "standard 250 million standard cubic feet per day (scf/d) plants".

The following text generally describes all three subsectors. The program begins in each subsector by calculating scenario planned capacities v(3), v(3P), v(73) for each of the industries by calling the function "energy" which contains the data for the scenarios being modeled. Note that these three calculations are made for times tc(3), tc(3P), and tc(73) into the future; these planning horizon time constants are the perceived times for construction of the three different types of facilities. For synthetic fuels and electrical generation the scenarios must be divided by the nominal capacity utilizations of these two industries, c(3) and c(3P), since the scenarios are for energy output and the model uses plant capacity. The model assures, for planning purposes, full use of export capacity. By setting switch (02) to a value of 1, the model will transfer all demand for energy to the export sector.

The next actions are to determine construction, planning, and regulatory delays that may be influenced by labor shortages and political climate for industrial growth, and to set the delay variables in the subsectors. Following this, the model determines plant and capacity depreciation rates. In the case of electrical generation the plants are derated rather than depreciated since older plants are generally used less and less.
The variables which initiate ordering are the capacity initiation rates $v(5)/v(40)/v(75)$. They are calculated from the deficit between scenario planned capacities and what is expected to be on line at the planning horizon times (present capacities plus those in planning and construction less those that will have also been depreciated). These rates can also be influenced by possible coal shortages and may be influenced by water shortages, if desired (by setting switch (01) to 1). Lastly, the subsectors calculate future coal needs to be used for coal mine planning in the mine sector.

Applicable switches in the sector (default value is 0 = off)

<table>
<thead>
<tr>
<th>Switch number</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Hypothetical water shortage feedback</td>
</tr>
<tr>
<td>02</td>
<td>Total export option</td>
</tr>
<tr>
<td>40</td>
<td>Political climate feedback</td>
</tr>
<tr>
<td>04</td>
<td>Construction labor shortage feedback</td>
</tr>
</tbody>
</table>

The Fermi function of political climate index, $Fermi$ has a value of $1/2$ at an index of $-0.1$.

The Fermi function is:

$$PCI = c(420)$$

$$PCI = v(420)$$

$$V(419) = tc(819)+tc(818)/(1.0+exp((PCI+0.1)/0.15))$$

$$TC(807) = V(819)$$

Coal mine construction delay time (nominal time divided by 10)
by one less the fractional constructional labor shortage years

c \( v(26) = t_c(26) \)
if \( v(23) < 0.0 \) \( v(23) = 0.0 \)
if(switch(04).eq.1) \( v(26) = t_c(26)/(1.0-v(23)) \)

c ------------------ synthetic fuel subsector ------------------

tpy is an abbreviation for tons per year

c synthetic fuel scenario (output) million tpy
\( v(1) = \text{energy}(3, \text{ncdp}, \text{time}) \)

cyn fuel scenario planned capacity million tpy (tcsf is the the planning horizon time, \( t_c(3) \), shortened by the Fermi function for times near the model starting time)
\( t_csf = t_c(3) \times (1.0/(1.0+\text{exp}((\text{time}-1970.0)/1.7))) \)
\( v(3) = c(2) \times \text{energy}(3, \text{ncdp}, \text{time}+t_csf)/c(3) \)

c total export option
if(switch(02).eq.1) \( v(3) = 0 \)

c synthetic fuel planning delay plus regulatory delay years
(see also analogous note for coal mine planning delay)
\( v(22) = t_c(22)+t_c(21)/(1.0+\text{exp}((\text{pci}+0.1)/0.15)) \)
\( t_c(6) = v(22) \)

c synthetic fuel construction delay time (nominal time divided by one less the fractional construction labor shortage years the total delay is apportioned into the three delay macro functions in a manner to better model the construction process)
\( v(26) = t_c(26) \)
if(switch(04).eq.1) \( v(26) = t_c(26)/(1.0-v(23)) \)

c synthetic fuel construction time constants years
\( t_c(9) = 0.1875 \times v(26) \)
\( t_c(10) = 0.1875 \times v(26) \)
\( t_c(12) = 0.6250 \times v(26) \)

c synthetic fuel water shortage multiplier (hypothetical)
\( v(23) = 1.0 \)
if(switch(01).eq.1) \( v(23) = (\sin(v(143) \times 3.14159/2.0))^{2.0} \)

c initialize synthetic fuel capacity in planning and in construction to steady state in 1970 (for syn fuel, nothing is assumed to be in planning or in construction in 1970)
if(time.gt.1970.0) go to 20
\( v(6) = \text{delay3}(v5, vtemp1, t_c(6), v(7)) \)
\( v(8) = \text{delay3}(v6, vtemp1, t_c(8), v(9)) \)
\( v(10) = \text{delay3}(v8, vtemp1, t_c(10), v(11)) \)
\( v(12) = \text{delay3}(v10, vtemp1, t_c(12), v(13)) \)

20 continue

c initialize coal shortage allocation function(assume no shortage in 1970)
if(time.eq.1970.0) \( v(823) = 1.0 \)

c synthetic fuel plant average lifetime years (initialize as if all previous plants were new in 1970)
\( t_c(16) = t_c(15)/2.0 \)
\begin{align*}
\text{tc}(18) &= \text{tc}(15)/2.0 \\
\text{if}(\text{time} \leq 1970.0)\quad \text{v}(16) &= \text{dlinf}3('v12'\cdot 0.0\cdot \text{tc}(16)) \\
\text{else}\quad \text{v}(16) &= \text{dlinf}3('v12'\cdot \text{v}(12)\cdot \text{tc}(16)) \\
\text{v}(18) &= \text{dlinf}3('v16'\cdot \text{v}(16)\cdot \text{tc}(18)) \\
\end{align*}

\text{c synthetic fuel capacity depreciation rate} \quad \text{million toy/year} \\
\text{v}(15) &= \text{v}(18) \\
\text{c synthetic fuel capacity in construction} \quad \text{million toy} \\
\text{v}(25) &= \text{v}(9) + \text{v}(11) + \text{v}(13) \\
\text{c synthetic fuel future capacity deficit} \quad \text{million toy} \\
\text{v}(4) &= \text{amax}1(\text{v}(3) - (\text{v}(14) + \text{v}(25) + \text{v}(7) - \text{v}(15) \cdot \text{tc}(3)) \cdot 0.0) \\
\text{c synthetic fuel capacity initiation rate} \quad \text{million toy/year} \\
\text{c (if an excess is evident, the deficit is taken as 0)} \\
\text{c (the functional relationships are to prevent unreal} \\
\text{c ordering rates even when deficits are very large; c(5) is max rate)} \\
\text{v}(5) &= \text{v}(23) \cdot \text{v}(23) \cdot \text{c}(5) \cdot \sin(1.11 \cdot \text{v}(4) / \text{c}(5)) / \text{t1}) \\
\text{if}(\text{v}(4) \geq 1.42 \cdot \text{c}(5))\quad \text{v}(5) &= \text{c}(5) \\
\text{c synthetic fuel construction initiation rate} \quad \text{million toy/year} \\
\text{v}(6) &= \text{delay}3('v5'\cdot \text{v}(5)\cdot \text{tc}(6)\cdot \text{v}(7)) \\
\text{c synthetic fuel capacity coming on line} \quad \text{million toy/year} \\
\text{c (that is, the amount coming out of the last delay macro, v(12))} \\
\text{v}(8) &= \text{delay}3('v6'\cdot \text{v}(6)\cdot \text{tc}(8)\cdot \text{v}(9)) \\
\text{v}(10) &= \text{delay}3('v8'\cdot \text{v}(8)\cdot \text{tc}(10)\cdot \text{v}(11)) \\
\text{v}(12) &= \text{delay}3('v10'\cdot \text{v}(10)\cdot \text{tc}(12)\cdot \text{v}(13)) \\
\text{c synthetic fuel standard plants (number)} \\
\text{v}(20) &= \text{v}(14) / \text{c}(20) \\
\text{c synthetic fuel standard plants under construction (number)} \\
\text{v}(28) &= \text{v}(25) / \text{c}(20) \\
\text{c synthetic fuel future coal capacity} \quad \text{million toy} \\
\text{c (present capacity + current mine planning and construction} \\
\text{c delay times multiplied by the difference between current} \\
\text{c synthetic fuel plant completion and depreciation rates times the} \\
\text{c nominal capacity utilization factor. This number is used} \\
\text{c for planning new coal mine development)} \\
\text{v}(24) &= (\text{v}(14) + (\text{tc}(807) + \text{v}(826)) \cdot (\text{v}(12) - \text{v}(15))) \cdot \text{c}(3) \\
\text{c synthetic fuel current coal needs} \quad \text{million toy} \\
\text{v}(27) &= \text{v}(14) \cdot \text{c}(3) \\
\text{c synthetic fuel capacity level equation} \quad \text{million toy} \\
\text{v}(14) &= \text{v}(14) + \text{dt} \cdot (\text{v}(12) - \text{v}(15)) \\
\text{--- electrical generation subsector ---} \\
\text{c electric generation scenario (coal input) million toy} \\
\text{v}(37) &= \text{energy(1\cdot \text{ncdp}\cdot \text{time})} \\
\text{c electric generation scenario planned capacity} \quad \text{million toy} \\
\text{c (see also the note for analogous synfuel statement)} \\
\text{tceg} &= \text{tc}(38) \cdot (1.0 - (1.0 / (1.0 + \exp((\text{time} - 1970.0) / 1.7))) \\
\text{v}(38) &= \text{c}(36) \cdot \text{energy(1\cdot \text{ncdp}\cdot \text{time} + \text{tceg})} / \text{c}(38) \\
\text{c total export option} \\
\text{if}(\text{switch(G2).eq.1})\quad \text{v}(38) &= 0.0 \\
\text{c electrical generation planning plus regulatory delay years} \\
\text{c (see also the note above for analogous coal mine delays)} \\
\end{align*}
\[ v(56) = tc(56) + tc(55)/(1.0+\exp((pc(0.1)/0.15)) \]
\[ tc(41) = v(56) \]

c electrical generation construction delay function (including c labor shortage effects years) (see also the note for c analogous synfuel statement)
\[ v(61) = tc(61) \]
\[ if(switch(04) .eq. 1) v(61) = tc(61)/(1.0-v(32)) \]
\[ tc(43) = 0.1875*v(61) \]
\[ tc(45) = 0.1875*v(61) \]
\[ tc(47) = 0.0625*v(61) \]

c electrical generation water shortage multiplier (hypothetical) c (see also the note for analogous synfuel statement)
\[ v(57) = 1.0 \]
\[ if(switch(01) .eq. 1) v(57) = (\sin(v(143) * 3.14159/2.0))^2.0 \]

c initialize electrical generation capacity in planning and in c construction to steady state in 1970 c (difference in 1970 between future planned capacity and c present existing capacity divided by 1 + the total time c through the planning and construction processes)
\[ if(time .eq. 1970.0) go to 30 \]
\[ vtemp2 = (v(3p) - v(55))/(1.0 + v(61) + tc(41)) \]
\[ v(41) = delay3('v40', vtemp2, tc(41), v(40)) \]
\[ v(43) = delay3('v41', vtemp2, tc(43), v(44)) \]
\[ v(45) = delay3('v42', vtemp2, tc(45), v(46)) \]
\[ v(47) = delay3('v43', vtemp2, tc(47), v(48)) \]

