APPENDIX IV:

ENGINEERING CALCULATIONS
1. **Coal Log Pipeline (Log-Water System)**

For a coal log pipeline (CLP) system that uses water to suspend and propel the coal logs (i.e., a log-water system), the engineering calculations are as follows:

The cross-sectional area of the pipe, $A$, and the cross-sectional area of the coal log, $A_c$, are calculated from, respectively,

$$A = \frac{\pi D^2}{4}$$  \hspace{1cm} (1)

and

$$A_c = \frac{\pi D_c^2}{4}$$  \hspace{1cm} (2)

where $D$ and $D_c$ are respectively the inner diameter of the pipe and the outer diameter of the coal logs. However, for simplicity, $D$ is taken to be the **nominal diameter** rather than the inner diameter of the pipe. This results in negligible errors for this study.

The diameter ratio, $k$, and the aspect ratio, $a$, are respectively calculated from:

$$k = \frac{D_c}{D}$$ \hspace{1cm} (3)

and

$$a = \frac{L_c}{D_c}$$ \hspace{1cm} (4)

where $L_c$ is the length of each log.

The **lift-off velocity**, $V_L$, is calculated from Liu's equation as follows:

$$V_L = 7.2 \sqrt{|S - 1| g a k (1 - k^2) D}$$ \hspace{1cm} (5)

where $S$ is the specific gravity of the log; and $g$ is the gravitational acceleration. Equation 5 is dimensionally homogeneous, and hence it can be used for any system.
of units—be it the SI units of the English units. The absolute value sign around the S-1 term can be replaced by a set of parenthesis when S is greater than one—denser than water logs. Otherwise, the absolute value sign must be retained.

To generate Tables 3 and 4 in APPENDIX I, we first select the maximum values of $k$ that will not cause practical problems such as jamming of coal logs at pipe bends. The $k$ values chosen are between 0.90 and 0.95—the practical range under normal conditions. Within this range, smaller $k$ values should be used for smaller pipes and vice versa.

The practical range of $V_L$ is expected to be between 6 and 10 ft/sec, with larger pipes requiring larger values of $V_L$ and vice versa. Using this criteria, the value of $V_L$ for each pipe diameter in Tables 3 and 4 was first chosen from intuition. Then, the value of $a$ was calculated from Eq. 5 or the following alternate form of the equation

$$a = \frac{V_L^2}{(7.2)^2|S-1|gkD(1-k^2)}$$  \hspace{1cm} (6)

If the value of $a$ determined from Eq. 6 was less than 1.2 or greater than 4.0, the velocity $V_L$ was adjusted by trial and error so that it stays within the practical range of $a = 1.2$ to 4.0. Note that $a$ values smaller than 1.2 cannot be tolerated because such short logs increase headloss and abrasion, and they run the risk of overturning in the pipe which can cause pipeline blockage. Values of $a$ greater than 4.0 are also undesirable because such long logs are difficult to manufacture by compaction (not by extrusion), are easy to break into halves, and run the risk of getting stuck in pipe bends.

The Reynolds Number, $Re$, for the pipe flow was calculated from

$$Re = \frac{\rho V_L D}{\mu}$$  \hspace{1cm} (7)

where $\rho$ is the water density; and $\mu$ is the water viscosity.
Using this $R_e$ and a pipe roughness, $e$, of 0.00015 ft which is that of commercial steel, the Darcy-Wiesbach friction factor, $f$, was calculated from:

$$f = \left( -2 \log \left( \frac{e}{3.7D} \right) - \frac{5.02}{R_e} \left( \log \left( \frac{e}{3.7D} \right) - \frac{14.5}{R_e} \right) \right)^2$$

(8)

The pressure gradient, $\frac{\Delta p_c}{\Delta L}$ without any polymer added to the CLP was calculated from

$$\frac{\Delta p_c}{\Delta L} = \kappa \left( \frac{f_p V_L^2}{2gD} \right)$$

(9)

This differs from the equation for an ordinary pipe by the constant $\kappa$ which accounts for the additional head lost due to the presence of the coal logs. For simplicity, $\kappa$ was assumed to be 1.4* which yields pressure gradients 40% higher than for ordinary water pipelines.

The pressure gradient with polymer, $\frac{\Delta p_{cp}}{\Delta L}$ was calculated from:

$$\frac{\Delta p_{cp}}{\Delta L} = (1 - F_{dr}) \frac{\Delta p_c}{\Delta L}$$

(10)

where $F_{dr}$ is the drag reduction factor (in these calculations $F_{dr} = 0.7$).

The power, $P$, without polymer was calculated from

$$P = \frac{\Delta p_c AV_L}{\eta}$$

(11)

where $\eta$ is the efficiency of the pumps used, assumed to be 75%.

With the use of polymer for drag reduction, the power, $P$, was calculated from

---

* Note that $\kappa = 1.4$ is an average value obtained from our laboratory tests under lift-off condition. In reality, $\kappa$ increases with decreasing aspect ratio, $a$, and it increases with increasing diameter ratio, $k$. Therefore, for a more accurate determination of the pressure gradient in a coal log flow, the values of $\kappa$ should vary as a function of $a$ and $k$. 
\[
\frac{\Delta p_{cp}}{\Delta L} \cdot A \cdot V_L \approx \frac{\Delta p_{cp}}{\eta} 
\]

(12)

The throughput of water, \( Q_w \), was determined from:

\[
Q_w = V_L (A - A_c \alpha) 
\]

(13)

where \( \alpha \) is the linefill (percentage of the pipeline containing coal logs). The throughput of coal, \( Q_c \), is calculated from

\[
Q_c = \frac{SQ_w \rho}{\frac{1}{\alpha k^2} - 1} 
\]

(14)

When no polymer is used, the distance between neighboring booster stations is

\[
L_b = \frac{P_{\text{max}} - P_{\text{min}}}{\Delta p_c} 
\]

(15)

where \( P_{\text{max}} \) is the maximum pressure in the pipeline (immediately downstream of the pumping station); and \( P_{\text{min}} \) is the minimum pressure in the pipeline (immediately upstream of the pumping station). While \( P_{\text{min}} \) is assumed to be 29.4 psig, \( P_{\text{max}} \) is either 500, 1000, 1500, or 2000 psig. With polymer added, the distance between booster stations is

\[
L_b = \frac{P_{\text{max}} - P_{\text{min}}}{\Delta p_{cp}} 
\]

(15)

2. **CLP Pipeline with Slurry Carrier**

Table 5 is generated assuming a 50-50 by weight coal water slurry to transport coal logs. In this table, \( D, L, V_L, k \) and \( a \) are calculated or chosen as in the previous section. The specific gravity of the slurry \( S_s = 1.35 \), and the specific gravity of the coal logs, \( S = 1.20 \), yield a density ratio of \( \varepsilon = 1.125 \). However, using a slurry as a carrier
fluid requires calculating a Reynolds Number, $R_e$, and a Hedstrom Number, $H_e$, as follows:

$$R_e = \frac{\rho_s V_L D}{\mu_s}$$  \hspace{1cm} (16)

and

$$H_e = \frac{\rho_s D^2}{\mu_s^2 \tau_y}$$  \hspace{1cm} (17)

where $\rho_s$ is the density of the slurry; $\mu_s$ is the viscosity of the slurry; and $\tau_y$ is the yield stress of the slurry. Using $R_e$, $H_e$, and figure 7 from [22], the Fanning friction factor, $f'$, is determined. The Darcy-Wiesbach friction factor, $f$, is then calculated from

$$f = 4 f'$$  \hspace{1cm} (19)

The pressure gradient, $\Delta p / \Delta L$, is calculated from Eq. 9 (where $\kappa$ is set equal to 1.0).

