# CE 3372 WATER SYSTEMS DESIGN

LESSON 11 PART 1: STORAGE AND EXTENDED PERIOD SIMULATION FALL 2020

# OVERVIEW

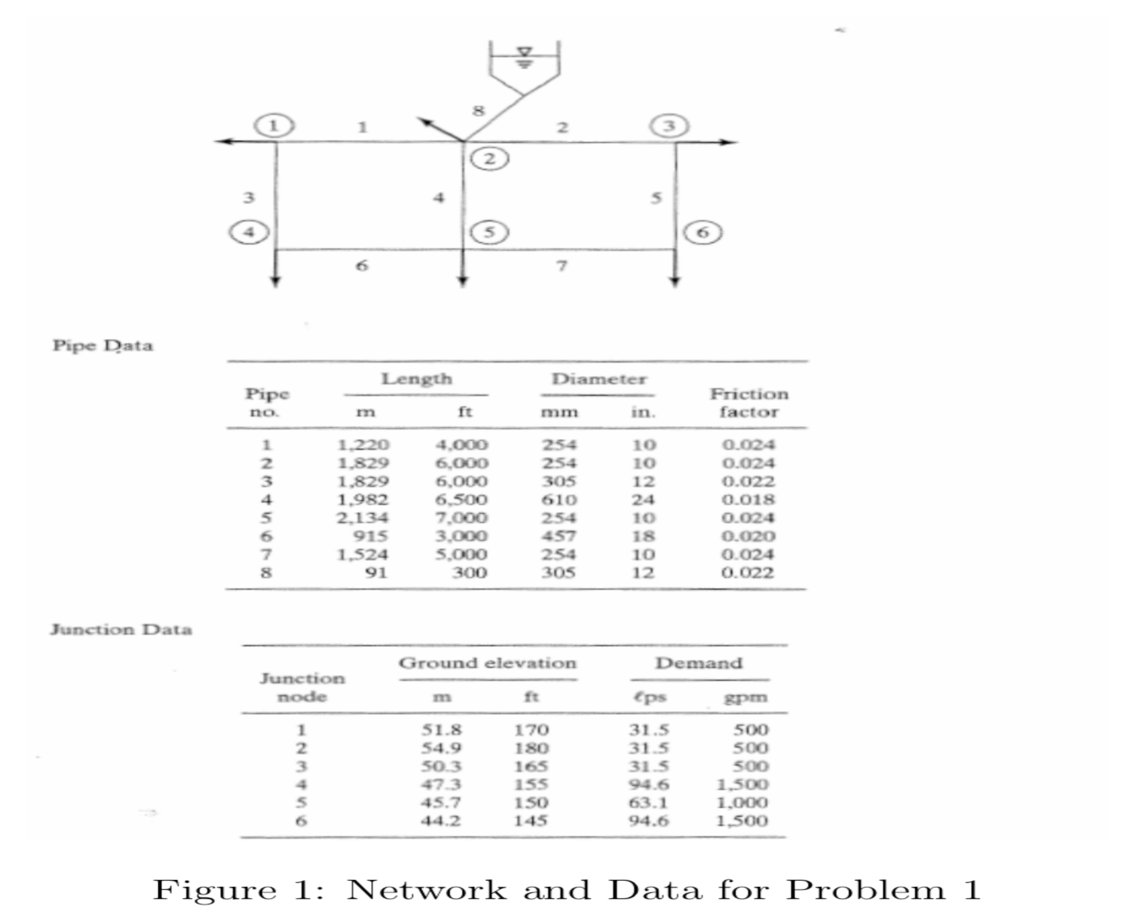
- EPANET Tank Model(s)
  - Single period simulation
- Multiple Period Simulation
  - Reasons
  - Multiplier Table

# READINGS

- EPA NET User Manual – how to model storage tanks in a water distribution system.
  - Interesting web-resources
  - http://www.invisiblestructures.com/rainstore3.html
  - http://www.upout.com/blog/san-francisco-3/heres-what-it-looks-like-under-those-brick-circles-in-the-street

# RECALL EARLIER EXAMPLE

Compute the discharge in each pipe and the pressure at each junction node for the 8-pipe system shown in Figure 1. The water surface elevation in the storage tank is 315.0 ft. Prepare your solution using EPA-NET. Report your results in U.S. Customary units. Identify the node with the lowest pressure in your solution. Include a transmittal letter with the solution.



Pipe Data

| Pipe no. | Length m | Length ft | Diameter mm | Diameter in. | Friction factor |
|---|---|---|---|---|---|
| 1 | 1,220 | 4,000 | 254 | 10 | 0.024 |
| 2 | 1,829 | 6,000 | 254 | 10 | 0.024 |
| 3 | 1,829 | 6,000 | 305 | 12 | 0.022 |
| 4 | 1,982 | 6,500 | 610 | 24 | 0.018 |
| 5 | 2,134 | 7,000 | 254 | 10 | 0.024 |
| 6 | 915 | 3,000 | 457 | 18 | 0.020 |
| 7 | 1,524 | 5,000 | 254 | 10 | 0.024 |
| 8 | 91 | 300 | 305 | 12 | 0.022 |

Junction Data

| Junction node | Ground elevation m | Ground elevation ft | Demand ℓps | Demand gpm |
|---|---|---|---|---|
| 1 | 51.8 | 170 | 31.5 | 500 |
| 2 | 54.9 | 180 | 31.5 | 500 |
| 3 | 50.3 | 165 | 31.5 | 500 |
| 4 | 47.3 | 155 | 94.6 | 1,500 |
| 5 | 45.7 | 150 | 63.1 | 1,000 |
| 6 | 44.2 | 145 | 94.6 | 1,500 |

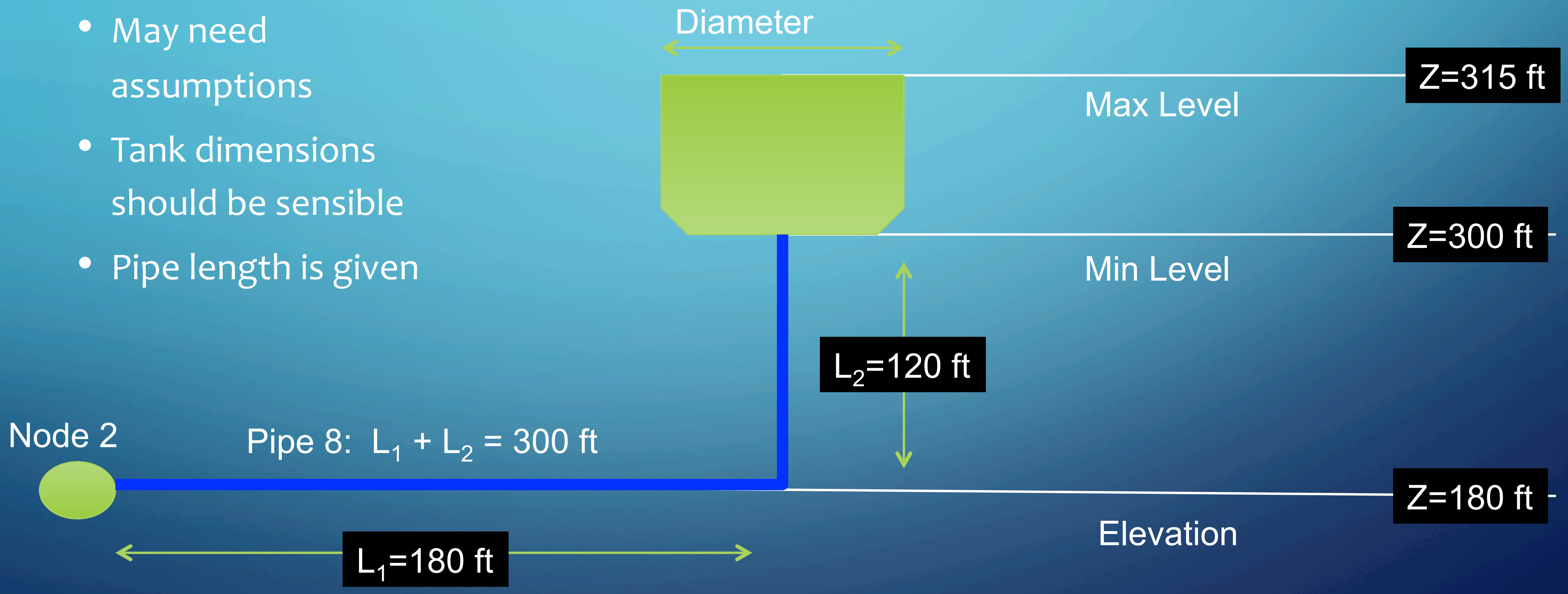
Figure 1: Network and Data for Problem 1

# MODELING PROTOCOL

- Sketch a layout on paper
- Identify pipe diameters; length; roughness values
- Identify node elevations; demands
- Supply reservoir (or tank); identify reservoir pool elevation
- Identify pumps; pump curve in problem units

# TANK

- Supply reservoir (or tank); identify reservoir pool elevation
  - May need assumptions
  - Tank dimensions should be sensible
  - Pipe length is given



# EXTENDED PERIOD SIMULATION

- EPANET and similar programs find steady-flow solutions
- Extended period simulation produces a sequence of steady states with approximations for:
  - Tanks drain and fill
  - Pressures can change at beginning and end of a time interval
  - Pump operating points moving along a pump curve

# USES

- Extended period simulation used for:
  - Modeling pressure in systems during changing demand –usually at hourly time scale
  - Storage tank operation and sizing
  - Water quality simulation
    - EPANET can approximate water quality from multiple sources – has uses in
      - Water age in system
      - Detection of intrusions into a system
      - Severity of contamination (impact assessment)

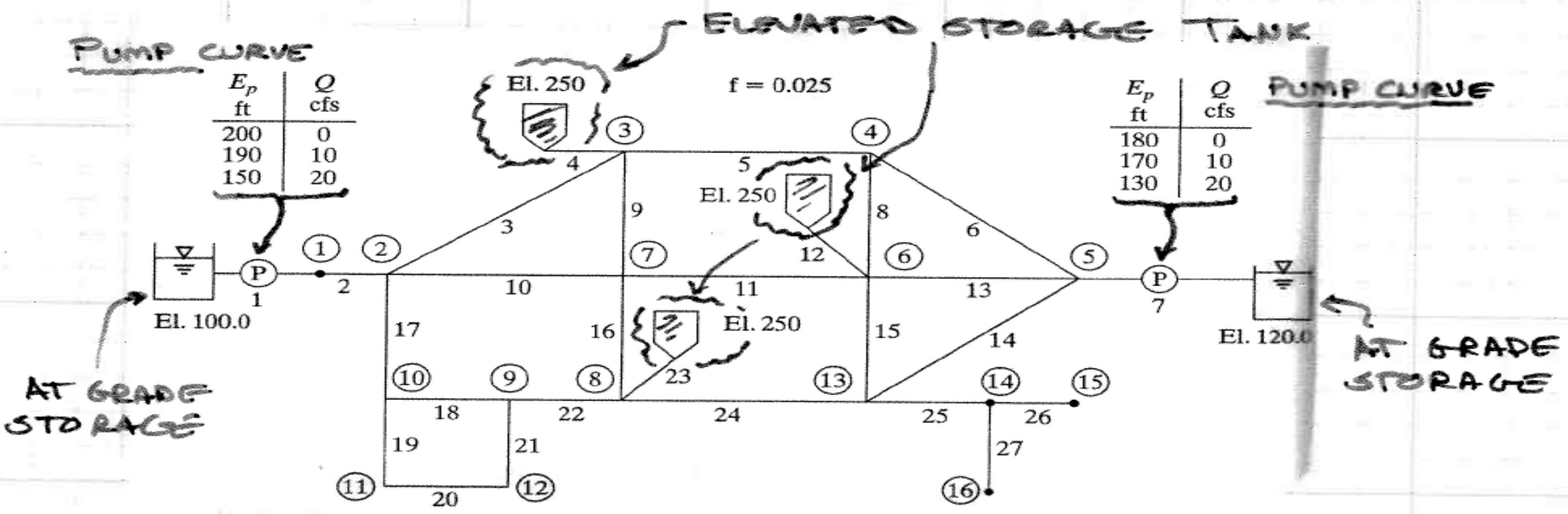
# HOW IMPLEMENTED?

- In EPANET assign a demand pattern to a node
- Set simulation times
- Program then follows the pattern

# MODELING PROTOCOL

- Sketch a layout on paper
- Identify pipe diameters; length; roughness values
- Identify node elevations; demands
- Supply reservoir (or tank); identify reservoir pool elevation
- Identify pumps; pump curve in problem units
- Identify demand pattern(s) and tank operating considerations

# EXAMPLE



PUMP CURVE

| $E_p$ ft | $Q$ cfs |
|---|---|
| 200 | 0 |
| 190 | 10 |
| 150 | 20 |

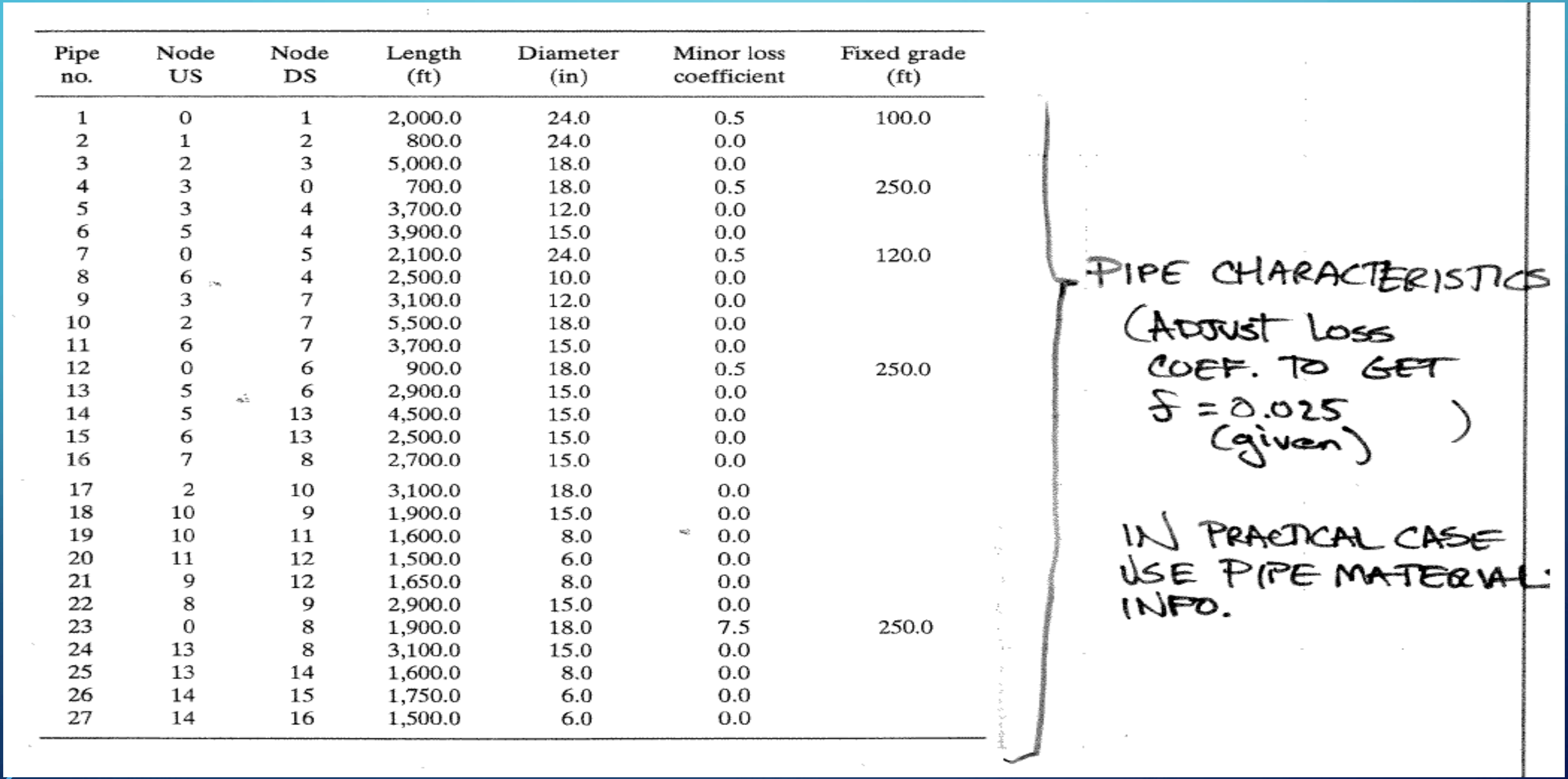
PUMP CURVE

| $E_p$ ft | $Q$ cfs |
|---|---|
| 180 | 0 |
| 170 | 10 |
| 130 | 20 |

| Elevation ft | Storage $ft^3$ |
|---|---|
| 220.0 | 0 |
| 230.0 | 40,000 |
| 240.0 | 120,000 |
| 250.0 | 200,000 |
| 260.0 | 250,000 |

ELEVATION / STORAGE RELATION FOR ELEVATED STORAGE TANKS

# ILLUSTRATE BY EXAMPLE

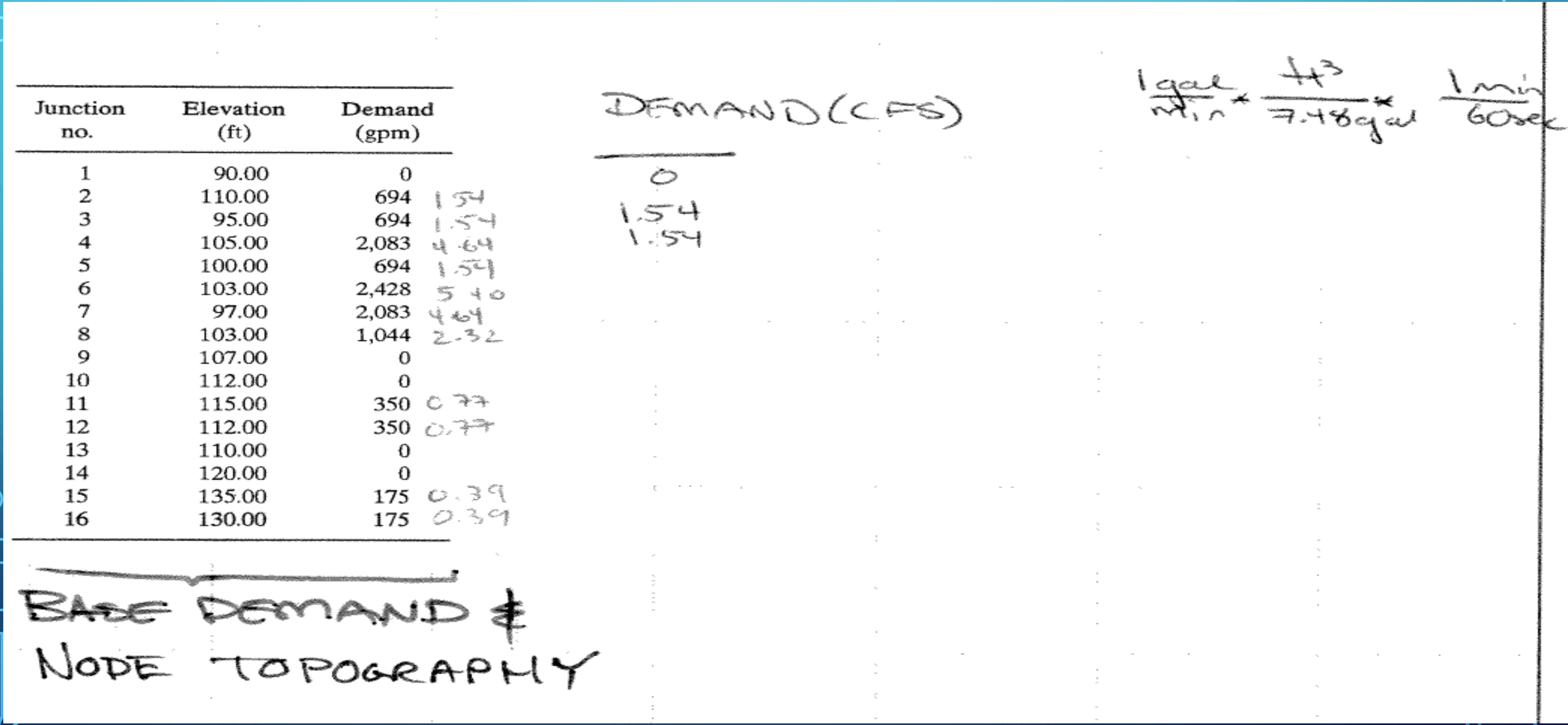


| Pipe no. | Node US | Node DS | Length (ft) | Diameter (in) | Minor loss coefficient | Fixed grade (ft) |
|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 2,000.0 | 24.0 | 0.5 | 100.0 |
| 2 | 1 | 2 | 800.0 | 24.0 | 0.0 | |
| 3 | 2 | 3 | 5,000.0 | 18.0 | 0.0 | |
| 4 | 3 | 0 | 700.0 | 18.0 | 0.5 | 250.0 |
| 5 | 3 | 4 | 3,700.0 | 12.0 | 0.0 | |
| 6 | 5 | 4 | 3,900.0 | 15.0 | 0.0 | |
| 7 | 0 | 5 | 2,100.0 | 24.0 | 0.5 | 120.0 |
| 8 | 6 | 4 | 2,500.0 | 10.0 | 0.0 | |
| 9 | 3 | 7 | 3,100.0 | 12.0 | 0.0 | |
| 10 | 2 | 7 | 5,500.0 | 18.0 | 0.0 | |
| 11 | 6 | 7 | 3,700.0 | 15.0 | 0.0 | |
| 12 | 0 | 6 | 900.0 | 18.0 | 0.5 | 250.0 |
| 13 | 5 | 6 | 2,900.0 | 15.0 | 0.0 | |
| 14 | 5 | 13 | 4,500.0 | 15.0 | 0.0 | |
| 15 | 6 | 13 | 2,500.0 | 15.0 | 0.0 | |
| 16 | 7 | 8 | 2,700.0 | 15.0 | 0.0 | |
| 17 | 2 | 10 | 3,100.0 | 18.0 | 0.0 | |
| 18 | 10 | 9 | 1,900.0 | 15.0 | 0.0 | |
| 19 | 10 | 11 | 1,600.0 | 8.0 | 0.0 | |
| 20 | 11 | 12 | 1,500.0 | 6.0 | 0.0 | |
| 21 | 9 | 12 | 1,650.0 | 8.0 | 0.0 | |
| 22 | 8 | 9 | 2,900.0 | 15.0 | 0.0 | |
| 23 | 0 | 8 | 1,900.0 | 18.0 | 7.5 | 250.0 |
| 24 | 13 | 8 | 3,100.0 | 15.0 | 0.0 | |
| 25 | 13 | 14 | 1,600.0 | 8.0 | 0.0 | |
| 26 | 14 | 15 | 1,750.0 | 6.0 | 0.0 | |
| 27 | 14 | 16 | 1,500.0 | 6.0 | 0.0 | |

PIPE CHARACTERISTICS
(ADJUST LOSS
COEF. TO GET
$f = 0.025$
(given) )

IN PRACTICAL CASE
USE PIPE MATERIAL
INFO.