30 continue

c electrical generation plants mean age years c (in the model the electrical plants are not physically c depreciated because it is assumed that the modeling time c does not go out far enough. However, their utilization c factors are degraded with time. A mean age c is needed for this)
\[ if(time .eq. 1970.0) v(50) = v(55) * time \]
\[ v(51) = 0.0 \]
\[ if(v(55) .gt. 0.0) v(51) = time - v(50)/v(55) \]

c electrical generation load factor c (new plants are assumed to operate at a load factor of c 80% for the first 9 years)
\[ v(52) = 0.0 + 0.4*(v(51) - 9.0)/28.0 \]
\[ if(v(52) .lt. 0.0) v(52) = 0.0 \]
\[ if(v(51) .lt. 9.0) v(52) = 0.8 \]

c electrical generation normal utilized capacity million tpy c (statements for v(62) through v(64) are used to determine c how much existing capacity will be degraded during the c planning horizon time interval for electrical plants)
\[ v(62) = v(51) + tc(38) \]
\[ v(63) = ((v(62) - 9.0)/tc(29)) \]
\[ if(v(62) .lt. 9.0) v(63) = 0.0 \]
\[ if(v(62) .gt. 9.0 .and. v(62) .le. 9.0 + tc(38)) v(63) = (1*0.0143) \]
if(v(62).gt.9.0+tc(38)) v(63)=0.0143

c elec. gen. planned capacity depreciation rate

v(64)=v(63)*v(55)

c million toy per year

v(65)=v(51)+tc(807)+v(826)

c (as for planning electrical plants, statements for v(65)
c through v(67) degrade the utilization over the planning
c horizon time interval for coal mines)

c elec. gen. coal use depreciation planning age years

v(65)=v(51)+tc(807)+v(826)

c elec. gen. coal use depreciation planning fraction per year

if(v(65).le.9.0) v(66)=0.0

if(v(65).lt.9.0+tc(807)+v(826)) v(66)=((v(65)-9.0)/
tc(807)+v(826)))*0.0143

if(v(65).lt.9.0+tc(807)+v(826)) v(66)=0.0143

c elec. gen. planned coal use depreciation million toy/year

v(67)=v(66)*v(55)

c electrical generation capacity in construction million toy

v(60)=v(44)+v(46)+v(45)

c electrical generation future capacity deficit million toy

v(39)=max(v(39)-v(55)/c(39)+v(45)+v(47)-v(67)+tc(38)),0.0)

c electrical generation capacity initiation rate million toy/yr

c (the functions prevent unduly large ordering rates)

v(40)=v(823)*v(57)*c(40)*sin(1.11*v(39)/c(40))/t1)

if(v(39).ge.1.42+c(40)) v(40)=c(40)

c electrical generation construction initiation rate million
c tpy/year

v(41)=delay3('v40',v(41),tc(41),v(42))

c electrical generation capacity coming on line million toy/yr

c (see also note for analogious synfuel statements)

v(43)=delay3('v41',v(43),tc(43),v(44))

v(45)=delay3('v43',v(45),tc(45),v(46))

v(47)=delay3('v45',v(47),tc(47),v(48))

c electrical generation standard 100^" mwe plants (number)

v(54)=v(55)/c(54)

c electrical generation effective standard 1000 mwe plants

v(59)=v(53)/c(54)

c electrical generation standard plants under construction (number)

v(68)=v(60)/c(54)

c electrical generation future coal capacity million toy

c (present utilized capacity + rates added - rates depreciated
c taken over the total mine planning + construction times)

v(58)=v(53)+(v(47)-v(67))*c(38)*tc(807)+v(826))

c time weighted electrical generation growth

v(49)=v(47)*time

c
c electrical generation level equations

c electrical generation nominal capacity million toy

v(55)=v(55)+dt*v(47)

c time weighted electrical generation capacity

v(50)=v(50)+dt*v(49)

c

------------------- coal export subsector --------------------

c
c coal export scenario million tpy
  v(71)=energy(2,ncdp,time)

c coal export scenario planned capacity million tpy
  c (see also note for analogous synfuel statements)
  tcce=tc(73)*(1.0-(1.6/(1.0+exp((tire-1°70.0)/1.7))))
  v(73)=c(72)*energy(2,ncdp,time+tcce)

c total export option
  if(switch(02).eq.1) v(73)=v(72)*totcol(ncdp,time+tc(73))

v(72)=v(72)*totcol(ncdp,time+tc(73))

c coal export planning plus regulatory delay years
  c (see also note for analogous statements concerning coal
  c mine planning at the beginning of this sector description)
  v(87)=tc(P7)+tc(86)/(1.0+exp((pci+0.1)/0.15))
  tc(76)=v(87)

c coal export construction delay function (including labor short-
c age effects years (see also note for analogous synfuel)
  v(91)=tc(91)
  if(switch(04).eq.1) v(91)=tc(91)/(1.0-v(232))
  tc(78)=0.1875*v(91)
  tc(92)=0.1875*v(91)
  tc(94)=0.6250*v(91)

c fraction exported by slurry pipeline
  v(89)=c(89)

c coal export water shortage multiplier (hypothetical)
  v(88)=1.0
  if(switch(01).eq.1) v(88)=1.0-v(89)*(sin(v(143)*3.14159/2.0)+0.5

c steady state in 1970. (see also note for analogous statements
  c in electrical generation subsector)
  if(time.gt.1970.0) go to 40
  vtemp3=(v(73)-v(SO))/(1.0+tc(76)+v(91))
  v(76)=delay3('v75',vtemp3,tc(76),v(77))
  v(78)=delay3('v76',vtemp3,tc(78),v(79))
  v(92)=delay3('v92',vtemp3,tc(92),v(92))
  v(94)=delay3('v94',vtemp3,tc(94),v(95))

40 continue

c coal export capacity average lifetime years (initialize as
  c if all capacity were new in 1970)
  tc(82)=tc(81)/2.0
  tc(84)=tc(81)/2.0
  if(time.eq.1970.0) v(P2)=dlinf3('v78',0.5,tc(82))
  if(time.gt.1970.0) v(82)=dlinf3('v94',v(94),tc(82))
  v(84)=dlinf3('v92',v(82),tc(84))

vc coal export capacity depreciation rate million tpy/year
  v(81)=v(81)

c coal export capacity under construction million tpy
  v(86)=v(79)+v(93)*v(95)

c coal export future capacity deficit million tpy
  v(74)=amax1(v(73)-v(80)+v(86)+v(77)-v(81)+tc(73)),0.0)

c coal export capacity initiation rate million tpy/year
  c (see also note for analogous synfuel statements)
  v(75)=v(232)*v(88)*tc(75)*sin(1.11*v(74)/c(75))/t1)
  if(v(74)>1.42*c(75)) v(75)=c(75)

c coal export capacity construction initiation rate million
c tpy/year
    v(76)=delay3('v75',v(75),tc(76),v(77))

v(78)=v(76)+delay3('v76',v(76),tc(78),v(79))

v(92)=delay3('v82',v(82),tc(92),v(93))

v(94)=delay3('v92',v(92),tc(94),v(95))

v(90)=v(90)+(tc(80)+v(826))*(v(94)-v(81))

c coal export capacity level equation million tpy
v(80)=v(80)+dt*(v(94)-v(81))

c return

c end
This sector models the growth of coal mines in response to the user industries and keeps an accounting of coal reserves and resources.

The coal mining subsector structure is very similar to the user industries, and the annotation for WCRind will explain the modeling rationale.

The reserves subsector removes coal from reserves according to mine output and initiates exploration to convert resources into reserves when the static reserve index gets too low. As resources are depleted, it becomes more difficult to prove up reserves, and more land must be stripped per unit of production.

Applicable switches (set to 1 to activate, default value is 0)

<table>
<thead>
<tr>
<th>Switch Number</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3</td>
<td>Political climate feedback</td>
</tr>
<tr>
<td>04</td>
<td>Construction labor shortage feedback</td>
</tr>
</tbody>
</table>

---

Mining sector file name

subroutine WCRmin(ncip,mingo)

integer mingo

common statements

common/system/v(1000),c(1000),tc(1000),t1

common time

common/dt/dt

switch link statements

common/switch/switch(100)

integer switch

See industry sector description concerning analogous indgo

if(mingo.eq.0) return
if(mingo.gt.0) go to 10
if(mingo.lt.0) mingo=mingo+1

10 continue

-------------- coal mining subsector ---------------

Coal mine planning delay plus regulatory delay years calculated in WCRind

Coal mine construction delay time (including labor shortage effects) years calculated in WCRind

Coal mine construction time constants years

\[ tc(809) = 0.1875 \cdot v(826) \]
\[ tc(828) = 0.1875 \cdot v(826) \]
\[ tc(830) = 0.6250 \cdot v(826) \]
c tpy is an abbreviation for tons per year

c future coal needs million tpy
\[ v(816) = v(24) + v(58) + v(90) \]

c initialize coal mine capacity in planning and construction to c steady state in 1970

\[
\begin{align*}
\text{if}(\text{time} . \gt . 1970.0) \text{ go to } 20 \\
v\text{temp4} & = (v(816) - v(825)) / (1.0 + tc(807) + v(826)) \\
v(807) &= \text{delay}3\left( v(806) \cdot v\text{temp4} \cdot tc(807) \cdot v(808) \right) \\
v(809) &= \text{delay}3\left( v(807) \cdot v\text{temp4} \cdot tc(809) \cdot v(810) \right) \\
v(828) &= \text{delay}3\left( v(809) \cdot v\text{temp4} \cdot tc(828) \cdot v(829) \right) \\
v(830) &= \text{delay}3\left( v(828) \cdot v\text{temp4} \cdot tc(830) \cdot v(831) \right)
\end{align*}
\]

20 continue

c coal mine average lifetime years (initialize as if all c mines are new in 1970)
\[ tc(812) = tc(811) / 2.0 \]

\[
\begin{align*}
\text{if}(\text{time} \leq 1970.0) & \ v(812) = d\text{linf3}\left( v(830) \cdot 0.0 \cdot tc(812) \right) \\
\text{if}(\text{time} . \gt . 1970.0) & \ v(812) = d\text{linf3}\left( v(830) \cdot v(832) \cdot tc(812) \right)
\end{align*}
\]

c coal mine depreciation rate million tpy/year
\[ v(811) = v(814) \]

c coal mines under construction million tpy
\[ v(832) = v(810) + v(829) + v(831) \]

c future coal mine capacity deficit million tpy
\[ v(817) = \text{amax1}\left( v(816) - (v(875) + v(832) + v(808) - v(811) \cdot (tc(807) + v(826))) \right) \]

1.0

c current coal capacity needs million tpy
\[ v(807) = v(53) + v(27) + v(80) \]

c fractional coal shortage v(820) = 0.0

\[
\begin{align*}
\text{if}(\text{time} \leq 1970.0) & \ v(820) = v(825) \\
\text{if}(v(821) . \gt . v(825)) & \ v(820) = (v(821) - v(825)) / v(825)
\end{align*}
\]

c long term (averaged) fractional coal shortage
\[ v(821) = d\text{linf1}\left( \text{vP?C} \cdot v(820) \cdot tc(821) \right) \]

c coal shortage allocation function
\[ v(823) = 1.0 - v(821) \]

c coal mine output million tpy
\[ v(802) = \text{amin1}\left( v(801) \cdot v(825) \right) \]

c coal mine utilization
\[ v(803) = 1.0 \]

\[
\begin{align*}
\text{if}(v(825) . \gt . 0.0) & \ v(803) = v(802) / v(825) \\
c \text{coal mine average utilization} & \ v(804) = d\text{linf1}\left( \text{v803} \cdot v(803) \cdot tc(804) \right)
\end{align*}
\]

c static reserve index multiplier
\[ v(824) = 1.0 \]

\[
\begin{align*}
\text{if}(v(848) . \lt . 1.0) & \ v(824) = (\sin ((v(848) / 10.0) \cdot (3.14159 / 2.0))) \cdot 0.3 \\
\text{if}(\text{time} \leq 1970.0) & \ v(824) = 1.0
\end{align*}
\]

c coal mine capacity initiation rate million tpy/year
\[ v(806) = v(824) \cdot v(804) \cdot \text{amax1}\left( (v(817) / t1 \cdot 0.0) \right) \]

c coal mine construction initiation rate million tpy/year
\[ v(807) = \text{delay3}\left( v(806) \cdot v(806) \cdot tc(807) \cdot v(808) \right) \]

c coal mine capacity coming on line million tpy/year
\[ v(809) = \text{delay3}\left( v(807) \cdot v(807) \cdot tc(809) \cdot v(810) \right) \]
\[ v(828) = \text{delay3('v809', v(809), tc(828), v(829))} \]
\[ v(830) = \text{delay3('v828', v(828), tc(830), v(831))} \]

\section*{Coal Mine Capacity Level Equation Million Tpy}
\[ v(825) = v(825) + dt*(v(830) - v(811)) \]

\section*{Total Coal Mine Production Scenario Million Tpy}
\[ v(827) = \text{totcol(ncdp, time)} \]

\section*{Coal Reserve Subsector}

\section*{Coal Extraction Rate Million Tpy}
\[ v(841) = v(802) \]

\section*{Average Coal Extraction Rate Million Tpy}
\[ v(845) = \text{dlinf1('v841', v(841), tc(845))} \]

\section*{Static Reserve Index Years}
\[ v(847) = 11.0 \]
\[ \text{if}(v(841) > 0.0) \]
\[ \text{v(847) = v(842)/v(841)} \]

\section*{Average Static Reserve Index Years}
\[ v(848) = \text{dlinf1('v847', v(847), tc(848))} \]

\section*{Perceived Exploration Needs}
\[ v(850) = 0.0 \]
\[ \text{if}(v(848) < 20.0) \]
\[ v(850) = 10.0*(1.0-(\sin((v(848)/20.0)*(3.1415/2.10)))**0.3) \]

\section*{Resource Depletion Ratio}
\[ v(851) = v(844)/(c(851)-v(844)) \]

\section*{Coal Grade Reserves Proving Multiplier}
\[ v(852) = 1.0 \]
\[ \text{if}(v(851) < 7.0) \]
\[ v(852) = (\sin((v(851)/7.0)*(3.1415/2.0)))**2.0 \]

\section*{Reserve Proving Rate Million Tpy}
\[ v(843) = v(845)*v(850)*v(852) \]

\section*{Coal Grade Land Stripping Multiplier}
\[ v(853) = 1.0 \]
\[ \text{if}(v(851) < 7.0) \]
\[ v(853) = (\sin((v(851)/7.0)*(3.1415/2.0)))**(-2.0) \]

\section*{Coal Reserves Level Equations}

\section*{Coal Reserves Tons}
\[ v(842) = v(842) + dt*(v(842) - v(841)) \]

\section*{Coal Resources Remaining Millions Tons}
\[ v(844) = v(844) - dt*v(843) \]

return
end
COAL RESERVES SUBSECTOR

WCRMIN

ORIG. COAL RESOURCES

COAL RESERVES

V(842)

COAL RESOURCES REMAINING

V(844)

resource depn. ratio

V(851)

coal grade landstripping mult.

