APPENDIX B

Example applications of GSTARS4

Table of contents for Appendix B

Note: The set of examples presented in this appendix are prepared to show the user how to set-up input data file for GSTARS4. Examples 1~5 are field studies carried out using the previous version GSTARS3 or earlier versions, and they can be found in the User's Manual for GSTARS3 also. Examples 6~8 contains unsteady flow simulations which can not be run by earlier versions. Examples should not be used for any other purpose without appropriate verification and validation of the input data and of the computed results.

GSTARS4 is in a stage of constant evolution and is subject to change without notice. Because of that, and because of the time lag between the writing of this manual and its actual typesetting and publication, there may be some differences between the released version of GSTARS4 and the version that was used to run the examples. As a result, there may be slight differences between the printed output presented in this appendix and the actual output generated by GSTARS4.

EXAMPLE 1

LAKE MESCALERO SPILLWAY CHANNEL

This example shows how to apply the concepts of bank stability and total stream power minimization implemented in GSTARS4. Together, these two concepts allow the computation of channel width variation and river meandering while maintaining the proper angle of repose of the river banks. To illustrate these features we use data from a study conducted on Lake Mescalero Dam and Dike. The study was performed by Song et al. (1995) using an earlier version of GSTARS. Their data was adopted, with modifications, for inclusion as an example in this manual.

The Lake Mescalero Dam and Dike were constructed in 1974 and are located at the confluence of Ciewegita and Carrige Creeks on the Mescalero Apache Indian Reservation about 2.5 miles southwest of Ruidoso, New Mexico. In this example we use data from the channel immediately downstream from the emergency spillway. The spillway is located in a bedrock cut in the sandstone and shale of the left abutment of the dam. The spillway consists of a 290-ft long approach channel, a 103.8-ft wide concrete weir, a 138-ft long concrete-lined discharge chute, a 15-ft long flip bucket, and a concrete erosion cutoff wall located about 250 ft downstream from the flip bucket. The spillway crest rises 5.0 ft above the spillway approach channel floor and the discharge chute floor, to a crest elevation of 6905.0 ft.

The data of the flood period of 20 December 1984 through 31 December 1984 is used in this example. The water surface elevation of the reservoir is available for that period. Cross-sectional data is taken from a detailed topographic survey of the study area carried out on 12 June 1979. Figure 1.1 shows the layout of the channel below the spillway at that time. Also, limited cross-sectional channel geometry is available after the 1984 flood. One of these sections is used later for comparison purposes.

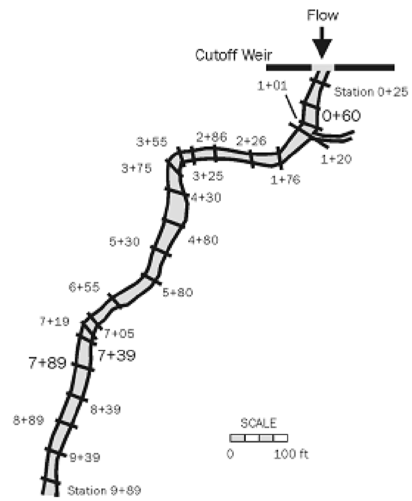

Figure 1.1 Plan view of the channel below spillway used in this example datafile.

The water surface elevation of the reservoir is available for the period of the flood. The discharge hydrograph was generated using the water levels and a standard weir equation, $Q = CLH^{3/2}$ with $C = 3.65$. The flood hydrograph is shown in figure 1.2.

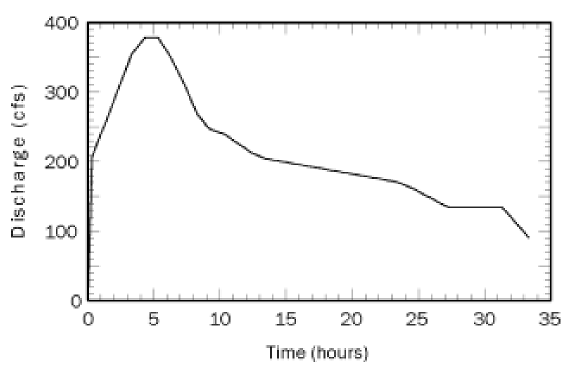

Figure 1.2 Spillway hydrograph for the December 1984 flood.

The sediment data used is based on bed samples collected from several sites along the channel. Two typical size distributions are plotted in figure 1.3. Based on the mean sediment size, a Manning's roughness coefficient of 0.06 is chosen for the stage-discharge computations.

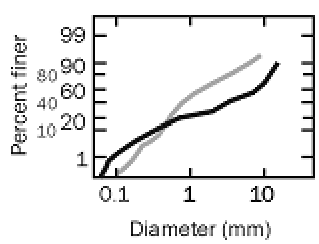

Figure 1.3 Typical sediment particle size distributions collected in the spillway channel.

1.1 Input Data File

The files shown in this and the next sections are part of the main GSTARS4 distribution package. They can be found under directory Example1.

```
TT  GSTARS version 4.0  -  Example data file for Appendix B of user's manual
TT  Lake Mescalero Dam Spillway  -  St. Anthony Falls data file
TT  Stream power minimization calculations with bank stability routine
*****************************************************************************
***                                                                       ***
***  NOTE: this is a simplified version of the datafile used to simulate  ***
***  the Lake Mescalero spillway.  It may not represent the actual flow and ***
***  geological conditions at the site, and is used here only as an example ***
***  of input data as it might be used in a GSTARS version 4.0 simulation. ***
***  This file was constructed for didactic purposes only.                ***
***                                                                       ***
*****************************************************************************

NS    23
*** Cross Section Coordinate Order is X-Y
*** section 1
ST  989.       22      0.0      0.0     0.0      1.0       0.0
ND      1    227.0
XS 178.0   503.0   186.0   498.9   188.0   495.0   190.0   494.4   193.0   494.4
XS 195.0   494.3   196.5   494.3   198.0   494.3   199.0   494.3   200.0   494.2
XS 201.0   494.4   202.0   494.5   203.0   494.8   204.0   495.3   205.5   495.5
XS 208.0   496.5   210.0   497.7   215.0   497.9   220.0   498.1   223.0   498.3
XS 225.0   499.0   227.0   502.6
***
RH 0.060
***
***  section 2
ST 964.0       22      0.0      0.0     0.0      1.0       0.0
ND      1    214.0
***
XS 180.0   498.5   186.0   497.0   188.0   496.0   190.0   495.3   192.0   494.8
XS 194.0   493.8   195.5   493.4   197.0   493.0   198.5   492.8   200.0   492.7
XS 201.0   494.0   202.0   493.5   203.0   493.0   204.0   492.9   206.0   493.0
XS 207.0   494.0   208.0   493.1   210.0   495.5   212.0   497.0   214.0   498.7
XS 217.0   499.0   226.0   499.0
***
RH 0.060
***
***   section 3
ST  929.0      20      0.0      0.0     0.0      1.0      0.0
ND       1   205.0
XS 172.0   498.5   178.0   494.1   180.0   491.5   183.0   491.0   185.0   490.5
XS 186.0   490.0   189.0   489.6   192.0   489.2   193.0   489.3   194.0   489.4
XS 195.0   489.5   196.0   489.6   197.0   489.7   198.4   489.8   199.0   490.1
XS 199.5   490.3   200.0   490.4   201.5   490.8   203.0   491.3   219.0   497.6
***
RH 0.060
***
*** section 4
ST  888.0      22      0.0      0.0     0.0      1.0       0.0
```

```
ND       1   221.0
XS 177.0   495.0   179.0   492.9   181.0   487.5   181.7   486.5   182.5   486.4
XS 183.5   486.3   185.0   486.3   186.0   486.2   187.5   486.0   189.0   485.8
XS 190.0   485.6   192.0   485.3   193.0   487.0   194.0   488.0   195.0   491.0
XS 196.0   492.7   198.0   493.5   200.0   494.8   205.0   495.1   210.0   495.4
XS 215.0   495.8   221.0   496.1
***
RH 0.060
***
*** section 5
ST  813.0      24      0.0      0.0      0.0      1.0      0.2
ND       1   182.0
XS 127.0   494.4   131.0   487.0   131.5   486.0   132.4   485.0   135.0   479.9
XS 136.0   480.3   137.0   480.6   138.0   480.8   139.0   481.0   140.0   481.5
XS 141.0   481.5   142.0   481.5   143.5   481.5   145.0   482.0   147.0   483.0
XS 150.0   484.0   157.0   486.0   161.0   487.7   165.0   489.0   170.0   490.0
XS 173.0   491.0   176.0   492.0   179.0   492.8   182.0   493.4
***
RH 0.060
***
*** section 6
ST  763.0      24      0.0      0.0      0.0      1.0      0.0
ND       1   185.0
XS 138.0   492.9   140.0   488.0   142.0   483.0   144.0   480.0   145.0   479.0
XS 148.0   479.0   150.0   478.6   151.0   478.6   153.0   478.7   155.0   478.7
XS 157.0   478.7   159.0   478.7   160.0   478.7   162.0   478.7   164.0   478.8
XS 165.0   478.8   167.0   478.9   168.5   478.9   170.0   478.9   172.0   479.2
XS 173.5   479.6   175.0   480.0   180.0   483.0   185.0   488.0
***
RH 0.060
***
*** section 7
ST  703.0      24      0.0      0.0      0.0      1.0      0.0
ND       1   198.5
XS 155.0   490.5   157.0   485.0   159.0   480.9   163.0   480.0   167.0   479.0
XS 168.5   478.0   170.0   478.0   171.0   477.8   172.0   477.8   173.0   477.0
XS 174.0   476.9   175.0   476.9   176.0   476.9   177.0   476.8   178.0   476.6
XS 179.0   476.6   180.0   476.3   181.5   478.0   183.0   480.0   186.0   484.5
XS 190.0   488.0   193.0   490.0   197.0   490.0   198.5   491.0
***
RH 0.060
***
*** section 8
ST 664.0      21      0.0      0.0      0.0      1.0      0.0
ND      1   194.0
XS 158.0   488.3   160.0   483.0   162.0   480.0   165.0   478.0   166.0   477.0
XS 167.0   476.0   168.0   474.3   169.0   475.0   170.0   475.1   171.0   475.1
XS 172.0   475.2   174.0   475.2   176.0   475.3   178.0   475.4   179.0   475.4
XS 180.0   477.0   183.0   480.0   187.0   483.0   190.0   487.0   192.0   489.0
XS 194.0   489.5
***
RH 0.060
***
```

```
***   section 9
ST 634.0       23      0.0      0.0      0.0      1.0      0.0
ND      1   194.0
XS 153.0  488.9  157.0  485.0  160.0  483.5  163.0  483.0  165.0  478.0
XS 166.0  476.0  167.0  475.0  168.0  474.0  169.0  474.0  170.0  474.1
XS 171.0  474.1  172.0  474.2  173.0  474.2  174.0  474.3  175.0  474.3
XS 176.0  474.4  177.0  475.4  178.0  476.0  180.0  477.0  183.0  480.0
XS 187.0  483.0  190.0  487.0  194.0  491.0
***
RH 0.060
***
***   section 10
ST  614.0       22      0.0      0.0      0.0      1.0      0.2
ND      1   204.0
XS 148.0  489.3  150.0  482.0  152.0  477.7  155.0  477.0  157.0  476.0
XS 160.0  475.0  163.0  474.0  165.0  473.5  167.0  473.1  168.5  473.1
XS 170.0  473.1  173.0  473.0  176.0  473.0  179.0  473.1  182.0  477.1
XS 185.0  478.0  188.0  480.0  191.0  483.0  194.0  487.0  197.0  490.0
XS 200.0  492.3  204.0  492.3
***
RH 0.060
***
***   section 11
ST  559.0       24      0.0      0.0      0.0      1.0      0.0
ND      1   190.0
XS 135.0  488.0  138.0  480.0  139.0  475.0  141.5  472.5  143.0  472.6
XS 144.5  472.6  146.0  472.7  147.0  472.7  148.0  472.7  149.0  472.8
XS 150.0  472.8  153.0  472.9  155.0  473.0  157.0  473.0  158.0  473.0
XS 159.0  473.1  160.0  473.1  162.0  473.2  164.0  473.2  166.0  473.3
XS 170.0  473.4  175.0  477.0  185.0  479.5  190.0  491.0
***
RH 0.060
***
***   section 12
ST 509.0       24      0.0      0.0      0.0      1.0      0.0
ND      1   204.0
XS 130.0  485.1  131.5  480.0  133.0  475.6  137.0  474.0  140.0  473.0
XS 143.0  472.0  147.0  471.5  153.0  470.1  157.0  471.0  160.0  471.0
XS 164.0  471.0  167.0  473.0  170.0  475.0  173.0  478.0  177.0  481.0
XS 180.0  482.0  183.0  483.5  187.0  485.0  190.0  486.3  193.0  486.8
XS 197.0  487.0  200.0  487.3  202.0  487.5  204.0  487.6
***
RH 0.060
***
***   section 13
ST 459.0       24      0.0      0.0      0.0      1.0      0.0
ND      1   190.0
XS 123.0  483.9  130.0  480.0  135.0  478.0  140.0  476.0  143.0  474.0
XS 147.0  478.0  150.0  472.7  151.0  469.0  152.0  469.0  153.0  468.0
XS 155.0  467.0  157.0  467.0  159.0  466.7  161.0  466.5  163.0  466.2
XS 164.5  467.0  166.0  468.0  170.0  470.0  173.0  473.0  177.0  476.0
XS 180.0  479.0  182.0  483.2  186.0  484.0  190.0  485.5
***
RH 0.060
***
***  section 14
```

```
ST 409.0     22    0.0    0.0    0.0    1.0    0.2
ND     1  205.0
XS 135.0  482.4  137.0  477.0  139.0  470.9  143.0  468.0  144.0  467.0
XS 146.0  466.0  148.0  465.0  150.0  464.0  151.0  463.6  153.0  463.2
XS 155.0  463.3  157.0  463.4  158.5  463.5  160.0  463.6  162.5  464.5
XS 165.0  466.0  170.0  469.0  175.0  472.0  180.0  474.0  185.0  476.0
XS 190.0  478.0  205.0  482.5
***
RH 0.060
***
***   section 15
ST 334.0     23    0.0    0.0    0.0    1.0    0.0
ND     1  200.0
XS 144.0  479.7  147.0  478.0  150.0  475.0  153.0  473.0  157.0  471.0
XS 160.0  469.4  162.0  467.4  164.0  465.2  166.0  464.2  168.0  463.2
XS 169.5  462.3  171.0  461.5  172.0  461.3  173.0  461.1  174.0  460.7
XS 175.0  460.4  177.0  461.5  178.5  463.5  180.0  465.0  185.0  470.0
XS 190.0  475.0  195.0  478.0  200.0  480.5
***
RH 0.060
***
***   section 16
ST 284.0     23    0.0    0.0    0.0    1.0    0.0
ND     1  197.0
XS 146.0  478.0  150.0  476.0  153.0  474.0  157.0  472.0  160.0  470.0
XS 164.0  468.5  167.0  465.5  168.5  464.5  170.0  463.5  172.0  461.5
XS 174.0  460.3  175.0  460.3  177.0  460.4  178.0  460.4  179.0  460.4
XS 180.0  460.5  182.0  460.6  184.0  465.0  187.0  470.0  189.0  475.2
XS 191.0  477.2  194.0  479.3  197.0  479.4
***
RH 0.060
***
***   section 17
ST 270.0     24    0.0    0.0    0.0    1.0    0.2
ND     1  200.0
XS 145.0  477.7  148.0  475.7  150.0  473.7  153.0  472.2  157.0  469.0
XS 160.0  466.0  161.5  465.9  163.0  463.0  165.0  461.0  167.0  459.0
XS 168.5  458.9  170.0  458.6  172.5  458.5  175.0  459.0  177.5  459.3
XS 180.0  459.5  182.0  460.0  184.0  460.5  185.5  465.0  187.0  470.0
XS 190.0  478.1  193.0  478.3  197.0  478.6  200.0  478.8
***
RH 0.060
***
***   section 18
ST 250.0     23    0.0    0.0    0.0    1.0    0.0
ND     1  211.0
XS 149.0  477.3  155.0  475.3  160.0  473.0  163.0  470.0  166.0  468.0
XS 167.0  462.0  169.0  460.0  171.0  458.0  172.5  458.0  174.0  458.1
XS 176.0  458.1  178.0  458.1  179.0  458.1  180.0  458.2  181.5  458.2
XS 183.0  458.2  185.5  460.0  187.0  462.0  190.0  466.0  197.0  472.0
XS 200.0  475.0  205.0  474.8  211.0  474.6
***
RH 0.060
***
***   section 19
ST 200.0     24    0.0    0.0    0.0    1.0    0.0
```

```
ND      1   188.0
XS 138.0  476.6  140.0  473.1  142.0  469.6  145.0  469.4  147.0  460.9
XS 149.0  457.4  151.0  457.2  153.0  457.0  155.0  456.8  157.0  456.6
XS 160.0  456.3  162.0  456.5  164.0  456.7  166.0  457.0  168.0  457.3
XS 170.0  457.6  172.0  457.8  174.0  458.0  176.0  458.2  178.0  460.7
XS 180.0  463.2  182.0  465.7  184.0  468.2  188.0  473.2
***
RH 0.060
***
***   section 20
ST 150.0      24     0.0     0.0     0.0     1.0     0.0
ND      1   190.0
XS 144.0  474.2  145.0  473.2  146.0  470.2  147.0  467.5  148.0  462.5
XS 150.0  461.3  152.0  460.1  154.0  459.0  156.0  457.8  158.0  456.5
XS 160.0  455.5  162.0  455.7  164.0  456.0  166.0  456.2  168.0  456.4
XS 170.0  456.6  172.0  456.7  174.0  456.6  176.0  456.9  178.0  457.0
XS 182.0  460.7  185.0  464.3  187.0  467.3  190.0  471.3
***
RH 0.060
***
***   section 21
ST 100.0      24     0.0     0.0     0.0     1.0     0.0
ND      1   190.0
XS 150.0  472.5  151.0  466.5  152.0  460.5  153.0  455.1  155.0  455.1
XS 157.0  455.1  159.0  455.0  161.0  455.0  163.0  455.0  165.0  454.9
XS 167.0  454.9  169.0  454.8  171.0  454.8  173.0  454.9  175.0  455.1
XS 177.0  455.2  179.0  455.4  181.0  455.5  183.0  455.6  186.0  455.7
XS 189.0  460.5  191.0  463.0  194.0  466.7  200.0  469.1
***
RH 0.060
***
***   section 22
ST   50.0     24     0.0     0.0     0.0     1.0     0.0
ND      1   184.0
XS 144.0  470.2  147.0  469.0  150.0  467.5  154.0  466.3  155.0  464.0
XS 156.0  462.3  157.0  459.6  159.0  459.4  161.0  459.2  163.0  459.0
XS 165.0  458.9  168.0  458.7  170.0  458.0  172.0  457.3  174.0  456.6
XS 176.0  456.0  177.0  455.3  178.0  454.7  179.0  454.0  180.0  457.0
XS 181.0  460.0  182.0  463.0  183.0  466.0  184.0  468.7
***
RH 0.060
***
***   section 23
ST     0.0     24     1.0     1.0     0.0     1.0     0.0
ND      1   170.0
XS 129.0  463.8  133.0  463.0  136.0  462.1  139.0  461.2  141.0  460.0
XS 143.0  458.8  145.0  457.6  147.0  456.4  149.0  455.2  151.0  454.0
XS 152.0  452.6  153.0  452.5  154.0  452.4  155.0  452.4  156.0  452.3
XS 157.0  452.3  158.0  452.2  160.0  452.2  162.0  452.1  163.0  452.1
XS 165.0  455.6  167.0  459.0  169.0  462.5  170.0  466.2
***
RH 0.060
***
RE     MANNING
*** number of stream tubes
NT     3
```

IT 100 1 20 min
QQ TABLE OF DISCHARGES
SS STAGE DISCHARGE TABLE
TL 23
*** stage discharge table for section cross section #23
SQ 206.4 454.0
SQ 222.8 454.0
SQ 239.3 454.0
SQ 255.7 454.0
SQ 272.1 454.0
SQ 288.6 454.0
SQ 305.0 454.0
SQ 321.4 454.0
SQ 337.8 454.0
SQ 354.2 454.0
SQ 362.4 454.0
SQ 370.7 454.0
SQ 378.9 454.0
SQ 378.9 454.0
SQ 378.9 454.0
SQ 378.9 454.0
SQ 368.7 454.0
SQ 358.6 454.0
SQ 348.2 454.0
SQ 335.6 454.0
SQ 323.0 454.0
SQ 310.4 454.0
SQ 295.9 454.0
SQ 281.4 454.0
SQ 267.0 454.0
SQ 260.0 454.0
SQ 251.0 454.0
SQ 246.1 454.0
SQ 243.9 454.0
SQ 241.7 454.0
SQ 239.6 454.0
SQ 235.3 454.0
SQ 231.0 454.0
SQ 226.6 454.0
SQ 222.3 454.0
SQ 218.3 454.0
SQ 213.6 454.0
SQ 210.6 454.0
SQ 207.6 454.0
SQ 204.7 454.0
SQ 203.6 454.0
SQ 202.5 454.0
SQ 201.4 454.0
SQ 200.3 454.0
SQ 199.2 454.0
SQ 198.0 454.0
SQ 196.9 454.0
SQ 195.8 454.0
SQ 194.6 454.0
SQ 193.5 454.0
SQ 192.4 454.0

```
SQ 191.3   454.0
SQ 190.2   454.0
SQ 189.1   454.0
SQ 187.9   454.0
SQ 186.9   454.0
SQ 185.7   454.0
SQ 184.5   454.0
SQ 183.4   454.0
SQ 182.3   454.0
SQ 181.2   454.0
SQ 180.1   454.0
SQ 179.0   454.0
SQ 177.8   454.0
SQ 176.7   454.0
SQ 175.6   454.0
SQ 174.4   454.0
SQ 173.3   454.0
SQ 172.2   454.0
SQ 171.1   454.0
SQ 168.6   454.0
SQ 166.2   454.0
SQ 163.7   454.0
SQ 160.4   454.0
SQ 157.1   454.0
SQ 153.8   454.0
SQ 150.5   454.0
SQ 147.2   454.0
SQ 143.9   454.0
SQ 140.6   454.0
SQ 137.3   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 134.0   454.0
SQ 127.0   454.0
SQ 120.0   454.0
SQ 112.7   454.0
SQ 105.6   454.0
SQ  98.5   454.0
SQ  91.4   454.0
***sediment
SE      6      100
QS    2.0      0.0
QS    2.0     11.0
QS    2.0     23.0
QS    2.0     17.0
QS    2.0     11.0
```

```
QS    2.0      6.0
QS  88.0     0.0
***water temperature
TM 100.0    70.0
***particle size classes
SF      5.0
SG     .06       .80
SG     .80     2.00
SG   2.00     5.00
SG   5.00   10.00
SG 10.00   20.00
***bed gradation
SD   .11      .17      .24      .41      .07
SD   .11      .17      .24      .41      .07
SD   .11      .17      .24      .41      .07
SD   .38      .30      .17      .10      .05
SD   .38      .30      .17      .10      .05
SD   .38      .30      .17      .10      .05
SD   .24      .26      .24      .09      .17
SD   .24      .26      .24      .09      .17
SD   .24      .26      .24      .09      .17
SD   .10      .23      .23      .19      .25
SD   .10      .23      .23      .19      .25
SD   .10      .23      .23      .19      .25
SD   .06      .26      .30      .23      .15
SD   .06      .26      .30      .23      .15
SD   .06      .26      .30      .23      .15
SD   .06      .26      .30      .23      .15
SD   .06      .26      .30      .23      .15
SD   .06      .26      .30      .23      .15
SD   .06      .26      .30      .23      .15
SD   .06      .26      .30      .23      .15
SD   .06      .26      .30      .23      .15
SD   .06      .26      .30      .23      .15
SD   .06      .26      .30      .23      .15
AR    60      90
PR     2     100
PX   100  CROSS SECTION PLOTS
PW  100  WATER SURFACE PROFILE PLOTS
***minimization instructions
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   420.0   700.0
MR   0.0   400.0   400.0   700.0
MR   0.0   400.0   400.0   700.0
```

MR 0.0 400.0 400.0 700.0
MR 0.0 400.0 400.0 700.0
MR 0.0 400.0 400.0 700.0
MR 0.0 400.0 400.0 700.0
MR 0.0 400.0 400.0 700.0
MR 0.0 400.0 400.0 700.0
MR 0.0 400.0 400.0 700.0
END

1.2 Output Data Files

All the output files for this example can be found in the standard GSTARS4 distribution package in electronic form, in directory Example1.

1.3 Results and Discussion

In the GSTARS4 distribution are included both the input file of section 1.1 (file name mescal.dat under directory Example1) and a similar file for a run without using the stream power minimization routines (file name mescal_nm.dat under directory Example1). The files are identical with the exception of the stream power minimization records: the file mescal_nm.dat uses LM records to enforce the erosion limits and, of course, has no MR records. The results produced using both datafiles are shown in figure 1.4 for a cross section, and in figure 1.5 for the changes in the thalweg profile. The survey data is also plotted in those graphs.

The cross section data used to produce the plot in figure 1.4 was taken from the GSTARS4 cross section profile output file (file .XPL), and from the water surface profile output file (file .WPL) for figure 1.5. Section 0+60 is located 60 ft downstream from the spillway (section #3 in the GSTARS4 file, at 929 ft). In this cross section, significant differences are observed when stream power minimization calculations are activated. Both the shape of the cross section and its thalweg are more accurately predicted when the stream power minimization computations were activated by the use of the MR records.

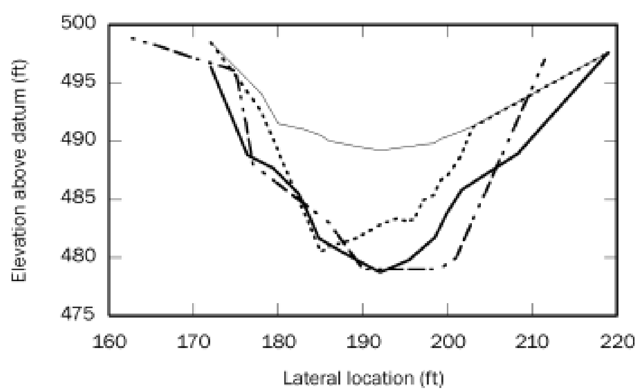

Figure 1.4 Comparison of results produced by GSTARS4 and survey data, for runs with and without width changes due to stream power minimization. Section 0+60.

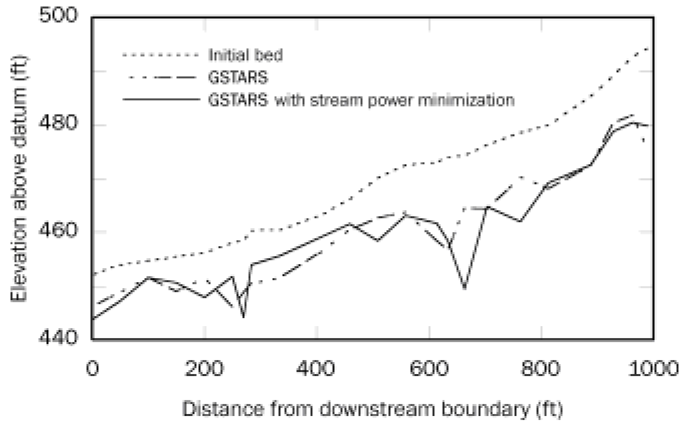

Figure 1.5 Plot of the thalweg for both GSTARS4 runs, i.e., for runs with and without stream power minimization computations.

Note that the results obtained with GSTARS4 and shown in this section differ from the results obtained earlier by Song et al. (1995). There are several reasons for these differences:

1. The version of GSTARS used by Song et al. (1995) was an early version, preceding even GSTARS 2.0, dated back to 1986. Their data file was adopted for the present example for didactic purposes only, therefore there was no attempt to recalibrate the data using GSTARS4.

2. Song et al. (1995) used an algorithm to compute exchange of sediment across stream tubes which is not activated in the present runs of GSTARS4.

3. Song et al. (1995) used a laboratory-derived method to compute the scour due to the water fall produced below the cut-off weir. That method uses an approach specifically developed to compute the scour by a free falling water jet. The free-falling jet occurs at the end of the spillway, which is formed by a concrete wall followed by an unpaved natural channel. As the unlined channel gets eroded, the difference in level between the lined (unerodible) spillway and the natural channel becomes too large and results in a free-falling jet. Such a method is not present in GSTARS4.

Furthermore, some differences between GSTARS4 output and its earlier versions, such as GSTARS3.0, may be apparent. This is because some of the algorithms in GSTARS4 are different from earlier versions of the program, resulting in slightly different results, even if the same input data file is used. This means that new calibration may be needed when using GSTARS4 on data files generated for older versions of the program.

1.4 References

Song. C.C.S., Zheng, Y., and Yang, C.T. (1995). “Modeling of river morphologic changes,” *Int. J. Sed. Res*. **10**(2), pp. 1-20.

EXAMPLE 2

RESERVOIR ROUTING AND VOLUME COMPUTATIONS

GSTARS4 can calculate reservoir capacity tables and use them to determine reservoir volumes and corresponding water surface elevations at the dam. That is accomplished using mass conservation principles, as described in chapter 5. This example shows how to set-up a simple reservoir routing problem and how to interpret the results of the computations. For this purpose an idealized small reservoir is used, similar to what could be constructed to serve as a settling basin or pond, for example. The problem to be solved consists in computing the basin's volume and stag during a cycle in which the basin is emptied and refilled.

The basin is a 600-ft square placed at the downstream end of a 30-ft wide rectangular channel. The principal geometric characteristics of this configuration are sketched in figure 2.1. The study uses 14 cross sections, 7 in the pond and 7 in the approaching channel. The cross sections are placed 50 ft apart. However, the last cross section in the channel is placed only 10 ft from the first in the pond, which is done to ensure a certain level of accuracy in the reservoir volume computations.

The channel discharge is a constant 100 cfs. In this example, the pond is emptied at a rate of 120 cfs. When the low water mark is reached, at 2 ft of elevation at the dam, the outlet discharge is reduced to 90 cfs to allow for a slower refilling of the pond. To simplify the problem, no sediment transport is involved. This allows for the pond's capacity table to be calculated only once, at the beginning of the computations: because the pond's geometry does not change, there is no need to recomputed that table. Using daily time steps and the hydrology described above, only ten daily time steps are needed to complete the cycle.

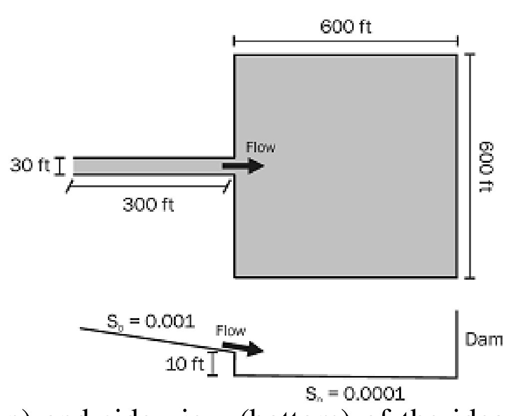

Figure 2.1 Plan view (top) and side view (bottom) of the idealized pond and approach channel used in example 2.

The hydrology is specified using DISCHARGE AT DAM in record SS, with DISCRETIZED DISCHARGES in record QQ. This configuration requires DD records for the inflow discharges, and RQ records for the pond outflow discharges. Record HR is used to define the major reservoir parameters.

Finally, due to the simplicity of this problem, minimal output is requested: *IPRLVL* set to 0 in record PR, with output requested every second time step. No cross-sectional or water profile plotting is requested in records PX and PW.

2.1 Input Data File

The files shown in this and the next section are part of the main GSTARS4 distribution package. They can be found under directory Example2

```
TT   GSTARS version 3.0  -  Example data file for Appendix B of user's manual
TT  Simulation of emptying and refilling of a retention pond to illustrate the
TT    reservoir routing capabilities of GSTARS3    ---HYDRAULICS ONLY---
********************************************************************************
***  NOTE: this is a datafile to be used as an example of input data as it       ***
***  might be used in a GSTARS version 3.0 simulation.  It represents a          ***
***  ficticious case and it sould be viewed as such.  It should not be used      ***
***  for any other purpose without appropriate verification and validation.      ***
***                                                                              ***
***  -----------------------------------------------------------                 ***
***  Problem Description: draw-down and refilling of impoundment                 ***
***  Data Filename: Pond.dat                                                     ***
***  Shape: square pond, 600 x 600 ft, rectangular cross sections                ***
***  Channel Length: 300 ft                                                      ***
***  Bed slope: 0.001 (channel) and 0.0001 (impoundment)                         ***
***  Number of Stations: 14 (7 on channel, 7 in impoundment)                     ***
***  Testing: reservoir routing and volume routines of GSTARS3                   ***
***  -----------------------------------------------------------                 ***
********************************************************************************
NS   14     10
***  Approach channel (S0 = 0.001).
ST   900     4              10.30
ND    1     600
XS    0     30     0     0     30     0     30     30
RH 0.030

ST   850     4              10.25
ND    1     600
XS    0     30     0     0     30     0     30     30
RH 0.030

ST   800     4              10.20
ND    1     600
XS    0     30     0     0     30     0     30     30
RH 0.030

ST   750     4              10.15
ND    1     600
XS    0     30     0     0     30     0     30     30
```

```
RH 0.030

ST   700      4                 10.10
ND     1     600
XS     0      30       0       0      30       0      30      30
RH 0.030

ST   650      4                 10.05
ND     1     600
XS     0      30       0       0      30       0      30      30
RH 0.030

ST   610      4                 10.01
ND     1     600
XS     0      30       0       0      30       0      30      30
RH 0.030

***  Pond starts here.
ST   600      4                  0.06
ND     1     600
XS     0      30       0       0     600       0     600      30
RH 0.030

ST   500      4                  0.05
ND     1     600
XS     0      30       0       0     600       0     600      30
RH 0.030

ST   400      4                  0.04
ND     1     600
XS     0      30       0       0     600       0     600      30
RH 0.030

ST   300      4                  0.03
ND     1     600
XS     0      30       0       0     600       0     600      30
RH 0.030

ST   200      4                  0.02
ND     1     600
XS     0      30       0       0     600       0     600      30
RH 0.030

ST   100      4                  0.01
ND     1     600
XS     0      30       0       0     600       0     600      30
RH 0.030

ST     0      4       1       1
ND     1     600
XS     0      30       0       0     600       0     600      30
RH 0.030

NT     1
IT    10      1       1     DAY
QQ      DISCRETIZED DISCHARGES
```

```
SS      DISCHARGE AT DAM
HR          15      2     25
DD    10     100
RQ     1     100
RQ     2     120
RQ     1     115
RQ     6      90
***Print control
PR           2
PX
PW
END
```

2.2 Output Data File

All the output data files for this example can be found, in electronic format, in the main GSTARS4 distribution package in directory Example2.

2.3 Results and Discussion

The reservoir routing tables are generated at the end of each time step. They show the state of the reservoir at the end of the time step. These quantities will only be used in the next time step, as starting conditions. Of interest are the computed discharges for each cross section and the coefficients that are used in eq. (5.2). The volume of reservoir is the result of the mass balance for the time step in question, computed at the end of the time step, and it is the initial condition for the following time step. The same can be said about the stage at the dam.