# ILLUSTRATE BY EXAMPLE



| Junction no. | Elevation (ft) | Demand (gpm) | |
|---|---|---|---|
| 1 | 90.00 | 0 | |
| 2 | 110.00 | 694 | 1.54 |
| 3 | 95.00 | 694 | 1.54 |
| 4 | 105.00 | 2,083 | 4.64 |
| 5 | 100.00 | 694 | 1.54 |
| 6 | 103.00 | 2,428 | 5.40 |
| 7 | 97.00 | 2,083 | 4.64 |
| 8 | 103.00 | 1,044 | 2.32 |
| 9 | 107.00 | 0 | |
| 10 | 112.00 | 0 | |
| 11 | 115.00 | 350 | 0.77 |
| 12 | 112.00 | 350 | 0.77 |
| 13 | 110.00 | 0 | |
| 14 | 120.00 | 0 | |
| 15 | 135.00 | 175 | 0.39 |
| 16 | 130.00 | 175 | 0.39 |

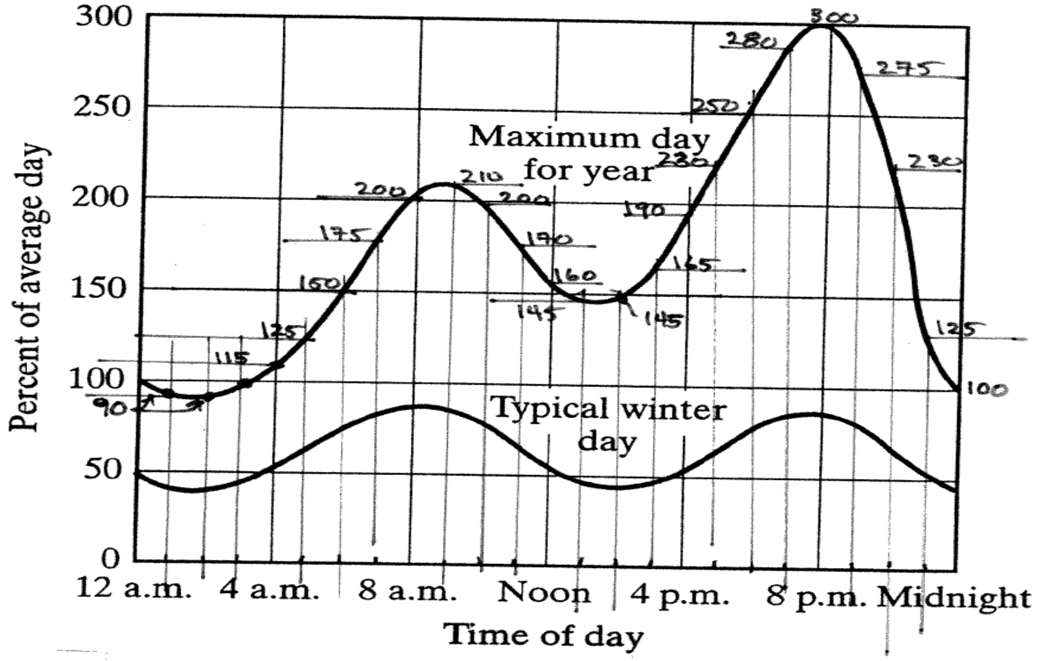
BASE DEMAND &
NODE TOPOGRAPHY

DEMAND (CFS)

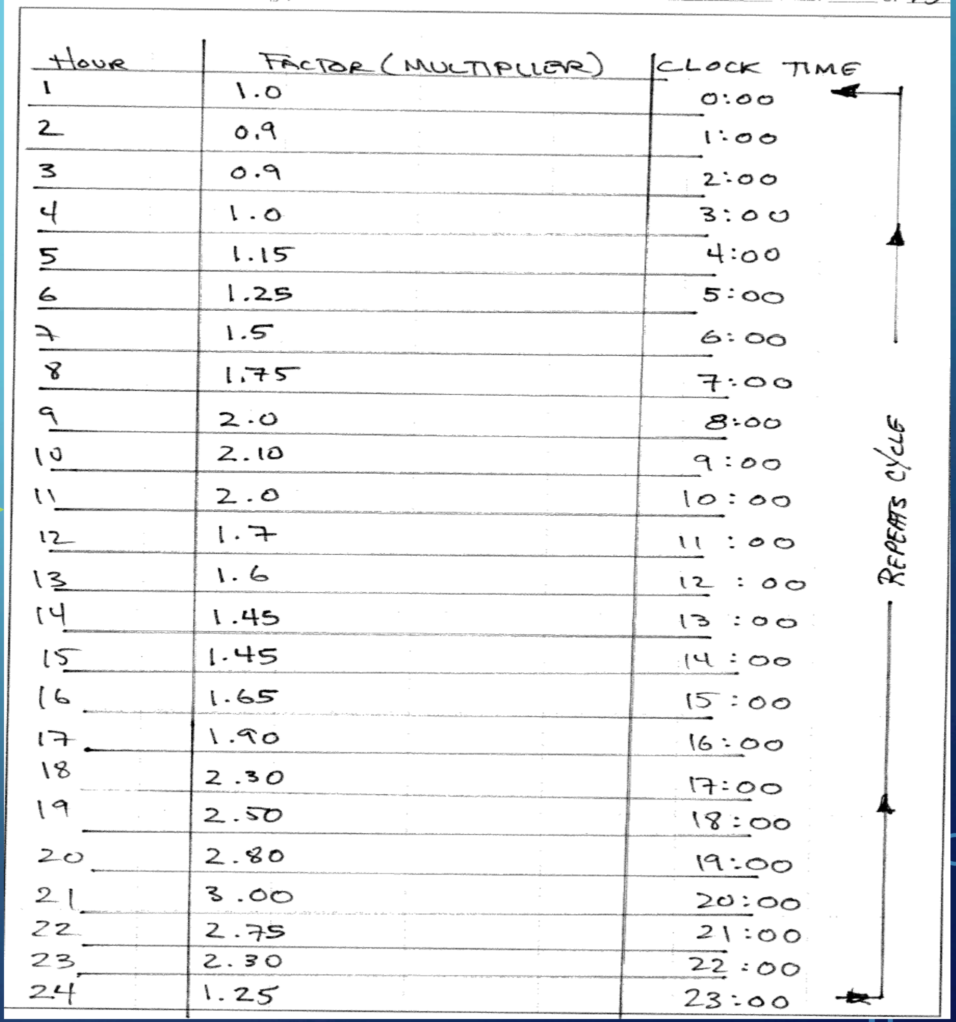
0
1.54
1.54

$$\frac{1\,gal}{min} * \frac{ft^3}{7.48\,gal} * \frac{1\,min}{60\,sec}$$

# ILLUSTRATE BY EXAMPLE



DEMAND MULTIPLIERS – READ FROM CHART FOR HOUR OF DAY,
BUILD MULTIPIER TABLE



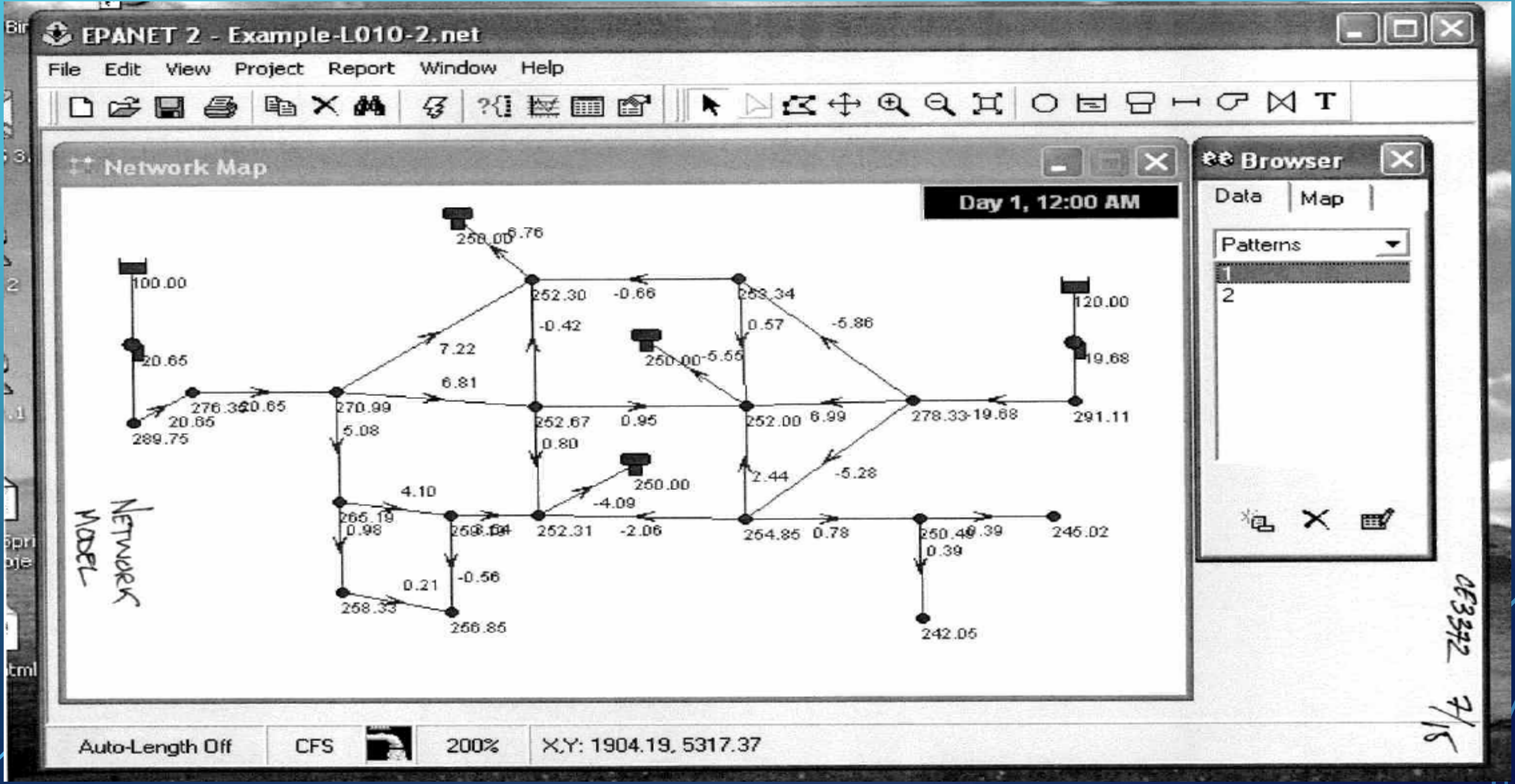
| HOUR | FACTOR (MULTIPLIER) | CLOCK TIME |
|---|---|---|
| 1 | 1.0 | 0:00 |
| 2 | 0.9 | 1:00 |
| 3 | 0.9 | 2:00 |
| 4 | 1.0 | 3:00 |
| 5 | 1.15 | 4:00 |
| 6 | 1.25 | 5:00 |
| 7 | 1.5 | 6:00 |
| 8 | 1.75 | 7:00 |
| 9 | 2.0 | 8:00 |
| 10 | 2.10 | 9:00 |
| 11 | 2.0 | 10:00 |
| 12 | 1.7 | 11:00 |
| 13 | 1.6 | 12:00 |
| 14 | 1.45 | 13:00 |
| 15 | 1.45 | 14:00 |
| 16 | 1.65 | 15:00 |
| 17 | 1.90 | 16:00 |
| 18 | 2.30 | 17:00 |
| 19 | 2.50 | 18:00 |
| 20 | 2.80 | 19:00 |
| 21 | 3.00 | 20:00 |
| 22 | 2.75 | 21:00 |
| 23 | 2.30 | 22:00 |
| 24 | 1.25 | 23:00 |

REPEATS CYCLE

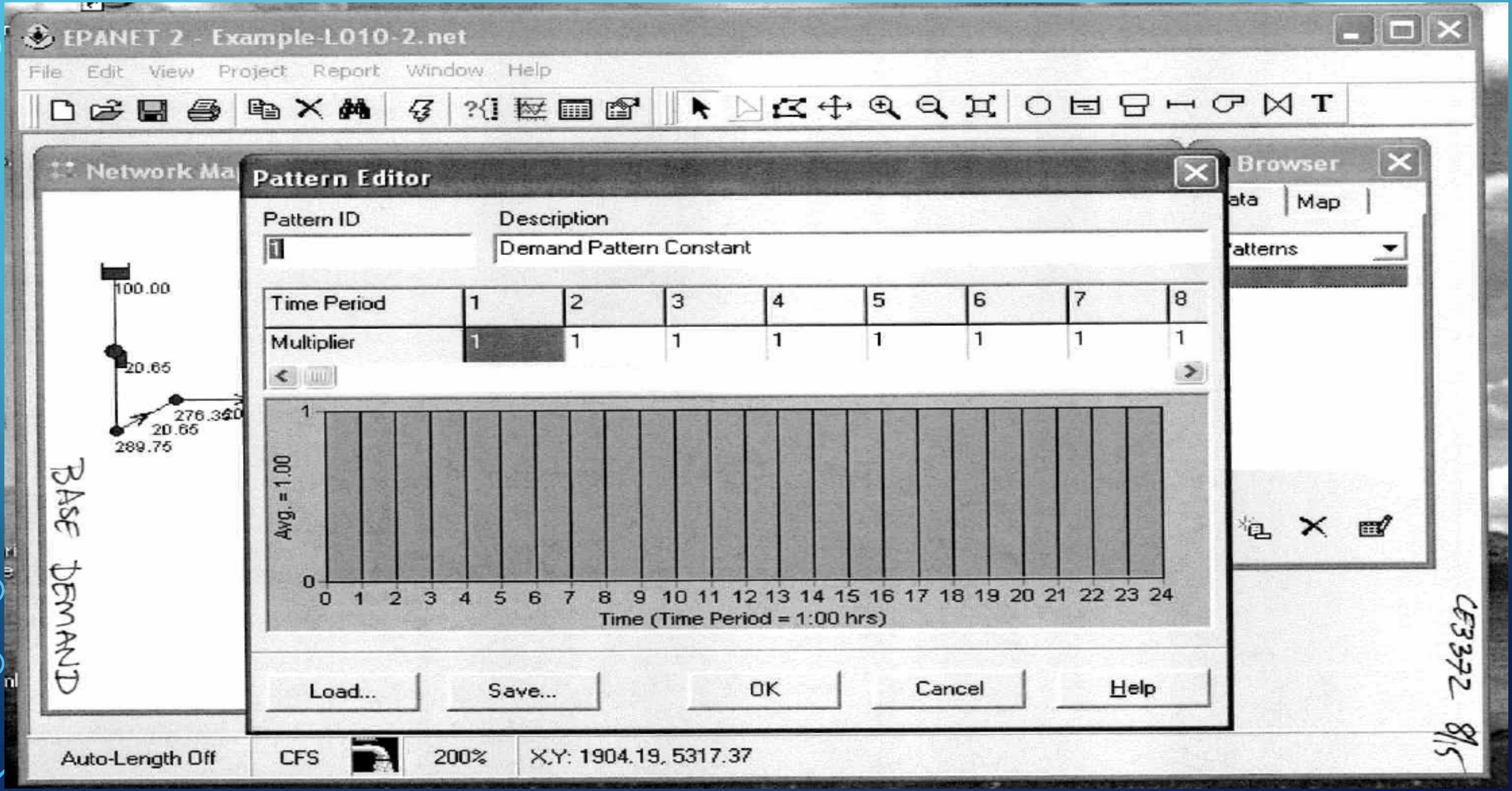
# ILLUSTRATE BY EXAMPLE

- Build network layout
  - Nodes (junctions, tanks, reservoirs)
  - Links (pipes, pumps, valves)
- Add pump curves
  - BROWSER/DATA/CURVES/ADD (TYPE=PUMP)
- Add storage curves
  - BROWSER/DATA/CURVES/ADD (TYPE=STORAGE)
- Add demand pattern(s)
  - BROWSER/PATTERNS/ADD

# ILLUSTRATE BY EXAMPLE



# ILLUSTRATE BY EXAMPLE



Pattern ID: 1

Description: Demand Pattern Constant

| Time Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Multiplier | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Auto-Length Off CFS 200% X,Y: 1904.19, 5317.37

BASE DEMAND

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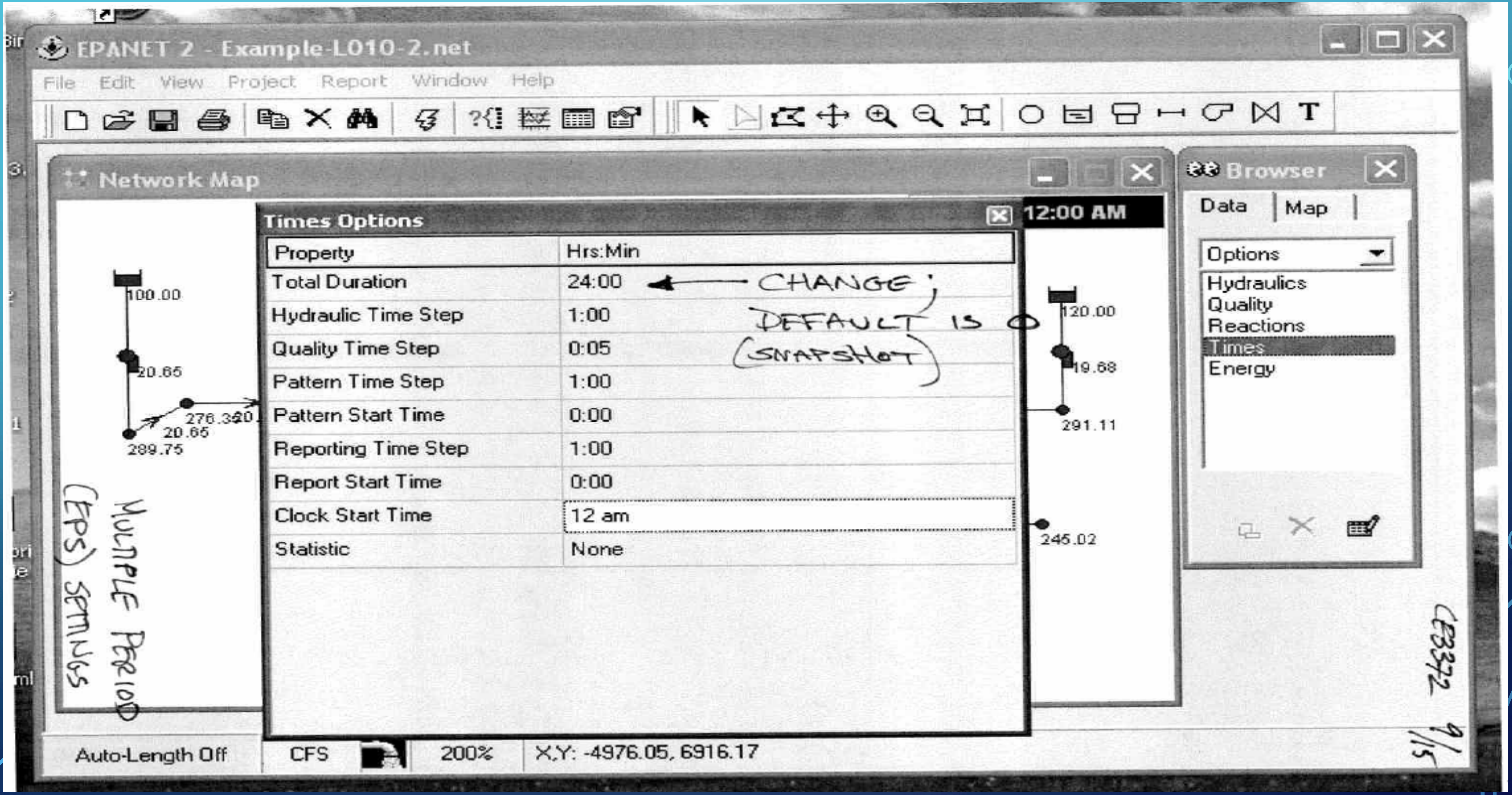
# ILLUSTRATE BY EXAMPLE



