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APPENDICES

Appendix A-1 Case Study 4.1.1 GAMS Code

```
Set
        i Source stream /i1*i3/
        j Sink stream /j1*j3/
;
Parameter
        SA Source concentration A (ppm)
        /i1     15
         i2     120
         i3     220/
        SB Source concentration B (ppm)
        /i1     400
         i2     12500
         i3     45/
        SC Source concentration C (ppm)
        /i1     35
         i2     180
         i3     9500/
        FS Source flowrate (ton per hour)
        /i1     45
         i2     34
         i3     56/
        DMA Sink Maximum concentration A (ppm)
        /j1     0
         j2     20
         j3     120/
```

```
      DMB Sink Maximum concentration B (ppm)
      /j1   0
       j2   300
       j3   20/
      DMC Sink Maximum concentration C (ppm)
      /j1   0
       j2   45
       j3   200/
      FD Sink flowrate (ton per hour)
      /j1   45
       j2   34
       j3   56/
;
Variable OBJ Objective function
;
Positive variable    x(i,j)  Source split fraction i to j
                 FW(j)   Freshwater flowrate (ton per hour)
                 WW(i)   Waste of each source (ton per hour)
                 F(i,j)  Splitting flowrate i to j (ton per hour)
                 DA(j)   Sink stream concentration A (ppm)
                 DB(j)   Sink stream concentration B (ppm)
                 DC(j)   Sink stream concentration C (ppm)
                 OFW     Overall freashwater (ton per hour)
                 OWW     Overall waste (ton per hour)
;
Binary variable      y(i,j)
                    z(j)
;

Scalar  OMEGA /10000/
;
```

```
Equation
      MB1(j)        Mass balance (flowrate A)
      MB2(j)        Mass balance (flowrate B)
      MB3(j)        Mass balance (flowrate C)
      MB4(j)        Mass balance (contaminant)
      Cons1(i)      Constraint for x
      Cons2(j)      Concentration constraint A
      Cons3(j)      Concentration constraint B
      Cons4(j)      Concentration constraint C
      Flow(i,j)     Flowrate source i to sink j
      Waste(i)      Waste of each source
      OFresh        Overall freshwater
      OWaste        Overall waste
      Logical1(i,j) Logical canstraint1
      Logical2(j)   Logical canstraint2
      Object        Objective
;
MB1(j)..sum(i,SA(i)*FS(i)*x(i,j))=e=DA(j)*FD(j);
MB2(j)..sum(i,SB(i)*FS(i)*x(i,j))=e=DB(j)*FD(j);
MB3(j)..sum(i,SC(i)*FS(i)*x(i,j))=e=DC(j)*FD(j);
MB4(j)..sum(i,FS(i)*x(i,j))+FW(j)=e=FD(j);
Cons1(i)..sum(j,x(i,j))=l=1;
Cons2(j)..DA(j)=l=DMA(j);
Cons3(j)..DB(j)=l=DMB(j);
Cons4(j)..DC(j)=l=DMC(j);
Flow(i,j)..F(i,j)=e=FS(i)*x(i,j);
Waste(i)..WW(i)=e=(1-sum(j,x(i,j)))*FS(i);
OFresh..OFW=e=sum(j,FW(j));
OWaste..OWW=e=sum(i,WW(i));
Logical1(i,j)..F(i,j)-y(i,j)*OMEGA=l=0;
Logical2(j)..FW(j)-z(j)*OMEGA=l=0;
Object..OBJ=e=OFW+sum((i,j),y(i,j))+sum(j,z(j));
```

Model CASE11/ALL/;

Solve CASE11 Using MINLP Minimizing OBJ;

Display OBJ.l, OFW.l, OWW.l, FW.l, WW.l, x.l, F.l, y.l, DA.l, DB.l, DC.l;

```
**** REPORT SUMMARY :        0   NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED
                             0     ERRORS
```

GAMS 24.2.1 r43572 Released Dec 9, 2013 WEX-WEI x86_64/MS Windows

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General Algebraic Modeling System

Execution

```
----   108 VARIABLE OBJ.L        =     111.662  Objective function
           VARIABLE OFW.L        =     105.662  Overall freashwater (ton per hour)
           VARIABLE OWW.L        =     105.662  Overall waste (ton per hour)

----   108 VARIABLE FW.L  Freshwater flowrate (ton per hour)
j1 45.000,    j2  8.500,    j3 52.162

----   108 VARIABLE WW.L  Waste of each source (ton per hour)
i1 16.832,    i2 34.000,    i3 54.831

----   108 VARIABLE x.L  Source split fraction i to j
          j2         j3
i1      0.567      0.059
i3                 0.021

----   108 VARIABLE F.L  Splitting flowrate i to j (ton per hour)
          j2         j3
i1     25.500      2.668
i3                 1.169
```

```
----  108 VARIABLE y.L
         j2        j3
i1     1.000      1.000
i3               1.000

----  108 VARIABLE DA.L  Sink stream concentration A (ppm)
j2 11.250,   j3  5.308

----  108 VARIABLE DB.L  Sink stream concentration B (ppm)
j2 300.000,   j3  20.000

----  108 VARIABLE DC.L  Sink stream concentration C (ppm)
j2  26.250,   j3 200.000

EXECUTION TIME      =       0.000 SECONDS      3 MB  24.2.1 r43572 WEX-WEI
USER: The Petroleum and Petrochemical College        G131219:2228AS-WIN
    Chulalongkorn University                         DC4365
    License for teaching and research at degree granting institutions
**** FILE SUMMARY
```

Appendix B-1 Case Study 4.2.1 GAMS Code

The first model: Non-liner programming (NLP)

```
Set
        i Source stream /i1*i3/
        j Sink stream /j1*j3/
;
Parameter
SMA Source concentration of Salts (ppm)
        /i1   15
         i2   120
         i3   220/
SMB Source concentration of Organics (ppm)
        /i1   400
         i2   12500
         i3   45/
SMC Source concentration of H2S (ppm)
        /i1   35
         i2   180
         i3   9500/
FS Maximun flowrate of fresh water
        /i1   45
        i2   33.184
        i3   54.821/
LA Load of Salts contaminant (kg per hour)
        /j1   0.675
         j2   3.40
         j3   5.60/
```

LB Load of Organics contaminant (kg per hour)

/j1 18.0

j2 414.80

j3 1.4/

LC Load of H2S contaminant (kg per hour)

/j1 1.575

j2 4.590

j3 520.8/

DMA Sink Maximum concentration of Salts (ppm)

/j1 0

j2 20

j3 120/

DMB Sink Maximum concentration of Organics (ppm)

/j1 0

j2 300

j3 20/

DMC Sink Maximum concentration of H2S (ppm)

/j1 0

j2 45

j3 200/

;

Variable OBJ Objective function

;

Positive variable

x(i,j)	Source split fraction i to j
FW(j)	Freshwater flowrate (ton per hour)
WW(i)	Waste of each source (ton per hour)
F(i,j)	Splitting flowrate i to j (ton per hour)
DA(j)	Sink stream concentration of Salts (ppm)
DB(j)	Sink stream concentration of Organics (ppm)
DC(j)	Sink stream concentration of H2S (ppm)
SA(i)	Source stream concentration of Salts (ppm)

SB(i) Source stream concentration of Organics (ppm)
SC(i) Source stream concentration of H2S (ppm)
OFW Overall freashwater (ton per hour)
OWW Overall waste (ton per hour)
LoadA(i,j) • Contaminant load of Salts of Process i to j (gram per hour)
LoadB(i,j) Contaminant load of Organics of Process i to j (gram per hour)
LoadC(i,j) Contaminantload of H2S of Process i to j (gram per hour)
Flowin(j) Total flowrate inlet of Salts contaminant of each process (ton per hour)
DeltaCA(i,j) Outlet concentration - Inlet concentration of Salts contaminant (ppm)
DeltaCB(i,j) Outlet concentration - Inlet concentration of Organics contaminant (ppm)
DeltaCC(i,j) Outlet concentration - Inlet concentration of H2S contaminant (ppm)

;

Equation

ConloadA1(i,j) Contaminantload of Salts of Process 1
ConloadA2(i,j) Contaminantload of Salts of Process 2
ConloadA3(i,j) Contaminantload of Salts of Process 3

ConloadB1(i,j) Contaminantload of Organics of Process 1
ConloadB2(i,j) Contaminantload of Organics of Process 2
ConloadB3(i,j) Contaminantload of Organics of Process 3

ConloadC1(i,j) Contaminantload of H2S of Process 1
ConloadC2(i,j) Contaminantload of H2S of Process 2
ConloadC3(i,j) Contaminantload of H2S of Process 3

MLoadA1(i,j)	Contaminantload balance of Salts of Process 1
MLoadA2(i,j)	Contaminantload balance of Salts of Process 2
MLoadA3(i,j)	Contaminantload balance of Salts of Process 3
MLoadB1(i,j)	Contaminantload balance of Organics of Process 1
MLoadB2(i,j)	Contaminantload balance of Organics of Process 2
MLoadB3(i,j)	Contaminantload balance of Organics of Process 3
MLoadC1(i,j)	Contaminantload balance of H2S of Process 1
MLoadC2(i,j)	Contaminantload balance of H2S of Process 2
MLoadC3(i,j)	Contaminantload balance of H2S of Process 3
TFlowin1(j)	Total flowrate inlet of process 1
TFlowin2(j)	Total flowrate inlet of process 2
TFlowin3(j)	Total flowrate inlet of process 3
FF1	Constraint for flowrate inlet of process 1
FF2	Constraint for flowrate inlet of process 2
FF3	Constraint for flowrate inlet of process 3
MconSA1(i)	Outlet concentration balance of Salts of process 1
MconSA2(i)	Outlet concentration balance of Salts of process 2
MconSA3(i)	Outlet concentration balance of Salts of process 3
MconSB1(i)	Outlet concentration balance of Organics of process1
MconSB2(i)	Outlet concentration balance of Organics of process2
MconSB3(i)	Outlet concentration balance of Organics of process3
MconSC1(i)	Outlet concentration balance of H2S of process 1
MconSC2(i)	Outlet concentration balance of H2S of process 2
MconSC3(i)	Outlet concentration balance of H2S of process 3

DCA1(i,j) Delta concentration of Salts of process 1
DCA2(i,j) Delta concentration of Salts of process 2
DCA3(i,j) Delta concentration of Salts of process 3

DCB1(i,j) Delta concentration of Organics of process 1
DCB2(i,j) Delta concentration of Organics of process 2
DCB3(i,j) Delta concentration of Organics of process 3

DCC1(i,j) Delta concentration of H2S of process 1
DCC2(i,j) Delta concentration of H2S of process 2
DCC3(i,j) Delta concentration of H2S of process 3

InconA1(j) New concentration of water inlet of Salts of process 1
InconA2(j) New concentration of water inlet of Salts of process 2
InconA3(j) New concentration of water inlet of Salts of process 3