The power is calculated from Eq. 11, and the throughput of water is determined from:

$$Q_w = 0.5 V_L (A - A_c \alpha)$$  \hspace{1cm} (13)

The throughput of coal is calculated from

$$Q_c = \frac{S Q_w p}{\kappa^2 - 1} + S_s Q_w p$$

The distance between pump stations, $L_b$, is calculated from Eq. 15.
APPENDIX V:

COMPUTER PROGRAMS
APPENDIX V: COMPUTER PROGRAMS

1. Program for Preparing Tables 3, 4, & 5:

Key parameters of CLP Systems Analyzed are shown in Table 3. In Table 4, the distance between booster stations in miles for CLP systems with different operating pressures is shown. In Table 5, key parameters of CLP systems using slurry to suspend logs are shown. These tables were created using Microsoft Excel, a spreadsheet for the Macintosh computer family. The computer used for these calculations was a Macintosh IIci. The spreadsheet uses the equations shown in Appendix IV: Engineering Calculations.

2. CLP Calculation Program:

The program that calculates the capital costs, operational/maintenance costs, and generates a life-cycle cost analysis for the CLP transportation of coal is called the CLP Calculation Program. This program was written in the "C" language using Think C 5.0 for the Macintosh computer family. The computer used is the same as the one mentioned before. The graphs were plotted using Cricket Graph, also on the same Macintosh. A flow chart is given on the next page. A listing of the program then follows the flow charts.

2. CLP Calculation Program:

The program that calculates the capital costs, O/M costs, and generates a life-cycle cost analysis for the economic analysis of transportation of coal by slurry pipeline is called the Slurry Calculation Program. This program was written in the "C" language using Think C 5.0 for the Macintosh computer family. The graphs were plotted using Cricket Graph, also on the same Macintosh. The flow chart and the listing of the program is given in this Appendix.
CLP Calculation Program Flowchart

START

SET discount rate, equity rate, tax rate, O/M increase rate, Energy increase rate, availability, linefill, log manufacture process, rate of log manufacturing, binder content, sealant, log specific gravity (S), operating pressure, water type, condition of pipeline, addition of drag reducing agents, system redundancy, water deaeration, pigs in pipeline, return rate, length of train, life of pipe, and initial diameter

READ Input Table (depends on S)

FOR j = 1; j < 10 "Diameter Loop"

DEFINE \( V_L \), \( a \), \( k \), \( \Delta p_c \), Power, distance between pumping stations, coal throughput, and water throughput from Input Table

SET Initial Pipeline Length

FOR k = 1; k < 30 "Length Loop"

CALCULATE number of booster stations = pipeline length / distance between pumping stations

CALCULATE O/M cost for year 1

\[
\begin{align*}
O/M \text{ cost@inlet} &= \text{CALL oper\_costin()} \\
O/M \text{ cost@outlet} &= \text{CALL oper\_costout()} \\
O/M \text{ cost@booster\_station} &= \text{CALL oper\_costboost()} \\
\text{Pipe O/M} &= 0.01 \text{ Cost of Pipeline} \\
O/M[1] &= \text{Pipe O/M} + O/M \text{ cost@inlet} + O/M \text{ cost@outlet} + (\text{number of booster stations}) \times O/M \text{ cost@booster\_station}
\end{align*}
\]

CALCULATE Capital cost

\[
\begin{align*}
\text{Capital cost@inlet} &= \text{CALL cap\_costin()} \\
\text{Capital cost@outlet} &= \text{CALL cap\_costout()} \\
\text{Capital cost@booster\_station} &= \text{CALL cap\_costboost()} \\
\text{Capital cost} &= \text{Pipe Cost} + \text{Capital cost@inlet} + \text{Capital cost@outlet} + (\text{number of booster stations}) \times \text{Capital cost@booster\_station}
\end{align*}
\]

CALCULATE Energy cost for year 1

\[
\begin{align*}
\text{Energy[1]} &= \text{CALL energy\_cost(number of booster stations)}
\end{align*}
\]

FOR i = 2; i ≤ life of pipe "O/M - Energy Increase Loop"

CALCULATE \( O/M[i] = O/M[i-1] \times (1.0 + O/M \text{ increase rate}) \)

\[
\begin{align*}
\text{Energy[i]} &= \text{Energy[i-1]} \times (1.0 + \text{Energy increase rate}) \\
\text{Tax \& Insurance} &= 0.025 \times \text{Capital cost}
\end{align*}
\]
SET \( \sum \text{Unit Cost PV} = 0 \)

FOR \( \text{year} = 1; \text{year} \leq \text{life of pipe} \) "Life-Cycle Loop"

CALCULATE Depreciation, Return, Taxes, Cost, Unit Cost

\[
\text{Unit Cost PV} = \text{CALL present value(Unit Cost, discount rate, year)}
\]

\[
\text{Freight Rate PV} = \text{CALL present value(Freight Rate, discount rate, year)}
\]

\[
\sum \text{Unit Cost PV} = \sum \text{Unit Cost PV} + \text{Unit Cost PV}
\]

CALCULATE average Unit Cost PV = \( \sum \text{Unit Cost PV} / \text{life of pipe} \)

average Freight Rate PV = average Unit Cost PV / length

OUTPUT length of pipeline, average Unit Cost PV, and average Freight Rate PV

IF length of pipeline < 50

SET length of pipeline = length of pipeline +10

IF length of pipeline < 1000

SET length of pipeline = length of pipeline +50

IF length of pipeline < 1000

SET length of pipeline = length of pipeline +200

SET Diameter = Diameter + 2

END
Subroutine present_value()

START

INPUT  Value, interest rate, number of periods

CALCULATE  Value / (1 + interest rate) ^ (number of periods)

RETURN

Subroutine energy(Nb)

START

INPUT  Number of booster stations, Nb

CALCULATE  Power_inlet + Power_outlet + Power_booster station * Nb

RETURN

Subroutine oper_costin()

START

CALCULATE  Extruder power (if used), Mixer power (if used),
            Binder cost (if used), Compactor power (if used),
            Horsepower of main and auxiliary pumps, Pump power,
            Valve power, Conveyor power, Binder heating power (if used),
            Building power, Misc. power, Water cost, Polymer cost (if used),
            Pig transportation cost (if used), Communication cost,
            Coal heating cost, Regular maintenance cost