Times Options

| Property | Hrs:Min |
|---|---|
| Total Duration | 24:00 |
| Hydraulic Time Step | 1:00 |
| Quality Time Step | 0:05 |
| Pattern Time Step | 1:00 |
| Pattern Start Time | 0:00 |
| Reporting Time Step | 1:00 |
| Report Start Time | 0:00 |
| Clock Start Time | 12 am |
| Statistic | None |

CHANGE; DEFAULT IS 0 (SNAPSHOT)

MULTIPLE PERIOD (EPS) SETTINGS

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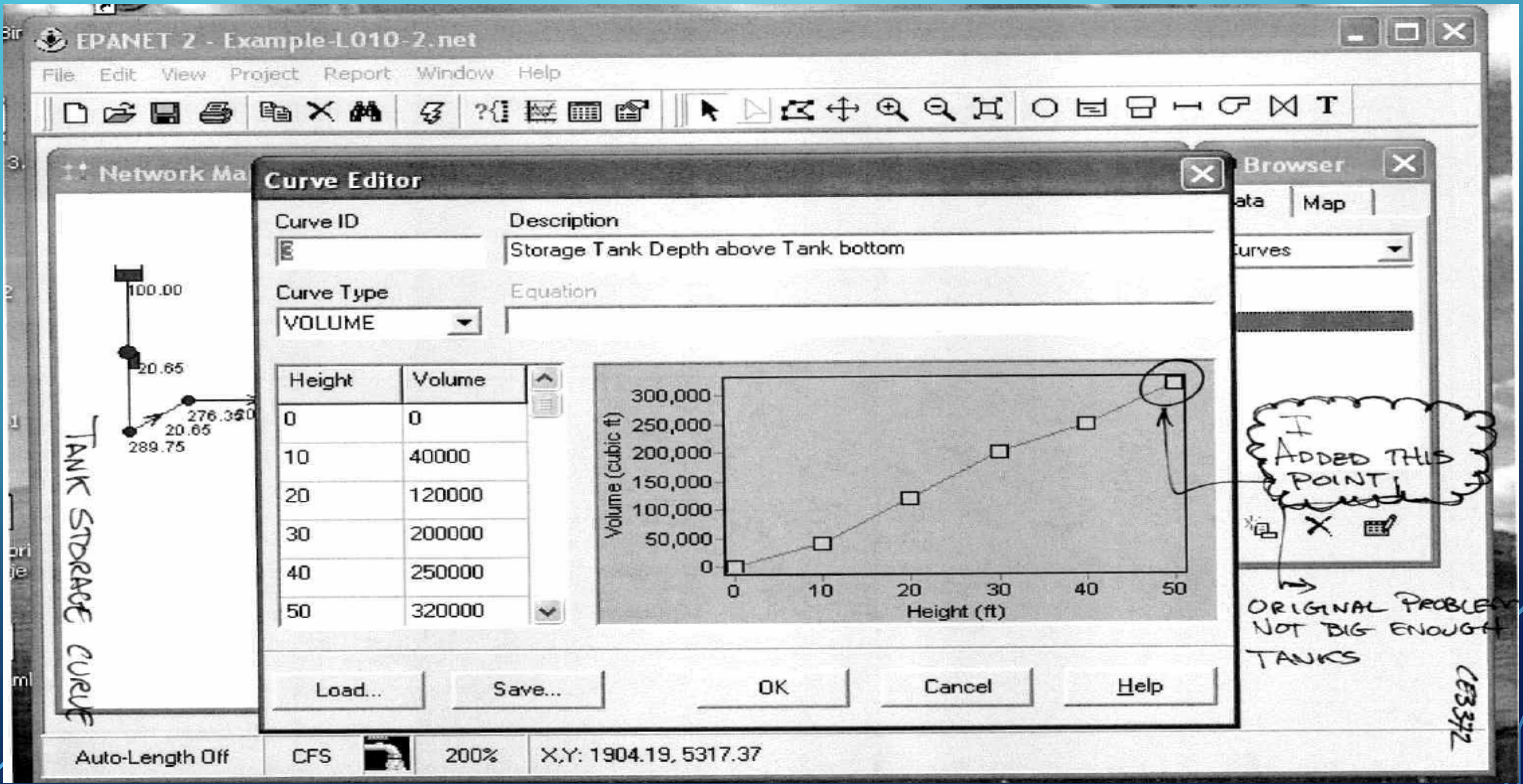
# ILLUSTRATE BY EXAMPLE



Curve ID: E

Description: Storage Tank Depth above Tank bottom

Curve Type: VOLUME

Equation:

| Height | Volume |
|---|---|
| 0 | 0 |
| 10 | 40000 |
| 20 | 120000 |
| 30 | 200000 |
| 40 | 250000 |
| 50 | 320000 |

X,Y: 1904.19, 5317.37

TANK STORAGE CURVE

I ADDED THIS POINT

ORIGINAL PROBLEM NOT BIG ENOUGH TANKS

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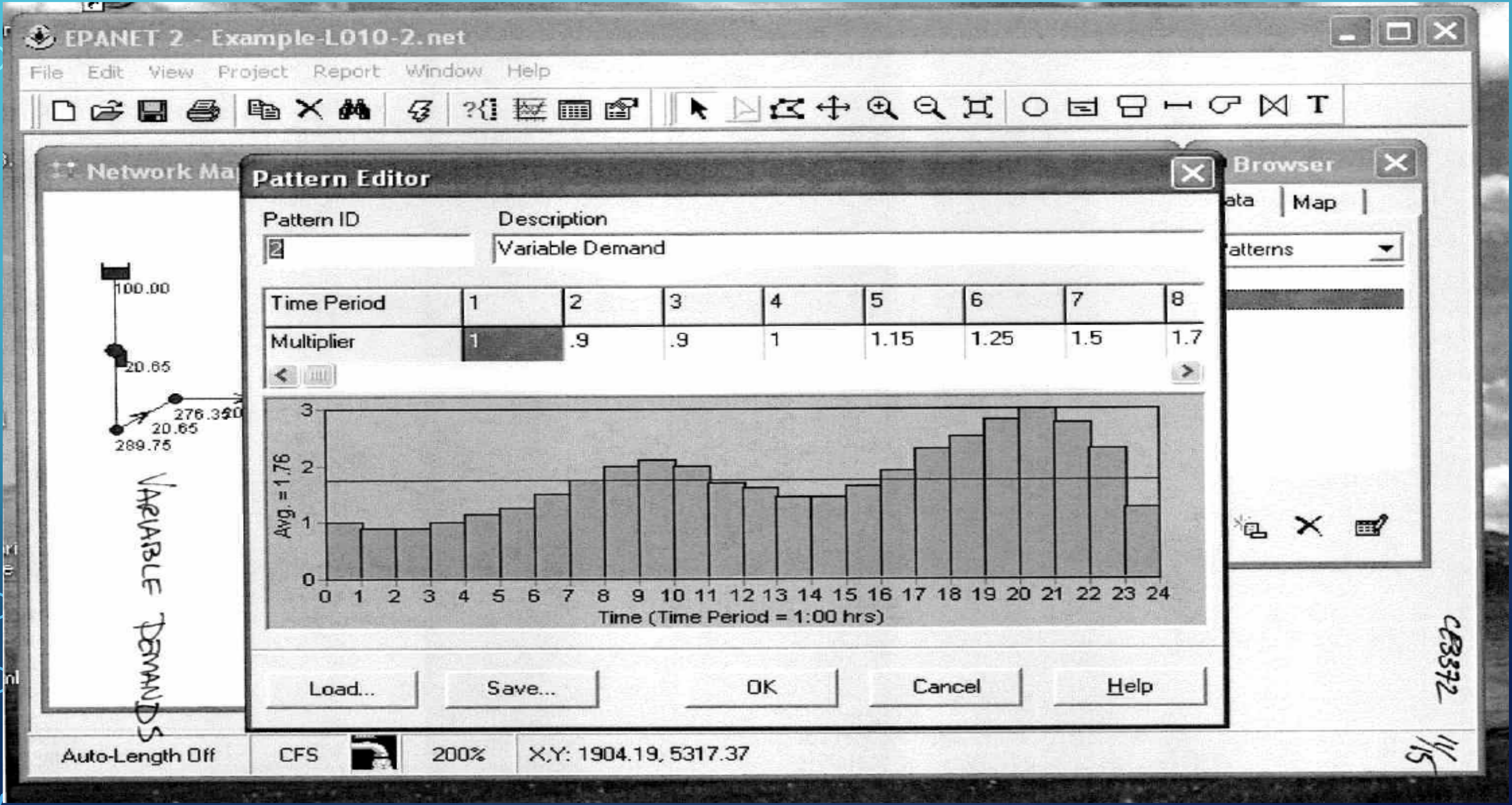
# ILLUSTRATE BY EXAMPLE



Pattern ID: 2

Description: Variable Demand

| Time Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Multiplier | 1 | .9 | .9 | 1 | 1.15 | 1.25 | 1.5 | 1.7 |

Auto-Length Off

CFS

200%

X,Y: 1904.19, 5317.37

VARIABLE DEMANDS

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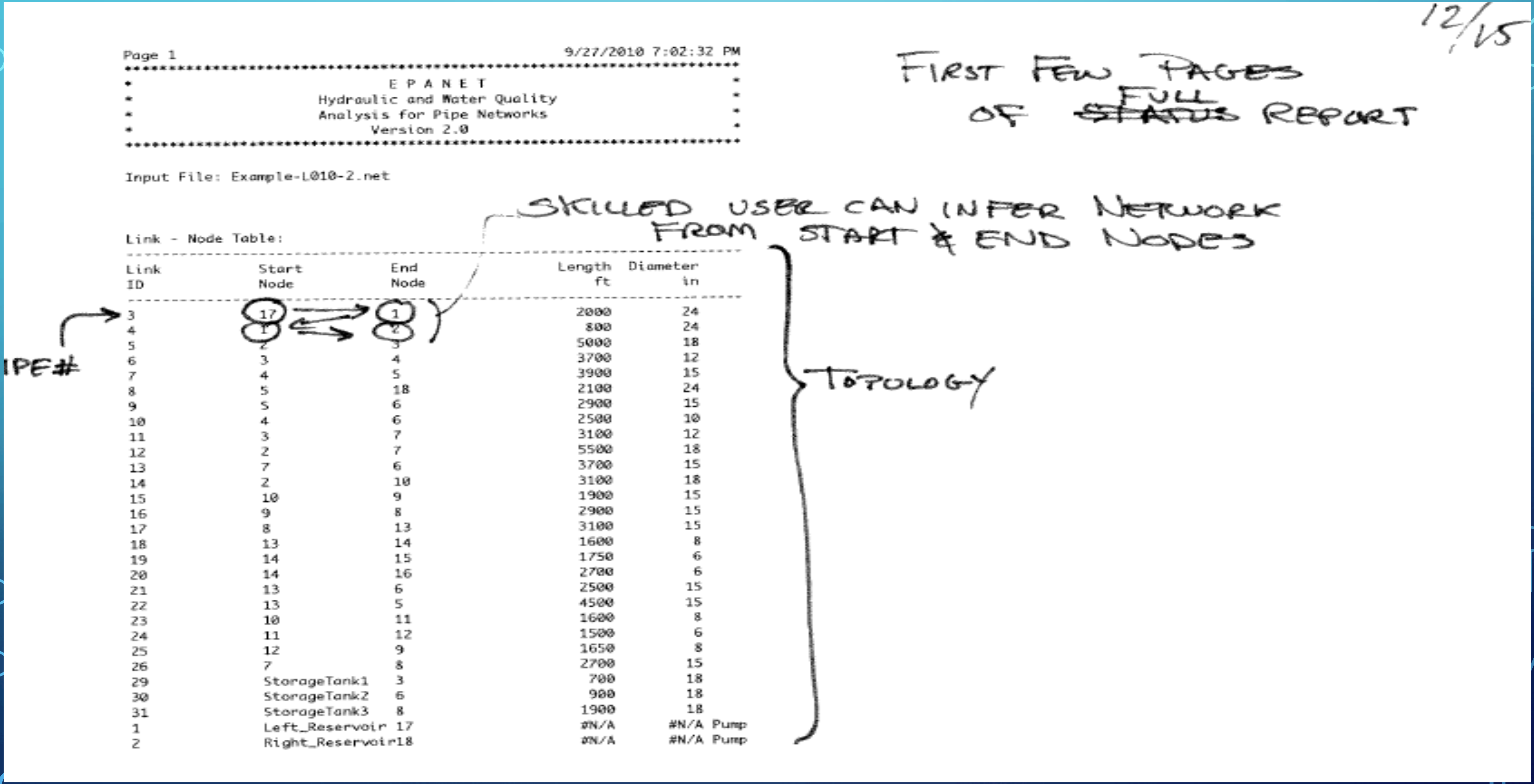
11/15

# REPORT OUTPUT



12/15

FIRST FEW PAGES OF FULL ~~STATUS~~ REPORT

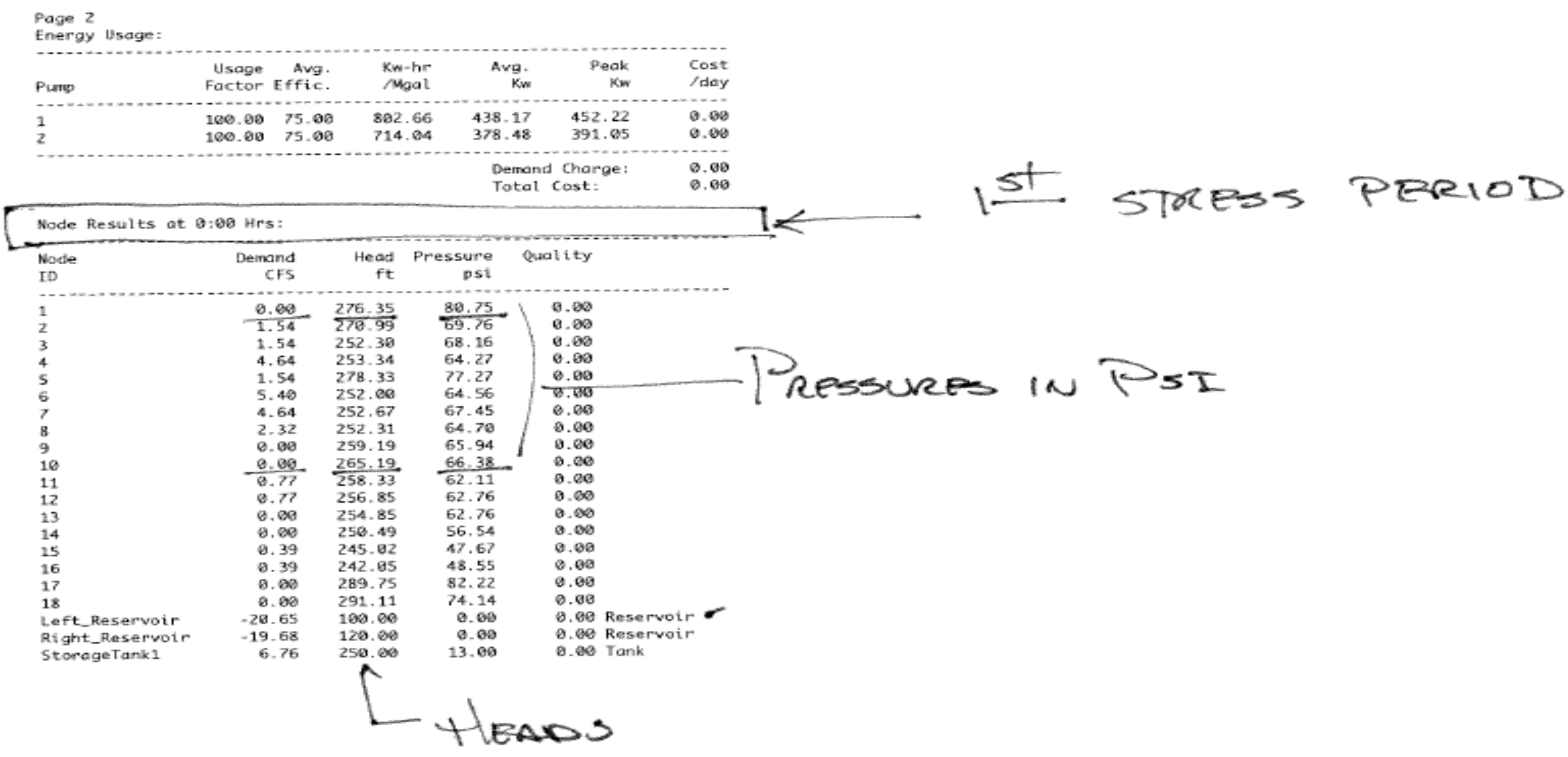
```
Page 1                                              9/27/2010 7:02:32 PM
**********************************************************************
*                            E P A N E T                             *
*                  Hydraulic and Water Quality                       *
*                  Analysis for Pipe Networks                        *
*                         Version 2.0                                *
**********************************************************************

Input File: Example-L010-2.net


Link - Node Table:
----------------------------------------------------------------------
Link            Start           End                 Length  Diameter
ID              Node            Node                    ft        in
----------------------------------------------------------------------
3               17              1                     2000        24
4               1               2                      800        24
5               2               3                     5000        18
6               3               4                     3700        12
7               4               5                     3900        15
8               5               18                    2100        24
9               5               6                     2900        15
10              4               6                     2500        10
11              3               7                     3100        12
12              2               7                     5500        18
13              7               6                     3700        15
14              2               10                    3100        18
15              10              9                     1900        15
16              9               8                     2900        15
17              8               13                    3100        15
18              13              14                    1600         8
19              14              15                    1750         6
20              14              16                    2700         6
21              13              6                     2500        15
22              13              5                     4500        15
23              10              11                    1600         8
24              11              12                    1500         6
25              12              9                     1650         8
26              7               8                     2700        15
29              StorageTank1    3                      700        18
30              StorageTank2    6                      900        18
31              StorageTank3    8                     1900        18
1               Left_Reservoir 17                     #N/A      #N/A Pump
2               Right_Reservoir18                     #N/A      #N/A Pump
```