InconB1(j) New concentration of water inlet of Organics of process 1

InconB2(j) New concentration of water inlet of Organics of process 2

InconB3(j) New concentration of water inlet of Organics of process 3

InconC1(j) New concentration of water inlet of H2S of process 1
InconC2(j) New concentration of water inlet of H2S of process 2
InconC3(j) New concentration of water inlet of H2S of process 3

CBA1(j) Concentretion balance of Salts of process 1
CBA2(j) Concentretion balance of Salts of process 2
CBA3(j) Concentretion balance of Salts of process 3

```
CBB1(j)        Concentretion balance of Organics of process 1
CBB2(j)        Concentretion balance of Organics of process 2
CBB3(j)        Concentretion balance of Organics of process 3

CBC1(j)        Concentretion balance of H2S of process 1
CBC2(j)        Concentretion balance of H2S of process 2
CBC3(j)        Concentretion balance of H2S of process 3

Cons1(i)       Constraint for x
Flowsplit(i,j) Splited flowrate source i to sink j
OFresh         Overall freshwater
Object         Objective
;
*Contaminantload of each process
ConloadA1('i1','j1') .. LoadA('i1','j1') =e= 1000*LA('j1');
ConloadA2('i2','j2') .. LoadA('i2','j2') =e= 1000*LA('j2');
ConloadA3('i3','j3') .. LoadA('i3','j3') =e= 1000*LA('j3');

ConloadB1('i1','j1') .. LoadB('i1','j1') =e= 1000*LB('j1');
ConloadB2('i2','j2') .. LoadB('i2','j2') =e= 1000*LB('j2');
ConloadB3('i3','j3') .. LoadB('i3','j3') =e= 1000*LB('j3');

ConloadC1('i1','j1') .. LoadC('i1','j1') =e= 1000*LC('j1');
ConloadC2('i2','j2') .. LoadC('i2','j2') =e= 1000*LC('j2');
ConloadC3('i3','j3') .. LoadC('i3','j3') =e= 1000*LC('j3');

*Contaminantload balance of each process
MLoadA1('i1','j1')..LoadA('i1','j1')=e=Flowin('j1')*DeltaCA('i1','j1');
MLoadA2('i2','j2')..LoadA('i2','j2')=e=Flowin('j2')*DeltaCA('i2','j2');
MLoadA3('i2','j3')..LoadA('i3','j3')=e=Flowin('j3')*DeltaCA('i3','j3');
```

```
MLoadB1('i1','j1')..LoadB('i1','j1')=e=Flowin('j1')*DeltaCB('i1','j1');
MLoadB2('i2','j2')..LoadB('i2','j2')=e=Flowin('j2')*DeltaCB('i2','j2');
MLoadB3('i2','j3')..LoadB('i3','j3')=e=Flowin('j3')*DeltaCB('i3','j3');

MLoadC1('i1','j1')..LoadC('i1','j1')=e=Flowin('j1')*DeltaCC('i1','j1');
MLoadC2('i2','j2')..LoadC('i2','j2')=e=Flowin('j2')*DeltaCC('i2','j2');
MLoadC3('i2','j3')..LoadC('i3','j3')=e=Flowin('j3')*DeltaCC('i3','j3');

*Total inlet flowrate of each process
TFlowin1('j1')..Flowin('j1')=e=sum(i,FS(i)*x(i,'j1'))+FW('j1');
TFlowin2('j2')..Flowin('j2')=e=sum(i,FS(i)*x(i,'j2'))+FW('j2');
TFlowin3('j3')..Flowin('j3')=e=sum(i,FS(i)*x(i,'j3'))+FW('j3');

*Constraint for flowrate inlet of each process
FF1..Flowin('j1')=g=FS('i1');
FF2..Flowin('j2')=g=FS('i2');
FF3..Flowin('j3')=g=FS('i3');

*Outlet concentration od each procerss
MconSA1('i1')..LA('j1')*1000=e=FS('i1')*SA('i1');
MconSA2('i2')..LA('j2')*1000=e=FS('i2')*SA('i2');
MconSA3('i3')..LA('j3')*1000=e=FS('i3')*SA('i3');

MconSB1('i1')..LB('j1')*1000=e=FS('i1')*SB('i1');
MconSB2('i2')..LB('j2')*1000=e=FS('i2')*SB('i2');
MconSB3('i3')..LB('j3')*1000=e=FS('i3')*SB('i3');

MconSC1('i1')..LC('j1')*1000=e=FS('i1')*SC('i1');
MconSC2('i2')..LC('j2')*1000=e=FS('i2')*SC('i2');
MconSC3('i3')..LC('j3')*1000=e=FS('i3')*SC('i3');
```

```
*Delta concentration of each process
DCA1('i1','j1') .. DeltaCA('i1','j1') =e= (SA('i1')-DA('j1'));
DCA2('i2','j2') .. DeltaCA('i2','j2') =e= (SA('i2')-DA('j2'));
DCA3('i3'.'j3') .. DeltaCA('i3','j3') =e= (SA('i3')-DA('j3'));
DCB1('i1','j1') .. DeltaCB('i1','j1') =e= (SB('i1')-DB('j1'));
DCB2('i2','j2') .. DeltaCB('i2','j2') =e= (SB('i2')-DB('j2'));
DCB3('i3','j3') .. DeltaCB('i3','j3') =e= (SB('i3')-DB('j3'));

DCC1('i1','j1') .. DeltaCC('i1','j1') =e= (SC('i1')-DC('j1'));
DCC2('i2','j2') .. DeltaCC('i2','j2') =e= (SC('i2')-DC('j2'));
DCC3('i3','j3') .. DeltaCC('i3','j3') =e= (SC('i3')-DC('j3'));

*New concentration of water inlet
InconA1('j1')..DA('j1')*Flowin('j1')=e=sum(i,FS(i)*x(i,'j1')*SA(i));
CBA1('j1')..DA('j1')=l=DMA('j1');
InconA2('j2')..DA('j2')*Flowin('j2')=e=sum(i,FS(i)*x(i,'j2')*SA(i));
CBA2('j2')..DA('j2')=l=DMA('j2');
InconA3('j3')..DA('j3')*Flowin('j3')=e=sum(i,FS(i)*x(i,'j3')*SA(i));
CBA3('j3')..DA('j3')=l=DMA('j3');

InconB1('j1')..DB('j1')*Flowin('j1')=e=sum(i,FS(i)*x(i,'j1')*SB(i));
CBB1('j1')..DB('j1')=l=DMB('j1');
InconB2('j2')..DB('j2')*Flowin('j2')=e=sum(i,FS(i)*x(i.'j1')*SB(i));
CBB2('j2')..DB('j2')=l=DMB('j2');
InconB3('j3')..DB('j3')*Flowin('j3')=e=sum(i,FS(i)*x(i,'j3')*SB(i));
CBB3('j3')..DB('j3')=l=DMB('j3');

InconC1('j1')..DC('j1')*Flowin('j1')=e=sum(i,FS(i)*x(i,'j1')*SC(i));
CBC1('j1')..DC('j1')=l=DMC('j1');
InconC2('j2')..DC('j2')*Flowin('j2')=e=sum(i,FS(i)*x(i,'j2')*SC(i));
CBC2('j2')..DC('j2')=l=DMC('j2');
InconC3('j3')..DC('j3')*Flowin('j3')=e=sum(i,FS(i)*x(i,'j3')*SC(i));
```

```
CBC3('j3')..DC('j3')=l=DMC('j3');
Cons1(i)..sum(j,x(i,j))=l=1;
Flowsplit(i,j)..F(i,j)=e=FS(i)*x(i,j);
OFresh..OFW=e=sum(j,FW(j));
Object..OBJ=e=OFW;
DB.lo('j2')=300;
DC.lo('j3')=200;

Model CASE11/ALL/;
Solve CASE11 Using NLP Minimizing OBJ;
Display LoadA.l, LoadB.l, LoadC.l, Flowin.l, SA.l, SB.l, SC.l, DeltaCA.l,
DeltaCB.l, DeltaCC.l, DA.l, DB.l, DC.l, FW.l, OBJ.l, OFW.l, x.l, F.l;
```

```
**** REPORT SUMMARY :        0     NONOPT
                             1 INFEASIBLE (INFES)
                    SUM  10200.000
                    MAX  10200.000
                    MEAN 10200.000
                             0  UNBOUNDED
                             0     ERRORS

GAMS 24.2.1  r43572 Released Dec  9, 2013 WEX-WEI x86_64/MS Windows
11/25/14 21:45:19 Page 6
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
E x e c u t i o n

----   275 VARIABLE LoadA.L  Contaminantload of Salts of Process i to j (gram p
                             er hour)

            j1          j2          j3

i1     675.000
i2                3400.000
i3                            5600.000
```

---- 275 VARIABLE LoadB.L Contaminantload of Organics of Process i to j

	j1	j2	j3
i1	18000.000		
i2		414800.000	
i3			1400.000

---- 275 VARIABLE LoadC.L Contaminantload of H2S of Process i to j (gram per hour)

	j1	j2	j3
i1	1575.000		
i2		4590.000	
i3			520800.000

---- 275 VARIABLE Flowin.L Total flowrate inlet of Salts contaminant of each process (ton per hour)

j1 45.000, j2 34.000, j3 56.000

---- 275 VARIABLE SA.L Source stream concentration of Salts (ppm)

i1 15.000, i2 102.459, i3 102.151

---- 275 VARIABLE SB.L Source stream concentration of Organics (ppm)

i1 400.000, i2 12500.000, i3 25.538

---- 275 VARIABLE SC.L Source stream concentration of H2S (ppm)

i1 35.000, i2 138.320, i3 9500.009

---- 275 VARIABLE DeltaCA.L Outlet concentration - Inlet concentration of Sa lts contaminant (ppm)

	j1	j2	j3
i1	15.000		
i2		100.000	
i3			100.000

---- 275 VARIABLE DeltaCB.L Outlet concentration - Inlet concentration of Or
ganics contaminant (ppm)

	j1	j2	j3
i1	400.000		
i2		12200.000	
i3			25.000

---- 275 VARIABLE DeltaCC.L Outlet concentration - Inlet concentration of H2
S contaminant (ppm)

	j1	j2	j3
i1	35.000		
i2		135.000	
i3			9300.009

---- 275 VARIABLE DA.L Sink stream concentration of Salts (ppm)
j2 2.459, j3 2.151

---- 275 VARIABLE DB.L Sink stream concentration of Organics (ppm)
j2 300.000, j3 0.538

---- 275 VARIABLE DC.L Sink stream concentration of H2S (ppm)
j2 3.320, j3 200.000

---- 275 VARIABLE FW.L Freshwater flowrate (ton per hour)
j1 45.000, j2 33.184, j3 54.821

---- 275 VARIABLE OBJ.L = 133.005 Objective function
VARIABLE OFW.L = 133.005 Overall freashwater (
ton per hour)