Note that in some cases the discharge at the first cross section is not the same as the inflow discharge. That happens when the stage at the reservoir is higher than the thalweg of the first cross section. GSTARS4 assumes that all cross sections with thalweg lower than the stage at the dam belong to the reservoir, therefore their corresponding discharges are computed using the technique described in chapter 5. That means that those cross sections effectively contribute to reservoir storage, therefore their discharge will be higher than the inflow discharge in the case of reservoir draw-down, and will be lower in the case of reservoir fill-up. That can be observed in time steps 10 and 4, respectively.

Note that time step 4 has an outlet discharge of only 115 cfs, versus 120 cfs for the previous time steps. This is done so that the reservoir level never drops below 2 ft, which is the minimum reservoir depth allowed (see variable *RSTGMIN* in record HR). This example was set in this manner to emphasize the nature of the GSTARS4 computations in this case. Although the computations would proceed in the usual manner, if the stage at the dam falls below *RSTGMIN*, GSTARS4 simply resets the stage back up to *RSTGMIN* for the next time step. However, this results in conservation of reservoir volume being violated, because volume is artificially introduced in the reservoir as a result of that water level increase. During the computations the user should verify that this condition never happens. *RSTGMIN* should be viewed as a “safety net” for the backwater computation. Similarly, the stage at the dam should never allowed to become higher that *RSTGMAX* (also in record HR), as the resetting of the stage in this instance would result in the loss of reservoir volume. In this example, this problem could also be avoided by using 11 quarter-day time steps with an outflow discharge of 105 cfs - instead of 2 one-day time steps with 120 cfs followed by one with 115 cfs. The computations would be longer (more time steps to compute), but the results would be more accurate. This also illustrates the importance of choosing the right time step for the job at hand.

Finally, for illustration purposes, the data in the main output data file was used to show the entire cycle simulated in this example (see figure 2.2). Note that the lowest stage at the dam reaches a value of 2.0017 ft, which is just above the minimum allowed in record HR. Note also that there is a change of slope in the draw-down rate of the reservoir at time step 3, which results from lowering the outlet discharge from 120 to 115 cfs. This change would not exist if the quarter-day time steps suggested in the previous paragraph were employed.

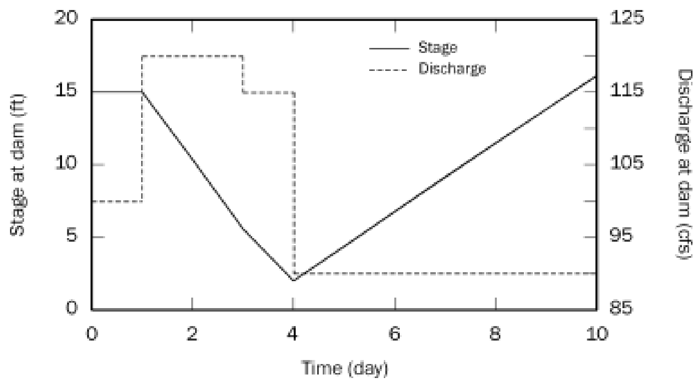

Figure 2.2 Outlet discharge and water surface elevation at the dam.

EXAMPLE 3

RIO GRANDE FLOODWAY

Example 3 is included here to illustrate the use of the cohesive sediment transport features of GSTARS4, as well as the use of non-equilibrium sediment transport. For this purpose some actual survey data collected in the Rio Grande floodway are used. The data corresponds to a stretch of the Rio Grande between San Marcial, New Mexico, and the upper end of Elephant Butte Reservoir, as shown in figure 3.1. This example consists of a reservoir sedimentation problem, with very fine sediments entering a reservoir and depositing in the upper reach of the modeled region (delta formation).

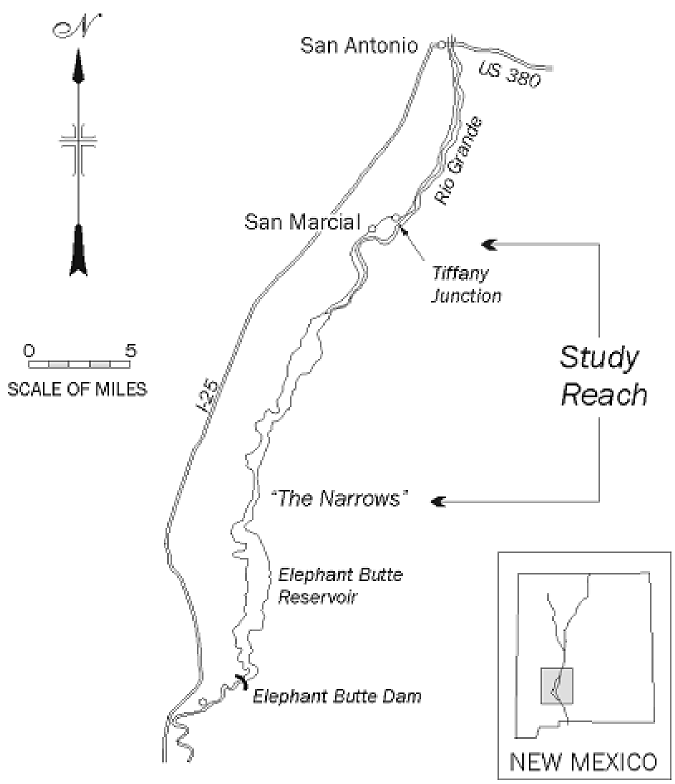

Figure 3.1 Location of the reach modeled in this example problem.

For this example, a total of 33 cross sections are used to represent a reach approximately 28 miles in length. The values of the Manning's roughness coefficients used are 0.024 for the main channel and 0.080 for the flood plains (RH records; see the input data file given in the next section). The hydrology data consist of daily flows and monthly water temperatures at the upstream end of the reach, and of daily reservoir elevations at the downstream end (figures 3.2 and 3.3). The input of these data is made by the use of the

STAGE DISCHARGE TABLE (records QQ and SS) using SQ and TM records. The simulation is carried out for an 8-year period with time steps of 1 day for the hydraulics, with 5 sediment time steps per day (see record IT).

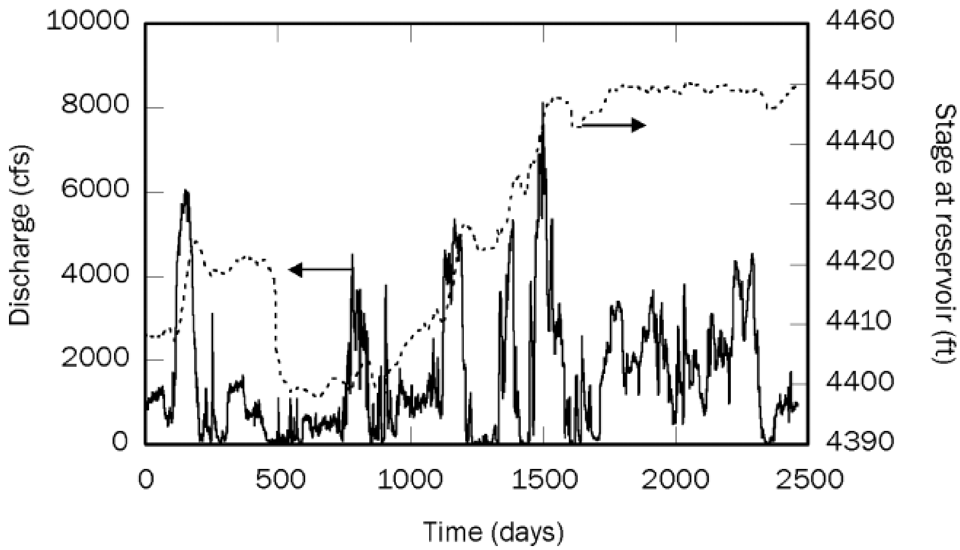

Figure 3.2 Hydrologic data for the Rio Grande example problem.

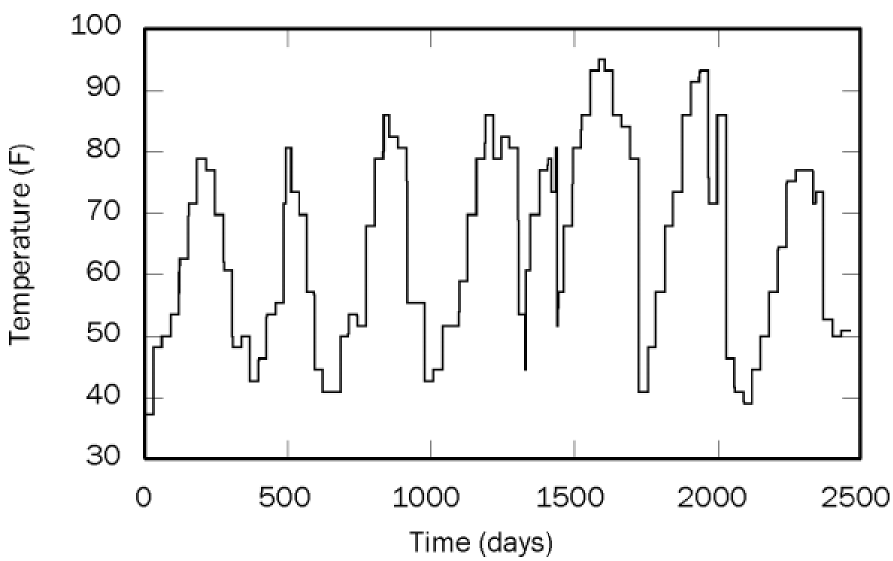

Figure 3.3 Monthly water temperatures used in the present example problem.

The incoming sediment discharge is specified as a function of the water discharge, and is given by the relation

$$Q_s = 1.415 Q^{1.261}$$

where Q_s = sediment discharge (ton/day) and Q = water discharge (ft^3/s). This rating curve was determined from least squares fitting to the data collected at the San Marcial gaging station (see figure 3.4) and is given in record QR. The bed material has a relatively high percentage of very fine particles, in the silt and clay range. The incoming sediment distribution is given as a function of the water discharge and specified by the use of IQ and IS records. The bed material distribution over the simulated reach is known at specific locations (rangelines) and interpolated between those locations. This is accomplished by the use of NB/BG records. Note that if NB/BG records are used, the locations where the bed distribution is specified do not need to coincide with the cross sections specified by ST/ND/XS/RH sets of records. In this example there are 33 cross sections, but only 8 sets of NB/BG records. The range of bed material size distributions is shown in figure 3.5.

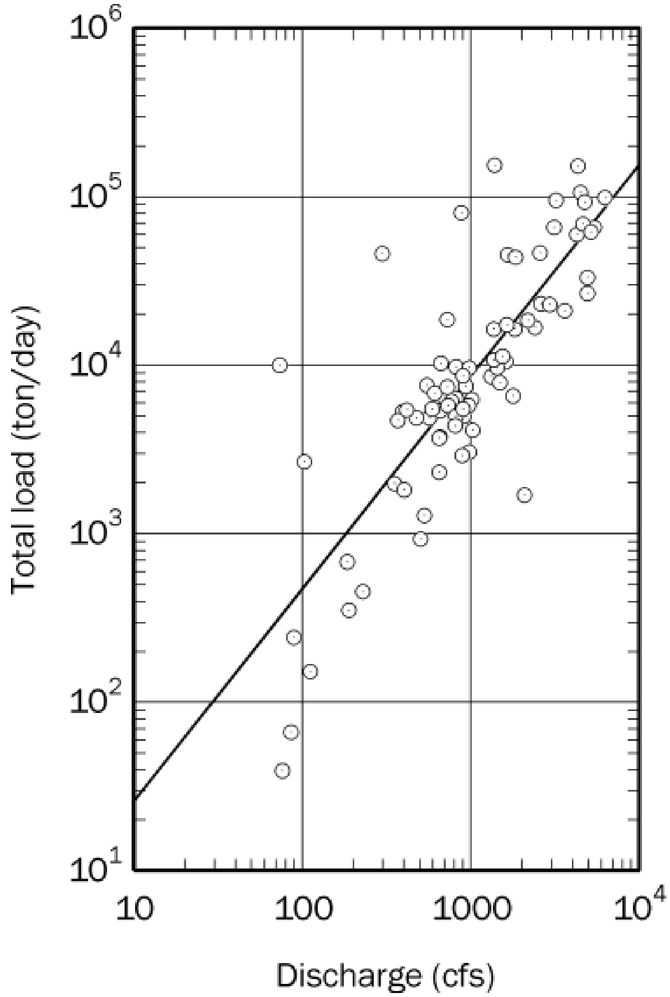

Figure 3.4 Rating curve used in the study. The data used (circles) were measured at the San Marcial gaging station during the 1980-1988 period.

The non-equilibrium parameters are specified using N0 records. Since we are modeling a reach with mixed characteristics (river-like upstream and reservoir-like downstream), different values for the recovery factors were defined. The reach is in depositional mode, therefore only the recovery factor for deposition is important In this case. The values were determined by numerical calibration, and vary between 0.5 and 0.0001.

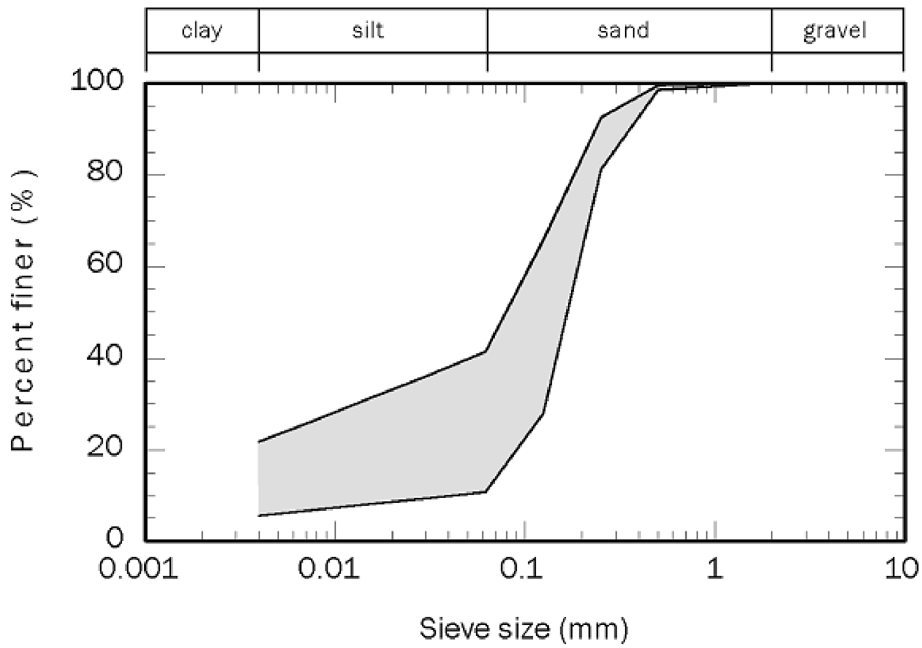

Figure 3.5 Range of bed material size distributions used in this study.

The cohesive sediment transport parameters are specified in record CS. These parameters, which characterize the particles with a diameter smaller than 62 μm, should be determined in situ or by laboratory tests. They are highly dependent on the local conditions and may vary widely from case to case, always requiring field verification. In the present example, the characteristics of the cohesive sediments are the following: the threshold value for the shear stress above which there is no deposition of silts or clays is 0.021 lb/ft^2; the threshold value for the shear stress above which there is particle erosion of cohesive sediments is 0.10 lb/ft^2; the threshold value for the shear stress above which there is mass erosion is 2.40 lb/ft^2; the slope of the mass erosion rate line is 0.63, in units of hour^{-1}; the erosion rate of cohesive sediment when the bed shear stress equals 2.40 lb/ft^2 is 0.250 lb/ft^2/hr; finally, the last entry indicates the threshold for the percentage of clay, in the bed, above which the erosion rates of the other particle sizes become limited to the erosion rate of clay. All these values are schematically represented in figure 3.6.

Unfortunately, there is no information about the flocculation or hindered settling limits, or their corresponding fall velocities. For that reason, only particulate fall velocities are used in the simulation runs. That is done by setting high values for the parameters *CS1* and *CS2* in record CH.

3.1 Input Data File

Due to the length of this data file, the full extent of records SQ and TM is not included. The complete data file is bundled in the GSTARS4 distribution files in directory Example3. All the files shown in this and the next sections are included in the main GSTARS4 distribution package.