SKILLED USER CAN INFER NETWORK FROM START & END NODES

IPE#

TOPOLOGY

# REPORT OUTPUT



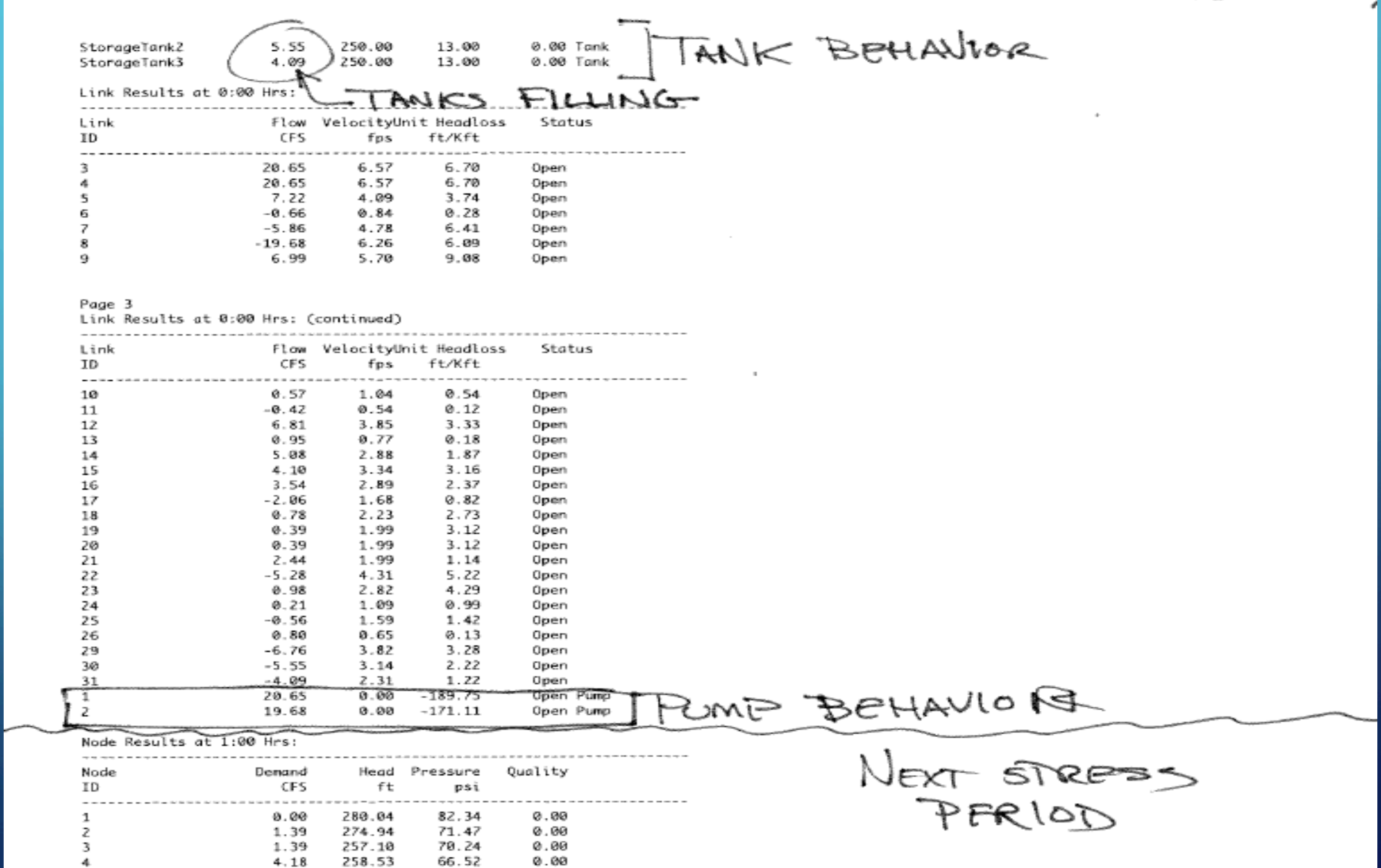
```
Page 2
Energy Usage:
----------------------------------------------------------------------
                  Usage   Avg.     Kw-hr      Avg.      Peak      Cost
Pump              Factor Effic.    /Mgal        Kw        Kw      /day
----------------------------------------------------------------------
1                100.00  75.00    802.66    438.17    452.22      0.00
2                100.00  75.00    714.04    378.48    391.05      0.00
----------------------------------------------------------------------
                                            Demand Charge:        0.00
                                            Total Cost:           0.00

Node Results at 0:00 Hrs:
----------------------------------------------------------------------
Node                    Demand      Head  Pressure  Quality
ID                         CFS        ft       psi
----------------------------------------------------------------------
1                         0.00    276.35     80.75     0.00
2                         1.54    270.99     69.76     0.00
3                         1.54    252.30     68.16     0.00
4                         4.64    253.34     64.27     0.00
5                         1.54    278.33     77.27     0.00
6                         5.40    252.00     64.56     0.00
7                         4.64    252.67     67.45     0.00
8                         2.32    252.31     64.70     0.00
9                         0.00    259.19     65.94     0.00
10                        0.00    265.19     66.38     0.00
11                        0.77    258.33     62.11     0.00
12                        0.77    256.85     62.76     0.00
13                        0.00    254.85     62.76     0.00
14                        0.00    250.49     56.54     0.00
15                        0.39    245.02     47.67     0.00
16                        0.39    242.05     48.55     0.00
17                        0.00    289.75     82.22     0.00
18                        0.00    291.11     74.14     0.00
Left_Reservoir          -20.65    100.00      0.00     0.00 Reservoir
Right_Reservoir         -19.68    120.00      0.00     0.00 Reservoir
StorageTank1              6.76    250.00     13.00     0.00 Tank
```

1st STRESS PERIOD

PRESSURES IN PSI

HEADS

# REPORT OUTPUT



```
StorageTank2          5.55    250.00      13.00       0.00 Tank
StorageTank3          4.09    250.00      13.00       0.00 Tank

Link Results at 0:00 Hrs:
----------------------------------------------------------------------
Link                  Flow  VelocityUnit Headloss     Status
ID                     CFS        fps     ft/Kft
----------------------------------------------------------------------
3                    20.65       6.57       6.70     Open
4                    20.65       6.57       6.70     Open
5                     7.22       4.09       3.74     Open
6                    -0.66       0.84       0.28     Open
7                    -5.86       4.78       6.41     Open
8                   -19.68       6.26       6.09     Open
9                     6.99       5.70       9.08     Open


Page 3
Link Results at 0:00 Hrs: (continued)
----------------------------------------------------------------------
Link                  Flow  VelocityUnit Headloss     Status
ID                     CFS        fps     ft/Kft
----------------------------------------------------------------------
10                    0.57       1.04       0.54     Open
11                   -0.42       0.54       0.12     Open
12                    6.81       3.85       3.33     Open
13                    0.95       0.77       0.18     Open
14                    5.08       2.88       1.87     Open
15                    4.10       3.34       3.16     Open
16                    3.54       2.89       2.37     Open
17                   -2.06       1.68       0.82     Open
18                    0.78       2.23       2.73     Open
19                    0.39       1.99       3.12     Open
20                    0.39       1.99       3.12     Open
21                    2.44       1.99       1.14     Open
22                   -5.28       4.31       5.22     Open
23                    0.98       2.82       4.29     Open
24                    0.21       1.09       0.99     Open
25                   -0.56       1.59       1.42     Open
26                    0.80       0.65       0.13     Open
29                   -6.76       3.82       3.28     Open
30                   -5.55       3.14       2.22     Open
31                   -4.09       2.31       1.22     Open
1                    20.65       0.00    -189.75     Open Pump
2                    19.68       0.00    -171.11     Open Pump

Node Results at 1:00 Hrs:
----------------------------------------------------------------------
Node                Demand       Head  Pressure    Quality
ID                     CFS         ft       psi
----------------------------------------------------------------------
1                     0.00     280.04     82.34       0.00
2                     1.39     274.94     71.47       0.00
3                     1.39     257.10     70.24       0.00
4                     4.18     258.53     66.52       0.00
```

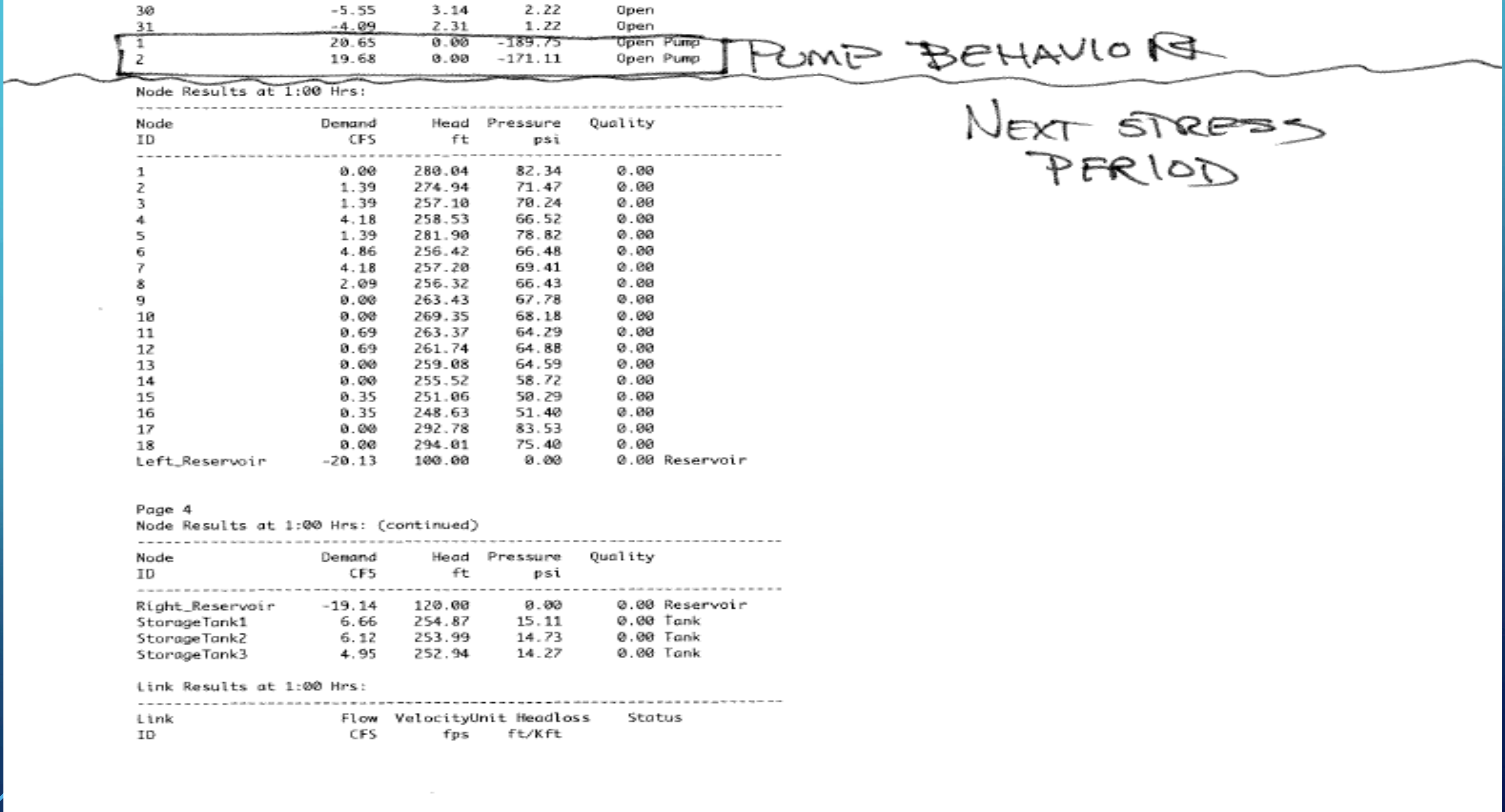
TANK BEHAVIOR

TANKS FILLING

PUMP BEHAVIOR

NEXT STRESS PERIOD

# REPORT OUTPUT

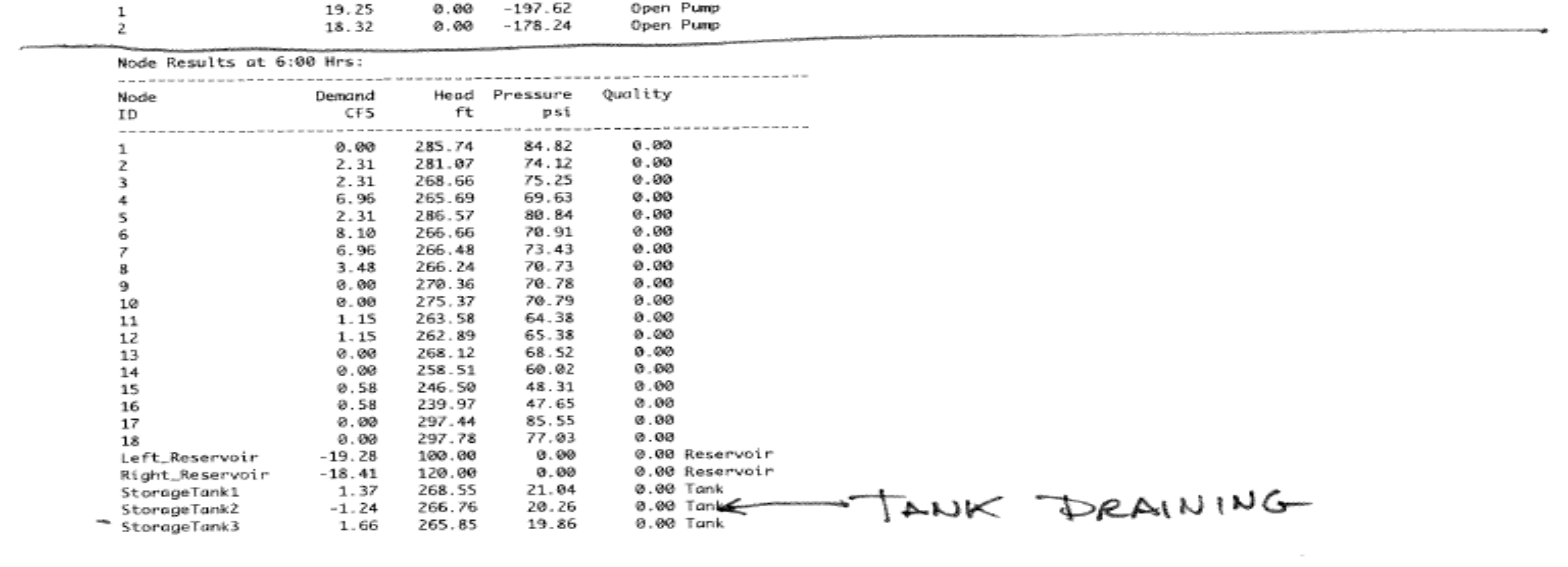


```
30                 -5.55      3.14      2.22      Open
31                 -4.09      2.31      1.22      Open
1                  20.65      0.00   -189.75      Open Pump
2                  19.68      0.00   -171.11      Open Pump

Node Results at 1:00 Hrs:
---------------------------------------------------------------------
Node                Demand      Head  Pressure    Quality
ID                     CFS        ft       psi
---------------------------------------------------------------------
1                     0.00    280.04     82.34      0.00
2                     1.39    274.94     71.47      0.00
3                     1.39    257.10     70.24      0.00
4                     4.18    258.53     66.52      0.00
5                     1.39    281.90     78.82      0.00
6                     4.86    256.42     66.48      0.00
7                     4.18    257.20     69.41      0.00
8                     2.09    256.32     66.43      0.00
9                     0.00    263.43     67.78      0.00
10                    0.00    269.35     68.18      0.00
11                    0.69    263.37     64.29      0.00
12                    0.69    261.74     64.88      0.00
13                    0.00    259.08     64.59      0.00
14                    0.00    255.52     58.72      0.00
15                    0.35    251.06     50.29      0.00
16                    0.35    248.63     51.40      0.00
17                    0.00    292.78     83.53      0.00
18                    0.00    294.01     75.40      0.00
Left_Reservoir      -20.13    100.00      0.00      0.00 Reservoir


Page 4
Node Results at 1:00 Hrs: (continued)
---------------------------------------------------------------------
Node                Demand      Head  Pressure    Quality
ID                     CFS        ft       psi
---------------------------------------------------------------------
Right_Reservoir     -19.14    120.00      0.00      0.00 Reservoir
StorageTank1          6.66    254.87     15.11      0.00 Tank
StorageTank2          6.12    253.99     14.73      0.00 Tank
StorageTank3          4.95    252.94     14.27      0.00 Tank

Link Results at 1:00 Hrs:
---------------------------------------------------------------------
Link                  Flow  VelocityUnit Headloss     Status
ID                     CFS       fps    ft/Kft
```

PUMP BEHAVIOR

NEXT STRESS
PERIOD

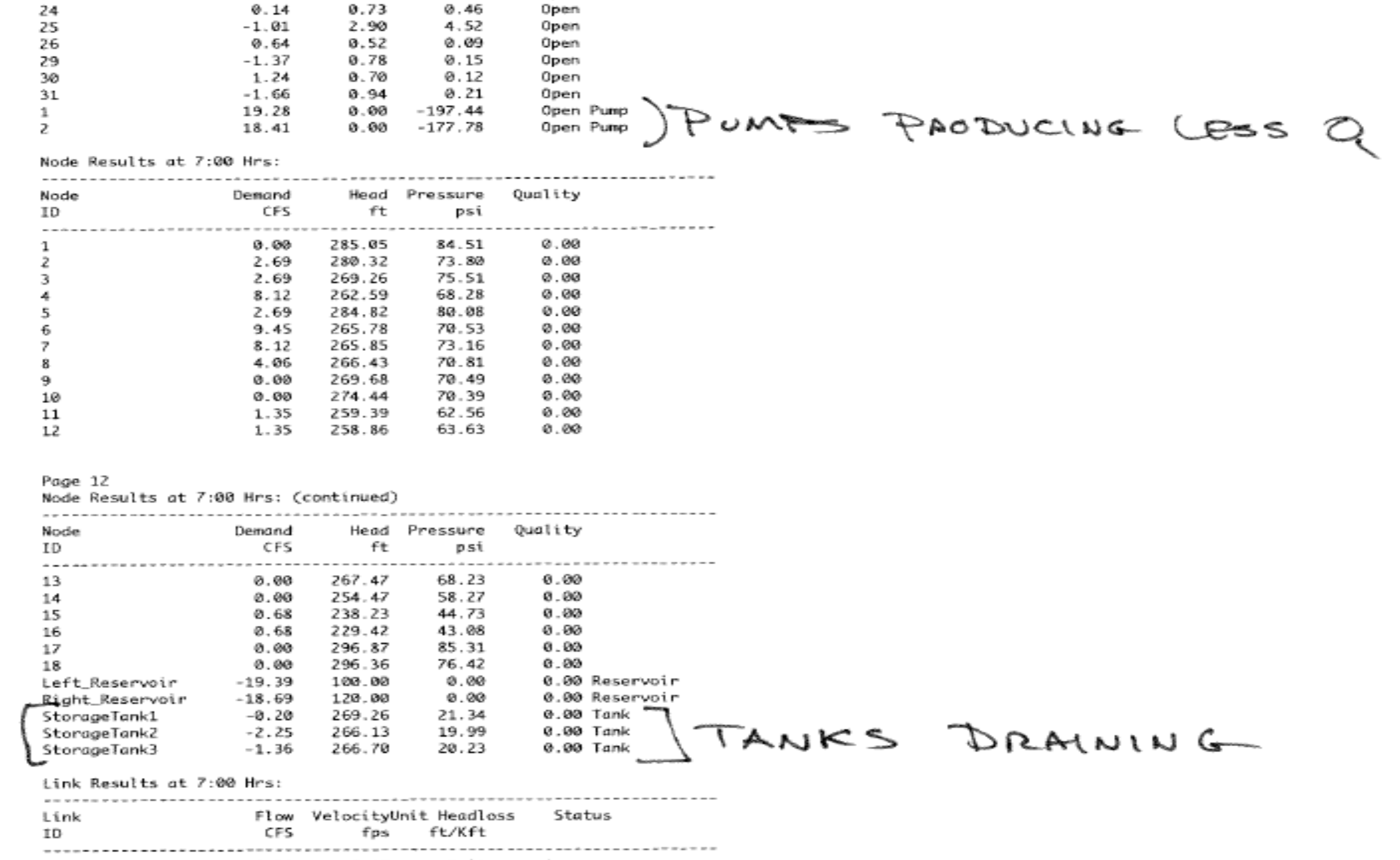
# REPORT OUTPUT



```
1                    19.25      0.00    -197.62      Open Pump
2                    18.32      0.00    -178.24      Open Pump

Node Results at 6:00 Hrs:
------------------------------------------------------------------------
Node                 Demand      Head   Pressure    Quality
ID                      CFS        ft        psi
------------------------------------------------------------------------
1                      0.00    285.74      84.82       0.00
2                      2.31    281.07      74.12       0.00
3                      2.31    268.66      75.25       0.00
4                      6.96    265.69      69.63       0.00
5                      2.31    286.57      80.84       0.00
6                      8.10    266.66      70.91       0.00
7                      6.96    266.48      73.43       0.00
8                      3.48    266.24      70.73       0.00
9                      0.00    270.36      70.78       0.00
10                     0.00    275.37      70.79       0.00
11                     1.15    263.58      64.38       0.00
12                     1.15    262.89      65.38       0.00
13                     0.00    268.12      68.52       0.00
14                     0.00    258.51      60.02       0.00
15                     0.58    246.50      48.31       0.00
16                     0.58    239.97      47.65       0.00
17                     0.00    297.44      85.55       0.00
18                     0.00    297.78      77.03       0.00
Left_Reservoir       -19.28    100.00       0.00       0.00 Reservoir
Right_Reservoir      -18.41    120.00       0.00       0.00 Reservoir
StorageTank1           1.37    268.55      21.04       0.00 Tank
StorageTank2          -1.24    266.76      20.26       0.00 Tank
StorageTank3           1.66    265.85      19.86       0.00 Tank
```