---- 275 VARIABLE x.L Source split fraction i to j

	j2	j3
i2	0.025	
i3		0.022

---- 275 VARIABLE F.L Splitting flowrate i to j (ton per hour)

	j2	j3
i2	0.816	
i3		1.179

EXECUTION TIME = 0.000 SECONDS 3 MB 24.2.1 r43572 WEX-WEI

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**** FILE SUMMARY

Input C:\Users\deepd_000\Documents\gamsdir\projdir\Data 1 Case 1 - Initialization step for Water Network.gms

Output C:\Users\deepd_000\Documents\gamsdir\projdir\Data 1 Case 1 - Initialization step for Water Network.lst

The second model: Mixed-integer non-liner programming (MINLP)

Set

i Source stream /i1*i3/

j Sink stream /j1*j3/

;

Parameter

SA Source concentration A (ppm)

/i1 15

i2 120

i3 220/

SB Source concentration B (ppm)

/i1 400

i2 12500

i3 45/

SC Source concentration C (ppm)

/i1 35

i2 180

i3 9500/

DMA Sink Maximum concentration A (ppm)

/j1 0

j2 20

j3 120/

DMB Sink Maximum concentration B (ppm)

/j1 0

j2 300

j3 20/

DMC Sink Maximum concentration C (ppm)

/j1 0

j2 45

j3 200/

;

```
Variable OBJ Objective function
;
Positive variable      x(i,j)  Source split fraction i to j
                   FW(j)   Freshwater flowrate (ton per hour)
                   WW(i)   Waste of each source (ton per hour)
                   FS(i)   Flowrate outlet (ton per hour)
                   FD(j)   Flowrate inlet (ton per hour)
                   F(i,j)  Splitting flowrate i to j (ton per hour)
                   DA(j)   Sink stream concentration A (ppm)
                   DB(j)   Sink stream concentration B (ppm)
                   DC(j)   Sink stream concentration C (ppm)
                   OFW     Overall freashwater (ton per hour)
                   OWW     Overall waste (ton per hour)
                   FWCost  Total cost of freshwater ($ per y)
                   nXCost  Total cost of water spliting units ($)
                   nFCost  Total cost of water feeding units ($)
                   OCost   Total operating cost ($ per year)
;
Binary variable        y(i,j)
                       z(j)
;

Scalar   OMEGA /10000/
         HY /8400/
         CostFW /2.00/
      CostnX /10000/
      CostnF /10000/
;
Equation
******************************** Water Network
**********************************
      MB1(j)        Mass balance (flowrate A)
```

```
      MB2(j)        Mass balance (flowrate B)
      MB3(j)        Mass balance (flowrate C)
      MB4(j)        Mass balance (contaminant)
      Cons1(i)      Constraint for x
      Cons2(j)      Concentration constraint A
      Cons3(j)      Concentration constraint B
      Cons4(j)      Concentration constraint C
      Cons5(i,j)    Constraint for water flowrate
      Flow(i,j)     Flowrate source i to sink j
      Waste(i)      Waste of each source
      OFresh        Overall freshwater
      OWaste        Overall waste
****************************** Number of units
******************************
      Logical1(i,j)  Logical canstraint1
      Logical2(j)    Logical canstraint2

****************************** Cost
*****************************************
      CostofFW      Total cost of Fresh water
      CostofnX      Total cost of water spliting units
      CostofnF      Total cost of water feeding units
      CostofO       Total cost of operation
****************************** Minimizing
***********************************
      Object        Objective
;
****************************** Water Network
********************************
MB1(j)..sum(i,SA(i)*FS(i)*x(i,j))=e=DA(j)*FD(j);
MB2(j)..sum(i,SB(i)*FS(i)*x(i,j))=e=DB(j)*FD(j);
MB3(j)..sum(i,SC(i)*FS(i)*x(i,j))=e=DC(j)*FD(j);
```

```
MB4(j)..sum(i,FS(i)*x(i,j))+FW(j)=e=FD(j);
Cons1(i)..sum(j,x(i,j))=l=1;
Cons2(j)..DA(j)=l=DMA(j);
Cons3(j)..DB(j)=l=DMB(j);
Cons4(j)..DC(j)=l=DMC(j);
Cons5(i,j)$(ord(i) eq ord(j))..FS(i)=e=FD(j);
Flow(i,j)..F(i,j)=e=FS(i)*x(i,j);
Waste(i)..WW(i)=e=(1-sum(j,x(i,j)))*FS(i);
OFresh..OFW=e=sum(j,FW(j));
OWaste..OWW=e=sum(i,WW(i));

****************************** Number of units
******************************
Logical1(i,j)..F(i,j)-y(i,j)*OMEGA=l=0;
Logical2(j)..FW(j)-z(j)*OMEGA=l=0;
****************************** Cost
*****************************************
CostofFW..FWCost=e=OFW*CostFW*HY;
CostofnX..nXCost=e=sum((i,j),y(i,j))*CostnX;
CostofnF..nFCost=e=sum(j,z(j))*CostnF;
CostofO..OCost=e=FWCost;
****************************** Minimizing
************************************
Object..OBJ=e=FWCost+nXCost+nFCost;
FS.lo('i1')=45;
FS.lo('i2')=34;
FS.lo('i3')=56;

Model CASE11/ALL/;
Solve CASE11 Using MINLP Minimizing OBJ;
Display OBJ.l, OCost.l, OFW.l, OWW.l, FW.l, WW.l, FS.l, FD.l, x.l, F.l, y.l,
DA.l, DB.l, DC.l, FWCost.l, nXCost.l, nFCost.l;
```

**** REPORT SUMMARY : 0 NONOPT
0 INFEASIBLE
0 UNBOUNDED
0 ERRORS

GAMS 24.2.1 r43572 Released Dec 9, 2013 WEX-WEI x86_64/MS Windows
11/25/14 22:42:20 Page 6
General Algebraic Modeling System
Execution

---- 137 VARIABLE OBJ.L = 1835128.478 Objective function
VARIABLE OCost.L = 1775128.478 Total operating cost ($ per year)
VARIABLE OFW.L = 105.662 Overall freashwater (ton per hour)
VARIABLE OWW.L = 105.662 Overall waste (ton per hour)

---- 137 VARIABLE FW.L Freshwater flowrate (ton per hour)
j1 45.000, j2 8.500, j3 52.162

---- 137 VARIABLE WW.L Waste of each source (ton per hour)
i1 16.832, i2 34.000, i3 54.831

---- 137 VARIABLE FS.L Flowrate outlet (ton per hour)
i1 45.000, i2 34.000, i3 56.000

---- 137 VARIABLE FD.L Flowrate inlet (ton per hour)
j1 45.000, j2 34.000, j3 56.000

---- 137 VARIABLE x.L Source split fraction i to j

	j2	j3
i1	0.567	0.059
i3		0.021

---- 137 VARIABLE F.L Splitting flowrate i to j (ton per hour)

	j2	j3
i1	25.500	2.668
i3	.	1.169

---- 137 VARIABLE y.L

	j2	j3
i1	1.000	1.000
i3		1.000

---- 137 VARIABLE DA.L Sink stream concentration A (ppm)

j2 11.250, j3 5.308

---- 137 VARIABLE DB.L Sink stream concentration B (ppm)

j2 300.000, j3 20.000

---- 137 VARIABLE DC.L Sink stream concentration C (ppm)

j2 26.250, j3 200.000

---- 137 VARIABLE FWCost.L = 1775128.478 Total cost of freshwa
ter ($ per y)

VARIABLE nXCost.L = 30000.000 Total cost of water s
pliting units ($)

VARIABLE nFCost.L = 30000.000 Total cost of water feeding units ($)

EXECUTION TIME = 0.000 SECONDS 3 MB 24.2.1 r43572 WEX-WEI

USER: The Petroleum and Petrochemical College G131219:2228AS-WIN
Chulalongkorn University DC4365
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**** FILE SUMMARY

Input C:\Users\deepd_000\Documents\gamsdir\projdir\Data 1 Case 2 - Water Ne
twork with out treatment.gms

Output C:\Users\deepd_000\Documents\gamsdir\projdir\Data 1 Case 2 - Water Ne
twork with out treatment.lst

Appendix B-2 Case Study 4.2.2 GAMS Code

The second model: Mixed-integer non-liner programming (MINLP)

```
Set
        i Sourœ stream /i1*i6/
        j Sink stream /j1*j6/
;
Parameter
        SA Source concentration A (ppm)
        /i1    367.5
         i2    154.4
         i3    80
         i4    293.34
         i5    220.1111
         i6    2375.043/
        SB Source concentration B (ppm)
        /i1    500
         i2    4000
         i3    3500
         i4    6000
         i5    1800
         i6    6500/
        SC Source concentration C (ppm)
        /i1    5655.5
         i2    10
         i3    175
         i4    127.5
         i5    340
         i6    167.2/
```

SD Source concentration C (ppm)

/i1 1537.5

i2 32

i3 116.65

i4 1096.67

i5 271.2

i6 400/

DMA Sink Maximum concentration A (ppm)

/j1 300

j2 10

j3 10

j4 100

j5 85

j6 1000/

DMB Sink Maximum concentration B (ppm)

/j1 50

j2 1

j3 1

j4 200

j5 200

j6 1000/

DMC Sink Maximum concentration C (ppm)