V(853)

RESERVE PROVING RATE

V(843)

coal grade reserves prov. mult.

V(852)

perceived expl. needs

V(850)

COAL RESERVES

V(842)

stat. res. index

V(847)

static res. index mult.

V(824)

AVER.STATIC RES. INDEX

V(848)

coalg. output

V(802)

COAL EXTRACTION RATE

V(841)

ava. coal extr. rate V(845)

perceived expl. needs
The demographic sector calculates the number of laborers required to construct and operate the mines, conversion plants and export facilities specified by the industrial sector of the model. This industrial labor force together with an exogenously determined agricultural labor force \( v(214) \) and other primary labor \( v(229) \) (primary manufacturing, recreation, etc.) work through multipliers to determine the needed public \( v(225) \) and private \( v(223) \) service labor. The available service labor \( v(226,224) \) is a time delayed function of the indicated service labor categories. Public and private service indices \( v(229,230) \) are indications of how well the need for service labor is being met.

Total population \( v(227) \) is determined by applying specific family multipliers to the various labor forces plus the exogenously determined Indian population \( v(215) \). Indians in the industrial labor force are accounted for separately \( v(208,210,216) \). This allows some flexibility to accommodate possible large and abrupt increases in Indian employment through specific Indian employment clauses in future leases for coal on the reservations.

A boom index (A. Ford, 1976) is calculated \( v(232) \) as a function of service shortages. Boom conditions cause a decrease in construction worker productivity \( v(235) \) and an increase in service delay times \( v(236) \), thus aggravating the boom conditions.

Note that there is no way of analyzing local "boom and bust" cycles related to local development. It is quite possible that specific towns within the region will experience a relatively large influx of construction labor and related service personnel and, after the construction phase is completed, the construction labor will move to a new site still within the region but far enough away from the first site so that town experiences a "bust" in population. Such an effect could not be recorded in this aggregated model of the region.

Demographic variables are aggregated over the entire region.

Switches (default value = 0)

- set switch(21)=1 to exclude Indian reservations population
- set switch(22)=1 to stabilize agricultural labor at 1975 level

************ start program statements ************
if (demgo.eq.0) return 
if (demgo.gt.0) goto 10 
if (demgo.lt.0) demgo=demgo+1 

continue

operations labor  (number of workers)

electrical operations labor 
$ v(240) = c(201)*v(54) $ 

synfuel operations labor 
$ v(241) = c(202)*v(20) $ 

export operations labor 
$ v(242) = c(203)*v(80) $ 

mine operations labor 
$ v(243) = c(204)*v(80) $ 

industrial operations labor 
$ v(201) = v(240) + v(241) + v(242) + v(243) $ 

construction labor  (number of workers)

electrical generation construction labor 
$ v(202) = c(205)*v(48)/(tc(61)*0.6250*c(54)) $ 

synthetic fuel construction labor 
$ v(203) = c(206)*v(13)/(tc(26)*0.6250*c(20)) $ 

export construction labor 
$ v(204) = c(207)*v(86)/tc(91) $ 

mining construction labor 
$ v(205) = c(208)*v(932)/tc(526) $ 

indicated industrial construction labor 
$ v(206) = v(202) + v(203) + v(204) + v(205) $ 

boom construction productivity multiplier 
$ v(235) = 0.5 + 0.5((1.0 + exp((v(234) - 0.21)/0.055))) $ 

industrial construction labor 
if (switch(25).eq.0) v(206) = v(206)/v(235) 

construction work force 
$ v(211) = v(209) + v(210) $ 

construction labor/employment ratio 
if (v(211).eq.0) v(212) = 1.0 
if (v(211).gt.0) v(212) = v(206)/v(211) 

construction labor deficit 
$ v(213) = v(206) - v(211) $ 

reference agricultural labor 
$ v(214) = 0.63*4292.0*exp(-0.0239*(time-1970.0)) $ 
if (switch(22).eq.1 and time.ge.1975.0) v(214) = 2400.0 

reference indian population 
$ v(215) = 4125.0*exp(0.0164*(time-1970.0)) + 2674*exp(0.0301*(time-1970
if(switch(21).eq.1) v(215)=0.0

\[ \text{c indian industrial work force fraction} \]
\[ v(216)=0.0 \]
\[ \text{if}(v(215)>.0) v(216) = \frac{c(225)}{(1.0+r}\exp\left(\frac{(v(208)+v(210))}{v(215)}\right)\frac{1-0.13}{0.025}) \]

\[ \text{c nonindian construction labor transfer rate} \]
\[ \text{if}(v(213).ge.0.0) v(217) = (1.0-v(216))*v(213)/tc(217) \]
\[ \text{if}(v(213).lt.0.0) v(217) = (1.0-v(216))*v(213)/tc(218) \]

\[ \text{c indian construction labor transfer rate} \]
\[ \text{if}(v(213).ge.0.0) v(218) = v(216)*v(213)/tc(219) \]
\[ \text{if}(v(213).lt.0.0) v(218) = v(216)*v(213)/tc(220) \]

\[ \text{c operations work force} \]
\[ v(219) = v(207)+v(208) \]

\[ \text{c operations labor deficit} \]
\[ v(220) = v(207)-v(219) \]

\[ \text{c nonindian operation labor transfer rate} \]
\[ \text{if}(v(220).ge.0.0) v(221) = (1.0-v(216))*v(220)/tc(221) \]
\[ \text{if}(v(220).lt.0.0) v(221) = (1.0-v(216))*v(220)/tc(222) \]

\[ \text{c indian operation labor transfer rate} \]
\[ \text{if}(v(220).ge.0.0) v(222) = v(216)*v(220)/tc(222) \]
\[ \text{if}(v(220).lt.0.0) v(222) = v(216)*v(220)/tc(230) \]

\[ \text{c other primary labor} \]
\[ v(229) = c(230) \]

\[ \text{c indicated private service labor} \]
\[ v(233) = c(209)*v(214)+c(210)*v(208)+c(211)*v(207)+c(212)*v(209)+c(213)*v(207)+c(214)*v(208)+c(215)*v(207)+c(216)*v(209)+c(217)*v(207)+c(218)*v(209)+c(219)*v(208)+c(220)*v(207)+c(221)*v(209)+c(222)*v(207)+c(223)*v(209)+c(224)*v(207)+c(225)*v(209)+c(226)*v(207)+c(227)*v(209)+c(228)*v(207)+c(229)*v(209) \]

\[ \text{c private service labor} \]
\[ v(237) = tc(224) \]
\[ \text{if}(\text{switch}(26).eq.0) v(237) = v(237)/v(236) \]
\[ v(224) = \text{dlinf1('v224',v(224),v(237))} \]

\[ \text{c indicated public service labor} \]
\[ v(225) = c(214)*v(214)+c(215)*v(208)+c(216)*v(207)+c(217)*v(209)+c(218)*v(208)+c(220)*v(207)+c(221)*v(209)+c(222)*v(207)+c(223)*v(209)+c(224)*v(207)+c(225)*v(209)+c(226)*v(207)+c(227)*v(209) \]

\[ \text{c public service labor} \]
\[ v(238) = tc(226) \]
\[ \text{if}(\text{switch}(26).eq.0) v(238) = v(238)/v(236) \]
\[ v(226) = \text{dlinf1('v226',v(225),v(238))} \]

\[ \text{c total population} \]
\[ v(227) = c(219)*v(214)+c(220)*v(207)+v(215)+c(222)*v(226)+c(223)*v(227)+c(224)*v(224)+c(225)*v(224)*(1.0+\exp((v(234)-0.165)/0.04)) \]
\[ \text{c public service labor index} \]
\[ v(228) = v(226)/v(225) \]

\[ \text{c private service labor index} \]
\[ v(23c) = \frac{v(224)}{v(223)} \]

- **boom index**
  \[ v(233) = \left( \frac{0.5}{v(228)} + \frac{0.5}{v(23c)} \right) - 1.0 \]

- **average boom index**
  \[ v(234) = \text{dlinf1('v234', v(233), tc(234))} \]

- **urban population**
  \[ v(231) = c(231) * (v(227) - v(215) + v(214) * c(219)) \]

- **fractional construction labor shortage**
  \[ v(232) = 0.0 \]
  \[ \text{if}(v(206) \neq 0.0) \quad v(232) = \frac{(v(206) - v(211))}{v(206)} \]

- **level equations**

  - **nonindian operations labor**
    \[ v(207) = v(207) + dt * v(221) \]

  - **indian operations labor**
    \[ v(208) = v(208) + dt * v(222) \]

  - **nonindian construction labor**
    \[ v(209) = v(209) + dt * v(217) \]

  - **indian construction labor**
    \[ v(210) = v(210) + dt * v(218) \]
    \[ \text{return} \]
    \[ \text{end} \]
The land sector keeps track of land used in agricultural/open-space, urban/industrial, and mine/reclamation categories. The agricultural/open-space categories are range and forest land $v(361)$, dry crop land $v(362)$, and irrigated land $v(363)$. Provision is made for exogenous transitions between these categories $v(332), v(333)$. Land is converted from agricultural to urban/industrial $v(360)$ in response to indicated requirements $v(302), v(303)$ calculated from industrial development and urban population. Conversion from agriculture/open-space to stripmined land $v(364)$ is governed by the land stripping rate $v(304)$. Mined land, after a mining and reclamation delay ($t_c(315), t_c(317), t_c(319)$) is converted to interim reclaimed (or non-reclaimed) categories. Land undergoing reclamation is in one of three categories, $v(316)$ (to range land), $v(318)$ (to dry crop land), or $v(320)$ (to irrigated land). From the interim categories, land either returns to the agricultural/open-space categories or deteriorates to induced badlands $v(373)$.

units are $10^3$ acres.