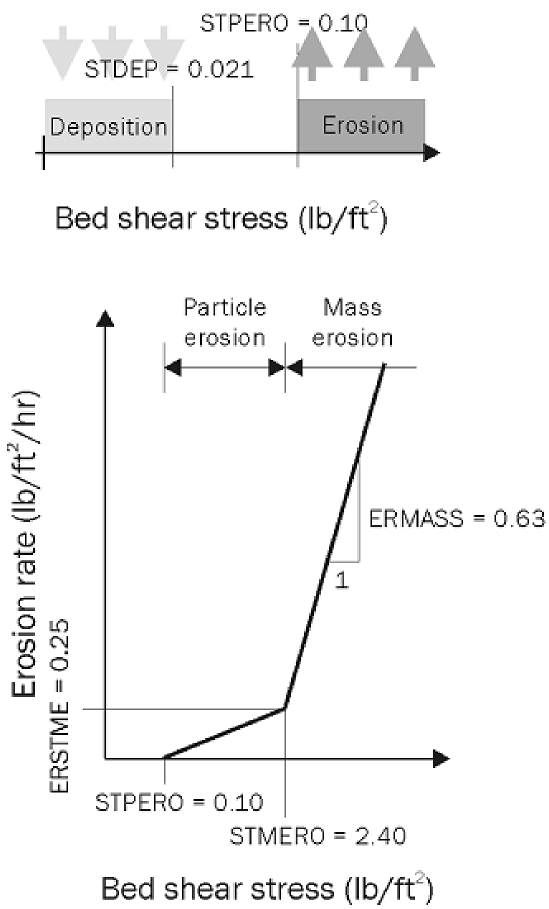

Figure 3.6 Schematic representation of the parameters used to model the transport of cohesive sediments in record CS of example 3.

```
TT GSTARS version 3.0  -  Example data file for Appendix B of user's manual
TT Middle Rio Grande, 1980 survey data, rangelines 9 to 59
TT Simulation of nonequilibrium and cohesive sediment transport
*******************************************************************************
***                                                                         ***
***  NOTE: this is a simplified version of the datafile used to simulate    ***
***  the Rio Grande floodway between San Marcial and the upper reach of the ***
***  Elephant Butte Reservoir (to The Narrows).  It may not contain an      ***
***  accurate representation of the actual flow and geological conditions  ***
***  at the site.  This data file should be viewed only as an example of    ***
***  input data as it might be used in a GSTARS version 3.0 simulation.     ***
***  This file was constructed for didactic purposes only.                  ***
***                                                                         ***
*******************************************************************************
***
NS    33     200
YX
*** Station #2
ST148011      50      0      0      0      0     0.0
ND     3   124.0   494.0  1882.0
XS4486.4       0  4479.3     21  4474.3     37  4472.6     68  4473.5     83
XS4479.7      95  4482.5    102  4484.2    106  4484.2    124  4482.6    129
XS4472.5     147    4471    178  4468.7    179  4464.3    182    4464    217
```

```
XS4464.1    237  4463.5    249  4464.5    264  4464.8    273  4464.5    288
XS4462.1    303  4462.8    321  4467.3    346  4469.8    355   4471    367
XS4471.3    470    4472    494   4471    526  4471.1    572  4471.4    696
XS4471.1    785  4473.2    804  4470.1    834  4471.1    861  4470.5    944
XS4470.4   1042  4469.4   1142  4468.9   1225  4470.4   1254  4469.9   1301
XS4469.8   1411  4470.1   1509  4469.2   1589  4466.9   1608  4470.1   1640
XS4469.4   1704  4469.6   1797  4473.6   1839  4478.9   1859  4479.1   1882
RH 0.080   0.024   0.080
*** Station #3
ST145471     35      0      0      0      0    0.0
ND     2  1012.0  2050.0
XS4478.5  298.0 4473.5  326.0 4472.7  333.0 4470.6  340.0 4463.8  346.0
XS4463.9  377.0 4469.3  391.0 4469.2  452.0 4468.6  551.0 4467.1  626.0
XS4464.5  635.0 4463.9  780.0 4464.5  810.0 4464.1  825.0 4463.2  830.0
XS4462.5  870.0 4462.6  890.0 4462.7  948.0 4462.3  972.0 4469.5  978.0
XS4469.7  981.0 4471.3 1012.0 4469.6 1043.0 4469.5 1121.0 4468.3 1196.0
XS4468.7 1290.0 4467.5 1390.0 4468.5 1494.0 4468.3 1587.0 4468.3 1693.0
XS4468.0 1794.0 4467.6 1904.0 4467.1 2010.0 4471.9 2041.0 4476.0 2050.0
RH 0.024   0.080
***
ST134151     47      0      0      0      0    0.0
ND     3  2021.0  2150.0  3119.0
XS4471.4 1521.0 4469.0 1561.0 4468.2 1610.0 4466.9 1654.0 4466.4 1690.0
XS4465.2 1734.0 4464.2 1762.0 4463.5 1809.0 4462.8 1836.0 4464.3 1873.0
XS4464.6 1910.0 4464.7 1943.0 4464.5 1968.0 4465.0 1991.0 4464.1 2003.0
XS4464.8 2021.0 4464.3 2028.0 4457.3 2037.0 4455.1 2057.0 4453.1 2074.0
XS4451.0 2089.0 4451.3 2107.0 4452.5 2119.0 4463.1 2140.0 4464.1 2144.0
XS4464.9 2150.0 4464.4 2219.0 4464.4 2286.0 4464.7 2355.0 4464.2 2427.0
XS4464.2 2502.0 4464.3 2573.0 4464.1 2642.0 4463.7 2706.0 4463.2 2786.0
XS4462.5 2847.0 4461.5 2867.0 4466.4 2898.0 4464.4 2914.0 4462.8 2981.0
XS4461.1 3013.0 4460.4 3056.0 4460.0 3072.0 4462.7 3087.0 4464.1 3097.0
XS4469.4 3112.0 4469.7 3119.0
RH 0.080   0.024   0.080
*** Station #5
ST133100     39      0      0      0      0    0.0
ND     3   199.0   319.0  1209.0
XS4468.0  111.0 4465.5  128.0 4463.7  164.0 4462.8  183.0 4464.1  199.0
XS4464.0  205.0 4454.8  220.0 4452.1  227.0 4450.4  240.0 4451.0  260.0
XS4450.8  276.0 4450.2  285.0 4461.8  302.0 4463.0  310.0 4463.5  319.0
XS4463.7  374.0 4463.5  451.0 4463.4  516.0 4463.4  587.0 4463.4  654.0
XS4463.2  710.0 4461.9  752.0 4461.6  808.0 4461.7  860.0 4461.7  901.0
XS4460.5  929.0 4462.2  970.0 4463.0 1013.0 4461.5 1031.0 4461.2 1072.0
XS4460.0 1116.0 4462.1 1138.0 4461.5 1147.0 4458.7 1170.0 4462.0 1184.0
XS4461.5 1189.0 4463.9 1197.0 4467.8 1206.0 4467.9 1209.0
RH 0.080   0.024   0.080
***
ST126460     44      0      0      0      0    0.0
ND     3   150.0   284.0  1226.0
XS4470.6   49.0 4463.6   61.0 4461.8   78.0 4458.9   90.0 4459.6   97.0
XS4459.3  117.0 4460.0  131.0 4459.9  150.0 4459.4  157.0 4459.4  161.0
XS4455.6  168.0 4451.6  171.0 4449.6  175.0 4454.2  203.0 4448.9  217.0
XS4448.2  238.0 4446.4  261.0 4454.2  268.0 4459.0  274.0 4460.1  284.0
XS4460.0  321.0 4459.9  355.0 4457.2  392.0 4458.1  419.0 4464.3  449.0
XS4459.9  499.0 4460.0  545.0 4457.7  568.0 4459.6  614.0 4460.4  664.0
XS4460.3  711.0 4460.2  766.0 4462.8  816.0 4460.5  868.0 4458.6  915.0
XS4461.2  975.0 4461.4 1027.0 4461.2 1073.0 4461.6 1119.0 4460.8 1163.0
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XS4462.7  1195.0  4466.1  1202.0  4468.5  1213.0  4468.7  1226.0
RH 0.080   0.024   0.080
*** Station #7
ST124560      40       0       0       0       0     0.0
ND     2   181.0  1095.0
XS4468.0    55.0  4462.2    64.0  4461.5    72.0  4460.6    77.0  4457.3    81.0
XS4444.3    95.0  4444.9   106.0  4446.9   118.0  4447.6   135.0  4447.8   148.0
XS4449.4   151.0  4450.8   154.0  4458.5   181.0  4457.6   209.0  4461.5   231.0
XS4457.4   266.0  4456.0   281.0  4457.2   300.0  4460.4   337.0  4460.0   379.0
XS4457.2   411.0  4458.8   464.0  4459.0   521.0  4455.6   572.0  4457.6   606.0
XS4458.6   644.0  4458.1   697.0  4457.8   756.0  4458.1   805.0  4457.6   848.0
XS4456.2   872.0  4458.7   898.0  4458.5   910.0  4460.1   921.0  4458.6   937.0
XS4457.6   972.0  4459.6   994.0  4460.7  1048.0  4466.5  1088.0  4467.5  1095.0
RH 0.024   0.080
***
ST118694      29       0       0       0       0     0.0
ND     3    89.0   194.0  1147.0
XS4464.0    56.0  4457.4    67.0  4453.8    85.0  4454.2    89.0  4444.4   105.0
XS4444.1   121.0  4444.3   137.0  4444.2   155.0  4444.4   171.0  4444.5   176.0
XS4451.4   187.0  4451.6   194.0  4450.7   230.0  4452.3   262.0  4453.5   314.0
XS4454.1   386.0  4454.7   456.0  4454.6   530.0  4454.9   602.0  4456.1   669.0
XS4455.4   728.0  4455.8   776.0  4455.6   828.0  4454.8   897.0  4456.4   949.0
XS4456.8   997.0  4459.0  1068.0  4462.1  1123.0  4464.8  1147.0
RH 0.080   0.024   0.080
*** Station #9
ST111414      48       0       0       0       0     0.0
ND     3   222.0   371.0  1178.0
XS4462.5   163.0  4455.7   178.0  4451.5   185.0  4451.9   222.0  4451.8   227.0
XS4447.3   237.0  4444.4   247.0  4441.4   251.0  4441.9   272.0  4442.3   294.0
XS4440.7   321.0  4440.1   341.0  4441.5   344.0  4444.5   350.0  4446.8   355.0
XS4448.3   363.0  4451.5   368.0  4451.9   371.0  4451.7   375.0  4450.7   389.0
XS4452.0   401.0  4451.5   404.0  4451.8   409.0  4455.0   417.0  4455.4   423.0
XS4451.8   438.0  4451.2   478.0  4452.5   515.0  4450.7   565.0  4450.2   615.0
XS4451.2   654.0  4450.5   697.0  4451.0   745.0  4450.9   792.0  4450.7   837.0
XS4450.6   886.0  4451.0   921.0  4450.9   946.0  4450.5   994.0  4450.2  1029.0
XS4448.8  1064.0  4448.9  1090.0  4450.8  1101.0  4452.3  1129.0  4454.2  1141.0
XS4460.9  1152.0  4461.1  1155.0  4461.0  1178.0
RH 0.080   0.024   0.080
***
ST100814      89       0       0       0       0     0.0
ND     2  6218.0  9249.0
XS4463.5  4922.0  4460.8  4934.0  4460.9  4945.0  4456.0  4954.0  4451.2  4970.0
XS4445.5  4978.0  4443.5  4996.0  4443.9  5004.0  4446.1  5021.0  4447.2  5040.0
XS4446.9  5065.0  4442.8  5087.0  4441.9  5108.0  4441.4  5122.0  4441.5  5127.0
XS4433.9  5140.0  4430.7  5158.0  4430.5  5178.0  4430.0  5197.0  4429.5  5215.0
XS4434.4  5220.0  4440.0  5232.0  4440.2  5237.0  4439.0  5287.0  4442.0  5316.0
XS4446.0  5331.0  4447.0  5376.0  4446.9  5426.0  4446.5  5481.0  4445.9  5558.0
XS4445.2  5634.0  4444.2  5701.0  4443.5  5783.0  4443.0  5859.0  4442.6  5936.0
XS4442.2  5981.0  4443.0  6019.0  4442.0  6079.0  4441.5  6139.0  4442.6  6169.0
XS4445.9  6192.0  4451.8  6208.0  4456.4  6218.0  4456.2  6245.0  4442.8  6284.0
XS4440.9  6299.0  4441.7  6336.0  4429.9  6359.0  4429.0  6373.0  4430.5  6392.0
XS4440.4  6413.0  4440.5  6416.0  4440.3  6455.0  4439.2  6458.0  4439.8  6463.0
XS4439.3  6512.0  4440.0  6528.0  4439.4  6615.0  4438.8  6704.0  4439.5  6795.0
XS4438.8  6884.0  4438.8  6977.0  4438.8  7061.0  4439.0  7151.0  4438.7  7250.0
XS4439.8  7350.0  4439.7  7446.0  4438.7  7548.0  4438.9  7648.0  4438.7  7746.0
XS4438.9  7845.0  4439.7  7944.0  4440.3  8039.0  4442.2  8077.0  4441.7  8184.0
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XS4443.0  8279.0  4441.2  8334.0  4441.6  8380.0  4439.8  8435.0  4440.0  8515.0
XS4442.7  8615.0  4446.9  8669.0  4448.7  8717.0  4451.0  8820.0  4453.8  8917.0
XS4454.9  9011.0  4451.7  9179.0  4455.0  9194.0  4459.4  9249.0
RH 0.024   0.080
*** Station #11
ST96977.     102       0       0       0       0     0.0
ND     3  3673.0  4785.0  9392.0
XS4450.3  3434.0  4447.3  3439.0  4443.9  3448.0  4442.2  3462.0  4442.3  3502.0
XS4443.8  3542.0  4444.2  3580.0  4445.8  3617.0  4448.2  3653.0  4449.0  3673.0
XS4448.0  3680.0  4443.7  3688.0  4441.7  3696.0  4439.5  3703.0  4431.2  3706.0
XS4431.3  3725.0  4431.2  3745.0  4431.5  3762.0  4431.5  3773.0  4432.2  3778.0
XS4435.2  3780.0  4440.2  3790.0  4441.0  3802.0  4440.8  3834.0  4445.4  3849.0
XS4449.0  3867.0  4447.8  3885.0  4447.2  3943.0  4446.7  4000.0  4446.5  4064.0
XS4445.4  4116.0  4446.2  4160.0  4445.1  4224.0  4444.2  4299.0  4444.2  4373.0
XS4444.0  4450.0  4444.2  4520.0  4443.6  4570.0  4441.5  4600.0  4443.8  4622.0
XS4442.5  4639.0  4442.6  4699.0  4443.6  4749.0  4446.6  4769.0  4456.0  4785.0
XS4455.1  4815.0  4443.8  4836.0  4442.7  4880.0  4431.5  4900.0  4431.7  4935.0
XS4441.0  4951.0  4440.1  5062.0  4440.6  5154.0  4440.7  5247.0  4441.0  5338.0
XS4439.9  5436.0  4440.5  5531.0  4440.3  5629.0  4439.8  5728.0  4439.6  5823.0
XS4439.6  5914.0  4440.5  6002.0  4439.9  6112.0  4439.4  6202.0  4438.9  6297.0
XS4439.4  6391.0  4440.0  6491.0  4439.3  6582.0  4439.7  6677.0  4439.2  6795.0
XS4439.1  6882.0  4439.0  6965.0  4437.6  7052.0  4438.4  7157.0  4438.1  7252.0
XS4438.6  7345.0  4438.3  7442.0  4437.9  7534.0  4437.7  7630.0  4437.5  7724.0
XS4437.4  7814.0  4437.7  7906.0  4437.6  7930.0  4437.6  8023.0  4438.2  8119.0
XS4437.9  8206.0  4435.7  8242.0  4435.3  8337.0  4435.8  8431.0  4436.2  8527.0
XS4435.5  8550.0  4436.3  8573.0  4436.5  8669.0  4435.4  8763.0  4435.3  8858.0
XS4435.3  8955.0  4435.7  9051.0  4435.7  9146.0  4435.6  9240.0  4435.5  9329.0
XS4444.6  9382.0  4450.3  9392.0
RH 0.080   0.024   0.080
***
ST88577.     170       0       0       0       0     0.0
ND     3  1181.0  8926.0  9726.0
XS4450.3   168.0  4449.9   174.0  4447.3   210.0  4444.5   225.0  4444.4   233.0
XS4446.5   246.0  4448.1   266.0  4447.3   290.0  4446.4   314.0  4445.6   321.0
XS4441.8   331.0  4437.1   346.0  4436.1   398.0  4436.8   447.0  4437.0   510.0
XS4436.8   551.0  4436.8   591.0  4436.4   612.0  4436.9   638.0  4436.7   680.0
XS4436.5   721.0  4436.2   754.0  4435.9   804.0  4436.2   843.0  4436.4   887.0
XS4436.6   922.0  4437.3   954.0  4437.3   985.0  4435.8   990.0  4436.2  1008.0
XS4435.7  1042.0  4436.4  1090.0  4436.5  1094.0  4430.5  1098.0  4438.9  1101.0
XS4439.3  1146.0  4432.8  1170.0  4439.7  1181.0  4428.6  1214.0  4428.1  1269.0
XS4429.3  1277.0  4430.5  1282.0  4436.0  1319.0  4436.6  1329.0  4436.0  1336.0
XS4437.4  1342.0  4437.5  1347.0  4436.8  1378.0  4438.1  1401.0  4442.1  1423.0
XS4442.6  1431.0  4439.7  1444.0  4437.2  1466.0  4436.7  1502.0  4436.8  1569.0
XS4437.1  1637.0  4437.3  1703.0  4437.5  1770.0  4437.8  1847.0  4437.5  1917.0
XS4437.5  1987.0  4437.8  2056.0  4438.4  2122.0  4436.9  2157.0  4438.0  2187.0
XS4437.3  2213.0  4439.0  2240.0  4438.3  2301.0  4441.2  2325.0  4438.5  2341.0
XS4438.0  2368.0  4439.0  2398.0  4445.8  2428.0  4449.9  2480.0  4441.1  2499.0
XS4439.4  2536.0  4440.6  2575.0  4427.9  2600.0  4426.6  2651.0  4438.8  2681.0
XS4439.1  2759.0  4439.4  2763.0  4438.4  2776.0  4438.5  2900.0  4438.2  3001.0
XS4438.0  3108.0  4438.0  3235.0  4438.1  3336.0  4438.2  3437.0  4438.4  3541.0
XS4438.5  3642.0  4439.2  3743.0  4439.4  3902.0  4439.5  4013.0  4439.4  4100.0
XS4439.9  4205.0  4439.6  4309.0  4439.4  4391.0  4439.6  4490.0  4439.7  4597.0
XS4439.8  4681.0  4439.5  4701.0  4440.1  4811.0  4440.4  4904.0  4440.3  4995.0
XS4440.9  5098.0  4440.4  5199.0  4441.3  5313.0  4441.1  5407.0  4441.0  5515.0
XS4440.6  5607.0  4441.8  5709.0  4442.3  5800.0  4441.3  5828.0  4441.2  5914.0
XS4440.6  5971.0  4439.9  6072.0  4440.5  6165.0  4440.1  6193.0  4439.6  6290.0
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XS4439.3  6384.0  4438.5  6465.0  4438.1  6568.0  4438.2  6662.0  4437.2  6782.0
XS4438.2  6826.0  4437.6  6876.0  4437.2  6973.0  4436.3  7006.0  4437.5  7040.0
XS4434.6  7152.0  4433.2  7251.0  4433.7  7316.0  4433.1  7383.0  4435.4  7418.0
XS4435.7  7447.0  4436.3  7542.0  4435.8  7638.0  4435.5  7735.0  4435.1  7804.0
XS4435.9  7857.0  4435.7  7892.0  4435.7  7990.0  4435.2  8085.0  4434.2  8185.0
XS4433.9  8284.0  4434.2  8394.0  4435.8  8503.0  4437.5  8605.0  4438.9  8705.0
XS4438.2  8748.0  4439.2  8780.0  4439.3  8831.0  4441.4  8926.0  4436.6  9016.0
XS4435.6  9074.0  4434.0  9095.0  4433.9  9146.0  4435.3  9239.0  4438.5  9289.0
XS4438.1  9358.0  4439.3  9391.0  4438.7  9414.0  4439.3  9434.0  4438.1  9468.0
XS4440.3  9563.0  4445.0  9617.0  4446.8  9669.0  4448.9  9699.0  4450.3  9726.0
RH 0.080   0.024   0.080
*** Station #13
ST83227.     196       0       0       0       0     0.0
ND     2  9908.0 12710.0
XS4447.4  1423.0  4448.2  1434.0  4446.5  1452.0
XS4444.5  1483.0  4444.0  1527.0  4443.7  1667.0  4444.4  1720.0  4442.2  1764.0
XS4441.8  1778.0  4443.5  1789.0  4441.8  1805.0  4444.4  1825.0  4442.0  1849.0
XS4440.6  1885.0  4440.1  1919.0  4439.3  1975.0  4440.3  1997.0  4438.9  2022.0
XS4441.5  2055.0  4438.7  2125.0  4439.2  2147.0  4437.3  2180.0  4437.6  2212.0
XS4439.5  2284.0  4440.2  2305.0  4439.6  2325.0  4437.5  2406.0  4435.5  2435.0
XS4433.7  2464.0  4433.1  2498.0  4433.5  2507.0  4433.9  2630.0  4432.4  2725.0
XS4430.6  2730.0  4427.1  2738.0  4424.3  2749.0  4420.3  2766.0  4420.9  2779.0
XS4422.9  2797.0  4423.8  2805.0  4426.8  2811.0  4427.1  2815.0  4430.1  2818.0
XS4433.0  2827.0  4433.4  2857.0  4432.5  2875.0  4433.9  2925.0  4433.2  3010.0
XS4434.7  3029.0  4432.8  3055.0  4433.4  3194.0  4433.0  3330.0  4433.0  3433.0
XS4432.3  3500.0  4431.2  3559.0  4432.0  3605.0  4436.9  3680.0  4439.1  3697.0
XS4430.5  3753.0  4430.1  3763.0  4429.4  3765.0  4430.4  3773.0  4430.7  3796.0
XS4419.6  3815.0  4419.2  3829.0  4430.2  3869.0  4429.4  3911.0  4429.8  3913.0
XS4430.2  3922.0  4429.5  3941.0  4429.1  4021.0  4430.6  4039.0  4430.8  4145.0
XS4429.7  4173.0  4430.4  4185.0  4430.9  4267.0  4430.6  4382.0  4429.8  4502.0
XS4431.2  4524.0  4430.7  4532.0  4430.3  4632.0  4430.8  4661.0  4429.9  4729.0
XS4430.9  4759.0  4430.5  4816.0  4430.9  4861.0  4431.2  4912.0  4429.8  4958.0
XS4430.7  4980.0  4431.3  5028.0  4430.6  5042.0  4431.2  5091.0  4431.7  5166.0
XS4430.8  5186.0  4431.1  5314.0  4430.4  5331.0  4431.1  5355.0  4431.3  5495.0
XS4431.2  5678.0  4430.7  5791.0  4428.2  5835.0  4429.6  5862.0  4430.0  5893.0
XS4431.0  5904.0  4431.5  5917.0  4430.7  5938.0  4431.8  5964.0  4431.3  5968.0
XS4431.9  5985.0  4431.3  6035.0  4431.7  6053.0  4430.1  6140.0  4430.7  6155.0
XS4430.2  6166.0  4431.0  6184.0  4431.4  6227.0  4429.6  6314.0  4431.1  6330.0
XS4432.0  6506.0  4431.7  6607.0  4431.2  6705.0  4431.2  6815.0  4430.8  6864.0
XS4431.3  6897.0  4430.7  6923.0  4431.4  6962.0  4431.9  6980.0  4431.5  7069.0
XS4430.5  7079.0  4431.7  7089.0  4430.7  7158.0  4431.7  7162.0  4432.1  7290.0
XS4431.6  7397.0  4432.2  7467.0  4431.9  7555.0  4432.5  7575.0  4431.8  7666.0
XS4432.8  7762.0  4431.7  7780.0  4432.6  7792.0  4433.1  7925.0  4432.6  8014.0
XS4432.1  8114.0  4432.0  8308.0  4432.4  8606.0  4433.3  8707.0  4433.6  8802.0
XS4434.8  8920.0  4435.1  8986.0  4434.6  9081.0  4437.0  9126.0  4432.2  9168.0
XS4435.7  9216.0  4436.5  9319.0  4436.9  9421.0  4437.3  9522.0  4438.0  9620.0
XS4438.4  9718.0  4438.9  9814.0  4439.9  9908.0  4438.2  9959.0  4438.7 10017.0
XS4433.1 10057.0  4437.6 10099.0  4439.6 10118.0  4439.1 10170.0  4438.8 10210.0
XS4437.8 10394.0  4437.3 10484.0  4436.2 10530.0  4437.4 10558.0  4437.1 10671.0
XS4437.6 10860.0  4437.3 10955.0  4436.7 11141.0  4436.5 11337.0  4436.3 11437.0
XS4435.2 11535.0  4434.4 11544.0  4436.3 11600.0  4434.0 11695.0  4433.5 11712.0
XS4435.1 11734.0  4435.2 11884.0  4435.8 11913.0  4436.7 12003.0  4436.4 12106.0
XS4437.6 12206.0  4438.9 12305.0  4440.1 12400.0  4442.2 12500.0  4444.2 12568.0
XS4443.8 12578.0  4446.0 12616.0  4450.1 12710.0
RH 0.024   0.080
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ST73142.    131      0      0      0      0    0.0
ND     1  7930.0
XS4450.3  2829.0  4442.3  2838.0  4429.0  2872.0  4426.9  2886.0  4425.9  2925.0
XS4426.1  2964.0  4427.0  2980.0  4427.0  2980.0  4426.3  2986.0  4425.9  2989.0
XS4424.0  2997.0  4421.3  2998.0  4421.0  3005.0  4417.6  3009.0  4417.4  3046.0
XS4419.0  3076.0  4419.6  3102.0  4416.9  3122.0  4416.6  3139.0  4421.0  3144.0
XS4425.2  3152.0  4425.4  3154.0  4426.4  3174.0  4425.0  3210.0  4426.1  3247.0
XS4430.2  3275.0  4426.7  3302.0  4426.9  3398.0  4427.4  3497.0  4426.5  3575.0
XS4425.2  3613.0  4426.5  3667.0  4426.8  3760.0  4426.2  3835.0  4425.9  3916.0
XS4424.8  3974.0  4426.3  3991.0  4425.1  4067.0  4424.2  4132.0  4431.6  4175.0
XS4434.0  4193.0  4432.5  4244.0  4423.0  4270.0  4423.2  4301.0  4415.4  4315.0
XS4414.0  4347.0  4425.1  4370.0  4424.6  4402.0  4422.4  4423.0  4423.2  4471.0
XS4428.1  4481.0  4428.2  4488.0  4428.3  4497.0  4422.3  4511.0  4420.1  4561.0
XS4420.6  4576.0  4420.6  4649.0  4421.5  4741.0  4422.2  4757.0  4420.9  4772.0
XS4421.0  4864.0  4420.4  4929.0  4420.9  4949.0  4420.3  4970.0  4420.8  5007.0
XS4420.4  5095.0  4420.5  5143.0  4419.8  5165.0  4419.7  5207.0  4420.3  5223.0
XS4420.3  5314.0  4419.4  5342.0  4420.3  5375.0  4420.6  5448.0  4420.4  5544.0
XS4420.6  5635.0  4420.3  5659.0  4419.7  5720.0  4420.6  5773.0  4419.9  5843.0
XS4419.1  5863.0  4417.2  5896.0  4418.9  5921.0  4419.4  6018.0  4419.6  6110.0
XS4419.9  6203.0  4419.4  6295.0  4419.8  6335.0  4419.2  6378.0  4419.0  6402.0
XS4418.4  6413.0  4418.4  6471.0  4418.6  6513.0  4418.3  6542.0  4418.8  6628.0
XS4418.3  6642.0  4419.1  6664.0  4417.7  6685.0  4418.6  6702.0  4418.7  6743.0
XS4418.6  6828.0  4418.6  6882.0  4417.7  6903.0  4419.7  6921.0  4418.3  6953.0
XS4413.9  6978.0  4414.3  6999.0  4417.1  7034.0  4418.1  7052.0  4418.1  7116.0
XS4418.7  7143.0  4418.5  7230.0  4417.6  7267.0  4419.0  7287.0  4418.7  7335.0
XS4417.2  7369.0  4417.9  7395.0  4417.0  7432.0  4417.7  7471.0  4417.0  7513.0
XS4418.7  7571.0  4418.3  7664.0  4418.8  7737.0  4421.5  7777.0  4424.4  7839.0
XS4428.6  7861.0  4436.6  7887.0  4436.1  7900.0  4443.5  7910.0  4445.2  7916.0
XS4450.3  7930.0
RH 0.024
*** Station #15
ST69002.    110      0      0      0      0    0.0
ND     1  6187.0
XS4450.3  2062.0  4448.6  2062.0  4440.3  2077.0  4433.9  2089.0  4431.9  2096.0
XS4425.5  2113.0  4422.9  2138.0  4422.5  2173.0  4421.9  2193.0  4421.1  2217.0
XS4421.4  2250.0  4422.9  2266.0  4422.8  2291.0  4423.9  2316.0  4425.3  2341.0
XS4423.5  2351.0  4423.6  2378.0  4423.9  2408.0  4424.3  2428.0  4423.9  2441.0
XS4421.7  2444.0  4420.4  2448.0  4419.3  2450.0  4415.8  2454.0  4408.0  2484.0
XS4406.3  2499.0  4415.1  2520.0  4419.3  2526.0  4419.3  2546.0  4418.8  2574.0
XS4419.8  2576.0  4422.1  2581.0  4423.3  2586.0  4423.7  2614.0  4423.8  2645.0
XS4422.8  2671.0  4423.7  2691.0  4424.6  2712.0  4424.2  2748.0  4424.2  2784.0
XS4424.4  2819.0  4423.9  2861.0  4424.3  2901.0  4424.4  2948.0  4423.4  2981.0
XS4423.4  3024.0  4423.2  3066.0  4423.6  3109.0  4422.5  3144.0  4423.6  3177.0
XS4424.0  3211.0  4422.6  3242.0  4427.2  3271.0  4431.0  3293.0  4431.0  3332.0
XS4421.2  3351.0  4421.1  3377.0  4411.6  3391.0  4411.6  3422.0  4423.1  3442.0
XS4422.6  3474.0  4421.3  3494.0  4421.8  3516.0  4425.9  3546.0  4426.0  3557.0
XS4423.6  3567.0  4421.4  3651.0  4419.9  3694.0  4420.0  3752.0  4420.5  3863.0
XS4419.6  3972.0  4419.5  4069.0  4420.0  4166.0  4420.1  4266.0  4419.8  4364.0
XS4419.4  4434.0  4421.2  4474.0  4421.1  4517.0  4420.7  4618.0  4419.7  4717.0
XS4419.2  4814.0  4420.2  4855.0  4418.8  4900.0  4419.2  4962.0  4419.3  5056.0
XS4419.2  5081.0  4419.7  5147.0  4419.4  5247.0  4419.7  5346.0  4422.1  5431.0
XS4422.1  5495.0  4421.1  5531.0  4418.7  5622.0  4417.9  5719.0  4416.1  5779.0
XS4412.9  5801.0  4412.3  5821.0  4414.2  5865.0  4414.3  5902.0  4413.8  5917.0
XS4416.0  6002.0  4415.8  6042.0  4419.2  6080.0  4423.4  6098.0  4424.0  6115.0
XS4429.7  6126.0  4433.1  6138.0  4439.0  6161.0  4444.9  6173.0  4450.3  6187.0
RH 0.024
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ST63722.    130      0      0      0      0     0.0
ND     1  4484.0
XS4450.3    75.0  4441.3    94.0  4427.4   120.0  4420.8   145.0  4420.3   171.0
XS4418.7   178.0  4418.5   187.0  4418.8   191.0  4417.9   197.0  4417.5   213.0
XS4418.2   231.0  4419.2   237.0  4419.5   269.0  4420.6   305.0  4420.8   324.0
XS4420.0   344.0  4418.9   350.0  4419.6   354.0  4418.7   367.0  4418.9   392.0
XS4418.4   429.0  4418.7   469.0  4418.5   501.0  4419.6   527.0  4418.7   530.0
XS4419.4   533.0  4419.2   571.0  4420.1   607.0  4420.1   642.0  4421.1   674.0
XS4421.5   706.0  4421.6   737.0  4421.7   756.0  4421.6   779.0  4421.5   782.0
XS4420.6   783.0  4420.6   790.0  4418.6   793.0  4417.2   797.0  4415.7   801.0
XS4415.1   822.0  4414.1   844.0  4411.4   878.0  4417.2   885.0  4420.9   888.0
XS4421.2   924.0  4421.9   929.0  4421.5  1029.0  4421.1  1059.0  4421.4  1067.0
XS4420.9  1085.0  4419.3  1096.0  4418.2  1115.0  4416.8  1127.0  4417.4  1159.0
XS4419.8  1164.0  4418.5  1174.0  4416.0  1180.0  4416.5  1228.0  4420.3  1269.0
XS4427.0  1298.0  4426.2  1344.0  4417.1  1362.0  4417.4  1388.0  4408.9  1403.0
XS4408.4  1412.0  4407.6  1420.0  4409.0  1432.0  4420.6  1453.0  4419.8  1475.0
XS4416.9  1498.0  4417.9  1526.0  4423.5  1537.0  4422.9  1541.0  4415.3  1577.0
XS4413.9  1638.0  4412.0  1657.0  4414.6  1690.0  4415.5  1726.0  4414.2  1761.0
XS4415.2  1793.0  4414.4  1894.0  4413.5  1912.0  4414.5  1932.0  4414.0  2023.0
XS4414.0  2108.0  4413.7  2209.0  4414.2  2245.0  4413.2  2285.0  4413.8  2300.0
XS4413.9  2354.0  4413.3  2376.0  4414.1  2404.0  4413.9  2507.0  4413.4  2528.0
XS4414.5  2558.0  4415.1  2628.0  4414.6  2663.0  4415.0  2753.0  4413.8  2810.0
XS4414.0  2831.0  4414.0  2872.0  4413.1  2882.0  4414.0  2890.0  4414.4  2983.0
XS4414.1  3075.0  4415.0  3119.0  4414.1  3155.0  4415.3  3218.0  4414.3  3264.0
XS4415.0  3281.0  4414.7  3376.0  4415.5  3472.0  4415.7  3565.0  4416.8  3650.0
XS4416.9  3695.0  4415.5  3723.0  4414.6  3778.0  4413.7  3803.0  4411.6  3820.0
XS4419.6  4027.0  4419.8  4121.0  4419.9  4127.0  4421.3  4218.0  4423.5  4310.0
XS4425.2  4325.0  4427.9  4374.0  4446.0  4456.0  4450.1  4483.0  4450.3  4484.0
RH 0.024
*** Station #17
ST59883.    101      0      0      0      0     0.0
ND     1  5842.0
XS4450.3   157.0  4418.3   258.0  4413.7   359.0  4414.6   663.0  4415.2   865.0
XS4416.0  1068.0  4415.3  1119.0  4417.3  1341.0  4408.9  1372.0  4419.0  1380.0
XS4417.7  1393.0  4417.6  1403.0  4419.1  1419.0  4419.3  1508.0  4418.4  1541.0
XS4419.4  1547.0  4419.2  1573.0  4418.5  1578.0  4419.3  1589.0  4419.4  1627.0
XS4417.9  1635.0  4418.3  1666.0  4418.4  1763.0  4417.4  1769.0  4417.2  1794.0
XS4417.9  1805.0  4418.1  1846.0  4417.7  1886.0  4415.5  1917.0  4415.9  1972.0
XS4423.3  2001.0  4423.9  2025.0  4421.9  2033.0  4422.1  2054.0  4414.7  2072.0
XS4415.0  2095.0  4410.6  2100.0  4410.6  2146.0  4418.5  2158.0  4418.0  2190.0
XS4414.3  2224.0  4415.1  2260.0  4419.7  2272.0  4419.5  2281.0  4416.2  2287.0
XS4414.7  2295.0  4413.3  2309.0  4410.2  2343.0  4410.6  2396.0  4410.2  2434.0
XS4411.3  2514.0  4410.8  2589.0  4410.3  2708.0  4409.2  2741.0  4410.5  2765.0
XS4411.5  2861.0  4412.0  2956.0  4411.3  3003.0  4413.3  3084.0  4413.1  3141.0
XS4412.1  3221.0  4413.1  3274.0  4413.7  3389.0  4414.6  3514.0  4415.0  3633.0
XS4413.8  3723.0  4412.8  3839.0  4412.3  3872.0  4413.4  3924.0  4412.7  4029.0
XS4413.1  4135.0  4412.6  4256.0  4412.0  4369.0  4412.2  4485.0  4411.5  4596.0
XS4411.4  4700.0  4410.1  4773.0  4411.1  4815.0  4411.3  4892.0  4412.0  4938.0
XS4410.8  4968.0  4411.9  5010.0  4411.8  5035.0  4407.0  5116.0  4413.7  5184.0
XS4413.7  5240.0  4410.4  5312.0  4412.5  5343.0  4413.1  5366.0  4412.5  5405.0
XS4414.1  5485.0  4413.4  5559.0  4409.2  5605.0  4405.3  5657.0  4411.3  5719.0
XS4425.3  5767.0  4425.2  5774.0  4425.6  5779.0  4427.7  5783.0  4430.1  5794.0
XS4450.3  5842.0
RH 0.024
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ST57665.     95      0      0      0      0    0.0
ND    1  3773.0
XS4450.3   210.0  4446.6   227.0  4438.3   250.0  4429.6   287.0  4421.4   344.0
XS4415.5   386.0  4414.1   479.0  4414.5   549.0  4417.1   636.0  4418.7   738.0
XS4417.5   793.0  4418.8   849.0  4419.1   901.0  4414.2   907.0  4407.9   912.0
XS4407.0   947.0  4412.2   983.0  4414.2   988.0  4418.9   999.0  4418.5  1071.0
XS4416.4  1088.0  4417.2  1102.0  4417.6  1115.0  4418.2  1124.0  4418.2  1167.0
XS4418.8  1173.0  4418.8  1228.0  4417.9  1235.0  4418.8  1241.0  4418.8  1315.0
XS4416.3  1361.0  4417.7  1431.0  4418.4  1451.0  4414.9  1483.0  4413.9  1519.0
XS4415.0  1529.0  4414.8  1587.0  4414.3  1595.0  4423.1  1631.0  4423.1  1649.0
XS4423.1  1681.0  4415.4  1697.0  4415.3  1749.0  4418.6  1753.0  4415.2  1758.0
XS4410.3  1777.0  4410.2  1785.0  4411.6  1800.0  4418.6  1811.0  4418.5  1824.0
XS4418.1  1838.0  4417.7  1856.0  4414.2  1901.0  4414.1  1928.0  4419.5  1952.0
XS4419.7  1966.0  4414.1  1985.0  4414.3  2006.0  4412.9  2033.0  4413.3  2050.0
XS4411.9  2071.0  4413.3  2094.0  4413.9  2122.0  4412.9  2173.0  4414.4  2207.0
XS4414.7  2250.0  4414.4  2308.0  4414.7  2381.0  4416.2  2490.0  4414.2  2610.0
XS4412.7  2707.0  4412.0  2803.0  4410.8  2817.0  4411.1  2864.0  4411.2  2900.0
XS4409.3  2954.0  4410.0  2982.0  4410.2  3002.0  4409.4  3030.0  4411.1  3071.0
XS4410.4  3126.0  4410.9  3206.0  4411.4  3222.0  4412.0  3310.0  4410.1  3334.0
XS4410.9  3350.0  4410.5  3363.0  4410.5  3391.0  4411.8  3407.0  4410.4  3416.0
XS4424.4  3660.0  4424.8  3678.0  4436.1  3721.0  4448.0  3765.0  4450.3  3773.0
RH 0.024
*** Station #19
ST54321.    108      0      0      0      0    0.0
ND    1  5521.0
XS4450.3   180.0  4445.1   198.0  4443.8   198.0  4436.8   212.0  4429.7   243.0
XS4424.5   314.0  4417.4   410.0  4415.6   492.0  4414.0   543.0  4413.3   587.0
XS4413.1   659.0  4412.3   751.0  4412.3   823.0  4411.8   892.0  4411.7   993.0
XS4412.5  1059.0  4412.4  1090.0  4414.2  1121.0  4413.3  1182.0  4412.4  1192.0
XS4414.3  1209.0  4414.3  1271.0  4415.0  1327.0  4416.5  1402.0  4416.7  1494.0
XS4405.6  1505.0  4405.4  1523.0  4407.6  1555.0  4414.5  1568.0  4415.7  1576.0
XS4416.1  1634.0  4414.6  1648.0  4414.2  1664.0  4415.0  1677.0  4415.1  1699.0
XS4414.3  1776.0  4414.4  1830.0  4415.6  1859.0  4415.6  1958.0  4416.3  2045.0
XS4414.2  2082.0  4413.3  2176.0  4415.0  2200.0  4414.1  2249.0  4420.9  2280.0
XS4421.2  2300.0  4421.3  2317.0  4413.6  2349.0  4413.2  2385.0  4404.8  2395.0
XS4405.1  2425.0  4417.5  2447.0  4417.6  2449.0  4417.7  2458.0  4417.3  2469.0
XS4413.3  2508.0  4413.0  2545.0  4417.8  2559.0  4417.5  2586.0  4413.1  2605.0
XS4412.2  2618.0  4407.9  2644.0  4413.3  2672.0  4416.1  2727.0  4416.4  2759.0
XS4415.1  2774.0  4417.5  2789.0  4416.7  2860.0  4416.4  2886.0  4416.9  2903.0
XS4416.6  2993.0  4416.0  3036.0  4416.9  3086.0  4417.3  3198.0  4418.2  3288.0
XS4419.1  3376.0  4420.4  3478.0  4421.7  3578.0  4423.3  3657.0  4423.3  3743.0
XS4425.7  3878.0  4427.0  3992.0  4428.7  4085.0  4431.3  4209.0  4431.4  4293.0
XS4432.5  4388.0  4433.7  4476.0  4435.8  4594.0  4438.1  4700.0  4440.5  4731.0
XS4440.2  4756.0  4441.7  4784.0  4442.6  4832.0  4444.3  4866.0  4442.6  4917.0
XS4441.8  4975.0  4441.7  5000.0  4441.5  5021.0  4443.7  5145.0  4445.5  5243.0
XS4446.6  5303.0  4446.5  5349.0  4450.5  5418.0  4452.8  5469.0  4449.8  5498.0
XS4449.2  5511.0  4447.7  5516.0  4450.3  5521.0
RH 0.024
***
ST50167.    127      0      0      0      0    0.0
ND    1  8110.0
XS4450.3   210.0  4428.6   253.0  4417.6   311.0  4412.5   359.0  4411.6   451.0
XS4414.0   530.0  4413.7   534.0  4411.5   536.0  4410.3   558.0  4409.4   588.0
XS4408.4   616.0  4410.6   626.0  4412.7   629.0  4414.1   701.0  4412.6   761.0
XS4412.9   864.0  4412.8   964.0  4416.0  1054.0  4413.3  1080.0  4413.2  1188.0
XS4411.8  1247.0  4411.1  1299.0  4412.3  1329.0  4412.9  1434.0  4411.0  1481.0
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XS4410.7  1536.0  4405.7  1572.0  4407.5  1596.0  4411.2  1634.0  4410.9  1686.0
XS4411.1  1715.0  4418.9  1747.0  4419.3  1765.0  4419.3  1781.0  4421.3  1810.0
XS4414.6  1823.0  4418.5  1840.0  4404.8  1854.0  4400.8  2038.0  4400.6  2050.0
XS4400.8  2068.0  4405.0  2076.0  4408.0  2091.0  4413.6  2107.0  4412.7  2131.0
XS4416.0  2154.0  4415.9  2207.0  4411.3  2240.0  4406.2  2267.0  4405.6  2303.0
XS4409.0  2327.0  4409.4  2372.0  4408.3  2433.0  4405.9  2468.0  4403.8  2505.0
XS4403.4  2555.0  4404.5  2636.0  4407.3  2697.0  4408.0  2763.0  4407.7  2817.0
XS4407.1  2889.0  4406.1  2984.0  4406.8  3058.0  4406.6  3138.0  4406.8  3211.0
XS4406.8  3215.0  4406.1  3289.0  4406.4  3370.0  4407.0  3453.0  4406.2  3471.0
XS4407.2  3496.0  4407.4  3559.0  4406.1  3602.0  4406.4  3634.0  4407.0  3729.0
XS4406.2  3848.0  4407.1  3929.0  4406.2  3962.0  4407.1  3979.0  4407.1  4053.0
XS4408.1  4114.0  4405.2  4170.0  4404.3  4260.0  4403.1  4293.0  4404.1  4317.0
XS4403.5  4333.0  4404.3  4356.0  4403.9  4432.0  4403.2  4484.0  4404.5  4508.0
XS4405.4  4559.0  4406.8  4609.0  4407.2  4630.0  4408.3  4657.0  4409.5  4716.0
XS4411.9  4791.0  4411.1  4933.0  4411.6  4998.0  4412.6  5072.0  4412.8  5171.0
XS4412.9  5255.0  4412.9  5385.0  4413.0  5470.0  4413.1  5599.0  4413.3  5712.0
XS4414.1  5818.0  4414.8  5913.0  4415.2  6026.0  4415.7  6129.0  4417.8  6235.0
XS4418.9  6353.0  4420.3  6466.0  4421.8  6590.0  4423.2  6696.0  4425.0  6804.0
XS4426.2  6889.0  4426.0  6913.0  4426.8  6940.0  4429.1  7048.0  4430.7  7171.0
XS4433.1  7305.0  4435.3  7414.0  4438.7  7567.0  4441.4  7696.0  4445.3  7865.0
XS4448.3  8026.0  4450.3  8110.0
RH 0.024
*** Station #21
ST47263.     93      0      0      0      0    0.0
ND     1  6911.0
XS4450.3    62.0  4443.2    73.0  4412.8   134.0  4411.1   252.0  4412.5   336.0
XS4409.9   365.0  4409.7   389.0  4409.4   481.0  4408.8   579.0  4407.5   669.0
XS4407.1   713.0  4406.1   816.0  4406.3   902.0  4406.3   993.0  4405.8  1089.0
XS4406.2  1184.0  4404.7  1242.0  4405.8  1263.0  4405.3  1342.0  4413.1  1390.0
XS4413.1  1398.0  4410.1  1487.0  4407.9  1490.0  4403.0  1496.0  4399.8  1503.0
XS4399.7  1521.0  4399.3  1534.0  4399.4  1546.0  4407.9  1553.0  4410.6  1557.0
XS4411.2  1568.0  4410.9  1579.0  4408.8  1601.0  4411.0  1615.0  4410.6  1667.0
XS4401.7  1723.0  4400.9  1736.0  4402.0  1746.0  4403.9  1760.0  4404.7  1797.0
XS4407.2  1809.0  4405.1  1893.0  4404.6  1999.0  4402.5  2077.0  4402.7  2134.0
XS4404.2  2175.0  4403.4  2227.0  4402.1  2281.0  4404.1  2328.0  4404.5  2433.0
XS4403.3  2538.0  4403.5  2631.0  4403.5  2749.0  4405.1  3797.0  4399.5  3977.0
XS4402.0  4023.0  4404.8  4160.0  4403.5  4280.0  4403.7  4355.0  4403.1  4416.0
XS4403.0  4462.0  4402.7  4539.0  4402.8  4611.0  4402.4  4654.0  4408.2  4752.0
XS4409.0  4841.0  4410.8  4923.0  4412.5  5019.0  4413.5  5121.0  4413.5  5226.0
XS4414.1  5328.0  4415.4  5349.0  4415.8  5425.0  4415.5  5443.0  4417.6  5478.0
XS4418.1  5517.0  4420.4  5613.0  4420.8  5657.0  4421.9  5681.0  4423.5  5770.0
XS4424.7  5868.0  4427.3  5958.0  4427.8  6004.0  4430.5  6104.0  4430.7  6139.0
XS4433.0  6177.0  4434.7  6232.0  4435.3  6316.0  4437.1  6365.0  4440.3  6493.0
XS4442.2  6622.0  4446.4  6828.0  4450.3  6911.0
RH 0.024
***
ST32521.     89      0      0      0      0    0.0
ND     1  7370.0
XS4450.3  1362.0  4449.9  1370.0  4448.0  1401.0  4445.7  1430.0  4442.8  1457.0
XS4441.4  1480.0  4439.7  1493.0  4435.7  1514.0  4432.8  1523.0  4432.1  1532.0
XS4425.7  1549.0  4426.5  1553.0  4423.6  1562.0  4423.1  1571.0  4419.9  1583.0
XS4416.8  1586.0  4412.0  1603.0  4410.0  1612.0  4410.5  1612.0  4404.6  1876.0
XS4403.0  1941.0  4402.2  2024.0  4404.1  2057.0  4411.8  2257.0  4411.8  2268.0
XS4411.7  2280.0  4410.5  2281.0  4407.9  2291.0  4404.9  2296.0  4395.9  2328.0
XS4394.9  2424.0  4395.2  2432.0  4403.9  2480.0  4392.2  2529.0  4391.9  2551.0
XS4390.9  2664.0  4390.3  2720.0  4390.9  2777.0  4392.9  2834.0  4392.9  2891.0
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XS4392.6  3006.0  4392.2  3122.0  4392.5  3239.0  4393.7  3357.0  4392.4  3477.0
XS4392.9  3597.0  4393.9  3699.0  4393.9  3802.0  4393.0  3843.0  4392.9  3968.0
XS4392.4  4095.0  4391.9  4224.0  4391.6  4355.0  4392.7  4487.0  4392.1  4622.0
XS4392.3  4760.0  4391.9  4900.0  4391.9  5042.0  4392.7  5188.0  4392.5  5336.0
XS4393.9  5488.0  4392.5  5643.0  4390.9  5801.0  4391.1  5964.0  4390.7  6130.0
XS4390.9  6238.0  4394.6  6524.0  4398.2  6596.0  4407.9  6737.0  4409.3  6746.0
XS4415.7  6802.0  4421.9  6845.0  4429.3  6891.0  4437.2  6910.0  4441.4  6925.0
XS4443.3  6934.0  4444.7  6960.0  4443.9  6982.0  4436.5  7021.0  4430.4  7056.0
XS4429.0  7076.0  4426.6  7118.0  4427.3  7161.0  4429.2  7239.0  4437.3  7295.0
XS4446.2  7344.0  4444.9  7347.0  4447.3  7351.0  4450.3  7370.0
RH 0.024
*** Station #23
ST30480.    111       0       0       0       0     0.0
ND     1  7975.0
XS4450.3   977.0  4446.8  1000.0  4444.9  1017.0  4441.1  1052.0  4439.1  1097.0
XS4436.8  1120.0  4433.9  1128.0  4436.7  1134.0  4439.1  1145.0  4442.0  1168.0
XS4442.5  1211.0  4443.4  1244.0  4442.5  1271.0  4440.7  1288.0  4440.0  1296.0
XS4439.1  1304.0  4435.9  1312.0  4433.2  1322.0  4428.4  1332.0  4424.5  1349.0
XS4423.0  1356.0  4419.0  1367.0  4416.8  1375.0  4415.5  1385.0  4411.0  1397.0
XS4409.6  1404.0  4403.9  1636.0  4398.4  1650.0  4397.6  1774.0  4397.4  1875.0
XS4398.1  1976.0  4407.9  2013.0  4405.9  2020.0  4392.9  2085.0  4392.6  2091.0
XS4392.7  2130.0  4403.7  2191.0  4405.4  2240.0  4392.7  2290.0  4394.4  2344.0
XS4392.7  2388.0  4394.4  2428.0  4392.9  2485.0  4393.9  2581.0  4392.4  2677.0
XS4391.6  2772.0  4391.0  2866.0  4390.9  2959.0  4390.8  3052.0  4390.7  3145.0
XS4390.4  3237.0  4390.4  3329.0  4390.9  3421.0  4390.4  3513.0  4391.1  3604.0
XS4391.2  3695.0  4391.1  3786.0  4391.2  3878.0  4391.9  3969.0  4391.3  4060.0
XS4390.7  4152.0  4391.7  4244.0  4391.9  4336.0  4391.9  4428.0  4391.5  4513.0
XS4389.9  4521.0  4390.1  4614.0  4390.9  4708.0  4391.0  4803.0  4391.4  4874.0
XS4390.6  4898.0  4390.0  4993.0  4389.7  5025.0  4390.6  5090.0  4390.8  5187.0
XS4390.2  5286.0  4388.9  5385.0  4388.6  5427.0  4389.9  5486.0  4389.8  5587.0
XS4389.8  5690.0  4389.8  5794.0  4389.6  5900.0  4389.7  6007.0  4389.4  6116.0
XS4389.1  6226.0  4389.4  6339.0  4389.4  6453.0  4394.4  6505.0  4388.4  6569.0
XS4388.9  6688.0  4389.1  6808.0  4390.1  6932.0  4391.8  6992.0  4389.7  7058.0
XS4389.3  7186.0  4388.8  7318.0  4389.0  7453.0  4389.7  7511.0  4397.4  7591.0
XS4407.9  7697.0  4413.1  7721.0  4416.4  7754.0  4419.9  7776.0  4425.8  7804.0
XS4430.0  7833.0  4435.5  7849.0  4439.7  7877.0  4441.4  7899.0  4445.3  7923.0
XS4450.3  7975.0
RH 0.024
***
ST27647.    101       0       0       0       0     0.0
ND     1  8963.0
XS4450.3  2377.0  4449.2  2412.0  4447.8  2465.0  4445.4  2513.0  4444.5  2535.0
XS4443.6  2591.0  4441.7  2649.0  4439.9  2663.0  4439.4  2675.0  4439.5  2735.0
XS4438.3  2778.0  4436.7  2832.0  4434.4  2886.0  4433.2  2900.0  4433.6  2916.0
XS4433.1  2955.0  4431.6  3008.0  4429.7  3062.0  4428.3  3114.0  4425.9  3167.0
XS4424.1  3221.0  4421.8  3269.0  4420.2  3319.0  4417.3  3374.0  4415.8  3425.0
XS4414.3  3482.0  4412.8  3541.0  4411.3  3593.0  4407.9  3624.0  4409.6  3640.0
XS4404.4  3649.0  4409.6  3717.0  4402.6  3734.0  4403.8  3769.0  4403.1  3772.0
XS4395.9  3810.0  4404.9  3848.0  4403.9  3894.0  4403.1  3904.0  4403.3  3992.0
XS4405.4  4020.0  4407.9  4061.0  4407.1  4068.0  4411.0  4076.0  4410.6  4084.0
XS4407.9  4088.0  4399.6  4146.0  4394.6  4162.0  4395.1  4235.0  4401.9  4284.0
XS4401.4  4319.0  4394.9  4329.0  4391.4  4360.0  4392.9  4428.0  4392.7  4533.0
XS4390.9  4645.0  4390.7  4764.0  4390.4  4891.0  4389.9  5027.0  4389.4  5173.0
XS4389.2  5413.0  4389.4  5500.0  4389.4  5590.0  4389.4  5684.0  4389.1  5816.0
XS4389.1  5885.0  4388.9  5956.0  4388.4  6105.0  4388.4  6183.0  4388.4  6263.0
XS4388.1  6346.0  4388.1  6432.0  4388.1  6521.0  4388.1  6614.0  4388.1  6709.0
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XS4388.1  6808.0  4388.3  6911.0  4388.3  7017.0  4388.1  7131.0  4387.9  7243.0
XS4388.1  7363.0  4387.9  7489.0  4387.7  7619.0  4387.9  7755.0  4388.4  7897.0
XS4388.9  8046.0  4389.9  8141.0  4393.3  8201.0  4407.9  8365.0  4409.7  8408.0
XS4415.1  8469.0  4416.5  8515.0  4419.1  8585.0  4422.2  8646.0  4425.3  8688.0
XS4431.3  8737.0  4436.9  8829.0  4436.0  8859.0  4437.5  8897.0  4443.2  8937.0
XS4450.3  8963.0
RH 0.024
*** Station #25
ST25059.     77       0       0       0       0     0.0
ND     1  5350.0
XS4450.3   836.0  4448.4   854.0  4449.0   879.0  4449.2   912.0  4448.4   959.0
XS4446.2  1015.0  4442.5  1052.0  4442.0  1090.0  4442.5  1111.0  4441.0  1150.0
XS4439.4  1182.0  4439.0  1185.0  4434.3  1207.0  4428.6  1229.0  4426.0  1246.0
XS4423.1  1262.0  4421.2  1276.0  4419.0  1306.0  4413.0  1355.0  4411.6  1379.0
XS4410.8  1393.0  4410.9  1419.0  4408.7  1454.0  4407.1  1481.0  4405.5  1550.0
XS4407.2  1577.0  4414.9  1607.0  4415.1  1636.0  4412.5  1665.0  4408.7  1700.0
XS4408.9  1707.0  4410.1  1708.0  4407.9  1731.0  4402.9  1751.0  4400.4  1807.0
XS4400.4  1889.0  4400.1  1972.0  4400.4  2055.0  4400.1  2139.0  4400.4  2225.0
XS4400.6  2311.0  4400.9  2366.0  4405.9  2764.0  4402.2  2832.0  4401.9  2855.0
XS4402.2  2871.0  4404.9  2950.0  4402.1  3048.0  4401.8  3147.0  4401.4  3234.0
XS4400.9  3248.0  4400.2  3267.0  4400.2  3306.0  4405.3  3339.0  4403.9  3352.0
XS4398.6  3371.0  4398.1  3457.0  4397.3  3565.0  4397.0  3675.0  4395.6  3788.0
XS4394.9  3904.0  4394.6  4023.0  4391.9  4145.0  4391.3  4270.0  4390.9  4399.0
XS4390.9  4531.0  4390.8  4668.0  4390.0  4809.0  4389.9  4955.0  4405.4  5063.0
XS4408.3  5107.0  4410.3  5122.0  4412.4  5156.0  4416.5  5184.0  4420.5  5249.0
XS4443.1  5319.0  4450.3  5350.0
RH 0.024
***
ST23335.     44       0       0       0       0     0.0
ND     1  1707.0
XS4450.3   132.0  4447.3   138.0  4446.3   142.0  4443.3   142.0  4434.6   154.0
XS4418.6   156.0  4414.1   168.0  4413.2   175.0  4414.1   178.0  4411.4   182.0
XS4408.4   190.0  4402.2   281.0  4398.2   329.0  4402.8   395.0  4400.2   471.0
XS4403.4   547.0  4403.7   595.0  4402.2   663.0  4402.5   702.0  4399.4   779.0
XS4397.7   780.0  4397.8   826.0  4403.8   836.0  4403.8  1423.0  4408.8  1431.0
XS4419.3  1449.0  4422.7  1451.0  4423.2  1453.0  4426.2  1453.0  4426.7  1456.0
XS4432.0  1467.0  4435.9  1469.0  4437.9  1474.0  4439.7  1475.0  4441.4  1481.0
XS4443.8  1508.0  4445.6  1524.0  4446.5  1574.0  4445.1  1602.0  4445.6  1612.0
XS4445.5  1625.0  4445.2  1655.0  4447.1  1682.0  4449.9  1707.0
RH 0.024
*** Station #27
ST20325.     89       0       0       0       0     0.0
ND     1  4129.0
XS4450.3   651.0  4450.0   652.0  4447.4   687.0  4447.6   710.0  4447.8   736.0
XS4444.7   762.0  4439.1   781.0  4439.2   803.0  4443.5   831.0  4442.4   866.0
XS4439.0   902.0  4435.9   929.0  4436.1   947.0  4432.2   985.0  4430.1  1011.0
XS4426.8  1038.0  4427.2  1070.0  4427.6  1086.0  4424.0  1096.0  4421.2  1111.0
XS4420.7  1120.0  4417.8  1130.0  4411.6  1135.0  4410.7  1149.0  4410.0  1159.0
XS4410.0  1160.0  4408.4  1164.0  4403.1  1205.0  4401.3  1252.0  4400.8  1294.0
XS4399.6  1390.0  4400.0  1626.0  4399.9  1688.0  4399.7  1738.0  4399.3  1993.0
XS4400.3  2004.0  4396.9  2021.0  4396.1  2065.0  4398.9  2102.0  4402.4  2181.0
XS4399.4  2443.0  4399.5  2466.0  4397.3  2475.0  4397.9  2480.0  4398.2  2508.0
XS4398.7  2540.0  4398.7  2946.0  4398.4  2983.0  4398.4  3040.0  4398.3  3097.0
XS4397.9  3153.0  4397.8  3208.0  4397.8  3261.0  4398.1  3314.0  4397.6  3366.0
XS4397.5  3418.0  4397.3  3469.0  4397.4  3493.0  4398.9  3519.0  4402.9  3568.0
XS4407.9  3598.0  4411.9  3609.0  4412.6  3622.0  4409.1  3651.0  4409.7  3663.0
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XS4408.3  3676.0  4407.9  3685.0  4405.9  3692.0  4403.8  3714.0  4399.3  3762.0
XS4398.9  3809.0  4399.1  3823.0  4404.3  3856.0  4408.5  3887.0  4411.5  3912.0
XS4411.9  3931.0  4412.4  3943.0  4412.1  3958.0  4410.5  3968.0  4410.6  3982.0
XS4411.9  4001.0  4409.2  4012.0  4411.2  4022.0  4414.4  4033.0  4412.7  4040.0
XS4420.8  4052.0  4426.7  4067.0  4427.4  4126.0  4450.3  4129.0
RH 0.024
***
ST17611.     36      0      0      0      0    0.0
ND    1  1536.0
XS4450.3   241.0  4447.0   266.0  4445.2   297.0  4440.3   332.0  4436.9   352.0
XS4433.4   381.0  4429.4   409.0  4426.3   441.0  4423.2   469.0  4420.6   489.0
XS4420.5   502.0  4418.4   512.0  4413.8   520.0  4407.9   526.0  4399.9   544.0
XS4399.0   586.0  4399.5   623.0  4401.7   713.0  4396.3   755.0  4393.9   788.0
XS4394.4   797.0  4397.9   801.0  4396.6   810.0  4398.1  1061.0  4395.7  1316.0
XS4394.9  1340.0  4393.0  1359.0  4396.0  1383.0  4395.6  1426.0  4395.9  1459.0
XS4407.9  1504.0  4408.4  1506.0  4411.4  1512.0  4420.6  1523.0  4427.5  1534.0
XS4450.3  1536.0
RH 0.024
*** Station #29
ST15288.     49      0      0      0      0    0.0
ND    1  1577.0
XS4450.3   199.0  4445.9   211.0  4439.1   229.0  4430.1   261.0  4425.9   273.0
XS4423.8   278.0  4426.2   287.0  4425.9   310.0  4422.5   346.0  4419.3   369.0
XS4416.0   389.0  4413.1   408.0  4410.1   424.0  4407.9   433.0  4399.9   468.0
XS4391.6   527.0  4391.2   533.0  4390.9   567.0  4393.2   617.0  4400.4   660.0
XS4400.2   668.0  4397.1   697.0  4396.1   806.0  4395.2   845.0  4395.8   896.0
XS4395.5   955.0  4395.3  1008.0  4395.7  1029.0  4395.9  1056.0  4395.9  1075.0
XS4396.7  1093.0  4404.9  1100.0  4409.9  1144.0  4413.1  1194.0  4415.3  1239.0
XS4418.3  1280.0  4418.9  1313.0  4418.3  1328.0  4420.5  1340.0  4424.0  1375.0
XS4425.3  1402.0  4425.5  1408.0  4429.9  1440.0  4434.6  1460.0  4438.8  1496.0
XS4438.6  1502.0  4440.7  1513.0  4446.7  1556.0  4450.3  1577.0
RH 0.024
***
ST13070.     62      0      0      0      0    0.0
ND    2   605.0  1588.0
XS4440.0     0.0  4442.1     6.0  4440.0    19.0  4437.4    34.0  4436.4    43.0
XS4433.3    48.0  4431.6    75.0  4425.8   106.0  4425.2   136.0  4423.5   168.0
XS4422.7   198.0  4422.8   226.0  4422.5   257.0  4422.1   275.0  4423.4   322.0
XS4424.9   361.0  4426.7   394.0  4427.8   426.0  4425.1   460.0  4422.8   492.0
XS4422.7   518.0  4425.7   546.0  4436.8   578.0  4443.2   605.0  4442.4   617.0
XS4440.8   618.0  4437.2   630.0  4432.1   630.0  4428.5   653.0  4420.9   669.0
XS4416.9   685.0  4413.8   707.0  4412.7   712.0  4409.3   724.0  4408.0   725.0
XS4395.6   743.0  4394.8   791.0  4394.9   840.0  4395.3   890.0  4396.0   911.0
XS4395.9   946.0  4398.9  1017.0  4393.9  1046.0  4391.9  1072.0  4392.0  1099.0
XS4394.1  1154.0  4399.2  1181.0  4400.2  1210.0  4398.7  1236.0  4398.2  1264.0
XS4395.9  1277.0  4403.9  1322.0  4407.9  1325.0  4416.6  1347.0  4418.1  1365.0
XS4419.0  1385.0  4426.7  1433.0  4427.6  1468.0  4429.4  1501.0  4432.5  1542.0
XS4436.4  1571.0  4438.5  1588.0
RH 0.080   0.024
*** Station #31
ST10470.     22      0      0      0      0    0.0
ND    1  1536.0
XS4450.3   766.0  4449.1   768.0  4446.4   773.0  4442.4   776.0  4433.2   790.0
XS4428.7   796.0  4424.5   811.0  4419.3   813.0  4417.1   819.0  4411.4   826.0
XS4393.3   895.0  4394.4   944.0  4390.4   998.0  4391.1  1046.0  4392.7  1094.0
XS4394.6  1203.0  4393.4  1250.0  4393.9  1334.0  4393.9  1353.0  4393.1  1414.0
```

```
XS4431.1  1498.0  4450.3  1536.0
RH 0.024
***
ST 5630.    41     0     0     0     0    0.0
ND    1  1508.0
XS4450.3   288.0  4446.5   294.0  4438.9   311.0  4430.2   335.0  4421.0   367.0
XS4412.7   395.0  4408.7   413.0  4407.9   414.0  4405.9   418.0  4397.1   458.0
XS4390.9   493.0  4390.2   518.0  4389.7   576.0  4389.7   634.0  4389.9   690.0
XS4390.0   746.0  4390.5   801.0  4390.8   855.0  4391.1   908.0  4391.1   934.0
XS4391.1   956.0  4394.1   961.0  4395.3  1003.0  4397.1  1011.0  4393.9  1013.0
XS4393.4  1065.0  4391.5  1116.0  4391.5  1138.0  4396.9  1148.0  4396.1  1167.0
XS4391.6  1217.0  4390.6  1267.0  4390.2  1316.0  4390.9  1354.0  4394.3  1365.0
XS4408.1  1438.0  4417.2  1453.0  4425.2  1453.0  4439.3  1485.0  4444.9  1504.0
XS4450.3  1508.0
RH 0.024
*** Station #33
ST 2709.    48     0     0     0     0    0.0
ND    1  2345.0
XS4450.3   853.0  4449.1   854.0  4442.4   861.0  4437.7   864.0  4434.2   871.0
XS4423.7   873.0  4417.0   880.0  4409.8   890.0  4408.0   893.0  4404.5   900.0
XS4389.3   915.0  4389.2   934.0  4389.5  1010.0  4391.8  1041.0  4393.5  1094.0
XS4387.4  1120.0  4386.6  1181.0  4386.8  1202.0  4391.5  1237.0  4391.7  1293.0
XS4390.4  1404.0  4389.0  1424.0  4389.2  1502.0  4390.8  1516.0  4398.0  1628.0
XS4403.6  1741.0  4405.0  1752.0  4405.2  1782.0  4400.5  1804.0  4401.0  1815.0
XS4408.5  1829.0  4409.5  1837.0  4410.1  1863.0  4407.5  1901.0  4409.8  1938.0
XS4408.4  1957.0  4409.3  2110.0  4411.9  2145.0  4417.1  2177.0  4422.4  2211.0
XS4428.3  2239.0  4434.5  2267.0  4438.3  2294.0  4440.6  2309.0  4440.9  2315.0
XS4441.3  2327.0  4449.3  2344.0  4450.3  2345.0
RH 0.024
***  Outlet
ST   0.0    46     1     1     0     0    0.0
ND    1  3289.0
XS4453.3  1890.0  4450.3  1920.0  4450.3  1920.0  4447.5  1925.0  4436.5  1932.0
XS4427.9  1951.0  4421.6  1969.0  4414.0  1986.0  4410.8  1992.0  4390.2  2084.0
XS4390.1  2110.0  4389.7  2157.0  4393.4  2347.0  4388.0  2373.0  4387.0  2396.0
XS4385.8  2446.0  4385.8  2472.0  4389.5  2494.0  4392.0  2496.0  4393.1  2504.0
XS4391.5  2547.0  4390.2  2599.0  4389.8  2622.0  4389.3  2651.0  4389.2  2705.0
XS4389.3  2759.0  4389.3  2814.0  4389.8  2871.0  4388.0  2877.0  4388.6  2928.0
XS4389.4  2973.0  4388.7  2987.0  4388.7  3000.0  4386.9  3010.0  4386.9  3027.0
XS4389.1  3037.0  4389.1  3047.0  4388.0  3108.0  4387.4  3166.0  4403.3  3211.0
XS4408.0  3228.0  4409.0  3230.0  4431.3  3266.0  4441.5  3287.0  4449.9  3288.0
XS4450.3  3289.0
RH 0.024
***  Number of stream tubes
NT    3
***
IT  2460     5    1.0    DAY
***
***  Boundary conditions: table with stage and discharge
***
QQ     TABLE OF DISCHARGES
SS     STAGE DISCHARGE TABLE
TL    33
SQ 1190.  4408.2      1
SQ 1010.  4408.2      1
...
```

```
...
SQ  965.  4449.9       1
SQ  965.  4449.9       1
***
***  Sediment transport data ***************************************************
***
SE     6
***
***  Non-equilibrium transport parameters
***
N0 79500    0.01      1.0
N0 80000   0.001      1.0
N0124500  0.0003     1.0
N0148000  0.0001     1.0
***
***  Sediment rating curve
***
QR 1.415   1.261
***
***  Temperature records
***
TM    31    37.4   F
TM    29    48.2   F
...
...
TM    31    50.0   F
TM    29    50.9   F
***
***  Bed sorting information
***
SF     9    99.3
SG.00025    .004    41.0
SG  .004    .008    50.0
SG  .008    .016    50.0
SG  .016    .031    50.0
SG  .031    .062    50.0
SG  .062    .125    74.0
SG  .125    .250    74.0
SG  .250    .50     74.0
SG  .50    2.0      74.0
***
***  Bed gradation using interpolated values from known stations.
***
***  Rangelines 59 and 24 have the same bed gradations
NB100814
BG.16800  .03635  .03635  .03468  .03635  .26545  .33341  .08469  .00472
***  Rangeline 20
NB111414
BG.21700  .04965  .04965  .04738  .04965  .24563  .26711  .06977  .00417
***  Rangeline 18
NB118694
BG.16300  .01734  .01734  .01655  .01734  .16472  .44834  .14730  .00806
***  Rangeline 17
NB124560
BG.05600  .01307  .01307  .01247  .01307  .17262  .53313  .17377  .01282
***  Rangeline 16
```

```
NB126460
BG.11700  .02756  .02756  .02629  .02756  .15085  .46832  .14821  .00665
***  Rangeline 14
NB133100
BG.15600  .03706  .03706  .03536  .03706  .21470  .36961  .10850  .00465
***  Rangeline 13
NB134151
BG.15100  .03587  .03587  .03423  .03587  .15747  .40906  .13405  .00658
***  Rangeline 10
NB145471
BG.12700  .02257  .02257  .02153  .02257  .25894  .39618  .12186  .00679
***
***  Cohesive sediment data
***
CS 0.021    0.10    2.40    0.63   0.250    0.05
CH 1.0e9   5.0e9            -1      -1      -1
***
***  Distribution of incoming sediment
***
IQ     1     20.     20.    225.    425.    700.   1175.   2000.   3250.   4750.
8000.
IS  clay    .020    .398    .176    .228    .149    .202    .209    .113    .213
.172
IS vfslt    .020    .051    .093    .062    .041    .045    .049    .023    .038
.027
IS  fslt    .020    .052    .093    .062    .042    .046    .050    .022    .040
.028
IS  mslt    .030    .032     .08     .10    .089    .091    .140    .158    .134
.100
IS  cslt    .100    .036     .08    .101    .094    .098    .142    .157    .137
.100
IS vfsnd    .400    .136    .087    .179    .236    .206    .201    .306    .249
.334
IS  fsnd    .350    .252    .344    .215    .291    .270    .191    .202    .174
.218
IS  msnd    .059    .042    .043    .051    .057    .041    .018    .019    .015
.021
IS other    .001    .001    .004    .002    .001    .001    .000    .000    .000
.000
***
***  Angle of repose
***
AR   -90     -90
***
***  Output options
***
PR     2    2460
PX  2460
PW  2460
END
```

