

Adaptive Hydraulics (AdH) Version 4.7.1 Sediment Transport User Manual

A TWO-DIMENSIONAL MODELING SYSTEM DEVELOPED BY THE COASTAL AND HYDRAULICS LABORATORY. Compiled by CHL, with contributions from Aaron Buesing (MVP).

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Abstract: Guidelines are presented for using the US Army Corps of Engineers (USACE) AdH modeling software to model two-dimensional shallow water problems with sediment transport (i.e. AdH linked to SEDLIB). This manual describes the inputs necessary to utilize the SEDLIB sediment transport library from within AdH, to perform coupled hydrodynamic, sediment, and morphological computations.

The SEDLIB sediment transport library is intended to be of general use and, as such, examples are given for basic sediment transport of cohesive, non-cohesive, and mixed suspended sediment loads and bedload.

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Table of Contents

1	Introduction.....	2
1.1	Sign Convention	4
1.2	A note on units	4
1.1	Sediment Transport.....	5
1.2	Files Needed to Run AdH	6
1.3	Specifically for Sediment Modeling	6
1.4	A Note on Units and Sediment Transport in AdH	7
1.5	Control Card Categories	7
2	Operation Parameters.....	11
3	Generic Transport Properties.....	12
3.1	Mesh refinement	12
3.2	Turbulent Diffusion and Dispersion	13
4	Sediment Transport Specific Properties	16
4.1	Definitions and Properties of Coarse Sediment (Sand, Gravel, and Cobble) and Fine Sediment (Silt and Clay)	16
4.2	General Sediment Boundary Condition Input	17
4.3	Boundary Condition Input for Coarse/Non-Cohesive Sediment (Sand, Gravel, and Cobble).....	21
4.4	Boundary Condition Input for Coarse/Non-Cohesive Sediment (Sand, Gravel, and Cobble).....	25
4.5	Boundary Condition Input for Fine/Cohesive Sediment (Silts and Clays)	22
4.6	Converting between bed porosity, wet bulk density, and dry bulk density	27
4.7	Model Protocols for Mixed Sediments (coarse and fine sediments)	28
4.8	Other Features	29
4.8.1	SEDFLUME erosion rate input.....	29
4.8.2	Sediment Dredging and Placement	31
4.8.3	Bed Consolidation	35
4.8.4	No Bed Displacement by Material Type.....	37
4.8.5	Approximation of Local Scour	38
4.8.6	Infiltration of Fine Sediment into Coarse Sediment Beds.....	39
	Water and Sediment Diversions.....	<i>Error! Bookmark not defined.</i>
4.8.7	<i>Error! Bookmark not defined.</i>
5	Sediment Processes.....	42
6	Coupled Vegetation Modeling: SEDLIB-VEG.....	45
7	Running AdH	50
8	References	53
	Appendix A: SEDLIB-VEG Theoretical Development	55

Appendix B: AdH/SEDLIB Boundary Condition and Bed Initialization Tips	59
Appendix C: Morphologic Time-Scaling with Modified Porosity.....	2

1 Introduction

The Adaptive Hydraulics (AdH) code is a finite element, numerical modeling package that can be used to model a wide-range of flow conditions. This includes both saturated and unsaturated 3D groundwater flow, 2D overland flow, 3D Navier-Stokes flow, 3D shallow water flow, and 2D (depth averaged) shallow water flow. However, the information contained in this manual is intended for application to the 2D shallow water flow module only.

AdH can be used in a serial or multiprocessor mode and on various operating systems after appropriate compilation. A single executable is available for multiprocessor and serial on a given operating system but different executables are needed for running on different operating systems.

The adaptive feature of AdH consists of its ability to dynamically refine and relax the spatial resolution (model mesh) and temporal resolution (time step) such that both model stability, accuracy and performance are optimized.

The ability of AdH to allow the domain to wet and dry as flow conditions or water surface elevations change is suitable for shallow marsh environments, beach slopes, floodplains, and the like.