start program statements

subroutine wcrln(f(lndgo))

integer lndgo

common/system/$v(1000), c(1000), t_c(1000), t_1$

common time

common/dt/dt

if ($lndgo.eq.0$) return

if ($lndgo.gt.0$) goto 10

if ($lndgo.lt.0$) lndgo=ndgo+1

10 continue

c
land stripping rate
$v(300)=v(802)*v(853)*c(300)$

c indicated industrial land
$v(302)=(v(54)+v(68))*c(301)+(v(20)+v(28))*c(302)+(v(824)+v(810))*c(303)$

c indicated urban land
$v(303)=c(304)*v(231)$

net urban land deficit
$v(304)=v(302)+v(303)-v(360)$

c fractional urban land surplus
$v(332)=\max(-v(304), 0.0)/v(360)$

c range land urbanization rate
$v(305)=\max(v(304), 0.0)*c(305)/t_1$

c dry crop land urbanization rate
$v(306)=\max(v(304), 0.0)*c(306)/t_1$

c irrigated land urbanization rate
$v(307)=\max(v(304), 0.0)*c(307)/t_1$

c range land/dry crop land conversion rate
$v(332)=0.0$

c dry crop land/irrigated land conversion rate

30
$v(333) = 0.0$

- Range land stripping rate:
  $v(308) = v(300) + c(308)$
- Dry crop land stripping rate:
  $v(309) = v(300) + c(309)$
- Irrigated land stripping rate:
  $v(310) = v(300) + c(310)$
- Non-reclamation initiation rate:
  $v(311) = v(364) + c(311)/tc(311)$
- Reclamation to range land initiation rate:
  $v(312) = v(364) + c(312)/tc(311)$
- Reclamation to dry crop land initiation rate:
  $v(313) = v(364) + c(313)/tc(311)$
- Range land reclamation completion rate:
  $v(315) = \text{delay3}'v(312',v(312/\text{tc}(315),v(316))$
- Dry crop land reclamation completion rate:
  $v(317) = \text{delay3}'v(313',v(313/\text{tc}(317),v(318))$
- Irrigated land reclamation completion rate:
  $v(319) = \text{delay3}'v(314',v(314/\text{tc}(319),v(320))$
- Long term unreclaimed rate:
  $v(324) = v(365) + (1.0-c(328))/\text{tc}(328)$
- Unreclaimed to badlands rate:
  $v(328) = v(365) + c(328)/\text{tc}(328)$
- Long term range land rate:
  $v(325) = v(366) + (1.0-c(329))/\text{tc}(329)$
- Range land to badlands rate:
  $v(329) = v(366) + c(329)/\text{tc}(329)$
- Long term dry crop land rate:
  $v(330) = v(367) + (1.0-c(330))/\text{tc}(330)$
- Dry crop land to badlands rate:
  $v(330) = v(367) + c(330)/\text{tc}(330)$
- Long term irrigated land rate:
  $v(331) = v(368) + (1.0-c(331))/\text{tc}(331)$
- Irrigated lands to badlands rate:
  $v(331) = v(368) + c(331)/\text{tc}(331)$
- Total land:
  $v(399) = v(360) + v(361) + v(362) + v(363) + v(364) + v(316) + v(318) + v(320) + v(319) + v(366) + v(367) + v(368) + v(369) + v(373)$

- Urbanized land:
  $v(360) = v(360) + \text{dt}*(v(305) + v(306) + v(307))$
- Range land:
  $v(361) = v(361) - \text{dt}*(v(305) + v(308) + v(332) - v(325))$
- Dry crop land:
  $v(362) = v(362) - \text{dt}*(v(306) + v(309) + v(333) - v(332) - v(326))$
- Irrigated land:
  $v(363) = v(363) - \text{dt}*(v(307) + v(310) - v(333) - v(327))$
- Stripped land:
  $v(364) = v(364) + \text{dt}*(v(308) + v(309) + v(310) - v(311) - v(312) - v(313) - v(314)
1)
\[ v(365) = v(365) + dt \times (v(311) - v(324) - v(328)) \]
\[ v(366) = v(366) + dt \times (v(315) - v(325) - v(329)) \]
\[ v(367) = v(367) + dt \times (v(317) - v(326) - v(330)) \]
\[ v(368) = v(368) + dt \times (v(319) - v(327) - v(331)) \]
\[ v(369) = v(369) + dt \times v(324) \]
\[ v(370) = v(370) - Mt \times (v(317) - v(326) - v(330)) \]
\[ v(371) = v(371) + dt \times (v(328) + v(329) + v(330) + v(331)) \]
\[ v(372) = v(372) + dt \times v(330) \]
\[ v(373) = v(373) + dt \times (v(328) + v(329) + v(330) + v(331)) \]
\[ v(374) = v(374) + dt \times v(330) \]
\[ v(375) = v(375) - v(361) - v(362) - v(363) - v(360) \]
\[ v(376) = v(316) + v(318) + v(320) \]

return

done
The water sector is based upon a functional relationship between expected water yield at some percent deficiency (e.g., a yield that is arbitrarily expected to be met in all but 2% of the years) and the active storage (reservoir) capacity $v(111,116)$. Both yield and storage capacity are normalized to mean annual flow $v(112,114)$. Net yield $v(112,117)$ is calculated by subtracting reservoir evaporation $v(110,115)$ from gross yield. The yield thus peaks at some finite value of the storage index (storage capacity/mean annual flow). The yield function depends upon the hydrologic statistics of the stream flow (Riggs and Henderson, 1973).

Since in-stream flow reservation schedules have been proposed for fish and wildlife protection (ranging from about 50% to 80% of the mean annual flow), an "effective flow" $v(109)$ is calculated as the remaining flow after reservation, and is used as a parameter in yield-storage function. Provision is made for "political feedback" to weaken fish and wildlife flow requirements in the event of severe shortage $v(134,150,135,136)$. The fish and game index $v(137)$ measures the degree to which the in stream flow reservation is met. A subjective "free flowing river index" $v(107)$ is also calculated as a function of the cumulative storage index $v(106)$.

The water sector represents the entire drainage basin. The industrial water requirements are taken to be $v(170)$ times the industrial requirements in the region.

Water requirements and projections are calculated from the industrial sector. The projected water deficit $v(146)$ is divided by the marginal yield $v(118)$ to calculate the projected storage deficit $v(119)$. The decision to build additional storage capacity depends upon a "benefit/cost" analysis $v(163,122)$. "Cost" $v(121)$ depends upon the annualized cost of storage capacity and the marginal yield (incremental acre-feet/year yield per acre-foot storage). "Benefit" $v(161)$ is calculated as a (linear) function of the projected fractional deficit $v(160)$. Available water is allocated by a "water allocation function" $v(139)$.

The aggregated drainage basin model tends to overestimate yield and underestimate resource development because it assumes that water available at any point within the basin is available at every point, and that reservoirs are of optimal efficiency. That is, storage is generally assumed to be on the lower, main stem portion of the basin's river system. For these reasons it can be assumed that water resource impacts would exceed those simulated.

Units are thousand acre-feet ($1.0e3af$)

************ start program statements ************
subroutine wcrwtr(wtrgo)
  integer wtrgo
  common/system/v(1000), c(1000), tc(1000), t1
  common time
  common/dt/dt

  c switch array (0 is off, 1 is on)
  common/switch/switch(100)
  integer switch
  real ifrf, myf, fgf

  c (see note for analogous indgo in industry sector description)
  if (wtrgo.eq.0) return
  if (wtrgo.gt.0) go to 10
  if (wtrgo.lt.0) wtrgo=wtrgo+1

10 continue

  c indicated irrigation water to agriculture in basin
  c (increase in consumptive use since 1970)
  v(126)=c(126)+((time-1970.)*c(125)/30.)*
  c miscellaneous water requirements (in basin)
  v(127)=c(123)+((time-1970.)*c(124)/30.)*
  c indicated industrial water requirements (in region)
  v(128)=v(20)*c(132)+v(59)*c(131)+v(802)*c(133)+v(80)*c(134)+v(89)*
  c developing industrial water requirements
  v(129)=v(128)+v(28)*c(132)+v(68)*c(131)+v(810)*c(133)+v(79)*
  1c(134)*v(89)
  c diversion point index
  c (fraction of industrial water from surface sources within basin)
  v(130)=c(130)
  c basin/region water to industry multiplier
  v(170)=(c(6)+c(7))/c(6)
  c effective indicated industrial water requirements (in basin)
  v(131)=v(130)+v(128)+v(170)
  c effective developing industrial water requirements
  v(132)=v(130)+v(129)+v(170)
  c indicated water requirements (in basin)
  v(133)=v(131)+v(127)+v(126)
  c cumulative storage index
  c (storage/mean annual flow years)
  v(106)=(v(105)+v(165))/c(106)
  c free flowing river index (Fermi function of storage index)
  v(107)=1.01/(1.0+exp((v(106)-0.5)/0.1))
  c instream flow reservation index
  c (political accommodation to shortage; c Fermi function of fractional deficit)
  v(135)=ifrf(v(150))
  c mean instream flow reservation
  v(136)=c(136)*v(135)
  c mean effective stream flow
c (initial instream flow - instream flow reservation)
  v(109)=lindf1('esf',c(106)-v(136),tc(109))
  c effective storage index
  v(108)=v(105)/v(109)
  c evaporation
\( v(110) = v(105) \times c(110) \)

c gross yield
\( v(111) = v(109) \times gyf(v(108), v(109) / c(106)) \)

c net yield
\( v(112) = v(111) + v(172) - v(110) \)

c yield deficit
\( v(113) = v(133) - v(112) \)

c fractional yield deficit
\( v(134) = \text{amax1}(0.0, v(113) / v(133)) \)

c perceived fractional yield deficit (perception delay)
\( v(150) = d\text{linf1}('v134', v(134), tc(120)) \)

c yield surplus (returned to instream flow)
\( v(151) = -\text{amin1}(v(113), 0.0) \)

c mean instream flow
\( v(152) = v(136) + v(151) \)

c fish & game index (fraction of reservation)
\( v(137) = f\text{qf}(v(152)) \)

c water allocation function
\( \text{call waf}(v(112), v(131), v(127), v(126), v(140), v(141), v(142)) \)

c \( v(140) \) water to industry

c \( v(141) \) water to miscellaneous

c \( v(142) \) water to agriculture

c fractional water to industry
\( v(143) = 1.0 \)
\( \text{if} (v(131) \geq 0.0) \ v(143) = 1.0 - v(130) \times (v(131) - v(140)) / v(131) \)

c fractional water to miscellaneous
\( v(144) = 1.0 \)
\( \text{if} (v(127) \geq 0.0) \ v(144) = v(141) / v(127) \)

c fractional water to agriculture
\( v(145) = 1.0 \)
\( \text{if} (v(126) \geq 0.0) \ v(145) = v(142) / v(126) \)

c developing effective storage index
\( c \) (includes storage under construction, \( v(103) \))
\( v(114) = (v(105) + v(103)) / v(109) \)

c developing evaporation
\( v(115) = (v(105) + v(103)) \times c(110) \)

c developing gross yield
\( v(116) = v(109) \times gyf(v(114), v(109) / c(106)) \)

c developing net yield
\( v(117) = v(116) + v(172) - v(115) \)

c marginal yield (acre-feet yield per year per acre-foot storage)

c decreasing function of storage index
\( v(118) = \text{myf}(v(114), v(109) / c(106)) - c(110) \)
\( v(118) = \text{amax1}(v(118), 0.0) \)

c weighted planning water deficit
\( v(146) = c(146) \times v(132) + c(147) \times v(127) + c(148) \times v(126) - v(117) \)

c fractional planning water deficit
\( v(160) = v(146) / (v(146) + v(117)) \)

c indicated storage capacity deficit
\( c \) (water deficit/marginal yield)
\( \text{if} (v(118) \geq 0.0) \ v(119) = v(146) / v(118) \)

c perceived storage capacity deficit (perception delay)
\( v(120) = d\text{linf1}('v119', v(119), tc(120)) \)
c marginal cost
v(121) = 10000.0
if (v(118) > 0.0) v(121) = c(121)/v(118)

v(161) = c(161) + v(160)*(c(162) - c(161))

v(163) = a*a*1(v(161)/v(121), 0.0)

v(122) = 1.0
if (v(163) < 8.0) v(122) = 1.0 - 1.0/(1.0 + exp((v(163) - c(127))/c(126)))
if (v(118) <= 0.0) v(122) = 0.0

v(101) = a*a*1(0.0, v(120)*v(122))/tc(101)

v(102) = delay3('v(101), v(101), tc(102), v(103))

v(104) = v(105)/tc(104)

v(105) = v(105) + dt*(v(102) - v(104))

v(165) = v(165) + dt*v(104)
REAL FUNCTION IFRF

INSTREAM FLOW RESERVATION INDEX (IFRF) REPRESENTS A POLITICAL
ACCOMMODATION TO WATER SHORTAGE BY RELAXING THE INSTREAM FLOW
RESERVATION. IFRF IS A FERMI FUNCTION OF FRACTIONAL WATER DEFICIT (F).