CALCULATE  Total Inlet O/M Cost

RETURN

Subroutine cap_costin()

START

CALCULATE  Inlet tank cost, Building cost, Land cost, Pipe cost,
            Valve cost, Pump cost, Conveyor cost, Extruder cost (if used),
            Mixer cost (if used), Binder heating tank cost (if used),
            Compactor cost (if used), Sealant cost (if used), Deaeration cost (if used),
            Substation cost, Additional Inlet cost, Access road cost,
            Pig cost (if used)

CALCULATE  Total Inlet Capital Cost

RETURN

Subroutine oper_costout()

START

CALCULATE  Flocculant Cost, Salaries & Wages cost,
            Other O/M cost

CALCULATE  Total Outlet O/M Cost

RETURN

Subroutine cap_costout()

START

CALCULATE  Sedimentation tank cost, Flocculation tank cost,
            Land cost, Conveyor cost, Crusher cost, Building cost,
            Automatic control cost, dewatering cost,
            Other costs

CALCULATE  Total Outlet Capital Cost

RETURN

Subroutine oper_costboost()

START

CALCULATE  Salaries & Wages cost, Materials cost, Polymer cost (if used)

CALCULATE  Total Booster Station O/M Cost

RETURN

Subroutine cap_costboost()

START

CALCULATE  Water storage cost, Pump Horsepower, Pump cost, Valve cost, Pipe cost, Building cost, Land cost, Automatic control equipment cost, Substation cost, Access road cost

CALCULATE  Total Booster Station Capital Cost

RETURN
CLP Calculation Program

#include<stdio.h>
#include<math.h>
#include<stdlib.h>

#define SIZE 31
#define number_of_years 30
#define D diameter/12
#define Qc throughput_coal/365/24*1000000
#define Qw throughput_water

FILE *out, *in;
double avg_frent_rate_PV, avg_unit_cost_PV, diameter, equity, throughput_coal;
double length, money, return_rate, tax_rate, Cost[SIZE], Depreciation[SIZE], Energy[SIZE];
double freight_rate[SIZE], freight_rate_PV[SIZE], Oper_Main[SIZE], Return[SIZE];
double Taxes[SIZE], Unit_cost[SIZE], Unit_cost_PV[SIZE], S, temp, Table[20][30];
double sum_Unit_cost_PV, sum_frent_rate_PV, Energy_increase_rate, OM_increase_rate;
double throughput_water, linefill, aspect_ratio, Liftoff_Vel, diameter_ratio;
double polymer, DPc, Power, dis_btwn_pmp_stb, binder, pressure1, Pi, Po, Pb, Lt, fabrication_rate;
double discount_rate, condition, RF, availability;
double Cct, Cci, Ce, Ccp, Cm, Cbh, Cde, Cai, Cpg, Ccr, Cao, Coo, Ccc;

int n[SIZE], year, i, j, k, pressure, extruder, compaction, sealant, pigs, water, deaeration;
int redundancy;

/**
 * Present Value Calculation
 **/

double present_value(double base, double rate, double period)
{
    return base/(pow((1.0+rate), period));
}

/**
 * Capital Cost Subprograms
 **/

/**
 * INLET CAPITAL COSTS
 **/

double cap_costin()
{
    double Lio, Lpi, Lci, Hpm, Hpa, expnt;
    double Cti, Cbi, Cli, Cpi, Co, Cvi, Cui;
    double Csi, Cri, C1;
    Lio = 210*Liftoff_Vel;
    Cti = 75000*D*D;
    Cbi = 2000000*D*D;
    Cli = 100000;
    Lpi = 4.0*Lio;
    Cpi = (129*pow(D, 1.34) + 102*pow(D, 0.87) + 24*D + 20)*1000*Lpi/5280;