AdH can simulate subcritical, transcritical, and supercritical flow conditions within the same domain. Boundary conditions can also be specified for both supercritical and subcritical conditions.

AdH can simulate several special conditions that are pertinent to many common shallow water problems, including vessel movement, ice cover, the influence of training structures and bridge decks, the influence of culvert entrances, and the presence of flow control structures such as weirs, flap and sluice gates, etc.

AdH can simulate the transport of conservative tracers, vorticity, heat, salinity, and non-cohesive and cohesive sediment that is coupled to bed and hydrodynamic changes.

AdH is developed and maintained at the Coastal and Hydraulics Laboratory (CHL) and has been used to model such varied conditions as sediment transport in sections of the Mississippi River (Heath et al., 2015; Sharp et al., 2013), tidal conditions in southern California (Tate et al., 2009), vessel traffic in the Houston Ship Channel (Tate and Ross,

2009), dam breaks (Savant et al., 2011), large scale terrestrial flooding (Tate et al. 2012), and numerous other situations.

In General, AdH-2D can be applied to problems such as the following:

- 1) Subcritical riverine or channel flows
- 2) Supercritical riverine or channel flows
- 3) Tidal flows
- 4) Dam and levee break flows
- 5) Flooding due to overland flow conditions: urban and others
- 6) Baroclinic transport (salinity, heat, as well as sediment induced)
- 7) Sediment transport

The code is designed to work in conjunction with the DoD Modeling Systems (XMS), developed and distributed by Aquaveo, Inc. The Surface Water Modeling System (SMS) is a modeling package for building models, running simulations, and visualizing results. However, the model setup and results can be performed through many different tools as long as the file formats are correct.

Additional information on AdH can be obtained at the AdH website, <https://www.erdc.usace.army.mil/Locations/CHL/AdH/>. The basic 2D shallow water equations and their formulation in AdH are provided in Savant et al. 2020.

Sign Convention

The sign convention in AdH is the standard Cartesian coordinate system and flow into the control volume is positive.

A note on units

AdH is designed so that the user can specify the unit system to use. However, all parameters must be consistent in that they are all given in English units or SI units and not mixed.

SI units must be used for sediment transport simulations since the equations employed in SEDLIB are valid for SI units only. English or SI units can be used for simulations not involving sediment transport.

The geometry file, boundary condition file, and hotstart file must all be given in the same unit system. There is no card that directly specifies the units being used. Rather, AdH uses the values given and calculates with them. If any equations internal to AdH are unit specific, the density or gravity terms are used to decipher which system is being used.

This manual will give unit specifications where necessary in dimensional form.

1.1 Sediment Transport

AdH allows the user to calculate the transport of non-cohesive sediment, cohesive sediment, and mixed sediments. The model is capable of running multiple grain sizes in a single simulation. These computations are performed through a link with SEDLIB.

SEDLIB is a sediment transport library. It is capable of solving problems consisting of multiple grain classes, non-cohesive, and cohesive sediment types, and multiple layers. It calculates erosion and deposition processes simultaneously, and simulates such bed processes as armoring, consolidation, and discrete depositional strata evolution.

The SEDLIB library system is designed to link to any appropriate hydrodynamic code (e.g., AdH). The hydrodynamic code must be capable of performing advection diffusion calculations for a constituent. SEDLIB interacts with the parent code by providing sources and sinks to the advection diffusion solver in the parent code. The solver is then used to calculate suspended load transport (for silt and clay classes), both bedload and suspended load transport (for sand classes) and bedload transport (for gravel and cobble classes), for each grain class. The sources and sinks are passed to the parent code via a source/sink bed sediment flux, for both suspended load and bedload.