REAL FUNCTION IFRF(F)
IF(F.GT.1.0) PAUSE 'IFRF'
IFRF = 0.1 + 0.9/(1.0 + EXP((F-0.6)*8.0))
RETURN
END

REAL FUNCTION GYF(X/M)
REAL X/M
A = 0.250 + 1.41*M + 0.20*M*M
B = 0.001 + 0.215*M - 0.237*M*M + 0.283*M*M*M
C = 0.366 + 0.878*M - 0.476*M*M + 0.356*M*M*M
IF(M.LT.0.0) PAUSE 'GYF M<0'
IF(M.GT.1.0) PAUSE 'GYF M>1'
GYF = (B + (C - A + B) * X - 1.0) * EXP(-A*X) + 1.0
RETURN
END

REAL FUNCTION FGF(X)
XX = X/1000.0
FGF = 0.011 + 0.123*XX + 0.00549*XX*XX
IF(X.GT.6187.0) FGF = 1.0
IF(X.LT.0.0) PAUSE 'FGF'
RETURN
END
c ************************water allocation function (04-13-76)************************
c
Allocates water net yield (ny) based upon indicated requirements
for industry (iw), misc. (mw), and agriculture (aw). Allocations
are wi, wm, and wa.
waf can be modified to reflect water rights.
c
subroutine waf(ny,iw,mw,aw,wi,wm,wa)
   f = ny/(iw+mw+aw)
   if(f.gt.1.0) f=1.0
   wi=iw*f
   wm=mw*f
   wa=aw*f
return
end

c *************************marginal yield function (05-06-76)*************************
c
The marginal yield function is the derivative of the gross yield
function (gyf) with respect to the effective storage index (x).
See gross yield function.
c
real function myf(x,m)
   real x,m
   a=.250+1.41*m+0.20*m*m
   b=0.001+0.215*m-0.237*m*m+0.287*m*m*m
   c=0.366+0.878*m-0.476*m*m+0.356*m*m*m
   if(m.lt.0.0) cause 'myf m<0'
   if(m.gt.1.0) cause 'myf m>1'
   myf=(-a*((c-a+a*b)*x-1.0)+(c-a+a*b))*exp(-a*x)
return
end
WATER SECTOR

WCRWTR
This sector calculates a "political climate for industrialization index," \( v(414) \), which is a time average of a weighted sum of several other indices. These are: (1) agricultural political index, \( v(402) \), based on an exogenously supplied estimate; (2) coal revenue political index, \( v(404) \), based on a ratio between a severance tax and all other revenue to the political unit; (3) industrial capital political index, \( v(406) \), based on the amount of industrial capital invested in the region; (4) perceived political climate for industrialization, \( v(407) \), based on some perception delay of political climate; (5) environmental political index, \( v(408) \), based on a perception of environmental quality; (6) future shock political index, \( v(410) \), which attempts to model resistance to rapid change; and (7) federal political index, \( v(412) \), which models pressure from the national level for development when there is a gap between actual and expected (scenario) capacities.

The hypothetical indices are calculated in various ways, but all have the property of having values between -1 (complete opposition to development) to +1 (thorough support for development). Values of 0 are neutral.

switch default value =0, set to 1 for feedback
switch number function
40 political climate index feedback

*************** start program statements ***************

subroutine wcrpol(polgo,ncdp)
integer polgo,ncdp
common/system/v(1000),c(1000),tc(1000),t1
common time
common/dt/dt

switch link statements

common/switch/switch(100)
integer switch

(see note for analogous index in industrial sector description)

if(polgo.eq.0) return
if(polgo.gt.0) go to 10
if(polgo.lt.0) polgo=polgo+1
10 continue

relative agricultural revenue
\( v(401)=c(401) \)
agricultural political index (relative agricultural revenue)
\[ v(402) = 2.0 / (1.0 + \exp((v(401) - 1.0) / 0.3)) - 1.0 \]

**Relative Coal Revenue**

\[ v(403) = v(802) / c(403) \]

**Coal Revenue Political Index (Relative Coal Revenue)**

\[ v(404) = 1.0 - 1.0 / (1.0 + \exp((v(403) - 0.1) / 0.04)) \]

**Relative Industrial Capital**

\[ v(405) = (v(59) + v(68)) * c(404) + (v(20) + v(28)) \]

\[ / c(405) * c(406) + (v(82) + v(86)) * c(407) + c(408) \]

**Industrial Capital Political Index (Relative Industrial Capital)**

\[ v(406) = 1.0 - 1.0 / (1.0 + \exp((v(405) - 5.0) / 1.5)) \]

**Perceived Political Climate Index (Perceived Political Climate)**

\[ v(407) = 2.0 * \sin(1.5708 * (v(415) + 1.0) / 2.0) - 1.0 \]

**Relative Industrial Capital Political Index (Relative Industrial Capital)**

\[ v(408) = 1.0 - 1.0 / (1.0 + \exp((v(407) - 0.1) / 0.04)) \]

**Perceived Political Climate**

\[ v(409) = (\text{energy}(1, \text{ncdp}, \text{time} + tc(409)) + \text{energy}(2, \text{ncdp}, \text{time} + tc(409)) \]

\[ - v(27) - v(53)) * c(416) + (\text{totcol}(\text{ncdp}, \text{time} + tc(409)) - v(825)) * c(417) / \]

\[ 1 (c(416) * (v(27) + v(53)) + c(417) * v(825)) \]

**Future Shock Political Index (Relative Lifestyle Change)**

\[ v(410) = 1.0 / (1.0 + \exp((v(409) - 3.5) / 0.1)) - 1.0 \]

**Relative Energy Production Gap**

\[ v(411) = (v(827) - v(802)) / v(827) \]

**Federal Political Index (Gap)**

\[ v(412) = 1.0 - 1.0 / (1.0 + \exp((v(411) - 0.25) / 0.1)) \]

**Weighted Indicated Political Climate for Industrialization Index**

\[ v(413) = (v(402) * c(409) + v(404) * c(410) + v(406) * c(411) + v(407) * c(412) + \]

\[ 1 v(408) * c(413) + v(410) * c(414) + v(412) * c(415) / (c(409) + c(410) + \]

\[ 1 c(411) + c(412) + c(413) + c(414) + c(415) \]

**Political Climate for Industrialization**

\[ v(414) = \text{dlinf1}('v413', v(413), tc(414)) \]

**Political Climate Output to Other Sectors**

\[ v(420) = v(416) \]

\[ \text{if(switch(40), eq. 0) v(420) = c(420)} \]

**Perceived Political Climate**

\[ v(415) = \text{dlinf1}('v414', v(414), tc(415)) \]

return

end
The environmental sector of the model estimates relevant effluent residuals as linear functions of the various industrial construction and operation activities and as functions of total population and land use.

Provision has been made to model a partial control of waterborne effluents and their delayed, partial release to the environment. In this way the model simulates short-term control of waterborne effluents and also a gradual leaching of these pollutants into the hydrologic system. Several of the air pollutants have been taken as specified by the New Source Performance Standards (NSPS) but provision has also been made to model additional control to hold the effluents below the NSPS. The degree of urban sewage treatment (none, primary, secondary) is considered to be a function of the public service index calculated in the demographic sector.

For ease of presentation, the effluent residuals are normalized to nominal values, which, it should be noted, are not meant to be viewed as acceptable or unacceptable values. These normalized values are also not equivalent to relative ambient concentrations and are no substitute for analyses of site specific ambient concentrations. Moreover, these normalized and averaged values underestimate impacts primarily because they do not recognize the nonlinearities, synergistic effects, or the critical near-source "hot spots."

This sector also calculates an average population growth rate which may be considered as a measure of local social and political disruption. Gilmore and Duff (1976) suggest that a 5 percent annual growth rate is about as much as a small community can manage without experiencing the ill effects of boom-town growth. The model also calculates an urban/industrial land impact parameter proportional to the land area in urban, industrial, and mining use. This parameter indicates roughly the degree of change in traditional land use.

In addition to the population growth impact and the land impact parameters, two other indices are calculated for use in the political sector for the calculation of a political environmental quality index. One is a coal conversion air impact area index, which is a measure of the portion of the area affected by stack emissions, and the other is a reciprocal instream flow index. The latter is a measure of how well the desired instream flows are being met and perhaps a measure of stream assimilative capacity.

It would be very desirable to derive ambient residual concentrations from the residuals emission data and calculate direct impacts that could then be incorporated into political environmental quality index. However, until this is possible,
The residuals are simply left in the form of separate normalized values.

***+*+**+*******+++* start program statements ****************

```fortran
subroutine wcenv(envgo)
integer envgo
common/system/v(100)/c(100)/tc(100)/t1
common/time
common/dt/dt
c (see note concerning analogous indgo in industry sector description)
if(envgo.eq.0) return
if(envgo.gt.0) go to 10
if(envgo.lt.0) envgo=envgo+1
10 continue
```

c fraction of new source performance standards (nsps) emitted
  \( v(501) = c(501) \)

c fraction controllable water-borne residuals promptly emitted
  \( v(502) = c(502) \)

c fraction controlled water-borne residuals ultimately emitted
  \( v(503) = c(503) \)

c sewage treatment coefficient
  \( v(504) = 0.3 + 0.7/(1.0 + \exp((v(22) - 0.8)/0.1)) \)

c residuals (water) tons/yr

c sediment runoff from construction
  \( v(505) = v(28)*c(505) + v(68)*c(506) + v(85)*c(507) + v(83)*c(508) \)

c sediment runoff from operations
  \( v(506) = v(502) + v(509) + (v(20)*c(510) + v(59)*c(511)) + v(502) \)

c delayed sediment runoff from operations
  \( v(507) = \text{delay3}'dso', (v(20)*c(510) + v(59)*c(511) + (1.0 - v(502)) * v(503)) + (1.0 - c(507)) * v(508) \)

c sediment from mined/reclaimed lands
  \( v(509) = (v(316) + v(318) + v(320)) * c(512) + (v(365) + v(366)) * c(513) + (v(367) + v(368)) * c(514) + v(373) * c(515) \)

c total sediment runoff
  \( v(510) = c(505) + v(506) + v(507) + v(509) \)

c dissolved solids

c current operations effluent
  \( v(511) = v(802) * c(571) + v(59) * (c(572) + c(573) * v(502)) + v(20) * c(574) * v(512) \)

c delayed operations effluent
  \( v(512) = \text{delay3}'doe', (v(59) * c(572) + v(20) * c(574)) + (1.0 - v(502)) * v(513) \)

c sewage effluent
  \( v(514) = v(504) * v(227) * c(575) \)

c mined lands leaching
  \( v(515) = v(374) * c(516) \)

c total dissolved solids effluent
\begin{verbatim}
v(517) = c(517) + v(511) + v(512) + v(514) + v(515)
c biochemical oxygen demand (bod) 
v(518) = c(518) + v(20) * v(502) * c(519) + v(227) * v(504) * c(520)
c organics 
v(521) = c(521) + (v(20) * c(522) + v(59) * c(523)) * v(502) * delay3('org', v(20) * c(522)) + v(502) * c(523) * (1.0 - v(502)) * v(503) * tc(521) * v(522)
c heavy metals 
v(525) = c(525)
c residuals (air) tons/yr 
c so2 
v(530) = c(530) + v(20) * c(531) + v(59) * c(532) * v(501)
c nox 
v(533) = c(533) + v(59) * c(534) + v(59) * c(535) + c(542) * v(227)
c hydrocarbons 
v(536) = c(536) + (v(20) * c(537) + v(59)) * c(538) + c(543) * v(227)
c particulates 
v(539) = c(539) + (v(20) * c(540) + v(59) * c(541)) * v(501)
c relative residuals normalized to nominal (1975) values 
c sediment 
v(545) = v(510) / c(545)
c fractional sediment 
v(544) = v(545) - 1.0
c dissolved solids 
v(546) = v(517) / c(546)
c bod 
v(547) = v(518) / c(547)
c fractional dissolved solids 
v(555) = v(546) - 1.0
c organics 
v(548) = v(521) / c(548)
c heavy metals 
v(549) = v(525) / c(549)
c so2 
v(550) = v(530) / c(550)
c nox 
v(551) = v(533) / c(551)
c hydrocarbons 
v(552) = v(536) / c(552)
c particulates 
v(553) = v(539) / c(553)
c relative or fractional indices 
c relative instream flow 
v(560) = v(152) / c(106)
c reciprocal instream flow index 
if(v(137) .ne. 0.0) v(569) = 1.0 / v(137) - 1.0
c fractional sediment/water index
\end{verbatim}
v(561) = 1.0
if (v(560).ne.0.0) v(561) = (v(545) - 1.0) / v(560)

c coal conversion air impact area index
v(564) = ((v(59) * c(564) + v(50) * c(565)) * v(501)**2) / (v(399) / 0.64)

v(566) = (v(360) + v(365) + v(369) + v(316) + v(318) + v(320)) * c(1(566))

v(567) = v(566) / c(567)

v(568) = v(566) / v(399)

v(570) = v(227)
if (v(570).eq.0.0) v(570) = v(227)

v(571) = (v(227) - v(570)) / (v(227) * dt)

v(572) = smooth('v571', v(571), tc(572))

v(570) = v(227)

return
derend
AIR AND WATER RESIDUALS SUBSECTOR
AIR RESIDUALS SUB-SECTOR
**Constants List (08-26-77)**

Some of these constants are based upon little or no data.