3.2 Output Data Files

All the output files for this example are included, in electronic format, in the GSTARS4 distribution in directory Example3.

3.3 Results and Discussion

In this section we present a brief discussion of the simulation results. The data used to set-up the input datafiles was based on a survey of 1980. Since we also have access to survey data of 1988, corresponding to the end of the time span of the GSTARS4 simulation in this example, that data is used for comparison purposes. Note that this example does not constitute a detailed sedimentation study of the region. It is included here for didactic purposes only. A more detailed and accurate analysis was presented in Yang et al. (1998). In this study there are several quantities that differ from the original Yang et al. (1998) study, as well as from Example 4 in the GSTARS 2.1 manual (Yang and Simoes, 2000). For example, a different rating curve was used. The rating curve used in this study is based directly on measured data, but it underlines the need for further model calibration, making it of pedagogic interest. Therefore, the results presented in this section are not directly comparable to those presented in Yang et al. (1998) and in Yang and Simoes (2000).

The results of the simulation are shown in figures 3.7 through 3.10 for four cross sections representative of the upper reach of the study. The results of the GSTARS4 generally match the 1988 measurements in this region of the modeled reach. The GSTARS4 calibration runs for this example were done by matching deposition volumes rather than thalwegs. As a result, the computed thalwegs are underpredicted in almost the entire reach of the study, as shown in figure 3.11. This choice of calibration is used here not only to present an example of reservoir sedimentation modeling, but also because in reservoir sedimentation it is often more important to predict deposition volumes accurately than the corresponding thalwegs.

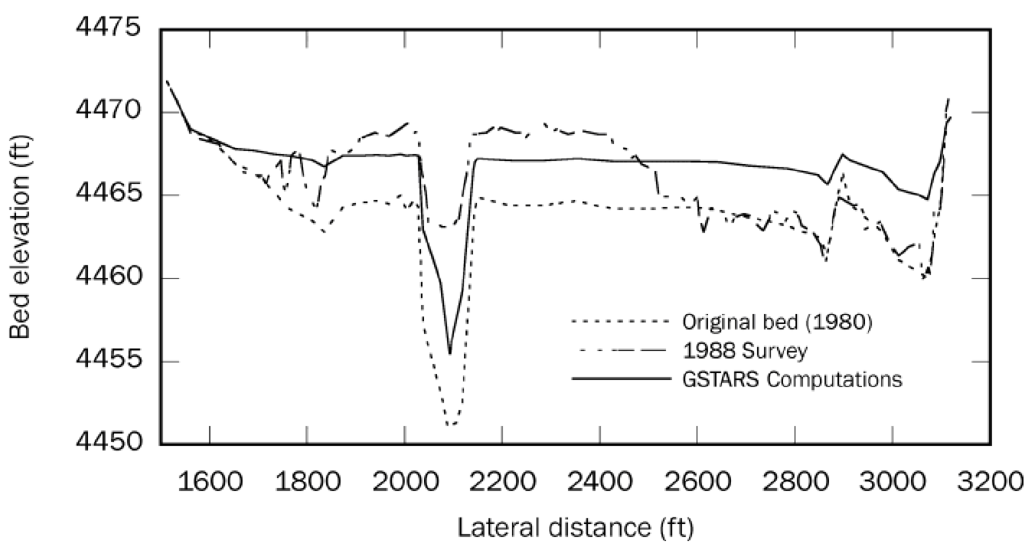

Figure 3.7 Computed and measured cross sections at rangeline 57, which is located at a distance of approximately 134,151 ft from the downstream boundary.

In this study, it is observed that there are no bed changes in the lower one third of the reach, therefore the computed deposition volumes there are nearly zero. Measurements indicate that they are small, but not negligible. The differences between measured and computed quantities in that region are attributed to a poor sediment inflow rating curve.

As can be seen in figure 3.4, the scatter of the data is high. With the rating curve derived using this data, the inflow volume of sediment into the reservoir is severely underpredicted. This underlines one more of the limitations and caveats of using sediment inflow rating curves that are a power function of the water discharge. Although this type of relationships is useful in many branches of hydrology, it is inadequate and sometimes even dangerous when used in complex sediment transport models, such as GSTARS4. A more appropriate procedure might be to try to match the rating curve not only to the data of figure 3.4, but also to the measured deposition volumes in the reservoir. That was accomplished in the study by Yang et al. (1998), resulting in a much accurate modeling of the reservoir deposits and thalwegs.

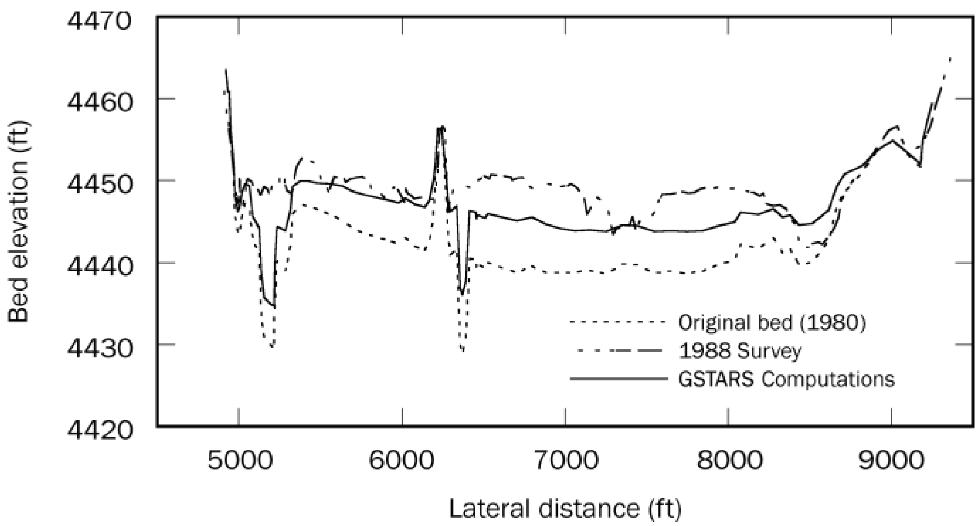

Figure 3.8 Computed and measured cross sections at rangeline 50, which is located at a distance of approximately 100,814 ft from the downstream boundary.

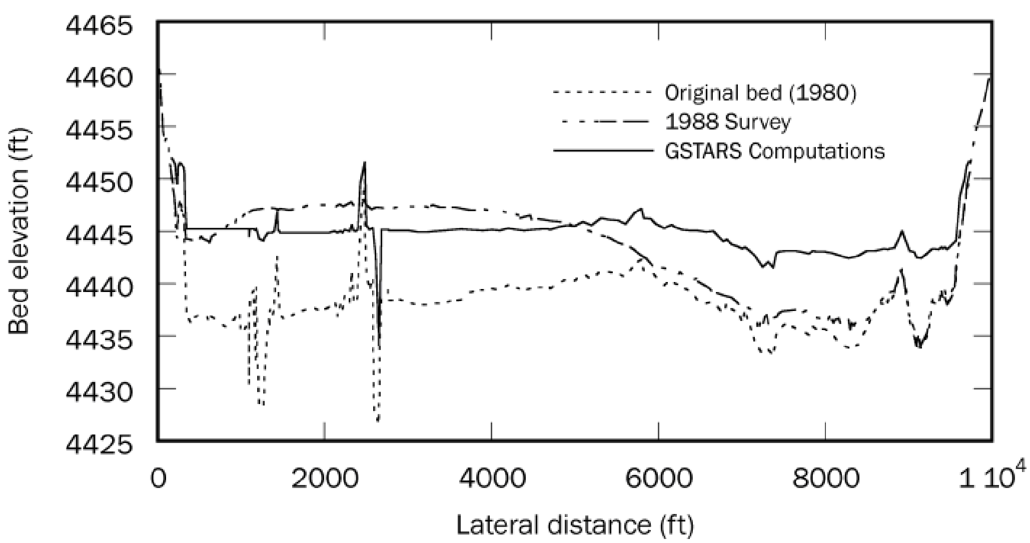

Figure 3.9 Computed and measured cross sections at range line 48, which is located at a distance of approximately 88,577 ft from the downstream boundary.

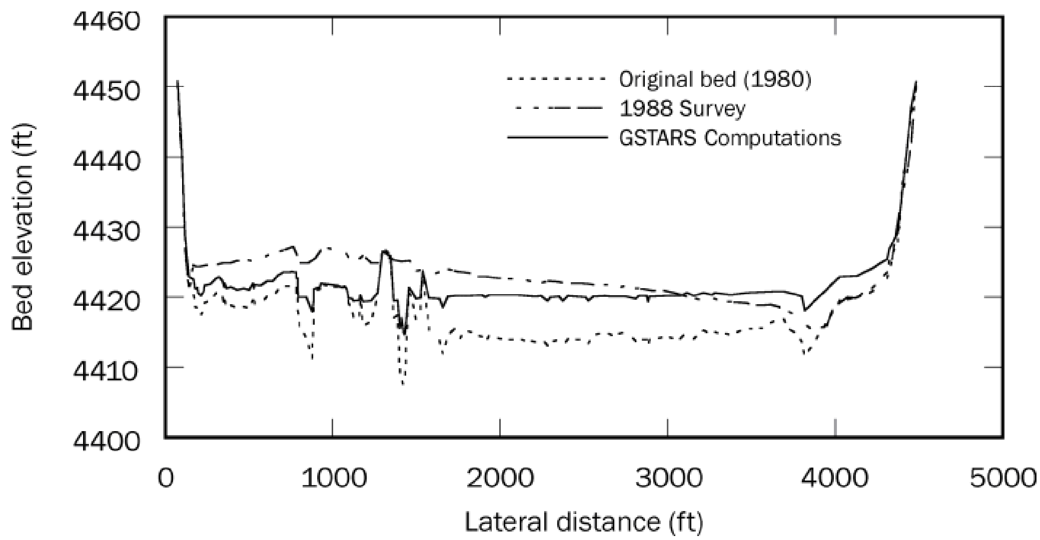

Figure 3.10 Computed and measured cross sections at rangeline 39, which is located at a distance of approximately 63,722 ft from the downstream boundary.

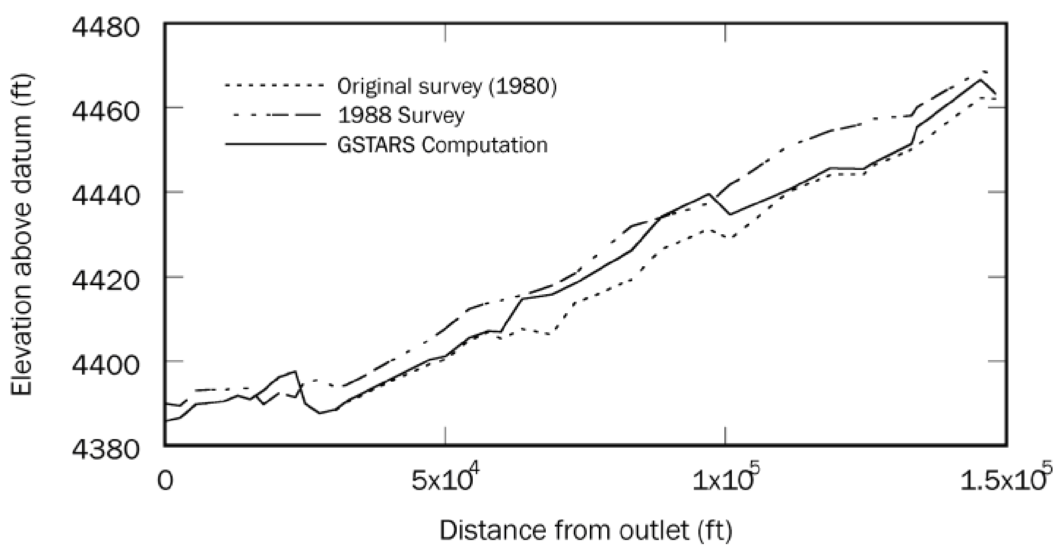

Figure 3.11 Thalweg elevations for the simulated reach.

3.4 References

Yang, C.T., Trevino, M.A., and Simoes, F.J.M. (1998). User's manual for GSTARS 2. (Generalized Stream Tube model for Alluvial River Simulation version 2.0). U.S. Bureau of Reclamation, Technical Service Center, Denver, Colorado.

Yang, C.T., and Simoes, F.J.M. (2000). User's manual for GSTARS 2.1 (Generalize Stream Tube model for Alluvial River Simulation version 2.1). U.S. Bureau of Reclamation, Technical Service Center, Denver, Colorado.

EXAMPLE 4

TAPU RESERVOIR, TAIWAN

This example is similar to example 3. Tapu reservoir is a run-of-the-river type of reservoir (except for a small lake-like area near the dam) located in the Au-Mei River, in the northern part of Taiwan, with a natural drainage area of 24,710 acres. Tapu is a multipurpose reservoir for irrigation, flood control, and water supply. Its concrete gravity dam was completed in 1960. The map of the reservoir is shown in figure 4.1.

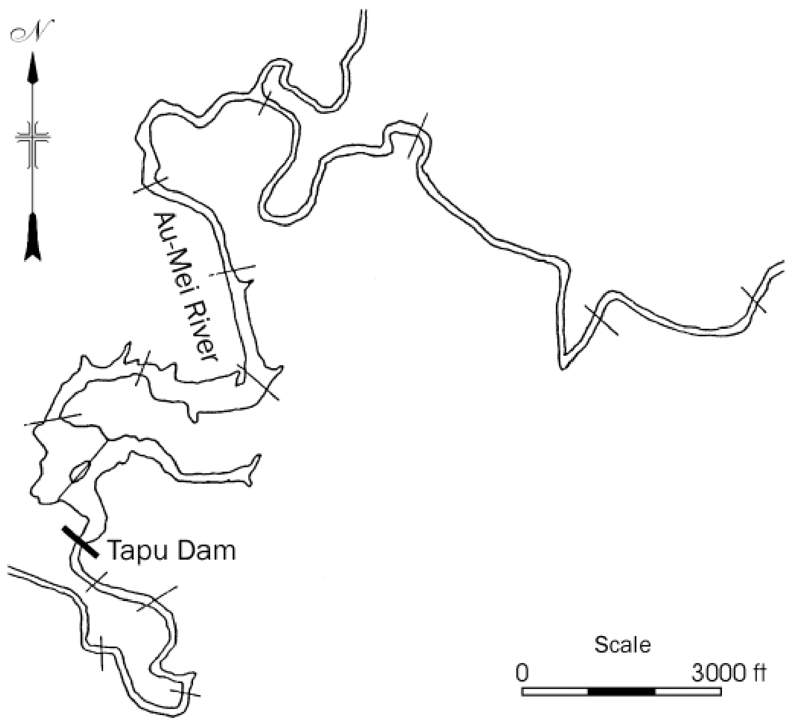

Figure 4.1 Tapu dam and reservoir in northern Taiwan.

Data collected in 1987 is used in the present study. 17 cross sections are used, comprising a reach with 41,561 ft in length. The run simulates a four-year period, ranging between 1987 and 1990. 144 10-day time steps are used in this run, with the corresponding hydrology shown in figure 4.2. River inflow discharge and stage at the dam are defined using TABLE OF DISCHARGE in record QQ and STAGE DISCHARGE TABLE in record SS, in which case the hydrology is supplied using TL and SQ records.

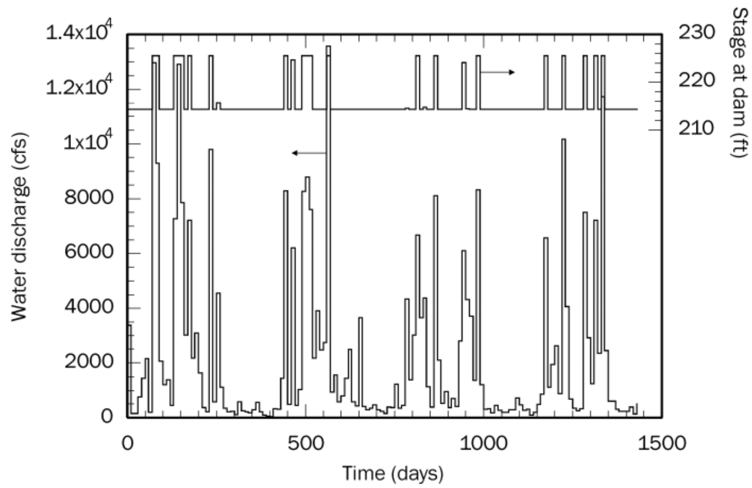

Figure 4.2 Hydrology for Tapu reservoir in the period of 1987 to 1990.

Bed composition comprises very fine material, as shown in figure 4.3, and is specified using sets of NB/BG records. Due to the presence of silt and clay fractions, it is necessary to use CS and CH records to define the appropriate cohesive sediment transport parameters. Inflow sediment distribution is defined using IQ/IS records, with an inflow sediment rating curve defined in a QR record:

$$Q_s = 12.153 Q^{0.5738}$$

where Q_s = sediment discharge (ton/day) and Q = water discharge (ft^3/s). Sediment transport is computed using Yang (1973) and (1984) sediment transport equations using quarter-day time steps and 5 stream tubes.

4.1 Input Data File

The files shown in this and the next sections are part of the main GSTARS4 distribution package. They can be found under directory Example4.