The sediment is transported separately as suspended load and bedload. Each grain class is transported as a moving constituent. So, in making a sediment transport calculation, one must determine how many grain classes are going to be modeled. Sediment calculations also depend on the number of layers used to define the bed strata, as well as how the sediment is distributed within the bed. Sediment modeling requires much more site specific data for the model set up than does hydrodynamic modeling alone. Also, small changes in these parameters can lead to large changes in the solutions, since morphologic change is the time-integrated result of everything that has happened before.

The AdH and SEDLIB developers recommend that anyone using AdH and SEDLIB to model sediment transport be familiar with the basic principles of both sediment transport and of numerical modeling. Large amounts of observed data and analysis are often needed when attempting to develop and validate a sediment transport model of a field site with any numerical model, and AdH is no exception. Please take your time when setting up your model and make all necessary sensitivity simulations to ensure that you fully understand the dynamics of the system and the driving forces. Without such careful analysis, it is easy to draw false conclusions from the model results, and hence provide misleading information to your sponsors. A good rule of thumb is this: if you cannot explain it, you don't understand it.

1.2 Files Needed to Run AdH

The same three input files necessary to run AdH are also needed when sediment is included. No additional files are required. The three files are the mesh file (*filename.3dm*), the boundary condition file (*filename.bc*), and the hotstart file (*filename.hot*), where *filename* is the root of the model's filenames. All three files must have the same *filename*. As an example, if *filename* is *pl8_AdH*, the following three files would be required: *pl8_AdH.3dm*, *pl8_AdH.hot*, and *pl8_AdH.bc*

The mesh file must be constructed first and can be generated directly with GMS (2D or 3D) or SMS (2D).

Once a mesh file has been constructed, the boundary conditions for the problem and operating parameters for AdH must be specified in the boundary condition file.

The hotstart file is then generated to establish the initial conditions of the problem.

Once the three required files have been created, first run *pre_AdH* to create the necessary input file for AdH. Then run AdH. The commands are:

```
pre_adh filename  
adh filename
```

After the model is run, GMS or SMS can be used to visualize the results.

1.3 Specifically for Sediment Modeling

When running AdH with sediment transport, there are a few required changes to some of the mandatory cards. Additional sediment specific cards are also required in order to model suspended and bedload sediment.

The mesh file can remain unchanged unless material designations need to be modified to match bed layer definitions. The hotstart file can also remain unchanged unless the initial conditions need to include concentrations or other sediment specific initial conditions, or unless one is hotstarting a sediment transport simulation, in which case all the relevant sediment parameters must be included in the hotstart file. These will be discussed in the hotstarting section.

Most of the modifications for sediment transport modeling will occur in the boundary condition files. This manual will describe the changes that must occur to a previously generated set of input files (such as for a hydrodynamic simulation) along with all the options for modeling sediment in AdH using SEDLIB.

1.4 A Note on Units and Sediment Transport in AdH

Although one can use any consistent units convention to run AdH without SEDLIB, SI units are required for modeling sediment transport. Specifically, all length quantities are given in meters, and all mass quantities are given in kilograms. This is done to avoid complex conversions between the inconsistent units that are associated with many of the typical sediment transport related quantities. These conversions can result in inadvertent errors and unnecessary confusion. To avoid these difficulties, AdH with SEDLIB is run in SI units, and the user can convert outputs to whatever convention they desire.

The one partial exception to the SI unit convention for AdH/SEDLIB is the units of concentration. For AdH/SEDLIB, concentration is given in units of micromass per unit mass, or parts per million by mass (ppm). Parts per million by mass is herein defined as 1,000,000 times the mass of sediment divided by mass of the suspension .

In SI units, 1 cubic centimeter of water happens to weigh 1 gram. Because of this, for relatively low sediment concentrations (such as those we typically model), ppm is essentially equal to mg/l. Hence, although the concentrations given for AdH may be expressed in terms of mg/l, which has units of mass per volume, the actual dimensions of concentration used in AdH are dimensionless (i.e. mass per unit mass, times 1,000,000).

