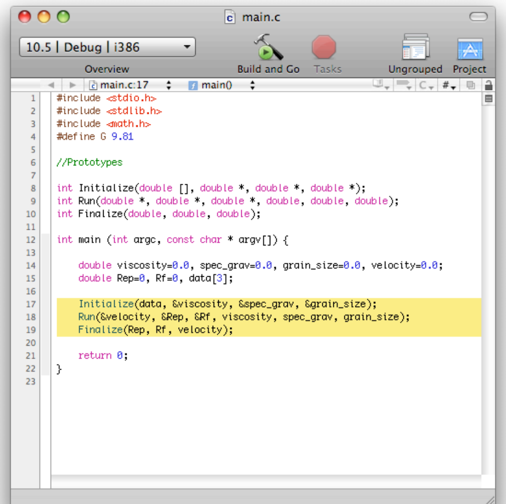
COMMON ELEMENTS

In this chapter some of the elements that are common for all the functions such as code format, instructions for use on various operating systems, elements of the input/output, and the GetData function are described.

IRF Formatting:

The code has been written to fit the Initialize, Run, Finalize format, as shown in the Figure. The Main function for each program includes all the data structure preparation (variable declaration, data structure definitions, etc.) and the three functions called Initialize, Run, and Finalize. What each consists of is explained below:



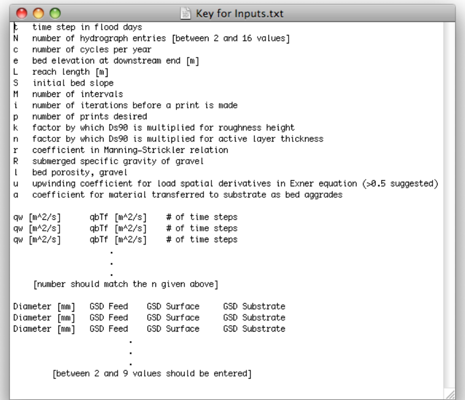
- **I** The Initialize function contains the sub-functions that a) call the data from the user's inputted text file, b) compute the constant parameters that will be used by the Run function to carry out the calculations, and c) prepare the data for use later on.
- **R** The Run function contains sub-functions that actually do the calculations. In codes with a time loop, the Run function calls all the sub-functions needed in the time loop. In codes without any time loop, it is simply the function that carries out the calculation.
- **F** The Finalize function sends the output to the user. It organizes the data computed by the Run function, and prints it out to a tab separated text file.

In the main function of some models there is another function called SaveDatatoMatrix, which is called after the Run function to store the data in a matrix.

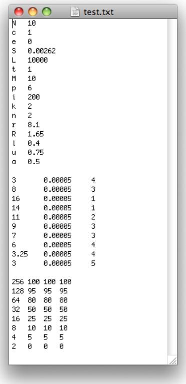
Input/Output:

The models are organized in folders. Each folder also contains the documentation that describes the input/output tab separated text files. The documentation consists of three or four text files that are called *Key for Inputs.txt*, *test.txt*, *Output.txt* and *Output1.txt*.

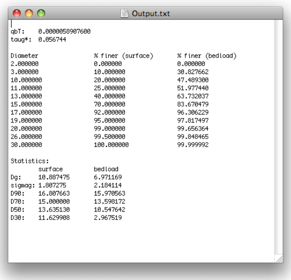
The *Key for Inputs* file explains how to prepare the input text file. In particular it contains information on a) the format of the text file, b) the units of the input parameters, and c) the physical meaning of the input parameters.



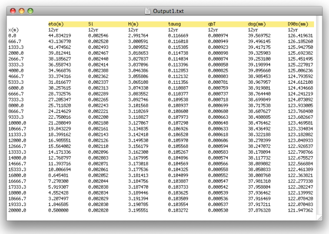
```
t   time step in flood days
N   number of hydrograph entries [between 2 and 16 values]
c   number of cycles per year
e   bed elevation at downstream end [m]
L   reach length [m]
S   initial bed slope
M   number of intervals
i   number of iterations before a print is made
p   number of prints desired
k   factor by which Ds90 is multiplied for roughness height
n   factor by which Ds90 is multiplied for active layer thickness
r   coefficient in Manning-Strickler relation
R   submerged specific gravity of gravel
l   bed porosity, gravel
u   upwinding coefficient for load spatial derivatives in Exner equation (>0.5 suggested)
a   coefficient for material transferred to substrate as bed aggrades

qw [m^2/s]      qbTf [m^2/s]    # of time steps
qw [m^2/s]      qbTf [m^2/s]    # of time steps
qw [m^2/s]      qbTf [m^2/s]    # of time steps
                    .
                    .
                    .
    [number should match the n given above]

Diameter [mm]   GSD Feed    GSD Surface     GSD Substrate
Diameter [mm]   GSD Feed    GSD Surface     GSD Substrate
Diameter [mm]   GSD Feed    GSD Surface     GSD Substrate
                        .
                        .
                        .
        [between 2 and 9 values should be entered]
```



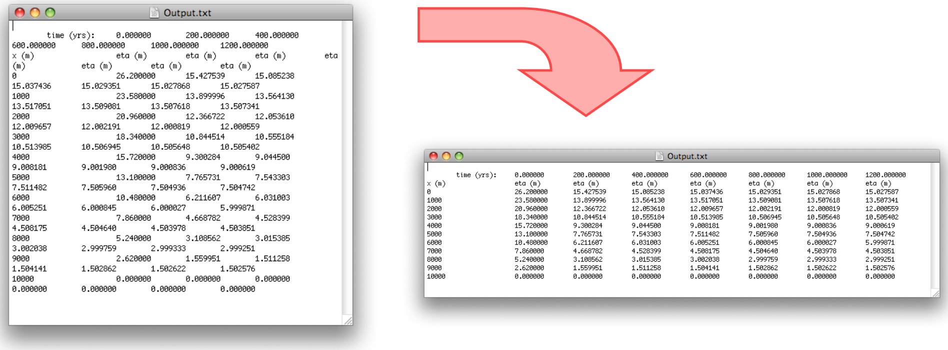
```
N   10
c   1
e   0
S   0.00262
L   10000
t   1
M   10
p   6
i   200
k   2
n   2
r   8.1
R   1.65
l   0.4
u   0.75
a   0.5

3       0.00005     4
8       0.00005     3
16      0.00005     1
14      0.00005     1
11      0.00005     2
9       0.00005     3
7       0.00005     3
6       0.00005     4
3.25    0.00005     4
3       0.00005     5

256 100 100 100
128 95  95  95
64  80  80  80
32  50  50  50
16  25  25  25
8   10  10  10
4   5   5   5
2   0   0   0
```



```
qbT:    0.0000058907600
taug*:  0.056744

Diameter            % finer (surface)       % finer (bedload)
2.000000            0.000000                0.000000
3.000000            10.000000               30.827662
10.000000           20.000000               47.489300
11.000000           25.000000               51.977440
13.000000           40.000000               63.732037
15.000000           70.000000               83.670479
17.000000           92.000000               96.306229
19.000000           95.000000               97.817497
20.000000           99.000000               99.656364
26.000000           99.500000               99.848465
30.000000           100.000000              99.999992

Statistics:
        surface         bedload
Dg:     10.887475       6.971169
sigmag: 1.807275        2.184114
D90:    16.807663       15.970563
D70:    15.000000       13.598172
D50:    13.635130       10.547642
D30:    11.629908       2.967519
```



The *test* file is an example of an input file that has been run during the test of the model. In the *Output* file the results of the *Test* run are reported. When the user opens the output file, the data may look somewhat convoluted at first, but once the text file is resized, they should line up in nice columns (see figure below). Some of the folders contain a fourth text file called *Output1*, which is the text file that contains the information stored by the GetData function.



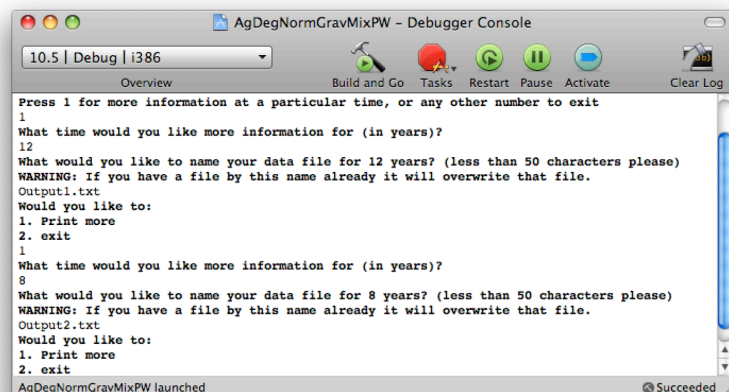
time (yrs):	0.000000	200.000000	400.000000	600.000000	800.000000	1000.000000	1200.000000
x (m)	eta (m)	eta (m)	eta (m)	eta (m)	eta (m)	eta (m)	eta (m)
0	26.200000	15.427539	15.085238	15.037436	15.029351	15.027868	15.027587
1000	23.580000	13.899996	13.564130	13.517051	13.509081	13.507618	13.507341
2000	20.960000	12.366722	12.053610	12.009657	12.002191	12.000819	12.000559
3000	18.340000	10.844514	10.555184	10.513985	10.506945	10.505648	10.505402
4000	15.720000	9.300284	9.044500	9.008181	9.001980	9.000836	9.000619
5000	13.100000	7.765731	7.543303	7.511482	7.505960	7.504936	7.504742
6000	10.480000	6.211607	6.031003	6.005251	6.000845	6.000027	5.999871
7000	7.860000	4.668782	4.528399	4.508175	4.504640	4.503978	4.503851
8000	5.240000	3.108562	3.015385	3.002038	2.999759	2.999333	2.999251
9000	2.620000	1.559951	1.511258	1.504141	1.502862	1.502622	1.502576
10000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

A synthetic description of the input and output parameters of the codes is reported in the continuation of this User's Guide. For a more detailed description of the problem and of the models the user should refer to Gary Parker's e-book 1D Sediment Transport Morphodynamics with applications to rivers and turbidity currents (simply called e-book in the continuation of the guide) downloadable at http://vtchl.uiuc.edu/people/parkerg/morphodynamics_e-book.htm.

GetData Function:

The GetData function is included in all the codes with a time loop to store additional information at each time step that might be useful for the user.

For example, if the program outputs the bed elevation, the GetData function allows the user to get additional information (i.e. water depth, sediment transport rate, shear stress, etc.) in the computational nodes. Values of the additional parameters are stored when the code sends the main output parameters. If Output.txt contains data for year 1, 2, 3, 4, and 5, then the program has not stored the data for year 2.5. In order to have information at t = 2.5 years, the user has to go back to the input file, and edit their initial parameters in order for the program to store the data at that time. The GetData function is called in the Finalize function.



Operating Systems:

The codes of the 1D Sediment Transport Morphodynamics C Function Library can run on various operating systems (i.e. Macintosh, Linux and Windows). In each folder there is a file with the extension .xcodeproj which is for use on a Macintosh computer. The active directory folder is the same folder in which all the text documents are stored. For documentation on XCode, see the following site http://developer.apple.com/documentation/DeveloperTools/Xcode-date.html .

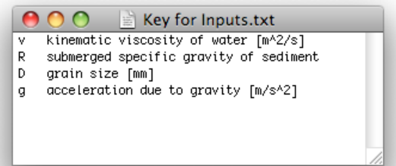
Otherwise, for use on a Linux machine, set the active directory to the folder in which all the .c documents are stored, and compile with

gcc –Wall <insert the names of all the functions here> -lm

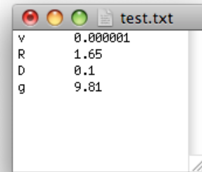
The –lm is important, because the programs use the <math.h> library, and therefore they will not compile properly without it.

1) Fall Velocity

The program computes the settling velocity, v_s, of a particle with the formulation of Dietrich (1982). Input parameters are, as shown in the windows below, the sediment particle size, D, the kinematic viscosity of the liquid, ν, the acceleration of gravity, g, and the submerged specific gravity of the sediment, R, defined as $(\rho_s - \rho)/\rho$, where ρ_s and ρ respectively denote the densities of the water and of the sediment.


Key for Inputs.txt

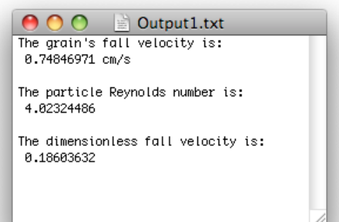
v	kinematic viscosity of water [m^2/s]
R	submerged specific gravity of sediment
D	grain size [mm]
g	acceleration due to gravity [m/s^2]


test.txt

v	0.000001
R	1.65
D	0.1
g	9.81

Outputs of the model are, the particle (or grain) settling velocity in cm/s, the particle Reynolds number Re_p and the dimensionless fall velocity R_f, as shown in the window below. These last two non-dimensional parameters are respectively defined as:

$$Re_p = \frac{\sqrt{RgD}D}{\nu} \quad \text{and} \quad R_f = \frac{v_s}{\sqrt{RgD}} \tag{1.i}$$


Output1.txt

The grain's fall velocity is:
0.74846971 cm/s

The particle Reynolds number is:
4.02324486

The dimensionless fall velocity is:
0.18603632

For a more detailed description of the theoretical formulation of the problem and of the code, the user should refer to Chapter 2 "Characterization of Sediment and Grain Size Distributions" of the e-book.

Notes:

- This formulation is only valid for Reynold's numbers less than or equal to $2.5 \cdot 10^6$. If R_{ep} is greater than this upper limit, the function will alert the user, and exit the program.

List of variables

INPUT

ν	kinematic viscosity of water in m^2/s;
R	submerged specific gravity of sediment, nondimensional
D	grain size in mm;
g	acceleration of gravity in m/s^2;

OUTPUT

v_s	particle settling velocity in cm/s;
Re_p	particle Reynolds number;
R_f	dimensionless fall velocity.

References:

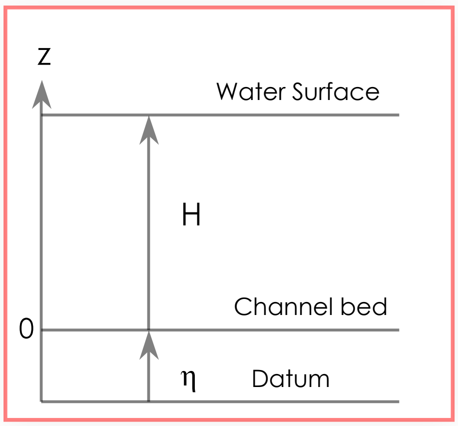
Dietrich, E. W., 1982, Settling velocity of natural particles, Water Resources Research, 18 (6), 1626-1982.

2) Rouse-Vanoni Equilibrium

The program computes the Rouse-Vanoni profile of suspended sediment concentration at equilibrium. For a more detailed description of the formulation the user should refer to Chapter 10 of the e-book "Relations for the Entrainment and 1D Transport of Suspended Sediment".