    switch (pressure)
    {
        case 2000:
            Co = 66.0;
            break;
        case 3000:
            Co = 75.0;
            break;
        case 4000:
            Co = 85.0;
            break;
        case 5000:
            Co = 95.0;
            break;
        default:
            Co = 0.0;
            break;
    }
}

```
break;
case 1500:
  Co = 63.0;
break;
case 1000:
  Co = 60.0;
break;
case 500:
  Co = 55.0;
break;
}
Cvi = 20000*Co*pow(D,1.15);  /* Valves ($) (eq. 23) ***/
Hpm = (DPC*10*dis_btwn_prmp_sta*144)*(Liftoff_Vel*3.14159*D*D/4)/550;  /* Horsepower of Main Pump ***/
Hpa = ((DPC+DPO/1.4)*10*144)*LIO/5280*(5.0*3.14159*D*D/4)/550;  /* Horsepower of Auxiliary Pump ***/
Cui = 930*(pow(2.0*Hpm,0.6)+5.0*pow(Hpa,0.6));  /* Pumps ($) (eq. 25) ***/
Lci = 2000*D;  /* Length of Conveyors (eq. 27) ***/
Cci = 325*Co*0.485*Lci;  /* Conveyors ($) (eq. 26) ***/
switch (extruder)
{
  case 0:
    C1 = 0.0;
    Co = 0.0;
    expnt = 0.0;
    break;
  case 1:
    C1 = 1.0;
    Co = 64.0;
    expnt = 0.73;
    break;
  case 2:
    C1 = 1.0;
    Co = 173.0;
    expnt = 0.73;
    break;
}
Ce = 1000*Co*(4.5*Liftoff_Vel+3)*pow((diameter_ratio*D),expnt);  /* Extruders ($) (eq. 31-32) ***/
Cm = 1000*C1*33*pow(Qc,0.404);  /* Mixers ($) (eq. 37) ***/
if(binder*Qc>10.0)
{
  Cbh = C1*20000*(0.2*binder*Qc+1);  /* Heat Tank ($) (eq. 42) ***/
}
else
{
  Cbh = C1*26000*pow((binder*Qc),0.361);  /* Heat Tank ($) (eq. 40) ***/
}
switch (compaction)
{
  case 0:
    Co = 0.0;
    break;
  case 1:
    Co = 55.0;
    break;
}
Co = 1.0;
break;
}
Ccp = 1000*Co*1560*pow(D,0.8)/fabrication_rate;
        /* Compactor ($) (eq. 33) */
switch (sealant)
{
    case 0:
        /* No Sealant */
        Co = 0.0;
        break;
    case 1:
        /* Sealed Logs */
        Co = 1.0;
        break;
}
Cct = 1000*Co*415*pow(D,0.8);
        /* Coating Chamber ($) (eq. 34) */
if(deaeration>0.0)
{
    Cde = 1000*(52+114*pow(Qw,0.585));
        /* Deaeration Cost ($) (eq. 44) */
}
else
{
    Cde = 0.0;
}
Csi = 560*pow(Pi,0.6);
        /* Substation ($) (eq. 43) */
Cai = 20000000.0;
        /* Add Inlet Eq($) (eq. 45) */
Cri = 10000000.0;
        /* Acess Road ($) (eq. 46) */
switch (pigs)
{
    case 0:
        /* No Pigs */
        Co = 0.0;
        break;
    case 1:
        /* Pig Leads Train */
        Co = 1.0;
        break;
}
Cpg = Co*24000*length*linefill/Liftoff_Vel;
        /* Pigs ($) (eq. 49) */
return RF*Cti+Cbi+RF*Cpi+Csi+Cai+Cri+Cpg+Cde
+1.5*(CLI+RF*Cvi+RF*CuI+Cci+RF*Ce+RF*Ccp+RF*Ctt+RF*Cm+RF*Cbh);
}

="/***********************************************************************************/
/***** OUTLET CAPITAL COSTS **************************************************************************/
/***********************************************************************************/
double cap_costout()
{
    double Ls,Lco;
    double Cs,Cf,Cbo,CLo,Co,Ccd;
    Cs = 337000+24200*Qw;
        /* Sedimentation Tank ($) (eq. 81) */
    Cf = 63000*pow(Qw,0.5);
        /* Flocculation Tank ($) (eq. 82) */
    CLo = 196*Qw+2000;
        /* Land ($) (eq. 84) */
    Cco = 1000*(30.8*Qw/pow(D,0.485));
        /* Conveyors Cost ($) (eq. 87) */
    if(Qc<735)
    {
Co = 2.0;
}
else
{
    Co = 1.5;
}
Ccr = Co*1000*(93.3+0.0188*pow(Qc,1.315));
Cbo = 160000;
Cao = 1000000;
Coo = 1000000;
Ccd = 0.0001533*Qc*length+197000;
return Cs+Cf+Cao+Cbo+Coo+1.5*(2*Ccd+Cco+Ccr+CLo);
}

double cap_costboost()
{
    double Hub,Pb,Co;
    double Cbb,Crb,Csb,Crwb,Cub,Cvb,Cpb,CLb;
    Cwb = 50000*Qw;
    Hub = (DPc*10*dis_btw_pmp_sta*144)/(Liftoff_Vel*3.14159*D/4)/550;
    Cub = 2400*pow(Hub,0.8);
    switch (pressure)
    {
        case 2000:
            Co = 66.0;
            break;
        case 1500:
            Co = 63.0;
            break;
        case 1000:
            Co = 60.0;
            break;
        case 500:
            Co = 55.0;
            break;
    }
    Cvb = 11000*Co*pow(D,1.15);
    Cpb = 4*Lt*(129*pow(D,1.34)+102*pow(D,0.87)+24*D+20)*1000/5280;
    Cbb = 240000*D*D;
    Clb = 100000;
    Cab = 1000000;
    Pb = 0.746*Hub+45*D+50;
    Csb = 560*pow(Pb,0.6);
    Crb = 1000000.0;
    return Cab+Cbb+Crb+Csb+RF*Crwb+1.5*(RF*Cub+RF*Cvb+RF*Cpb+CLb);
}
double oper_costin()
{
    double Cbp,Hpm,Hpa,Cwp,Csip,Cpp,Cdap,Cgpp,Ccip,Cop,Cchp,Llo;
    double Pcpco,Pe,Pm,Pui,Pvi,Pci,Pbh,Pbi,Poi,Pde,El,Co,DifferCrush;
    if(extruder>0.0)
    {
        Pe = 1410*pow(D,2.14);  // Extruder Power (kW)  (eq. 54)
        Pm = 1.0*Qc;            // Mixer Power (kW)    (eq. 55)
        Cbp = 1310000*binder*Qc;  // Binder Cost ($)  (eq. 51)
    }
    else
    {
        Pe = 0.0;
        Pm = 0.0;
        Cbp = 0.0;
    }
    Pcpco = 12*Qc;            // Compaction/Coating Power (kW)  (eq. 53)
    Llo = 210*Liftoff_Vel;    // Length of Locks    (eq. 9)
    Hpm = (DPc*10*dis_btwn_pmp_stu*144)*(Liftoff_Vel*3.14159*D/4)/550;
    Hpa = ((DPc-DPc/1.4)*10*144)*Llo/5280*(5.0*3.14159*D/4)/550;
    Pui = 0.746*(Hpm+4.0*Hpa);            // Pump Power (kW)    (eq. 56)
    Pvi = 100*D;                    // Valve Power (kW)    (eq. 57)
    Pci = 200*D;                    // Conveyor Power (kW)  (eq. 58)
    Pbh = 87*binder*Qc;            // Binder Heating Power (kW)  (eq. 59)
    Pbi = 100;                      // Building Power (kW)   (eq. 61)
    Poi = 100;                      // Misc. Power (kW)    (eq. 62)
    if(deaeration>0.0)
    {
        Pde = 111.0*pow(Qw,0.62)-20.0;  // Deaeration Power (kW)  (eq. 60)
    }
    else
    {
        Pde = 0.0;
    }
    Pl = Pcpco+Pe+Pm+Pui+Pvi+Pci+Pbh+Pbi+Poi+Pde;
    // Total Power (kW)    (eq. 52)
    if(water>0.0)
    {
        Cwp = 158000*Qw;  // Fresh Water Cost ($)    (eq. 65)
    }
    else
    {
        Cwp = 634000*Qw;  // Brackish Water Cost ($)    (eq. 66)
    }
    Csip = (1000+0.88*Qc)*1000;
    // Salary and Wages ($)    (eq. 67)
    if(polymer>0.0)
    {
        Cpp = 197000*Qw;  // Polymer Cost ($)    (eq. 69)
    }
else
{
    Cpp = 0.0;
}
switch (pigs)
{
    case 0:  
        // No Pigs
        Co = 0.0;
        break;
    case 1:  
        // Pig Leads Train
        Co = 1.0;
        break;
}
if(length<1000)
{
    Cpgp = Co*7730*linefill*pow(D,3)*length*(0.45-0.0003*length);
    // Pig transportation Cost ($)
    (eq. 74) ***
}
else
{
    Cpgp = Co*1160*linefill*pow(D,3);
    // Pig transportation Cost ($)
    (eq. 74a) ***
}
Cclp = 500000;
// Communications Cost ($)
(eq. 75) ***
Chcp = 6657*Qc;
// Coal Heating Cost ($)
(eq. 76) ***
Coip = 381000+784*Qc;
// Other Reg Maintenance Cost ($)
(eq. 77) ***
DifferCrush = 0.23*throughput_coal*1000000;
return DifferCrush+Cbp+Cwp+Csip+Cpp+Cdap+Cpgp+Cclp+Chcp+Coop;

*****************************************************************************/
// OUTLET O/M COSTS  
*****************************************************************************/
double oper_costout()
{
    double Cfp,Csop,Coop;
    Cfp = 0.00003863*Qc*length;  // Flocculant Cost ($)
    (eq. 93) ***
    Po = 0.29*pow(Qc,0.934)+200*D+61.6+0.000112*Qc*length;
    // Total Output Power (kW)
    (eq. 98) ***
    Csop = 217000*pow(D,0.756);
    // Salaries and Wages Cost ($)