All time constants (tc) in years.

```plaintext
subroutine wrcco
common/system/v(100C)*c(1000)*tc(1000)*t1
```

Rate at which plant ordering decisions are made years

`t1=1.0`

Abbreviations list

1.0e6 million
syn. synthetic
tpy tons per year
msccfpd million standard cubic feet per day
btu british thermal unit
lb pound
elec. electrical
gen. generation
mwe megawatt electric
1.0e3 thousand
af acre-feet
std. standard
misc. miscellaneous
ac acres
sed. sediment
ds dissolved solids
eis environmental impact statement
bod biochemical oxygen demand
org. organics
so2 sulphur dioxide
nox nitrous oxides
part. particulates
nsps new source performance standards
agri. agriculture

Industrial constants (energy in million tons coal)

- syn. fuel exogenous scenario modification value
  `c(2)=1.0`
- syn. fuel nominal capacity utilization
  `c(3)=0.7`
- Synthetic fuel maximum ordering rate million tpy/year
  `c(5)=35.0`
- syn. fuel standard plant coal use
  `c million tpy/250 mscfpd std. plant at 9000 btu/lb`
  `c(20)=8.0`
- syn. fuel planning horizon time years
  `tc(3)=2.0`

53
c syn. fuel plant average lifetime years
tc(15)=25.0

c syn. fuel maximum regulatory delay years
tc(21)=6.0

c syn. fuel minimum facility planning time years
tc(22)=1.0

c syn. fuel nominal construction time years
tc(26)=3.0

c elec. gen. exogenous scenario modification value
c(36)=1.0

c elec. gen. nominal capacity utilization (new plants)
c(38)=0.8

c electrical generation maximum ordering rate million tpy/year
c(40)=4.2

c elec. gen. standard plant coal use
c million tpy/1000 mwe std. plant at 9000 btu/lb
c(54)=4.0

c elec. gen. planning horizon time years
tc(38)=8.0

c elec. gen. maximum regulatory delay time years
tc(55)=6.0

c elec gen. minimum facility planning time years
tc(56)=1.0

c elec. gen. nominal construction time years
tc(61)=3.0

c coal export exogenous scenario modification value
c(72)=1.0

c coal export maximum ordering rate million tpy/year
c(75)=30.0

c fraction exported by slurry pipeline
c(89)=0.0

c coal export facilities average life time years
tc(81)=40.0

c coal export planning horizon time years
tc(73)=7.0

c coal export maximum regulatory delay years
tc(86)=6.0

c coal export minimum facility planning time years
tc(87)=1.0

c coal export nominal construction time years
tc(91)=2.0

c original coal resources million tons
(c851)=60000.6

c average mine utilization time constant years
tc(804)=3.0

c coal mine average lifetime years
tc(811)=40.0

c coal mine maximum regulatory delay years
tc(818)=4.0

c coal mine minimum facility planning time years
tc(819)=1.0

c coal mine nominal construction time years
tc(826)=1.0

c coal production shortage averaging time years
tc(821)=5.0

c coal extraction rate averaging time years
tc(845)=5.0

c static researve index averaging time years
tc(848)=5.0

------------------------------------------

c eis region fraction of coal development profile
c(6)=0.39

c river basin fraction of cdp
c(7)=0.44

------------------------------------------

c water sector constants (water in 1.0e3 acre-feet)
c

c storage construction initiation
tc(101)=1.0

c storage construction
tc(102)=5.0

c sediment filling
tc(104)=100.0

c effective stream flow averaging time
tc(109)=3.0

c yield deficit perception
tc(120)=5.0

c approx. mean river flow at mouth (at 1970 diversion level)
c(106)=8800.0

c evaporation/storage ratio
c(110)=0.03

c mean annualized storage cost [$/af/yr] at 7.35 discount rate
c(121)=13.5

c misc. shortage in 1970

c in Yellowstone Basin
c(123)=0.

c misc. consumptive use increase (1970-2000) in drainage basin
c(124)=140.

c consumptive use shortage for irrigation (in 1970)
c in drainage basin
c(126)=0.

c increase in consumptive use (1970-2000) for irrigation
c in drainage basin
c(125)=540.

c Fermi function "b" for reservoir utility multiplier
c(127)=1.5

c Fermi function "a"
c(128)=0.1

c fraction industrial water diverted within drainage basin
c(130)=1.0

c water (1.0e3 af/yr)/1000 mwe plant
c(131)=15.0

c water (1.0e3 af/yr)/250 mscf/d syn. fuel plant
\( c(132) = 10.0 \)

water/coal (1.0e3 af/1.0e6 tons coal)

\( c(133) = 0.05 \)

water/export by slurry pipeline (1.0e3 af/1.0e6 tons coal)

\( c(134) = 0.7 \)

nominal mean annual instream flow reservation

\( c(136) = 4000.0 \)

planning weight for industry

\( c(146) = 1.0 \)

planning weight for misc.

\( c(147) = 1.0 \)

planning weight for agriculture

\( c(148) = 1.0 \)

'\textit{marginal value}' of water at 0\% deficit (\$/af)

\( c(161) = 5.0 \)

'\textit{marginal value}' of water at 100\% deficit

\( c(162) = 300.0 \)

--------------------------------------------------------------------------

demographic sector constants (workers/1.0e6 tons coal/year)

c operations workers/1000 mwe plant

\( c(201) = 100.0 \)

c operations workers/250 mscfd syn. fuel plant

\( c(202) = 600.0 \)

c operations workers/1.0e6 tpy coal exported

\( c(203) = 3.8 \)

c operations workers/1.0e6 tpy mined

\( c(204) = 25.0 \)

c construction worker-years/1000 mwe plant

\( c(205) = 350.0 \)

c construction worker-years/250 mscfd syn. fuel plant

\( c(206) = 5400.0 \)

c construction worker-years/1.0e6 tpy coal export capacity

\( c(207) = 40.0 \)

c construction worker-years/1.0e6 tpy coal mine capacity

\( c(208) = 20.0 \)
c private service/agri. labor

\( c(209) = 0.99 \)
c private service indian industrial operations labor

\( c(210) = 0.99 \)
c private service/nonindian industrial operations labor

\( c(211) = 0.99 \)
c private service/nonindian industrial construction labor

\( c(212) = 0.99 \)
c private service/indian industrial construction labor

\( c(213) = 0.99 \)
c public service/agri. labor

\( c(214) = 0.38 \)
c public service/indian industrial operations labor

\( c(215) = 0.38 \)
c public service/nonindian industrial operations labor

\( c(216) = 0.38 \)
c public service/nonindian industrial construction labor

56
c(217) = 3.38
\( c_{\text{public service/indian industrial construction labor}} \)
\( c(218) = 0.38 \)
\( c_{\text{agri. labor family multiplier}} \)
\( c(219) = 2.77 \)
\( c_{\text{nonindian operations labor family multiplier}} \)
\( c(220) = 2.0 \)
\( c_{\text{public service family multiplier}} \)
\( c(222) = 2.77 \)
\( c_{\text{private service family multiplier}} \)
\( c(223) = 2.77 \)
\( c_{\text{nonindian construction labor family multiplier}} \)
\( c(224) = 2.3 \)
\( c_{\text{indians in industry}} \)
\( c(225) = 0.1 \)
\( c_{\text{private service/other primary labor}} \)
\( c(227) = 0.99 \)
\( c_{\text{public service/other primary labor}} \)
\( c(228) = 0.38 \)
\( c_{\text{other primary labor family multiplier}} \)
\( c(229) = 2.0 \)
\( c_{\text{other primary labor-indiginous}} \)
\( c(230) = 1000.0 \)
\( c_{\text{urban fraction of non-indian & non-agri.}} \)
\( c(231) = 0.66 \)
\( c_{\text{nonindian construction labor in-migration time}} \)
\( tc(217) = 1.0 \)
\( c_{\text{nonindian construction labor out-migration time}} \)
\( tc(218) = 1.0 \)
\( c_{\text{indian construction labor in-transfer time}} \)
\( tc(219) = 1.0 \)
\( c_{\text{indian construction labor out-transfer time}} \)
\( tc(220) = 1.0 \)
\( c_{\text{nonindian operation labor in-migration time}} \)
\( tc(221) = 1.0 \)
\( c_{\text{nonindian operation labor out-migration time}} \)
\( tc(229) = 1.0 \)
\( c_{\text{indian operation labor in-transfer time}} \)
\( tc(222) = 1.0 \)
\( c_{\text{indian operation labor out-transfer time}} \)
\( tc(223) = 1.0 \)
\( c_{\text{private service labor time constant}} \)
\( tc(224) = 1.0 \)
\( c_{\text{public service labor time constant}} \)
\( tc(226) = 3.0 \)
\( c_{\text{boom index smoothing time}} \)
\( tc(234) = 0.5 \)

\[ c_{\text{land sector constants (land in 1.0e3 acres)}} \]
\( c(300) = 0.0024 \)
\( c_{\text{striped land/coal ratio (1.0e3 acres/1.0e6 tons coal)}} \)
\( c(300) = 0.0024 \)
\( c_{\text{land (1.0e3 ac)/1000 mwe plant}} \)

57
c(301) = 0.5
cland \((1.0e3 \text{ ac})/250\text{mscfpd syn. fuel plant}\)
c(302) = 1.0
cland \((1.0e3 \text{ ac})/1.0e6\text{ tpy mining capacity}\)
c(303) = 0.15
C urban land/urban population \((1.0e3 \text{ ac/capita})\)
c(304) = 0.0003
c rangeland urbanization fraction
c(305) = 0.91
c dry crop land urbanization fraction
c(306) = 0.08
c irrigated land urbanization fraction
c(307) = 0.01
c rangeland mining fraction
c(308) = 0.91
c dry crop land mining fraction
c(309) = 0.08
c irrigated land mining fraction
c(310) = 0.01
c non-reclamation fraction
c(311) = 0.20
c reclamation to rangeland fraction
c(312) = 0.70
c reclamation to dry crop land fraction
c(313) = 0.05
c reclamation to irrigated land fraction
c(314) = 0.05
c unreclaimed to badlands fraction
c(315) = 0.75
c 'reclaimed rangeland' to badlands fraction
c(316) = 0.25
c 'reclaimed dry crop land' to badlands fraction
c(317) = 0.10
c 'reclaimed irrigated land' to badlands fraction
c(318) = 0.05

c time constants

tc(311) = 1.0
tc(315) = 5.0
tc(317) = 5.0
tc(319) = 5.0
tc(328) = 10.0
tc(329) = 25.0
tc(330) = 25.0

c 'reclaimed rangeland'/badlands

tc(329) = 25.0

c 'reclaimed dry crop land'/badlands
tc(330) = 25.0
c 'reclaimed irrigated land'/badlands
tc(331) = 30.0

c political sector constants (1.0e6 dollars/1.0e6 tons coal)

c relative agri. revenue
c(401) = 2.0

c coal severance tax rate
c(402) = 0.3

c 1970 political unit revenue
c(403) = 500.0

c capital ($1.0e6)/1000 mwe plant
c(404) = 250.0

c capital ($1.0e6)/250 mscfpd synthetic fuel plant
c(405) = 450.0

c export capital/output ratio ($1.0e6/1.0e6 tpy coal)
c(406) = 0.0

c mining capital/output ratio ($1.0e6/1.0e6 tpy coal)
c(407) = 0.7

c capital normalizer
c(408) = 1.000.0

c conversion / lifestyle weight
c(416) = 0.8

c mining / lifestyle weight
c(417) = 0.2

c lifestyle perception time
tc(409) = 15.0

c agri. revenue index weight
c(409) = 7.0

c coal revenue index weight
c(410) = 10.0

c industrial capital index weight
c(411) = 10.0

c perceived industrial climate index weight
c(412) = 5.0

c environmental index weight
c(413) = 5.0

c future shock index weight
c(414) = 7.0

c energy gap index weight
c(415) = 8.0

c political adjustment time
tc(414) = 3.0

c political perception time
tc(415) = 2.0

c political climate optional constant
c(420) = 0.0

c
c environmental sector constants (tons/year)

c elec. gen. std. plant: 1000 mwe at 80% load factor

c syn. fuel std. plant: 250 mncf I at 70% load factor
Fraction of new source performance stds. (NSPS) emitted
\( c(501) = 1.0 \)

Fraction controllable water-borne residuals promptly emitted
\( c(502) = 0.1 \)

Fraction controlled water-borne residuals ultimately emitted
\( c(503) = 0.5 \)

Sediment runoff (tons/year)
\( c(505) = 0 \)

Sediment per syn. fuel std. plant under construction
\( c(506) = 0 \)

Sediment per elec. gen. std. plant under construction
\( c(507) = 0 \)

Sediment per 1.0e6 tpy transportation facility under construction
\( c(508) = 0 \)