The parameters of the model are:

a) H, water depth (see Figure below);
b) ζ, vertical coordinate in the cross section, i.e. $\zeta = 0$ on the bed surface and $\zeta = H$ on the water surface (see Figure below);
c) ζ_b, position near the bed surface where the volumetric concentration of suspended sediment is equal to c_b (see point g below);
d) u^*, shear velocity;
e) v_s, particle settling velocity computed with the formulation presented by Dietrich (1982) described in the previous chapter;
f) c, concentration of suspended sediment in the water column at elevation ζ averaged over turbulence;
g) c_b, concentration of suspended sediment in the water column at $\zeta = \zeta_b$ averaged over turbulence. c_b can computed, for example, with one of the entrainment relations presented in Chapter 10 of the e-book.

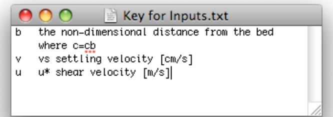


The non-dimensional expression of the Rouse-Vanoni profile is

$$\frac{c}{c_b} = \left[\frac{(1-z)/z}{(1-b)/b}\right]^{\frac{v_s}{ku^*}} \qquad (2.i)$$

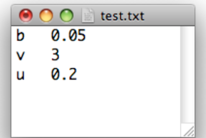
where k denotes the constant of VonKarman, set equal to 0.4, z is a non-dimensional vertical coordinate defined as ζ/H and b is the non dimensional near-bed distance equal to ζ_b/H.

Input parameters for the model are the non-dimensional distance from the bed surface where c_b is computed, b, the settling velocity of the particles, v_s, in cm/s and the shear velocity, u^*, in m/s. In the windows below the files "Key for Inputs.txt" and "test.txt" are represented.



Key for Inputs.txt

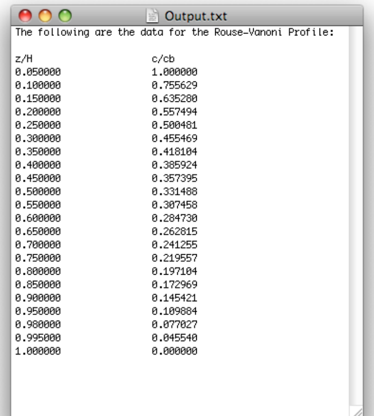
```
b   the non-dimensional distance from the bed
    where c=cb
v   vs settling velocity [cm/s]
u   u* shear velocity [m/s]
```



test.txt

```
b   0.05
v   3
u   0.2
```

The output of the model is the non-dimensional equilibrium profile of suspended sediment concentration, i.e. the height in the water column is expressed in terms of $z = \zeta/H$ and the volumetric concentration averaged over the turbulence as c/c_b, in the next window the output text file is represented.



Output.txt

```
The following are the data for the Rouse-Vanoni Profile:

z/H                 c/cb
0.050000            1.000000
0.100000            0.755629
0.150000            0.635280
0.200000            0.557494
0.250000            0.500481
0.300000            0.455469
0.350000            0.418104
0.400000            0.385924
0.450000            0.357395
0.500000            0.331488
0.550000            0.307458
0.600000            0.284730
0.650000            0.262815
0.700000            0.241255
0.750000            0.219557
0.800000            0.197104
0.850000            0.172969
0.900000            0.145421
0.950000            0.109884
0.980000            0.077027
0.995000            0.045540
1.000000            0.000000
```

Notes:

- To compute the equilibrium profile the user can choose between
  a) the grid of the excel workbook *RTe-bookRouseSpreadsheetFun.xls*. This grid has 22 points in the vertical direction. The lowest 19 are equally spaced between z = b and z = b + 18(1-b)/19. The upper three points are located at z = 0.98, z = 0.995 and z = 1, where the concentration of suspended sediment goes to zero;
  b) an equally spaced grid with a user specified number of points in the vertical.

List of variables

H water depth in m;

ζ dimensional vertical coordinate, $\zeta = 0$ on the channel bed and $\zeta = H$ at the water surface;

z non-dimensional height in the water column equal to ζ/H;

c volumetric concentration of sediment averaged over turbulence;

c_b volumetric near-bed concentration of suspended sediment averaged over turbulence, i.e. value of c at elevation ζ_b;

INPUT

b non-dimensional distance from the bed where $c = c_b$, $b = \zeta_b/H$;

v settling velocity of the particles in cm/s;

u* shear velocity in m/s;

OUTPUT

Non-dimensional profile of suspended sediment concentration in a two-column tab separated text file. In the first column the user finds the non-dimensional height of the point in the water column and in the second column the corresponding ratio c/c_b is reported. For $\zeta = b$, $c/c_b = 1$ and for $\zeta = 1$, $c/c_b = 0$.

3) GSD Calculator

Given a grain size distribution, the program computes the geometric mean diameter, D_g, the geometric standard deviation, σ_g. Characteristic diameters based on percent finer, D_x (i.e. size such that x percent of the sample is finer than D_x) can also be computed if requested by the user.

If the inputted size distribution does not have a lower bound, D_{xL}, such that xL = 0 and an upper bound, D_{xU}, such that xU = 100, the program computes these bounds with a linear interpolation of the data. To linearly interpolate the data and to perform the calculations the code uses the ψ scale defined as

$$\psi = \log_2 D \qquad (3.i)$$

where D is expressed in millimeters.

For a more detailed description of the theoretical formulation of the problem and of the code, the user should refer to Chapter 2 "Characterization of Sediment and Grain Size Distributions" of the e-book.

The input grain size distribution is specified, as indicated in the text files "Key for Inputs" and "test" represented in the windows below, in terms of M+1(with M < 100) bound diameters in millimeters and the corresponding value of percent finer (or passing) with a scale that can be either 0 - 1 or 0 - 100.

Key for Inputs.txt

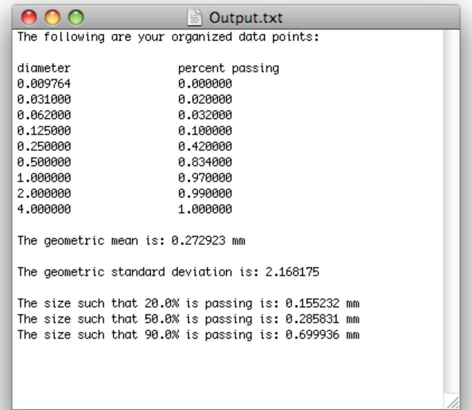
```
Grain Size (mm)                 Percent Passing
Grain Size (mm)                 Percent Passing
Grain Size (mm)                 Percent Passing
Grain Size (mm)                 Percent Passing
                    .
                    .
                    .
          (no more than 100 values)
```

test.txt

```
4        100
2        99
1        97
0.5      83.4
0.25     42
0.125    10
0.062    3.2
0.031    2
```

The output file, shown in the next window, is organized as follows. First the grain size distribution used in the calculations is reported, and then the values of the geometric mean diameter and standard deviation are printed. Finally the computed characteristic diameters based on percent finer, D_x, are reported, if requested by the user

> Enrica 11/8/2009 11:32 PM
>
> **Comment [1]:** How can the user specify the characteristic grain sizes he wants to compute?
>
> **Answer:** the program prompts the user for whatever grain sizes they want to put in. The user will enter them when prompted. Do we want to put those into the inputs?



Output.txt

```
The following are your organized data points:

diameter                percent passing
0.009764                0.000000
0.031000                0.020000
0.062000                0.032000
0.125000                0.100000
0.250000                0.420000
0.500000                0.834000
1.000000                0.970000
2.000000                0.990000
4.000000                1.000000

The geometric mean is: 0.272923 mm

The geometric standard deviation is: 2.168175

The size such that 20.0% is passing is: 0.155232 mm
The size such that 50.0% is passing is: 0.285831 mm
The size such that 90.0% is passing is: 0.699936 mm
```

Notes:

- Input data may be entered either from the finer to the coarser size or from the coarser to the finer. The program will automatically reorder the data;
- Data may be on either a 0.00-1.00 scale or a 0-100 scale. The program will always use a 0-1 scale to do the calculations;
- If there are no lower and upper bounds in the inputted distribution such that their percent finer are respectively equal to 0 and 100 (or 1), the program will compute these bounds with a linear interpolation on the ψ scale and will add these diameters to the input size distribution;
- The program will prompt users if they want to calculate characteristic diameters based on percent finer, D_x, and what diameters they would like to know;
- The program can calculate up to 10 characteristic diameters based on percent finer;
- The geometric mean diameter, D_g, the geometric standard deviation, σ_g, and the user-defined characteristic diameters based on percent finer will be appended to a file with the reorganized, scaled, and bounded grain size distribution

4) Backwater Calculator

The program solves the backwater equation for subcritical flow with a predictor – corrector scheme. To compute the water depth, H, everywhere in the channel for a given water discharge per unit channel width, q_w, and downstream boundary condition, i.e. a user specified water depth, the equation is formulated as

$$\frac{dH}{dx} = \frac{S - S_f}{1 - Fr^2} \qquad (4.i)$$

where x is a streamwise coordinate, S denotes the bed slope, S_f the friction slope, and Fr is the Froude number.

The bed slope, S, is assumed constant in the streamwise direction, the friction slope, S_f, and the Froude number, Fr, are defined below

$$S_f = C_f \cdot Fr^2 \qquad Fr = \frac{q_w}{\sqrt{gH^3}} \qquad (4.ii\ a,\ b)$$

where C_f represents a non-dimensional friction coefficient that can be evaluated with both a Chézy and a Manning-Strickler formulation, and g is the acceleration of gravity.

In the Chezy formulation (that is implemented in the excel workbook *RTe-bookBackwate.xlsr*) the friction coefficient is a user specified constant in space and time:

$$C_f = \frac{1}{Cz^2} \qquad Cz = \frac{K_{Cz}}{\sqrt{g}} \qquad (4.iii\ a,\ b)$$

where Cz denotes the non-dimensional Chezy friction coefficient and K_{cz} is the dimensional Chezy friction coefficient.

In the Manning-Strickler formulation the friction coefficient is a function of the water depth. In the present model it is assumed that the cross section is wide, therefore the friction coefficient is computed as

$$C_f^{-1/2} = \alpha_r \left(\frac{H}{k_s}\right)^{1/6} \qquad (4.iv)$$

where α_r is a user specified parameter and k_s is a roughness height due to skin friction defined as

$$k_s = n \cdot D_{90} \qquad (4.v)$$

For a more detailed description of the theoretical formulation of and of the code, the user should refer to Chapter 5 "Review of 1D open channel hydraulics" of the e-book.

Input parameters of the model are the bed slope, S, the water discharge per unit width, q_w,a starting water depth at the downstream end of the channel, H_1, a spatial step length, Δx, and a starting point x. If the user wants to perform the calculation with a Chezy formulation, he should also input the non-dimensional Chezy friction coefficient, Cz, defined in equation (4.iii a, b). If a Manning-Strickler formulation is chosen, the user is asked to input the parameter α_r in equation (iv) and the parameters to evaluate the roughness height, k_s, i.e. the coefficient n and the D_{90} of the bed surface defined in equation (4.v). The text file with the definition of the input parameters and an example of input file are shown in the two windows below.

Key for Inputs

```
S = Slope [m/m]
C = Chezy coefficient
q = water discharge/width [m^2/s]
R = hydraulic radius [m]
M = Mean diameter [mm]
D = D90 of the surface [mm]
n = roughness coefficient
a = alpha(r)
x = starting point [m]
d = step size [m]
H = initial depth [m]
```

test.txt

```
D   .91
R   1.65
C   22
H   30
M   .27
a   8.1
n   2
x   123000
S   .00025
q   5.7
d   1000
```

Enrica 11/8/2009 11:06 PM

Comment [2]: The order of the input parameters is different. Is this a problem?

Answer: this does not make a difference, I'm not sure how you would like to proceed here. I can rearrange them, or we can make a comment in the beginning of the user guide that the order doesn't matter (as long as the right letter is in front of it)

Output parameters of the model are the water depth, H, the mean flow velocity, U, the shear stress, τ_b, the bed elevation, η, and the water surface elevation, ξ, equal to the sum of the bed elevation and the water depth. In the output file water depth, mean flow velocity, Froude number and shear stress are also reported for normal flow conditions with the critical values of water depth and mean flow velocity. An example of the output file is reported in the window below.

Output.txt

```
The chezy formulation H is: 3.013689
The chezy formulation U is: 1.891370
The chezy formulation Fr is: 0.347851
The chezy formulation tau(b) is: 7.391072

The critical value for H is: 1.490597
The critical value for U is: 3.823971

For the Chezy formulation:
x          H          U          tau(b)     eta        ksi
123000     30.000000  0.190000   0.074587   0.000000   30.000000
122000     29.750225  0.191595   0.075844   0.250000   30.000225
121000     29.500456  0.193217   0.077134   0.500000   30.000456
120000     29.250692  0.194867   0.078457   0.750000   30.000692
119000     29.000937  0.196545   0.079814   1.000000   30.000937
118000     28.751186  0.198253   0.081207   1.250000   30.001186
117000     28.501442  0.199990   0.082636   1.500000   30.001442
116000     28.251705  0.201758   0.084104   1.750000   30.001705
115000     28.001976  0.203557   0.085610   2.000000   30.001976
114000     27.752254  0.205389   0.087158   2.250000   30.002254
113000     27.502541  0.207254   0.088748   2.500000   30.002541
112000     27.252834  0.209153   0.090382   2.750000   30.002834
111000     27.003136  0.211087   0.092061   3.000000   30.003136
110000     26.753445  0.213057   0.093787   3.250000   30.003445
109000     26.503763  0.215064   0.095563   3.500000   30.003763
108000     26.254091  0.217109   0.097389   3.750000   30.004091
107000     26.004429  0.219193   0.099268   4.000000   30.004429
106000     25.754776  0.221318   0.101202   4.250000   30.004776
105000     25.505133  0.223484   0.103193   4.500000   30.005133
104000     25.255501  0.225693   0.105243   4.750000   30.005501
103000     25.005880  0.227946   0.107354   5.000000   30.005880
102000     24.756271  0.230245   0.109530   5.250000   30.006271
101000     24.506674  0.232590   0.111773   5.500000   30.006674
100000     24.257090  0.234983   0.114085   5.750000   30.007090
99000      24.007517  0.237426   0.116469   6.000000   30.007517
98000      23.757959  0.239920   0.118929   6.250000   30.007959
97000      23.508415  0.242466   0.121467   6.500000   30.008415
96000      23.258886  0.245068   0.124087   6.750000   30.008886
95000      23.009373  0.247725   0.126793   7.000000   30.009373
94000      22.759874  0.250441   0.129588   7.250000   30.009874
93000      22.510393  0.253216   0.132476   7.500000   30.010393
92000      22.260929  0.256054   0.135462   7.750000   30.010929
91000      22.011484  0.258956   0.138550   8.000000   30.011484
90000      21.762058  0.261924   0.141744   8.250000   30.012058
89000      21.512651  0.264960   0.145050   8.500000   30.012651
```

Notes:

- The program will automatically recognize the formulation (i.e. Chezy or Manning-Strickler) the user wants to implement from the input file. If a value of the Chezy friction coefficient is specified in the input file but the parameters to compute the friction coefficient with equation (4.v) are not given, the code will use a Chézy formulation. On the contrary, if values for α_r, D_{90} and n are specified while there is no Chezy friction coefficient in the input file, the program will automatically use a Manning-Strickler formulation. If all the four parameters are specified, the program will ask the user which formulation he would prefer to use

List of variables

x	streamwise coordinate, in m
	INPUT
S	bed slope
q_w	water discharge per unit width in m^2/s
Cz	non-dimensional Chézy friction coefficient
D_{90}	diameter of the bed surface such that 90% of the distribution is finer in mm
n	parameter to compute roughness height with equation (v)
α_r	dimensionless constant in equation (iv)
x_1	starting position in m
Δx	step size in m
H_1	initial depth in m
	OUTPUT
H	water depth in m
U	mean flow velocity in m/s
tau(b)	shear stress on the bed surface in N/m^2
eta	bed surface elevation in m
csi	water surface elevation in m
H_n	water surface at normal flow in m
H_c	critical water depth in m
Fr_n	Froude number at normal flow
U_n	mean flow velocity at normal flow in m/s
U_c	critical flow velocity
$tau(b)_n$	bed shear stress at normal flow in N/m^2

5) AgDegNormal

The program calculates a) an ambient mobile-equilibrium sediment transport rate and b) the morphodynamic evolution of a reach due to a change in sediment input rate. For a detailed description of the theory and of the model, the user should refer to Chapter 14 "1D aggradation and degradation of rivers: normal flow assumption" of the e-book, and to the word file *RTe-bookAgDegNormalFormul.doc*, downloadable at
http://vtchl.uiuc.edu/people/parkerg/word_files.htm.