    (eq. 99) ***
    Coop = 125000*D;
    // Other O/M Cost ($)
    (eq. 100) ***
    return Cfp+Csop+Coop;
}

*****************************************************************************/
// BOOSTER STATION O/M COSTS  
*****************************************************************************/
double oper_costboost()
{
    double Hub,Cspb,Cmbp,Cpbp;
    Hub = (DPc*10*dis_btwn_pmp_stata*144)*(LiftOff_Vel*3.14159*D*D/4)/550;
    // Pump Horsepower ***
    Pb = 0.746*Hub+45*D+50;  
    // Booster Power (kW)
    (eq. 115) ***
    Cspb = 122000*pow(D,0.756);
    // Salaries and Wages Cost ($)
    (eq. 118) ***
    Cmbp = 100000*D;
    // Materials/Supply Cost ($)
    (eq. 119) ***
    if(polymer>0.0)
Cpbp = 99000 * Qw;  
*** Polymer Cost ($)  
(eq. 120)  
***
else
{
 Cpbp = 0.0;
}
return Cspb + Cmbp + Cpbp;

******************************************************************************
******  Energy Cost Subprogram  ******
******************************************************************************
double energy_cost(double Numb_boost)
{
 double Ceip, Ceop, Cebp;
 Ceip = 526 * Pi;  
*** Inlet Energy Cost ($)  
(eq. 64)  
***
 Ceop = 526 * Po;  
*** Outlet Energy Cost ($)  
(eq. 98)  
***
 Cebp = 526 * Pb;  
*** Electricity Cost ($)  
(eq. 117)  
***
return availability * (Ceip + Ceop + Numb_boost * Cebp);
}

main()
{
 double Cpc, Nb, new_machines, new_items, PipeOM, Tax_and_Ins, Tc, OMavail;
 out = fopen(" Scenario 1.out","w");
 discount_rate = 0.08;  
/** Discount Rate of 8%  
**/
 equity = 1.0;  
/** Equity Rate of 100%  
**/
 tax_rate = 0.37;  
/** Tax rate 37%  
**/
 OM_increase_rate = 0.06;  
/** Assume O/M Costs Are Raised 6% annualy  
**/
 Energy_increase_rate = 0.07;  
/** Assume Energy Costs Are Raised 7% annualy  
**/

******************************************************************************
******  Scenario Variables  ******
******************************************************************************

 availability = .90;  
/** amount of availability (90%)  
**/
 extruder = 0;  
/** 0 = no extruder 1 = low cost 2 = high cost  
**/
 compaction = 1;  
/** 0 = no compaction 1 = with compaction  
**/
 binder = 0.00;  
/** % binder in logs  
**/
 fabrication_rate = 0.2;  
/** fabrication rate in fps  
**/
 sealant = 1;  
/** 0 = no sealant 1 = sealed logs  
**/
 S = 1.20;  
/** Specific Gravity of Coal Logs  
**/
 pressure = 1500;  
/** Operating Pressure of the Pipeline  
**/
 pressure1 = pressure * 1.0;  
/** 1 = fresh water 0 = brackish water  
**/
 water = 0;  
/** Length of Train is defined in the MAIN LOOP  
**/
 condition = 1;  
/** 1 = new pipeline 0.3 = existing pipeline  
**/
 linefill = 0.9;  
/** 90% linefill  
**/
 polymer = 0;  
/** 1 = polymer added 0 = No polymer added  
**/
 redundancy = 0;  
/** 1 = second pump 0 = no second pump  
**/
 deaeration = 1;  
/** 1 = de-aired water 0 = plain water  
**/
 pigs = 0;  
/** 0 = no pigs 1 = pig leads train  
**/
 return_rate = 0.15;  
/** Rate of Return 15%  
**/
 diameter = 4.0;  
/** Initial Diameter of Pipe in Inches  
**/
if(S == 1.05)
    {in = fopen("S=1.05table","r");}
else
    if(S == 1.1)
        {in = fopen("S=1.10table", "r");}
    else
        if(S == 1.2)
            {in = fopen("S=1.20table","r");}
        else
            if(S == 1.35)
                {in = fopen("S=1.35table","r");}
            else
                {in = fopen("S=1.125slurrytable","r");} }

for(i=1;i<=9;i++)
{ 
    for(j=1;j<=20;j++)
    { 
        fscanf(in,"%lf", &temp); 
        Table[i][j] = temp; 
    }
}

/*-----------MAIN LOOP START-----------*/

for(j = 1;j<10;j++)
{
    money = 0.0;
    Oper_Main[1]=0.0;

/*-----------Define Values from Table-----------*/

Liftoff_Vel = Table[j][2];
aspect_ratio = Table[j][3];
diameter_ratio = Table[j][4];

if(polymer==0)
{
    DPe = Table[j][5];
    Power = Table[j][7];
    if(pressure1==500)
        {dis_btwn_pmp_sta = Table[j][13];}
    else
        if(pressure1==1000)
            {dis_btwn_pmp_sta = Table[j][14];}
        else
            if(pressure1==1500)
                {dis_btwn_pmp_sta = Table[j][15];}
else
    {dis_btwn_pmp_sta = Table[j][16];})
}
else
{
    DPc = Table[j][6];
    Power = Table[j][8];
    if(pressure1==500)
    {dis_btwn_pmp_sta = Table[j][17];}
    else
    {if(pressure1==1000)
     {dis_btwn_pmp_sta = Table[j][18];}
     else
     {if(pressure1==1500)
      {dis_btwn_pmp_sta = Table[j][19];}
     else
     {dis_btwn_pmp_sta = Table[j][20];})}}
}
if(linefill==0.8)
{
    throughput_water = Table[j][9]; /* Amount of water Transported cfs */
    throughput_coal = Table[j][10]; /* Amount of Coal Transported MT/yr */
}
else
{
    throughput_water = Table[j][11]; /* Amount of water Transported cfs */
    throughput_coal = Table[j][12]; /* Amount of Coal Transported MT/yr */
}

/* Length of Train */

fprintf(out,"%10.2f   %10.2f   %10.2fh\n",1.0,throughput_coal*availability,diameter);
Lt = 200*Litoff_Vel; /* Length of Coal Log Train in FEET */
length = 10.0; /* Initial Length of Pipeline in MILES */
if(redundancy>0)
    {
        RF = 2.0;
    }
else
    {
        RF = 1.0;
    }
for(k = 1;k<30;k++)
{

/* Calculate Initial C/M and Energy Costs for Year 1992 */

Nb = length/dis_btwn_pmp_sta-1.0; /* Number of Booster Stations */
if(Nb < 0)
    {
        Nb = 0.0;
    }
else
    {
        Nb = Nb;
    }
if(availability > 0.9)
OMavail = 0.96;
}
else
{
    OMavail = 0.92;
}
Oper_Main[1] = oper_costin()+oper_costout()+N>oper_costboost();
    /* 1992 Operation/Maintainence Costs in $Million */
Oper_Main[1] = OMavail*Oper_Main[1];
Energy[1] = energy_cost(Nb);    /* 1992 Energy Costs in $Million */

/**************************************************************************
 -------- Calculate Capital Costs --------
**************************************************************************

   Cpc = (length-Nb*Lt/5280)*(129*pow(D,1.34)+102*pow(D,0.87)+24*D+20)*1000;
   /* Pipeline Cost New ($) (eq. 122) */
   money = cap_costin() + cap_costout() + Nb*cap_costboost()+Cpc*condition;
   /* 1992 Capital Costs in $Million */
   money = money/1000000;
   new_machines = Ccl+Cco+Ccp+Cde+Cct+Cai+Ccr+Cao+Coo;
   new_machines = new_machines/1000000;
   Tax_and_Ins = 0.025*money;
   PipeOM = Cpc*0.01/1000000;

/**************************************************************************
 -------- Calculate O/M and Energy Costs for Each Year for total sequence --------
**************************************************************************

   Oper_Main[1] = Oper_Main[1]/1000000 + PipeOM;
   for(i = 2; i<SIZE;i++)
   {
      Oper_Main[i] = Oper_Main[i-1]*(1.0+OM_increase_rate);
      Energy[i] = Energy[i-1]*(1.0+Energy_increase_rate);
   }

/**************************************************************************
 -------- Life Cycle Cost --------
**************************************************************************

   Tc = throughput_coal;
   sum_Unit_cost_PV = 0.0;
   for(year = 1; year<SIZE;year++)
   {
      n[year] = year;
      Depreciation[year] = money/number_of_years;
      Return[year] = (money-(n[year]-1)*Depreciation[year])*return_rate;