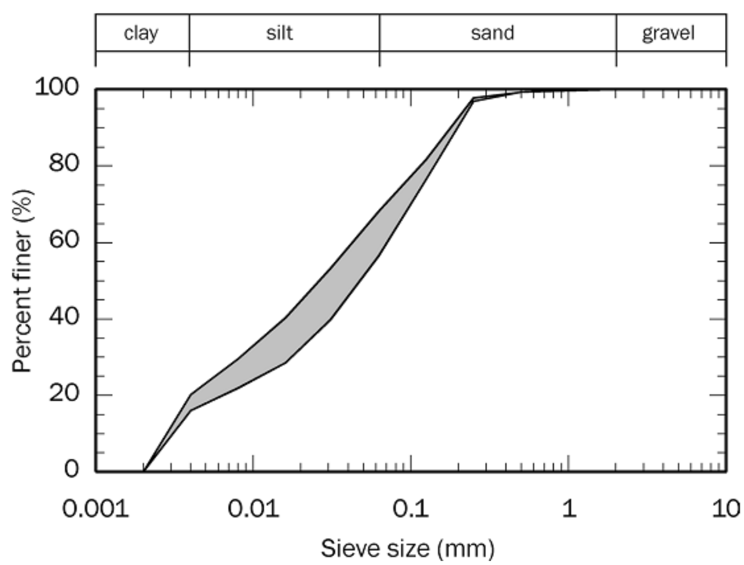

Figure 4.3 Range of particle sizes for the bed sediment composition in the reach of interest.

```
TT        Simulation of the Tapu Reservoir from 1987 to 1990
TT
*********************************************************************************
*** NOTE: this is a datafile to be used as an example of input data as it   ***
*** might be used in a GSTARS version 3.0 simulation.  It should not be     ***
*** used for any other purpose without appropriate verification and         ***
*** validation.                                                   ***
***                                                          ***
*********************************************************************************
NS    17
YX
ST 41561     15      0      0      0
ND    1   220.8
XS 265.7   0.00   264.4   42.65   256.1   45.28   248.7   46.29   242.9   56.76
XS 242.0   85.31   239.0   109.9   236.0   127.3   237.3   140.1   235.6   154.2
XS 237.0   169.3   258.7   174.5   264.4   176.5   264.7   187.0   266.6   220.8
RH 0.035
ST 39887     21      0      0      0
ND    1   255.9
XS 241.9   0.00   257.0   8.203   258.0   52.50   250.3   54.79   244.8   55.78
XS 241.7   80.23   236.18   90.56   236.9   104.3   235.2   133.9   234.8   152.9
XS 233.7   183.7   235.2   192.6   241.9   200.8   244.1   214.6   250.3   215.6
XS 257.9   216.5   258.2   223.1   257.7   234.6   251.4   239.5   248.2   244.4
XS 248.2   255.9
RH 0.035
ST 36643     13      0      0      0
ND    1   203.4
XS 241.8   0.00   246.8   62.34   239.2   63.65   235.5   65.62   235.5   68.90
XS 227.1   79.73   226.2   101.7   225.4   114.8   224.9   141.1   229.8   150.9
XS 233.0   160.8   246.8   180.5   247.9   203.4
RH 0.035
ST 34365     13      0      0      0
ND    1   295.3
XS 255.7   0.00   257.1   42.65   239.2   45.93   228.7   49.22   226.6   69.89
XS 222.2   125.3   224.7   168.0   226.5   195.2   232.9   207.4   232.6   268.1
XS 240.8   287.4   257.2   289.4   257.2   295.3
RH 0.035
ST 31262     19      0      0      0
ND    1    269
XS 232.0   0.00   236.3   2.625   236.6   16.73   242.8   65.95   242.8   70.21
XS 232.9   73.17   232.3   81.70   226.0   85.96   221.3   118.8   222.6   164.4
XS 225.9   188.3   233.5   207.4   243.5   210.0   243.5   212.9   243.7   218.8
XS 238.7   247.7   239.2   258.9   237.8   264.8   235.1   269.0
RH 0.035
ST 28430     18      0      0      0
ND    1   429.8
XS 259.7   0.00   256.2   39.37   236.0   43.31   239.8   59.39   237.0   71.53
XS 242.3   99.74   241.9   135.5   236.4   154.2   232.0   183.7   226.1   250.0
XS 222.1   269.0   214.4   312.7   220.1  344.20   247.8  378.30   256.3  383.90
XS 256.5  389.10   257.0  400.00   259.2  429.80
RH 0.035
ST 25965     19      0      0      0
ND    1   328.1
XS 259.9   0.00  256.90   8.203   256.3   13.12   241.9   35.76   240.3   47.25
XS 229.6   69.89   226.5   161.8   223.1   168.3   215.8   182.4   209.1   212.0
XS 207.0   234.3   221.0   281.5   229.5   282.8   240.5   295.0   241.2   298.9
```

```
XS 241.8   302.8   251.7   304.5   252.6   310.4   265.8  328.10
RH 0.035
ST 22780      14       0       0       0
ND    1   358.6
XS 277.4    0.00   228.8   37.40   221.5   72.18   220.3   89.90   214.9   111.6
XS 211.5   142.7   210.8   180.8   213.5   212.6   222.2   229.7   224.7   254.3
XS 225.9   265.8   233.5   270.4   249.0   298.6   296.4  358.60
RH 0.035
ST 20695      15       0       0       0
ND    1   465.6
XS 295.4    0.00   281.2   31.83   262.5   55.45   232.0   114.8   226.4   130.6
XS 219.2  160.77  216.55  180.13  197.06  208.67  200.14  238.20  219.56  272.32
XS 229.7   306.8   238.7  328.10   246.4  370.80   275.3  418.00   295.9  465.60
RH 0.035
ST 18113      16       0       0       0
ND    1   462.6
XS 240.6    0.00   239.7   9.843   222.4   21.65  194.80   53.48   196.1   93.51
XS 208.7   145.0   214.9   168.0   225.0   221.8   231.4   260.8   239.1   262.5
XS 239.6   315.6   233.4  345.80   234.7  360.36   241.3  368.50   240.9  382.20
XS 239.4  462.60
RH 0.035
ST 15199      15       0       0       0
ND    1     962
XS 262.9    0.00   232.8   82.68   230.0   213.6   230.2   316.9   226.1  372.70
XS 223.1  443.60   217.9  469.80   204.1  555.50   210.3  641.10   218.5  730.70
XS 219.5  771.70   223.1  835.00   229.3  876.00   262.8  922.00   278.9  962.00
RH 0.035
ST 12440      20       0       0       0
ND    1   334.7
XS 285.5    0.00   251.3   8.203   249.4   16.41   247.7   20.01   234.8   43.31
XS 230.3   47.25   224.1   82.03   224.5   114.8   221.5   147.6   218.9   180.5
XS 217.4   213.3   219.7   246.1   227.5   270.7   237.1   273.6   242.2   283.8
XS 274.5   289.1   249.5   295.3   250.3   301.9   258.5   305.1   259.9  334.70
RH 0.035
ST  9009      14       0       0       0
ND    1    1087
XS 277.1    0.00   262.6   91.21   231.6   158.1   225.1   246.1   223.8  400.30
XS 222.5  557.80   219.8  602.40   210.0  675.90   215.2  787.40   219.8  908.80
XS 228.7  933.10   236.6  1004.0   249.4  1076.0   257.9  1087.0
RH 0.035
ST  6893      15       0       0       0
ND    1   505.9
XS 257.6    0.00   250.6   66.28   249.6   93.51  213.50   105.6   203.3   133.5
XS 204.3   168.3   210.7   238.2   222.6   316.9   226.2  418.00   227.9  427.80
XS 239.5  429.80   239.5  434.40   250.7  437.00   252.9  472.80   256.8  505.90
RH 0.035
ST  3830      15       0       0       0
ND    1    1092
XS 274.8    0.00   268.3   49.22   225.9   108.9   224.1   242.8   223.6   319.9
XS 219.2  374.00   208.7  470.20   206.6  553.20   205.4  616.80   207.4  699.80
XS 214.5  805.20   217.4  854.00   224.4  971.20   226.4  1000.0   233.0  1092.0
RH 0.035
ST  2815      20       0       0       0
ND    1    2077
XS 268.1    0.00  219.20   86.62   218.4   201.8   208.2   322.9   207.7  557.80
XS 214.9  774.60   256.0  887.80   270.6  954.80   269.5  984.30   250.7  1049.0
```

```
XS 249.5  1111.0   271.7  1214.0   263.1  1324.0   221.4  1417.0   219.4  1542.0
XS 212.3  1723.0   217.6  1814.0   230.0  1867.0   262.6  1996.0   292.2  2077.0
RH 0.035
ST     0      14       1       1       0
ND     1   323.8
XS 236.8    0.00   226.7    10.5   195.5   44.95   191.6   75.13   193.5   92.20
XS 194.3   107.3   190.7   139.4   191.1   171.6   180.3   203.8   181.6   236.2
XS 214.4   269.0   221.3   304.5   226.7   309.1   236.2   323.8
RH 0.035
NT     5
IT   144      40      10 DAY
QQ      TABLE OF DISCHARGES
SS      STAGE DISCHARGE TABLE
TL    17
SQ3380.1 214.410
SQ151.88 214.410
SQ158.94 214.410
SQ762.91 214.410
SQ1441.1 214.410
SQ2168.6 214.410
SQ201.32 214.410
SQ 12976 225.570
SQ9292.6 225.570
SQ2069.7 214.410
SQ1204.4 214.410
SQ  1381 214.410
SQ 441.5 214.410
SQ7282.9 225.570
SQ 12919 225.570
SQ7858.7 225.570
SQ3019.8 214.410
SQ7222.9 225.570
SQ2186.3 214.410
SQ3104.6 214.410
SQ1631.7 214.410
SQ370.86 214.410
SQ208.39 214.410
SQ9804.9 225.570
SQ586.31 214.410
SQ4552.7 215.659
SQ1119.6 214.410
SQ 353.2 214.410
SQ208.39 214.410
SQ233.11 214.410
SQ109.49 214.410
SQ586.31 214.410
SQ243.71 214.410
SQ215.45 214.410
SQ 176.6 214.410
SQ300.22 214.410
SQ558.06 214.410
SQ215.45 214.410
SQ102.42 214.410
SQ 52.98 214.410
SQ 35.32 214.410
SQ335.54 214.410
```

SQ321.41 214.410
SQ 1434 214.410
SQ 8279 225.570
SQ480.35 214.410
SQ6202.2 224.674
SQ448.56 214.410
SQ1031.3 214.410
SQ8275.5 225.570
SQ8798.2 225.570
SQ 7615 225.570
SQ2182.8 214.410
SQ3906.4 214.410
SQ2479.5 214.410
SQ2740.8 214.410
SQ 13577 225.570
SQ932.45 214.410
SQ1557.6 214.410
SQ575.72 214.410
SQ 794.7 214.410
SQ1437.5 214.410
SQ2486.5 214.410
SQ579.25 214.410
SQ427.37 214.410
SQ3655.6 214.410
SQ406.18 214.410
SQ300.22 214.410
SQ356.73 214.410
SQ473.29 214.410
SQ286.09 214.410
SQ229.58 214.410
SQ 155.4 214.410
SQ384.99 214.410
SQ381.46 214.410
SQ1225.6 214.410
SQ360.26 214.410
SQ 441.5 214.410
SQ4333.8 214.540
SQ 1381 214.410
SQ3016.3 214.410
SQ6668.4 225.570
SQ3662.7 214.410
SQ4376.1 214.755
SQ1123.2 214.410
SQ384.99 214.410
SQ8109.5 225.570
SQ 2098 214.410
SQ 529.8 214.410
SQ957.17 214.410
SQ367.33 214.410
SQ709.93 214.410
SQ416.78 214.410
SQ2804.4 214.410
SQ6099.8 224.087
SQ4316.1 214.450
SQ3715.7 214.410
SQ1363.4 214.410

SQ8324.9 225.570
SQ1211.5 214.410
SQ310.82 214.410
SQ335.54 214.410
SQ 166 214.410
SQ445.03 214.410
SQ268.43 214.410
SQ 187.2 214.410
SQ201.32 214.410
SQ286.09 214.410
SQ296.69 214.410
SQ 717 214.410
SQ462.69 214.410
SQ275.49 214.410
SQ317.88 214.410
SQ102.43 214.410
SQ 187.2 214.410
SQ490.95 214.410
SQ865.34 214.410
SQ6573.1 225.570
SQ1116.1 214.410
SQ1949.7 214.410
SQ2634.9 214.410
SQ875.94 214.410
SQ 10168 225.570
SQ4065.3 214.410
SQ678.14 214.410
SQ360.26 214.410
SQ250.77 214.410
SQ328.48 214.410
SQ7497.8 225.570
SQ 2928 214.410
SQ1253.9 214.410
SQ7208.8 225.570
SQ2345.2 214.410
SQ 11733 225.570
SQ2461.8 214.410
SQ600.44 214.410
SQ600.44 214.410
SQ321.41 214.410
SQ233.11 214.410
SQ240.18 214.410
SQ229.58 214.410
SQ392.05 214.410
SQ134.22 214.410
SQ505.08 214.410
SE 10
NE 0.25 1
QR12.153 0.5738
TM 144 65
SF 10
SG 0.002 0.004
SG 0.004 0.008
SG 0.008 0.016
SG 0.016 0.031
SG 0.031 0.0625

```
SG0.0625   0.125
SG 0.125    0.25
SG  0.25     0.5
SG   0.5       1
SG     1       2
NB     0
BG  0.16    0.06  0.0652  0.1127   0.166     0.2   0.206  0.0243  0.0032  0.0026
NB  3830
BG0.2015  0.0948   0.107   0.128   0.149  0.1366  0.1613  0.0148  0.0051  0.0019
CS  0.02     0.1    0.15      60     1.5     0.1
CH 1.0e8   2.0e8             -1      -1      -1
IQ     5  388.52  1483.4  4944.8  8829.9 31787.9
IS       0.1068  0.1136  0.1136  0.1136  0.1136
IS       0.0747  0.1533  0.1533  0.1533  0.1533
IS       0.0747  0.1136  0.1136  0.1136  0.1136
IS       0.0747  0.0795  0.0795  0.0795  0.0795
IS       0.2028  0.2044  0.2044  0.2044  0.2044
IS       0.1966  0.1264  0.1264  0.1264  0.1264
IS       0.2357  0.1871  0.1871  0.1871  0.1871
IS       0.0236  0.0137  0.0137  0.0137  0.0137
IS       0.0038   0.006   0.006   0.006   0.006
IS       0.0005  0.0004  0.0004  0.0004  0.0004
PR     3     144
PX   144
PW   144
END
```

4.2 Output Data Files

All the output data files for this example are given, in electronic format, in the GSTARS4 distribution package in directory Example4.

4.3 Results and Discussion

At the time of writing of this manual there wasn't enough information to write detailed analysis of the results for this example, which will be done at a later time. Here, the thalweg resulting from the GSTARS4 computations is presented in figure 4.4. Figure 4.4 was plotted using the data in the GSTARS4 main output data file (.OUT) and a typical plotting software package.

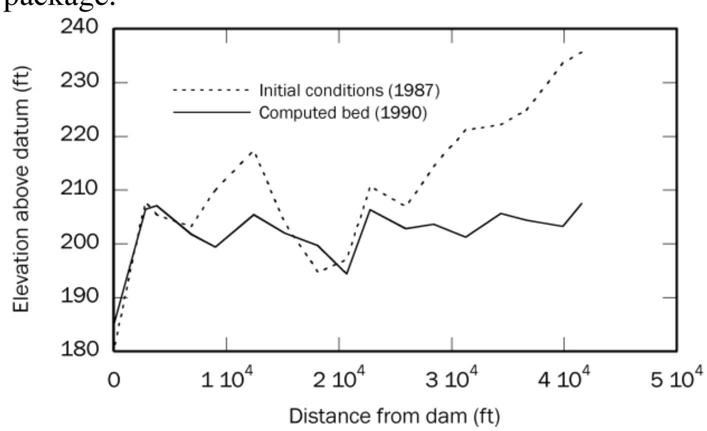

Figure 4.4 Initial (measured) and computed thalweg profiles for a four-year GSTARS4 simulation of Tapu reservoir.

EXAMPLE 5

TARBELA RESERVOIR, PAKISTAN

This is yet another example of reservoir sedimentation. Here, GSTARS4 is applied to Tarbela Dam and Reservoir to compute reservoir sedimentation and delta movement. Tarbela Dam, located in northern Pakistan along the Indus River, is the largest earth-filled dam in the world. The reservoir, with a gross storage capacity of 506.4 billion cubic feet, is a 60 mile long run of the river type of reservoir with two major tributaries, the Siran and the Brandu. Tarbela's main function is of providing water for irrigation, releasing 388 million cubic feet of irrigation water annually. Additionally, the hydropower capacity of the power station totals 3478 MW and produces 32% of Pakistan's needs. The reservoir's storage capacity has been continuously depleted since the dam has been built, in 1974, with an annual inflow rate of 265 million tons of sediment, most of which in the silt and clay range. This loss in capacity threatens the resources and revenue associated with the dam and reservoir.

In this example, GSTARS4 is used to simulate 22 years of reservoir sedimentation (from 1974 through 1996) for a reach that spans nearly 58 miles upstream from the dam (see figure 5.1). The hydrology of the system is given in figure 5.2, together with the dam operation. The tributaries have a relatively small contribution when compared with the main stem discharge, therefore they are not included in figure 5.2 (but they are included in the computations).

This case has three interesting differences from the Rio Grande study presented in example 3. First, there is a large percentage of silt and clay in the sediments in transport, but there is no data to simulate them using the Krone/Ariathurai methods. Second, analysis of 1996 cross-sectional data suggests that deposition occurs in the form of a uniform fill, such as that described in figure 5.4 of chapter 5, as can be observed in figure 5.3 below. Finally, there exists a rating curve derived much in the same way as that in example 3, but during the calibration runs it was observed that the amount of deposition was severely underpredicted. That rating curve was adjusted to correctly reproduce the reservoir deposition volume. For that, it was also used the fact that the first cross section was observed not to change much during the 1974-1994 period concerning this study. The distribution of the incoming sediment load was also subject of calibration. More details on how these factors were taken into account are presented in the discussion that follows.

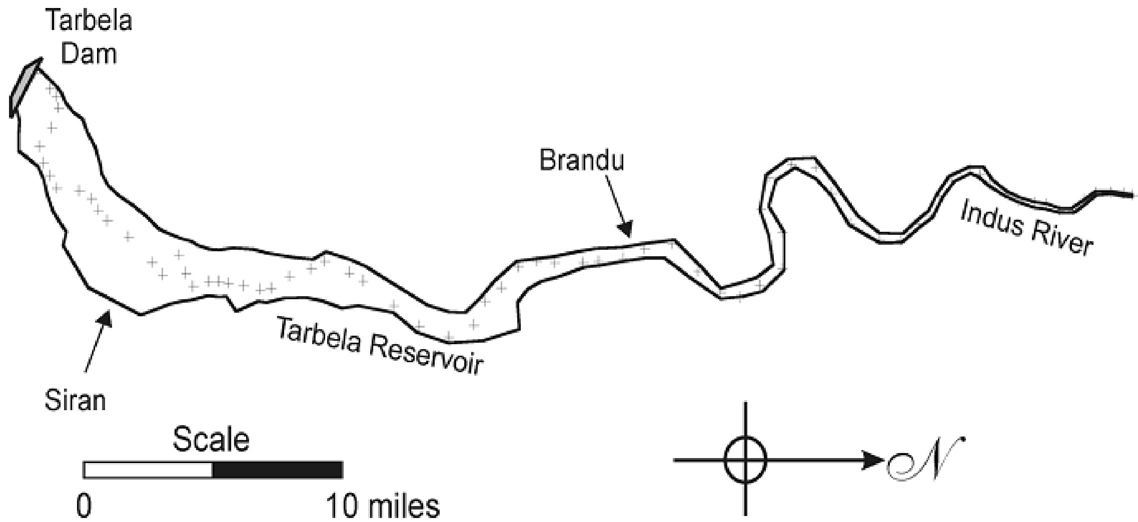

Figure 5.1 Tarbela dam and reservoir. The points (+) mark the thalweg and the locations of the cross sections used in this study.

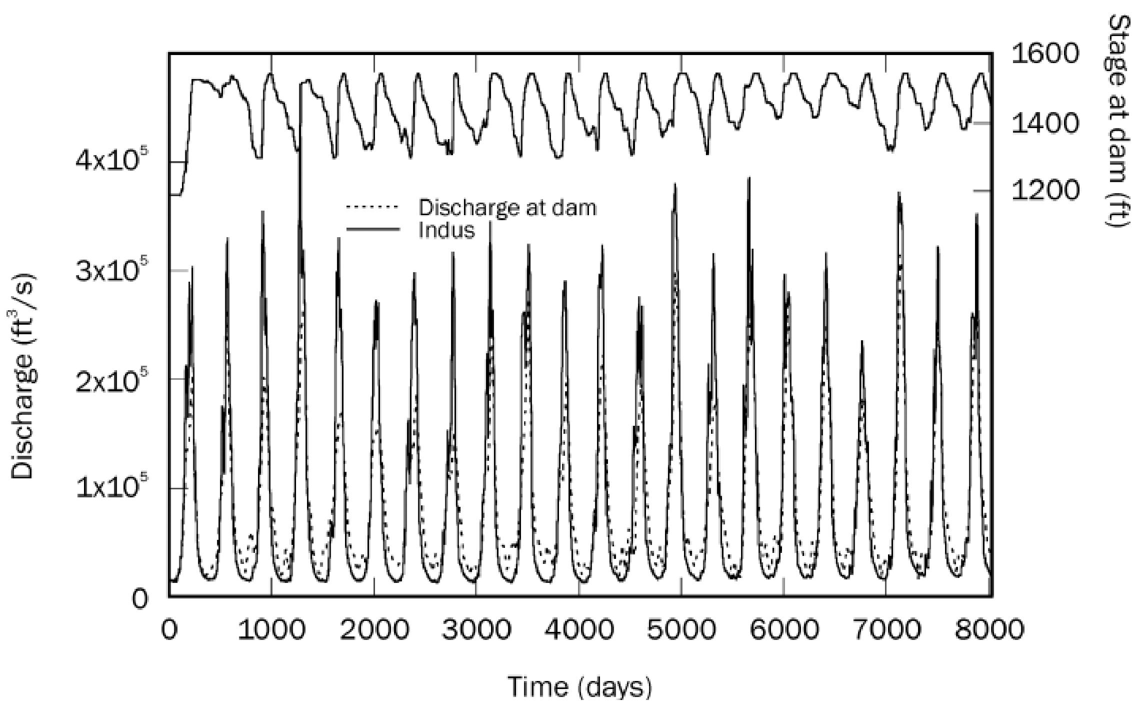

Figure 5.2 Hydrology and dam operation for Tarbela in the period of 1974 to 1996.

The Tarbela reservoir's bathymetry was dscretized using existing surveyed cross sections, which are marked in figure 5.1. The uniform fill observed in figure 5.3 indicates that there is not much transverse variation in the sedimentation processes, therefore the GSTARS4 simulations were carried out using one stream tube. Uniform fill is indicated setting RFILL equal to 1 in record SE.

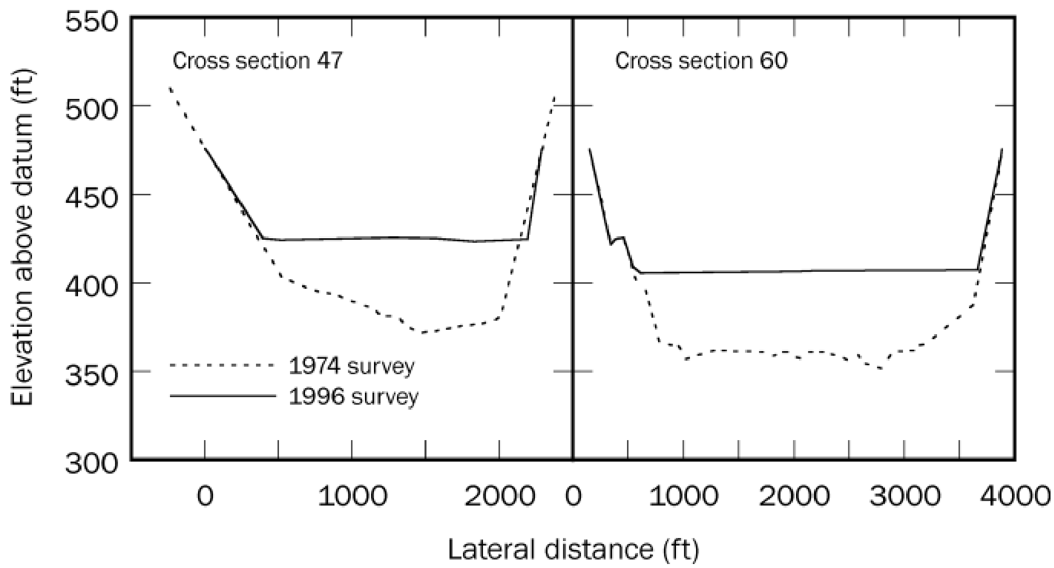

Figure 5.3 Two reservoir cross sections showing uniform sedimentation.

Yang's (1973) equation was used for this study. Because there is no information concerning the deposition characteristics of the silt and clay fractions, it is difficult to use the Krone/Ariathurai methods effectively. Instead, the Yang (1973) was extrapolated for these size ranges by setting *STDEP* equal to -1 in record CS (the particle size distributions are in the range of 0.002 to 2.0 mm). Under this circumstance, record CH should not be used. This approach can sometimes yield good results, especially in mainly depositional processes such as those occurring in large reservoirs. However, care should be exercised, and the results of the simulations should always be confirmed by careful validation using field data.

Daily time steps for the hydraulic computations and 4.8 hours for sediment routing computations (8,040 time steps for hydraulics, 40,200 time steps for sediment) are used (see record IT). Using these parameters, computer runs on a fairly modern PC compatible desktop workstation running Microsoft Windows XP took less than 20 minutes.

5.1 Input Data File

Due to the length of this data file, the full extent of records SQ and TM is not included. The complete data file is bundled in the GSTARS4 distribution files in directory Example5. Also, the tributary input datafiles are not included here, but they can be found under directory Example5. All the files shown in this and the next sections are included in the main GSTARS4 distribution package.

```
TT GSTARS version 3.0  -  Example data file for Appendix B of user's manual
TT Tarbela Reservoir, simulation run for the period of 1975-1996
*********************************************************************************
***                                                                           ***
***  NOTE: this is a simplified version of the datafile used to simulate     ***
***  the delta formation at the Tarbela Reservoir duriong the period of      ***
***  1975 to 1996.  It may not contain an accurate representation of the     ***
***  actual flow and geological conditions at the site.  This data file      ***
***  should be viewed only as an example of input data as it might be used   ***
```

```
***  in a GSTARS version 3.0 simulation.  This file was constructed for      ***
***  didactic purposes only.                                                 ***
***                                                                          ***
********************************************************************************
NS    76
ST289093      13
ND     1  600.00
XS              10.01 1560.01   64.99 1550.00   89.99 1527.49
XS             270.01 1504.99  289.99 1496.00  343.50 1491.01
XS             395.01 1487.50  414.99 1487.50  464.99 1539.99
XS             520.01 1521.00  539.99 1519.00  585.01 1550.00
XS             600.00 1560.01
RH 0.020
ST287254      13
ND     1  704.99
XS             118.01 1570.01  149.02 1560.01  179.99 1550.00
XS             339.99 1510.99  350.00 1502.00  370.01 1502.99
XS             400.00 1495.01  439.99 1496.00  500.00 1510.99
XS             560.01 1512.99  654.99 1550.00  679.99 1560.01
XS             704.99 1570.01
RH 0.020
ST284725      11
ND     1  479.99
XS            -374.80 1641.60  -87.17 1576.21   29.99 1550.00
XS             179.99 1519.00  229.99 1471.00  285.01 1468.50
XS             310.01 1473.00  350.00 1472.01  379.99 1485.01
XS             450.00 1550.00  479.99 1643.86
RH 0.020
ST281630      11
ND     1  535.01
XS              39.99 1560.01   60.01 1550.00  175.00 1523.00
XS             185.01 1510.99  210.01 1506.99  279.99 1471.00
XS             310.01 1469.00  439.99 1535.01  475.00 1527.00
XS             514.99 1550.00  535.01 1560.01
RH 0.020
ST278777      13
ND     1 1365.12
XS            -397.24 1647.57  179.99 1550.00  314.99 1529.00
XS             450.00 1501.51  600.00 1496.00  639.99 1497.51
XS             739.99 1493.50  800.00 1485.99  870.01 1493.01
XS             900.00 1508.01  939.99 1503.51 1070.01 1550.00
XS            1365.12 1647.57
RH 0.020
ST275973      11
ND     1  960.01
XS             114.99 1560.01  150.00 1537.01  220.01 1537.01
XS             370.01 1508.99  420.01 1506.99  450.00 1491.99
XS             639.99 1491.99  770.01 1524.02  800.00 1525.00
XS             920.01 1550.00  960.01 1560.01
RH 0.020
ST273235      15
ND     1  810.01
XS              70.01 1560.01   79.99 1550.00  150.00 1479.99
XS             189.99 1479.99  225.00 1475.00  245.01 1464.99
XS             275.00 1461.52  314.99 1464.50  389.99 1460.99
XS             539.99 1510.01  639.99 1520.01  700.00 1537.99
```

```
XS             795.01 1541.01  800.00 1550.00  810.01 1560.01
RH 0.020
ST270364      14
ND     1 1110.01
XS              70.01 1560.01  100.00 1550.00  150.00 1533.99
XS             220.01 1527.00  250.00 1514.99  289.99 1514.01
XS             350.00 1516.99  450.00 1518.01  639.99 1514.99
XS             729.99 1506.99  929.99 1504.00 1000.00 1510.01
XS            1089.99 1550.00 1110.01 1560.01
RH 0.020
ST268052      12
ND     1 1269.19
XS              65.72 1643.86  129.99 1550.00  139.99 1539.01
XS             420.01 1537.99  520.01 1527.49  704.99 1487.01
XS             829.99 1466.01  889.99 1463.48  979.99 1510.01
XS            1020.01 1514.99 1100.00 1550.00 1269.19 1643.86
RH 0.020
ST264701      19
ND     1  860.01
XS              85.01 1560.01   89.99 1550.00  120.01 1500.98
XS             150.00 1498.00  189.99 1450.98  220.01 1439.01
XS             250.00 1443.01  300.00 1445.01  350.00 1458.01
XS             400.00 1491.99  510.01 1512.01  585.01 1506.00
XS             670.01 1527.00  714.99 1527.99  750.00 1535.99
XS             800.00 1535.99  829.99 1541.01  839.99 1550.00
XS             860.01 1560.01
RH 0.020
ST261807      11
ND     1 1425.00
XS             137.30 1697.18  149.11 1550.00  150.00 1472.51
XS             185.01 1471.00  214.99 1464.99  250.00 1435.99
XS             575.00 1469.00  629.99 1490.49  660.01 1487.99
XS             985.01 1550.00 1425.00 1655.97
RH 0.020
ST258204      14
ND     1 1014.99
XS             106.99 1560.01  110.01 1550.00  120.01 1496.00
XS             179.99 1493.01  189.99 1479.99  425.00 1495.51
XS             485.01 1494.00  550.00 1487.01  589.99 1496.00
XS             639.99 1496.49  700.00 1512.01  789.99 1525.00
XS             950.00 1550.00 1014.99 1560.01
RH 0.020
ST255382      19
ND     1 1900.00
XS             250.00 1560.01  400.00 1543.50  429.99 1539.99
XS             475.00 1538.48  520.01 1529.99  529.99 1510.01
XS             564.99 1489.50  600.00 1486.52  700.00 1487.01
XS             729.99 1489.99  820.01 1489.01 1279.99 1502.99
XS            1560.01 1506.99 1720.01 1525.00 1739.99 1522.51
XS            1800.00 1537.99 1879.99 1539.99 1889.99 1550.00
XS            1900.00 1560.01
RH 0.020
ST253042      13
ND     1 1463.35
XS               2.03 1648.03   75.00 1550.00  110.01 1500.00
XS             177.99 1481.00  379.99 1462.01  650.00 1454.00
```

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XS           814.99 1450.00  839.99 1468.01  879.99 1479.00
XS           989.99 1510.01 1160.01 1535.99 1200.00 1550.00
XS          1463.35 1648.03
RH 0.020
ST249004      18
ND     1 1400.00
XS            68.01 1560.01   70.01 1550.00  114.99 1441.99
XS           181.99 1431.99  204.99 1429.99  350.00 1426.51
XS           439.99 1425.49  489.99 1425.49  660.01 1425.98
XS           820.01 1437.01  900.00 1450.00 1079.99 1458.99
XS          1239.99 1470.01 1320.01 1481.99 1335.01 1485.99
XS          1350.00 1494.00 1389.99 1550.00 1400.00 1560.01
RH 0.020
ST245092      17
ND     1 1627.95
XS           -36.35 1697.18   20.01 1550.00   39.99 1489.99
XS           160.01 1481.99  200.00 1477.99  300.00 1450.98
XS           379.99 1441.99  500.00 1435.01  620.01 1431.99
XS           779.99 1429.99  960.01 1431.99 1200.00 1439.01
XS          1260.01 1444.00 1279.99 1448.00 1425.00 1539.99
XS          1439.99 1550.00 1627.95 1697.18
RH 0.020
ST241273      12
ND     1 1404.99
XS          -125.00 1560.01 -114.99 1550.00 -100.00 1539.99
XS            64.99 1431.99  200.00 1424.02  439.99 1422.01
XS           760.01 1429.99  879.99 1439.01 1279.99 1479.99
XS          1360.01 1494.00 1395.01 1550.00 1404.99 1560.01
RH 0.020
ST238300       8
ND     1 2162.43
XS          -238.32 1696.46   79.99 1550.00  345.01 1416.99
XS           479.99 1414.01  739.99 1469.00  950.00 1502.00
XS          1300.00 1550.00 2162.43 1670.51
RH 0.020
ST234014      10
ND     1 1810.01
XS             0.00 1560.01   20.01 1550.00  164.99 1419.00
XS           329.99 1389.01  500.00 1460.01  879.99 1470.01
XS           920.01 1475.98 1360.01 1531.99 1650.00 1550.00
XS          1810.01 1560.01
RH 0.020
ST229488      16
ND     1 1866.86
XS           -75.95 1622.93   79.99 1550.00  339.99 1441.99
XS           360.01 1425.98  400.00 1408.01  500.00 1394.00
XS           539.99 1394.00  760.01 1429.99 1039.99 1458.01
XS          1139.99 1474.02 1260.01 1485.99 1389.99 1494.00
XS          1400.00 1498.00 1679.99 1539.99 1720.01 1550.00
XS          1866.86 1622.93
RH 0.020
ST223195      10
ND     1 2727.95
XS            -8.10 1630.74   14.99 1550.00   39.99 1447.01
XS           360.01 1373.00  700.00 1452.00 1000.00 1462.01
XS          1620.01 1475.98 2135.01 1510.01 2400.00 1550.00
```