The assumptions and the simplifications at the basis of the formulation are:

1) the quasi steady approximation (deVries, 1965), i.e. the bed changes so slowly compared to the characteristic response time of the flow that the flow can be approximated as responding immediately. This assumption greatly simplifies the problem, but it limits the applicability of the model. In particular, this model cannot be applied in cases when a) it is desired to characterize the sediment transport over an entire rapidly varying hydrograph; b) one wishes to capture the effect of a flood wave (with a high water surface slope on the upstream side of the wave and a low water surface slope on the downstream side) on sediment transport; and c) the flow makes transitions between subcritical and supercritical flow, in which case a shock-capturing method capable of automatically locating hydraulic jumps is required. For more information on the quasi- steady approximation, the user can refer to Chapter 13 "The quasi-steady approximation" of the e-book;
2) the channel width, B_c, is constant in the streamwise direction and in time;
3) the floodplain is absent;
4) the flow is assumed normal;
5) the sediment is uniform;
6) the Exner equation of channel bed sediment conservation is based on the computation of total bed material load;
7) the relevant morphodynamic changes of the river occur during floods. The full hydrograph or flow duration curve is replaced by flood intermittency factor, I_f, (Paola et al., 1992) and a constant flood discharge, Q_w, (or discharge per unit channel width $q_w = Q_w/B_c$).

The water depth can be computed either with a Manning-Strickler (implemented in the excel file *RTe-bookAgDegNormal.xls*) or with a Chezy formulation. In the Chezy formulation, the non-dimensional friction coefficient Cz, eq. (4.iii a, b), is a user specified parameter. In the Manning-Strickler formulation the friction coefficient, C_f, is still computed as

$$C_f = \alpha_r \left(\frac{H}{k_c}\right)^{1/6} \qquad (5.i)$$

This expression has the same form of eq. (4.iv). α_r is a user specified parameter and the roughness height, k_s, due to skin friction is substituted with a composite roughness, k_c, which may include the effect of bedforms, if present. For further information on the normal flow calculation, the user can refer to Chapter 5 "Review of 1D open channel hydraulics" of the e-book". Some techniques to estimate k_c when bedforms are expected are explained in

Chapters 9 "Relations for Hydraulic Resistance in Rivers", 10 "Relations for the Entrainment and 1D Transport of Suspended Sediment" and 14 "1D Aggradation and Degradation of Rivers: Normal Flow Assumption" of the e-book.

The total bed material load per unit width, q_t, is computed with the generic equation

$$\frac{q_t}{\sqrt{RgD}D} = \alpha_t \left(\frac{\varphi_s \tau_b}{\rho RgD} - \tau_c^* \right)^{n_t} \qquad (5.ii)$$

where

- q_t is computed in m^2/s;
- R denotes the submerged specific gravity of the sediment and is defined as $(\rho_s-\rho)/\rho$, where ρ and ρ_s are the densities of the water and of the sediment;
- g is the acceleration of gravity;
- D is the diameter of the sediment;
- $\varphi_s \leq 1$ is a constant to convert total boundary shear stress to that due to skin friction (if necessary);
- τ_b is the total boundary shear stress defined as ρgHS (with H to denote the water depth and S the bed slope) for the normal flow assumption (refer to Chapter 5 of the e-book);
- α_r , τ_c^* and n_t are user specified parameters that depend on the load relation. For the version of the Meyer-Peter and Muller bedload relation due to Wong and Parker (2006) α_r = 3.97, τ_c^* = 0.0495 and n_t = 1.5. For the relation of Engelund and Hansen (1967) to compute the total load of sand, α_r =0.05/C_f, τ_c^* = 0 and n_t = 2.5. For more details on the relations to compute bedload and total sediment transport rates, the user can refer to Chapters 7 "Relations for 1D Bedload Transport" and 12 "Bulk Relations for Transport of Total Bed Material Load" of the e-book.

The Exner equation, eq. (5.iii) below, is solved with a finite difference scheme. For the derivation of the Exner equation the user can refer to Chapter 4 "Relations for the Conservation of Bed Sediment" of the e-book.

$$(1-\lambda_p)\frac{\partial \eta}{\partial t} = -I_f \frac{\partial q_t}{\partial x} \qquad (5.iii)$$

where λ_p denotes the bed porosity, η is the bed elevation above the datum, x is the streamwise coordinate and t is the temporal coordinate. The length of the fluvial reach is denoted as L. The domain is divided in M sub-reaches bounded by (M+1) computational nodes. The spatial step length Δx is thus equal to L/M. The annual sediment transport rate is fed in a ghost node one step length upstream of the first node, i.e. $q_{tghost} = q_{tfeed}$.
The Exner equation is discretized as

$$\eta\big|_{i,t+\Delta t} = \eta\big|_{i,t} - \frac{I_f}{1-\lambda_p}\frac{\Delta q_{t,i}}{\Delta x}\Delta t \qquad (5.iv)$$

where the index i denotes the computational node, the index t denotes the time and Δt is the time step. The spatial derivative of the total bed material load per unit width, $\Delta q_{ti}/\Delta x$ is computed as

$$\frac{\Delta q_{t,i}}{\Delta x} = a_u \frac{q_{t,i} - q_{t,i-1}}{\Delta x} + (1 - a_u)\frac{q_{t,i+1} - q_{t,i}}{\Delta x} \quad (5.v)$$

where a_u is an upwinding coefficient. In a pure upwinding scheme a_u = 1, in a central difference scheme a_u = 0.5. In computing eq. (5.vi) at the first node it is assumed that $q_{ti-1} = q_{tghost} = q_{tfeed}$.

The bed slope is computed in each node with the following relation

$$S = \begin{cases} \dfrac{\eta_1 - \eta_2}{\Delta x} & i = 1 \\ \dfrac{\eta_{i-1} - \eta_{i+1}}{2\Delta x} & i = 2 \ldots M \\ \dfrac{\eta_M - \eta_{M+1}}{\Delta x} & i = M+1 \end{cases} \quad (5.vi)$$

The upstream boundary conditions are specified in terms of a water discharge, Q_w, flood intermittency, I_f, and annual sediment transport rate in metric tons per year, G_{tf}. The downstream boundary condition is expressed as a fix bed elevation at the downstream end of the fluvial reach. Thus the Exner equation is not implemented at node M+1. The bed elevation at the downstream end of the modeled reach is set equal to zero.

The initial condition is that of a given bed profile. In the model the initial profile, $\eta(x,t)|_{t=0}$ is given in terms of a specified initial downstream bed elevation η_{Id} and constant initial slope S_I

$$\eta(x,t)|_{t=0} = \eta_{Id} + S_I(L - x) \quad (5.vii)$$

Input parameters of the model are

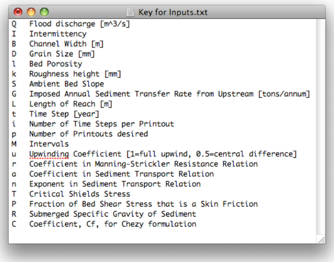
- the characteristic flood discharge, Q_w, and the flood intermittency, I_f;
- the channel width, B_c;
- the characteristic diameter of the sediment, D;
- the bed porosity, λ_p;
- the roughness height, k_c;
- the ambient bed slope, S;
- the imposed annual sediment transport rate, G_{tf};
- the length of the fluvial reach, L;

The user also has to specify the following parameters to perform the calculations and to control the output:

- the number of sub-reaches, M;
- the temporal step length, Δt;
- the upwinding coefficient a_u;
- the number of time steps to printout, $N_{toprint}$;
- the numbers of printout in addition to the initial equilibrium state, N_{print};
- the coefficient α_r in eq. (5.i);
- the parameters to define the load relation, α_r, τ_c^* and n_t, defined in eq. (5.ii);

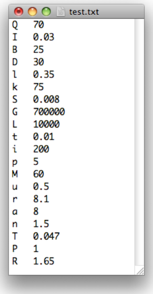
- the constant to convert the total boundary shear stress to that due to skin friction, φ_s;
- the submerged specific gravity of the sediment, R.

The text file with the definition of the input parameters and an example of input file are shown in the two windows below.



Key for Inputs.txt

```
Q   Flood discharge [m^3/s]
I   Intermittency
B   Channel Width [m]
D   Grain Size [mm]
l   Bed Porosity
k   Roughness height [mm]
S   Ambient Bed Slope
G   Imposed Annual Sediment Transfer Rate from Upstream [tons/annum]
L   Length of Reach [m]
t   Time Step [year]
i   Number of Time Steps per Printout
p   Number of Printouts desired
M   Intervals
u   Upwinding Coefficient [1=full upwind, 0.5=central difference]
r   Coefficient in Manning-Strickler Resistance Relation
a   Coefficient in Sediment Transport Relation
n   Exponent in Sediment Transport Relation
T   Critical Shields Stress
P   Fraction of Bed Shear Stress that is a Skin Friction
R   Submerged Specific Gravity of Sediment
C   Coefficient, Cf, for Chezy formulation
```



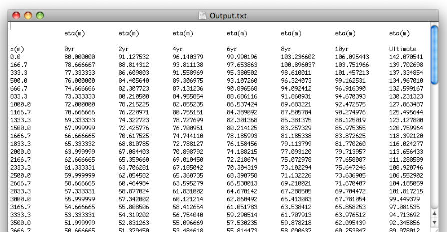
test.txt

```
Q  70
I  0.03
B  25
D  30
l  0.35
k  75
S  0.008
G  700000
L  10000
t  0.01
i  200
p  5
M  60
u  0.5
r  8.1
a  8
n  1.5
T  0.047
P  1
R  1.65
```

The outputs of the model are N_{print} longitudinal profiles at different times $t_{plot,j}$

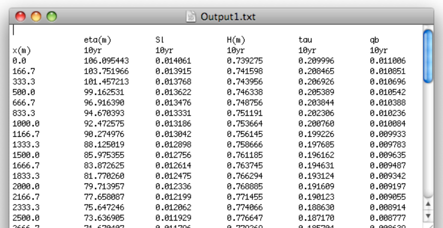
$$t_{plot,j} = j \cdot N_{toprint} \Delta t \,, \qquad j = 1 \ldots N_{print} \tag{5.viii}$$

An example of the output file *Output.txt* is reported in the window below with an example of the additional parameters that the user may want to plot in the text file *Output1.txt*, i.e. bed slope, S, water depth, H, Shield's number, τ_b, and the total bed material load, q_t. The initial bed profile is the bed profile at mobile-bed equilibrium, given the water discharge, the flow intermittency and the initial bed slope.



Output.txt

	eta(m)	eta(m)	eta(m)	eta(m)	eta(m)	eta(m)	eta(m)
x(m)	0yr	2yr	4yr	6yr	8yr	10yr	Ultimate
0.0	80.000000	91.127532	96.140379	99.990196	103.236602	106.095443	142.070541
166.7	78.666667	88.814312	93.811138	97.653863	100.896037	103.751966	139.702698
333.3	77.333333	86.609803	91.558969	95.380502	98.610011	101.457213	137.334854
500.0	76.000000	84.405640	89.306975	93.107260	96.324073	99.162531	134.967010
666.7	74.666666	82.307723	87.131236	90.896568	94.092412	96.916390	132.599167
833.3	73.333333	80.210500	84.955854	88.686116	91.860931	94.670393	130.231323
1000.0	72.000000	78.215225	82.855235	86.537424	89.683221	92.472575	127.863487
1166.7	70.666666	76.220971	80.755151	84.389092	87.505784	90.274976	125.495644
1333.3	69.333333	74.322723	78.727699	82.301368	85.381375	88.125019	123.127800
1500.0	67.999999	72.425776	76.700951	80.214125	83.257329	85.975355	120.759964
1666.7	66.666665	70.617525	74.744110	78.185993	81.185338	83.872625	118.392120
1833.3	65.333332	68.810785	72.788127	76.158456	79.113799	81.770260	116.024277
2000.0	63.999999	67.084403	70.898792	74.188215	77.093120	79.713957	113.656433
2166.7	62.666665	65.359660	69.010450	72.218674	75.072978	77.658087	111.288589
2333.3	61.333331	63.706281	67.185042	70.304319	73.102294	75.647246	108.920746
2500.0	59.999999	62.054582	65.360735	68.390758	71.132226	73.636905	106.552902
2666.7	58.666665	60.464984	63.595279	66.530013	69.210021	71.670407	104.185059
2833.3	57.333331	58.877024	61.831002	64.670142	67.288505	69.704472	101.817215
3000.0	55.999999	57.342002	60.121214	62.860492	65.413083	67.781054	99.449379
3166.7	54.666665	55.808506	58.412654	61.051783	63.538412	65.858253	97.081535
3333.3	53.333331	54.319202	56.754040	59.290514	61.707913	63.976512	94.713692
3500.0	51.999999	52.831263	55.096669	57.530235	59.878218	62.095439	92.345856
3666.7	50.666665	51.379450	53.484618	55.814473	58.090637	60.253847	89.978012