1.5 Control Card Categories

The sediment control cards listed here are in addition to those required to run hydrodynamics only. These cards include some that are necessary to run any constituent (each sediment grain class is a separate constituent) and some that are necessary to run sediment. There are also several cards that are optional. In order to help clarify which cards are necessary and which are optional for sediment transport calculations, required cards are annotated with comments in red capitalized italic text, and optional cards are annotated with comments in green capitalized italic text. The sediment control cards and their categories are:

Operation Parameters

OP TRN

Transport Constituents *REQUIRED*

Sediment Constituent Properties

<u>CN CLA</u>	Fine Sediment (Clay, Silt) <i>REQUIRED FOR SILT AND CLAY TRANSPORT</i>
<u>CN SND</u>	Coarse Sediment (Sand, Gravel, Cobble) <i>REQUIRED FOR SAND GRAVEL, AND COBBLE TRANSPORT</i>

Material Properties

<u>MP TRT</u>	Transport Refinement Tolerance (Transport Constituent Property) <i>REQUIRED</i>
<u>MP NBL</u>	Number of Bed Layers (Constant for all nodes) <i>REQUIRED</i>
<u>MP SBA</u>	Bed layer distribution applied to all nodes <i>REQUIRED (ALTHOUGH CAN BE APPLIED BY NODE OR MATERIAL TYPE INSTEAD)</i>
<u>MP SBN</u>	Bed layer distribution applied to selected nodes <i>REQUIRED (SEE ABOVE)</i>
<u>MP SBM</u>	Bed layer distribution applied by material <i>REQUIRED (SEE ABOVE)</i>
<u>MP CBA</u>	Cohesive bed sediment applied to all nodes <i>OPTIONAL (ALTHOUGH CAN BE APPLIED BY NODE OR MATERIAL TYPE INSTEAD)</i>
<u>MP CBN</u>	Cohesive bed sediment properties applied to selected nodes <i>OPTIONAL (SEE ABOVE)</i>
<u>MP CBM</u>	Cohesive bed sediment properties applied by material <i>OPTIONAL (SEE ABOVE)</i>
<u>MP NCP</u>	Number of consolidation time intervals <i>OPTIONAL</i>
<u>MP CPA</u>	Consolidation properties applied to all nodes <i>OPTIONAL (ALTHOUGH CAN BE APPLIED BY NODE OR MATERIAL TYPE INSTEAD)</i>
<u>MP CPN</u>	Consolidation properties applied to selected nodes <i>OPTIONAL (SEE ABOVE)</i>
<u>MP CPM</u>	Consolidation properties applied by material <i>OPTIONAL (SEE ABOVE)</i>
	Toggle off bed displacement for all nodes <i>OPTIONAL (ALTHOUGH CAN BE APPLIED BY MATERIAL TYPE INSTEAD)</i>
<u>MP NDM</u>	Toggle off bed displacement by material type <i>OPTIONAL (SEE ABOVE)</i>
<u>MP LSM</u>	Local scour imposition by material type <i>OPTIONAL</i>
<u>MP BLD</u>	Bedload diffusion scale factor <i>OPTIONAL</i>
<u>MP DRD</u>	Dredge by material type <i>OPTIONAL</i>
<u>MP DRP</u>	Dredge Placement by material type <i>OPTIONAL</i>