TANK DRAINING

# REPORT OUTPUT



```
24                   0.14        0.73       0.46       Open
25                  -1.01        2.90       4.52       Open
26                   0.64        0.52       0.09       Open
29                  -1.37        0.78       0.15       Open
30                   1.24        0.70       0.12       Open
31                  -1.66        0.94       0.21       Open
1                   19.28        0.00    -197.44       Open Pump
2                   18.41        0.00    -177.78       Open Pump

Node Results at 7:00 Hrs:
----------------------------------------------------------------------
Node                   Demand       Head   Pressure     Quality
ID                        CFS         ft        psi
----------------------------------------------------------------------
1                        0.00     285.05      84.51        0.00
2                        2.69     280.32      73.80        0.00
3                        2.69     269.26      75.51        0.00
4                        8.12     262.59      68.28        0.00
5                        2.69     284.82      80.08        0.00
6                        9.45     265.78      70.53        0.00
7                        8.12     265.85      73.16        0.00
8                        4.06     266.43      70.81        0.00
9                        0.00     269.68      70.49        0.00
10                       0.00     274.44      70.39        0.00
11                       1.35     259.39      62.56        0.00
12                       1.35     258.86      63.63        0.00


Page 12
Node Results at 7:00 Hrs: (continued)
----------------------------------------------------------------------
Node                   Demand       Head   Pressure     Quality
ID                        CFS         ft        psi
----------------------------------------------------------------------
13                       0.00     267.47      68.23        0.00
14                       0.00     254.47      58.27        0.00
15                       0.68     238.23      44.73        0.00
16                       0.68     229.42      43.08        0.00
17                       0.00     296.87      85.31        0.00
18                       0.00     296.36      76.42        0.00
Left_Reservoir         -19.39     100.00       0.00        0.00 Reservoir
Right_Reservoir        -18.69     120.00       0.00        0.00 Reservoir
StorageTank1            -0.20     269.26      21.34        0.00 Tank
StorageTank2            -2.25     266.13      19.99        0.00 Tank
StorageTank3            -1.36     266.70      20.23        0.00 Tank

Link Results at 7:00 Hrs:
----------------------------------------------------------------------
Link                     Flow VelocityUnit Headloss        Status
ID                        CFS        fps     ft/Kft
----------------------------------------------------------------------
```

PUMPS PRODUCING LESS Q

TANKS DRAINING

# CE 3372 WATER SYSTEMS DESIGN

## LESSON 11 PART 2 : WATER QUALITY IN EPANET FALL 2020

# OUTLINE

- EPA-NET Water Quality Models
  - Theory:
    - Advective Transport in Pipeline
    - Decay
  - Practice:
    - Estimate water age in system
    - Estimate concentration of constituent at different points in network
    - Respond to intrusions into the system

# WATER QUALITY IN EPANET

- Transport theory in EPANET
    - Lagrangian Approach (Discrete Parcel Advection)
    - Mixing Approach (in tanks)

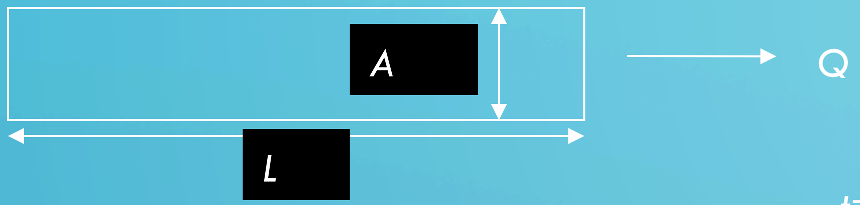
# ADVECTIVE TRANSPORT

- Advection (convection) is the transport of dissolved or suspended material by motion of the host fluid.

- Requires knowledge of the fluid velocity field (the velocity of a fluid particle)

- Velocity from EPANET hydraulics

# MEAN SECTION VELOCITY



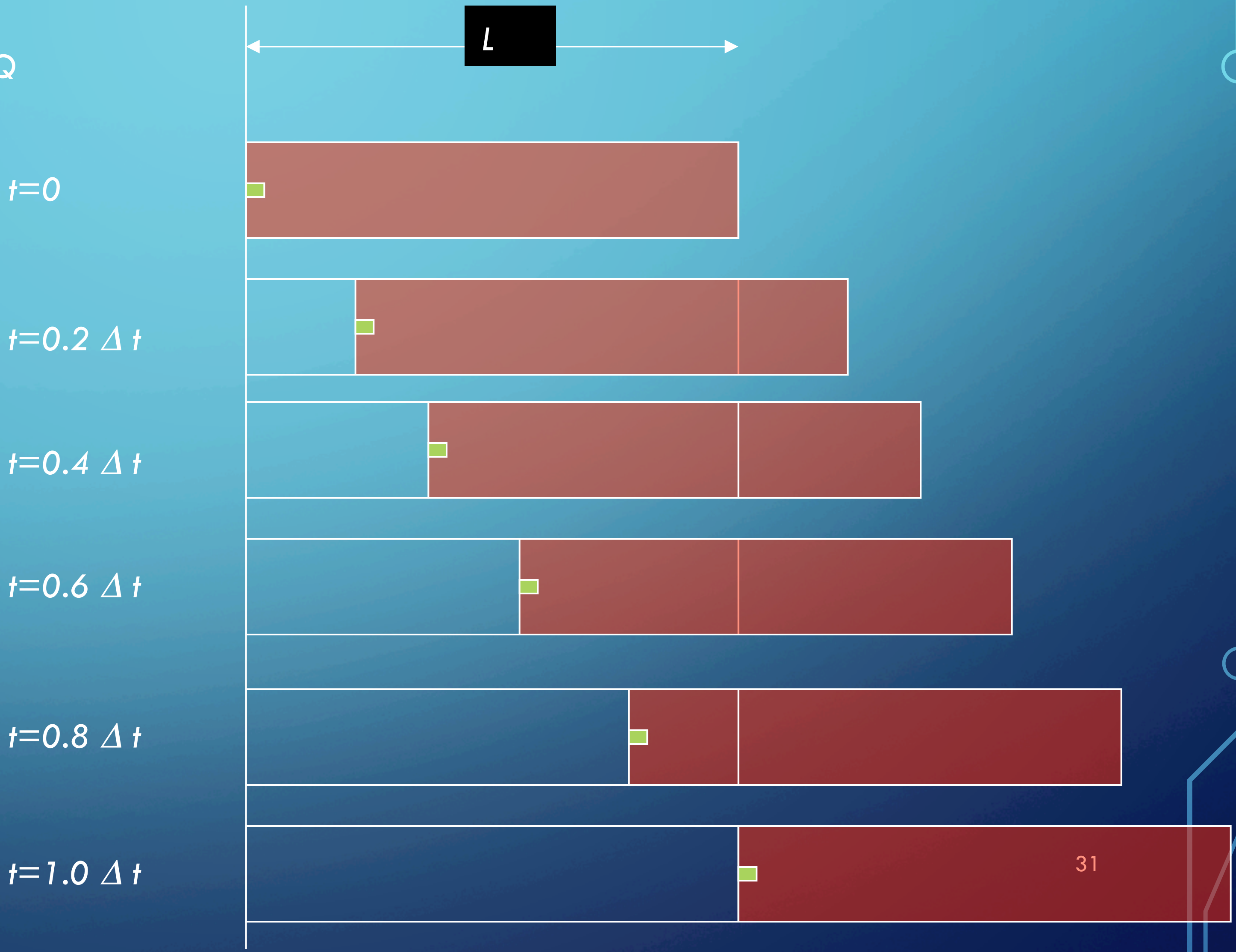
Pipe Segment:
Volume = L*A
Flow Rate = Q

Displacement of one segment volume takes a certain time, Δt

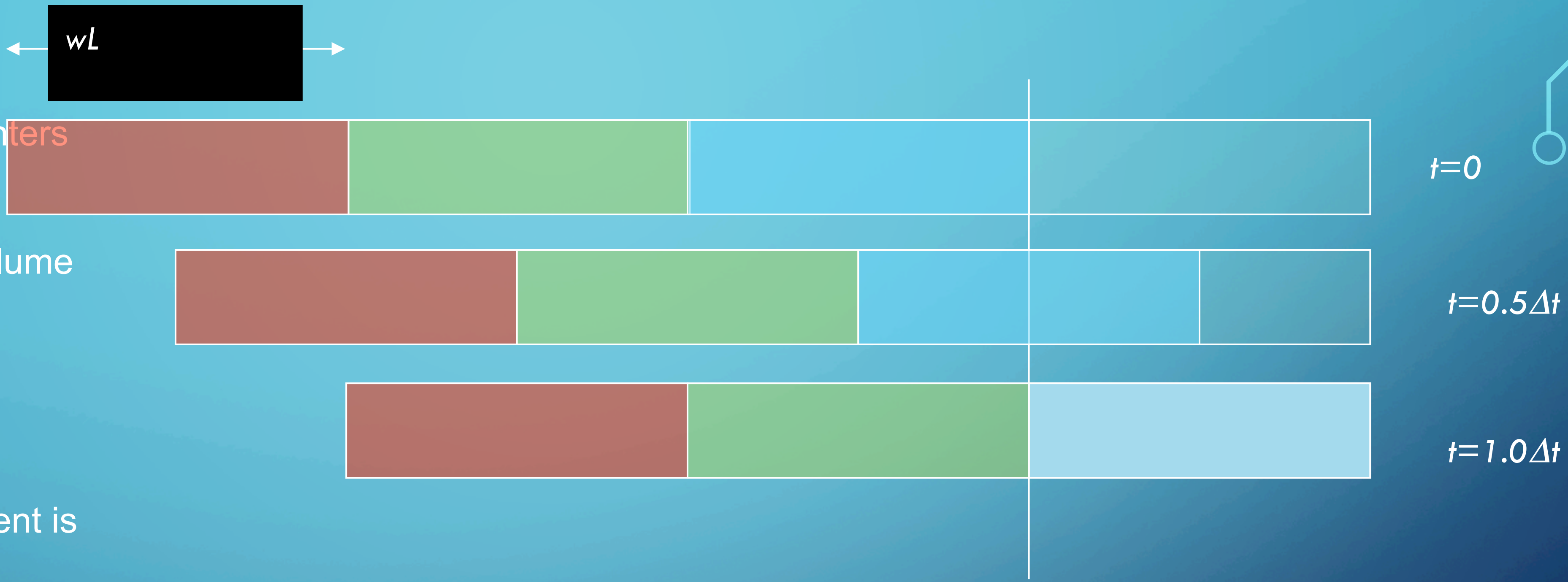
$$\Delta t = L*A/Q$$

Distance traveled by marker is segment length, *L*;
Marker velocity is distance/time

$$u = \frac{Q}{A}$$



# MASS FLUX



Suppose one "blue" volume enters the pipe segment.

The mass of "blue" per unit volume is the concentration of blue.

Let one pipe volume enter the segment.

Total mass of blue in the segment is the concentration*fluid volume

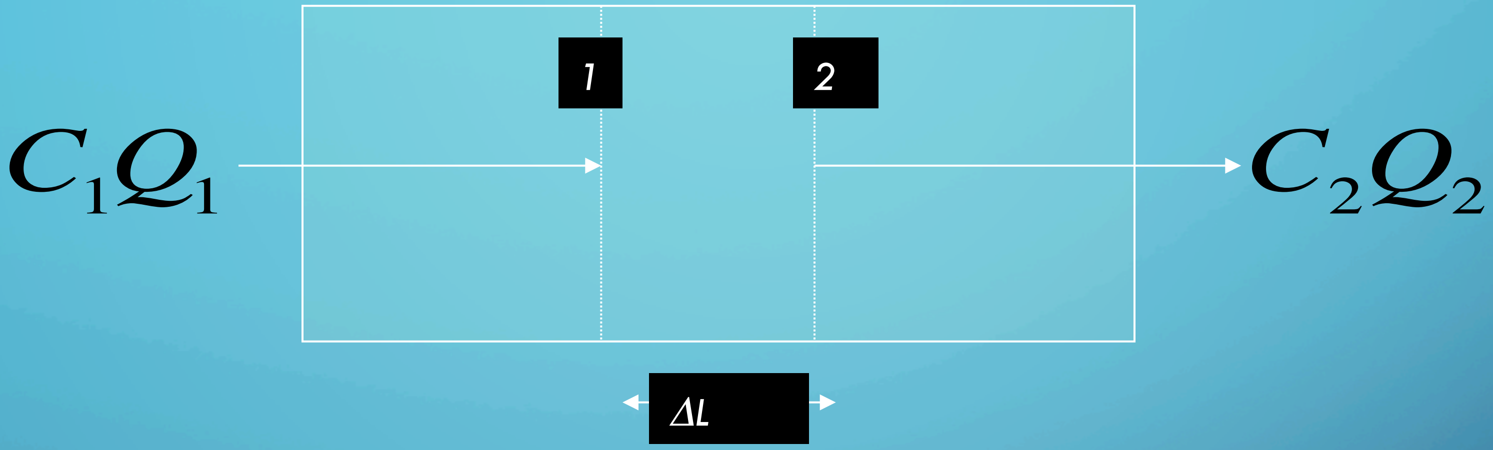
Rate of blue entering the segment is mass/time

$$M_{blue} = ALC_{blue}$$

$$\frac{M_{blue}}{\Delta t} = \frac{ALC_{blue}Q}{AL} = c_{blue}Q$$

# MASS BALANCE

Now consider a small portion of the pipe.



Mass flow into segment.

Mass flow out of segment.

Rate of accumulation in segment.

$$C_1Q_1 \quad - \quad C_2Q_2 \quad = \quad \frac{\partial}{\partial t}\left[CA\Delta L\right]$$

# BALANCE EQUATIONS

For a non-deforming medium this mass balance is expressed as:

$$\frac{C_1Q_1 - C_2Q_2}{A\Delta L} = \frac{\partial C}{\partial t}$$

Substituting the definition of average linear velocity:

$$\frac{C_1u_1 - C_2u_2}{\Delta L} = \frac{\partial C}{\partial t}$$

Taking the limit as $\Delta L$ vanishes produces the fundamental equation governing convective transport.

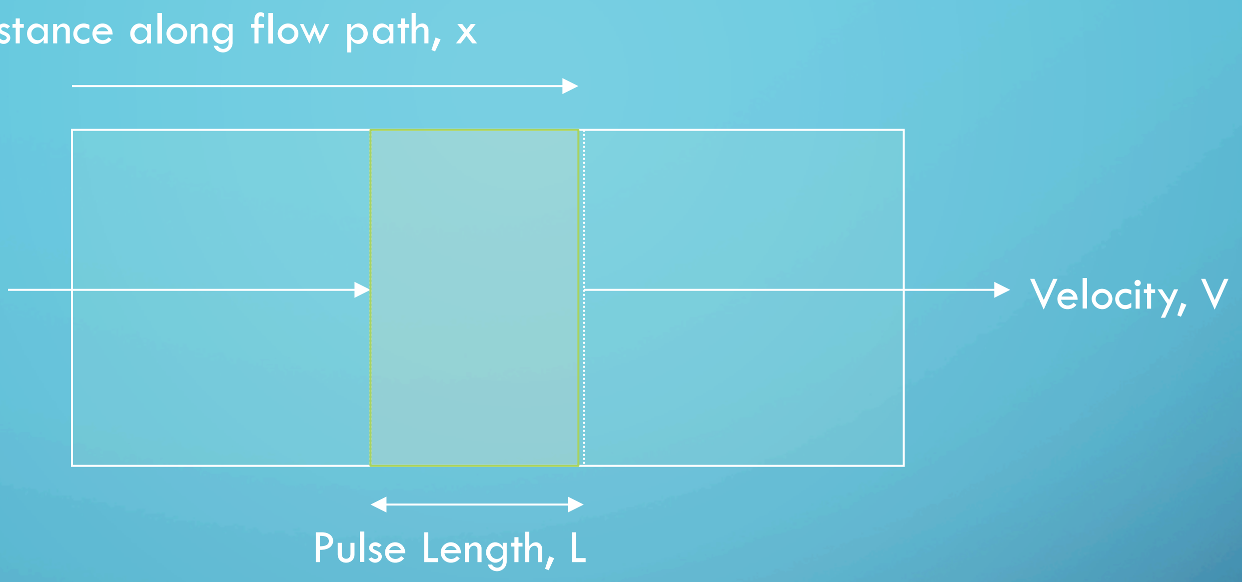
$$-\frac{\partial(uC)}{\partial L} = \frac{\partial C}{\partial t}$$

# GENERALIZATION

$$\frac{\partial C}{\partial t} = -div(\vec{U}C)$$

- Express last term in more conventional form – divergence of the mass flux is equal to the rate of change of concentration at a point.
- Observe the obvious dependence on the velocity field *(u,v,w).*
- In order to compute any mass fluxes we must first determine the velocity values in the domain of interest.

# ANALYTICAL MODEL



- Water at a constant velocity, *V* , is flowing through the zone carrying the dissolved component at a specific concentration, $C_o$.
- There is no degradation of the component, no dispersion of the component, nor is there any interaction with the solid phase (walls).
- The zone translates in space at a rate determined by the water velocity.
- The contaminant is dissolved, and does not alter the density of the flowing water.
- The contaminant is assumed to be uniformily mixed in contaminated zone.

# GOVERNING EQUATIONS, INITIAL, AND BOUNDARY CONDITIONS

The governing equation of mass transport for this case is:

$$\frac{\partial C}{\partial t} = -v\frac{\partial C}{\partial x}$$

The initial conditions throughout the pipe segment are:

$$C(x,t) = 0 \text{ for all } t \geq \frac{L}{v}, x = 0$$

$$C(x,t) = C_o \text{ for all } t \geq 0, t \leq \frac{L}{v} \text{ at } x = 0$$

$$C(x,t) = 0 \text{ for all } x > 0, t = 0$$

The boundary conditions at the source are:

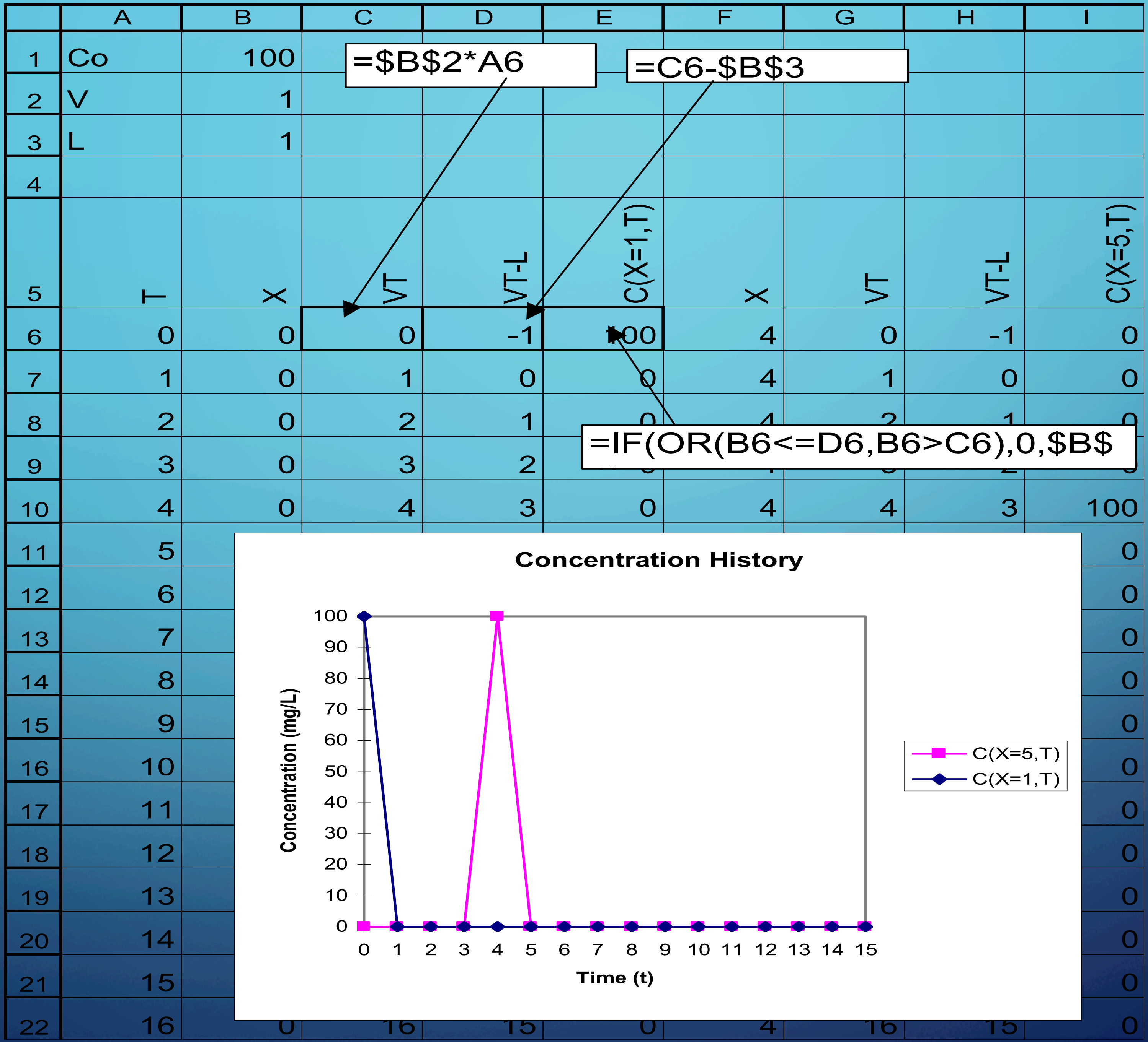
$$C(x,t) = 0 \text{ for } t \leq 0; x \notin [-L,0]$$