      Taxes[year] = Return[year]*equity*tax_rate;
                   +Return[year]+Taxes[year]+Tax_and_Ins;
      Unit_cost[year] = Cost[year]/Tc/availability;
      Unit_cost_PV[year] = present_value(Unit_cost[year],discount_rate,year);
      sum_Unit_cost_PV = sum_Unit_cost_PV+Unit_cost_PV[year];
   }
   avg_unit_cost_PV = sum_Unit_cost_PV/number_of_years;
   avg_freight_rate_PV = avg_unit_cost_PV/length;
fprintf(out,"\%10.2f  \%14.4f  \%14.4fn", length, avg_unit_cost_PV, avg_freight_rate_PV);
if(length<50.0)
   { length = length+10.0; }
else
   { if(length<1000.0)
      { length = length+50.0; }
   else
      { length = length+200.0; }
   }
diameter = diameter+2.0;
fprintf(out,"n");
Oper_Main[1]=0.0;
money=0.0;
Energy[1]=0.0;
} fclose(out);
fclose(in);
**Slurry Calculation Program Flowchart**

**START**

**SET**
- discount rate, equity rate, tax rate, O/M increase rate, Energy increase rate, availability, linefill, log specific gravity (S), return rate, life of pipe, and initial diameter

**READ**
- Input Table (depends on S)

**FOR**
- \( j = 1; j < 10 \) "Diameter Loop"

**DEFINE**
- \( V_L, a, k, \Delta p_C \) Power, distance between pumping stations, coal throughput, and water throughput from Input Table

**SET**
- Initial Pipeline Length

**FOR**
- \( k = 1; k < 30 \) "Length Loop"

**CALCULATE**
- number of booster stations = pipeline length / distance between pumping stations

**CALCULATE** O/M cost for year 1
- \( O/M \) cost@inlet = CALL oper_costin()
- \( O/M \) cost@outlet = CALL oper_costout()
- \( O/M \) cost@booster_station = CALL oper_costboost()
- Pipe \( O/M = 0.01 \) Cost of Pipeline
- \( O/M[j] = P_{pipe} O/M + O/M \) cost@inlet + \( O/M \) cost@outlet + (number of booster stations) * \( O/M \) cost@booster_station

**CALCULATE** Capital cost
- Capital cost@inlet = CALL cap_costin()
- Capital cost@outlet = CALL cap_costout()
- Capital cost@booster_station = CALL cap_costboost()
- Capital cost = Pipe Cost + Capital cost@inlet + Capital cost@outlet + (number of booster stations) * Capital cost@booster_station

**FOR**
- \( i = 2; i \leq \) life of pipe "O/M - Energy Increase Loop"

**CALCULATE** O/M[i] = O/M[i-1] * (1.0 + O/M increase rate)
- Energy[i] = Energy[i-1] * (1.0 + Energy increase rate)
- Tax & Insurance = 0.025 * Capital cost
SET \( \Sigma \text{Unit Cost PV} = 0 \)

FOR \( \text{year} = 1; \text{year} \leq \text{life of pipe} \) "Life-Cycle Loop"

CALCULATE Depreciation, Return, Taxes, Cost, Unit Cost

\[
\text{Unit Cost PV} = \text{CALL present value(Unit Cost, discount rate, year)}
\]

\[
\text{Freight Rate PV} = \text{CALL present value(Freight Rate, discount rate, year)}
\]

\[
\Sigma \text{Unit Cost PV} = \Sigma \text{Unit Cost PV} + \text{Unit Cost PV}
\]

CALCULATE average Unit Cost PV = \( \frac{\Sigma \text{Unit Cost PV}}{\text{life of pipe}} \)

average Freight Rate PV = average Unit Cost PV / length

OUTPUT length of pipeline, average Unit Cost PV, and average Freight Rate PV

IF length of pipeline < 50

\( \text{Yes} \) SET length of pipeline = length of pipeline + 10

No

IF length of pipeline < 1000

\( \text{Yes} \) SET length of pipeline = length of pipeline + 50

No

SET length of pipeline = length of pipeline + 200

SET Diameter = Diameter + 2

END
Slurry Calculation Program Subroutine Flowcharts

Subroutine present value()

START

INPUT Value, interest rate, number of periods

CALCULATE Value / (1 + interest rate)^(number of periods)

RETURN

Subroutine energy(Nb)

START

INPUT Number of booster stations, Nb

CALCULATE Power in + Power out + Power booster station * Nb

RETURN

Subroutine oper_costin()

START

CALCULATE Labor cost, Materials cost, and Administration cost

RETURN

Subroutine cap_costin()

START

CALCULATE Slurry Preparation Facility, and Pump Station cost

RETURN

Subroutine oper_costout()

START

CALCULATE Labor cost, Materials cost, Flocculant cost, and Administration cost

RETURN

Subroutine cap_costout()

START

CALCULATE Dewatering Facility cost

RETURN

Subroutine oper_costboost()

START

CALCULATE Labor cost, Materials cost, and Administration cost

RETURN

Subroutine cap_costboost()

START

CALCULATE Pumping Station cost

RETURN
Slurry Calculation Program

#include<stdio.h>
#include<math.h>
#include<cstdlib.h>

#define SIZE 31
#define number_of_years 30
#define D diameter/12
#define Qc throughput_coal
#define Qw throughput_water

FILE *out, *in;
double avg_freight_rate_PV,avg_unit_cost_PV,diameter,equity,throughput_coal;
double length,money,return_rate,tax_rate,Cost[SIZE],Depreciation[SIZE],Energy[SIZE];
double freight_rate[SIZE],freight_rate_PV[SIZE],Oper_Main[SIZE],Return[SIZE];
double Taxes[SIZE],Unit_cost[SIZE],Unit_cost_PV[SIZE],Stemp,Table[20][30];
double sum_Unit_cost_PV,sum_freight_rate_PV,Energy_increase_rate,OM_increase_rate;
double throughput_water,linfill,aspect_ratio,Liftoff_Vel,diameter_ratio;
double polymer,DPC,Power,dis_btwn_pmp_sta,binder,pressure1,PI,Po,Pb,Lf,fabrication_rate;
double discount_rate,RF,Slurry;
double Pipe_cost,Dewatering,Slurry_prep,Pump_Station;
int n[SIZE],year,i,j,k,pressure,extruder,compaction,sealant,pigs,water,deaeration;
int condition, redundancy;

/*******************************************/
****** Present Value Calculation ******
*******************************************/

double present_value(double base, double rate, double period)
{
    return base/(pow((1.0+rate),period));
}

/*******************************************/
****** Capital Cost Subprograms ******
*******************************************/

/*******************************************/
****** INLET CAPITAL COSTS **************
/*******************************************/

double cap_costin()
{
    double Slurry_Prep;
    Slurry_Prep=7294*pow(Qc,0.823);
    Pump_Station=1210*pow(Qc,0.827);

    return Slurry_Prep+Pump_Station;
}

/*******************************************/
****** OUTLET CAPITAL COSTS **************
/*******************************************/

double cap_costout()
{
    double Dewatering;
    Dewatering=11808*pow(Qc,0.886);
return Dewatering;
}

/******
BOOSTER STATION CAPITAL COSTS
******/

double cap_costboost()
{
    Pump_Station=1210*pow(Qc,0.827);
    return Pump_Station;
}

/******
Operational/Maintaining Cost Subprograms
******/

/******
INLET O/M COSTS
******/

double oper_costin()
{
    double Labor, Materials, Admin;
    Labor=1186+175*Qc;
    Materials=282*pow(Qc,0.888);
    Admin=782+38*Qc;
    return Labor+Materials+Admin;
}

/******
OUTLET O/M COSTS
******/

double oper_costout()
{
    double Labor, Materials, Admin, Flocc;
    Labor=1024+218*Qc;
    Materials=452*pow(Qc,0.963);
    Admin=756+52*Qc;
    Flocc=589*Qc;
    return Labor+Materials+Admin+Flocc;
}

/******
BOOSTER STATION O/M COSTS
******/

double oper_costboost()
{
    double Labor, Materials, Admin;
    Labor=145+2*Qc;
    Materials=92*pow(Qc,0.695);
    Admin=73+Qc;
    return Labor+Materials+Admin;
}
```c
double energy_cost(double Numb_boost)
{
    double Power, Labor, Materials, Admin;
    Power = 864 * pow(Qc, 0.808) + Numb_boost * (254 * pow(Qc, 1.01)) + 923 * pow(Qc, 0.837);
    return Power;
}