/j1 5000

j2 0

j3 0

j4 50

j5 300

j6 150/

DMD Sink Maximum concentration D (ppm)

```
/j1   1500
 j2   0
 j3   0
 j4   1000
 j5   200
 j6   200/
;
Variable OBJ Objective function
;
Positive variable
            x(i,j)  Source split fraction i to j
            FS(i)   Flowrate outlet (ton per hour)
            FD(j)   Flowrate inlet (ton per hour)
            FW(j)   Freshwater flowrate (ton per hour)
            WW(i)   Waste of each source (ton per hour)
            F(i,j)  Splitting flowrate i to j (ton per hour)
            DA(j)  Sink stream concentration A (ppm)
            DB(j)  Sink stream concentration B (ppm)
            DC(j)  Sink stream concentration C (ppm)
            DD(j)  Sink stream concentration D (ppm)
            OFW     Overall freashwater (ton per hour)
            OWW     Overall waste (ton per hour)
            FWCost  Total cost of freshwater ($ per y)
            nXCost  Total cost of water spliting units ($)
            nFCost  Total cost of water feeding units ($)
            OCost   Total operating cost ($ per year)
;

Binary variable     y(i,j)
            z(j)
;
```

```
Scalar   OMEGA /10000/
        HY /8400/
        CostFW /2.00/
        CostnX /10000/
        CostnF /10000/
;
Equation
****************************** Water Network
********************************
        MB1(j)        Mass balance (flowrate A)
        MB2(j)        Mass balance (flowrate B)
        MB3(j)        Mass balance (flowrate C)
        MB4(j)        Mass balance (flowrate D)
        MB5(j)        Mass balance (contaminant)
        Cons1(i)      Constraint for x
        Cons2(j)      Concentration constraint A
        Cons3(j)      Concentration constraint B
        Cons4(j)      Concentration constraint C
        Cons5(j)      Concentration constraint D
        Cons6(i,j)    Constraint for water flowrate
        Flow(i,j)     Flowrate source i to sink j
        Waste(i)      Waste of each source
        OFresh        Overall freshwater
        OWaste        Overall waste

****************************** Number of units
******************************
        Logical1(i,j)  Logical canstraint1
        Logical2(j)    Logical canstraint2
****************************** Cost
*****************************************
        CostofFW       Total cost of Fresh water
```

```
      CostofnX      Total cost of water spliting units
      CostofnF      Total cost of water feeding units
      CostofO       Total cost of operation
****************************** Minimizing
***********************************
      Object        Objective
;
****************************** Water Network
*********************************
MB1(j)..sum(i,SA(i)*FS(i)*x(i,j))=e=DA(j)*FD(j);
MB2(j)..sum(i,SB(i)*FS(i)*x(i,j))=e=DB(j)*FD(j);
MB3(j)..sum(i,SC(i)*FS(i)*x(i,j))=e=DC(j)*FD(j);
MB4(j)..sum(i,SD(i)*FS(i)*x(i,j))=e=DD(j)*FD(j);
MB5(j)..sum(i,FS(i)*x(i,j))+FW(j)=e=FD(j);
Cons1(i)..sum(j,x(i,j))=l=1;
Cons2(j)..DA(j)=l=DMA(j);
Cons3(j)..DB(j)=l=DMB(j);
Cons4(j)..DC(j)=l=DMC(j);
Cons5(j)..DD(j)=l=DMD(j);
Cons6(i,j)$(ord(i) eq ord(j))..FS(i)=e=FD(j);
Flow(i,j)..F(i,j)=e=FS(i)*x(i,j);
Waste(i)..WW(i)=e=(1-sum(j,x(i,j)))*FS(i);
OFresh..OFW=e=sum(j,FW(j));
OWaste..OWW=e=sum(i,WW(i));
****************************** Number of units
******************************
Logical1(i,j)..F(i,j)-y(i,j)*OMEGA=l=0;
Logical2(j)..FW(j)-z(j)*OMEGA=l=0;
****************************** Cost
*****************************************
CostofFW..FWCost=e=OFW*CostFW*HY;
CostofnX..nXCost=e=sum((i,j),y(i,j))*CostnX;
```

```
CostofnF..nFCost=e=sum(j,z(j))*CostnF;
CostofO..OCost=e=FWCost+nXCost+nFCost;
****************************** Minimizing
***********************************
Object..OBJ=e=OCost;
FS.lo('i1')=2.67;
FS.lo('i2')=25;
FS.lo('i3')=8.574;
FS.lo('i4')=10.3448;
FS.lo('i5')=28.125;
FS.lo('i6')=87.27;

Model CASE11/ALL/;
Solve CASE11 Using MINLP Minimizing OBJ;
Display OBJ.l, OCost.l, OFW.l, OWW.l, FW.l, WW.l, FS.l. x.l, F.l, DA.l,
DB.l, DC.l, DD.l, FWCost.l, nXCost.l, nFCost.l;
```

```
**** REPORT SUMMARY :        0     NONOPT
                    0 INFEASIBLE
                    0  UNBOUNDED
                    0     ERRORS
GAMS 24.2.1  r43572 Released Dec  9, 2013 WEX-WEI x86_64/MS Windows
11/26/14 19:16:23 Page 6
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
E x e c u t i o n

----    180 VARIABLE OBJ.L             =  2141389.067  Objective function
        VARIABLE OCost.L           =  2141389.067  Total operating cost
                                   ($ per year)
        VARIABLE OFW.L             =      120.916  Overall freashwater (
                                   ton per hour)
        VARIABLE OWW.L             =      120.916  Overall waste
```

---- 180 VARIABLE FW.L Freshwater flowrate (ton per hour)

j1 2.670, j2 25.000, j3 8.574, j4 10.345, j5 25.415, j6 48.912

---- 180 VARIABLE WW.L Waste of each source (ton per hour)

i1 1.180, i2 22.121, i4 10.345, i6 87.270

---- 180 VARIABLE FS.L Flowrate outlet (ton per hour)

i1 2.670, i2 25.000, i3 8.574, i4 10.345, i5 28.125, i6 87.270

---- 180 VARIABLE x.L Source split fraction i to j

	j5	j6
i1	0.558	
i2	0.049	0.066
i3		1.000
i5		1.000

---- 180 VARIABLE F.L Splitting flowrate i to j (ton per hour)

	j5	j6
i1	1.490	
i2	1.220	1.659
i3		8.574
i5		28.125

---- 180 VARIABLE DA.L Sink stream concentration A (ppm)

j5 26.164, j6 81.731

---- 180 VARIABLE DB.L Sink stream concentration B (ppm)

j5 200.000, j6 1000.000

---- 180 VARIABLE DC.L Sink stream concentration C (ppm)

j5 300.000, j6 126.957

---- 180 VARIABLE DD.L Sink stream concentration D (ppm)
j5 82.828, j6 99.470

---- 180 VARIABLE FWCost.L = 2031389.067 Total cost of freshwa
ter ($ per y)
VARIABLE nXCost.L = 50000.000 Total cost of water s
pliting units ($)
VARIABLE nFCost.L = 60000.000 Total cost of water f
eeding units ($)

EXECUTION TIME = 0.000 SECONDS 3 MB 24.2.1 r43572 WEX-
WEI

USER: The Petroleum and Petrochemical College G131219:2228AS-WIN
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**** FILE SUMMARY
Input C:\Users\deepd_000\Documents\gamsdir\projdir\Data 2 Case 2 - Water Ne
twork with out treatment.gms
Output C:\Users\deepd_000\Documents\gamsdir\projdir\Data 2 Case 2 - Water Ne
twork with out treatment.lst

Appendix C-1 Case Study 4.3.1 GAMS Code

The second model: Mixed-integer non-liner programming (MINLP)

```
Set
      i Source stream /i1*i7/
      j Sink stream /j1*j6/
;
Parameter
      SA Source concentration A (ppm)
      /i1   367.5
       i2   154.4
       i3   80
       i4   293.34
       i5   220.1111
       i6   2375.043
       i7   20/
      SB Source concentration B (ppm)
      /i1   500
       i2   4000
       i3   3500
       i4   6000
       i5   1800
       i6   6500
       i7   50/
      SC Source concentration C (ppm)
      /i1   5655.5
       i2   10
       i3   175
       i4   127.5
       i5   340
       i6   167.2
       i7   5/
```

SD Source concentration C (ppm)

/i1 1537.5

i2 32

i3 116.65

i4 1096.67

i5 271.2

i6 400

i7 30/

DMA Sink Maximum concentration A (ppm)

/j1 300

j2 10

j3 10

j4 100

j5 85

j6 1000/

DMB Sink Maximum concentration B (ppm)

/j1 50

j2 1

j3 1

j4 200

j5 200

j6 1000/

DMC Sink Maximum concentration C (ppm)

/j1 5000

j2 0

j3 0

j4 50

j5 300

j6 150/

```
DMD Sink Maximum concentration D (ppm)
/j1    1500
j2     0
j3     0
j4     1000
j5     200
j6     200/
;
Variable OBJ Objective function
;
Positive variable     x(i,j)  Source split fraction i to j
                      FW(j)   Freshwater flowrate (ton per hour)
                      WW(i)   Waste of each source (ton per hour)
                      FS(i)   Flowrate outlet (ton per hour)
                      FD(j)   Flowrate inlet (ton per hour)
                      F(i,j)  Splitting flowrate i to j (ton per hour)
                      DA(j)  Sink stream concentration A (ppm)
                      DB(j)  Sink stream concentration B (ppm)
                      DC(j)  Sink stream concentration C (ppm)
                      DD(j)  Sink stream concentration D (ppm)
                      OFW     Overall freashwater (ton per hour)
                      OWW     Overall waste (ton per hour)
                      OWD     Overall waste water disposal (ton per hour)
                      CWA(i)  waste concentration A (ppm)
                      CWB(i)  waste concentration B (ppm)
                      CWC(i)  waste concentration C (ppm)
                      CWD(i)  waste concentration D (ppm)
                      OCWA    Overall waste concentration A (ppm)
                      OCWB    Overall waste concentration B (ppm)
                      OCWC    Overall waste concentration C (ppm)
                      OCWD    Overall waste concentration D (ppm)
                      WTA     Concentration of waste treatment A (ppm)
```

WTB Concentration of waste treatment B (ppm)

WTC Concentration of waste treatment C (ppm)

WTD Concentration of waste treatment D (ppm)

t treatment fraction

FT Overall treatment flowrate

FWCost Total cost of freshwater ($ per y)

TCost Total cost of Treatment ($ per y)

nXCost Total cost of water spliting units ($)

nFCost Total cost of water feeding units ($)

OCost Total operating cost ($ per year)

OCostPAPER Total operating cost PAPER ($ per year)

;

Binary variable y(i,j)

z(j)

;

Scalar OMEGA /10000/

HY /8400/

CostFW /2.00/

CostT /1.68/

CostnX /10000/

CostnF /10000/

ECostFW /0.32/

;

Equation

******************************** Water Network

****

MB1(j) Mass balance (Contaminant A)

MB2(j) Mass balance (Contaminant B)

MB3(j) Mass balance (Contaminant C)

MB4(j) Mass balance (Contaminant D)

MB5(j) Mass balance (Flowrate)