The solution for this case is:

$$C(x,t) = 0 \text{ when } x \leq vt - L$$

$$C(x,t) = C_o \text{ when } vt - L \leq x \leq vt$$

$$C(x,t) = 0 \text{ when } x > vt$$



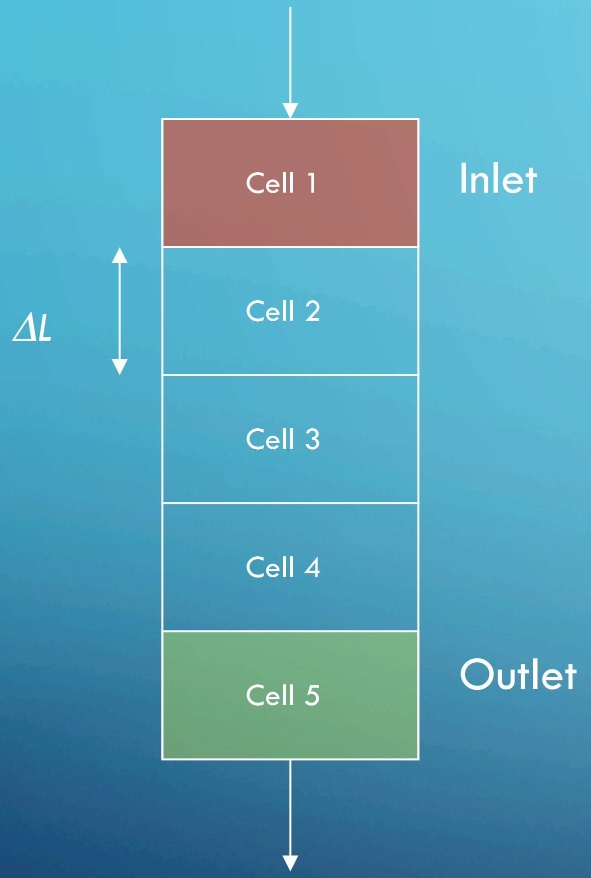
=$B$2*A6

=C6-$B$3

=IF(OR(B6<=D6,B6>C6),0,$B$

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Co | 100 | | | | | | | |
| 2 | V | 1 | | | | | | | |
| 3 | L | 1 | | | | | | | |
| 4 | | | | | | | | | |
| 5 | T | X | VT | VT-L | C(X=1,T) | X | VT | VT-L | C(X=5,T) |
| 6 | 0 | 0 | 0 | -1 | 100 | 4 | 0 | -1 | 0 |
| 7 | 1 | 0 | 1 | 0 | 0 | 4 | 1 | 0 | 0 |
| 8 | 2 | 0 | 2 | 1 | 0 | 4 | 2 | 1 | 0 |
| 9 | 3 | 0 | 3 | 2 | | | | | |
| 10 | 4 | 0 | 4 | 3 | 0 | 4 | 4 | 3 | 100 |
| 11 | 5 | | | | | | | | 0 |
| 12 | 6 | | | | | | | | 0 |
| 13 | 7 | | | | | | | | 0 |
| 14 | 8 | | | | | | | | 0 |
| 15 | 9 | | | | | | | | 0 |
| 16 | 10 | | | | | | | | 0 |
| 17 | 11 | | | | | | | | 0 |
| 18 | 12 | | | | | | | | 0 |
| 19 | 13 | | | | | | | | 0 |
| 20 | 14 | | | | | | | | 0 |
| 21 | 15 | | | | | | | | 0 |
| 22 | 16 | 0 | 16 | 15 | 0 | 4 | 16 | 15 | 0 |

# CELL BALANCE MODEL APPROACH

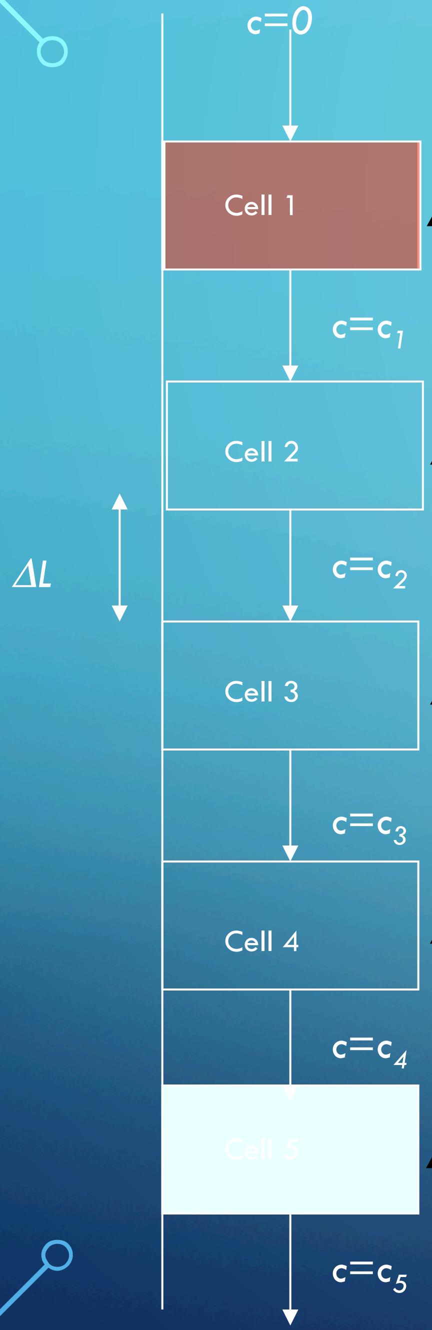


Suppose at t=0 the concentration in the inlet cell is Co. We want to determine the concentration in the pipe segment at future times.

We will assume the velocity is identical throughout the column.

A simple modeling approach is to treat each cell as completely mixed.

This means that the concentration at the cell exit is identical to the concentration in the cell.



c=0

Cell 1

$c=c_1$

Cell 2

$\Delta L$

$c=c_2$

Cell 3

$c=c_3$

Cell 4

$c=c_4$

Cell 5

$c=c_5$

$$\Delta C_1 = u\frac{\Delta t}{\Delta L}(C_o - C_1)$$

$$\Delta C_2 = u\frac{\Delta t}{\Delta L}(C_1 - C_2)$$

$$\Delta C_3 = u\frac{\Delta t}{\Delta L}(C_2 - C_3)$$

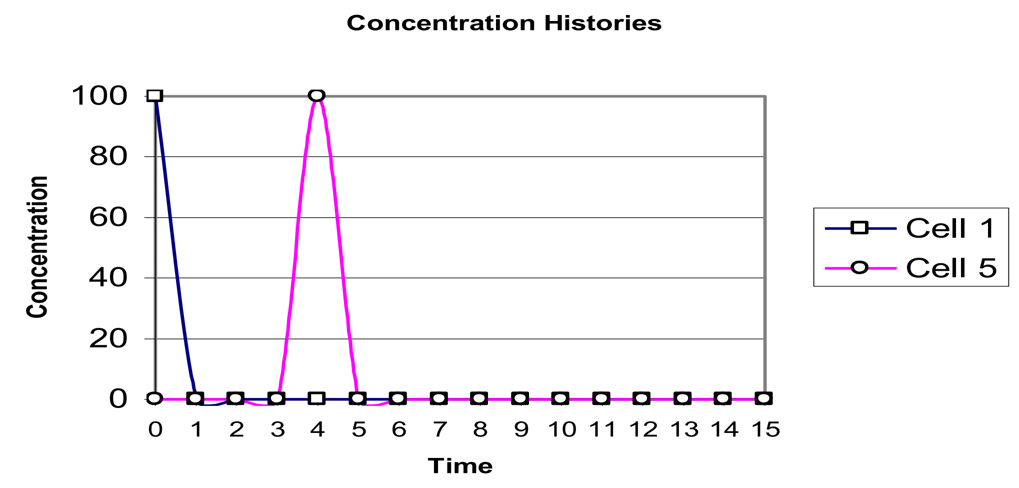
$$\Delta C_4 = u\frac{\Delta t}{\Delta L}(C_3 - C_4)$$

$$\Delta C_5 = u\frac{\Delta t}{\Delta L}(C_4 - C_5)$$

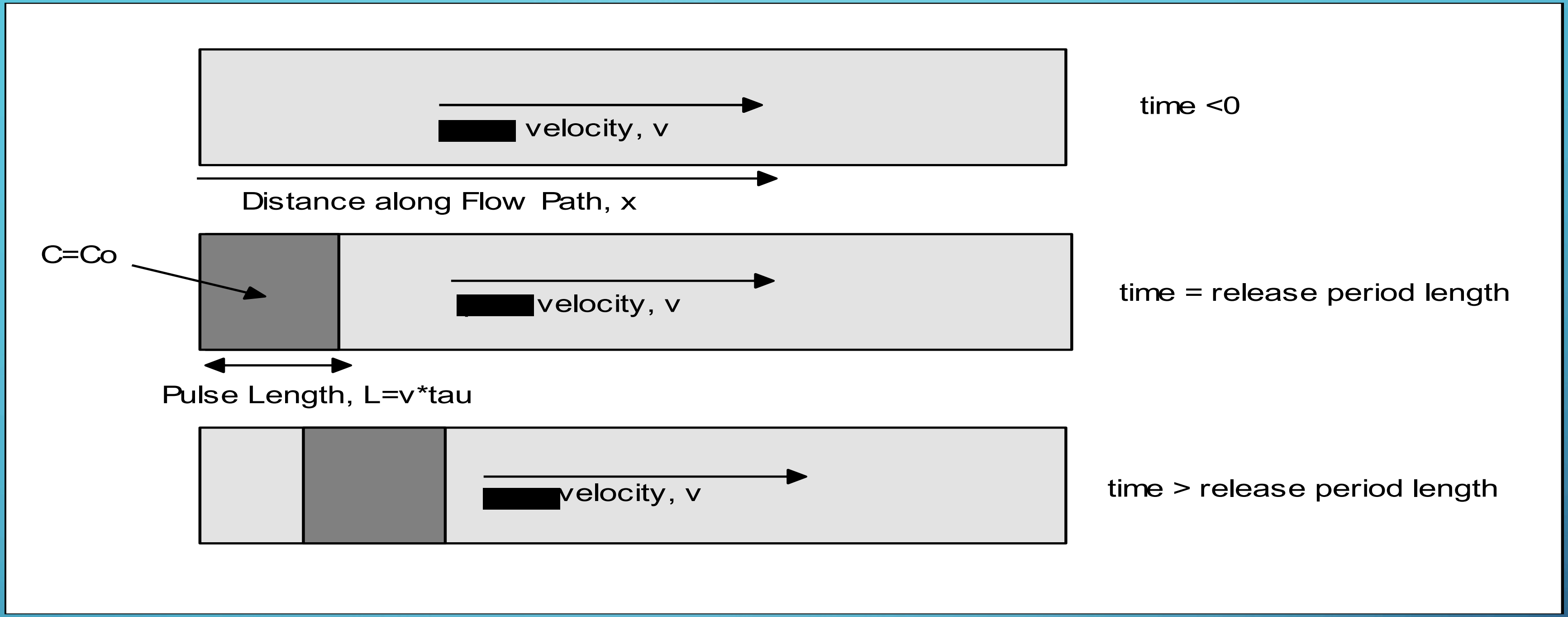
$$\frac{C_{in}u_{in} - C_{out}u_{out}}{\Delta L} = \frac{\Delta C}{\Delta t}$$

=C5+($B$1*$B$3/$B$2)*(B5-C5)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | *u* | 1 | *Co* | 100 | | |
| 2 | Δ *L* | 1 | | | | |
| 3 | Δ *t* | 1 | | | | |
| 4 | *t* | Cell 1 | Cell 2 | Cell 3 | Cell 4 | Cell 5 |
| 5 | 0 | 100 | 0 | 0 | 0 | 0 |
| 6 | 1 | 0 | 100 | 0 | 0 | 0 |
| 7 | 2 | 0 | 0 | 100 | 0 | 0 |
| 8 | 3 | 0 | 0 | 0 | 100 | 0 |
| 9 | 4 | 0 | 0 | 0 | 0 | 100 |
| 10 | 5 | 0 | 0 | 0 | 0 | 0 |
| 11 | 6 | | | | | 0 |
| 12 | 7 | | | | | 0 |
| 13 | 8 | | | | | 0 |
| 14 | 9 | | | | | 0 |
| 15 | 10 | | | | | 0 |
| 16 | 11 | | | | | 0 |
| 17 | 12 | | | | | 0 |
| 18 | 13 | 0 | 0 | 0 | 0 | 0 |
| 19 | 14 | 0 | 0 | 0 | 0 | 0 |
| 20 | 15 | 0 | 0 | 0 | 0 | 0 |



# TIMED RELEASE CASE



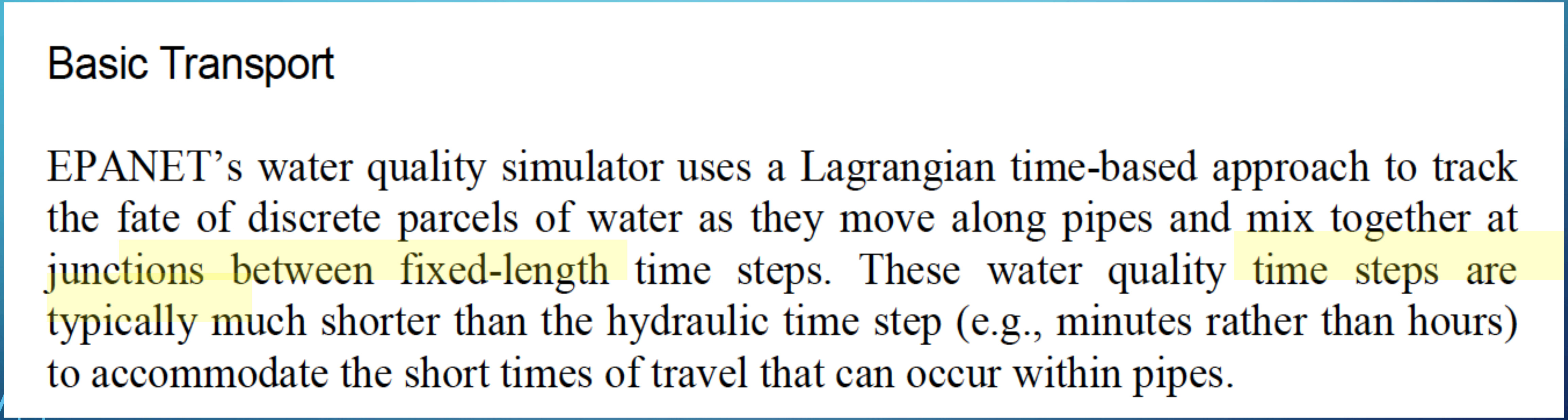
- At the origin (*x=0*) a contaminant is added to the flowing water at fixed concentration $C_o$ for a period of time t.
- At the end of the time period the contaminant addition is stopped.
- By the end of the time period a "parcel" of contaminated water is created.
- Mechanism of release does not disturb the local flow field in any fashion.
- Contaminant is assumed to be uniformily mixed in the parcel (zone)

# SOLUTION

$$C(x,t) = 0 \text{ when } x \le vt - v\tau$$
$$C(x,t) = C_o \text{ when } vt - v\tau \le x \le vt$$
$$C(x,t) = 0 \text{ when } x > vt$$

- Solution identical to first case.
- Substitute $v\tau = L$ into the previous solution.

# IN EPANET HOW THESE ARE IMPLEMENTED



## Basic Transport

EPANET's water quality simulator uses a Lagrangian time-based approach to track the fate of discrete parcels of water as they move along pipes and mix together at junctions between fixed-length time steps. These water quality time steps are typically much shorter than the hydraulic time step (e.g., minutes rather than hours) to accommodate the short times of travel that can occur within pipes.

# MIXING AT NODE

- When parcels (concentration) reaches a node where there are multiple mass fluxes, a flow-weighted mixing model is used to compute the concentration at that node (which will become a new $C_0$ for any downstream links)

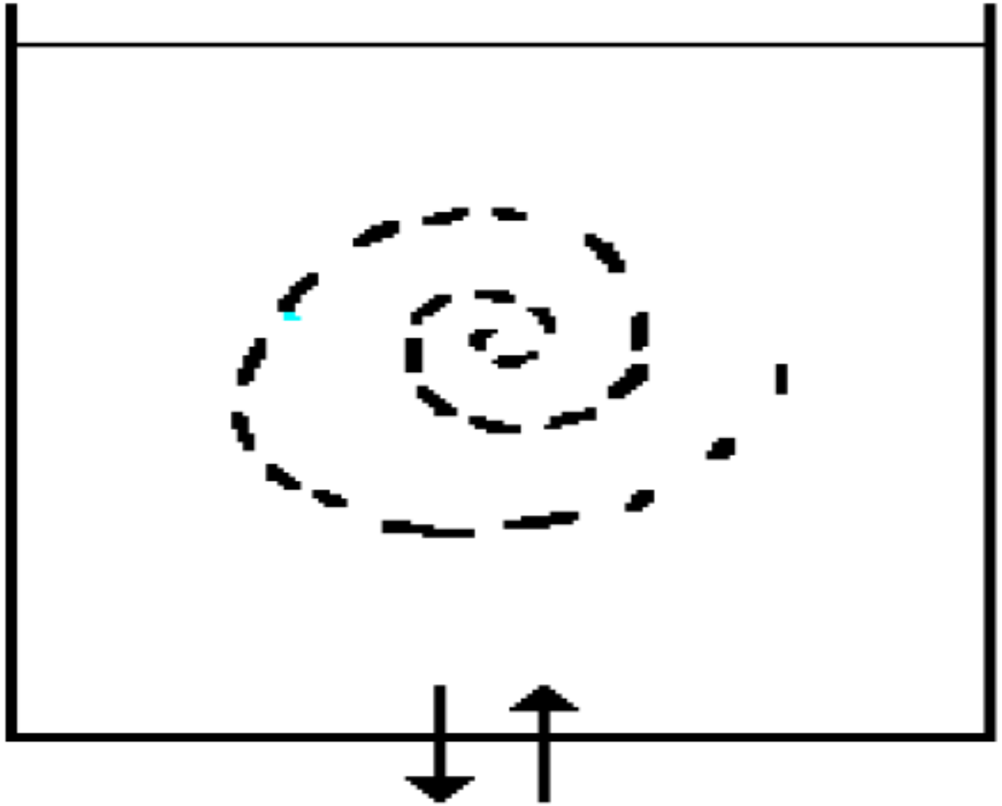
$$C_{out} = \frac{\sum C_{in} Q_{in}}{\sum Q_{in}}$$

# MIXING IN A TANK

- Tank mixing is handled by four possible models:
  - Completely mixed (CFSTR)
  - Two-Compartment Mixing
  - FIFO Plug Flow
  - LIFO Plug Flow