main()
{
    double Cpc, Nb, new_machines, new_items, availability, OMavail, Tax_and_Ins, PipeOM, Tc;
    out = fopen("Slurry.out", "w");
    discount_rate = 0.08; /* Discount Rate of 8% */
    equity = 1.0; /* Equity Rate of 100% */
    tax_rate = 0.37; /* Tax rate 37% */
    OM_increase_rate = 0.06; /* Assume O/M Costs Are Raised 6% annually */
    Energy_increase_rate = 0.07; /* Assume Energy Costs Are Raised 7% annually */

    availability = .90; /* amount of availability (90%) */
    S = 1.125; /* Specific Gravity of Coal Logs */
    pressure = 1500; /* Operating Pressure of the Pipeline */
    pressure1 = pressure * 1.0;
    condition = 1; /* 1 = new pipeline 0 = existing pipeline */
    polymer = 0; /* 1 = polymer added 0 = No polymer added */
    return_rate = 0.15; /* Rate of Return 15% */
    diameter = 4.0; /* Initial Diameter of Pipe in Inches */

    if(S==1.05)
    {
        in = fopen("S=1.05table", "r");
    }
    else
    {
        if(S==1.1)
        {
            in = fopen("S=1.10table", "r");
        }
        else
        {
            if(S==1.2)
            {
                in = fopen("S=1.20table", "r");
            }
            else
            {
                if(S==1.35)
                {
                    in = fopen("S=1.35table", "r");
                }
                else
                {
                    in = fopen("Slurry table", "r");
                }
            }
        }
    }