Cons1(i) Constraint for x

Cons2(j) Concentration constraint A

Cons3(j) Concentration constraint B

Cons4(j) Concentration constraint C

Cons5(j) Concentration constraint D

Cons6(i,j) Flowrate constraint

Flow(i,j) Flowrate source i to sink j

OFresh Overall freshwater

******************************* Waste Water ***********************************

Waste(i) Waste of each source

MBW1(i) Mass balance for waste concentration A

MBW2(i) Mass balance for waste concentration B

MBW3(i) Mass balance for waste concentration C

MBW4(i) Mass balance for waste concentration D

MBW5 Mass balance for overall waste concentration A

MBW6 Mass balance for overall waste concentration B

MBW7 Mass balance for overall waste concentration C

MBW8 Mass balance for overall waste concentration D

OWaste Overall waste

OWasteD Overall waste disposal

******************************* Treatment *************************************

MBT1 Mass balance for waste treatment A

MBT2 Mass balance for waste treatment B

MBT3 Mass balance for waste treatment C

MBT4 Mass balance for waste treatment D

MBT5 Constraint for waste treatment A

MBT6 Constraint for waste treatment B

MBT7 Constraint for waste treatment C

MBT8 Constraint for waste treatment D

MBT9 Mass balance for treatment treatment

```
****************************** Number of units
******************************
      Logical1(i,j)  Logical canstraint1
      Logical2(j)    Logical canstraint2

****************************** Cost
*****************************************
      CostofFW       Total cost of Fresh water
      CostofT        Total cost of Treatment
      CostofnX       Total cost of water spliting units
      CostofnF       Total cost of water feeding units
      CostofO        Total cost of operation
      CostofPAPER    Total cost of operation with PAPER
****************************** Minimizing
***********************************
      Object         Objective function
;
****************************** Water Network
********************************
MB1(j)..sum(i,SA(i)*FS(i)*x(i,j))=e=DA(j)*FD(j);
MB2(j)..sum(i,SB(i)*FS(i)*x(i,j))=e=DB(j)*FD(j);
MB3(j)..sum(i,SC(i)*FS(i)*x(i,j))=e=DC(j)*FD(j);
MB4(j)..sum(i,SD(i)*FS(i)*x(i,j))=e=DD(j)*FD(j);
MB5(j)..sum(i,FS(i)*x(i,j))+FW(j)=e=FD(j);
Cons1(i)..sum(j,x(i,j))=l=1;
Cons2(j)..DA(j)=l=DMA(j);
Cons3(j)..DB(j)=l=DMB(j);
Cons4(j)..DC(j)=l=DMC(j);
Cons5(j)..DD(j)=l=DMD(j);
Cons6(i,j)$(ord(i) eq ord(j))..FS(i)=e=FD(j);
Flow(i,j)..F(i,j)=e=FS(i)*x(i,j);
OFresh..OFW=e=sum(j,FW(j));
```

```
******************************* Waste Water
***********************************
Waste(i)..WW(i)=e=FS(i)-sum(j,F(i,j));
MBW1(i)..CWA(i)=e=WW(i)*SA(i);
MBW2(i)..CWB(i)=e=WW(i)*SB(i);
MBW3(i)..CWC(i)=e=WW(i)*SC(i);
MBW4(i)..CWD(i)=e=WW(i)*SD(i);
MBW5..OCWA*125.285=e=sum(i,CWA(i))-CWA('i7');
MBW6..OCWB*125.285=e=sum(i,CWB(i))-CWB('i7');
MBW7..OCWC*125.285=e=sum(i,CWC(i))-CWC('i7');
MBW8..OCWD*125.285=e=sum(i,CWD(i))-CWD('i7');
OWaste..OWW=e=sum(i,WW(i))-WW('i7');
OWasteD..OWD=e=OWW-(sum(j,x('i7',j))*FS('i7'));
******************************* Treatment
*************************************
MBT1..WTA*33.574=e=(OCWA*(33.574-t))+(SA('i7')*t);
MBT2..WTB*33.574=e=(OCWB*(33.574-t))+(SB('i7')*t);
MBT3..WTC*33.574=e=(OCWC*(33.574-t))+(SC('i7')*t);
MBT4..WTD*33.574=e=(OCWD*(33.574-t))+(SD('i7')*t);
MBT5..WTA=l=100;
MBT6..WTB=l=100;
MBT7..WTC=l=100;
MBT8..WTD=l=100;
MBT9..FT=e=(sum(j,x('i7',j))*FS('i7'))+t;
******************************* Number of units
*******************************
Logical1(i,j)..F(i,j)-y(i,j)*OMEGA=l=0;
Logical2(j)..FW(j)-z(j)*OMEGA=l=0;

******************************* Cost
*******************************************
CostofFW..FWCost=e=OFW*CostFW*HY;
```

```
CostofT..TCost=e=FT*HY*CostT;
CostofnX..nXCost=e=sum((i,j),y(i,j))*CostnX;
CostofnF..nFCost=e=sum(j,z(j))*CostnF;
CostofO..OCost=e=FWCost+TCost;
CostofPAPER..OCostPAPER=e=(OWW*CostT*HY)+(OFW*ECostFW*HY
);
******************************* Minimizing
***********************************
Object..OBJ=e=FWCost+TCost+nXCost+nFCost;

FS.lo('i1')=2.67;
FS.lo('i2')=25;
FS.lo('i3')=8.574;
FS.lo('i4')=10.3448;
FS.lo('i5')=28.125;
FS.lo('i6')=87.27;
FS.fx('i7')=1000;

Model CASE11/ALL/;
Solve CASE11 Using MINLP Minimizing OBJ;

Display OBJ.l, OCost.l, OCostPAPER.l, OFW.l, OWD.l, FT.l, OWW.l, FW.l,
WW.l, FS.l, FD.l, x.l, F.l, y.l, DA.l, DB.l, DC.l, DD.l,
 CWA.l, CWB.l, CWC.l, CWD.l, OCWA.l, OCWB.l, OCWC.l, OCWD.l,
WTA.l, WTB.l, WTC.l, WTD.l, t.l, FWCost.l, TCost.l, nXCost.l, nFCost.l;
```

**** REPORT SUMMARY : 0 NONOPT
0 INFEASIBLE
0 UNBOUNDED
0 ERRORS

GAMS 24.2.1 r43572 Released Dec 9, 2013 WEX-WEI x86_64/MS Windows
11/26/14 21:11:58 Page 6
General Algebraic Modeling System
Execution

---- 252 VARIABLE OBJ.L = 2407965.113 Objective function
VARIABLE OCost.L = 2327965.113 Total operating cost ($ per year)
VARIABLE OCostPAPER.L = 1858266.010 Total operating cost PAPER ($ per year)
VARIABLE OFW.L = 33.574 Overall freashwater (ton per hour)
VARIABLE OWD.L = 33.574 Overall waste water d isposal (ton per hour)
VARIABLE FT.L = 124.994 Overall treatment flo wrate
VARIABLE OWW.L = 125.285 Overall waste (ton pe r hour)

---- 252 VARIABLE FW.L Freshwater flowrate (ton per hour)
j2 25.000, j3 8.574

---- 252 VARIABLE WW.L Waste of each source (ton per hour)
i1 2.670, i2 25.000, i4 10.345, i6 87.270, i7 908.289
---- 252 VARIABLE FS.L Flowrate outlet (ton per hour)
i1 2.670, i2 25.000, i3 8.574, i4 10.345, i5 28.125
i6 87.270, i7 1000.000

---- 252 VARIABLE FD.L Flowrate inlet (ton per hour)

j1 2.670, j2 25.000, j3 8.574, j4 10.345, j5 28.125, j6 87.270

---- 252 VARIABLE x.L Source split fraction i to j

	j1	j4	j5	j6
i3			1.000	
i5			1.000	
i7	0.003	0.010	0.028	0.051

---- 252 VARIABLE F.L Splitting flowrate i to j (ton per hour)

	j1	j4	j5	j6
i3			8.574	
i5			28.125	
i7	2.670	10.345	28.125	50.571

---- 252 VARIABLE y.L

	j1	j4	j5	j6
i3			1.000	
i5			1.000	
i7	1.000	1.000	1.000	1.000

---- 252 VARIABLE DA.L Sink stream concentration A (ppm)

j1 20.000, j4 20.000, j5 20.000, j6 90.386

---- 252 VARIABLE DB.L Sink stream concentration B (ppm)

j1 50.000, j4 50.000, j5 50.000, j6 952.934

---- 252 VARIABLE DC.L Sink stream concentration C (ppm)

j1 5.000, j4 5.000, j5 5.000, j6 129.664

---- 252 VARIABLE DD.L Sink stream concentration D (ppm)

j1 30.000, j4 30.000, j5 30.000, j6 116.246

---- 252 VARIABLE CWA.L waste concentration A (ppm)

i1 981.225, i2 3860.000, i4 3034.544, i6 207270.003
i7 18165.784

---- 252 VARIABLE CWB.L waste concentration B (ppm)

i1 1335.000, i2 100000.000, i4 62068.800, i6 567255.000
i7 45414.460

---- 252 VARIABLE CWC.L waste concentration C (ppm)

i1 15100.185, i2 250.000, i4 1318.962, i6 14591.544, i7 4541.446

---- 252 VARIABLE CWD.L waste concentration D (ppm)

i1 4105.125, i2 800.000, i4 11344.832, i6 34908.000, i7 27248.676

---- 252 VARIABLE OCWA.L = 1717.251 Overall waste concent
ration A (ppm)
VARIABLE OCWB.L = 5831.974 Overall waste concent
ration B (ppm)
VARIABLE OCWC.L = 249.517 Overall waste concent
ration C (ppm)
VARIABLE OCWD.L = 408.333 Overall waste concent
ration D (ppm)
VARIABLE WTA.L = 34.677 Concentration of wast
e treatment A (ppm)
VARIABLE WTB.L = 100.000 Concentration of wast
e treatment B (ppm)
VARIABLE WTC.L = 7.114 Concentration of wast
e treatment C (ppm)
VARIABLE WTD.L = 33.272 Concentration of wast
e treatment D (ppm)
VARIABLE t.L = 33.284 treatment fraction
VARIABLE FWCost.L = 564043.200 Total cost of freshwa
ter ($ per y)

VARIABLE TCost.L = 1763921.913 Total cost of Treatme
nt ($ per y)
VARIABLE nXCost.L = 60000.000 Total cost of water s
pliting units ($)
VARIABLE nFCost.L = 20000.000 Total cost of water f
eeding units ($)

EXECUTION TIME = 0.000 SECONDS 3 MB 24.2.1 r43572 WEX-
WEI
USER: The Petroleum and Petrochemical College G131219:2228AS-WIN
Chulalongkorn University DC4365
License for teaching and research at degree granting institutions
**** FILE SUMMARY
Input C:\Users\deepd_000\Documents\gamsdir\projdir\Data 2 Case 3 - Water Ne
twork with end of pipe.gms
Output C:\Users\deepd_000\Documents\gamsdir\projdir\Data 2 Case 3 - Water Ne
twork with end of pipe.lst