Sediment Process Controls

<u>SP NSE</u>	Non-cohesive Suspended Sediment Entrainment <i>OPTIONAL: DEFAULT WILL BE USED IF NOT INVOKED</i>
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<u>SP NBE</u>	Non-cohesive Bedload Sediment Entrainment <i>OPTIONAL: DEFAULT WILL BE USED IF NOT INVOKED</i>
<u>SP HID</u>	Non-cohesive Hiding Factor <i>OPTIONAL: DEFAULT WILL BE USED IF NOT INVOKED</i>
<u>SP CSV</u>	Concentration Dependent Cohesive Settling Velocity <i>OPTIONAL</i>
<u>SP WWS</u>	Bed Shear Stress due to Wind waves <i>OPTIONAL</i>
<u>SP SIF</u>	Bed sediment infiltration of fines <i>OPTIONAL</i>
<u>SP NST</u>	Pause sediment transport for a specified time window <i>OPTIONAL</i>
Solution Controls	
<u>DB TRN</u>	Dirichlet – Transport <i>OPTIONAL</i>
<u>NB TRN</u>	Natural – Transport <i>OPTIONAL</i>
<u>EQ TRN</u>	Equilibrium Coarse Sediment Transport Boundary <i>OPTIONAL</i>
Vegetation Model Controls	
<u>VEG</u>	Vegetation model basic parameters <i>OPTIONAL</i>
<u>MP VGM</u>	Vegetation Model properties by material type <i>OPTIONAL</i>

1.6 Sediment Grain Sizes

While any sediment classification system can be used to define the grain sizes modeled, the American Geophysical Union (AGU) sediment classification system is recommended and provided in the table below. The geometric mean is recommended for the modeled grain diameter.

SEDIMENT MATERIAL	SIZE RANGE (mm)	Geometric Mean (m)
Coarse Clay	0.0020 - 0.0040	0.00000283
Very Fine Silt	0.0040 - 0.0080	0.00000566
Fine Silt	0.0080 - 0.0160	0.0000113
Medium Silt	0.0160 - 0.0320	0.0000226
Coarse Silt	0.0320 - 0.0625	0.0000447
Very Fine Sand	0.0625 - 0.125	0.0000884
Fine Sand	0.125 - 0.25	0.000177
Medium Sand	0.25 - 0.5	0.000354
Coarse Sand	0.5 - 1	0.000707
Very Coarse Sand	1 - 2	0.00141
Very Fine Gravel	2 - 4	0.00283

Fine Gravel	4 - 8	0.00566
Medium Gravel	8 - 16	0.0113
Coarse Gravel	16 - 32	0.0226
Very Coarse Gravel	32 - 64	0.0453
Small Cobbles	64 - 128	0.0905
Large Cobbles	128 - 256	0.181
Small Boulders	256 - 512	0.362
Medium Boulders	512 - 1024	0.724
Large Boulders	1024 - 2048	1.448

2 Operation Parameters

The number of transported constituents is given on an OP TRN card. The OP TRN card is a required input card. If the problem does not involve transport, zero (0) is specified on the OP TRN card. If 2 sediment classes and salinity are being modeled, then three (3) will be specified on the OP TRN card.

In addition, if transport equations are not being modeled, no transport properties or boundary conditions should be specified. An error message will be displayed if transport properties are included in the input file but no transport constituents have been specified.

The following card specifies one transported constituent:

OP TRN 1

Operation parameter cards

OP TRN

TRANSPORT CONSTITUENTS

Field	Type	Value	Description
1	char	OP	Card type
2	char	TRN	Parameter
3	int	≥ 0	Total number of transported constituents [vorticity, heat, salinity, coarse/non-cohesive sediment (cobble, sand, gravel), and fine/cohesive sediment (silt, clay)]

3 Generic Transport Properties

Material properties are used to define features and parameters associated with a collection of elements in the model domain, as defined in the mesh file. Material property cards begin with **MP** and are followed by specific card indicators. Some **MP** cards are used for hydrodynamics and others are specific to sediment transport.

3.1 Mesh refinement

Mesh refinement is defined on the **MP ML** card for both hydrodynamic and sediment models. An **MP TRT** card is required to define the tolerance for the sediment adaption. A transport refinement tolerance is required for all transport constituents for all materials. Just as with hydrodynamics, if the transport solution error on an element exceeds the transport refinement error tolerance given on the **TRT** card, the element is split. This card is only a tolerance, however. The material must be set to allow refinement in order for any adaption to occur.