    for(i=1;i<=9;i++)
    {
        for(j=1;j<=20;j++)
        {
            fscanf(in, "%f", &temp);
        }
    }
```
Table[i][j] = temp;
}

/----------------------------------------/
/***** MAIN LOOP START *****
/----------------------------------------/

for(j = 1;j<10;j++)
{
    money = 0.0;
    Oper_Main[1]=0.0;
    /----------------------------------------/
    /***** Define Values from Table *****
    /----------------------------------------/

    Liftoff_Vel = Table[i][2];
    aspect_ratio = Table[i][3];
    diameter_ratio = Table[i][4];

    if(polymer==0)
    {
        DPC = Table[i][5];
        Power = Table[i][7];
        if(pressure==500)
            {dis_between_pmp_sta = Table[i][13];}
        else
            if(pressure==1000)
                {dis_between_pmp_sta = Table[i][14];}
            else
                if(pressure==1500)
                    {dis_between_pmp_sta = Table[i][15];}
                else
                    {dis_between_pmp_sta = Table[i][16];}
    }
    else
    {
        DPC = Table[i][6];
        Power = Table[i][8];
        if(pressure==500)
            {dis_between_pmp_sta = Table[i][17];}
        else
            if(pressure==1000)
                {dis_between_pmp_sta = Table[i][18];}
            else
                if(pressure==1500)
                    {dis_between_pmp_sta = Table[i][19];}
                else
                    {dis_between_pmp_sta = Table[i][20];}
    }

    if(linefill==0.8)
    {
        throughput_water = Table[i][9];  /* Amount of water Transported cfs */
        throughput_coal = Table[i][10];  /* Amount of Coal Transported MT/YR */
    }
else 
{ 
    throughput_water = Table[j][11];  // Amount of water Transported cfs 
    throughput_coal = Table[j][12];  // Amount of Coal Transported MT/YR 
} 
length = 10.0;  // Initial Length of Pipeline in MILES 
println("%10.2f  %10.2f %10.2f/n",1.0,throughput_coal*availability,diameter); 
for(k = 1;k<30;k++) 
{ 
    // Calculate Initial O/M and Energy Costs for Year 1992  
    Nb = length/distance_bw_pumpsta-1.0  // Number of Booster Stations 
    if(Nb < 0) 
    { 
        Nb = 0.0; 
    } 
    else 
    { 
        Nb = Nb; 
    } 
    Oper_Main[1] = oper_costin()+oper_costout()+Nb*oper_costboost(); 
    Oper_Main[1] = Oper_Main[1]/1000;  // 1992 Operation/Maintenance Costs in $Million 
    Energy[1] = energy_cost(Nb); 

    // Calculate Capital Costs 
    Pipe_cost=(0.206*Qc*Qc+35.91*Qc+269.0)/1000*length; 
    money = cap_costin()+cap_costout()+Nb*cap_costboost()+Pipe_cost; 
    money = money/1000;  // 1992 Capital Costs in $Million 

    // Calculate O/M and Energy Costs for Each Year for total sequence 
    if(availability > 0.9) 
    { 
        OMavail = 0.96; 
    } 
    else 
    { 
        OMavail = 0.92; 
    } 
    PipeOM = Pipe_cost*0.01; 
    Oper_Main[1] = OMavail*Oper_Main[1]+PipeOM; 
    for(i = 2;i<SIZE;i++) 
    { 
        Oper_Main[i] = Oper_Main[i-1]*(1.0+OM_increase_rate); 
        Energy[i] = Energy[i-1]*(1.0+Energy_increase_rate); 
    } 
    Tax_and_Ins = 0.025*money;
Tc = throughput_coal;
sum_Unit_cost_PV = 0.0;
for(year = 1; year<SIZE; year++)
{
    n[year] = year;
    Depreciation[year] = money/number_of_years;
    Return[year] = (money-(n[year]-1)*Depreciation[year])*return_rate;
    Taxes[year] = Return[year]*equity*tax_rate;
                            +Return[year]+Taxes[year]+Tax_and_Ins;
    Unit_cost[year] = Cost[year]/Tc/availability;
    Unit_cost_PV[year] = present_value(Unit_cost[year],discount_rate,year);
    sum_Unit_cost_PV = sum_Unit_cost_PV+Unit_cost_PV[year];
}
avg_unit_cost_PV = sum_Unit_cost_PV/number_of_years;
avg_freight_rate_PV = avg_unit_cost_PV/length;

OUTPUT
fprintf(out,"%10.2f %14.4f %14.4f
",length,avg_unit_cost_PV,avg_freight_rate_PV);
if((length<50.0)
{
    length = length+10.0;
}
else
{
    if((length<1000.0)
    {
        length = length+50.0;
    }
    else
    {
        length = length+200.0;
    }
}
diameter = diameter+2.0;
fprintf(out,"n");
Oper_Main[1]=0.0;
money=0.0;
Energy[1]=0.0;
}
fclose(out);
close(in);
APPENDIX VI:

COMPARISON WITH WTI MODEL
WILLIAMS TECHNOLOGIES, INC.
UNIT COST CALCULATIONS
for
COAL LOG PIPELINES

Based on capital and operating and maintenance cost data provided by the University of Missouri-Columbia (UMC), Williams Technologies, Inc. (WTI) has calculated the unit cost, in terms of dollars per ton, to transport coal in selected scenarios of coal log pipeline systems. The computer model used to project these costs was developed by WTI and has been successfully used for a number of years to assess the economic viability of a many proposed projects, as well as to consummate the acquisition of certain investments. The results produced by this model compare almost identically with the output of a financial analysis program used by Mapco, Inc.

Scenarios No. 1, 15, 17 and 21 as described in the UMC Economic Analysis of Coal Log Pipeline Transportation of Coal Report provide the basis for the cost projections. For each scenario transportation costs were developed for pipeline lengths of 100, 300, 700, and 950 miles each transporting 3, 5, 10 and 20 million tons of coal per year.

The following investment assumptions were used to calculate a pipeline tariff ($/ton of coal) in the first year of operation that would yield an after tax internal rate of return of 15.00 percent for each case:

VARIABLE ASSUMPTIONS:

(1) The capital cost for each pipeline system was provided by UMC.

(2) The "ordinary" operation and maintenance costs for each pipeline system, including energy (electric power), fuel, materials and supplies, repair, maintenance, wages and salaries, were provided by UMC.

FIXED ASSUMPTIONS USED IN ALL CASES:

(1) All dollar values are expressed in 1992 dollars.

(2) The effective tax rate, intended to include federal, state and local taxes, was set at 37.00 percent.

(3) To cover ad valorem taxes and insurance an annual cost of 2.50 percent of the original capital cost was used.
(4) The internal rate of return was based on 100.00 percent equity.

(5) The depreciation method used was 150 percent declining balance with a depreciation period of 15 years.

(6) The useful life of the pipeline was set at 20 years.

(7) The pipeline revenues were not escalated on an annual bases. Industry practice would suggest that pipeline revenues are only allowed to escalate by the amount of the annual increase in operating costs. Therefore, if the revenues are escalated the operating cost must also be escalated which would result in no impact on the projected rate of return.

In the calculations to determine the average present values the following assumptions were used:

(1) The first year pipeline tariff was escalated annually at a rate of 2.00 percent to offset projected operating cost increases.

(2) Discussions with the Fuel Purchasing Group at Kansas City Power and Light have revealed that in the long term railroad tariffs will inflate at a rate of 2.40 percent annually. Therefore this rate was used as a discount rate in the calculations.

(3) The useful life of the property was set at 20 years.

The attached tables compare the results of calculations of the unit cost of transporting coal as produced by the UMC model and the WTI model. The primary difference in the UMC and WTI results is that UMC assumed an 8 percent escalation factor for future railroad tariffs while WTI use a 2.4 percent escalation factor.
WILLIAMS TECHNOLOGIES, INC.
COAL LOG PIPELINE
UNIT COST CALCULATIONS

SCENARIO #1

<table>
<thead>
<tr>
<th>Pipeline Thruput (MT/Yr)</th>
<th>Unit Cost ($/Ton of Coal)</th>
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<th></th>
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<td></td>
<td></td>
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<td><strong>WTI MODEL</strong></td>
</tr>
<tr>
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<td><strong>First Year</strong></td>
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<td>Pres. Value</td>
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WILLIAMS TECHNOLOGIES, INC.
COAL LOG PIPELINE
UNIT COST CALCULATIONS

SCENARIO #17

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### WILLIAMS TECHNOLOGIES, INC.
### COAL LOG PIPELINE
### UNIT COST CALCULATIONS

**SCENARIO #21**

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<th>Pipeline Thruput (MT/Yr)</th>
<th>Unit Cost ($/Ton of Coal)</th>
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