Sediment per 1.0e6 tpy coal mines under construction
\( c(509) = 950. \)

Sediment per syn. fuel std. plant operation ('controllable')
\( c(510) = 57. \)

Sediment per elec. gen. std. plant operation ('controllable')
\( c(511) = 438. \)

Sediment per 1.0e6 tpy coal mine operation
\( c(512) = 5. \times 10^3 \)

Delay time for 'controlled' sediment years
\( t_c(507) = 20. \)

Excess sed. per 1.0e3 acres mined/reclaimed lands
\( c(513) = 5. \times 10^3 \)

Unreclaimed lands
\( c(514) = 6. \times 10^3 \)

Reclaimed lands
\( c(515) = 10. \times 10^3 \)

Induced badlands
\( c(516) = 10. \times 10^3 \)

Misc. sediment runoff (EIS region)
\( c(517) = 8.6 \times 10^6 \)

Dissolved solids (DS) (tons/year)

Dissolved solids per 1.0e6 tpy coal mine operation
\( c(518) = 620. \)

Dissolved solids per elec. gen. std. plant operation ('uncontrollable')
\( c(519) = 252. \)

Dissolved solids per elec. gen. std. plant operation ('controllable')
\( c(520) = 3758. \)

Dissolved solids per syn. fuel std. plant operation ('controllable')
\( c(521) = 2722. \)

Delay time for 'controlled' dissolved solids years
\( t_c(512) = 2. \)

Dissolved solids per capita, untreated sewage effluent
\( c(522) = 0.05 \)

Dissolved solids per 1.0e3 acres mined lands leaching

60
c(516)=0
misc. ds effluent from eis region
c(517)=6.6e6

---------------------------------------------
biochemical oxygen demand (bod) tons/year
misc. bod effluent (eis region)
c(518)=0
bod per syn. fuel std. plant operation ('controllable')
c(519)=1.8
bod per capita, untreated sewage effluent
c(520)=0.03

---------------------------------------------
organics tons/year
misc. organic effluent (eis region)
c(521)=0
org. per syn. fuel std. plant operation ('controllable')
c(522)=27
org. per elec. gen. std. plant operation ('controllable')
c(523)=58
delay time for 'controlled' organics years
tc(521)=20

---------------------------------------------
heavy metals tons/year
misc. heavy metals effluent (eis region)
c(525)=0

---------------------------------------------
s02 effluent tons/year
misc. s02 effluent (eis region)
c(530)=2
s02 per syn. fuel std plant operation
c(531)=1800
s02 per elec. gen. std. plant operation
c(532)=45600

---------------------------------------------
nox effluent tons/year
misc. nox effluent (eis region)
c(533)=0
nox per syn. fuel std. plant operation
c(534)=3900
nox per elec. gen. std. plant operation
c(535)=33600
nox per capita
c(542)=0

---------------------------------------------
hydrocarbons tons/year
misc. hydrocarbon effluent (eis region)
c(536)=0
c hydrocarbons per syn. fuel std. plant operation
c(537) = 132.
c hydrocarbons per elec. gen. std. plant operation
c(538) = 528.
c hydrocarbons per capita
c(543) = 0

c-------------------------------
c particulates tons/year
c misc. particulate effluent (eis region)
c(539) = 0
c part. per syn. fuel std. plant operation
c(540) = 412.
c part. per elec. gen. std. plant operation
c(541) = 20000.

c-------------------------------
c nominal (1975) values for residual normalization tons/year
c sediment
c(545) = .86e7
c dissolved solids
c(546) = .66e7
c bod
c(547) = .46e3
c organics
c(548) = 7.1
c heavy metals
c(549) = 1

c so2

c(550) = .14e5
c nox
c(551) = .11e5
c hydrocarbons
c(552) = .17e3
c particulates
c(553) = .63e4

c-------------------------------
c impact area for air pollution square miles
c std. syn. fuel plant
c(565) = 3600.
c std. elec. gen. plant (at nsps)
c(564) = 3600.
c

c impact area multiplier for urban-industrial lands acre/acre
c(566) = 1.5
c nominal (1975) impacted land area acres
c(567) = 1.0e3 acres

c population growth rate smoothing time constant
tc(57?) = 5.
return
end
c ************************ Initial Levels (09-24-77) ************************
c
subroutine wcrin
  c common/system/v(1000),c(1000),tc(1000),t1
  c industrial sector (million tons coal)
  c coal reserves
  v(842)=26600.0
  c coal resources remaining
  v(844)=34000.0
  c initial time weighted electrical generation capacity
  v(50)=0.0
  c demographic sector (number of workers)
  c nonindian operations labor
  v(207)=300.0
  c nonindian construction labor
  v(209)=75.0
  c water sector (thousand acre-feet)
  c mean instream flow
  v(102)=delay3('v101',0.0,tc(102),v(103))
  c storage capacity
  v(105)=0.0
  c mean instream flow reservation
  v(136)=c(136)
  c sediment filled storage
  v(165)=0.0
  c land sector (thousand acres)
  c urbanized land
  v(360)=6.5
  c (indicated urban land)
  v(303)=v(360)
  c range land
  v(361)=9389.0
  c dry crop land
  v(362)=1980.0
  c irrigated land
  v(363)=184.0
  c stripmined land
  v(364)=0.0
  c reclamation land
  v(365)=0.0
  v(366)=0.0
  v(367)=0.0
  v(368)=0.0
  v(369)=0.0

63
c induced badlands
  v(373) = 0.0

c
  return
end
c ****************************Real Function Energy (06-28-77)***************************
c
Values of ncdp less than 50 are routed to polynomial
calculation. Values of ncdp greater than 50 are
routed to the table look-up calculation

c
real function energy(ntyp,ncdp,etime)
common/system/v(1000),c(1000),tc(1000),t1
common r t i ire
common/energy/ctime

rtime is real time, ctime is clip time, etime is energy planning
time, and time is a local variable.
real syn1(11),syn2(11),syn3(11),syn4(11)
real ele1(11),ele2(11),ele3(11),ele4(11)
real exp1(11),exp2(11),exp3(11),exp4(11),exp5(18)

data syn1/*syn1,5.0,1970.0,2000.0,0.0,0.0,0.0,0.0,0.7,5.0,7
1.6/
data syn2/*syn2,5.0,1970.0,2000.0,0.0,0.0,0.0,0.0,23.0,30.3,37.
17,45.0/
data syn3/*syn3,5.0,1970.0,2000.0,0.0,0.0,0.0,0.0,61.0,67.8,74.
16,81.4/
data syn4/*syn4,5.0,1970.0,2000.0,0.0,0.0,0.0,0.0,61.0,78.7,96.
13,114.0/
data ele1/*ele1,5.0,1970.0,2000.0,0.8,1.2,3.8,3.8,3.8,3.8,3
1.8/
data ele2/*ele2,5.0,1970.0,2000.0,0.8,1.2,3.8,5.4,9.6,13.9
118.1/
data ele3/*ele3,5.0,1970.0,2000.0,0.8,1.2,9.4,9.4,11.3,13.1
1.15.0/
data ele4/*ele4,5.0,1970.0,2000.0,0.8,1.2,9.4,11.0,15.2,19.
15,23.7/
data exp1/*exp1,5.0,1970.0,2000.0,6.1,19.5,41.4,41.4,41.4,4
11.4,41.4/
data exp2/*exp2,5.0,1970.0,2000.0,6.1,19.6,41.4,49.0,55.3,6
11.7,68.0/
data exp3/*exp3,5.0,1970.0,2000.0,6.1,19.6,41.4,49.0,55.3,6
128.0,167.5/
data exp4/*exp4,5.0,1970.0,2000.0,6.1,19.6,41.4,49.0,145.7
1202.3,259.0/
data exp5/*exp5,5.0,1970.0,19.3,0.3,5.7,0.10.5,14.0,17.5,21.0
124.0,27.0,28.0,29.0,61.0,61.0,96.0,96.0

c
if ctime > 1970 then scenarios are clipped after rtime > ctime
to scenario value at ctime.

c
time=etime
if(ctime.gt.1970.0.and.rtime.gt.ctime) time=amin1(etime,ctime)
c
if(ncdp.gt.50) go to 1000

c
c polynomial calculations ---------------------

e = 0.0

goto(100,200,300,ntyp)

c synthetic fuel

goto(110,120,130,140,150,160,ncdn)

110 a = 0.727161
    b = 0.851666
    c = -3.54572e-2
    d = 5.19651e-4
    goto 4000

120 a = 1.26895
    b = 0.314412
    c = 4.86387e-2
    d = -1.17682e-3
    goto 4000

130 a = 3.39982
    b = -1.62899
    c = 0.32283
    d = -6.00905e-3
    goto 4000

140 a = 6.24355
    b = 1.49346
    c = 0.328828
    d = -1.87024e-2
    e = 3.04421e-4
    goto 4000

150 goto 160

160 a = 6.04196
    b = 1.63108
    c = 0.324294
    d = -2.02947e-2
    e = 4.29213e-4
    goto 4000

c electric generation

goto(210,220,230,240,250,260,ncdo)

210 a = 0.397743
    b = 0.307076
    c = -4.89236e-3
    d = 0.0
    goto 4000

220 a = 1.29894
    b = 0.561536
    c = -0.040981
    d = 9.70258e-4
    goto 4000

230 a = 6.22447
    b = 0.253134
    c = -2.11733e-2
    d = 6.42339e-4
    goto 4000

240 a = 1.57729
    b = 0.31602
cc=-0.617522
d=1.76564e-2
e=-1.80021e-4
goto 4000

250  a=3.50975
     b=5.98206
     cc=0.167302
     d=-1.92489e-2
     e=3.66135e-4
     goto 4000

260  if(time.lt.1920.12)goto 250
     a=-78.7665
     b=3.28419
     cc=1.5848
     d=-5.79633e-2
     e=7.9609e-4
     goto 4000

c export
300  goto(310,320,330,340,350,360),ncdo
310  a=0.0
     b=0.0
     cc=0.0
     d=0.0
     goto 4000
320  a=-9.30001
     b=1.12333
     cc=-1.93334e-2
     d=0.0
     goto 4000
330  a=-2.37182
     b=.574696
     cc=-.75558e-3
     d=0.0
     goto 4000
340  a=0.0
     b=0.0
     cc=0.0
     d=0.0
     e=0.0
     goto 4000
350  a=-201.346
     b=28.3339
     cc=-0.934234
     d=1.14103e-2
     e=0.0
     goto 4000
360  a=-38.9533
     b=3.31451
     cc=0.882511
     d=-2.04806e-2
     e=0.0
     goto 4000

c
c ------------ table look-up calculation ------------
c
1000 continue

c
c
         r, ew = ncdp-50
       go to (1200,1300,1100),ntyp

c synthetic fuel
1100 go to (1110,1120,1130,1140,1150,1160),new
1110 energy=tlu(syn1,time)
         return
1120 energy=tlu(syn2,time)
         return
1130 energy=tlu(syn3,time)
         return
1140 energy=tlu(syn4,time)
         return
1150 energy=0.0
         return
1160 energy=0.0
         return
c electric generation
1200 go to (1210,1220,1230,1240,1250,1260),new
1210 energy=tlu(ele1,time)
         return
1220 energy=tlu(ele2,time)
         return
1230 energy=tlu(ele3,time)
         return
1240 energy=tlu(ele4,time)
         return
1250 energy=0.3
         return
1260 energy=0.3
       if(time.ge.1975.0) energy=4.3
       if(time.ge.1980.0) energy=10.8
         return
c export
1300 go to (1310,1320,1330,1340,1350,1360),new
1310 energy=tlu(exp1,time)
         return
1320 energy=tlu(exp2,time)
         return
1330 energy=tlu(exp3,time)
         return
1340 energy=tlu(exp4,time)
         return
1350 energy=tlu(exp5,time)
         return
1360 energy=tlu(exp5,time)
         return
c
.
4000 t=time-1970.0
   if(t.gt.30.0)goto 5000
   y=a+b*t+cc*t*t+d*t*t*t+e*t*t*t*t*t*t
4000 t=time-1970.0
   if(t.gt.30.0)goto 5000
   y=a+b*t+cc*t*t+d*t*t*t+e*t*t*t*t*t*t

6000 if(ncdo.ge.4.and.ncdo.le.6)y=0.1+y
   energy=c(6)*10.0*a*x1(y)*y
   return
5000 t=a+b*30.0+cc*900.0+d*2700.0+e*81000
   d=b+cc*60.0+d*2700.0+e*108000
   y=tt+dd*(t-30.0)
goto 6000 ,

end


**********Real Function Totcol (04-C8-76)**********

real function totcol(ncdp,etime)
totcol=energy(1,ncdp,etime)+energy(2,ncdp,etime)
1+energy(3,ncdp,etime)
return
end
**Table Look Up (real function tlu)**