# COMPLETELY MIXED

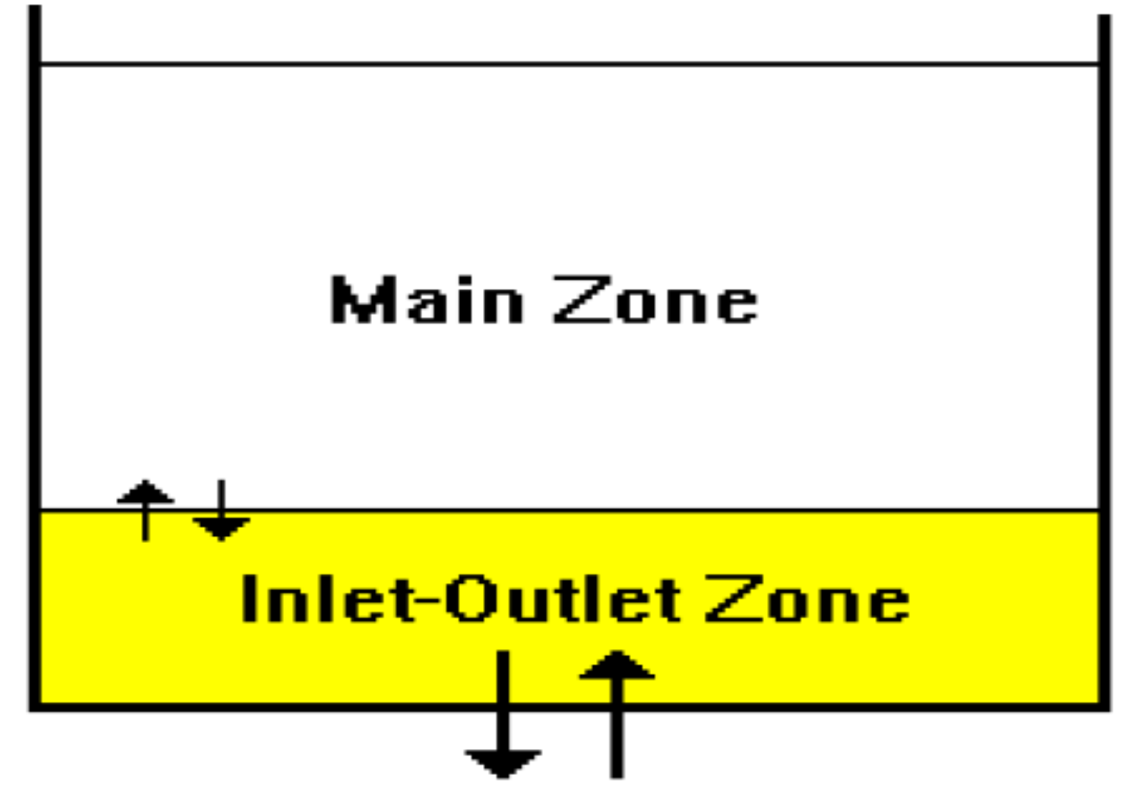
- All water entering tank instantly and completely mixes
    - Reasonable for small tanks, or hydraulic time steps that are long compared to transport time steps



(A) Complete Mixing

# TWO-COMPARTMENT MIXING

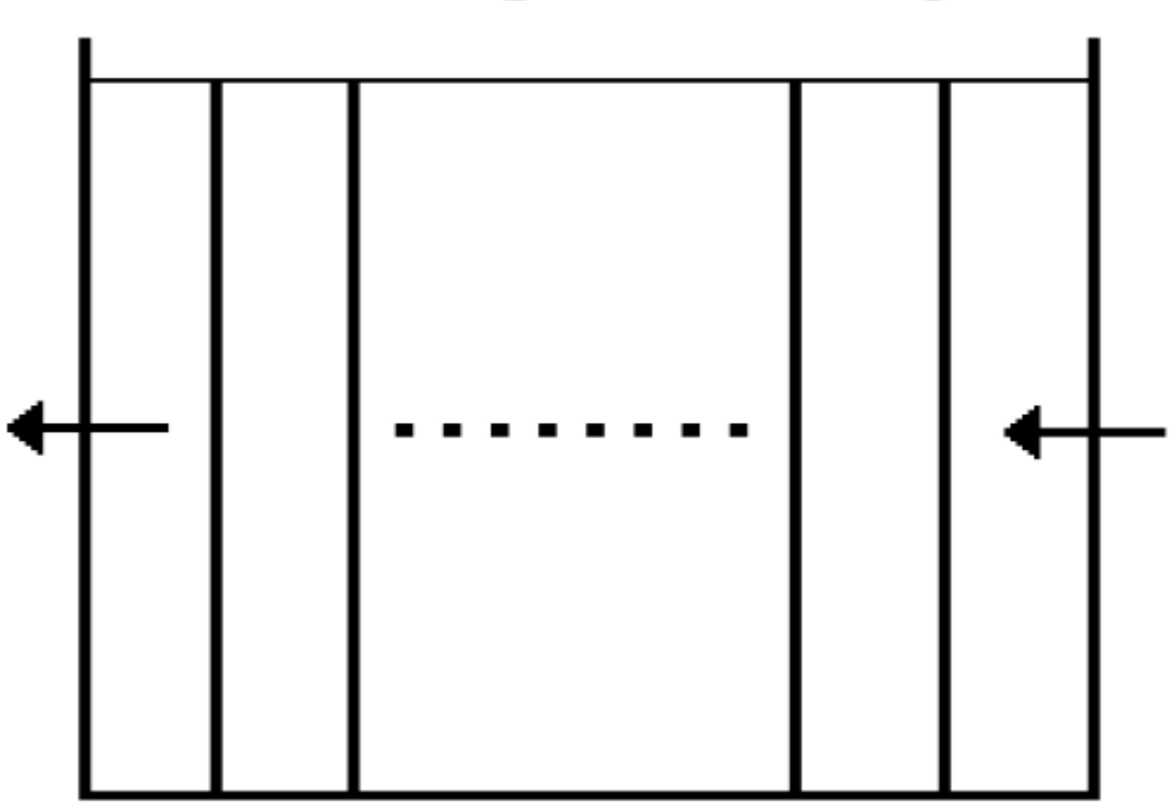
- Tank storage divided into two compartments
    - Inlet/Outlet zone
    - Main Zone
- When Inlet/Outlet zone is filled, then spills into main zone



(B) Two-Compartment Mixing

# FIFO MIXING

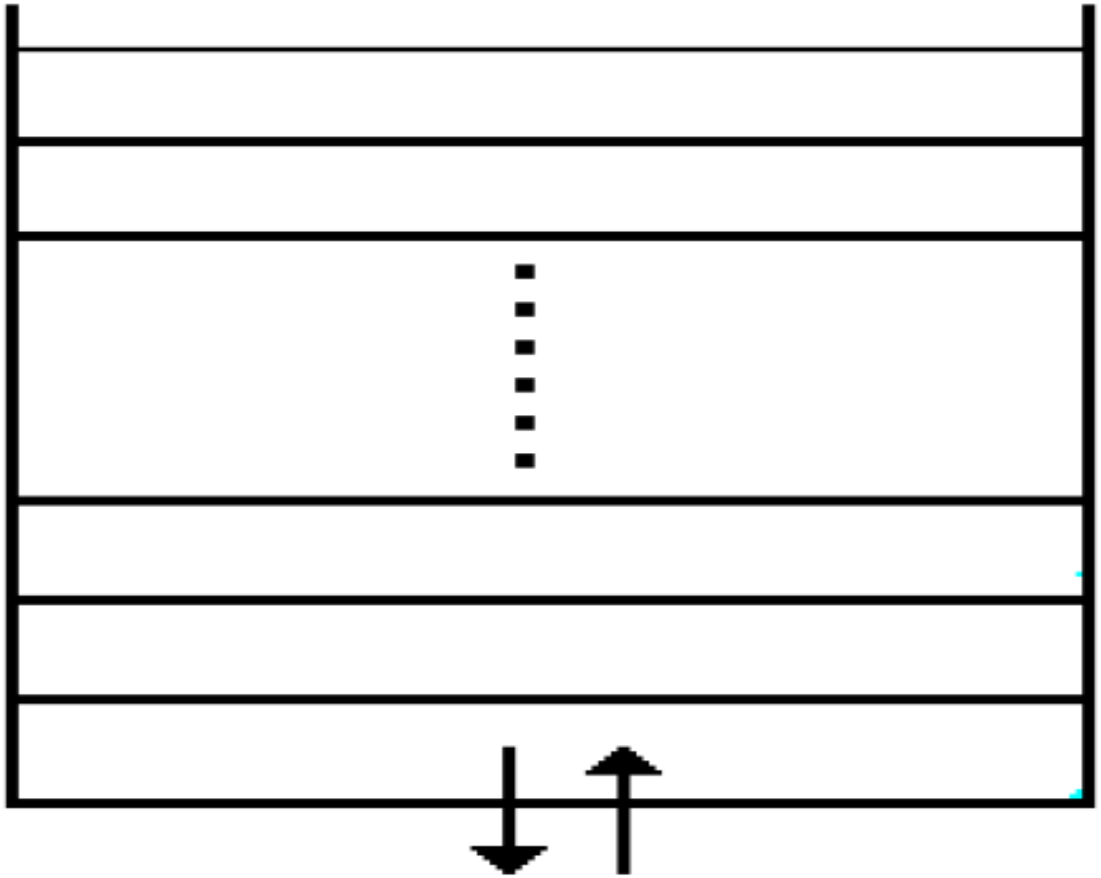
- The first parcel (volume) of water to enter the tank, is first parcel to leave
- Essentially plug-flow in the tank



(C) Plug Flow - FIFO

# LIFO MIXING

- The last (most recent) parcel (volume) of water to enter the tank, is first parcel to leave
- Essentially stratified-flow in the tank



(D) Plug Flow - LIFO

# WATER QUALITY REACTIONS

- Bulk reactions (in the parcel)
- Wall reactions (at the parcel, pipe-wall interface)

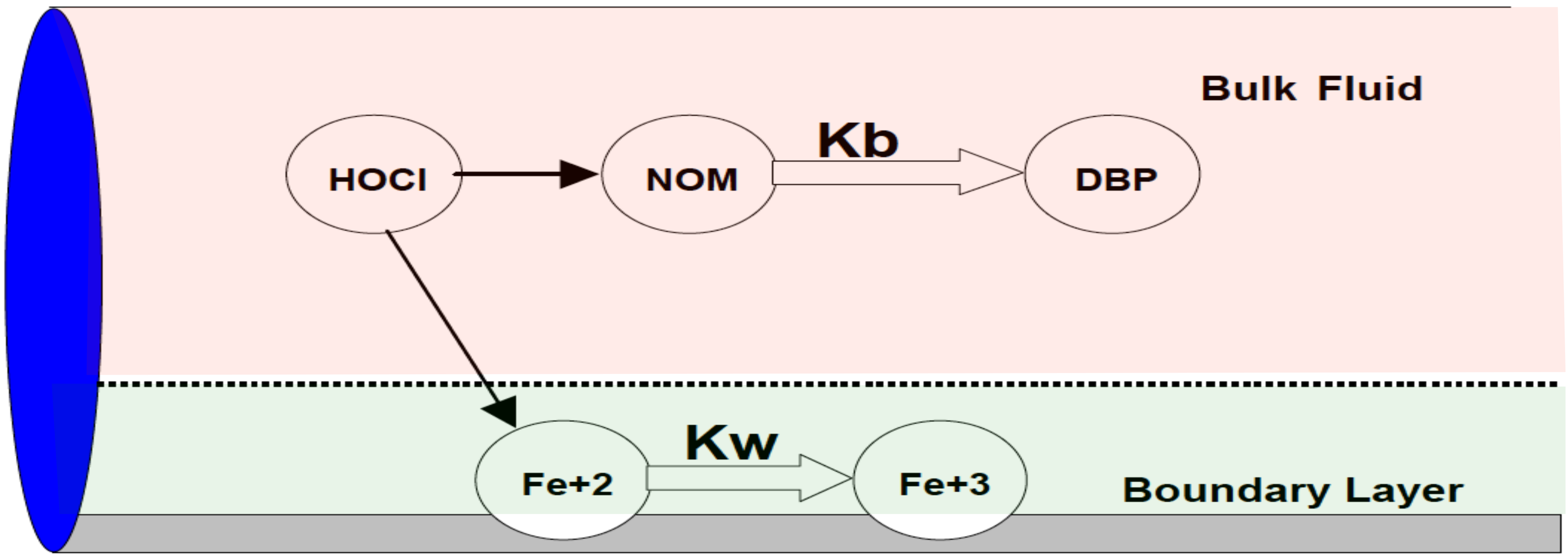


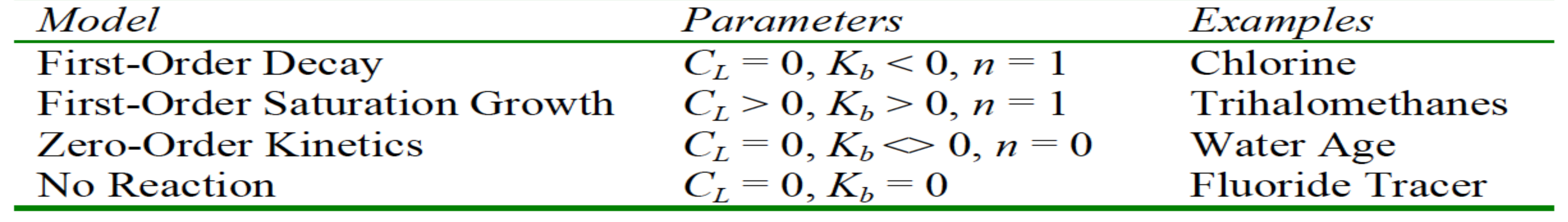
**Figure 3.6** Reaction Zones Within a Pipe

# BULK REACTIONS

- Growth and decay of constituent in the bulk phase (parcel)
- Uses choice of
- No reaction
- Zero-Order kinetics
- 1-st Order Decay
- 1-st Order Saturation

$$\frac{\partial C}{\partial t} = -div(\vec{U}C) + r(C)$$

$$r(C) = \begin{cases} K_b C^n \\ K_b(C_L - C) \\ K_b C(C - C_L) \\ \dfrac{K_b C}{C_L - C} \end{cases}$$



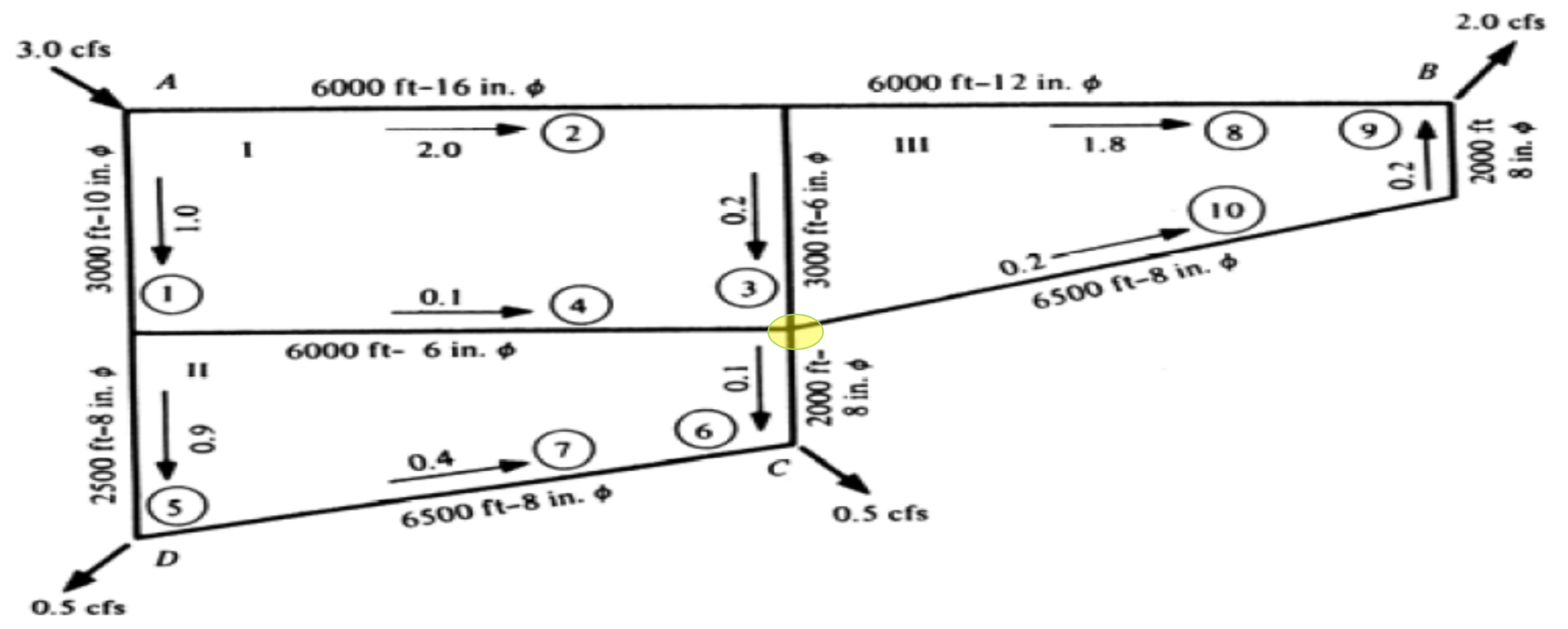
| *Model* | *Parameters* | *Examples* |
|---|---|---|
| First-Order Decay | $C_L = 0$, $K_b < 0$, $n = 1$ | Chlorine |
| First-Order Saturation Growth | $C_L > 0$, $K_b > 0$, $n = 1$ | Trihalomethanes |
| Zero-Order Kinetics | $C_L = 0$, $K_b <> 0$, $n = 0$ | Water Age |
| No Reaction | $C_L = 0$, $K_b = 0$ | Fluoride Tracer |

# WALL REACTIONS

- Handled in similar fashion – generally a secondary  reaction term based on location in the network

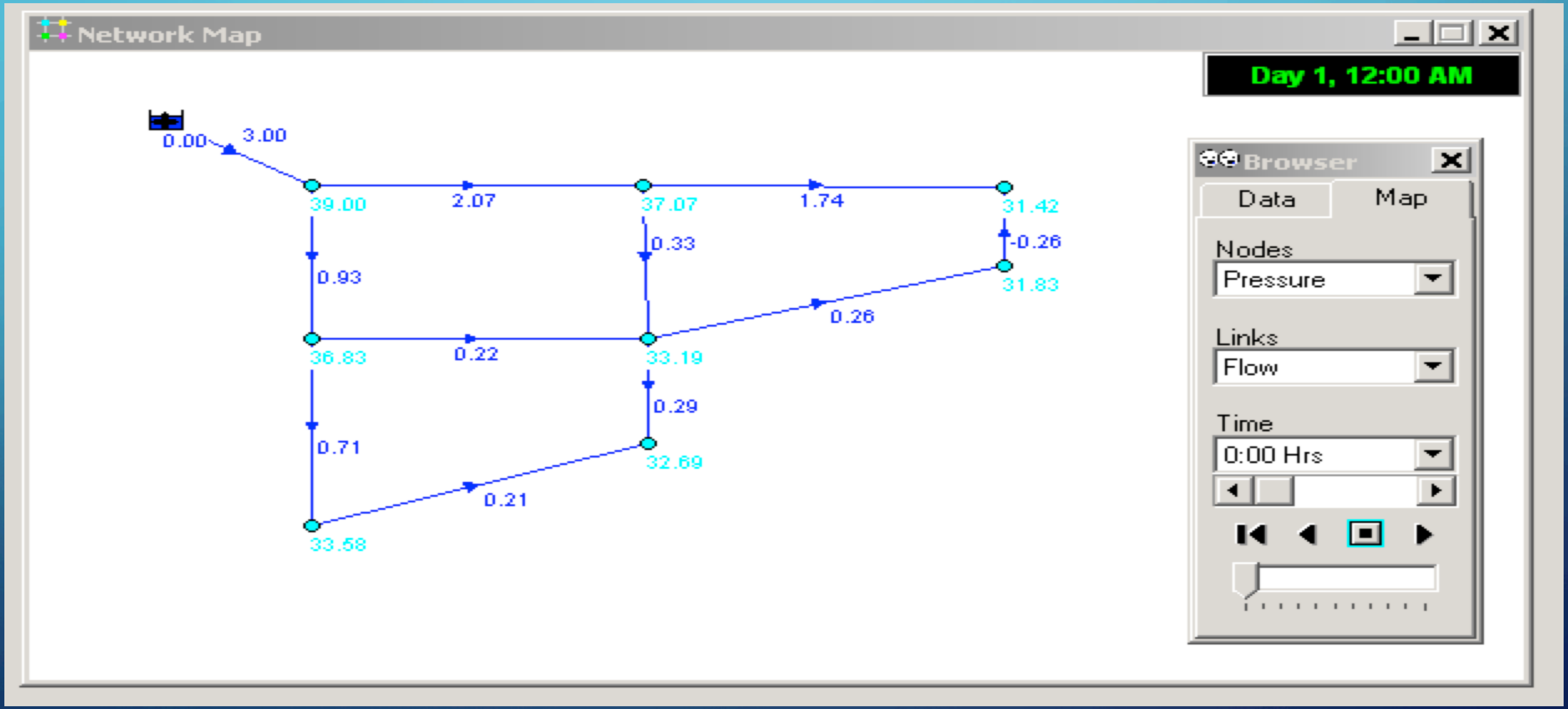
# EXAMPLE

- What is the disinfection residual in the system below if the source water has chloramine at 10 mg/L and the first-order decay mass transfer coefficient ($K_b$) is -5?