Output1.txt

	eta(m)	Sl	H(m)	tau	qb
x(m)	10yr	10yr	10yr	10yr	10yr
0.0	106.095443	0.014061	0.739275	0.209996	0.011006
166.7	103.751966	0.013915	0.741598	0.208465	0.010851
333.3	101.457213	0.013768	0.743956	0.206926	0.010696
500.0	99.162531	0.013622	0.746338	0.205389	0.010542
666.7	96.916390	0.013476	0.748756	0.203844	0.010388
833.3	94.670393	0.013331	0.751191	0.202306	0.010236
1000.0	92.472575	0.013186	0.753664	0.200760	0.010084
1166.7	90.274976	0.013042	0.756145	0.199226	0.009933
1333.3	88.125019	0.012898	0.758666	0.197685	0.009783
1500.0	85.975355	0.012756	0.761185	0.196162	0.009635
1666.7	83.872625	0.012614	0.763745	0.194631	0.009487
1833.3	81.770260	0.012475	0.766294	0.193124	0.009342
2000.0	79.713957	0.012336	0.768885	0.191609	0.009197
2166.7	77.658087	0.012199	0.771455	0.190123	0.009055
2333.3	75.647246	0.012062	0.774066	0.188630	0.008914
2500.0	73.636905	0.011929	0.776647	0.187170	0.008777
2666.7	71.670407	0.011796	0.779269	0.185704	0.008639

Notes:

- The maximum number of computational nodes, M, is 99 (this is the case for all of the AgDeg functions)
- Calculates the water depth with a Chézy formulation, if only the Chézy coefficient is specified in the input text file. The code uses a Manning-Strickler formulation, when only the roughness height, k_c, and the coefficient α_r are given in the input text file. If all these parameters are in the text file, the program will ask the user which formulation he would like to use

- Prompts user whether they would like to append certain parameters (i.e. flow depth at flood, Shield's number at flood, Einstein number at flood, etc.) to the data file, or write them in a separate file

List of variables

x	streamwise coordinate in m
Δx	spatial step length in m
t	temporal coordinate in seconds
C_f	non-dimensional friction coefficient
	INPUT
Q_w	flood discharge in m^3/s
I_f	flood intermittency
B_c	channel width in m
D	characteristic grain size in mm
λ_p	bed porosity
k_c	composite roughness height in mm
S_I	ambient bed slope
G_{tf}	imposed annual sediment transport rate in tons/annum
L	length of reach in m
Δt	time step in yr
$N_{toprint}$	number of timesteps to printout
N_{print}	number of printouts
M	number of spatial intervals
a_u	upwinding coefficient (1=full upwind, 0.5=central difference)
α_r	coefficient in Manning-Strickler
α_s	coefficient in sediment transport relation
n_t	exponent in sediment transport relation
τ_c^*	reference Shields number in sediment transport relation
φ_s	fraction of bed shear stress due to skin friction
R	submerged specific gravity
Cz	non-dimensional Chézy friction coefficient
	OUTPUT
η	bed surface elevation in m
S	bed slope
H	water depth in m
τ_b	total boundary shear stress on bed surface N/m^2
q_t	total bed material load in m^2/s

References:

de Vries, M. 1965. Considerations about non-steady bed-load transport in open channels. *Proceedings*, 11th Congress, International Association for Hydraulic Research, Leningrad: 381-388.

Engelund, F. and E. Hansen, 1967, *A Monograph on Sediment Transport in Alluvial Streams*, Technisk Vorlag, Copenhagen, Denmark.

Paola, C., Heller, P. L. & Angevine, C. L., 1992, The large-scale dynamics of grain-size variation in alluvial basins. I: Theory, *Basin Research*, 4, 73-90.

Wong M. and G. Parker, 2006, Reanalysis and correction of bed-load relation of Meyer-Peter and Müller using their own database, Journal of Hydraulic Engineering, 132(11), 1159-1168;

6) AgDegBW

The model calculates a) an ambient mobile-bed equilibrium, and b)the response of a river reach to either 1) changed sediment input rate at the upstream end of the reach starting from t = 0 or 2) changed downstream water surface elevation at the downstream end of the reach starting from t = 0, where t is the temporal coordinate. The code is very similar to AgDegNorm described in Chapter 5 of this user's guide. The main difference between the two codes is in the procedure to compute the water depth. In AgDegNorm the flow is assumed normal (i.e. steady and uniform), while in AgDegBW the flow is assumed steady and it is computed solving the backwater equation. The case of Froude-subcritical flow, for which Fr < 1 (refer to Chapter 5 "Review of 1D open channel hydraulics" of the e-book), is considered herein. This implies that integration of the backwater equation must proceed upstream from x = L, with x streamwise coordinate and L length of the modeled reach. Both a Chezy and a Manning-Strickler formulation can be used to compute the flow.
For a detailed description of the theory and of the model, the user should refer to Chapter 20 "Aggradation and Degradation of Rivers: Backwater Formulation" of the e-book, and to the word file *RTe-bookAgDegBWFormul.doc*, downloadable at
http://vtchl.uiuc.edu/people/parkerg/word_files.htm.

The upstream boundary conditions are specified in terms of a sediment feed rate in metric tons per year, G_{tf}, a characteristic flood discharge, Q_w, and a flow intermittency, I_f. The downstream boundary condition is given in terms of a known water surface elevation, ξ_d, with

$$\xi_d = \left[\eta(x,t) + H(x,t)\right]_{x=L} \tag{6.i}$$

where η denotes the bed elevation and H the water depth. As opposed to the normal flow calculation, downstream bed elevation $\eta(L,t)$ is no longer specified, and is free to vary during the run, i.e. the Exner equation is implemented at node M+1.

The initial bed profile is the same as the one used for the calculations using the normal flow approximation, eq. (5.vii) i.e. at t = 0 the initial bed elevation at the downstream end of the reach is set equal to zero.

Input parameters of the model are

- the characteristic flood discharge, Q_w, and the flood intermittency, I_f;
- the channel width, B_c;
- the characteristic diameter of the sediment, D;
- the bed porosity, λ_p;
- the roughness height, k_c;
- the ambient bed slope, S;
- the imposed annual sediment transport rate, G_{tf};
- the imposed water surface elevation at the downstream end of the reach, ξ_d;
- the length of the fluvial reach, L;

The user also has to specify the following parameters to perform the calculations and to control the output:

- the number of sub-reaches, M;
- the temporal step length, Δt;
- the upwinding coefficient a_u;
- the number of time steps to printout, $N_{toprint}$;
- the numbers of printout in addition to the initial equilibrium state, N_{print};
- the coefficient α_r in eq. (5.i);
- the parameters to define the load relation, α_s, τ_c^* and n_t, defined in eq. (5.ii);
- the constant to convert the total boundary shear stress to that due to skin friction, φ_s;
- the submerged specific gravity of the sediment, R.

The text file with the definition of the input parameters and an example of input file are shown in the two windows below.

Key for Inputs

```
Q   Flood discharge [m^3/s]
I   Intermittency
B   Channel Width [m]
D   Grain Size [mm]
l   Bed Porosity
k   Roughness height [mm]
S   Ambient Bed Slope
G   Imposed Annual Sediment Transfer Rate from Upstream [tons/annum]
L   Length of Reach [m]
t   Time Step [year]
i   Number of Time Steps per Printout
p   Number of Printouts desired
M   Intervals
u   Upwinding Coefficient [1=full upwind, 0.5=central difference]
r   Coefficient in Manning-Strickler Resistance Relation
a   Coefficient in Sediment Transport Relation
n   Exponent in Sediment Transport Relation
T   Critical Shields Stress
P   Fraction of Bed Shear Stress that is Skin Friction
R   Submerged Specific Gravity of Sediment
C   Coefficient, Cf, for Chezy formulation
x   Imposed Water Surface Elevation [m]
```

test.txt

```
Q   400
I   0.1
B   60
D   0.6
l   0.4
k   75
S   0.0002
G   187059.99
x   15
M   60
L   50000
i   200
p   6
u   1
r   8.1
a   8
n   1.5
T   0.047
P   1
R   1.65
t   0.1
```

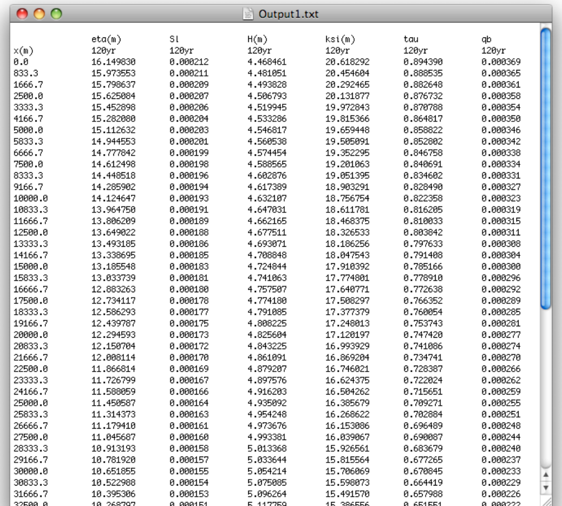
The output parameters of the model printed in the text file *Output.txt* are the bed elevation, η, the channel slope, S, the water depth, H, and the water surface elevation, ξ, at the different times $t_{plot,j}$ defined in eq. (5.viii). An example of output file is reported in the window below. The values of bed elevation, water surface and water elevation at t = 0 are representative of the condition of mobile-bed equilibrium antecedent to the change in annual sediment input rate or downstream water elevation.

Output.txt

x(m)	eta(m) 0yr	H(m) 0yr	ksi(m) 0yr	eta(m) 20yr	H(m) 20yr	ksi(m) 20yr	eta(m) 40yr	H(m) 40yr	ksi(m) 40yr
0.0	10.000000	5.978186	15.978186	12.824447	4.483893	17.308340	13.741689	4.476830	18.218519
833.3	9.833333	6.086486	15.919819	12.635547	4.512800	17.148347	13.558677	4.498158	18.056834
1666.7	9.666667	6.198283	15.864950	12.449029	4.542832	16.991861	13.377700	4.520051	17.897751
2500.0	9.500000	6.313404	15.813404	12.264864	4.574054	16.838918	13.198754	4.542527	17.741281
3333.3	9.333333	6.431675	15.765009	12.083015	4.606536	16.689551	13.021834	4.565604	17.587438
4166.7	9.166667	6.552922	15.719589	11.903432	4.640362	16.543795	12.846930	4.589304	17.436234
5000.0	9.000000	6.676973	15.676973	11.726055	4.675630	16.401685	12.674032	4.613648	17.287680
5833.3	8.833333	6.803660	15.636993	11.550806	4.712451	16.263257	12.503126	4.638659	17.141785
6666.7	8.666667	6.932823	15.599489	11.377589	4.750962	16.128551	12.334198	4.664363	16.998562
7500.0	8.500000	7.064305	15.564305	11.206276	4.791334	15.997610	12.167231	4.690787	16.858018
8333.3	8.333333	7.197959	15.531292	11.036642	4.833845	15.870487	12.002202	4.717961	16.720163
9166.7	8.166667	7.333643	15.500309	10.867630	4.879694	15.747324	11.839088	4.745917	16.585005
10000.0	8.000000	7.471223	15.471223	10.689708	4.939374	15.629082	11.677859	4.774694	16.452553
10833.3	7.833333	7.610573	15.443906	10.419981	5.103270	15.523250	11.518483	4.804332	16.322815
11666.7	7.666667	7.751575	15.418241	9.693547	5.762064	15.455611	11.360922	4.834879	16.195801
12500.0	7.500000	7.894117	15.394117	8.571054	6.851747	15.422801	11.205133	4.866385	16.071518
13333.3	7.333333	8.038096	15.371429	7.927678	7.468596	15.396273	11.051063	4.898913	15.949977
14166.7	7.166667	8.183414	15.350081	7.627474	7.743700	15.371174	10.898655	4.932532	15.831188
15000.0	7.000000	8.329981	15.329981	7.405388	7.942415	15.347803	10.747838	4.967325	15.715163
15833.3	6.833333	8.477713	15.311047	7.198839	8.127289	15.326128	10.598512	5.003406	15.601919
16666.7	6.666667	8.626531	15.293198	6.998039	8.307956	15.305994	10.450217	5.041285	15.491502
17500.0	6.500000	8.776362	15.276362	6.801234	8.486013	15.287247	10.295163	5.089396	15.384559
18333.3	6.333334	8.927139	15.260473	6.607752	8.662000	15.269753	9.992048	5.299586	15.291634
19166.7	6.166667	9.078799	15.245466	6.417122	8.836272	15.253394	8.626240	6.630190	15.256430
20000.0	6.000000	9.231283	15.231283	6.228962	9.009107	15.238069	6.920299	8.325014	15.245313
20833.3	5.833334	9.384538	15.217871	6.042957	9.180732	15.223689	6.356859	8.873838	15.230697
21666.7	5.666667	9.538513	15.205180	5.858842	9.351333	15.210174	6.108198	9.107954	15.216152
22500.0	5.500000	9.693162	15.193162	5.676392	9.521064	15.197455	5.896714	9.305793	15.202507
23333.3	5.333334	9.848441	15.181774	5.495415	9.690055	15.185470	5.692939	9.496810	15.189749
24166.7	5.166667	10.004310	15.170977	5.315747	9.858414	15.174161	5.493732	9.684064	15.177796
25000.0	5.000000	10.160733	15.160733	5.137245	10.026234	15.163479	5.298217	9.868358	15.166575