```
XS           2727.95 1630.74
RH 0.020
ST216194      20
ND     1 2560.01
XS            150.00 1560.01  175.00 1550.00  285.01 1500.00
XS            370.01 1429.99  400.00 1420.01  529.99 1399.02
XS            560.01 1398.00  789.99 1398.00 1139.99 1420.01
XS           1620.01 1431.00 1800.00 1450.00 1979.99 1429.99
XS           1989.99 1441.01 2079.99 1450.00 2120.01 1441.01
XS           2300.00 1439.99 2400.00 1450.00 2479.99 1520.01
XS           2539.99 1550.00 2560.01 1560.01
RH 0.020
ST210919      15
ND     1 3036.91
XS          -1275.72 1687.14 -531.89 1593.83  500.00 1550.00
XS            920.01 1533.99 1360.01 1516.99 1620.01 1489.99
XS           1889.99 1412.99 2139.99 1383.99 2239.99 1377.99
XS           2300.00 1379.99 2479.99 1393.01 2550.00 1425.98
XS           2560.01 1450.98 2760.01 1550.00 3036.91 1704.79
RH 0.020
ST205917      15
ND     1 2160.01
XS              0.00 1560.01   50.00 1550.00  100.00 1539.99
XS            360.01 1491.01  610.01 1400.98  800.00 1364.99
XS            920.01 1360.01 1100.00 1391.99 1200.00 1416.01
XS           1629.99 1479.00 1739.99 1487.99 1860.01 1512.99
XS           1939.99 1520.01 2100.00 1550.00 2160.01 1560.01
RH 0.020
ST201014      14
ND     1 2426.21
XS           -213.78 1630.74   79.99 1550.00  200.00 1519.00
XS            339.99 1499.02  539.99 1483.99  610.01 1472.01
XS           1039.99 1441.99 1160.01 1429.00 1279.99 1385.01
XS           1404.00 1364.01 1600.00 1366.99 1960.01 1489.99
XS           2179.99 1550.00 2426.21 1630.74
RH 0.020
ST195283      11
ND     1 2379.99
XS            560.01 1560.01  600.00 1550.00  710.01 1520.01
XS           1279.99 1416.01 1610.01 1370.01 1720.01 1370.01
XS           1939.99 1374.02 2075.00 1383.99 2179.99 1454.99
XS           2360.01 1550.00 2379.99 1560.01
RH 0.020
ST189956      19
ND     1 3592.95
XS           -217.36 1802.53  120.01 1550.00  200.00 1510.99
XS            279.99 1400.00  439.99 1362.01  560.01 1345.01
XS            660.01 1348.00  770.01 1370.01 1039.99 1402.00
XS           1239.99 1439.99 1289.99 1460.01 1400.00 1479.00
XS           1439.99 1481.99 2000.00 1489.99 2760.01 1512.99
XS           3100.00 1519.00 3200.00 1529.00 3300.00 1650.00
XS           3592.95 1802.76
RH 0.020
ST183812      15
ND     1 2370.01
XS             29.99 1560.01   39.99 1550.00  239.99 1360.01
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XS            389.99 1335.99  529.99 1322.01  650.00 1333.99
XS            939.99 1419.00 1139.99 1439.99 1289.99 1450.00
XS           1550.00 1500.00 2100.00 1510.01 2200.00 1531.99
XS           2300.00 1541.01 2339.99 1550.00 2370.01 1560.01
RH 0.020
ST178802     19
ND    1 3241.57
XS           -351.15 1638.81  200.00 1550.00  600.00 1498.00
XS            860.01 1427.00  960.01 1349.02 1010.01 1329.99
XS           1039.99 1324.02 1200.00 1314.01 1279.99 1316.01
XS           1679.99 1389.99 1879.99 1410.01 2110.01 1420.01
XS           2300.00 1439.99 2500.00 1450.00 2639.99 1462.01
XS           2660.01 1470.01 2800.00 1489.01 3000.00 1550.00
XS           3241.57 1638.81
RH 0.020
ST174680     19
ND    1 2010.01
XS             50.00 1560.01   52.00 1550.00   60.01 1460.01
XS            100.00 1437.99  145.01 1429.99  250.00 1339.99
XS            310.01 1333.99  329.99 1320.01  389.99 1314.01
XS            460.01 1310.01  679.99 1302.99  800.00 1302.00
XS           1200.00 1310.01 1204.00 1320.01 1600.00 1360.01
XS           1760.01 1394.00 1879.99 1439.99 2000.00 1550.00
XS           2010.01 1560.01
RH 0.020
ST170206     11
ND    1 2142.19
XS            -50.46 1647.51   70.01 1550.00  264.99 1422.01
XS            479.99 1397.01 1000.00 1308.01 1129.99 1300.00
XS           1660.01 1400.00 1700.00 1450.00 1920.01 1500.00
XS           1989.99 1550.00 2142.19 1647.51
RH 0.020
ST163908     25
ND    1 3305.77
XS             89.30 1647.51  189.99 1550.00  250.00 1475.98
XS            439.99 1450.00  600.00 1429.99  870.01 1410.01
XS            920.01 1389.99 1079.99 1370.01 1120.01 1360.01
XS           1239.99 1339.99 1270.01 1329.99 1620.01 1310.01
XS           1679.99 1289.99 1720.01 1285.99 1920.01 1281.99
XS           2100.00 1287.99 2200.00 1300.00 2429.99 1360.01
XS           2679.99 1360.01 2850.00 1370.01 2939.99 1379.99
XS           2970.01 1389.99 3020.01 1446.00 3179.99 1550.00
XS           3305.77 1647.51
RH 0.020
ST156915     15
ND    1 4127.53
XS           -418.34 1655.94  160.01 1550.00  400.00 1500.00
XS           1000.00 1444.00 1379.99 1420.01 1920.01 1368.01
XS           2120.01 1329.99 2389.99 1310.01 2429.99 1300.00
XS           3120.01 1262.01 3220.01 1262.01 3650.00 1298.00
XS           3820.01 1450.00 3979.99 1550.00 4127.53 1655.94
RH 0.020
ST151965     20
ND    1 2600.00
XS              0.00 1560.01   10.01 1550.00   79.99 1500.00
XS            339.99 1398.00  500.00 1370.01  579.99 1329.99
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XS              700.00 1339.99  960.01 1329.99 1039.99 1320.01
XS             1439.99 1302.00 1700.00 1266.99 1739.99 1269.00
XS             1920.01 1350.00 1989.99 1350.00 2100.00 1302.00
XS             2200.00 1344.00 2220.01 1400.00 2400.00 1450.00
XS             2579.99 1550.00 2600.00 1560.01
RH 0.020
ST147429      17
ND     1 2773.13
XS              -16.47 1655.94   60.01 1550.00   79.99 1447.01
XS              139.99 1389.99  239.99 1358.01  300.00 1289.99
XS              439.99 1264.99  520.01 1264.01  660.01 1268.01
XS             1170.01 1310.99 1220.01 1323.00 1320.01 1335.99
XS             1760.01 1360.01 2279.99 1379.99 2360.01 1400.00
XS             2589.99 1550.00 2773.13 1655.94
RH 0.020
*** Lateral tributary: Brandu
LI Brandu.dat
ST142248      18
ND     1 3189.99
XS              104.99 1560.01  110.01 1550.00  114.99 1450.00
XS              339.99 1379.99  479.99 1362.01  679.99 1291.99
XS              750.00 1279.00  889.99 1295.01 1125.00 1322.01
XS             1279.99 1329.99 1400.00 1339.99 1860.01 1350.00
XS             2389.99 1370.01 2760.01 1379.99 2979.99 1400.00
XS             3160.01 1516.01 3179.99 1550.00 3189.99 1560.01
RH 0.020
ST139071      19
ND     1 3338.45
XS               76.64 1643.14  204.99 1550.00  314.99 1350.00
XS              439.99 1287.01  600.00 1269.00  760.01 1266.01
XS              960.01 1266.01 1150.00 1279.99 1220.01 1300.00
XS             1639.99 1320.01 1720.01 1329.99 1839.99 1339.99
XS             1879.99 1350.00 2250.00 1360.01 2460.01 1379.99
XS             2800.00 1400.00 3079.99 1450.00 3200.00 1550.00
XS             3338.45 1655.94
RH 0.020
ST133600      11
ND     1 4056.36
XS               41.34 1655.94  220.01 1550.00  400.00 1400.00
XS             2000.00 1310.99 2400.00 1258.99 2600.00 1250.98
XS             2889.99 1260.01 3070.01 1256.00 3650.00 1348.00
XS             3929.99 1550.00 4056.36 1655.94
RH 0.020
ST129961      14
ND     1 4379.99
XS              170.01 1560.01  179.99 1550.00  479.99 1391.01
XS              750.00 1379.00 2100.00 1350.00 2600.00 1329.99
XS             2720.01 1320.01 3450.00 1300.00 3560.01 1279.99
XS             3679.99 1256.00 3720.01 1254.99 3800.00 1258.01
XS             4370.01 1550.00 4379.99 1560.01
RH 0.020
ST126499      17
ND     1 5776.25
XS             -192.22 1655.94  129.99 1550.00  439.99 1452.00
XS              789.99 1418.01 1039.99 1400.00 2639.99 1379.00
XS             3539.99 1341.01 3860.01 1310.01 3979.99 1300.00
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XS           4079.99 1322.01 4170.01 1322.01 4400.00 1262.01
XS           4560.01 1254.00 4860.01 1254.00 5039.99 1272.01
XS           5600.00 1550.00 5776.25 1655.94
RH 0.020
ST122032     21
ND     1 6370.01
XS            239.99 1560.01  320.01 1550.00  660.01 1502.99
XS            879.99 1489.99 1600.00 1433.99 1710.01 1427.99
XS           2300.00 1420.01 2460.01 1410.01 2620.01 1381.00
XS           3479.99 1360.99 4120.01 1260.99 4260.01 1254.00
XS           4600.00 1300.00 4720.01 1300.00 4820.01 1277.99
XS           4970.01 1279.00 5129.99 1300.98 5760.01 1320.01
XS           6160.01 1420.01 6360.01 1550.00 6370.01 1560.01
RH 0.020
ST117863     35
ND     110090.68
XS          -3720.14 1654.66 -720.01 1550.00  600.00 1500.00
XS            860.01 1491.01 1000.00 1479.99 1410.01 1470.01
XS           1510.01 1450.00 1700.00 1450.00 1920.01 1441.99
XS           1989.99 1433.99 2100.00 1427.99 2239.99 1420.01
XS           2400.00 1420.01 2479.99 1429.99 2560.01 1429.99
XS           2820.01 1410.01 3810.01 1410.01 4110.01 1400.00
XS           5000.00 1350.00 5260.01 1350.00 5489.99 1420.01
XS           5760.01 1420.01 6070.01 1408.01 6439.99 1400.00
XS           6660.01 1387.99 7189.99 1310.01 7720.01 1300.00
XS           8400.00 1264.01 8720.01 1258.01 8900.00 1258.99
XS           9329.99 1275.98 9479.99 1298.00 9800.00 1400.00
XS           9989.99 1550.0010090.68 1655.94
RH 0.020
ST112080     13
ND     1 6932.22
XS           -655.61 1655.94 1600.00 1372.01 2060.01 1327.99
XS           2779.99 1302.00 3200.00 1260.01 3300.00 1252.00
XS           3479.99 1250.98 3660.01 1250.98 4039.99 1258.01
XS           6110.01 1337.01 6439.99 1352.99 6779.99 1550.00
XS           6932.22 1655.94
RH 0.020
ST106871     13
ND     1 5979.99
XS            350.00 1560.01  360.01 1550.00  370.01 1479.99
XS            679.99 1300.00  960.01 1237.99 2200.00 1250.00
XS           2529.99 1250.00 5000.00 1379.99 5150.00 1400.00
XS           5639.99 1431.99 5810.01 1450.00 5970.01 1550.00
XS           5979.99 1560.01
RH 0.020
ST101269     20
ND     1 5731.10
XS             89.30 1672.05  189.99 1550.00  200.00 1493.01
XS            489.99 1297.01  670.01 1247.01 1010.01 1231.99
XS           1200.00 1229.99 2339.99 1229.99 2679.99 1237.01
XS           2800.00 1244.00 2879.99 1252.99 3279.99 1341.01
XS           3439.99 1354.99 4339.99 1391.99 5200.00 1450.00
XS           5239.99 1472.01 5479.99 1493.01 5560.01 1548.00
XS           5570.01 1550.00 5731.10 1672.05
RH 0.020
ST94542.     12
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ND     1 5195.08
XS             -221.78 1672.05   50.00 1550.00  579.99 1300.00
XS              920.01 1237.99  979.99 1229.99 1300.00 1218.01
XS             2200.00 1220.01 3410.01 1250.00 4300.00 1250.00
XS             4800.00 1370.01 5039.99 1550.00 5195.08 1672.05
RH 0.020
ST87562.     16
ND     1 7821.13
XS             -774.48 1671.49   20.01 1560.01  110.01 1550.00
XS             1710.01 1323.00 2400.00 1299.02 2920.01 1291.01
XS             3800.00 1262.99 3920.01 1250.00 4300.00 1250.00
XS             4460.01 1233.01 4760.01 1220.01 5000.00 1221.00
XS             6400.00 1239.01 6589.99 1250.00 7479.99 1550.00
XS             7821.13 1672.05
RH 0.020
ST84327.     18
ND     1 9060.01
XS                0.00 1560.01   29.99 1550.00  579.99 1329.99
XS             1200.00 1383.01 1400.00 1389.99 2000.00 1320.01
XS             2760.01 1300.00 4560.01 1279.99 4820.01 1250.00
XS             4879.99 1260.01 5560.01 1250.98 6679.99 1214.01
XS             7100.00 1218.01 8520.01 1310.01 8789.99 1356.00
XS             9029.99 1548.00 9039.99 1550.00 9060.01 1560.01
RH 0.020
ST79498.     13
ND     1 9044.00
XS             -279.69 1672.05   39.99 1550.00  270.01 1446.00
XS              339.99 1454.99  479.99 1337.01  939.99 1318.01
XS             6039.99 1239.99 6400.00 1212.99 7120.01 1206.00
XS             7600.00 1275.98 8400.00 1327.99 8820.01 1550.00
XS             9044.00 1672.05
RH 0.020
ST76511.     16
ND     1 6960.01
XS                0.00 1560.01   20.01 1550.00  379.99 1314.01
XS              520.01 1308.01  900.00 1306.00 2300.00 1279.99
XS             3400.00 1271.00 3539.99 1260.01 5050.00 1250.00
XS             5200.00 1220.01 5300.00 1210.01 5800.00 1210.01
XS             6479.99 1248.00 6760.01 1335.99 6939.99 1550.00
XS             6960.01 1560.01
RH 0.020
ST72402.     16
ND     1 7850.00
XS             -151.12 1672.05   29.99 1550.00  439.99 1329.99
XS              760.01 1268.01 1100.00 1239.99 2620.01 1229.99
XS             3700.00 1202.99 4100.00 1200.00 4300.00 1200.00
XS             5600.00 1231.00 6070.01 1239.99 6800.00 1239.99
XS             7039.99 1270.01 7639.99 1550.00 7660.01 1560.01
XS             7850.00 1670.83
RH 0.020
ST69310.     18
ND     1 9029.99
XS              250.00 1560.01  320.01 1550.00  700.00 1489.99
XS              810.01 1485.99 1279.99 1239.99 1360.01 1216.99
XS             1570.01 1206.00 2160.01 1206.00 2579.99 1189.99
XS             2760.01 1170.01 3350.00 1172.01 4260.01 1202.00
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XS           4970.01 1200.00 5279.99 1216.01 7879.99 1248.00
XS           8579.99 1320.01 9000.00 1550.00 9029.99 1560.01
RH 0.020
ST66946.     18
ND     1 9200.00
XS            320.01 1570.01  339.99 1560.01  360.01 1550.00
XS            770.01 1439.01  979.99 1466.01 1279.99 1429.99
XS           2229.99 1158.01 2370.01 1185.99 2839.99 1198.00
XS           3639.99 1175.00 4000.00 1198.00 7160.01 1258.01
XS           7629.99 1258.01 8400.00 1287.01 8800.00 1366.99
XS           9120.01 1550.00 9139.99 1560.01 9200.00 1572.01
RH 0.020
ST63272.     21
ND     111570.01
XS           -120.01 1560.01  -89.99 1550.00  700.00 1439.01
XS           2320.01 1316.99 2539.99 1349.02 2679.99 1354.00
XS           4400.00 1183.01 4800.00 1162.99 5029.99 1187.99
XS           5300.00 1179.99 5420.01 1179.99 5600.00 1189.99
XS           6360.01 1200.98 6500.00 1200.00 9900.00 1275.98
XS          10300.00 1456.0010839.99 1324.0211079.99 1325.98
XS          11239.99 1344.0011560.01 1550.0011570.01 1560.01
RH 0.020
ST59957.     16
ND     1 9200.00
XS            300.00 1620.01  400.00 1560.01  420.01 1550.00
XS           1189.99 1198.00 1400.00 1200.00 1839.99 1189.99
XS           1970.01 1198.00 2400.00 1171.00 4600.00 1204.00
XS           4900.00 1197.01 7900.00 1266.01 8679.99 1489.01
XS           8779.99 1433.99 9100.00 1550.00 9120.01 1560.01
XS           9200.00 1589.99
RH 0.020
ST57772.     21
ND     1 8760.01
XS            360.01 1560.01  370.01 1558.01  400.00 1550.00
XS            879.99 1375.98 1000.00 1360.01 1120.01 1246.00
XS           1400.00 1191.01 1760.01 1202.00 2000.00 1196.00
XS           2479.99 1172.01 2839.99 1171.00 3200.00 1185.99
XS           3560.01 1189.99 3900.00 1200.98 4560.01 1181.00
XS           4720.01 1196.00 6600.00 1214.01 8560.01 1254.00
XS           8720.01 1550.00 8739.99 1554.99 8760.01 1560.01
RH 0.020
ST55650.     18
ND     1 8779.99
XS            379.99 1572.01  389.99 1570.51  400.00 1570.01
XS           1320.01 1187.99 1839.99 1183.99 2639.99 1156.00
XS           2800.00 1179.99 3300.00 1200.98 3439.99 1194.00
XS           4300.00 1175.98 5200.00 1198.00 6439.99 1239.99
XS           6779.99 1256.00 8000.00 1287.99 8439.99 1300.00
XS           8760.01 1560.01 8770.01 1560.99 8779.99 1562.01
RH 0.020
ST52767.     26
ND     1 9939.99
XS            220.01 1560.01  260.01 1550.00  529.99 1497.01
XS            879.99 1344.00 1220.01 1260.01 1420.01 1250.00
XS           1600.00 1250.00 2000.00 1187.99 2150.00 1181.99
XS           2250.00 1187.99 2400.00 1185.01 2560.01 1162.01
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XS           3079.99 1172.01 3300.00 1185.99 5000.00 1177.99
XS           6039.99 1194.00 6450.00 1185.99 7520.01 1202.00
XS           7660.01 1223.00 7800.00 1206.00 8000.00 1206.00
XS           8200.00 1197.01 9300.00 1231.00 9479.99 1260.01
XS           9929.99 1550.00 9939.99 1560.01
RH 0.020
ST51020.     24
ND     111160.01
XS            -39.99 1560.01    0.00 1550.00  800.00 1406.99
XS           1100.00 1300.98 1320.01 1279.99 1450.00 1279.99
XS           1839.99 1229.99 2000.00 1239.99 2300.00 1181.00
XS           2820.01 1169.00 3160.01 1191.01 3879.99 1168.01
XS           4660.01 1181.00 5239.99 1154.99 6100.00 1189.99
XS           7000.00 1177.99 7839.99 1194.00 8689.99 1195.01
XS           8839.99 1187.0110439.99 1258.9911039.99 1469.00
XS          11139.99 1539.9911150.00 1550.0011160.01 1560.01
RH 0.020
ST48856.     35
ND     112729.99
XS            479.99 1560.01  520.01 1550.00  600.00 1529.99
XS           1129.99 1383.01 1250.00 1393.01 1510.01 1396.00
XS           1629.99 1375.00 1779.99 1329.99 1879.99 1318.01
XS           2160.01 1298.00 2550.00 1204.00 2950.00 1197.01
XS           3079.99 1200.98 3350.00 1171.00 4200.00 1187.01
XS           5750.00 1183.01 5950.00 1175.98 6239.99 1183.01
XS           6500.00 1183.01 6620.01 1174.02 6750.00 1173.00
XS           6929.99 1183.99 7500.00 1183.99 8229.99 1168.01
XS           8479.99 1177.99 8600.00 1164.01 9160.01 1154.00
XS           9500.00 1183.9910179.99 1185.9910300.00 1197.01
XS          10500.00 1199.0211900.00 1270.0112700.00 1539.99
XS          12720.01 1550.0012729.99 1560.01
RH 0.020
ST46154.     38
ND     115820.01
XS           3279.99 1560.01 3289.99 1550.00 3300.00 1454.99
XS           4279.99 1302.00 4439.99 1262.01 4920.01 1223.00
XS           5800.00 1206.00 5960.01 1150.98 6039.99 1179.00
XS           6410.01 1158.99 6589.99 1170.01 6979.99 1179.00
XS           8000.00 1179.99 8300.00 1185.01 8760.01 1181.99
XS           9020.01 1168.01 9279.99 1171.00 9600.00 1164.01
XS          10679.99 1181.0011300.00 1173.0011410.01 1177.99
XS          11560.01 1169.0011670.01 1172.0111779.99 1160.01
XS          11920.01 1158.9912639.99 1175.9813320.01 1175.98
XS          13529.99 1169.0013770.01 1175.0013939.99 1160.01
XS          14320.01 1206.9914700.00 1212.0115000.00 1212.99
XS          15200.00 1225.0015439.99 1252.9915800.00 1470.01
XS          15810.01 1550.0015820.01 1560.01
RH 0.020
ST43417.     35
ND     115029.99
XS            860.01 1560.01  870.01 1550.00  879.99 1466.99
XS            889.99 1468.01  900.00 1469.00 1000.00 1462.01
XS           1750.00 1404.00 1929.99 1402.99 2329.99 1362.99
XS           2579.99 1312.99 2960.01 1354.00 3560.01 1254.00
XS           3960.01 1241.99 4600.00 1198.00 6279.99 1170.01
XS           6800.00 1175.98 7460.01 1174.02 7600.00 1162.99
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XS           7889.99 1166.01 8010.01 1143.01 8479.99 1162.01
XS           9760.01 1162.99 9920.01 1141.9910560.01 1154.99
XS          11079.99 1166.9912120.01 1154.0012379.99 1173.00
XS          12520.01 1162.0113260.01 1170.0114100.00 1175.98
XS          14900.00 1289.9915000.00 1320.0115010.01 1320.31
XS          15020.01 1550.0015029.99 1560.01
RH 0.020
ST35803.     28
ND     116239.99
XS           1800.00 1560.01 1810.01 1550.00 1820.01 1321.00
XS           2229.99 1252.99 2479.99 1312.99 2620.01 1327.99
XS           2960.01 1372.01 3600.00 1214.99 3960.01 1223.00
XS           4600.00 1193.01 8679.99 1162.9911000.00 1148.00
XS          11360.01 1160.9911560.01 1150.0011760.01 1156.00
XS          12260.01 1131.0012660.01 1212.9913200.00 1187.99
XS          14420.01 1262.9914560.01 1254.9915239.99 1348.00
XS          15639.99 1320.0115839.99 1272.0116200.00 1293.01
XS          16210.01 1296.0016220.01 1304.9916229.99 1550.00
XS          16239.99 1560.01
RH 0.020
*** Lateral tributary: Siran
LI Siran.dat
ST29765.     28
ND     114539.99
XS           -100.00 1560.01  -89.99 1550.00  -79.99 1360.01
XS           1000.00 1179.99 1900.00 1171.00 2620.01 1175.00
XS           2839.99 1183.01 3120.01 1158.99 5479.99 1162.99
XS           6160.01 1154.00 6400.00 1162.99 7860.01 1164.01
XS           8420.01 1150.00 8889.99 1166.9910079.99 1147.01
XS          10900.00 1167.4911700.00 1152.9912079.99 1250.00
XS          12779.99 1291.0113120.01 1241.9913329.99 1279.99
XS          13510.01 1289.0113720.01 1279.9913939.99 1279.99
XS          14220.01 1329.9914520.01 1339.0114529.99 1550.00
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XS           3600.00 1152.00 4450.00 1154.99 5350.00 1162.99
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XS         5200.00 1139.99 7000.00 1158.01 7520.01 1143.01
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XS         5500.00 1154.00 6960.01 1150.00 7070.01 1145.01
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ST13845.    15
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```

```
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XS             8360.01 1129.99 9179.99 1123.00 9600.00 1154.00
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XS             4600.00 1160.01 4739.99 1174.02 5200.00 1129.99
XS             5920.01 1139.99 6439.99 1133.99 7039.99 1139.99
XS             7350.00 1154.00 7479.99 1149.02 7720.01 1152.00
XS             7860.01 1137.99 8020.01 1137.99 8200.00 1131.99
XS             8600.00 1189.99 8960.01 1172.01 9160.01 1122.01
XS             9800.00 1120.0110200.00 1152.9910520.01 1158.01
XS            10939.99 1354.0011039.99 1360.0111239.99 1400.00
XS            11400.00 1550.0011410.01 1560.01
RH 0.020
ST4399.8      46
ND     1 9860.01
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XS             3160.01 1131.99 3400.00 1129.99 3539.99 1127.00
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XS             5810.01 1154.00 5979.99 1135.99 6139.99 1133.01
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XS          7479.99 1124.02 7700.00 1122.01 7760.01 1120.01
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XS          2812.55 1146.00 2966.64 1146.00 3159.28 1150.00
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NT     1
IT  8030      5      1
QQ      TABLE OF DISCHARGES
SS      STAGE DISCHARGE TABLE
TL    76
SQ 15407 1190.94
SQ 15407 1190.94
...
SQ 19358 1456.02
SQ 19249 1455.81
SE     6       8       1
N0     0    0.80    0.10
N0130000    0.09    0.10
```

```
*** Sediment rating curve at Besham.
  QR4.4e-8    2.51
  QR8.8e-8    2.51
QR1.8e-7    2.51
  QR EQUILIBRIUM
*** Synthesized temperatures.
TM    31    40.0
TM    28    40.0
...
TM    30    40.0
TM    31    40.0
SF     7
SG 0.002   0.004    30.0
SG 0.004   0.008    30.0
SG 0.008   0.016    65.0
SG 0.016   0.031    65.0
SG 0.031  0.0625    65.0
SG0.0625    0.25    93.0
SG  0.25     2.0    93.0
NB   0.0
BG   0.0    0.00    0.00    0.00    0.10    0.10    0.80
CS    -1
IQ     1 10000.0
IS         0.05
IS         0.05
IS         0.25
IS         0.25
IS         0.25
IS         0.15
IS         0.00
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LM  1100   99999
LM  1100   99999
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LM  1100   99999
LM  1100   99999
PR     3    8030
PX  8030
PW  8030
END
```

5.2 Output Data Files

All the output data files for this example can be found, in electronic format, in the main GSTARS4 distribution package in directory Example5.

5.3 Results and Discussion

Here, the results of the GSTARS4 run of this example are presented and briefly analyzed. The results of a 1996 survey carried out in Tarbela reservoir, corresponding to the conclusion of the period of the simulation, are used here. That data are used for comparison purposes. Note that this example does not constitute an exhaustive and definitive study of the sedimentation processes in Tarbela reservoir for the 1974-1996 period. Rather, it is presented here for didactic purposes only.

The simulation results for the thalwegs are shown in figure 5.4. They are in good agreement with measurements, especially as in what concerns the location of the frontset of the delta and its slope. This is important to determine capacity loss, the useful life of the reservoir, and the impact that dam operations have on the reservoir's deposition pattern.

Cross-sectional geometries were better predicted in the downstream reservoir region than in the upstream region. That is because the upstream part is has mostly riverine characteristics, and uniform deposition is not the most appropriate technique for this circumstance (recall figure 3.3, which shows the depositional pattern in a river, versus figure 5.4, which shows the depositional pattern in a reservoir). However, this region is limited to the first 21 cross sections, which represents less than one fourth of the entire simulated reach. Even then, deposition volumes are in general well predicted, even if thalweg elevations are not very accurate. Two representative cross section in this region are shown in figure 5.5 for comparison purposes.

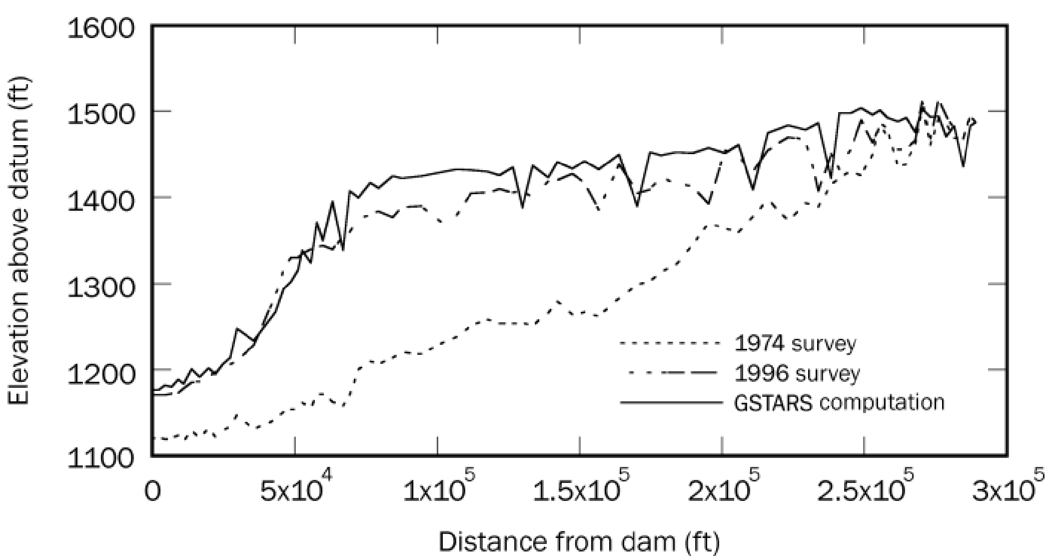


Figure 5.4 Results of the simulation of the Tarbela delta advancement over a period of 22 years.

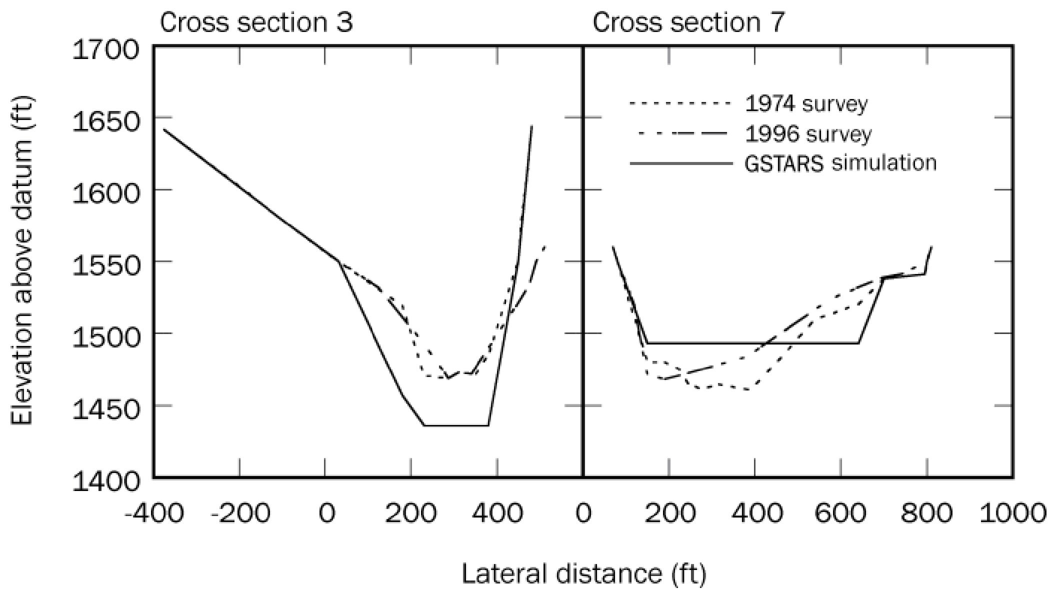


Figure 5.5 Comparison of measurements and GSTARS4 computation for two cross sections in the upstream region of Tarbela reservoir.

In the reservoir region, which constitutes the focus of the study, deposition volumes are well predicted, in spite of a small tendency to overpredict the thalweg elevations. Four representative cross sections are shown in figures 5.6 and 8.7. These cross sections were taken from the full breath of the reservoir region.

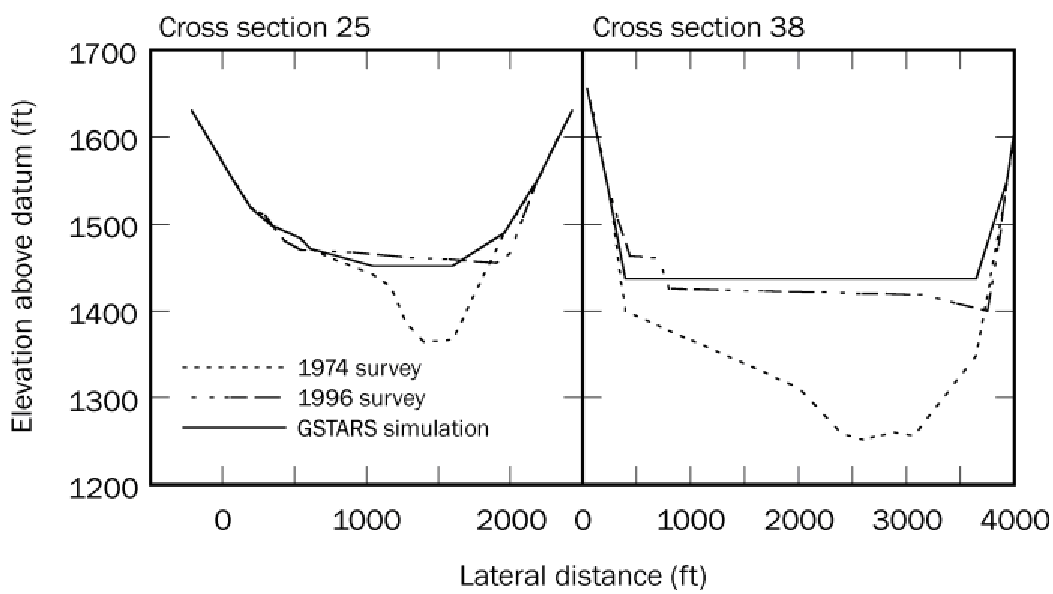


Figure 5.6 Comparison of measurements and GSTARS4 computation for two cross sections in the reservoir region of the study reach.

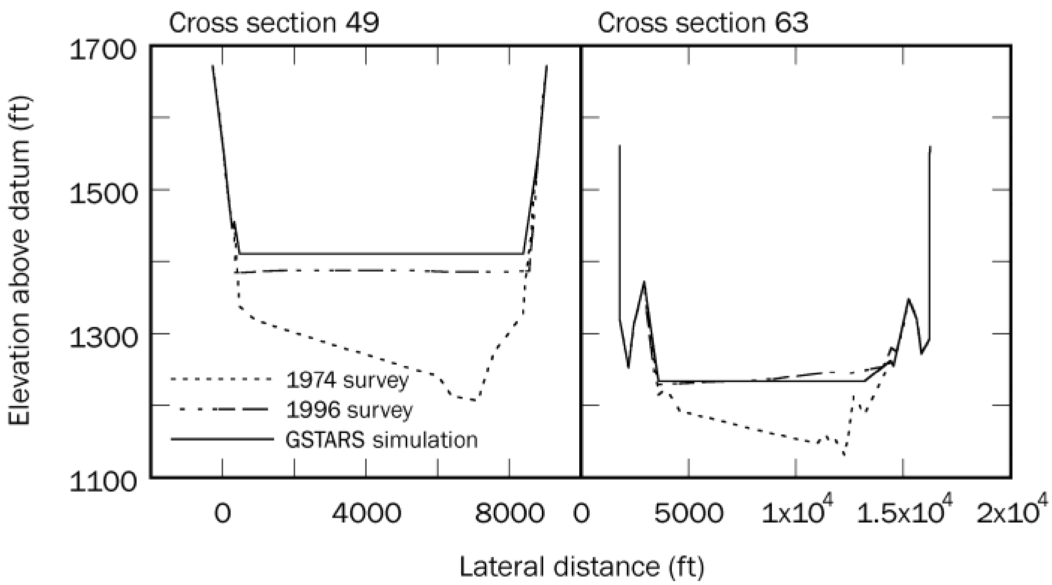


Figure 5.7 More comparisons of measurements and GSTARS4 computations, for two cross sections in the reservoir region of the study reach downstream from those in figure 5.6.