In AdH, the error is defined in terms of the root mean square of the mass conservation residual at each node in the element. This technique indicates which elements require more resolution in order to properly resolve local gradients. More details on the error indicator can be found in Tate et al (2006).

The error indicator for (sediment) concentration is expressed mathematically as follows:

$$K_j = \sum_{i=1}^{i=n_j} \left(h_i \frac{\partial c_i}{\partial t} + u_i h_i \frac{\partial c_i}{\partial x} + c_i h_i \frac{\partial u_i}{\partial x} + v_i h_i \frac{\partial c_i}{\partial y} + c_i h_i \frac{\partial v_i}{\partial y} \right)^2 \quad (1)$$

$$E_j = A_j \sqrt{K_j} \quad (2)$$

Where j is the element number, i is a counter for the nodes in element j, n_j is the total number of nodes in element j, A_j is the surface area of element j, c is the constituent (e.g. sediment) concentration, h is the water depth, u is the x-velocity, v is the y-velocity, and E_j is the transport solution error associated with element j.

In models with transport, the larger of the hydro error or the transport error will determine each element's value in the *project_name_err.dat* file. It is this value that is used to determine whether or not an element is refined or relaxed. The value given in the *project_name_err.dat* file is normalized by the refinement tolerance. This means that values

greater than 1 can be interpreted as locations where the error exceeds the refinement tolerance.

Some users prefer to examine the error results for each transported constituent separately. To facilitate this, the hydrodynamic and transport errors are stored separately in files labeled as such: *project_name_err_hydro.dat* and *project_name_err_con#.dat*. The values stored in these files are not normalized by the refinement tolerance: they are the actual computed values of error.

The unrefine tolerance is currently set within the code as 10 percent of the refine tolerance for both flow conditions and transport conditions. When the grid solution error improves, the elements are recombined, although never coarser than the original mesh.

During normal model operations, the solutions are always saved to the original (coarse) mesh. This means that the user will not see the adapted mesh, even though the solutions that are shown are computed on the adapted mesh. If the user desires to see the adapted mesh, he/she can invoke the **PC ADP** card (see below).

The following is an example of how to set the adaption parameters. For this case, for material type 1, a maximum of 5 levels of adaption are permitted (i.e. the individual elements can be split 5 times). For material type 1, the refinement tolerance for constituent 1 is 100, and the refinement tolerance for constituent 2 is 50.

```
MP ML  1 5
MP TRT 1 1 100
MP TRT 1 2 50
```

Different material types can have different levels of refinement. Some experimentation with the error tolerance is usually necessary to gain the desired level of refinement. If desired, the adapted meshes can be output during the simulation by including a **PC ADP** card. By including this card, the mesh and associated solution files will be saved at the time step intervals specified on the output control card. The output files will be named like so: “filename.3dm-timestep#.o”, “filename.dep-timestep#.o”, “filename.ovl-timestep#.o” which is a geometry file for each time step, the depths for each time step, and the velocities for each time step.

3.2 Turbulent Diffusion and Dispersion

Diffusion and dispersion are handled with the eddy viscosity cards and must be defined for every material with either an **MP EEV** or **MP EVS** card (see the AdH Hydrodynamic User Manual). When using either the **MP EEV** or the **MP EVS** option for eddy viscosity, the diffusion is computed based on the parameters provided on those cards. (Note that

vorticity induced dispersion is also active when vorticity transport is active). If the user wishes to override these diffusion values for a specific constituent and/or material type, the **MP DF** card can be invoked. Also, an optional **MP BLD** card can be invoked to scale the bedload diffusion, if desired.