x(m)	eta(m) 60yr	H(m) 60yr	ksi(m) 60yr	eta(m) 80yr	H(m) 80yr	ksi(m) 80yr	eta(m) 100yr	H(m) 100yr	ksi(m) 100yr	eta(m) 120yr	H(m) 120yr	ksi(m) 120yr
0.0	14.470701	4.473326	18.944026	15.094103	4.471158	19.565261	15.647427	4.469609	20.117036	16.149830	4.468461	20.618292
833.3	14.290542	4.490961	18.781503	14.915690	4.486528	19.402218	15.470238	4.483386	19.953624	15.973553	4.481051	20.454604
1666.7	14.112164	4.508973	18.621137	14.738887	4.502171	19.241058	15.294515	4.497388	19.791903	15.798637	4.493828	20.292465
2500.0	13.935565	4.527371	18.462936	14.563691	4.518096	19.081787	15.120263	4.511616	19.631879	15.625084	4.506793	20.131877
3333.3	13.760746	4.546163	18.306909	14.390101	4.534309	18.924410	14.947483	4.526072	19.473554	15.452898	4.519945	19.972843
4166.7	13.587708	4.565354	18.153062	14.218113	4.550817	18.768930	14.776177	4.540756	19.316932	15.282080	4.533286	19.815366
5000.0	13.416446	4.584954	18.001401	14.047729	4.567624	18.615353	14.606345	4.555671	19.162016	15.112632	4.546817	19.659448
5833.3	13.246959	4.604971	17.851930	13.878946	4.584736	18.463682	14.437987	4.570820	19.008807	14.944553	4.560538	19.505091
6666.7	13.079240	4.625416	17.704656	13.711764	4.602155	18.313919	14.271100	4.586208	18.857307	14.777842	4.574454	19.352295
7500.0	12.913282	4.646299	17.559581	13.546179	4.619888	18.166067	14.105682	4.601838	18.707520	14.612498	4.588565	19.201063
8333.3	12.749077	4.667633	17.416711	13.382189	4.637940	18.020129	13.941730	4.617714	18.559444	14.448518	4.602876	19.051395
9166.7	12.586617	4.689430	17.276047	13.219789	4.656317	17.876107	13.779242	4.633841	18.413083	14.285902	4.617389	18.903291
10000.0	12.425892	4.711701	17.137594	13.058974	4.675027	17.734000	13.618215	4.650221	18.268437	14.124647	4.632107	18.756754
10833.3	12.266891	4.734462	17.001353	12.899737	4.694075	17.593812	13.458647	4.666859	18.125506	13.964750	4.647031	18.611781
11666.7	12.109601	4.757725	16.867326	12.742072	4.713469	17.455541	13.300532	4.683758	17.984290	13.806209	4.662165	18.468375
12500.0	11.954008	4.781507	16.735516	12.585973	4.733216	17.319188	13.143867	4.700922	17.844789	13.649022	4.677511	18.326533
13333.3	11.800096	4.805826	16.605922	12.431431	4.753323	17.184754	12.988647	4.718355	17.707002	13.493185	4.693071	18.186256
14166.7	11.647848	4.830699	16.478547	12.278438	4.773799	17.052237	12.834867	4.736061	17.570929	13.338695	4.708848	18.047543
15000.0	11.497244	4.856147	16.353390	12.126984	4.794652	16.921637	12.682521	4.754046	17.436568	13.185548	4.724844	17.910392
15833.3	11.348262	4.882191	16.230454	11.977060	4.815892	16.792952	12.531603	4.772315	17.303918	13.033739	4.741063	17.774801
16666.7	11.200880	4.908857	16.109737	11.828653	4.837528	16.666181	12.382106	4.790871	17.172977	12.883263	4.757507	17.640771
17500.0	11.055070	4.936171	15.991241	11.681753	4.859570	16.541323	12.234022	4.809721	17.043743	12.734117	4.774180	17.508297
18333.3	10.910804	4.964163	15.874967	11.536345	4.882029	16.418374	12.087344	4.828869	16.916213	12.586293	4.791085	17.377379
19166.7	10.768049	4.992865	15.760915	11.392417	4.904917	16.297334	11.942064	4.848322	16.790386	12.439787	4.808225	17.248013
20000.0	10.626769	5.022317	15.649087	11.249952	4.928248	16.178200	11.798172	4.868086	16.666258	12.294593	4.825604	17.120197
20833.3	10.486923	5.052562	15.539484	11.108935	4.952034	16.060969	11.655660	4.888167	16.543827	12.150704	4.843225	16.993929
21666.7	10.348452	5.083660	15.432112	10.969347	4.976291	15.945638	11.514517	4.908572	16.423089	12.008114	4.861091	16.869204
22500.0	10.210773	5.116241	15.327014	10.831170	5.001035	15.832206	11.374733	4.929307	16.304040	11.866814	4.879207	16.746021
23333.3	10.051160	5.174738	15.225898	10.694384	5.026284	15.720669	11.236296	4.950382	16.186677	11.726799	4.897576	16.624375
24166.7	9.245128	5.920022	15.165150	10.558966	5.052058	15.611024	11.099194	4.971803	16.070997	11.588059	4.916203	16.504262
25000.0	6.525093	8.641671	15.166764	10.424892	5.078379	15.503270	10.963415	4.993579	15.956995	11.450587	4.935092	16.385679

The additional parameters that the user may print at times $t_{plot,j}$ in the text file *Output1.txt* are the channel slope, S, the Shields number, τ_b, and the total sediment transport rate, q_t. An example of the file *Output1.txt* is reported in the windows below. The parameters at t = 0 are representative of the condition of mobile-bed equilibrium antecedent to the change in annual sediment input rate or downstream water elevation.



Output1.txt

	eta(m)	Sl	H(m)	ksi(m)	tau	qb
x(m)	120yr	120yr	120yr	120yr	120yr	120yr
0.0	16.149830	0.000212	4.468461	20.618292	0.894390	0.000369
833.3	15.973553	0.000211	4.481051	20.454604	0.888535	0.000365
1666.7	15.798637	0.000209	4.493828	20.292465	0.882648	0.000361
2500.0	15.625084	0.000207	4.506793	20.131877	0.876732	0.000358
3333.3	15.452898	0.000206	4.519945	19.972843	0.870788	0.000354
4166.7	15.282080	0.000204	4.533286	19.815366	0.864817	0.000350
5000.0	15.112632	0.000203	4.546817	19.659448	0.858822	0.000346
5833.3	14.944553	0.000201	4.560538	19.505091	0.852802	0.000342
6666.7	14.777842	0.000199	4.574454	19.352295	0.846758	0.000338
7500.0	14.612498	0.000198	4.588565	19.201063	0.840691	0.000334
8333.3	14.448518	0.000196	4.602876	19.051395	0.834602	0.000331
9166.7	14.285902	0.000194	4.617389	18.903291	0.828490	0.000327
10000.0	14.124647	0.000193	4.632107	18.756754	0.822358	0.000323
10833.3	13.964750	0.000191	4.647031	18.611781	0.816205	0.000319
11666.7	13.806209	0.000189	4.662165	18.468375	0.810033	0.000315
12500.0	13.649022	0.000188	4.677511	18.326533	0.803842	0.000311
13333.3	13.493185	0.000186	4.693071	18.186256	0.797633	0.000308
14166.7	13.338695	0.000185	4.708848	18.047543	0.791408	0.000304
15000.0	13.185548	0.000183	4.724844	17.910392	0.785166	0.000300
15833.3	13.033739	0.000181	4.741063	17.774801	0.778910	0.000296
16666.7	12.883263	0.000180	4.757507	17.640771	0.772638	0.000292
17500.0	12.734117	0.000178	4.774180	17.508297	0.766352	0.000289
18333.3	12.586293	0.000177	4.791085	17.377379	0.760054	0.000285
19166.7	12.439787	0.000175	4.808225	17.248013	0.753743	0.000281
20000.0	12.294593	0.000173	4.825604	17.120197	0.747420	0.000277
20833.3	12.150704	0.000172	4.843225	16.993929	0.741086	0.000274
21666.7	12.008114	0.000170	4.861091	16.869204	0.734741	0.000270
22500.0	11.866814	0.000169	4.879207	16.746021	0.728387	0.000266
23333.3	11.726799	0.000167	4.897576	16.624375	0.722024	0.000262
24166.7	11.588059	0.000166	4.916203	16.504262	0.715651	0.000259
25000.0	11.450587	0.000164	4.935092	16.385679	0.709271	0.000255
25833.3	11.314373	0.000163	4.954248	16.268622	0.702884	0.000251
26666.7	11.179410	0.000161	4.973676	16.153086	0.696489	0.000248
27500.0	11.045687	0.000160	4.993381	16.039067	0.690087	0.000244
28333.3	10.913193	0.000158	5.013368	15.926561	0.683679	0.000240
29166.7	10.781920	0.000157	5.033644	15.815564	0.677265	0.000237
30000.0	10.651855	0.000155	5.054214	15.706069	0.670845	0.000233
30833.3	10.522988	0.000154	5.075085	15.598073	0.664419	0.000229
31666.7	10.395306	0.000153	5.096264	15.491570	0.657988	0.000226
32500.0	10.268797	0.000151	5.117759	15.386556	0.651551	0.000222

Notes:

- The downstream water surface elevation must exceed the H_c, critical depth, which is equal to $(Q_w^2/(B_c^2 g))^{1/3}$, otherwise the user is alerted, and the program exits;
- In the original version of the code embedded in the excel file RTe-bookAgDegBW.xls the Manning-Strickler formulation is implemented;
- The water depth is calculated using a Chézy formulation, when only the Chézy coefficient is specified in the input text file. The Manning-Strickler formulation is implemented, when only the roughness height, k_c, and the coefficient α_r in eq. (5.i) are given in the input text file. When all the three parameters are present, the program will ask the user which formulation they would like to use
- Program prompts user whether they would like to append certain parameters to their output file (*i.e. Output.txt*), or whether they would like to create a separate file for these parameters. Included in these parameters are values such as flow depth at flood, Einstein number at flood, initial normal Froude number, ultimate normal Froude number, etc.

List of variables

x	streamwise coordinate in m
Δx	spatial step length in m
t	temporal coordinate in seconds
C_f	non-dimensional friction coefficient

INPUT

Q_w	flood discharge in m^3/s
I_f	flood intermittency
B_c	channel width in m
D	characteristic grain size in mm
λ_p	bed porosity
k_c	composite roughness height in mm
S_I	ambient bed slope
ξ_d	imposed downstream water elevation in m
G_{tf}	imposed annual sediment transport rate in tons/annum
L	length of reach in m
Δt	time step in yr
$N_{toprint}$	number of time steps to printout
N_{print}	number of printouts
M	number of spatial intervals
a_u	upwinding coefficient (1=full upwind, 0.5=central difference)
α_r	coefficient in Manning-Strickler
α_s	coefficient in sediment transport relation
n_t	exponent in sediment transport relation
τ_c^*	reference Shields number in sediment transport relation
φ_s	fraction of bed shear stress due to skin friction
R	submerged specific gravity
Cz	non-dimensional Chézy friction coefficient

OUTPUT

η	bed surface elevation in m
S	bed slope
H	water depth in m
ξ	water surface elevation in m
τ_b	total boundary shear stress on bed surface N/m^2
q_t	total bed material load in m^2/s

7) AgDegNormalSub

The program computes the approach to mobile-bed equilibrium in a river carrying uniform material and flowing into a subsiding basin. It is a descendant of AgDegNormal. Three relatively minor changes have been implemented as follows:

a) The input parameters have been modified to include the following parameters: subsidence rate σ, ratio of depositional width to channel width r_B, ratio of wash load deposited per unit bed material load Λ and channel sinuosity Ω;
b) The code has been modified so as to include subsidence in the calculation of mass balance;
c) The output has been modified to show the time evolution of not only the profile of bed elevation η, but also the profiles of bed slope S and the ratio q_t/q_{tf}, where q_{tf} denotes the volume feed rate of bed material load per unit width.

The new input parameters, i.e. ratio of depositional to channel width, r_B, units of wash load deposited per unit bed material load, Λ, and channel sinuosity, ω, have been introduced to generalize the Exner equation for uniform sediment from a flume-like setting, eq. (6.i) below, to a river, eq. (6.ii).

$$(1-\lambda_p)\frac{\partial\eta}{\partial t} = -\frac{\partial q_t}{\partial x} \tag{7.i}$$

$$(1-\lambda_p)\left(\frac{\partial\eta}{\partial t}+\sigma\right) = -\frac{I_f}{r_B}(1+\Lambda)\Omega\frac{\partial q_t}{\partial x} \tag{7.ii}$$

where λ_p denotes the bed porosity, η is the bed elevation, q_t is the total sediment transport rate per unit channel width, I_f is the flow intermittency, t is the temporal coordinate and x is the streamwise (i.e. downchannel) coordinate.

The ratio of depositional to channel width, r_B, has been introduced to model the fact that in an aggrading river sediment deposits not only in the channel itself, but also in a much wider belt (e.g. the floodplain or basin width, due to overbank deposition, channel migration and avulsion). Here channel width is denoted as B_c (which can be taken to be synonymous with bankfull width) and effective depositional width is denoted as B_d. Both of these are taken as constant here for simplicity. r_B is thus defined as

$$r_B = \frac{B_d}{B_c} \tag{7.iii}$$

The parameter Λ that represents the units of wash load deposited per unit of bed material is introduced to consider that in the 1D formulation implemented in this model it is assumed that deposition occurs not only in the channel but on a much wider area (e.g. the floodplain). Sediment deposited in the channel is mostly made of bed material but sediment deposited around the channel contains a significant amount of wash load. A precise mass balance for wash load is beyond the scope of this model. For simplicity it is assumed that for every unit of sand deposited in the system, Λ units of wash load are deposited. It is also assumed that the supply of wash load from upstream is always sufficient for deposition at such a rate. This is not likely to be strictly true, but should serve as a useful starting assumption.

The parameter Ω has been introduced to consider that channels may be sinuous. Here it is assumed that the channel has a sinuosity, Ω, but that the depositional surface across which it wanders is rectangular. In the present formulation the sinuosity is defined as the ratio of downchannel distance per unit of downvalley distance.

For a detailed description of the theory and of the model, the user should refer to Chapters 4 "Relations for the Conservation of Bed Sediment", 25 "Long Profiles of Rivers, with an Application on the Effect of Base Level Rise on Long Profiles" and 26 "Rivers Flowing into Subsiding Basins: Upward Concavity of Long Profile and Downstream Fining" of the e-book.

Boundary and initial conditions are equal to that implemented for the ancestor model AgDegNormal.

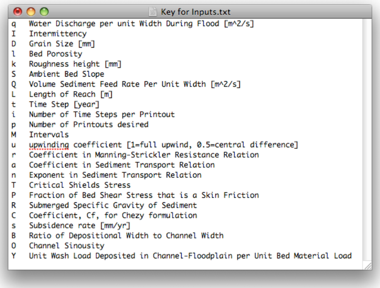
The input parameters of the model are specified in a slightly different form than those of AgDegNormal. The input parameters of AgDegNormalSub are listed below:

- the characteristic flood discharge per unit channel width, q_w, and the flood intermittency, I_f;
- the characteristic diameter of the sediment, D;
- the bed porosity, λ_p;
- the roughness height, k_c;
- the ambient bed slope, S;
- the volume sediment feed rate per unit channel width, q_{tf};
- the subsidence rate, σ;
- the ratio of depositional width to channel width, r_B;
- the channel sinuosity, Ω;
- the units of wash load deposited in the system per unit of bed material load, Λ;
- the length of the fluvial reach, L;

The user also has to specify the following parameters to perform the calculations and to control the output:

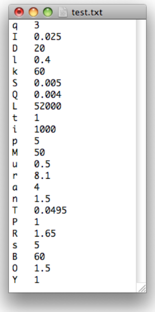
- the number of sub-reaches, M;
- the temporal step length, Δt;
- the upwinding coefficient a_u;
- the number of time steps to printout, $N_{toprint}$;
- the numbers of printout in addition to the initial equilibrium state, N_{print};
- the coefficient α_r in eq. (5.i);
- the parameters to define the load relation, α_s, τ_c^* and n_t, defined in eq. (5.ii);
- the constant to convert the total boundary shear stress to that due to skin friction, φ_s;
- the submerged specific gravity of the sediment, R.

The text file with the definition of the input parameters and an example of input file are shown in the two windows below.