The error associated with the predicted thalwegs is shown in figure 5.8. Most data is inside the 20% error band, which is a very good result for this type of simulation (22 years of sedimentation spanning a 58-mile reach). However, this study could easily be improved with the use of little additional data. Such data would comprise more accurate bed-sediment size distributions, as well as more information about the inflowing sediment sizes travelling through the Indus. Further improvements would be attained from a study of the cohesive-sediment fraction properties within the reach.

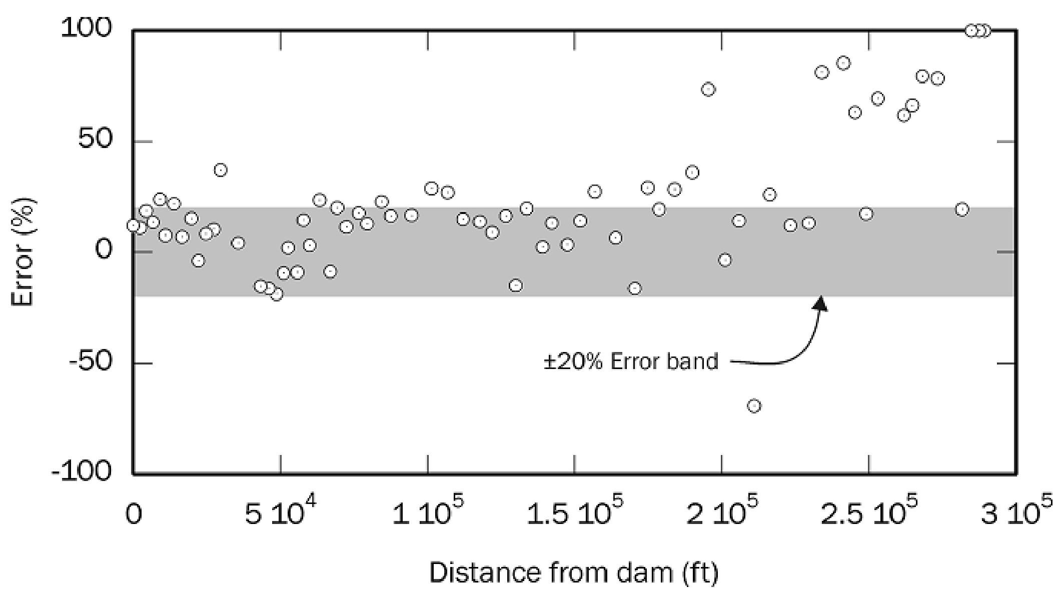


Figure 5.8 Relative error of the thalweg elevation predictions. Note the larger magnitude of the errors upstream, in the riverine part of the reach, compared to the lower magnitude of the errors in the reservoir reach.

EXAMPLE 6

All American Canal Sediment Transport

The All American Canal (AAC) is located in southern California to transport water to the San Diego area. There are two channels shown in figurer 6.1. The existing old canal is not lined and a large amount of water is lost through seepage. The new canal is lined. Figures 6.2 (a) and (b) show the old and new canals, respectively.

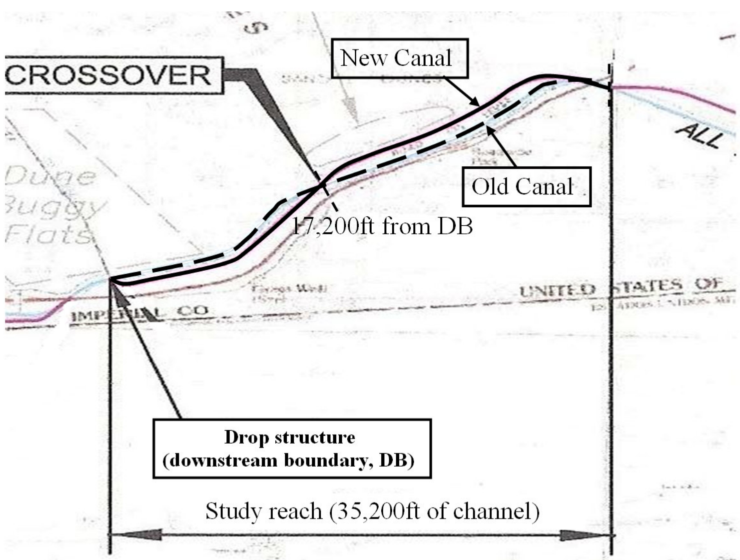


Figure 6.1 Plan view of study area

(a) Old AAC canal (b) New AAC canal (c) Sediment slip into the old canal

Figure 6.2 Photos of the old and the new AAC canal

During the construction of the new canal, excavated sandy materials were piled between the old and new canals. Large amount of sediments have been falling into the old canal due to wind and gravitational forces as shown in figure 6.2 (c). Once sediments were slipped into the old canal, they were transported to the downstream of the old canal. It is import to determine the impacts of sediment inflows, sediment transport rate, scour, and

deposition in the old canal using a computer model. The study focuses on the channel geomorphic changes in the old canal after sediment falling into the canal.
The study reach is 35,200 ft long. There is a drop structure at the downstream end of the study reach which is used as the downstream boundary of GSTARS4 simulations. There are some mild curves along the canal. Localized flow variations near a mild curvature are negligible for simulations purpose. The initial canal has trapezoidal cross sections as shown in figure 6.3.
GSTARS4 model is applicable to sediment transport studies of the old AAC. GSTARS4 can simulate lateral variations of sediment conditions in a semi-three dimensional manner by using the stream tube concept. Sediment scour, deposition, and transport were computed by using Yang's unit stream power sediment transport formulas for sand (1973) and for gravel (1984), respectively.

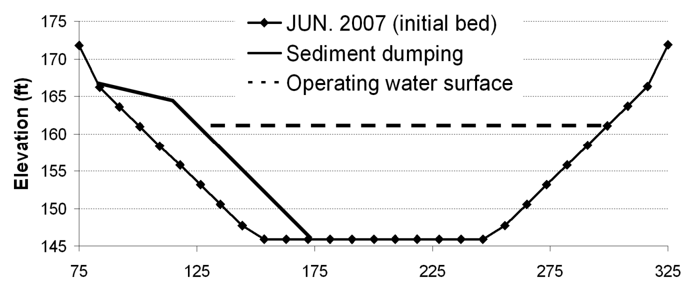


Figure 6.3 Sediment falling on the old ACC at 24,800 ft

Water surface elevation variations at the downstream drop structure and water inflow from the upstream end of the study reach are shown in figure 6.4. Water inflow and water surface elevation are used as upstream and downstream flow boundary conditions, respectively.
It is assumed that sediment transport rate at the upstream boundary is the same as the sediment transport capacity (EQUILIBRIUM for QR record) computed by Yang's 1973 and 1984 formulas for sand and gravel, respectively.

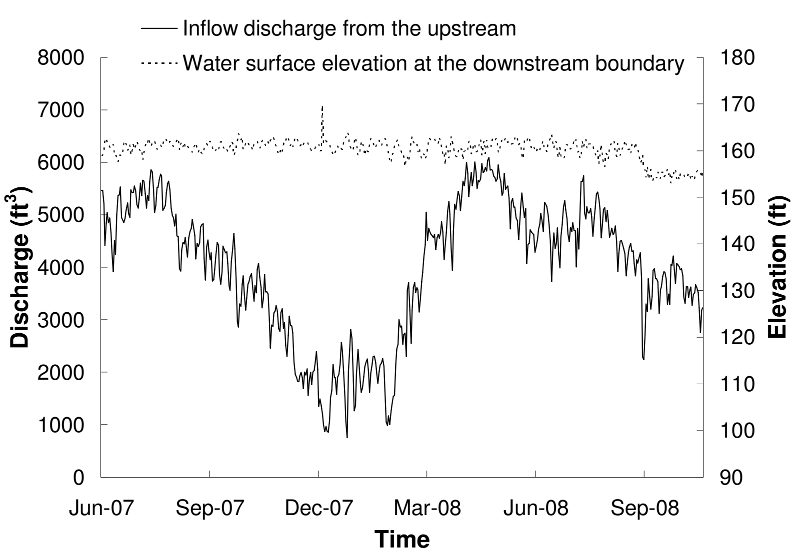


Figure 6.4 Flow boundary condition

This study includes sediment inflows at several locations along the study reach. Because sediments inflows enter the channel either from the left or the right side of the channel, truly 1-D model can not simulate this uneven sediment distribution across the channel. Location, duration, and quantity of sediment inflows are summarized in Table 6.1. It is assumed that the amount of each sediment inflow is evenly distributed in time and space within a short reach where sediments were piled on the road between the old and new AAC. For example, there are no spatial or temporal variations of 200,000 yd^3 of sediment for the first inflow period. Sediment falling into the old ACC was considered as lateral inflow by using LI records.

Table 6.1 Locations and durations of sediment falling into the old canal

Period	Date Range	Station Range from the downstream boundary (ft)	Falling bank	Quantity (yd^3)
1	11/13/2007 ~ 1/17/2008	24,800 to 19,500	Left	200,000
2	1/18/2008 ~ 2/24/2008	19,500 to 17,000	Left	100,000
3	2/25/2008 ~ 7/24/2008	15,900 to 13,900	Right	80,000
4	9/2/2008 ~ 9/4/2008	9,000 to 4,700	Right	220,000
5	9/9/2008 ~ 9/11/2008	13,100 to 1,170	Right	40,000
Total				640,000

The simulation duration is 510 days, between June 1, 2007 and October 24, 2008. Three stream tubes were used to simulate lateral variations of sediment transport, scour, and deposition. Steady and unsteady hydraulic simulations were conducted for comparison. GSTARS4 is capable of deciding whether scour and depositional adjustments are in the lateral or vertical directions by using stream power minimization routine. The routine iterates a cross section change until the cross section reaches a minimum value of stream power. Simulated results of both with and without using the minimization routine are compared in this example. Four cases of simulations were conducted as shown in Table 6.2.

Table 6.2 Four simulation cases

Simulation case	Flow simulation	Stream power minimization
U&noM	Unsteady	Not used
S&noM	Steady	Not used
U&M	Unsteady	Activated
S&M	Steady	Activated

6.1 Input and Output Data File

All the input and output data files for this example can be found, in electronic format, in the main GSTARS4 distribution package in directory Example 6.

6.2 Results and Discussion

Thalweg profiles for both steady and unsteady simulation results have similar trend as shown in figure 6.5. Unsteady flow with no minimization (U&noM) and steady flow with no minimization (S&noM) have almost the same thalweg profiles. Simulated results using stream power minimization for unsteady with minimization (U&M) and steady flow with minimization (S&M) have similar results. Water surface variation at the downstream boundary is about 5 ft during the 450 days of simulation. Unsteady and steady flow simulations have similar results. Most canals do not have sudden water surface variation, and steady simulation is adequate. If unsteady effect is not negligible, such as during sediment flushing, unsteady simulation should be used.

Simulated results with and without using stream power minimization routine have noticeable difference. Between station at 20,000 ft and 25,000 ft, simulated profiles with stream power minimization routine resulted in higher thalweg than those without using the routine. Stream power minimization routine can decide whether deposition or scour is in the lateral or vertical direction by minimizing the stream power. Stream power minimization routine resulted in more lateral migration than vertical scour between stations 20,000 ft and 25,000 ft.

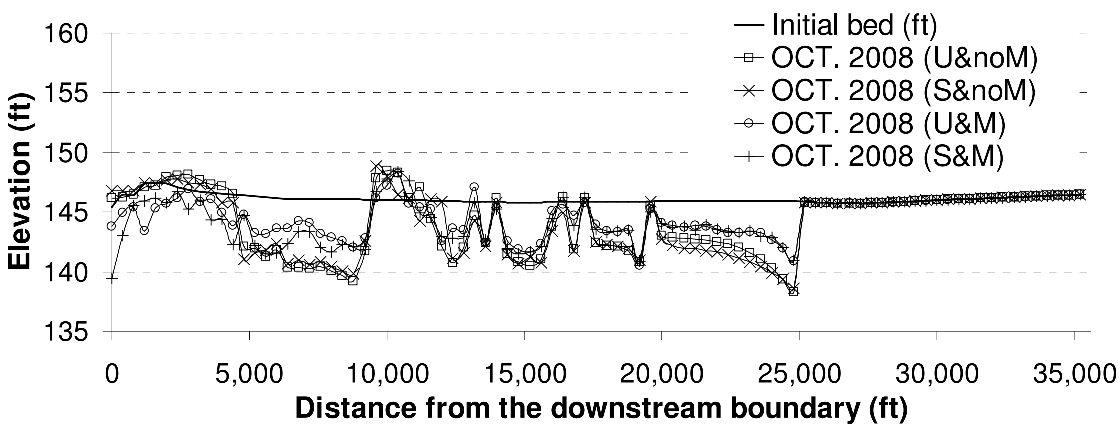


Figure 6.5 Comparison of simulated thalweg profiles

Figure 6.6 shows simulated cross sectional changes of the old AAC using unsteady flow routing without stream power minimization. Figure 6.6 (a) shows almost no change of cross section because the location is just upstream of the first sediment falling while figure 6.6 (b) has gradual sediment deposition on the left side of the channel and channel migrated to the right side due to sediment falling on the left side. Deposition on the right side and channel migration to the left can be found in figure 6.6 (c). Downstream of sediment falling, formation of submerged middle bars can be seen in figure 6.6 (f). Sediment supply to the downstream reach is increased due to sediment slipping into the canal. Some of the sediment slipped into the old canal transported further downstream while some of them are deposited in the channel and forms middle bars.

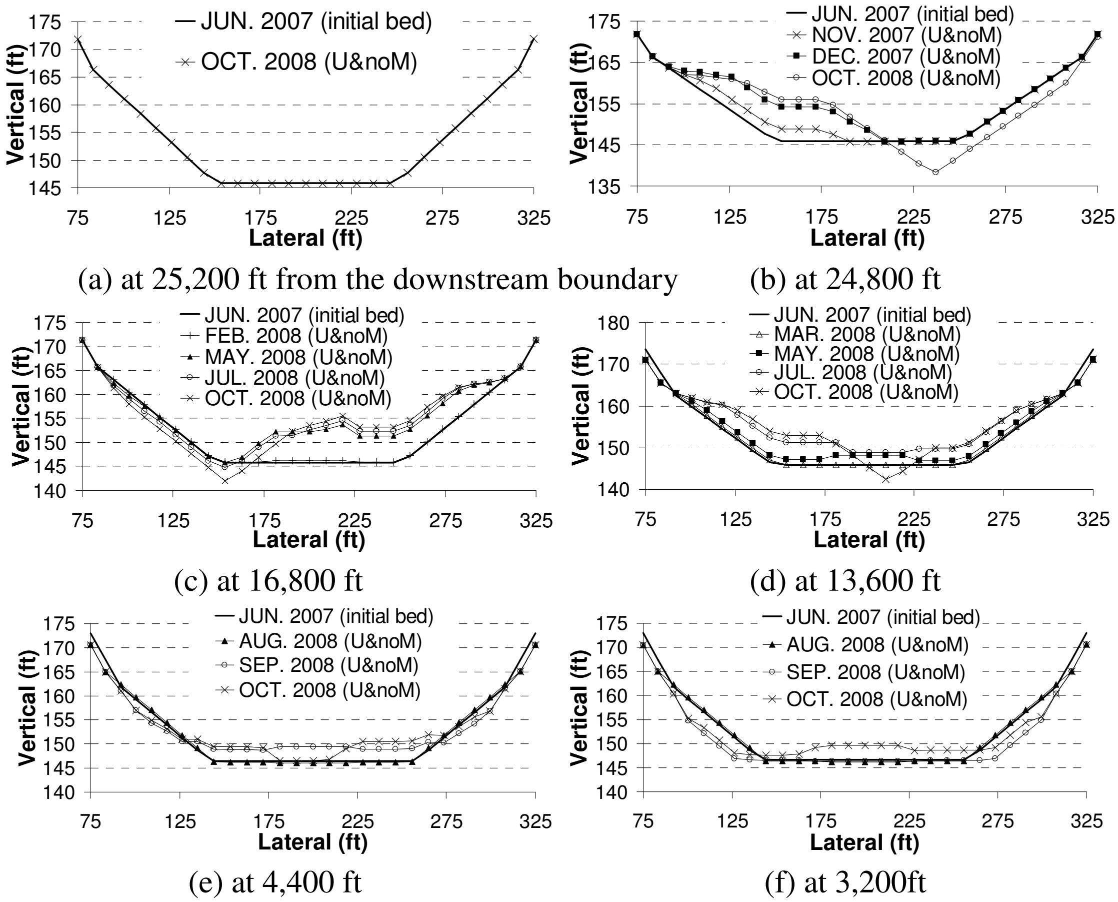
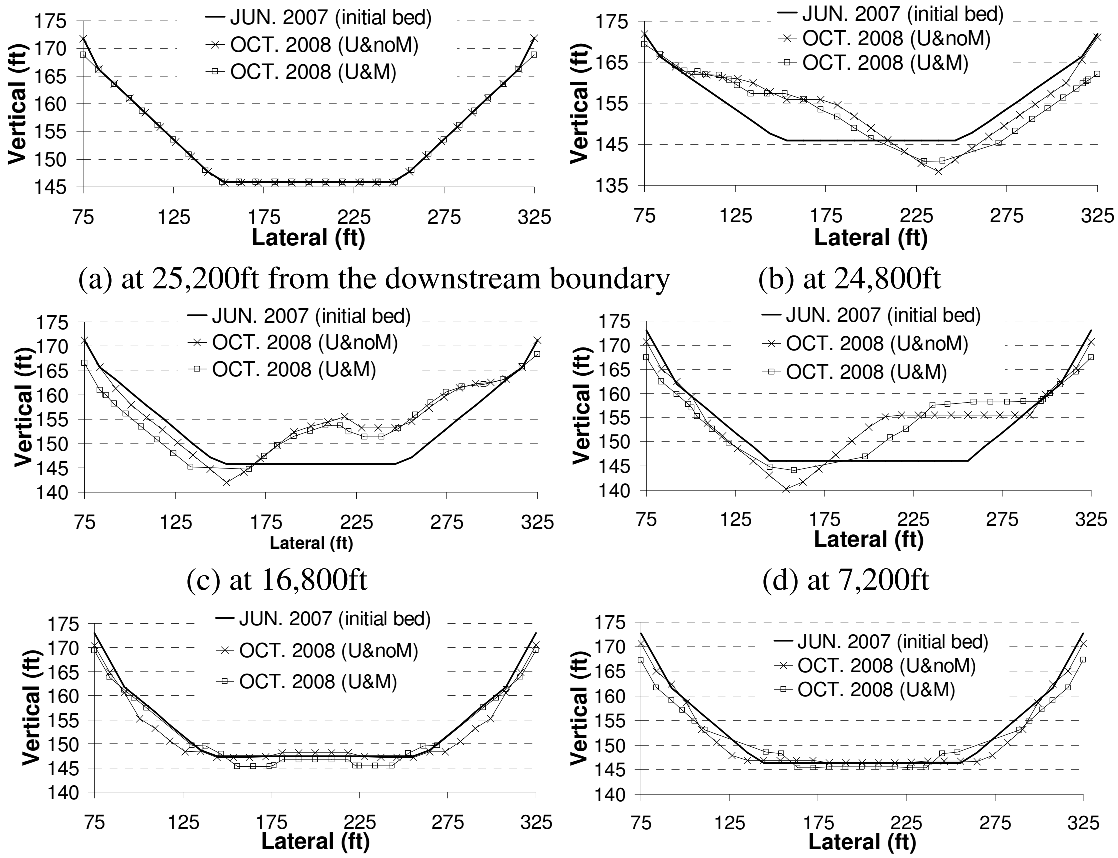


Figure 6.6 Cross sectional change of unsteady simulation without stream power minimization

Comparisons between those with and without using stream power minimization are shown in figure 6.7. These two results have similar trend of deposition on one side and channel migration to the other side. However, simulation with stream power minimization has more lateral migration than the one without minimization. Stream power minimization routine can adjust channel width and depth to minimize stream power while simulation without it can only adjust vertical deposition or scour. Stream power minimization option is important where lateral deposition or scour is significant. However, stream power minimization requires large computational capacity and simulation takes much longer time than that without using it. The adjustments in the lateral and vertical directions must be decided at every time step of computation based on the theory of minimum stream power.

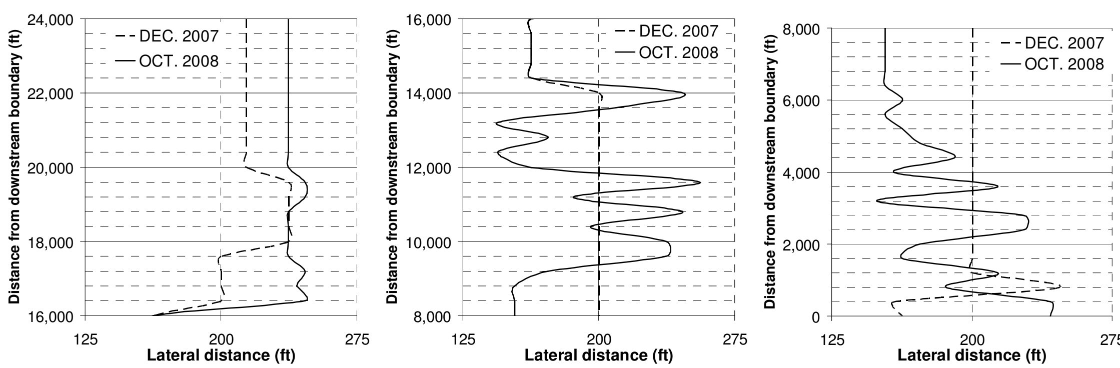


(a) at 25,200ft from the downstream boundary (b) at 24,800ft

(c) at 16,800ft (d) at 7,200ft

(e) at 1,600ft (f) at 800ft

Figure 6.7 Comparison between with and without using stream power minimization



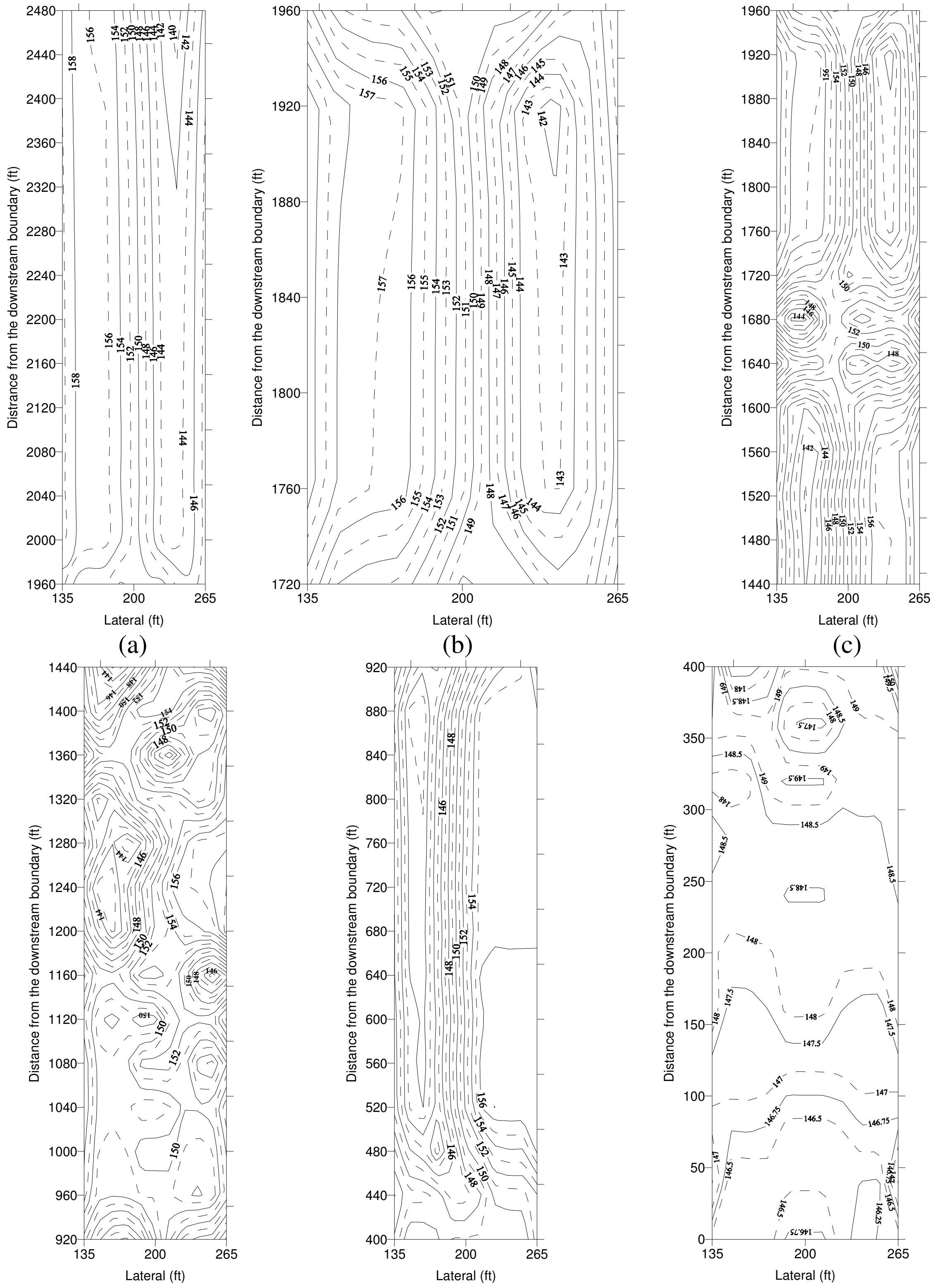
(a) Upstream reach (b) Middle reach (c) Downstream reach

Figure 6.8 Lateral migration of thalweg of unsteady with stream power minimization simulation

Figure 6.8 shows lateral migration of the thalweg line. The thalweg line was in the middle of the channel and was straight before sediment slipping into the old ACC. Due to uneven sediment slipping from one or the other side of the old AAC, the thalweg migrates in the lateral direction. Comparison between the December 2007 and October 2008 thalwegs clearly indicates that the lateral variation of thalweg line increases with respect to time. In figure 6.6 and 6.7, channel banks move with thalweg migration. It is possible for a straight channel to become a meandering pattern with some middle bars.

Figure 6.9 (a) and (b) show higher bottom elevation on the left side due to sediment slipping period 1 and 2 as shown in Table 6.1. Formation of submerged middle bars at the downstream reach is shown in figure 6.9 (f).

GSTARS4 is applied to simulated uneven sediment inputs from either side of the banks of the old ACC canal. GSTARS4 predicts channel migration and formation of bars reasonably well by using the stream tube concept and the theory of minimum stream power. Because flow condition in the old AAC did not have significant unsteady effect, unsteady and steady simulations have similar results. Simulated results with and without the use of stream power minimization have similar trends of lateral channel movement and formation of submerged bars. However, simulations with stream power minimization predict more width change than simulations without minimization. If the channel bank is erodible and lateral migration is not negligible, stream power minimization routine should be activated for the accuracy of the simulated results.



(a) (b) (c)

(d) (e) (f)

Figure 6.9 Channel shape in OCT. 2008 with U&noM

EXAMPLE 7

Xiaolangdi Reservoir Sedimentation and Flushing

The Xiaolangdi Reservoir is located at 40km north of Loyang and 128.42km downstream of Sanmenxia dam on the main stem of the Yellow River. The drainage basin area is about 7.0×10^5km^2, and average annual discharge at the dam location is 400×10^9m^3. The average annual sediment load is $13.47\text{x}10^9$ tons. The top of the reservoir storage is at 275m. There are more than 40 tributaries flowing into the Xiaolangdi Reservoir as shown in figure 7.1. 12 of them are considered as major tributaries. Simulations were made to include 12 major tributaries and one "imaginary tributary" which accounts for all the remaining tributary volumes.

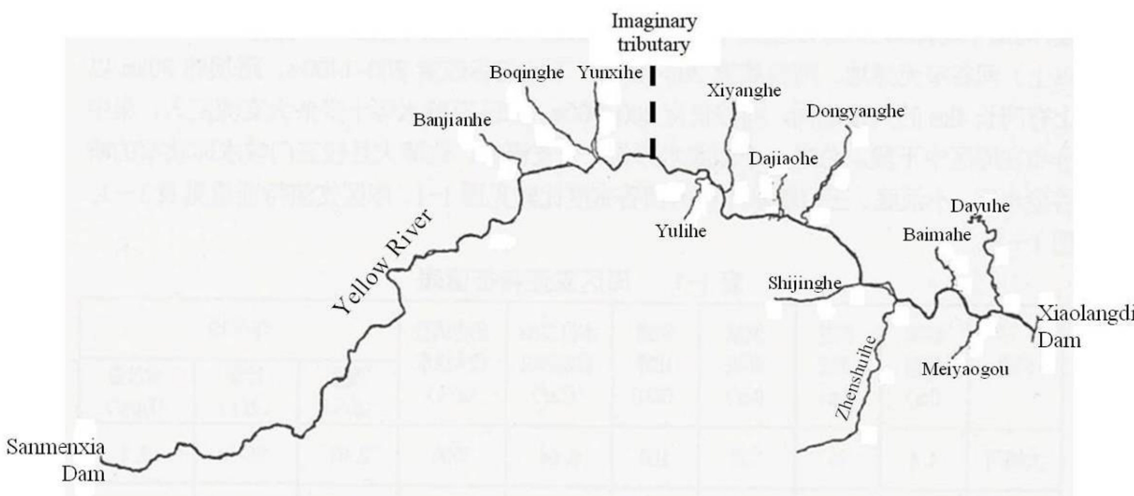
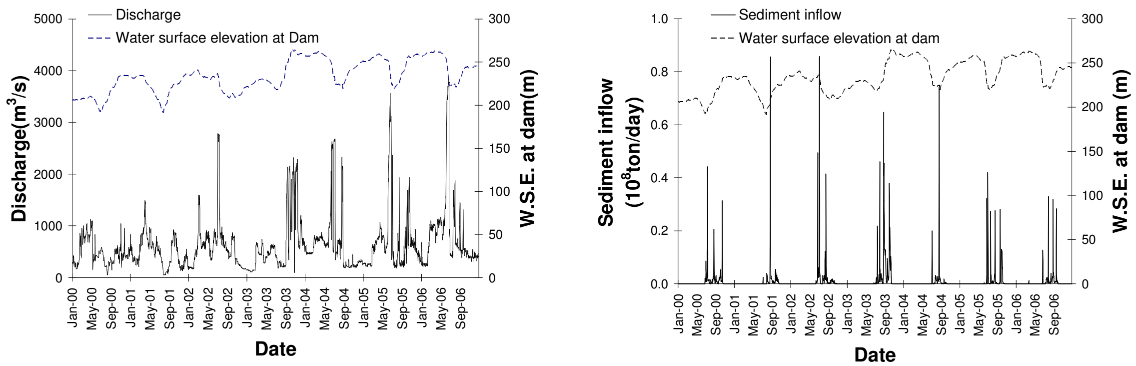


Figure 7.1 Plan view of the Xiaolangdi Reservoir and tributaries

Due to high concentration of fine materials, the Yellow River is complex and special considerations must be made. The Xiaolangdi Reservoir sedimentation study should be carried out carefully considering high sediment concentration flow mechanism. Yang et al. (1996) modified unit stream power formula for high-concentration sediment laden flow is used for this study.

Flow characteristics in the Xiaolangdi Reservoir are complex. There is a sudden water surface drop every year, usually from May to October for draw down flushing. Without drawdown sluicing, the reservoir will be filled up by sediment in a short period because of high sediment concentration. Figure 7.2 (a) shows that there are rapid and significant water surface elevation change at the Xiaolangdi dam every year. Incoming water and sediment discharge is controlled by the upstream Sanmenxia dam. There are drawdown flushings for the Sanmenxia Reservoir. So upstream boundary condition depends on operation of the Sanmenxia Reservoir. Figure 7.2 (b) shows the variation of incoming sediment load from the upstream Sanmenxia Reservoir.



(a) Water discharge data (b) Sediment load and water surface elevation

Figure 7.2 Water and sediment discharge and water surface at the Xiaolangdi dam

The inflow of water and sediment of tributaries along Xiaolagndi Reservoir are very small, compared with those in the reservoir, and may be ignored for reservoir routing. However, the total volume of all the tributaries is about 40% of the reservoir volume and can not be ignored. The “level pool” concept is used to compute the reservoir volume and discharge of tributaries as described in 2.1.5.2. TR and TI records should be used to simulate influence of tributaries of the Xiaolangdi Reservoir.

Non-equilibrium sediment transport equation was applied to simulate spatial and temporal delay effect to scour and deposition. The recovery factor is a function of sediment size. Sediment size was divided into 9 groups and each group should have one NA record.

Basic factors influencing the density of sediment deposited in a reservoir depend on reservoir operation, the texture and size of deposited sediment particle, and the compaction or consolidation rate (Yang, 1996 and 2003). GSTARS4 model requires dry specific mass, which is the dry mass per unit volume of deposited sediment (lb/ft^3 or kg/m^3), of each sediment size group. GSTARS3 is able to use one set of sediment density. However, deposited sediment density may vary with respect to location and whether the reach is a reservoir or river reach. For the Xiaolangdi Reservoir sedimentation study, both river and reservoir regimes exist between Xiaolangdi dam and Sanmenxia dam. GSTARS4 has capability of using different sediment density with respect to cross section (recall SL record in Appendix A). Referring Table 7.1 and 7.2, deposited sediment densities of operation 1 and operation 4 are used for reservoir and river regime of Xiaolangdi Reservoir, respectively.

Table 7.1 Four types of reservoir operation (Yang, 1996 and 2003)

Operation	Reservoir operation
1	Sediment always submerged or nearly submerged
2	Normally moderated to considerable reservoir drawdown
3	Reservoir normally empty
4	Riverbed sediments

Table 7.2 Dry specific mass with respect to operation number (Yang, 1996 and 2003)

Operation	Initial dry specific mass (kg/m^3)		
	Clay	Silt	Sand
1	416	1120	1550
4	961	1170	1550

Both quasi-steady and truly unsteady flow simulations were carried out for 3.5 year, May 2003 to October 2006 by using two sets of density of bed material with respect to reservoir operation number, 1 and 2. Four cases of simulation, shown in Table 7.3, were compared in this section.