Material property cards

MP ML

REFINEMENT LEVELS

Field	Type	Value	Description
1	char	MP	Card type
2	char	ML	Parameter
3	int	≥ 1	Material type ID number
4	int	≥ 0	Maximum number of refinement levels

MP TRT

TRANSPORT CONSTITUENT REFINEMENT TOLERANCE

Field	Type	Value	Description
1	char	MP	Card type.
2	char	TRT	Parameter.
3	int	≥ 1	Material type ID number
4	int	≥ 1	Constituent ID number
5	real	≥ 0	Error tolerance for refinement terms

MP DF

TURBULENT DIFFUSION RATE

Field	Type	Value	Description
1	char	MP	Card type
2	char	DF	Parameter
3	int	≥ 1	Material type ID number
4	int	> 0	Constituent ID number
5	real	≥ 0.0	Turbulent diffusion rate

MP BLD

BEDLOAD DIFFUSION

Field	Type	Value	Description
1	char	MP	Card type
2	char	BLD	Parameter

3	int	≥ 0	Material type ID number
4	int	≥ 0	Bedload diffusion constant K_{BL} (default = 1.0)

The bedload diffusion is computed as follows:

$$D_{BL} = 2.5K_{BL}hu_*$$

Where D_{BL} is the bedload diffusion, K_{BL} is the bedload diffusion constant (default = 1.0), h is the water depth, and u_* is the shear velocity.

4 Sediment Transport Specific Properties

In addition to the general transport properties that are provided above, many properties are required for the sediment definitions within the AdH input files. These properties include details to define the grain properties (such as grain size and porosity) the bed layering (such as layer thickness and grain distributions) and the sediment processes (such as the entrainment function).

4.1 Definitions and Properties of Coarse Sediment (Sand, Gravel, and Cobble) and Fine Sediment (Silt and Clay)

In SEDLIB, coarse sediments (sands, gravels and cobbles) are defined as sediment classes with a grain diameter greater than $63 \times 10^{-6} \text{ m}$ ($1 \times 10^{-6} \text{ m} = 1 \text{ } \mu\text{m} = 1 \text{ micron}$). Fine sediments (silts and clays) are defined as sediment classes with a grain diameter less than $63 \text{ } \mu\text{m}$.

Sediment beds consisting of only coarse sediment classes are essentially non-cohesive. That is, the sediment grains are of a large enough size that the electrostatic forces between the particles are very small relative to gravitational, inertial, and viscous forces, and are therefore negligible. This means that coarse grains tend to both deposit and to erode grain-by-grain; hence the erosional and depositional properties of coarse sediment can be defined purely as grain properties. The transport of coarse sediments can occur as either bedload transport (particles hopping, rolling, or sliding along the bed, typically forming moving bedforms), or suspended bed material load transport (particles injected into the flowfield, subjected to turbulent fluctuations, and translating multiple dune-lengths downstream before making contact with the bed again). Most coarse classes can be modeled as bedload or suspended load (suspended bed material load), or (as is most often the case) both. However, for simplicity, SEDLIB transports grains with a diameter greater than $2500 \text{ } \mu\text{m}$ as bedload only (the transport equations that are typically used to describe the transport of sediments coarser than this are bedload or total load equations, so for simplicity their movement is lumped into one mode of transport).

Fine sediment beds consist of silt and clay classes. The smallest of the fine sediment classes, consisting of grains with a grain diameter of $3.9 \text{ } \mu\text{m}$ or finer, are clays. Clays are considered fully cohesive classes. Cohesive sediment is sediment that is of such a small size that the electrostatic forces between particles become significant (relative to gravitational, inertial, and viscous forces).

Grains with a diameter greater than $3.9 \text{ } \mu\text{m}$ but smaller than $63 \text{ } \mu\text{m}$ are considered silts. Silts are also cohesive, but in AdH/SEDLIB, their cohesiveness is assumed to reduce in proportion to their size (i.e. coarser silts are less cohesive than finer silts).