**tlu(t,x) should be in the form**

\[ tlu(t_1, x) = \text{for } t_2 \leq t \leq t_3, \text{ where } t_2 \text{ is the abscissa interval between successive data points, } t_3 \text{ and } t_4 \text{ are the lower and upper ranges of the abscissa, and } t_5, \ldots \text{ are the ordinate values starting at } t_3. \]  
\( x \) is the input variable for which the value of \( tlu \) is desired.

```fortran
real function tlu(t,x)

real x,t(1),a
common /t/ tnam(35),tmxx(35),ttim(35),tcnt(35)
common time
if (x-t(3)) 15,10,20
10 tlu=t(5)
return
15 write(6,16) x*t(1)
16 format(' x='e10.4,' below range of table 'a4)
pause 'tlu'
return
20 if (x-t(4)) 55,50,25
25 do 40 i=1,35
30 tnam(i)=t(1)
tmxx(i)=x
ttim(i)=time
tcnt(i)=1
   goto 50
35 if (t(1)=t(i)) goto 45
40 continue
write(6,41)
41 format(' capacity of tlu error tables exceeded')
pause 'tlu'
goto 50
45 tcnt(i)=tcnt(i)+1
   if (x .gt. tmxx(i)) tmxx(i)=x
50 i=(t(4)-t(3))/t(2)+1.0e-7
   i=i-1
   goto 60
55 i=(x-t(3))/t(2)
60 a=i*t(2)+t(3)
i=i+5
   tlu=t(i)+(t(i+1)-t(i))*(x-a)/t(2)
return
end
```
c ************ Subroutine Graph (06-77-77) ************
c
It scales the variables and plots them. It is a modified
version of a routine written by Patrick C. Doherty of the
Computer Center Division
c
subroutine graph
coirmon/graph/put(10)/max(10)/min(10)/fup(10)/opsym(10)/
i(10)/nput
common /t/ tnam(35),tmax(35),ttim(35),tcnt(35)
implicit real (i,m)
integer i,plot,implot,ii,opsym
character*24 string
double precision time
real put/max,rrin,lolim(10),ulolim(10)
integer pline(61)
real atem(5)
write(6,99)
write(21,99)
opsyfr(2)="1"
opsyfr(3)="2"
opsyfr(4)="3"
opsyfr(5)="4"
opsyfr(6)="5"
98 format (1x,5i14/
99 format(///)
write(6,98) ii(1),ii(2),ii(3),ii(4),ii(5)
write(21,98) ii(1),ii(2),ii(3),ii(4),ii(5)
call clock(time)
call date_time_(time,string)
write(6,122) string
write(21,122) string
122 format (3x,a24/
800 format (1x,2a4,2x,2a4)
do 120 i=2,nout
if(min(i)==0.0) min(i)=0.0
if(fup(i),eq.0.0) goto 101
max(i)=fup(i)
101 if(flo(i),eq.0.0) goto 102
min(i)=flo(i)
102 a=(max(i)-min(i))/4.0
if(a,le.0.0) a=1.0
b=aint(a)
c=alog10(a)
if(b,gt.-1.0) b=b-1.0
a=1.0*b+aint(a*10.0**(-b))
c=a
if(c,gt.-5.0) a=5.0
if(c,gt.-10.0) a=10.0
if(min(i),eq.0.0) goto 103
b=aint(abs(max(i))/c)
e=aint(abs(min(i))/c)
f=d+e
if(f.gt.2.0) a=a+a

103 a=a*10.0**b

j=0
if(min(i)) 104,110,106
104 if(j*a.le.min(i)) goto 110
j=j-1
goto 104
106 if(j*a.gt.min(i)) goto 108
j=j+1
goto 106
108 j=j-1
110 continue
do 112 k=1,5
atem(k)=j+a
112 j=j+1
lolim(i)=atem(1)
uplim(i)=atem(5)
write(6,114) oosym(i),atem
write(21,114) oosym(i),atem
114 format(1x,a1,?x,*»8.2,4(7x,e8.2))
120 continue
do 200 iplot = 1,10
read (20,end=205) (put(i),i=1,nput)
if (iplot .eq. 1) go to 150
do 140 i=1,61
140 pline(i) = " 
pline(1) = "Mrs
pline(16) = "M rs
pline(31) = "Mr s
pline(46) = "Ms sr
pline(61) = "Ms sr
goto 160
150 do 155 i=1,61
155 pline(i) = " s
160 continue
itemp = out(1)+1.0e-2
do 170 i=2,nput
l=60.0*(put(i)-lolim(i))/(uplim(i)-lolim(i))
if (l .gt. 60) l=60
170 pline(l+1) = oosym(i)
if (iplot .eq. 1) go to 190
write(6,130) (pline(i),i=1,61)
write(21,130) (pline(i),i=1,61)
180 format(1x,6x,61a1)
go to 200
190 write(6,195) itemp,(pline(i),i=1,61)
write(21,195) itemp,(pline(i),i=1,61)
195 format(1x,i5,1x,61a1)
200 continue
go to 130
205 continue
go to 240
240 write(6,245)
   write(21,245)
245 format(/###/)
c
end file 20
do 340 i=1,35
   if(tnam(i).eq.0.0) goto 350
   write(6,330) tnam(i),tmxx(i),ttim(i),ttcnt(i)
330 format(" exceeded table ",a4,": max x="e10.4,": 1st time="f6.0,": count="f5.0)
340 continue
350 continue
return
end
c *************** Subroutine Indic (10-14-77) ***************
c
  initializes dictionary for delay functions
  subroutine indic
    common/sm/ansm(35),arsm(35),alsm(35)
    common/dl1/andl1(35),aldl1(35)
    common/dl3/andl3(35),al2dl3(35),al3dl3(35),ar1dl3(35),
    ar2dl3(35),ar3dl3(35)
    common/de3/ande3(35),al1de3(35),al2de3(35),al3de3(35),ar1de3(35),
    ar2de3(35),ar3de3(35)
    do 10 i=1,35
      ansm(i)=0.0
      andl1(i)=0.0
      andl3(i)=0.0
      ande3(i)=0.0
    10 continue
    return
  end

  subroutine Output (05-02-77)**************************************
c
  sets output variables for plotting
  uses system command read_list_5prompt
  requires link >sss>read_list_ prompt
  use n=0 for prompting, n=9 for repeat
  other values of n can be preset
  use n=99 to stop

  subroutine output(ii)
    integer ii(10)
    call prompt("n: ",n)
    if(n.eq.99) stop
    if(n.eq.99) return
    call prompt("ii(1): ",&ii(1),"ii(2): ",&ii(2),"ii(3): ",&ii(3),
    "ii(4): ",&ii(4),"ii(5): ",&ii(5))
    return
  end
/* ******** Procedures wcrcat and prbcat ******** */
/* */
wrcat:probc at: proc (v* c* tc* switch, ncdp* flo* fup* tstop* ctime);
dcl (v (1000)* c (1000)* tc (1000)* flo (10)* fup (10)* tstop* ctime) float;
dcl (switch (100)* ncdp) fixed;
dcl (in1* in2) fixed* (string* sub1* sub2) char (12) var;
dcl (name* conversion) cond;
     on name (sysin) go to error;
     on conversion begin;
         put skip list ("error\try again");
         go to enter;
end;
dcl (sysin* sysprint* file?1) file;
dcl a char (A) ;
   put file (file?1) edit (" 01A") (a);
   put skip file (file?1);
   put skip file (file?1);
enter:   put skip list ("ENTER show*set OR run.");
   get list (a);
   if a = "show" then go to show;
   if a = "set " then go to set;
   if a = "run " then go to run;
   go to enter;
show:   put skip list ("show:");
   get list (string);
   if string = ";" then go to enter;
   if string = "ncdp" then put list (string, "="* ncdp);
   if string = "ncdp" then go to show;
   if string = "tstop" then put list (string, "="* tstop);
   if string = "ctime" then put list (string, "="* ctime);
   if string = "ctime" then go to show;
   if string = "tstop" then go to show;
   in1 = index (string, ")");
in2 = index (string, ")") ;
   if in1*in2 = 0 then go to error2;
   sub1 = substr (string, 1, in1-1);
   sub2 = substr (string, in1+1, in2-in1-1);
   if sub1 = "v" then do;
       put list (string, "="* v (sub2));
       go to show;
   end;
   if sub1 = "c" then do;
       put list (string, "="* c (sub2));
       go to show;
   end;
   if sub1 = "tc" then do;
       put list (string, "="* tc (sub2));
       go to show;
   end;
   if sub1 = "switch" then do;
       put list (string, "="* switch (sub2));
       go to show;
   end;
if sub1 = "flo" then do;
  put list (string, "="), flo (sub2));
  go to show;
end;
if sub1 = "fup" then do;
  put list (string, "="), fup (sub2));
  go to show;
end;
error2: put skip list ("error, try again.");
  go to show;
error: put skip list ("error, try again.");
set: put list ("set:");
  get data;
  if tstop <1970.0
    then go to error3;
  else if tstop >2050.0
    then go to error3;
  put skip;
  go to enter;
error3: put skip list ("tstop out of bounds");
  go to set;
run: put skip file (file21) data (ncdp);
  put skip file (file21);
  return;
end;
c *************Real Function Delay3 (02-27-76)*************
c
c third order exponential material (conservative) delay
c
real function delay3(qn,q,del,ql)
common/dt/dt
common/ie3/an(35),al1(35),al2(35),al3(35),ar1(35),ar2(35),ar3(35)
do 10 i=1,35
if(an(i).eq.0.0)goto 20
if(an(i).eq.qn)goto 30
10 continue
write(6,15)
15 format('/// dictionary capacity exceeded in function delay3')
pause 'delay3'
ql=q*del
delay3=q
return
20 an(i)=qn
ar1(i)=q
ar2(i)=q
ar3(i)=q
al1(i)=q*del/3
al2(i)=q*del/3
al3(i)=q*del/3
delay3=q
ql=q*del
return
30 ar1(i)=3.0*al1(i)/del
ar2(i)=3.0*al2(i)/del
ar3(i)=3.0*al3(i)/del
al1(i)=al1(i)+dt*(q-ar1(i))
al2(i)=al2(i)+dt*(ar1(i)-ar2(i))
al3(i)=al3(i)+dt*(ar2(i)-ar3(i))
delay3=ar3(i)
ql=al1(i)+al2(i)+al3(i)
return
end
c ************ Real Function Dlinf1 (3-31-77) ************
c
C first order exponential information delay
c
real function dlinf1(xn,x,t)
common/dt/dt
common/dl1/an(35),al(35)
do 10 i=1,35
if(an(i).eq.0.0)goto 20
if(an(i).eq.xn)goto 30
10 continue
write(6,15)
15 format('// dictionary capacity exceeded in function dlinf1')
pause 'dlinf1'
dlinf1=x
return
20 an(i)=xn
al(i)=x
dlinf1=x
return
30 al(i)=al(i)+dt*(x-al(i))/t
dlinf1=al(i)
return
end
c ****************************Real Function Smooth**************************
c
c first order exponential information delay
c
real function smooth(xn,x,t)
common/dt/dt
common/sm/an(35),ar(35),al(35)
tt=t
    do 10 i=1,35
        if(an(i).eq.0.0)goto 20
        if(an(i).eq.xn)goto 30
    continue
    write(6,15)
15 format(//' dictionary capacity exceeded in function smooth' )
    pause 'smooth'
    smooth=x
    return
20    an(i)=xn
    ar(i)=x
    al(i)=x*tt
    smooth=x
    return
30    al(i)=al(i)+dt*(x-ar(i))
    ar(i)=al(i)/tt
    smooth=ar(i)
    return
end
& wcr.ec
& This is a series of multics commands which are invoked
& by typing "ec wcr". If the model user wants to
& store simulation runs in a file (segment named record)
& which can be renamed, saved, printed, etc. then type
& "ec wcr record".
& &command_line off
& if [exists file file20] &then delete file20
& io attach file20 vfile_ file20
& if [equal &1. record.]
& &then &goto record
& &else &goto no_record
& &label record
& io attach file21 vfile_ record -append
& wcr crd
& close_file -all
& &quit
& &label no_record
& io attach file21 vfile_ discard
& wcr crd
& close_file -all
& if [exists file discard] &then delete discard
& &quit

The last two pages contain an example of one of the models simulation runs.