Appendix D-1 Case Study 4.4.1 GAMS Code

The model: Liner programming (LP)

```
Set
        i Source stream /i1*i4/
        u Sink stream /u1*u1/
;

Parameter
        CSA Source concentration A (ppm)
        /i1   15
        i2   120
        i3   220
        i4   50/

        CSB Source concentration B (ppm)
        /i1   400
        i2   12500
        i3   45
        i4   5/

        CSC Source concentration C (ppm)
        /i1   35
        i2   180
        i3   9500
        i4   20/

        FS Source flowrate (ton per hour)
        /i1   16.832
        i2   34
        i3   54.831
        i4   200/
```

```
          CKLA Sink concentration A (ppm)
          /u1     100/

          CKLB Sink concentration B (ppm)
          /u1     100/

          CKLC Sink concentration C (ppm)
          /u1     100/

          FK Sink flowrate (ton per hour)
          /u1     105.662/
;

Variable OBJ Objective function
;

Positive variable      x(i,u)  Source split fraction i to j
                       F(i,u)  Splitting flowrate i to j (ton per hour)
                       CKA(u)  Sink stream concentration A (ppm)
                       CKB(u)  Sink stream concentration B (ppm)
                       CKC(u)  Sink stream concentration C (ppm)
;

Equation
          MB1(u)        Mass balance (flowrate A)
          MB2(u)        Mass balance (flowrate B)
          MB3(u)        Mass balance (flowrate C)
          MB4(u)        Mass balance (contaminant)
          Cons1(i)      Constraint for x
          Cons2(u)      Concentration constraint A
          Cons3(u)      Concentration constraint B
          Cons4(u)      Concentration constraint C
```

```
        Flow(i,u)     Flowrate source i to sink j
        Object        Objective
    ;

    MB1(u)..sum(i,CSA(i)*FS(i)*x(i,u))=e=CKA(u)*FK(u);
    MB2(u)..sum(i,CSB(i)*FS(i)*x(i,u))=e=CKB(u)*FK(u);
    MB3(u)..sum(i,CSC(i)*FS(i)*x(i,u))=e=CKC(u)*FK(u);
    MB4(u)..sum(i,FS(i)*x(i,u))=e=FK(u);
    Cons1(i)..sum(u,x(i,u))=l=1;
    Cons2(u)..CKA(u)=l=CKLA(u);
    Cons3(u)..CKB(u)=l=CKLB(u);
    Cons4(u)..CKC(u)=l=CKLC(u);
    Flow(i,u)..F(i,u)=e=FS(i)*x(i,u);
    Object..OBJ =e= F('i4','u1');

    x.fx('i2','u1')=0;
    x.fx('i3','u1')=0;

    Model CASE11/ALL/;
    Solve CASE11 Using LP Minimizing OBJ;
    Display OBJ.l, x.l, F.l, CKA.l, CKB.l, CKC.l;
**** REPORT SUMMARY :       0     NONOPT
                            0 INFEASIBLE
                            0  UNBOUNDED
    GAMS 24.2.1  r43572 Released Dec  9, 2013 WIN-VS8 x86/MS Windows
    03/15/15 22:09:33 Page 6
    G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
    E x e c u t i o n

    ----     85 VARIABLE OBJ.L             =       88.830  Objective function
```

```
----      85 VARIABLE x.L  Source split fraction i to j
           u1
i1      1.000
i4      0.444

----      85 VARIABLE F.L  Splitting flowrate i to j (ton per hour)
           u1
i1     16.832
i4     88.830

----      85 VARIABLE CKA.L  Sink stream concentration A (ppm)
u1 44.424

----      85 VARIABLE CKB.L  Sink stream concentration B (ppm)
u1 67.924

----      85 VARIABLE CKC.L  Sink stream concentration C (ppm)
u1 22.390

EXECUTION TIME      =      0.015 SECONDS      3 MB  24.2.1 r43572
WIN-VS8

USER: The Petroleum and Petrochemical College       G131219:2228AS-
WIN
    Chulalongkorn University                        DC4365
    License for teaching and research at degree granting institutions

**** FILE SUMMARY
Input     C:\Users\DoNuT\Documents\gamsdir\projdir\Data 1 Case 5 -
Treatment part of case 2.gms
Output    C:\Users\DoNuT\Documents\gamsdir\projdir\Data 1 Case 5 -
Treatment part of case 2.lst
```

Appendix E-1 Case Study 4.5.1 GAMS Code

The first model: Non-liner programming (NLP)

```
Set
        i Source stream /i1*i3/
        j Sink stream /j1*j3/
;
Parameter
SMA Source concentration of Salts (ppm)
        /i1   15
         i2   120
         i3   220/
SMB Source concentration of Organics (ppm)
        /i1   400
         i2   12500
         i3   45/
SMC Source concentration of H2S (ppm)
        /i1   35
         i2   180
         i3   9500/
FS Maximun flowrate of fresh water
        /i1   45
        i2   33.184
        i3   54.821/
LA Load of Salts contaminant (kg per hour)
        /j1   0.675
         j2   3.40
         j3   5.60/
LB Load of Organics contaminant (kg per hour)
        /j1   18.0
        j2   414.80
        j3   1.4/
```

LC Load of H2S contaminant (kg per hour)

/j1 1.575

j2 4.590

j3 520.8/

DMA Sink Maximum concentration of Salts (ppm)

/j1 0

j2 20

j3 120/

DMB Sink Maximum concentration of Organics (ppm)

/j1 0

j2 300

j3 20/

DMC Sink Maximum concentration of H2S (ppm)

/j1 0

j2 45

j3 200/

;

Variable OBJ Objective function

;

Positive variable

x(i,j)	Source split fraction i to j
FW(j)	Freshwater flowrate (ton per hour)
WW(i)	Waste of each source (ton per hour)
F(i,j)	Splitting flowrate i to j (ton per hour)
DA(j)	Sink stream concentration of Salts (ppm)
DB(j)	Sink stream concentration of Organics (ppm)
DC(j)	Sink stream concentration of H2S (ppm)
SA(i)	Source stream concentration of Salts (ppm)
SB(i)	Source stream concentration of Organics (ppm)
SC(i)	Source stream concentration of H2S (ppm)
OFW	Overall freashwater (ton per hour)
OWW	Overall waste (ton per hour)

LoadA(i,j) Contaminant load of Salts of Process i to j (gram per hour)

LoadB(i,j) Contaminant load of Organics of Process i to j (gram per hour)

LoadC(i,j) Contaminantload of H2S of Process i to j (gram per hour)

Flowin(j) Total flowrate inlet of Salts contaminant of each process (ton per hour)

DeltaCA(i,j) Outlet concentration - Inlet concentration of Salts contaminant (ppm)

DeltaCB(i,j) Outlet concentration - Inlet concentration of Organics contaminant (ppm)

DeltaCC(i,j) Outlet concentration - Inlet concentration of H2S contaminant (ppm)

;

Equation

ConloadA1(i,j) Contaminantload of Salts of Process 1

ConloadA2(i,j) Contaminantload of Salts of Process 2

ConloadA3(i,j) Contaminantload of Salts of Process 3

ConloadB1(i,j) Contaminantload of Organics of Process 1

ConloadB2(i,j) Contaminantload of Organics of Process 2

ConloadB3(i,j) Contaminantload of Organics of Process 3

ConloadC1(i,j) Contaminantload of H2S of Process 1

ConloadC2(i,j) Contaminantload of H2S of Process 2

ConloadC3(i,j) Contaminantload of H2S of Process 3

MLoadA1(i,j) Contaminantload balance of Salts of Process 1

MLoadA2(i,j) Contaminantload balance of Salts of Process 2

MLoadA3(i,j) Contaminantload balance of Salts of Process 3

MLoadB1(i,j) Contaminantload balance of Organics of Process 1

MLoadB2(i,j) Contaminantload balance of Organics of Process 2

MLoadB3(i,j) Contaminantload balance of Organics of Process 3

MLoadC1(i,j)	Contaminantload balance of H2S of Process 1
MLoadC2(i,j)	Contaminantload balance of H2S of Process 2
MLoadC3(i,j)	Contaminantload balance of H2S of Process 3
TFlowin1(j)	Total flowrate inlet of process 1
TFlowin2(j)	Total flowrate inlet of process 2
TFlowin3(j)	Total flowrate inlet of process 3
FF1	Constraint for flowrate inlet of process 1
FF2	Constraint for flowrate inlet of process 2
FF3	Constraint for flowrate inlet of process 3
MconSA1(i)	Outlet concentration balance of Salts of process 1
MconSA2(i)	Outlet concentration balance of Salts of process 2
MconSA3(i)	Outlet concentration balance of Salts of process 3
MconSB1(i)	Outlet concentration balance of Organics of process1
MconSB2(i)	Outlet concentration balance of Organics of process2
MconSB3(i)	Outlet concentration balance of Organics of process3
MconSC1(i)	Outlet concentration balance of H2S of process 1
MconSC2(i)	Outlet concentration balance of H2S of process 2
MconSC3(i)	Outlet concentration balance of H2S of process 3
DCA1(i,j)	Delta concentration of Salts of process 1
DCA2(i,j)	Delta concentration of Salts of process 2
DCA3(i,j)	Delta concentration of Salts of process 3
DCB1(i,j)	Delta concentration of Organics of process 1
DCB2(i,j)	Delta concentration of Organics of process 2
DCB3(i,j)	Delta concentration of Organics of process 3

DCC1(i,j) Delta concentration of H2S of process 1
DCC2(i,j) Delta concentration of H2S of process 2
DCC3(i,j) Delta concentration of H2S of process 3

InconA1(j) New concentration of water inlet of Salts of process 1
InconA2(j) New concentration of water inlet of Salts of process 2
InconA3(j) New concentration of water inlet of Salts of process 3

InconB1(j) New concentration of water inlet of Organics of process 1
InconB2(j) New concentration of water inlet of Organics of process 2
InconB3(j) New concentration of water inlet of Organics of process 3

InconC1(j) New concentration of water inlet of H2S of process 1
InconC2(j) New concentration of water inlet of H2S of process 2
InconC3(j) New concentration of water inlet of H2S of process 3

CBA1(j) Concentretion balance of Salts of process 1
CBA2(j) Concentretion balance of Salts of process 2
CBA3(j) Concentretion balance of Salts of process 3

CBB1(j) Concentretion balance of Organics of process 1
CBB2(j) Concentretion balance of Organics of process 2
CBB3(j) Concentretion balance of Organics of process 3