# EXAMPLE

- What is the disinfection residual in the system below if the source water has chloramine at 10 mg/L and the first-order decay mass transfer coefficient ($K_b$) is -5



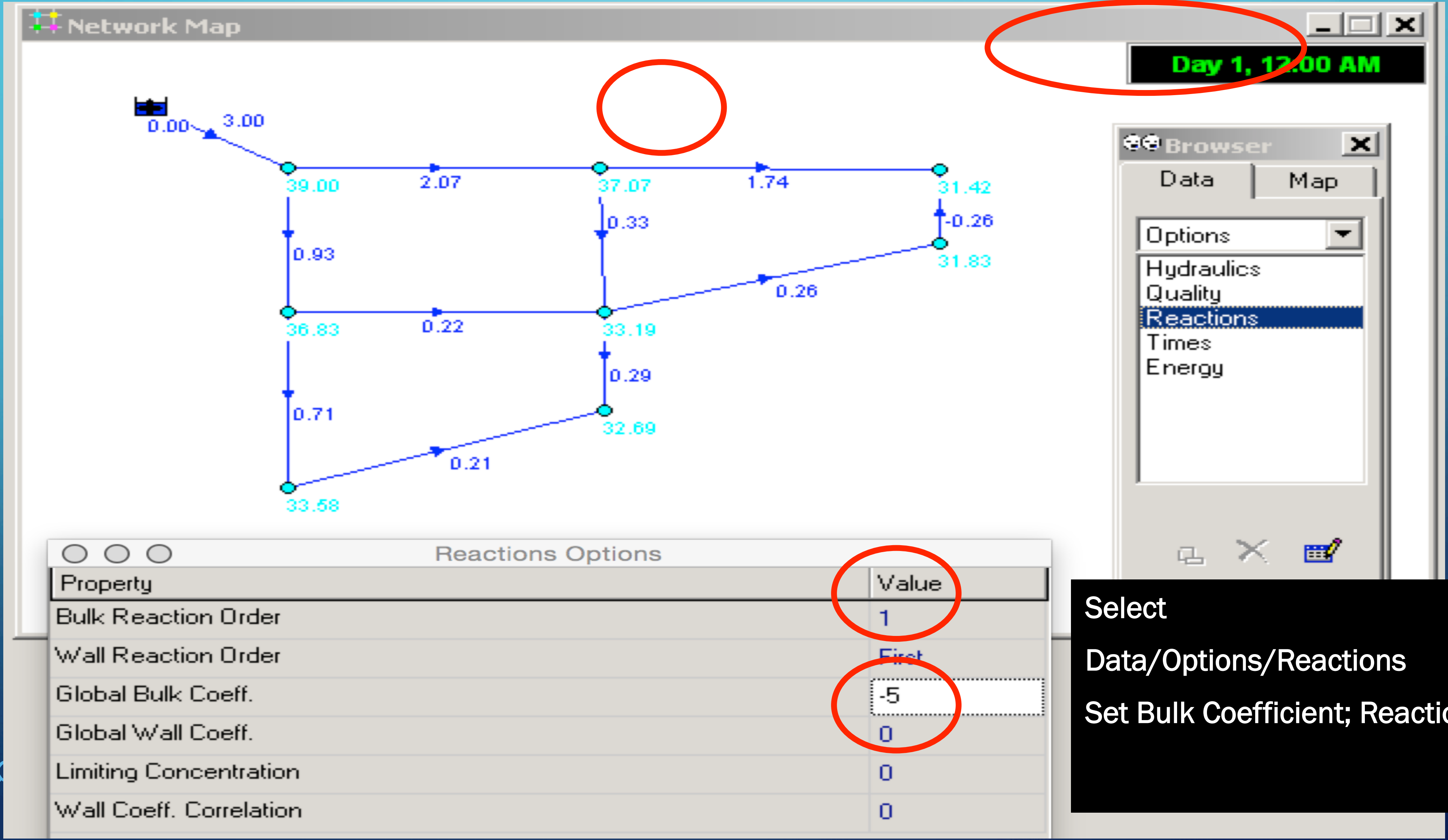
Day 1, 12:00 AM

Nodes: Pressure

Links: Flow

Time: 0:00 Hrs

# EXAMPLE



Reactions Options

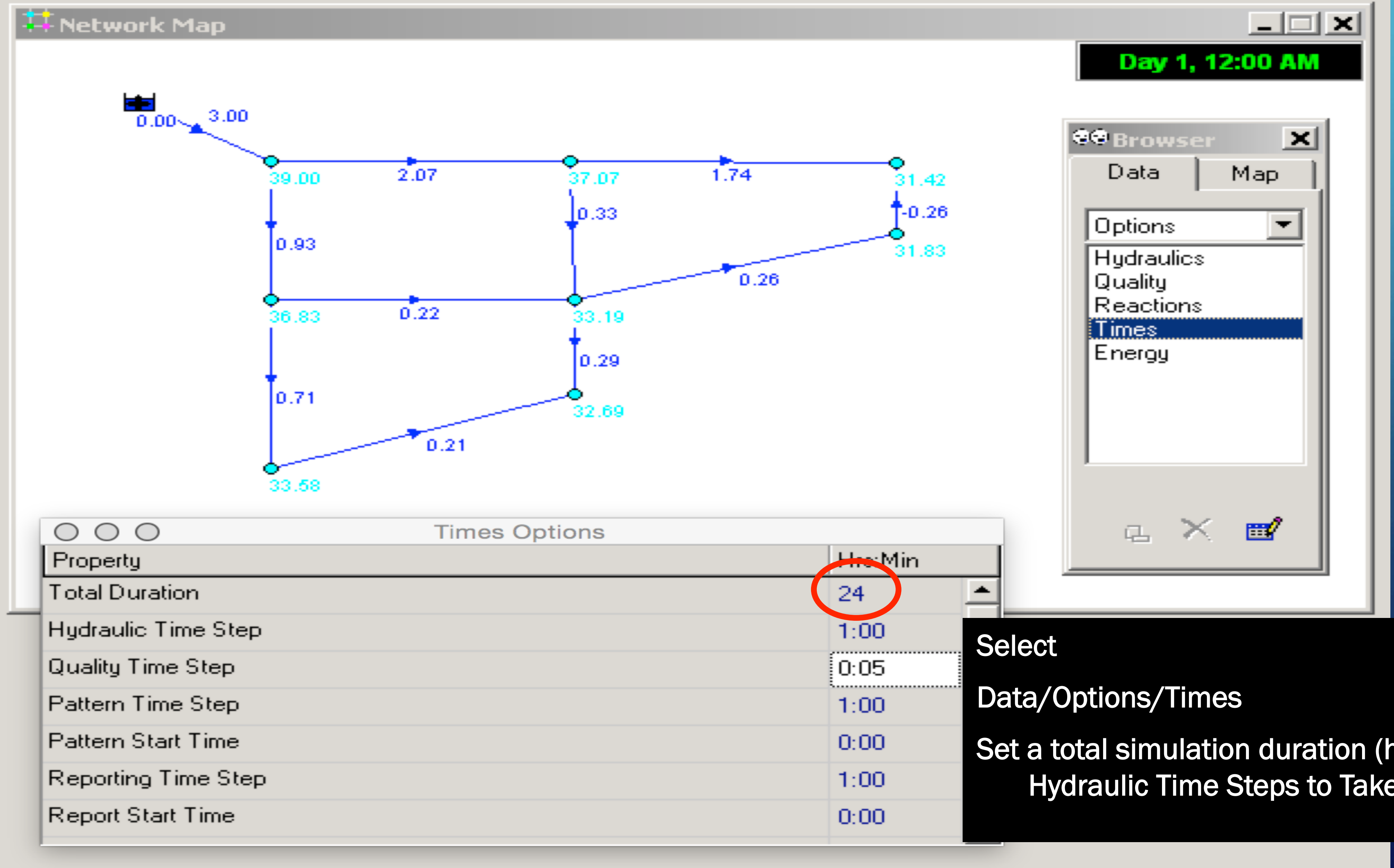
| Property | Value |
|---|---|
| Bulk Reaction Order | 1 |
| Wall Reaction Order | First |
| Global Bulk Coeff. | -5 |
| Global Wall Coeff. | 0 |
| Limiting Concentration | 0 |
| Wall Coeff. Correlation | 0 |

Select

Data/Options/Reactions

Set Bulk Coefficient; Reaction Order

# EXAMPLE



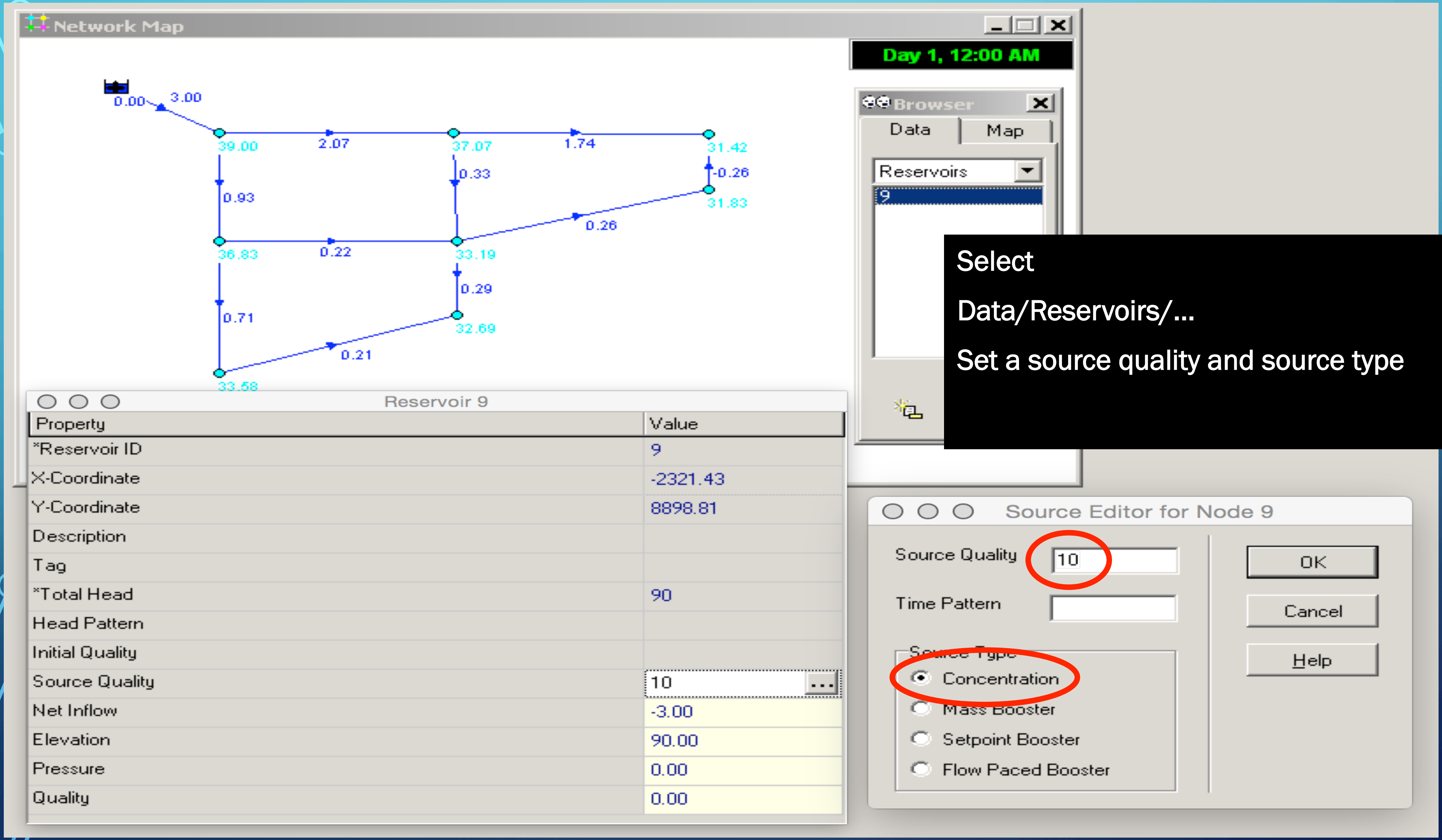
| Property | Hrs:Min |
|---|---|
| Total Duration | 24 |
| Hydraulic Time Step | 1:00 |
| Quality Time Step | 0:05 |
| Pattern Time Step | 1:00 |
| Pattern Start Time | 0:00 |
| Reporting Time Step | 1:00 |
| Report Start Time | 0:00 |

Select

Data/Options/Times

Set a total simulation duration (how many Hydraulic Time Steps to Take

# EXAMPLE



Select

Data/Reservoirs/…

Set a source quality and source type

Reservoir 9

| Property | Value |
|---|---|
| *Reservoir ID | 9 |
| X-Coordinate | -2321.43 |
| Y-Coordinate | 8898.81 |
| Description | |
| Tag | |
| *Total Head | 90 |
| Head Pattern | |
| Initial Quality | |
| Source Quality | 10 |
| Net Inflow | -3.00 |
| Elevation | 90.00 |
| Pressure | 0.00 |
| Quality | 0.00 |

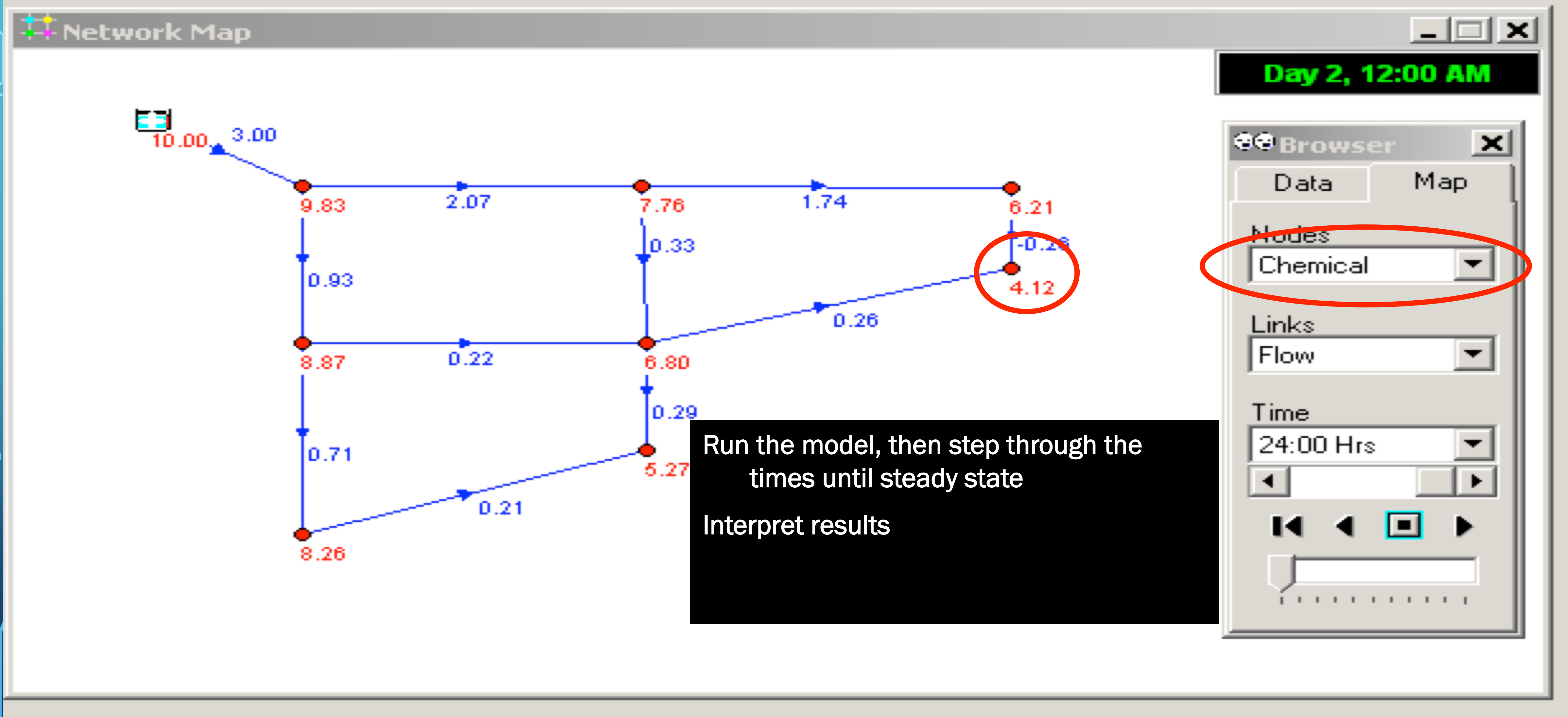
Source Editor for Node 9

Source Quality: 10

Time Pattern:

Source Type
- ● Concentration
- ○ Mass Booster
- ○ Setpoint Booster
- ○ Flow Paced Booster

# EXAMPLE



Nodes: Chemical

Links: Flow

Time: 24:00 Hrs

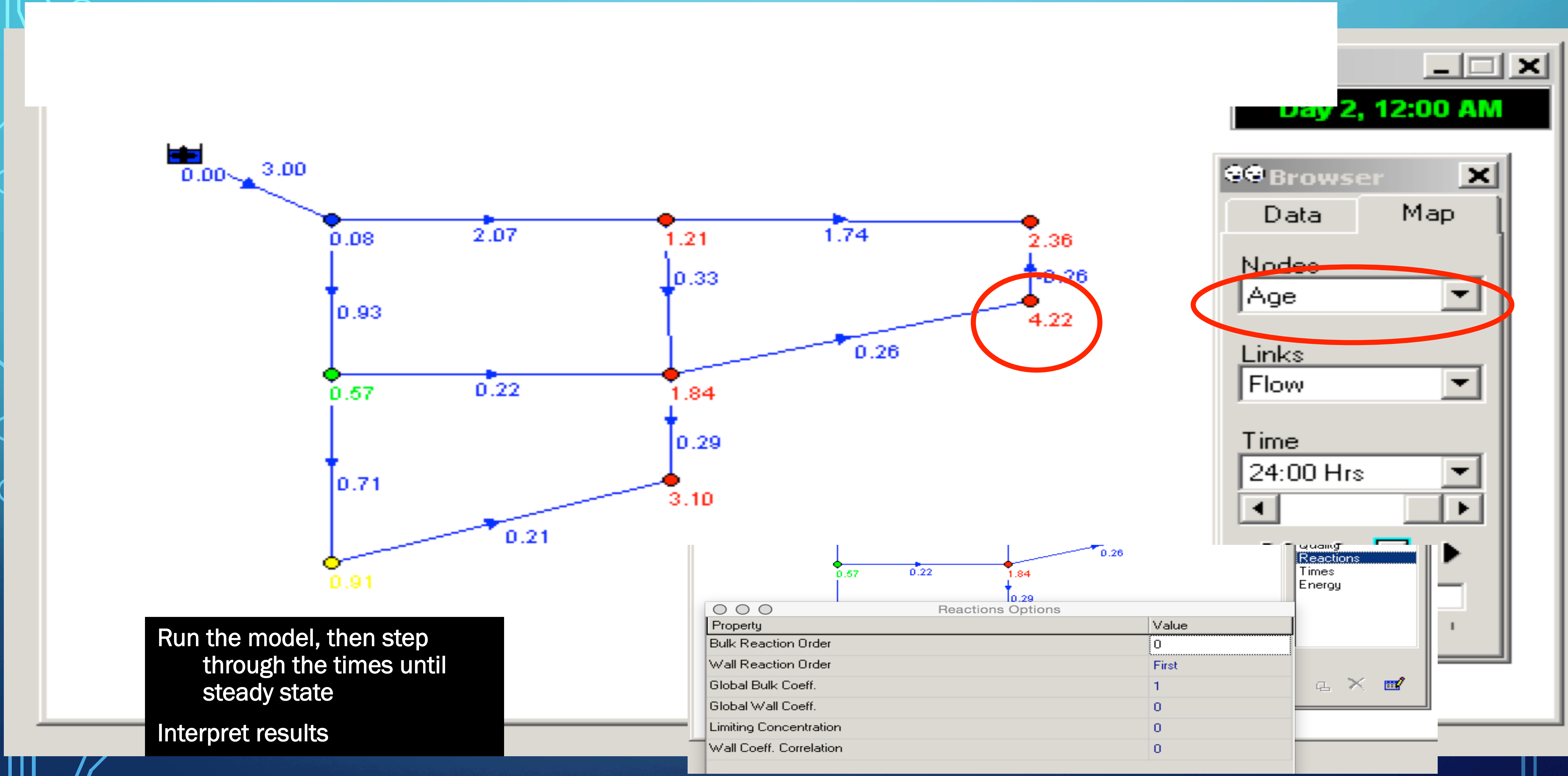
Run the model, then step through the times until steady state

Interpret results

# ADDITIONAL CONCEPTS

- A “tracer” can be used to estimate water age in the system (its treated as a different constituent)
- Use Zero-Order reaction with $K_b = 1$; resulting “concentration” is water age in Hydraulic Time Steps
- Multiple sources can be used to estimate mixing in a system (homework)
- Intrusions of contaminants can be modeled (inject a dose at a node, and see where it arrives).

# EXAMPLE



Reactions Options

| Property | Value |
|---|---|
| Bulk Reaction Order | 0 |
| Wall Reaction Order | First |
| Global Bulk Coeff. | 1 |
| Global Wall Coeff. | 0 |
| Limiting Concentration | 0 |
| Wall Coeff. Correlation | 0 |

Run the model, then step through the times until steady state

Interpret results

# NEXT TIME

- Open Channel Flow
    - Uniform flow
    - Gradually Varied Flow
    - Hydraulic Elements