Key for Inputs.txt

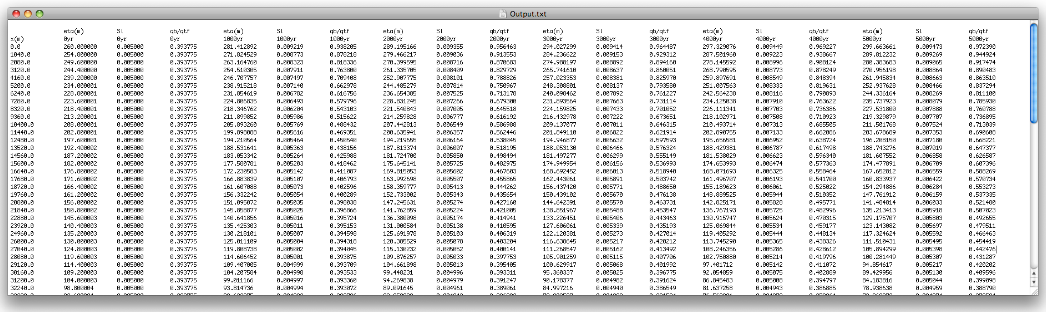
q	Water Discharge per unit Width During Flood [m^2/s]
I	Intermittency
D	Grain Size [mm]
l	Bed Porosity
k	Roughness height [mm]
S	Ambient Bed Slope
Q	Volume Sediment Feed Rate Per Unit Width [m^2/s]
L	Length of Reach [m]
t	Time Step [year]
i	Number of Time Steps per Printout
p	Number of Printouts desired
M	Intervals
u	upwinding coefficient [1=full upwind, 0.5=central difference]
r	Coefficient in Manning-Strickler Resistance Relation
a	Coefficient in Sediment Transport Relation
n	Exponent in Sediment Transport Relation
T	Critical Shields Stress
P	Fraction of Bed Shear Stress that is a Skin Friction
R	Submerged Specific Gravity of Sediment
C	Coefficient, Cf, for Chezy formulation
s	Subsidence rate [mm/yr]
B	Ratio of Depositional Width to Channel Width
O	Channel Sinousity
Y	Unit Wash Load Deposited in Channel-Floodplain per Unit Bed Material Load



test.txt

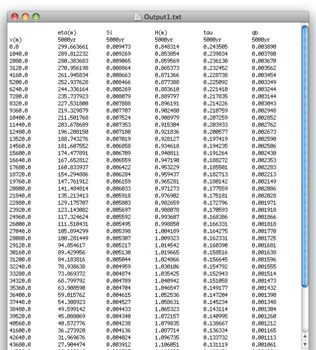
q	3
I	0.025
D	20
l	0.4
k	60
S	0.005
Q	0.004
L	52000
t	1
i	1000
p	5
M	50
u	0.5
r	8.1
a	4
n	1.5
T	0.0495
P	1
R	1.65
s	5
B	60
O	1.5
Y	1

The output parameters of the model printed in the text file *Output.txt* are the bed elevation, η, the channel slope, S, and the ratio between the transport and the feed rate of bed material load.



Output.txt

The additional parameters that the user may print at times $t_{plot,j}$ in the text file *Output1.txt* are the channel slope, S, the water depth, H, the Shields number, τ_b, and the total sediment transport rate, q_t. An example of the file *Output1.txt* is reported in the windows below.



Output1.txt

Notes:

- Flow is calculated assuming normal flow approximation;
- In the original version of the code embedded in the excel file RTe-bookAgDegNormSub.xls the Manning-Strickler formulation is implamented;
- The water depth is calculated using a Chézy formulation, when only the Chézy coefficient is specified in the input text file. The Manning-Strickler formulation is implemented, when only the roughness height, k_c, and the coefficient α_r in eq. (5.i) are given in the input text file. When all the three parameters are present, the program will ask the user which formulation they would like to use
- If the input channel length is longer than the maximum possible length of the fluvial reach, the program cannot perform the calculation. The maximum possible length of the fluvial reach, L_{max}, is defined as the maximum length of basin that the sediment supply can fill; at this length the sediment transport rate out of the basin drops precisely to zero (see Chapter 26 "Rivers Flowing into Subsiding Basins: Upward Concavity of Long Profile and Downstream Fining" of the e-book). For the Exner equation generalized for a river, eq. (7.ii), L_{max} is computed as

$$L_{max} = \frac{I_f(1+\Lambda)\Omega}{r_B}\frac{q_{tf}}{(1-\lambda_p)\sigma} \tag{7.iv}$$

List of variables

x downchannel coordinate in m
Δx spatial step length in m
t temporal coordinate in seconds
B_c channel width in m
B_d width of the depositional area in m
L_{max} maximum possible length of the modeled reach in m

INPUT

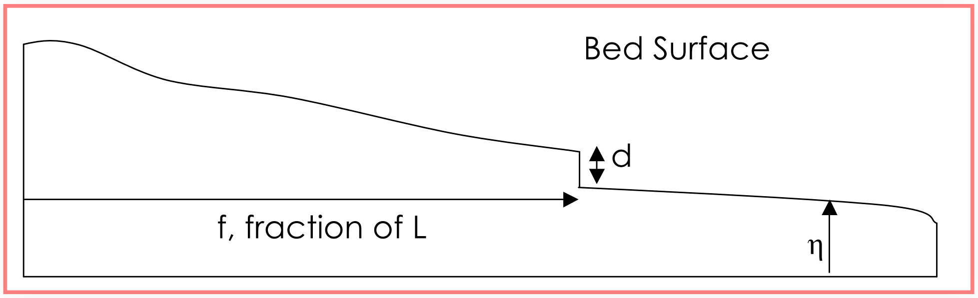
q_w flood discharge per unit channel width m^2/s
I_f flood intermittency
D grain size in mm
λ_p bed porosity
k_c composite roughness height in mm
SI initial bed slope
qtf sediment input rate of bed material load per unit channel width in m^2/s
σ subsidence rate in mm/yr
r_B ratio between the depositional and the channel width
Ω channel sinuosity
Λ units of wash load deposited per unit of deposited bed material load
L length of reach in m
Δt time step in yr
$N_{toprint}$ number of time steps to printout
N_{print} number of printouts
M number of spatial intervals
a_u upwinding coefficient (1=full upwind, 0.5=central difference)
α_r coefficient in Manning-Strickler
α_s coefficient in sediment transport relation
n_t exponent in sediment transport relation
τ_c^* reference Shields number in sediment transport relation
φ_s fraction of bed shear stress due to skin friction
R submerged specific gravity
Cz non-dimensional Chézy friction coefficient

OUTPUT

η bed surface elevation in m
S bed slope
H water depth in m
τ_b total boundary shear stress on bed surface N/m^2
q_t total bed material load in m^2/s
q_t/q_{tf} ratio between the sediment transport and feed rate of bed material

8) AgDegNormalFault

The program AgDegNormalFault is an extension of AgDegNormal for sudden vertical faulting of the bed, as shown in the figure below.



The bed downstream of the point $x = r_f L$ ($0 < r_f < 1$), where x is a streamwise coordinate and L is the length of the modeled reach, is suddenly faulted downward by an amount $\Delta\eta_f$ at time t_f. The eventual smearing out of the long profile is then computed.

The initial condition for the model is the bed at mobile equilibrium for the specified boundary conditions, i.e. characteristic flood discharge, Q_w, flood intermittency, I_f, and bed slope.

Input parameters of the model are

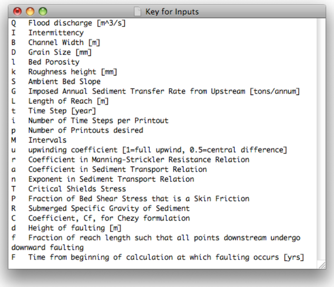
- the characteristic flood discharge, Q_w, and the flood intermittency, I_f;
- the channel width, B_c;
- the characteristic diameter of the sediment, D;
- the bed porosity, λ_p;
- the roughness height, k_c;
- the ambient bed slope, S;
- the imposed annual sediment transport rate, G_{tf};
- the fraction of reach length such that all points downstream of $x = r_f L$ undergo downward faulting, r_f;
- the height of faulting, $\Delta\eta$;
- the time from beginning of calculation at which faulting occurs, t_f;
- the length of the fluvial reach, L;

The user also has to specify the following parameters to perform the calculations and to control the output:

- the number of sub-reaches, M;
- the temporal step length, Δt;
- the upwinding coefficient a_u;
- the number of time steps to printout, $N_{toprint}$;
- the numbers of printout in addition to the initial equilibrium state, N_{print};
- the coefficient α_r in eq. (5.i);

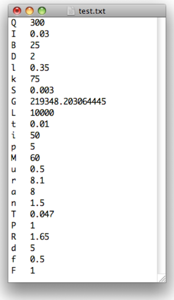
- the parameters to define the load relation, α_s, τ_c^* and n_t, defined in eq. (5.ii);
- the constant to convert the total boundary shear stress to that due to skin friction, φ_s;
- the submerged specific gravity of the sediment, R.

The text file with the definition of the input parameters and an example of input file are shown in the two windows below.



Key for Inputs

```
Q   Flood discharge [m^3/s]
I   Intermittency
B   Channel Width [m]
D   Grain Size [mm]
l   Bed Porosity
k   Roughness height [mm]
S   Ambient Bed Slope
G   Imposed Annual Sediment Transfer Rate from Upstream [tons/annum]
L   Length of Reach [m]
t   Time Step [year]
i   Number of Time Steps per Printout
p   Number of Printouts desired
M   Intervals
u   upwinding coefficient [1=full upwind, 0.5=central difference]
r   Coefficient in Manning-Strickler Resistance Relation
a   Coefficient in Sediment Transport Relation
n   Exponent in Sediment Transport Relation
T   Critical Shields Stress
P   Fraction of Bed Shear Stress that is a Skin Friction
R   Submerged Specific Gravity of Sediment
C   Coefficient, Cf, for Chezy formulation
d   Height of faulting [m]
f   Fraction of reach length such that all points downstream undergo
downward faulting
F   Time from beginning of calculation at which faulting occurs [yrs]
```

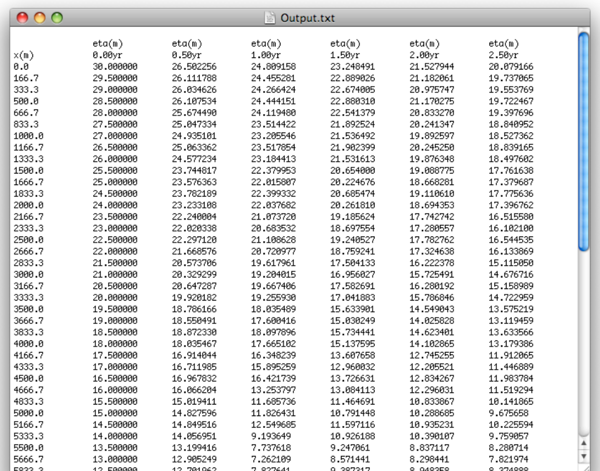


test.txt

```
Q   300
I   0.03
B   25
D   2
l   0.35
k   75
S   0.003
G   219348.203064445
L   10000
t   0.01
i   50
p   5
M   60
u   0.5
r   8.1
a   8
n   1.5
T   0.047
P   1
R   1.65
d   5
f   0.5
F   1
```

The outputs of the model are N_{print} longitudinal profiles at different times $t_{plot,j}$ defined by eq. (5.viii).

An example of the output file *Output.txt* is reported in the window below with an example of the additional parameters that the user may want to plot in the text file *Output1.txt*, i.e. bed slope, S, water depth, H, Shields number, τ_b, and the total bed material load, q_t. The initial bed profile is the bed profile at mobile-bed equilibrium, given the water discharge, the flow intermittency and the initial bed slope.



Output.txt

	eta(m)	eta(m)	eta(m)	eta(m)	eta(m)	eta(m)
x(m)	0.00yr	0.50yr	1.00yr	1.50yr	2.00yr	2.50yr
0.0	30.000000	26.502256	24.809158	23.248491	21.527944	20.079166
166.7	29.500000	26.111788	24.455281	22.889026	21.182061	19.737065
333.3	29.000000	26.034626	24.266424	22.674005	20.975747	19.553769
500.0	28.500000	26.107534	24.444151	22.880310	21.170275	19.722467
666.7	28.000000	25.674490	24.119480	22.541379	20.833270	19.397696
833.3	27.500000	25.047334	23.514422	21.892524	20.241347	18.840952
1000.0	27.000000	24.935101	23.205546	21.536492	19.892597	18.527362
1166.7	26.500000	25.063362	23.517854	21.902399	20.245250	18.839165
1333.3	26.000000	24.577234	23.184413	21.531613	19.876348	18.497602
1500.0	25.500000	23.744817	22.379953	20.654000	19.088775	17.761638
1666.7	25.000000	23.576363	22.015807	20.224676	18.668281	17.379687
1833.3	24.500000	23.782189	22.399332	20.685474	19.110610	17.775636
2000.0	24.000000	23.233108	22.037682	20.261810	18.694353	17.396762
2166.7	23.500000	22.240004	21.073720	19.185624	17.742742	16.515580
2333.3	23.000000	22.020338	20.683532	18.697554	17.280557	16.102100
2500.0	22.500000	22.297120	21.108628	19.240527	17.782762	16.544535
2666.7	22.000000	21.668576	20.720977	18.759241	17.324638	16.133869
2833.3	21.500000	20.573706	19.617961	17.504133	16.222378	15.115050
3000.0	21.000000	20.329299	19.204015	16.956027	15.725491	14.676716
3166.7	20.500000	20.647287	19.667406	17.582691	16.280192	15.158989
3333.3	20.000000	19.920182	19.255930	17.041883	15.786846	14.722959
3500.0	19.500000	18.786166	18.035489	15.633901	14.549043	13.575219
3666.7	19.000000	18.550491	17.600416	15.030249	14.025828	13.119459
3833.3	18.500000	18.872330	18.097896	15.734441	14.623401	13.633566
4000.0	18.000000	18.035467	17.665102	15.137595	14.102865	13.179386
4166.7	17.500000	16.914044	16.348239	13.607658	12.745255	11.912065
4333.3	17.000000	16.711985	15.895259	12.960032	12.205521	11.446889
4500.0	16.500000	16.967832	16.421739	13.726631	12.834267	11.983784
4666.7	16.000000	16.066204	13.253797	13.084113	12.296031	11.519294
4833.3	15.500000	15.019411	11.685736	11.464691	10.833867	10.141865
5000.0	15.000000	14.827596	11.826431	10.791448	10.288685	9.675658
5166.7	14.500000	14.849516	12.549685	11.597116	10.935231	10.225594
5333.3	14.000000	14.056951	9.193649	10.926188	10.390107	9.759057
5500.0	13.500000	13.199416	7.737618	9.247061	8.837117	8.280714
5666.7	13.000000	12.905249	7.262109	8.571441	8.298441	7.821974
5833.3	12.500000	12.701962	7.827641	9.387317	8.948358	8.374888

Notes:

- If the channel slope is negative and the water depth is not a number, "nan", check the time step and the spatial step length. In particular, the time step may be too large or equivalently the spatial step length may be too small. Change these values and run the model again;
- The water depth is calculated using a Chézy formulation, when only the Chézy coefficient is specified in the input text file. The Manning-Strickler formulation is implemented, when only the roughness height, k_c, and the coefficient α_r in eq. (5.i) are given in the input text file. When all the three parameters are present, the program will ask the user which formulation they would like to use.