CBC1(j) Concentretion balance of H2S of process 1
CBC2(j) Concentretion balance of H2S of process 2
CBC3(j) Concentretion balance of H2S of process 3

```
Cons1(i)        Constraint for x
Flowsplit(i,j)  Splited flowrate source i to sink j
OFresh          Overall freshwater
Object          Objective

;
*Contaminantload of each process
ConloadA1('i1','j1') .. LoadA('i1','j1') =e= 1000*LA('j1');
ConloadA2('i2','j2') .. LoadA('i2','j2') =e= 1000*LA('j2');
ConloadA3('i3','j3') .. LoadA('i3','j3') =e= 1000*LA('j3');

ConloadB1('i1','j1') .. LoadB('i1','j1') =e= 1000*LB('j1');
ConloadB2('i2','j2') .. LoadB('i2','j2') =e= 1000*LB('j2');
ConloadB3('i3','j3') .. LoadB('i3','j3') =e= 1000*LB('j3');

ConloadC1('i1','j1') .. LoadC('i1','j1') =e= 1000*LC('j1');
ConloadC2('i2','j2') .. LoadC('i2','j2') =e= 1000*LC('j2');
ConloadC3('i3','j3') .. LoadC('i3','j3') =e= 1000*LC('j3');

*Contaminantload balance of each process
MLoadA1('i1','j1')..LoadA('i1','j1')=e=Flowin('j1')*DeltaCA('i1','j1');
MLoadA2('i2','j2')..LoadA('i2','j2')=e=Flowin('j2')*DeltaCA('i2','j2');
MLoadA3('i2','j3')..LoadA('i3','j3')=e=Flowin('j3')*DeltaCA('i3','j3');

MLoadB1('i1','j1')..LoadB('i1','j1')=e=Flowin('j1')*DeltaCB('i1','j1');
MLoadB2('i2','j2')..LoadB('i2','j2')=e=Flowin('j2')*DeltaCB('i2','j2');
MLoadB3('i2','j3')..LoadB('i3','j3')=e=Flowin('j3')*DeltaCB('i3','j3');

MLoadC1('i1','j1')..LoadC('i1','j1')=e=Flowin('j1')*DeltaCC('i1','j1');
MLoadC2('i2','j2')..LoadC('i2','j2')=e=Flowin('j2')*DeltaCC('i2','j2');
MLoadC3('i2','j3')..LoadC('i3','j3')=e=Flowin('j3')*DeltaCC('i3','j3');
```

```
*Total inlet flowrate of each process
TFlowin1('j1')..Flowin('j1')=e=sum(i,FS(i)*x(i,'j1'))+FW('j1');
TFlowin2('j2')..Flowin('j2')=e=sum(i,FS(i)*x(i,'j2'))+FW('j2');
TFlowin3('j3')..Flowin('j3')=e=sum(i,FS(i)*x(i,'j3'))+FW('j3');

*Constraint for flowrate inlet of each process
FF1..Flowin('j1')=g=FS('i1');
FF2..Flowin('j2')=g=FS('i2');
FF3..Flowin('j3')=g=FS('i3');

*Outlet concentration od each procerss
MconSA1('i1')..LA('j1')*1000=e=FS('i1')*SA('i1');
MconSA2('i2')..LA('j2')*1000=e=FS('i2')*SA('i2');
MconSA3('i3')..LA('j3')*1000=e=FS('i3')*SA('i3');

MconSB1('i1')..LB('j1')*1000=e=FS('i1')*SB('i1');
MconSB2('i2')..LB('j2')*1000=e=FS('i2')*SB('i2');
MconSB3('i3')..LB('j3')*1000=e=FS('i3')*SB('i3');

MconSC1('i1')..LC('j1')*1000=e=FS('i1')*SC('i1');
MconSC2('i2')..LC('j2')*1000=e=FS('i2')*SC('i2');
MconSC3('i3')..LC('j3')*1000=e=FS('i3')*SC('i3');

*Delta concentration of each process
DCA1('i1','j1') .. DeltaCA('i1','j1') =e= (SA('i1')-DA('j1'));
DCA2('i2','j2') .. DeltaCA('i2','j2') =e= (SA('i2')-DA('j2'));
DCA3('i3','j3') .. DeltaCA('i3','j3') =e= (SA('i3')-DA('j3'));

DCB1('i1','j1') .. DeltaCB('i1','j1') =e= (SB('i1')-DB('j1'));
DCB2('i2','j2') .. DeltaCB('i2','j2') =e= (SB('i2')-DB('j2'));
DCB3('i3','j3') .. DeltaCB('i3','j3') =e= (SB('i3')-DB('j3'));
```

```
DCC1('i1','j1') .. DeltaCC('i1','j1') =e= (SC('i1')-DC('j1'));
DCC2('i2','j2') .. DeltaCC('i2','j2') =e= (SC('i2')-DC('j2'));
DCC3('i3','j3') .. DeltaCC('i3','j3') =e= (SC('i3')-DC('j3'));

*New concentration of water inlet
InconA1('j1')..DA('j1')*Flowin('j1')=e=sum(i,FS(i)*x(i,'j1')*SA(i));
CBA1('j1')..DA('j1')=l=DMA('j1');
InconA2('j2')..DA('j2')*Flowin('j2')=e=sum(i,FS(i)*x(i,'j2')*SA(i));
CBA2('j2')..DA('j2')=l=DMA('j2');
InconA3('j3')..DA('j3')*Flowin('j3')=e=sum(i,FS(i)*x(i,'j3')*SA(i));
CBA3('j3')..DA('j3')=l=DMA('j3');

InconB1('j1')..DB('j1')*Flowin('j1')=e=sum(i,FS(i)*x(i,'j1')*SB(i));
CBB1('j1')..DB('j1')=l=DMB('j1');
InconB2('j2')..DB('j2')*Flowin('j2')=e=sum(i,FS(i)*x(i,'j1')*SB(i));
CBB2('j2')..DB('j2')=l=DMB('j2');
InconB3('j3')..DB('j3')*Flowin('j3')=e=sum(i,FS(i)*x(i,'j3')*SB(i));
CBB3('j3')..DB('j3')=l=DMB('j3');

InconC1('j1')..DC('j1')*Flowin('j1')=e=sum(i,FS(i)*x(i,'j1')*SC(i));
CBC1('j1')..DC('j1')=l=DMC('j1');
InconC2('j2')..DC('j2')*Flowin('j2')=e=sum(i,FS(i)*x(i,'j2')*SC(i));
CBC2('j2')..DC('j2')=l=DMC('j2');
InconC3('j3')..DC('j3')*Flowin('j3')=e=sum(i,FS(i)*x(i,'j3')*SC(i));
CBC3('j3')..DC('j3')=l=DMC('j3');
Cons1(i)..sum(j,x(i,j))=l=1;
Flowsplit(i,j)..F(i,j)=e=FS(i)*x(i,j);
OFresh..OFW=e=sum(j,FW(j));
Object..OBJ=e=OFW;
DB.lo('j2')=300;
DC.lo('j3')=200;
```

```
Model CASE11/ALL/;
Solve CASE11 Using NLP Minimizing OBJ;
Display LoadA.l, LoadB.l, LoadC.l, Flowin.l, SA.l, SB.l, SC.l, DeltaCA.l,
DeltaCB.l, DeltaCC.l, DA.l, DB.l, DC.l, FW.l, OBJ.l, OFW.l, x.l, F.l;
**** REPORT SUMMARY :        0     NONOPT
                             1 INFEASIBLE (INFES)
                    SUM  10200.000
                    MAX  10200.000
                    MEAN 10200.000
                             0  UNBOUNDED
                             0     ERRORS

GAMS 24.2.1  r43572 Released Dec  9, 2013 WEX-WEI x86_64/MS Windows
11/25/14 21:45:19 Page 6
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
E x e c u t i o n

----    275 VARIABLE LoadA.L  Contaminantload of Salts of Process i to j (gram p
                              er hour)

           j1          j2          j3

i1    675.000
i2              3400.000
i3                          5600.000

----    275 VARIABLE LoadB.L  Contaminantload of Organics of Process i to j (gra
                              m per hour)

           j1          j2          j3

i1  18000.000
i2            414800.000
i3                          1400.000
```

---- 275 VARIABLE LoadC.L Contaminantload of H2S of Process i to j (gram per hour)

	j1	j2	j3
i1	1575.000		
i2		4590.000	
i3			520800.000

---- 275 VARIABLE Flowin.L Total flowrate inlet of Salts contaminant of each process (ton per hour)

j1 45.000, j2 34.000, j3 56.000

---- 275 VARIABLE SA.L Source stream concentration of Salts (ppm)

i1 15.000, i2 102.459, i3 102.151

---- 275 VARIABLE SB.L Source stream concentration of Organics (ppm)

i1 400.000, i2 12500.000, i3 25.538

---- 275 VARIABLE SC.L Source stream concentration of H2S (ppm)

i1 35.000, i2 138.320, i3 9500.009

---- 275 VARIABLE DeltaCA.L Outlet concentration - Inlet concentration of Sa lts contaminant (ppm)

	j1	j2	j3
i1	15.000		
i2		100.000	
i3			100.000

---- 275 VARIABLE DeltaCB.L Outlet concentration - Inlet concentration of Or
ganics contaminant (ppm)

	j1	j2	j3
i1	400.000		
i2		12200.000	
i3			25.000

---- 275 VARIABLE DeltaCC.L Outlet concentration - Inlet concentration of H2
S contaminant (ppm)

	j1	j2	j3
i1	35.000		
i2		135.000	
i3			9300.009

---- 275 VARIABLE DA.L Sink stream concentration of Salts (ppm)
j2 2.459, j3 2.151

---- 275 VARIABLE DB.L Sink stream concentration of Organics (ppm)
j2 300.000, j3 0.538

---- 275 VARIABLE DC.L Sink stream concentration of H2S (ppm)
j2 3.320, j3 200.000

---- 275 VARIABLE FW.L Freshwater flowrate (ton per hour)
j1 45.000, j2 33.184, j3 54.821

---- 275 VARIABLE OBJ.L = 133.005 Objective function
VARIABLE OFW.L = 133.005 Overall freashwater (
ton per hour)

---- 275 VARIABLE x.L Source split fraction i to j

	j2	j3
i2	0.025	
i3		0.022

---- 275 VARIABLE F.L Splitting flowrate i to j (ton per hour)

	j2	j3
i2	0.816	
i3		1.179

EXECUTION TIME = 0.000 SECONDS 3 MB 24.2.1 r43572 WEX-WEI

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**** FILE SUMMARY

Input C:\Users\deepd_000\Documents\gamsdir\projdir\Data 1 Case 1 - Initialization step for Water Network.gms
Output C:\Users\deepd_000\Documents\gamsdir\projdir\Data 1 Case 1 - Initialization step for Water Network.lst

The second model: Mixed-integer non-liner programming (MINLP)

Set

i Source stream /i1*i4/

j Sink stream /j1*j3/

;

Parameter

SA Source concentration A (ppm)

/i1 15

i2 120

i3 220

i4 50/

SB Source concentration B (ppm)

/i1 400

i2 12500

i3 45

i4 5/

SC Source concentration C (ppm)

/i1 35

i2 180

i3 9500

i4 20/

DMA Sink Maximum concentration A (ppm)

/j1 0

j2 20

j3 120/

```
        DMB Sink Maximum concentration B (ppm)
        /j1    0
         j2    300
         j3    20/

        DMC Sink Maximum concentration C (ppm)
        /j1    0
         j2    45
         j3    200/
;

Variable OBJ Objective function
;

Positive variable     x(i,j)  Source split fraction i to j
                  FW(j)   Freshwater flowrate (ton per hour)
                  WW(i)   Waste of each source (ton per hour)
                  FS(i)   Flowrate outlet (ton per hour)
                  FD(j)   Flowrate inlet (ton per hour)
                  F(i,j)  Splitting flowrate i to j (ton per hour)
                  DA(j)   Sink stream concentration A (ppm)
                  DB(j)   Sink stream concentration B (ppm)
                  DC(j)   Sink stream concentration C (ppm)
                  OFW     Overall freashwater (ton per hour)
                  OWW     Overall waste (ton per hour)
                  OWD     Overall waste water disposal (ton per hour)
                  CWA(i)  waste concentration A (ppm)
                  CWB(i)  waste concentration B (ppm)
                  CWC(i)  waste concentration C (ppm)
                  OCWA    Overall waste concentration A (ppm)
                  OCWB    Overall waste concentration B (ppm)
                  OCWC    Overall waste concentration C (ppm)
```

WTA Concentration of waste treatment A (ppm)
WTB Concentration of waste treatment B (ppm)
WTC Concentration of waste treatment C (ppm)
t treatment fraction
FT Overall treatment flowrate
FWCost Total cost of freshwater ($ per y)
TCost Total cost of Treatment ($ per y)
nXCost Total cost of water spliting units ($)
nFCost Total cost of water feeding units ($)
OCost Total operating cost ($ per year)
SCost Saving Cost ($ per y)

;

Binary variable y(i,j)
z(j)

;

Scalar OMEGA /10000/
HY /8400/
CostFW /2.00/
CostnX /10000/
CostnF /10000/
CostT /1.68/