Table 7.3 Four simulations of Xiaolangdi Reservoir from May 2003 to October 2006

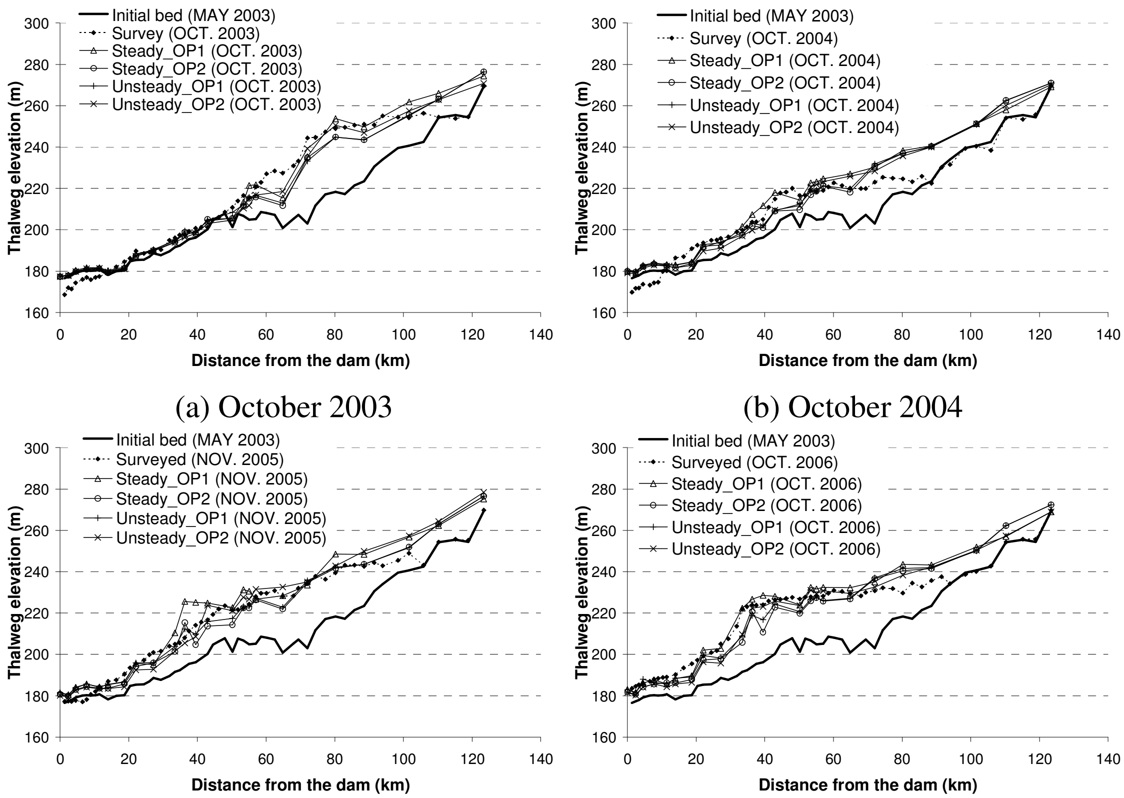
Case of simulation	Flow routing	Density of bed sediment (values shown in Table 7.2)	
		In reservoir regime	In river regime
Steady_OP1	Quasi-steady	Operation No. 1	Operation No. 4
Steady_OP2		Operation No. 2	Operation No. 4
Unsteady_OP1	Truly unsteady	Operation No. 1	Operation No. 4
Unsteady_OP2		Operation No. 2	Operation No. 4

7.1 Input and Output Data File

All the input and output data files for this example can be found, in electronic format, in the main GSTARS4 distribution package in directory Example 7.

7.2 Results and Discussion

Density of deposit sediment has effect on the simulated results. Comparison between operation number 1 and 2 reveals that simulation results with operation number 2 generally have higher thalweg elevation than those with operation number 1 as shown in figures. 7.3 (a) ~ (d). Because sediment density of operation number 1 is lower than that of operation number 2, simulated results with operation number 1 have lower bed.



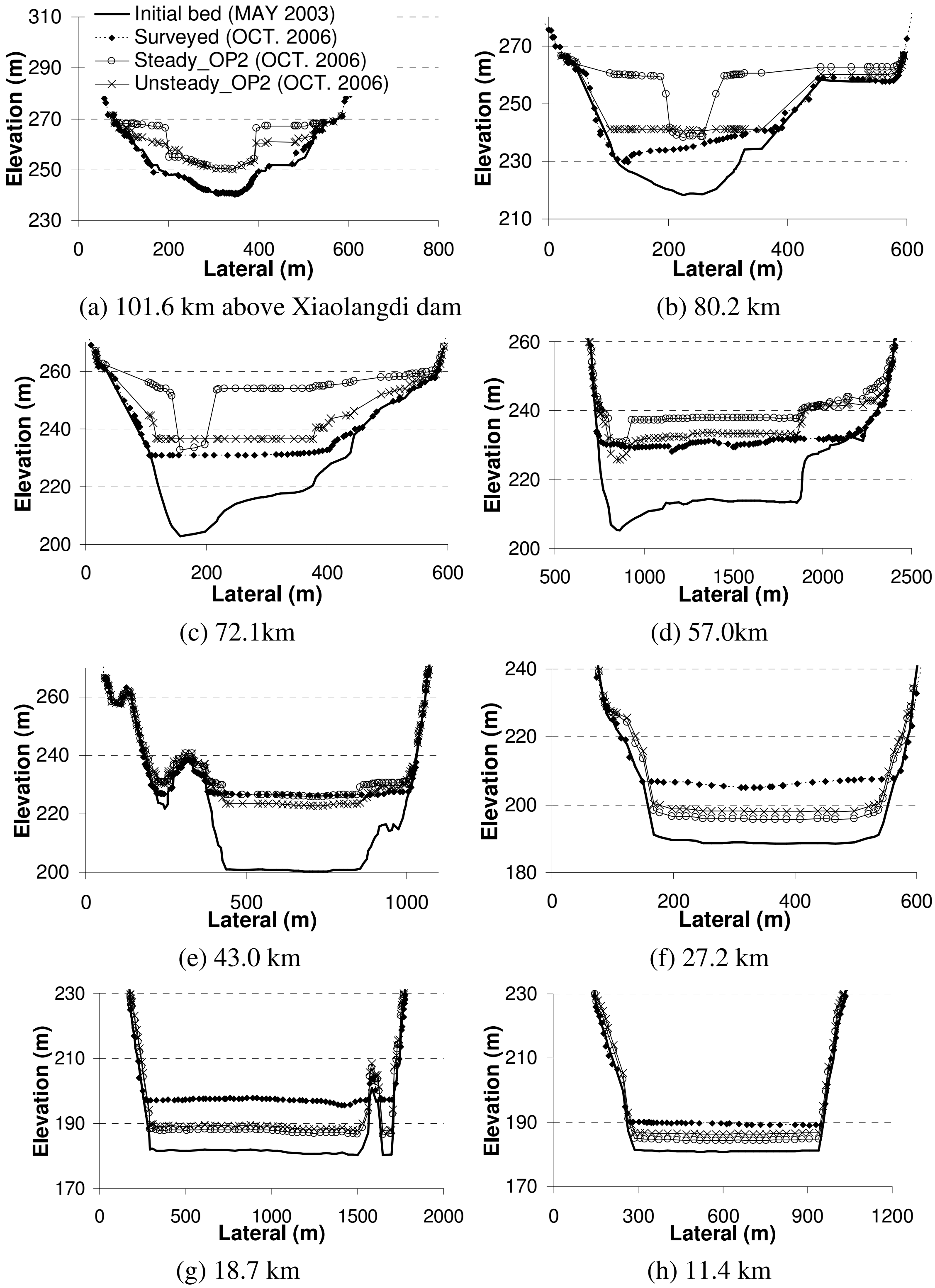
(a) October 2003 (b) October 2004

(c) November 2005 (d) October 2006

Figure 7.3 Comparison of surveyed and simulated thalweg elevation

Simulation results of the lower reach are better than that of the upper reach. The upstream cross sections are directly influenced by the discharged water and sediment from Sanmenxia dam, and the sediment transport mechanism in the upstream reach is very unstable to model due to huge variation of sediment inflow from the upstream boundary as shown in figure 7.2. The amount of scour and deposition in the lower reaches, about 10 ~ 60 km above the dam, is less depend on the upstream condition. Results shown in figure 7.4 indicate that the unsteady simulation results are in good agreement with measured results. Steady flow simulation predicts narrowing of the river regime after October 2004. Figures 7.4 (a), (b), and (c) show that formation of narrow channel for the steady simulation while unsteady flow simulations predicts wide channel. Stream power minimization was not applied for this example, because lateral channel migration in the Xiaolangdi Reservoir is significant.

The predicted bed material size variation with steady and unsteady flow simulations are in good agreement with measurements regardless of the time of measurement as shown in figure 7.5. These results indicate that GSTARS4 can be used to predict the variation of bed material size distribution along the study areas with river and reservoir regimes.



(a) 101.6 km above Xiaolangdi dam

(b) 80.2 km

(c) 72.1km

(d) 57.0km

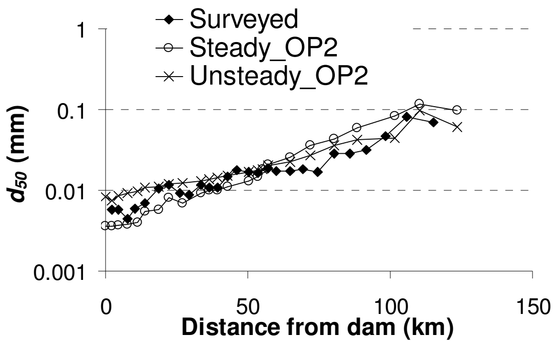
(e) 43.0 km

(f) 27.2 km

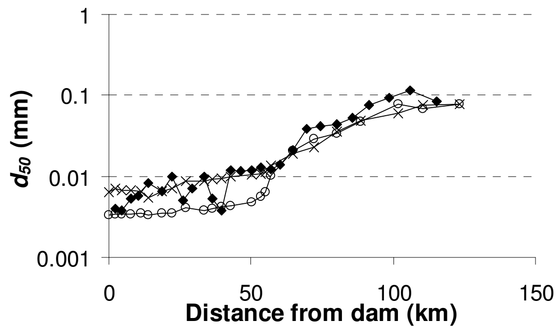
(g) 18.7 km

(h) 11.4 km

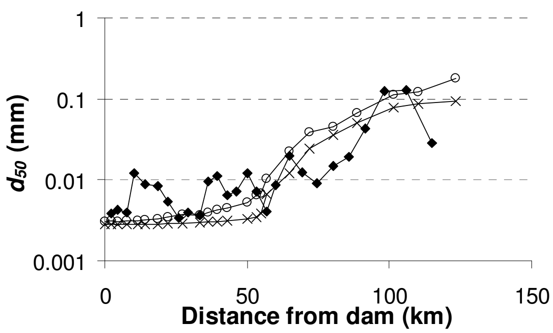
Figure 7.4 Comparison of measurement and GSTARS4 simulation, in October 2006



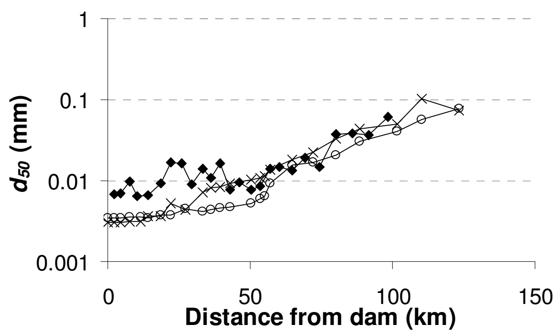
(a) October 2003



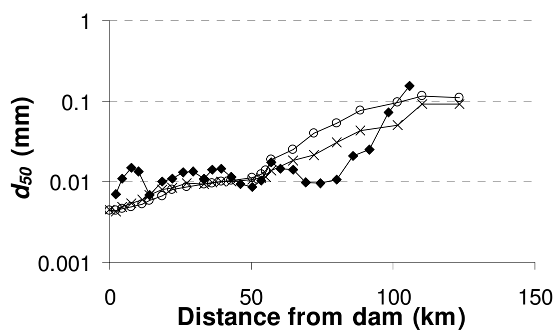
(b) May 2004



(c) October 2004



(d) April 2005



(e) November 2005

Figure 7.5 Comparison of bed material size variations

EXAMPLE 8

Lewis and Clark Lake, USA

The Lewis and Clark Lake is located on the main stem of the Missouri River. The study reaches are from the Gavins Point Dam up to Fort Randall Dam. Total length of the reaches is about 65 mile and the Lewis and Clark Reservoir reach is about 20 mile from the Gavins Point Dam as shown in figure 8.1. There are three main lateral inflows, Ponca Creek, Niobrara River, and Bazille Creek. These three tributaries, especially the Niobrara River, supplied large amount of sediment to the lake and formed the delta. Within the study boundaries, an aggrading reach is associated with three confluences and the headwaters of the Lewis and Clark Lake. The original storage capacity of 492,000 acre·ft has been reduced about 30~40% after its construction.

The delta continues to expand with accelerated losses of reservoir capacity, increased the risk of flooding, and reduced recreational access to the Lewis and Clark Reservoir. Figure 8.2 shows that there are many bars down stream of the confluences. Sediment inflows from tributaries begin to settle down right below their confluences.

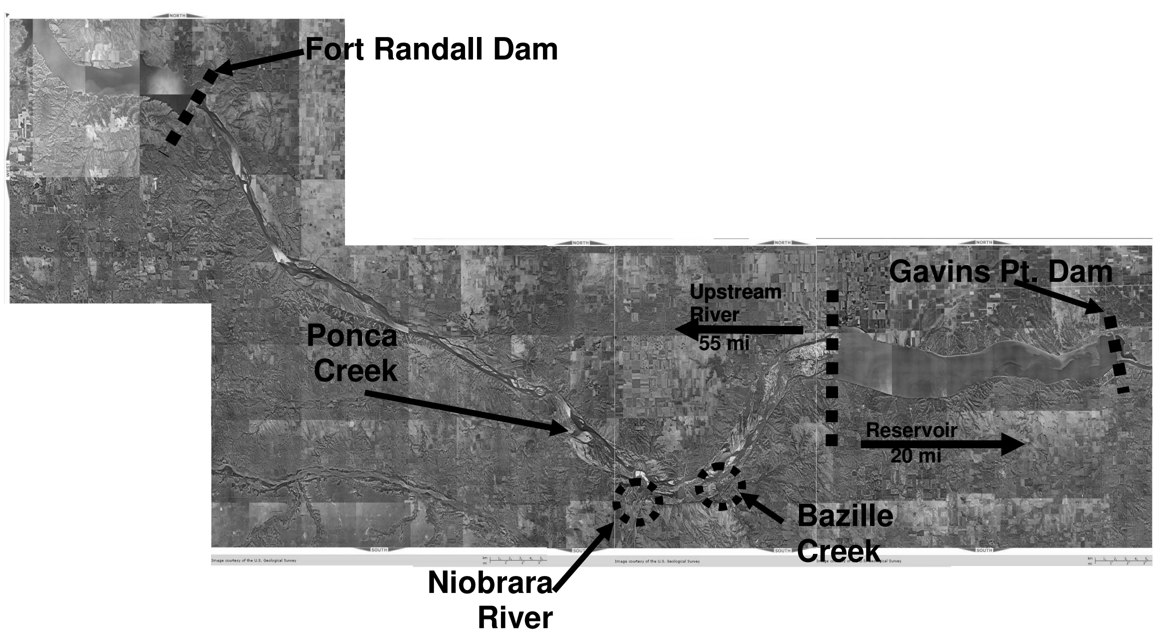


Figure 8.1 Lewis and Clark Lake

(a) Satellite photo (Google Earth)

(b) Photo taken at marked spot on (a)

Figure 8.2 Reservoir Delta of the Lewis and Clark Reservoir

The simulation started from 1975. To calibrate the model, GSTARS4 was run with the hydraulic and sediment data for 20 years of record in an attempt to match the 1995 survey information. Figure 8.3 shows measured bed profiles.

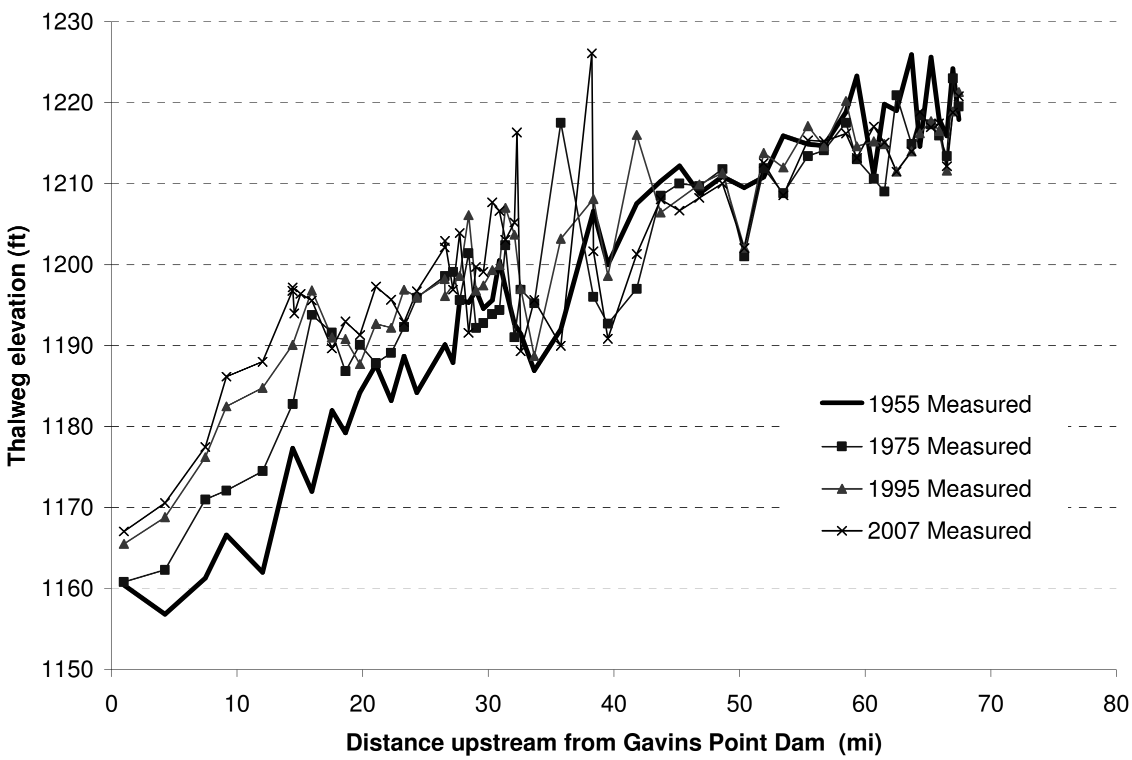


Figure 8.3 Measured bed profile

The upstream boundary condition is water discharge from Fort Randall Dam and the downstream boundary condition is water surface elevation of the Lewis and Clark Lake at Gavins Point Dam, as shown in figure 8.4. For sediment inflow from the upstream boundary, it was assumed that sediment transport at the first upstream cross section is under equilibrium condition because, there is no data of sediment released from Fort Randall dam. In other word, it is assumed that sediment inflow from the upstream is the same as sediment transport capacity at the first cross section calculated by using Yang (1973) and (1984) sediment transport equations (use “EQUILIBRIUM” for QR record).

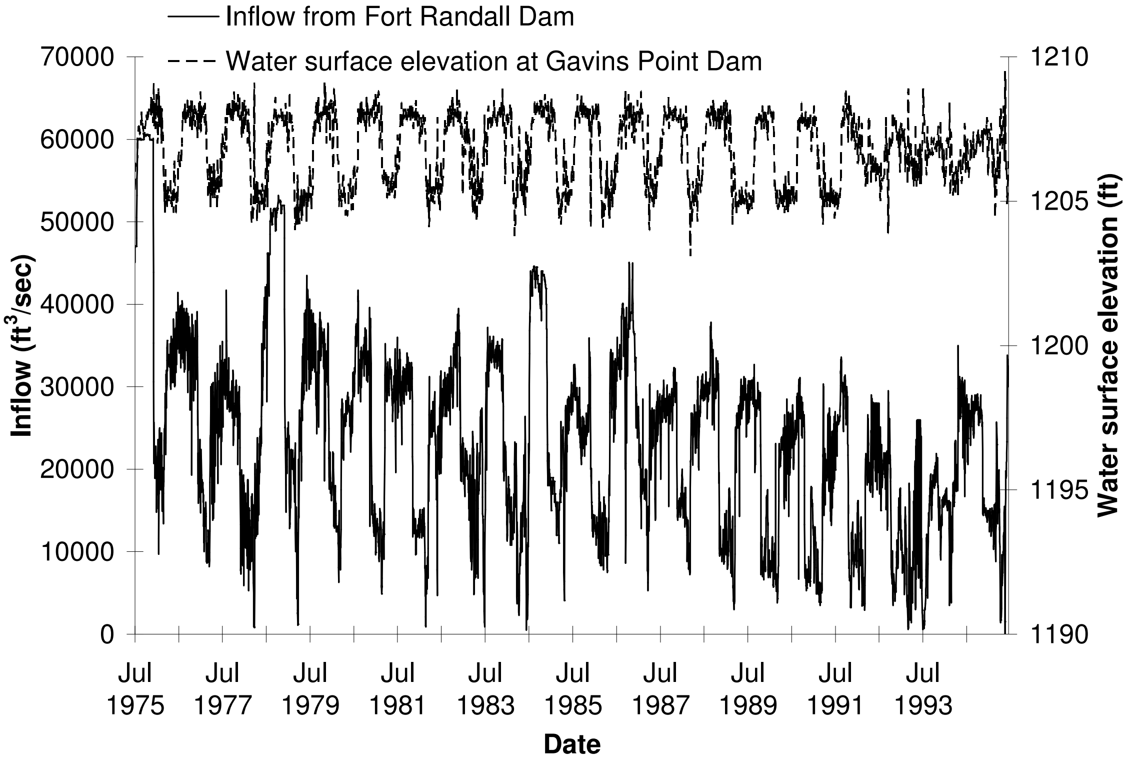


Figure 8.4 Flow boundary conditions

Water and sediment inflows from three tributaries, the Niobrara River, Ponca Creek, and Bazile Creek were considered. Because lateral sediment inflow from tributaries should be given for the sediment routing, a sediment rating curve was used, assuming that three tributaries have the same sediment rating curve as that of the Missouri River shown in figure 8.5, i.e.,

$$Q_{s,lat} = 2.79\times10^{-6} Q_{lat}^{\ 2.799}$$

where $Q_{s,lat}$ = sediment inflow from a tributary in ton/day ; and

Q_{lat} = water discharge from a tributary in ft^3/sec.

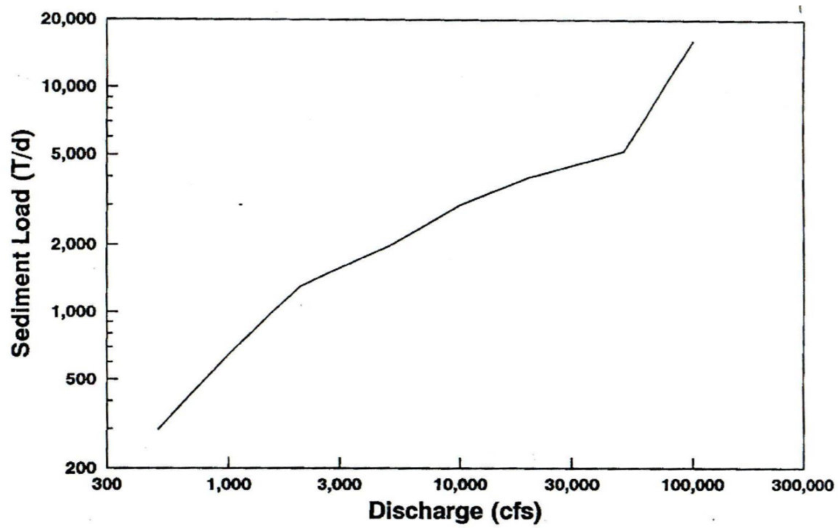


Figure 8.5 Sediment inflows from tributary (from inflow sediment rating curve, Missouri River pre-project conditions, Army Corps of Engineers Omaha District, 1993)

8.1 Input and Output Data File

All the input and output data files for this example can be found, in electronic format, in the main GSTARS4 distribution package in directory Example 8.

8.2 Results and Discussion

It is very important to use proper values of site specific coefficients such as roughness coefficient and active bed layer thickness. In the upper river reach, just downstream of Fort Randall Dam, armoring is dominant. To simulate armoring, GSTARS4 uses the active bed layer thickness concept (see section 3.4). The thickness values should be calibrated before the model is applied to the sedimentation process in a reservoir.

Figure 8.6 shows results of unsteady simulations with changing Manning's *n*. The simulated results are not too sensitive to the variation of Manning's *n* values. n = 0.04 is the most reasonable value.

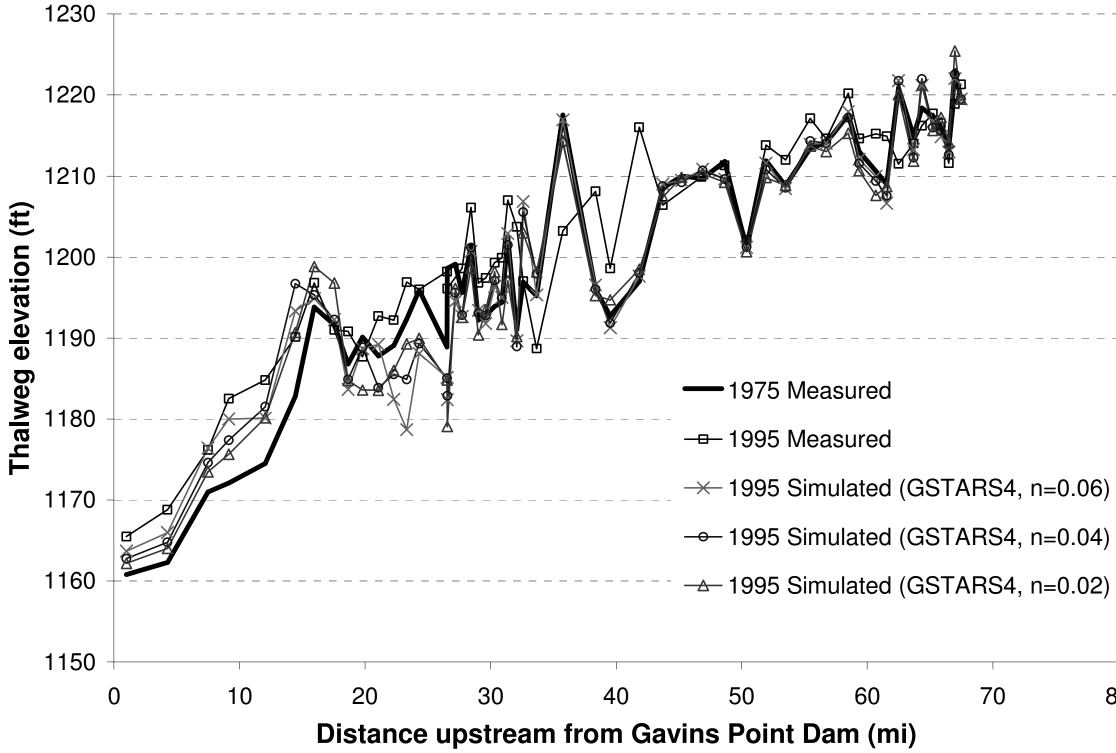


Figure 8.6 Unsteady simulation using various Manning's *n*

If the bed material is coarse, the active bed layer should be thick. The largest sediment particle is coarser than 2.00 mm, such as coarse sand and gravels. The active bed layer should be thicker than the coarsest bed material. In this study, the coarsest bed material is assumed as measured d_{99}, about 4 cm. In general, the measured d_{99} becomes finer in downstream direction and it is about 0.1 ~ 0.2 mm in the open lake. Many trial-and-error tests using various active layer thicknesses were conducted. It was concluded that 28 cm of active bed layer thickness is most reasonable. In Figure 8.7, 28 cm active bed layer thickness is more reasonable than 4 cm, because the coarsest bed material is about 4 cm, and more than one layer of coarse material is needed to form a stable active layer.

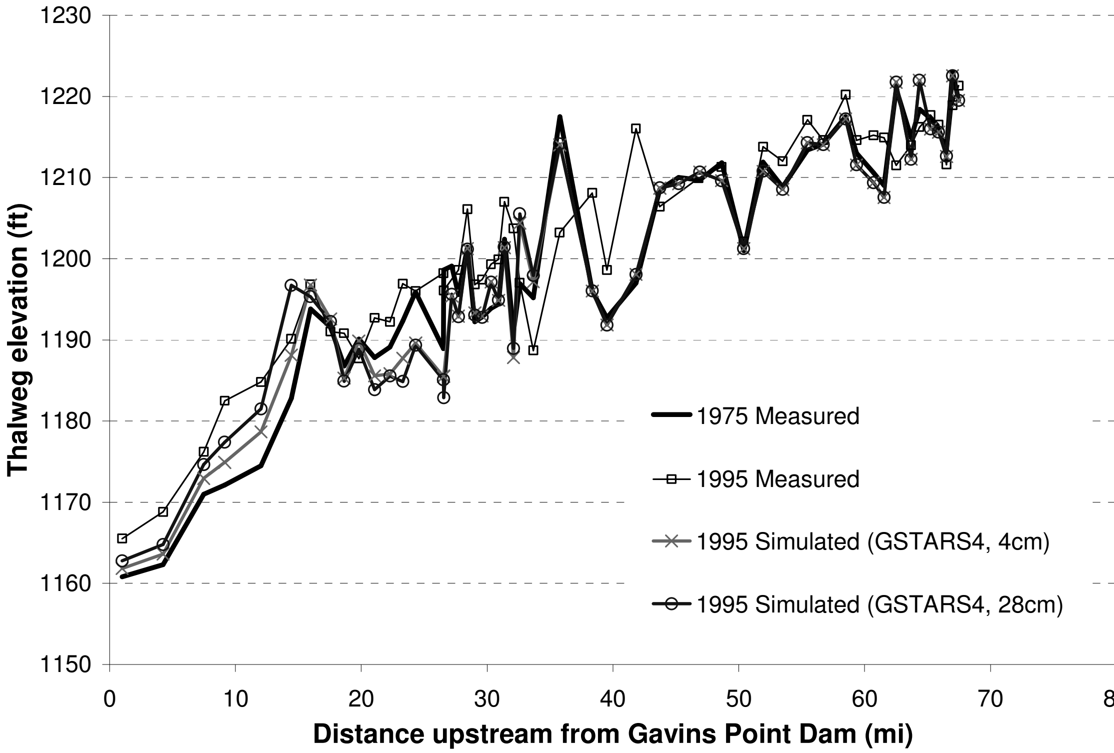


Figure 8.7 Unsteady simulation results with respect to active bed layer thickness

With calibrated coefficients, summarized in Table 8.1, both quasi-steady and unsteady simulations were conducted.

Table 8.1 Summary of the Calibration

Coefficients	Calibrated values	Remarks
Manning's n	0.04	For entire reach
Active layer thickness	28 cm	Close to measured d_{99}.
Water Temperature	46.5° F	Seasonal variation of water temperature is not sensitive to the simulated results.

The simulated results are close to the measured data as shown in figure 8.8 and 8.9. The simulated bed profile between 20 - 40 miles above Gavins Point dam is not very close to the measured one because cross section geometry of the upper reach is sensitive to sediment and water flushed out from the upstream Sanmenxia Reservoir. Unsteady and quasi-steady simulations have similar results because the unsteady effect was not significant in the case of normal reservoir operation from 1975 to 1995.

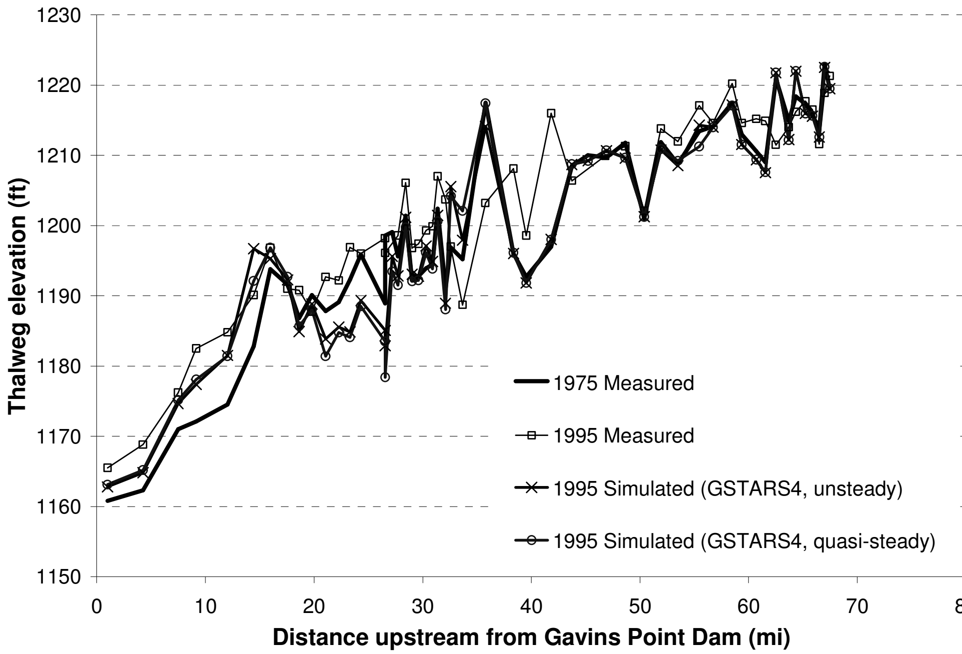
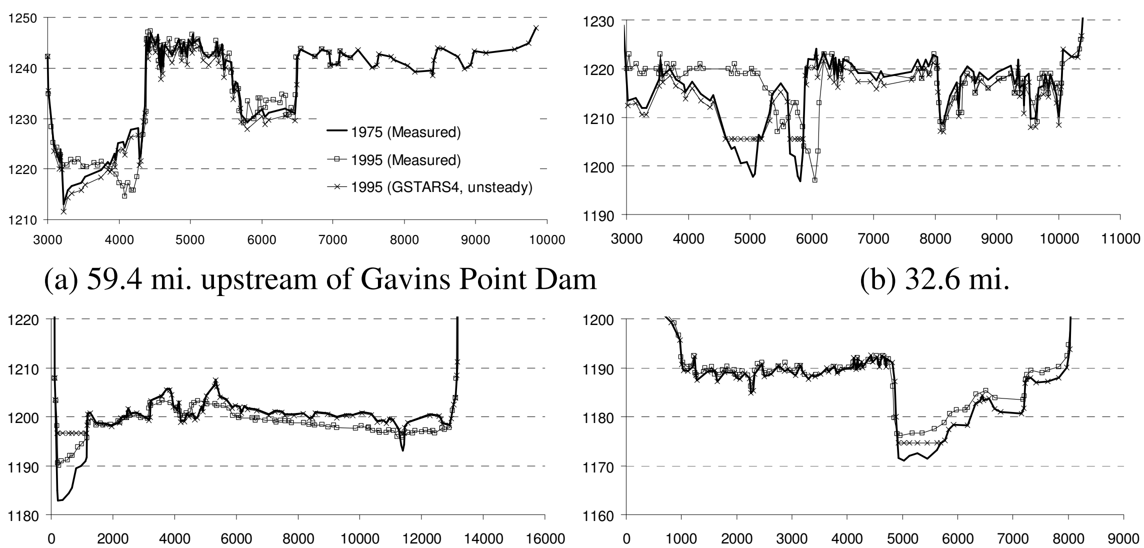


Figure 8.8 Comparison of bed profile



(a) 59.4 mi. upstream of Gavins Point Dam (b) 32.6 mi.

(c) 13.4mi (d) 7.5mi

Figure 8.9 Comparison of 1975 to 1995 cross sections