List of variables

x	streamwise coordinate in m
Δx	spatial step length in m
t	temporal coordinate in seconds
C_f	non-dimensional friction coefficient

INPUT

Q_w	flood discharge in m^3/s
I_f	flood intermittency
B_c	channel width in m
D	characteristic grain size in mm
λ_p	bed porosity
k_c	composite roughness height in mm
S_I	ambient bed slope
G_{tf}	imposed annual sediment transport rate in tons/annum
r_f	faction of reach length such that all points downstream of $x = r_f L$ undergo downward faulting.
$\Delta\eta$	height of faulting in m
t_f	time from beginning of calculation at which faulting occurs in years
L	length of reach in m
Δt	time step in years
$N_{toprint}$	number of time steps to printout
N_{print}	number of printouts
M	number of spatial intervals
a_u	upwinding coefficient (1=full upwind, 0.5=central difference)
α_r	coefficient in Manning-Strickler
α_s	coefficient in sediment transport relation
n_t	exponent in sediment transport relation
τ_c^*	reference Shields number in sediment transport relation
φ_s	fraction of bed shear stress due to skin friction
R	submerged specific gravity
Cz	non-dimensional Chézy friction coefficient

OUTPUT

η	bed surface elevation in m
S	bed slope
H	water depth in m
τ_b	total boundary shear stress on bed surface N/m^2
q_t	total bed material load in m^2/s

9) AgDegNormGravMixPW

The program AgDegNormGravMixPW is an extension of AgDegNormal for sediment mixtures in gravel bed rivers where the channel bed material is transported as bedload only. Gravel-bed rivers tend to be poorly-sorted. During floods, bed material load consists almost exclusively of bedload. (Sand is often transported in copious quantities as washload during floods.) The surface material (armor or pavement) tends to be coarser than the substrate. By definition the median size D_{sub50} or geometric mean size D_{subg} of the substrate is in the gravel range, but the substrate may contain up to 30% sand in the interstices of an otherwise clast-supported deposit. The Exner equation of conservation of channel bed sediment, eq. (5.iii), is thus written as

$$(1-\lambda_p)\frac{\partial \eta}{\partial t} = -I_f \frac{\partial q_{bT}}{\partial x} \tag{9.i}$$

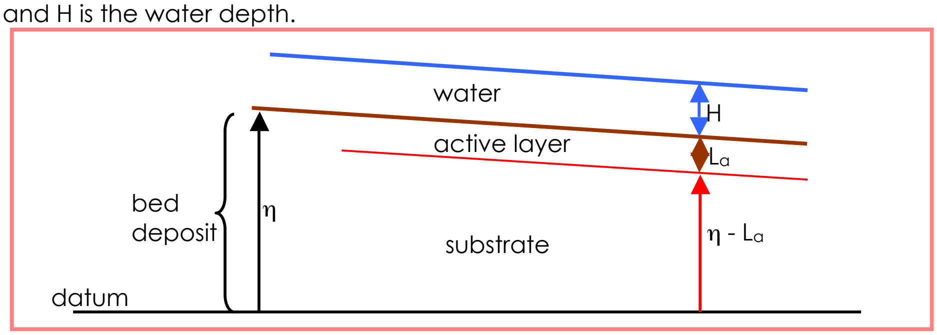
where λ_p is the bed porosity, η is the bed elevation above a datum, t is a temporal coordinate, I_f is the flow intermittency, x is a streamwise coordinate and q_{bT} denotes the total volumetric bedload transport rate per unit channel width.

The grain size distribution of the bed material is specified in terms of 12 size bounds, D_{bi} with i = 1 ...12, such that f_{fi} denotes the mass fraction of the sample that is finer than D_{bi}. The 12 bound diameters specify 11 grain size ranges defined by ($D_{b,i}$, $D_{b,i+1}$) and ($f_{f,i}$, $f_{f,i+1}$). For each size range the model computes the characteristic diameter, D_i, and the fraction of sample in the ith size range, f_i, with the equations (9.ii a, b) reported below.

$$D_i = (D_{b,i} \cdot D_{b,i+1})^{1/2} \qquad f_i = f_{f,i+1} - f_{f,i} \tag{9.ii a, b}$$

The flow is assumed normal and the water depth can be computed with either a Manning-Strickler (implemented in the worksheet *Rte-bookAgDegNormGravMixPW.xls*) or a Chezy formulation can be used.

The exchange of sediment between the bedload and the bed deposit is modeled with a two-layer model for the channel bed. The bed deposit is divided in two regions, 1) the substrate and 2) the active (or surface or armor) layer, as represented in the figure below, where η denotes the channel bed elevation above a datum, L_a is the thickness of the active layer and H is the water depth.



The grain size distribution of the active layer is assumed to be constant in the vertical and it may vary in the streamwise direction and in time, i.e. the active layer is assumed well-mixed. The grain size distribution of the substrate, in principle, may vary in both streamwise and vertical direction, but it is constant in time. The only way the grain size distribution of the substrate may vary in time is by creating new substrate via bed aggradation. In the present model, the grain size distribution of the substrate is assumed to be constant in space and in time, therefore it works only for the cases of aggradation always and everywhere or degradation always and everywhere. In the case of aggradation followed by degradation, it is necessary to modify the code so that the vertical variation of the grain size distribution of the new substrate created by aggradation is stored in memory.

The evolution in time and space of the grain size distribution of the active layer is described by the grain-size based Exner equation, eq. (9.iii), that expresses the conservation of sediment in each grain size range.

$$\left(1-\lambda_p\right)\left[L_a \frac{\partial F_i}{\partial t} + \left(F_i - f_{Ii}\right)\frac{\partial L_a}{\partial t}\right] = -I_f \frac{\partial q_{bT} p_i}{\partial x} + I_f f_{Ii} \frac{\partial q_{bT}}{\partial x} \qquad (9.iii)$$

F_i, p_i and f_{Ii} respectively represent the fraction of sediment in the ith grain size range in the active layer, in the bedload and at the active-layer substrate interface. The grain size distribution of the sediment at the active layer substrate interface is defined in eq. (9.iv). It is equal to the weighted average between the grain size distribution of the active layer and of the bedload when the bed aggrades and the grain size distribution of the substrate when the bed degrades.

$$f_{Ii} = \begin{cases} \alpha F_i + \left(1-\alpha\right)p_i & \text{if } \dfrac{\partial \eta}{\partial t} > 0 \\ f_{sub,i} & \text{if } \dfrac{\partial \eta}{\partial t} < 0 \end{cases} \qquad (9.iv)$$

where α is a user specified parameter and $f_{sub,i}$ denotes the fraction of substrate material in the ith size range.

No attempt is made in this code to decompose the bed resistance into skin friction and form drag. The constant to convert total boundary shear stress to that due to skin friction, φ_s, is set equal to 1 and consequently the composite roughness height for the Manning-Strickler formulation, k_c, is equal to the roughness height due to skin friction, k_s, eq. (4.iv). The roughness height and the thickness of the active layer are computed with the liner functions of the diameter of the bed surface such that the 90% of the sediment is finer, D_{s90}, reported in eq. (9.v a, b)

$$k_s = n_k D_{s90} \qquad L_a = n_a D_{s90} \qquad (9.v\ a, b)$$

where n_k and n_a are user specified order-one non dimensional constants.

To compute the bedload transport rate the user can choose from two surface-based bedload transport formulations; those of Parker (1990) and Wilcock and Crowe (2003). In the relation of Parker (1990) the surface grain size distributions need to be renormalized to exclude sand before specification as input to the program. This step is neither necessary nor desirable in the case of the relation of Wilcock and Crowe (2003), where the sand plays an important role in mediating the gravel bedload transport.

For a detailed description of the theory and of the model the user may refer to Chapters 4 "Relations for the Conservation of Bed Sediment", 7 "Relations for 1D Bedload Transport", 17 "Aggradation and Degradation of Rivers Transporting Gravel Mixtures" and 18 "Mobile and Static Armor in Gravel-bed Streams" of the e-book.

The upstream boundary conditions are given in terms of specified values of water discharge per unit width, q_w, and volumetric total gravel input rate per unit width, q_{bTf}, with its grain size distribution, given in terms of bound diameters, D_{bi}, and percent finer, p_{ffi}. The downstream boundary condition is a fixed bed elevation η_d at the downstream end of the modeled reach, i.e. the Exner equation (9.i) is not implemented at node M+1.

The initial conditions are a specified initial bed profile here simplified to a specified initial bed slope S_I (S_{fbI} in the excel file *RTe-bookAgDegNormGravMixPW.xls*), see eq. (5.vii). The grain size distributions of the active layer, F_{fi}, and of the substrate, f_{subfi}, have to be specified and they are assumed to be the same in each computational node. These grain size distributions are expressed in terms of bound diameters, D_{bi}, and percent finer, respectively F_{fIi} for the bed surface and F_{subfi} (F_{fsi} in the excel file *RTe-bookAgDegNormGravMixPW.xls*).

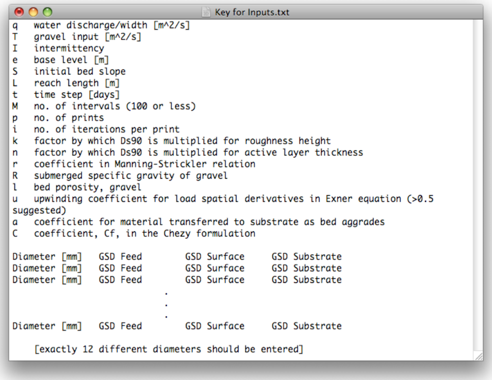
Input parameters of the model are

- the characteristic flood discharge per unit channel width, q_w, and the flood intermittency, I_f;
- the volumetric gravel input rate per unit channel width, q_{bTf};
- the downstream bed elevation, η_d;
- the bed porosity, λ_p;
- the initial bed slope, S_I;
- the length of the fluvial reach, L;
- the grain size distributions of the substrate of the active layer and of the gravel feed rate. The bound diameters, D_{bi}, are the same for the three distributions;

The user also has to specify the following parameters to perform the calculations and to control the output:

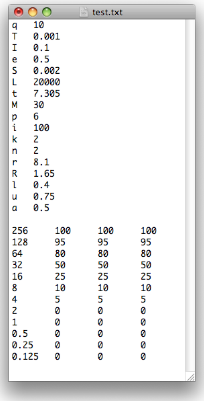
- the number of sub-reaches, M;
- the temporal step length, Δt;
- the upwinding coefficient a_u;
- the number of time steps to printout, $N_{toprint}$;
- the numbers of printout in addition to the initial equilibrium state, N_{print};
- the coefficient α_r in eq. (4.iv);
- the coefficient n_k in eq. (9.v a) to compute the roughness height;
- the coefficient n_a in eq. (9.v b) to compute the thickness of the active layer;
- the load relation, i.e. Parker (1990) or Wilcock and Crowe (2003);
- the submerged specific gravity of the sediment, R;
- the parameter α in eq. (9.iv) that governs the grain size distribution of the sediment at the active layer-substrate interface during bed aggradation.

The text file with the definition of the input parameters and an example of input file are shown in the two windows below.



Key for Inputs.txt

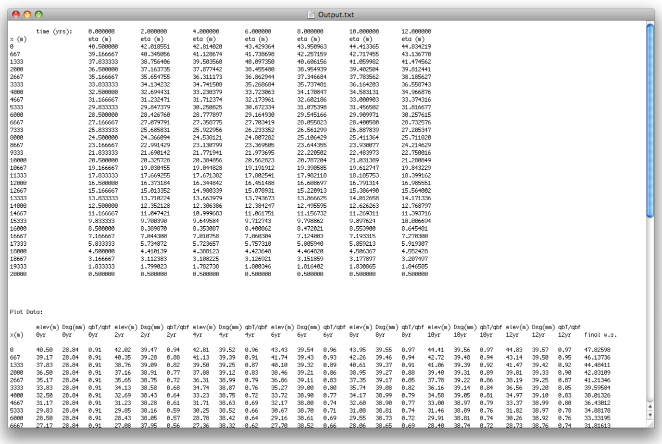
```
q    water discharge/width [m^2/s]
T    gravel input [m^2/s]
I    intermittency
e    base level [m]
S    initial bed slope
L    reach length [m]
t    time step [days]
M    no. of intervals (100 or less)
p    no. of prints
i    no. of iterations per print
k    factor by which Ds90 is multiplied for roughness height
n    factor by which Ds90 is multiplied for active layer thickness
r    coefficient in Manning-Strickler relation
R    submerged specific gravity of gravel
l    bed porosity, gravel
u    upwinding coefficient for load spatial derivatives in Exner equation (>0.5
suggested)
a    coefficient for material transferred to substrate as bed aggrades
C    coefficient, Cf, in the Chezy formulation

Diameter [mm]    GSD Feed        GSD Surface     GSD Substrate
Diameter [mm]    GSD Feed        GSD Surface     GSD Substrate
Diameter [mm]    GSD Feed        GSD Surface     GSD Substrate
                                     .
                                     .
                                     .
Diameter [mm]    GSD Feed        GSD Surface     GSD Substrate

    [exactly 12 different diameters should be entered]
```



test.txt

```
q    10
T    0.001
I    0.1
e    0.5
S    0.002
L    20000
t    7.305
M    30
p    6
i    100
k    2
n    2
r    8.1
R    1.65
l    0.4
u    0.75
a    0.5

256     100     100     100
128     95      95      95
64      80      80      80
32      50      50      50
16      25      25      25
8       10      10      10
4       5       5       5
2       0       0       0
1       0       0       0
0.5     0       0       0
0.25    0       0       0
0.125   0       0       0
```

The output parameters of the model printed in the text file *Output.txt* are the bed elevation, η, the geometric mean diameter of the bed surface, D_{sg}, and the ratio between the bedload transport rate and the feed rate.