;

Equation

******************************** Water Network
****

MB1(j) Mass balance (flowrate A)
MB2(j) Mass balance (flowrate B)
MB3(j) Mass balance (flowrate C)

MB4(j)	Mass balance (contaminant)
Cons1(i)	Constraint for x
Cons2(j)	Concentration constraint A
Cons3(j)	Concentration constraint B
Cons4(j)	Concentration constraint C
Cons5(i,j)	Flowrate constraint
Flow(i,j)	Flowrate source i to sink j
OFresh	Overall freshwater

****************************** Waste Water ***********************************

Waste(i)	Waste of each source
MBW1(i)	Mass balance for waste concentration A
MBW2(i)	Mass balance for waste concentration B
MBW3(i)	Mass balance for waste concentration C
MBW4	Mass balance for overall waste concentration A
MBW5	Mass balance for overall waste concentration B
MBW6	Mass balance for overall waste concentration C
OWaste	Overall waste
OWasteD	Overall waste disposal

****************************** Treatment ************************************

MBT1	Mass balance for waste treatment A
MBT2	Mass balance for waste treatment B
MBT3	Mass balance for waste treatment C
MBT4	Constraint for waste treatment A
MBT5	Constraint for waste treatment B
MBT6	Constraint for waste treatment C
MBT7	Mass balance for treatment treatment

```
****************************** Number of units
******************************
        Logical1(i,j)  Logical canstraint1
        Logical2(j)    Logical canstraint2

****************************** Cost
*****************************************
        CostofFW       Total cost of Fresh water
        CostofT        Total cost of Treatment
        CostofnX       Total cost of water spliting units
        CostofnF       Total cost of water feeding units
        CostofO        Total cost of operation
        CostofS        Total saving cost

****************************** Minimizing
***********************************
        Object         Objective function
;

****************************** Water Network
********************************
MB1(j)..sum(i,SA(i)*FS(i)*x(i,j))=e=DA(j)*FD(j);
MB2(j)..sum(i,SB(i)*FS(i)*x(i,j))=e=DB(j)*FD(j);
MB3(j)..sum(i,SC(i)*FS(i)*x(i,j))=e=DC(j)*FD(j);
MB4(j)..sum(i,FS(i)*x(i,j))+FW(j)=e=FD(j);
Cons1(i)..sum(j,x(i,j))=l=1;
Cons2(j)..DA(j)=l=DMA(j);
Cons3(j)..DB(j)=l=DMB(j);
Cons4(j)..DC(j)=l=DMC(j);
Cons5(i,j)$(ord(i) eq ord(j))..FS(i)=e=FD(j);
Flow(i,j)..F(i,j)=e=FS(i)*x(i,j);
OFresh..OFW=e=sum(j,FW(j));
```

```
****************************** Waste Water
**********************************
Waste(i)..WW(i)=e=FS(i)-sum(j,F(i,j));
MBW1(i)..CWA(i)=e=WW(i)*SA(i);
MBW2(i)..CWB(i)=e=WW(i)*SB(i);
MBW3(i)..CWC(i)=e=WW(i)*SC(i);
MBW4..OCWA*106.495=e=sum(i,CWA(i))-CWA('i4');
MBW5..OCWB*106.495=e=sum(i,CWB(i))-CWB('i4');
MBW6..OCWC*106.495=e=sum(i,CWC(i))-CWC('i4');
OWaste..OWW=e=sum(i,WW(i))-WW('i4');
OWasteD..OWD=e=OWW-(sum(j,x('i4',j))*FS('i4'));

****************************** Treatment
************************************
MBT1..WTA*47.602=e=(OCWA*(47.602-t))+(SA('i4')*t);
MBT2..WTB*47.602=e=(OCWB*(47.602-t))+(SB('i4')*t);
MBT3..WTC*47.602=e=(OCWC*(47.602-t))+(SC('i4')*t);
MBT4..WTA=l=100;
MBT5..WTB=l=100;
MBT6..WTC=l=100;
MBT7..FT=e=(sum(j,x('i4',j))*FS('i4'))+36.153;

****************************** Number of units
******************************
Logical1(i,j)..F(i,j)-y(i,j)*OMEGA=l=0;
Logical2(j)..FW(j)-z(j)*OMEGA=l=0;

****************************** Cost
****************************************
CostofFW..FWCost=e=OFW*CostFW*HY;
CostofT..TCost=e=CostT*FT*HY;
```

```
CostofnX..nXCost=e=sum((i,j),y(i,j))*CostnX;
CostofnF..nFCost=e=sum(j,z(j))*CostnF;
CostofO..OCost=e=FWCost+TCost;
CostofS..SCost=e=(133*3.68*HY)-OCost;

******************************* Minimizing
***********************************
Object..OBJ=e=FWCost+TCost+nXCost+nFCost;

FS.lo('i1')=45;
FS.lo('i2')=34;
FS.lo('i3')=56;
FS.fx('i4')=200;

Model CASE11/ALL/;

Solve CASE11 Using MINLP Minimizing OBJ;

Display OBJ.l, OCost.l, SCost.l, OFW.l, OWD.l, FT.l, OWW.l, FW.l, WW.l,
FS.l, FD.l, x.l, F.l, y.l, DA.l, DB.l, DC.l,
 CWA.l, CWB.l, CWC.l, OCWA.l, OCWB.l, OCWC.l, WTA.l, WTB.l,
WTC.l, t.l, FWCost.l, TCost.l, nXCost.l, nFCost.l;
```

```
**** REPORT SUMMARY :       0     NONOPT
                            0 INFEASIBLE
                            0  UNBOUNDED
                            0     ERRORS
GAMS 24.2.1  r43572 Released Dec  9, 2013 WIN-VS8 x86/MS Windows 03/15/15
22:14:14 Page 6
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
E x e c u t i o n

----    197 VARIABLE OBJ.L             =  2211008.076  Objective function
            VARIABLE OCost.L           =  2141008.076  Total operating cost
                                       ($ per year)
            VARIABLE SCost.L           =  1970287.924  Saving Cost ($ per y)
            VARIABLE OFW.L             =       47.602  Overall freashwater (
                                       ton per hour)
            VARIABLE OWD.L             =       47.602  Overall waste water d
                                       isposal (ton per hour)
            VARIABLE FT.L              =       95.046  Overall treatment flowrate
            VARIABLE OWW.L             =      106.495  Overall waste (ton per hour)

----    197 VARIABLE FW.L  Freshwater flowrate (ton per hour)
j1 45.000,    j2  2.602

----    197 VARIABLE WW.L  Waste of each source (ton per hour)
i1  17.555,    i2  34.000,    i3  54.940,    i4 141.107

----    197 VARIABLE FS.L  Flowrate outlet (ton per hour)
i1  45.000,    i2  34.000,    i3  56.000,    i4 200.000

----    197 VARIABLE FD.L  Flowrate inlet (ton per hour)
j1 45.000,    j2 34.000,    j3 56.000
```

---- 197 VARIABLE x.L Source split fraction i to j

	j2	j3
i1	0.565	0.045
i3		0.019
i4	0.030	0.265

---- 197 VARIABLE F.L Splitting flowrate i to j (ton per hour)

	j2	j3
i1	25.425	2.019
i3		1.060
i4	5.972	52.921

---- 197 VARIABLE y.L

	j2	j3
i1	1.000	1.000
i3		1.000
i4	1.000	1.000

---- 197 VARIABLE DA.L Sink stream concentration A (ppm)

j2 20.000, j3 51.956

---- 197 VARIABLE DB.L Sink stream concentration B (ppm)

j2 300.000, j3 20.000

---- 197 VARIABLE DC.L Sink stream concentration C (ppm)

j2 29.686, j3 200.000

---- 197 VARIABLE CWA.L waste concentration A (ppm)

i1 263.331, i2 4080.000, i3 12086.779, i4 7055.347

---- 197 VARIABLE CWB.L waste concentration B (ppm)

i1 7022.170, i2 425000.000, i3 2472.296, i4 705.535

---- 197 VARIABLE CWC.L waste concentration C (ppm)

i1 614.440, i2 6120.000, i3 521929.087, i4 2822.139

---- 197 VARIABLE OCWA.L = 154.281 Overall waste concent
ration A (ppm)

VARIABLE OCWB.L = 4079.952 Overall waste concent
ration B (ppm)

VARIABLE OCWC.L = 4964.210 Overall waste concent
ration C (ppm)

VARIABLE WTA.L = 51.687 Concentration of wast
e treatment A (ppm)

VARIABLE WTB.L = 70.934 Concentration of wast
e treatment B (ppm)

VARIABLE WTC.L = 100.000 Concentration of wast
e treatment C (ppm)

VARIABLE t.L = 46.832 treatment fraction

VARIABLE FWCost.L = 799717.942 Total cost of freshwa
ter ($ per y)

VARIABLE TCost.L = 1341290.134 Total cost of Treatme
nt ($ per y)

VARIABLE nXCost.L = 50000.000 Total cost of water s
pliting units ($)

VARIABLE nFCost.L = 20000.000 Total cost of water feeding units
($)

EXECUTION TIME = 0.016 SECONDS 3 MB 24.2.1 r43572 WIN-VS8

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**** FILE SUMMARY

Input C:\Users\DoNuT\Documents\gamsdir\projdir\Data 1 Case 3 - Water Networ
k with end of pipe.gms
Output C:\Users\DoNuT\Documents\gamsdir\projdir\Data 1 Case 3 - Water
Networ
k with end of pipe.lst

CURRICULUM VITAE

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Work Experience:

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Publications:

1. Pungthong, K; and Siemanond K. (2015) Multiple-contaminant Water Network Synthesis. Computer Aided Chemical Engineering, in press.
2. Pungthong, K; and Siemanond K. (2015) The Retrofit Design for Water Network with Multiple Contaminants of Industrial Process. Chemical Engineering Transactions, in press.

Proceedings:

1. Pungthong, K; and Siemanond K. (2015, April 21) Multiple-contaminant Water Network Synthesis. Proceedings of The 6th Research Symposium on Petroleum, Petrochemicals and Advanced Materials and The 21th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.

Presentations:

1. Pungthong, K; and Siemanond K. (2015, April 21) Multiple-contaminant Water Network Synthesis. Poster presented at Proceedings of The 6th Research Symposium on Petroleum, Petrochemicals and Advanced Materials and The 21th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.

2. Pungthong, K; and Siemanond K. (2015, May 31 – June 4) MINLP optimization model for water/wastewater networks with multiple contaminants. Poster presented at 12th International Symposium on Process Systems Engineering and 25th European Symposium on Computer Aided Process Engineering (PSE2015/ESCAPE25), Copenhagen, Denmark.
3. Pungthong, K; and Siemanond K. (2015, Aug 23 – 27) The Retrofit Design for Water Network with Multiple Contaminants of Industrial Process. Poster presented at Proceedings of The 18th International Conference on Process Integration, Modelling and Optimization for Energy Saving and Pollution (PRES'15), Kuching, Sarawak, Malaysia.