Output.txt

time (yrs):	0.000000	2.000000	4.000000	6.000000	8.000000	10.000000	12.000000
x (m)	eta (m)	eta (m)	eta (m)	eta (m)	eta (m)	eta (m)	eta (m)
0	40.500000	42.018551	42.814020	43.429364	43.950963	44.413365	44.834219
667	39.166667	40.345056	41.128674	41.738698	42.257159	42.717455	43.136770
1333	37.833333	38.756406	39.503560	40.097350	40.606156	41.059982	41.474562
2000	36.500000	37.163735	37.877442	38.455480	38.954939	39.402504	39.812441
2667	35.166667	35.654755	36.311173	36.862944	37.346684	37.783562	38.185627
3333	33.833333	34.134232	34.741508	35.268684	35.737481	36.164203	36.558743
4000	32.500000	32.694431	33.230379	33.723063	34.170847	34.583131	34.966876
4667	31.166667	31.232471	31.712374	32.173961	32.602186	33.000903	33.374316
5333	29.833333	29.847379	30.250825	30.672334	31.075398	31.456502	31.816677
6000	28.500000	28.426760	28.777897	29.164930	29.545166	29.909971	30.257615
6667	27.166667	27.079791	27.358775	27.703419	28.055823	28.400580	28.732576
7333	25.833333	25.685831	25.922956	26.233352	26.561299	26.887839	27.205347
8000	24.500000	24.366094	24.538121	24.807282	25.106429	25.411364	25.711820
8667	23.166667	22.991429	23.130799	23.369505	23.644355	23.930077	24.214629
9333	21.833333	21.690142	21.771941	21.973695	22.220502	22.483973	22.750016
10000	20.500000	20.325728	20.384856	20.562823	20.787204	21.031389	21.280849
10667	19.166667	19.030455	19.044828	19.191912	19.390585	19.612747	19.843229
11333	17.833333	17.669255	17.671382	17.802541	17.982118	18.185753	18.399162
12000	16.500000	16.373184	16.344842	16.451488	16.608697	16.791314	16.985551
12667	15.166667	15.013352	14.980339	15.078931	15.220913	15.386490	15.564002
13333	13.833333	13.710224	13.663979	13.743673	13.866625	14.012658	14.171336
14000	12.500000	12.352128	12.306386	12.384247	12.495595	12.626263	12.768797
14667	11.166667	11.047421	10.999683	11.061751	11.156732	11.269311	11.393716
15333	9.833333	9.700390	9.649584	9.712743	9.798862	9.897624	10.006694
16000	8.500000	8.389870	8.353087	8.400862	8.472021	8.553900	8.645481
16667	7.166667	7.044300	7.010758	7.060304	7.124003	7.193315	7.270300
17333	5.833333	5.734872	5.723657	5.757310	5.805940	5.859213	5.919307
18000	4.500000	4.410139	4.388123	4.423648	4.464820	4.506367	4.552428
18667	3.166667	3.112383	3.108225	3.126921	3.151859	3.177897	3.207497
19333	1.833333	1.799023	1.782738	1.800346	1.816402	1.830865	1.846585
20000	0.500000	0.500000	0.500000	0.500000	0.500000	0.500000	0.500000

Plot Data:

x(m)	elev(m) 0yr	Dsg(mm) 0yr	qbT/qbf 0yr	elev(m) 2yr	Dsg(mm) 2yr	qbT/qbf 2yr	elev(m) 4yr	Dsg(mm) 4yr	qbT/qbf 4yr	elev(m) 6yr	Dsg(mm) 6yr	qbT/qbf 6yr
0	40.50	28.84	0.91	42.02	39.47	0.94	42.81	39.52	0.96	43.43	39.54	0.96
667	39.17	28.84	0.91	40.35	39.28	0.88	41.13	39.39	0.91	41.74	39.43	0.93
1333	37.83	28.84	0.91	38.76	39.09	0.82	39.50	39.25	0.87	40.10	39.32	0.89
2000	36.50	28.84	0.91	37.16	38.91	0.77	37.88	39.12	0.83	38.46	39.21	0.86
2667	35.17	28.84	0.91	35.65	38.75	0.72	36.31	38.99	0.79	36.86	39.11	0.83
3333	33.83	28.84	0.91	34.13	38.58	0.68	34.74	38.87	0.76	35.27	39.00	0.80
4000	32.50	28.84	0.91	32.69	38.43	0.64	33.23	38.75	0.72	33.72	38.90	0.77
4667	31.17	28.84	0.91	31.23	38.28	0.61	31.71	38.63	0.69	32.17	38.80	0.74
5333	29.83	28.84	0.91	29.85	38.16	0.59	30.25	38.52	0.66	30.67	38.70	0.71
6000	28.50	28.84	0.91	28.43	38.05	0.57	28.78	38.42	0.64	29.16	38.61	0.69
6667	27.17	28.84	0.91	27.08	37.95	0.56	27.36	38.32	0.62	27.70	38.52	0.66

x(m)	elev(m) 8yr	Dsg(mm) 8yr	qbT/qbf 8yr	elev(m) 10yr	Dsg(mm) 10yr	qbT/qbf 10yr	elev(m) 12yr	Dsg(mm) 12yr	qbT/qbf 12yr	final w.s.
0	43.95	39.55	0.97	44.41	39.56	0.97	44.83	39.57	0.97	47.82598
667	42.26	39.46	0.94	42.72	39.48	0.94	43.14	39.50	0.95	46.13736
1333	40.61	39.37	0.91	41.06	39.39	0.92	41.47	39.42	0.92	44.48411
2000	38.95	39.27	0.88	39.40	39.31	0.89	39.81	39.33	0.90	42.83109
2667	37.35	39.17	0.85	37.78	39.22	0.86	38.19	39.25	0.87	41.21346
3333	35.74	39.08	0.82	36.16	39.14	0.84	36.56	39.20	0.85	39.59584
4000	34.17	38.99	0.79	34.58	39.05	0.81	34.97	39.10	0.83	38.01326
4667	32.60	38.90	0.77	33.00	38.97	0.79	33.37	38.99	0.80	36.43012
5333	31.08	38.81	0.74	31.46	38.89	0.76	31.82	38.97	0.78	34.88178
6000	29.55	38.73	0.72	29.91	38.81	0.74	30.26	38.92	0.76	33.33195
6667	28.06	38.65	0.69	28.40	38.74	0.72	28.73	38.76	0.74	31.81613

The additional parameters that the user may print at times $t_{plot,j}$ in the text file *Output1.txt* are the channel slope, S, the water depth, H, the total bedload transport rate, q_{bT}, the diameter of the bed surface such that 90% of the sediment is finer, D_{s90}, the Shields number, τ^*_{sg}, i.e. the non-dimensional Shields number, defined as

$$\tau^*_{sg} = \frac{\tau_b}{(\rho_s - \rho)gD_{sg}} \tag{9.vi}$$

where τ_b is the bed shear stress, ρ_s and ρ respectively denote the density of the sediment and of the water, g is the acceleration of gravity and D_{sg} is the geometric mean diameter of the bed surface.

An example of the file *Output1.txt* is reported in the windows below.

Output1.txt

	eta(m)	Sl	H(m)	tausg	qbT	dsg(mm)	D90s(mm)
x(m)	12yr	12yr	12yr	12yr	12yr	12yr	12yr
0.0	44.834219	0.002546	2.991764	0.116669	0.000974	39.569752	126.419631
666.7	43.136770	0.002520	3.000591	0.116018	0.000949	39.496145	126.185260
1333.3	41.474562	0.002493	3.009552	0.115385	0.000923	39.417175	125.942750
2000.0	39.812441	0.002467	3.018653	0.114738	0.000898	39.325903	125.692382
2666.7	38.185627	0.002440	3.027837	0.114034	0.000874	39.253100	125.451495
3333.3	36.558743	0.002414	3.037096	0.113396	0.000850	39.198994	125.227017
4000.0	34.966876	0.002388	3.046386	0.112853	0.000825	39.095660	125.006236
4666.7	33.374316	0.002362	3.055806	0.112132	0.000803	38.985453	124.793592
5333.3	31.816677	0.002337	3.065108	0.111356	0.000781	38.967957	124.612108
6000.0	30.257615	0.002313	3.074330	0.110887	0.000759	38.919801	124.434668
6666.7	28.732576	0.002289	3.083552	0.110377	0.000737	38.764440	124.241219
7333.3	27.205347	0.002265	3.092746	0.109538	0.000718	38.699849	124.073092
8000.0	25.711820	0.002243	3.101568	0.108937	0.000699	38.717538	123.933005
8666.7	24.214629	0.002221	3.110269	0.108600	0.000680	38.607627	123.768480
9333.3	22.750016	0.002200	3.118827	0.107973	0.000663	38.480885	123.602667
10000.0	21.280849	0.002180	3.127067	0.107290	0.000648	38.476462	123.469581
10666.7	19.843229	0.002161	3.134835	0.106926	0.000633	38.436492	123.334034
11333.3	18.399162	0.002143	3.142410	0.106520	0.000618	38.322188	123.182082
12000.0	16.985551	0.002126	3.149530	0.105970	0.000606	38.270399	123.048933
12666.7	15.564002	0.002110	3.156179	0.105568	0.000594	38.247072	122.926537
13333.3	14.171336	0.002096	3.162300	0.105267	0.000583	38.178094	122.798766
14000.0	12.768797	0.002083	3.167995	0.104896	0.000574	38.117732	122.675527
14666.7	11.393716	0.002071	3.173018	0.104569	0.000566	38.089082	122.566884
15333.3	10.006694	0.002061	3.177536	0.104325	0.000558	38.050833	122.461389
16000.0	8.645481	0.002052	3.181413	0.104099	0.000552	38.008760	122.363821
16666.7	7.270300	0.002044	3.184756	0.103887	0.000547	37.981310	122.277338
17333.3	5.919307	0.002038	3.187470	0.103733	0.000542	37.958804	122.202247
18000.0	4.552428	0.002034	3.189446	0.103625	0.000539	37.936462	122.139992
18666.7	3.207497	0.002029	3.191394	0.103509	0.000536	37.916469	122.078420
19333.3	1.846585	0.002030	3.190785	0.103554	0.000537	37.917211	122.070483
20000.0	0.500000	0.002020	3.195551	0.103272	0.000530	37.876328	121.947362

Notes:

- In the case of the load relation due to Parker (1990), the grain size distributions are automatically renormalized because the relation is for the transport of gravel only
- In the case of the load relation due to Wilcock-Crowe (2003), the sand and the fine sediment are retained for the computation;
- The user will be prompted by the program as to which bedload relation he would like to use;
- The input grain size distributions may be on a 0-100% or a 0.00-1.00 scale, and the program will automatically scale;
- The input grain size distributions must have bounds at 0% and 100% (1.00) to properly perform the calculation. If the user does not input the bounds the program will automatically interpolate upper and lower bounds D_{bU} and D_{bL} such that f_{fU} = 100 (1.00) and f_{fL} = 0;
- The water depth is calculated using a Chézy formulation, when only the Chézy coefficient is specified in the input text file. The Manning-Strickler formulation is implemented, when only the coefficients α_r and n_k in equations (4.iv) and (4.v) are given in the input text file. When all the three parameters are present, the program will ask the user which formulation they would like to use.

List of variables

x	downchannel coordinate in m
Δx	spatial step length in m
t	temporal coordinate in seconds
k_s	roughness height due to skin friction only in mm
C_f	Manning-Strickler friction coefficient
L_a	thickness of the active layer in m
f_{fi}	fraction of sediment finer than the ith bound diameter
f_i	fraction of sediment in the ith grain size range

INPUT

q_w	flood discharge per unit channel width m^2/s
I_f	flood intermittency
λ_p	bed porosity
S_I	initial bed slope
η_d	bed elevation at the downstream end of the reach in m
q_{bTf}	total bedload input rate per unit channel width in m^2/s
L	length of reach in m
Δt	time step in days
$N_{toprint}$	number of time steps to printout
N_{print}	number of printouts
M	number of spatial intervals
a_u	upwinding coefficient (1=full upwind, 0.5=central difference)
α_r	coefficient in Manning-Strickler formulation
α	parameter in eq. (9.iv) that governs the grain size distribution of the sediment at the active layer-substrate interface during bed aggradation
n_k	coefficient to estimate the roughness height as a function of the D_{s90}
n_a	coefficient to estimate the thickness of the active layer as a function of the D_{s90}
R	submerged specific gravity of the sediment
Cz	non-dimensional Chézy friction coefficient
D_{bi}	bound diameters of the grain size distribution
D_i	characteristic diameters of the grain size distribution defined in eq. (9.ii a)
F_i, f_{subi}, p_i, f_{Ii},	fractions of sediment in the ith grain size range of the bed surface, of the substrate, of the bedload and at the active layer-substrate interface

OUTPUT	
η	bed surface elevation in m
S	bed slope
H	water depth in m
τ_{sg}	Shields number computed with eq. (9.vi)
q_{bT}	total bedload transport rate per unit channel width in m^2/s
q_{bT}/q_{bTf}	ratio between the total bedload transport and the feed rate per unit channel width
D_{sg}	geometric mean diameter of the bed surface in mm
D_{s90}	diameter of the active layer such that the 90% of the sediment is finer in mm

References:

Parker, G., 1990, Surface-based bedload transport relation for gravel rivers, *Journal of Hydraulic Research*, 28(4): 417-436.

Wilcock, P. R., and Crowe, J. C., 2003, Surface-based transport model for mixed-size sediment, *Journal of Hydraulic Engineering*, 129(2), 120-128.

10) AgDegNormGravMixHyd

This program is a close relative of AgDegNormGravMixP. It computes aggradation and degradation in gravel-bed river subject to a repeated hydrograph. The sediment is modeled as mixture of different grain sizes and the bedload formulation is that of Parker (1990) that was derived to compute the transport of gravel only. For a more extensive description of the theory and of the model the user can refer to Chapter 19 "Effect of Hydrograph on Morphology of Gravel-bed Streams" of the e-book.

To perform a numerical calculation with a flow hydrograph, the actual hydrograph must be specified in terms of W constant water discharges Q_w, where w = 1 … W, each extending for time duration Δt_w. The river is assumed to be morphologically inactive when it is not in flood. The morphodynamic evolution is computed solving the equation of sediment continuity (i.e. Exner equation). A short flood time step, Δt_f, is used to solve the Exner equation. It is convenient to choose each time duration Δt_w to be an integer number, $n_{step,w}$, of the flood time step, so that

$$\Delta t_w = n_{step,w} \Delta t_f \tag{10.i}$$

Once Δt_f is specified along with Q_w and $n_{step,w}$ for all the W constant water discharges, it is possible to determine a discharge Q_p for each time step p = 1 … P in the hydrograph, where

$$P = \sum_{w=1}^{W} n_{step,w} \tag{10.ii}$$

The flow is assumed locally normal and it is computed with a Manning-Strickler formulation, eq. (4.iv). No attempt is made to decompose the bed resistance into skin friction and form drag. The roughness height and the active layer thickness are assumed functions of the grain size distribution of the bed surface and they are computed with eqs. (9.v a, b).

Enrica 11/19/2009 2:02 AM
Comment [1]: Andrew, did you also implement a Chezy formulation?
Answer: I did not implement a Chezy formulation…would you like me too? It would just be adding some inputs and adding a line of code to the depth calculation.

Initial conditions are the initial bed profile and the grain size distribution of the bed surface and of the substrate. The initial bed profile, as in AgDegNormGravMixPW, is specified in terms of a constant slope, S_I (S_{fbI} in the excel worksheet *RTe-bookAgDegGravMixHyd.xls*), and a downstream bed elevation, η_d. The grain size distributions of the bed surface and of the substrate are specified in terms of percent finer and n_{pp} bound diameters, D_{bi}, with n_{pp} = 2 ~ 9. All the grain size distributions must be specified with the same n_{pp} bound diameters and the fractions of sediment finer than the bound diameters can be given either on a 0 – 100 or 0 – 1 scale. If the fraction of sediment finer than the lower (upper) bound of the input distributions is grater than zero (100 or 1), the program automatically computes a new lower (upper), D_{bnew}, bound of the distribution such that the fraction of sediment finer than D_{bnew} is equal to 0 (100 or 1). The fraction of sand ($D_{b,i}$ < 2 mm) in the input the grain size distributions has to be removed and the distributions need to be renormalized before starting the calculations.

The upstream boundary condition is given in terms of W values of water discharge, bedload input rate and $n_{step,w}$.