Cohesive sediment behaves differently than non-cohesive sediment. Cohesiveness can cause flocculation of settling sediments, thus altering the depositional behavior. Cohesiveness also results in erosion behavior that is more generally a property of the condition of the sediment bed than a property of the individual grains. In SEDLIB, the transport of fine sediments is modeled as suspended load only (i.e. sediment suspended into the water column, that does not make contact with the bed again unless the shear stress drops below some user-defined critical value).

In rivers, fine sediment transport is often referred to colloquially as “wash-load”, meaning that the fines are not typically found in the bed material samples. However, even in rivers, fine sediments can settle in quiescent backwaters. In estuaries and reservoirs, the behavior of fine sediments is typically much more complex, and the “wash-load” paradigm is much less relevant.

When coarse and fine sediment classes are mixed together in the sediment bed, the behavior becomes even more complex. A bed consisting of both non-cohesive and cohesive sediment classes may exhibit non-cohesive or cohesive behavior, depending on the fraction of silt and clay classes that are present in the mixture. The behavior of mixed non-cohesive and cohesive sediment beds is discussed in more detail in section 4.5.

4.2 General Sediment Bed Initialization Input

The following card descriptions are for general parameters that are applicable for any sediment simulation. Subsequent sections will describe parameters needed for specific sediment types.

The number of bed layers is given with the **MP NBL** card. This card requires the number of layers and a bed layer thickness assignment protocol flag. A bed layer thickness assignment protocol value of 0 indicates that the **MP SBx** (where ‘x’ will be either ‘A’, ‘M’ or ‘N’) card must specify the bed layer thickness. A bed layer thickness assignment protocol value of 1 indicates that the **MP SBx** card must specify the bottom elevation of each bed layer.

The **SBx** card defines the grain class fraction of each sediment class within the individual bed layers (i.e. the grain class distribution). After the layer number (where layer 1 is the deepest layer, and the maximum layer number is the layer at the bed surface), the thickness and grain class distribution for that layer are listed. This distribution can be given by individual node (**SBN**), by material type (**SBM**), or for all nodes at once (**SBA**). Note that the model overwrites any prior designation with subsequent information for the same location, so for convenience one could specify an **SBA** card first, followed by a few material types, followed by individual nodes.

An example is given below. For two layers and 3 grain classes we might have the following:

```
MP NBL 2 0
MP SBA 1 0.5 0.0 0.4 0.6
MP SBA 2 0.5 0.4 0.3 0.3
```

The **MP NBL** card tells AdH to expect two bed layers to be defined on the sediment bed fraction cards and that thickness magnitude will be specified directly (bed layer thickness assignment protocol = 0). **MP SBA** means that the sediment bed description for all nodes will be used. The next number is the layer number, followed by the layer thickness. The final three numbers are the fractions of each of the sediments shown in the **CN SND** cards. In this example, there are three sediment grains and two layers. Layer 1 is the deepest (or bottom) layer, and layer 2 is the top layer.

Note that the sediment grain distribution must sum to exactly 1 for each assigned bed layer.

If desired, individual materials and/or nodes can now be designated with **SBM** or **SBN** cards, and these nodes would be modified to reflect the difference.

Note that it is often desirable to have several layers of zero thickness specified at the bed surface (i.e. the highest layer numbers). These are used by the model as depositional layers, each one storing information from discrete depositional events, and thereby generating new strata in the bed.

When using the bed layer thickness assignment protocol = 1, the bed layer thickness is computed based on the elevation of each node. The bed layer thickness is zero if the bed elevation is below the bottom elevation of the layer. The bed layer thickness is the difference between the bed elevation and the bottom elevation of the layer if the bed elevation is below the bottom elevation of next layer above. The bed layer thickness is the full thickness of the layer if the bed elevation is above the bottom elevation of the next layer above.

The elevation horizon option functions as follows:

For layer n, the thickness of the layer is equal to:

$$t_n = \text{MAX} \left[\left(\text{MIN}(\eta_{n+1}, \eta_{bed}) - \eta_n \right), 0 \right] \quad (3)$$

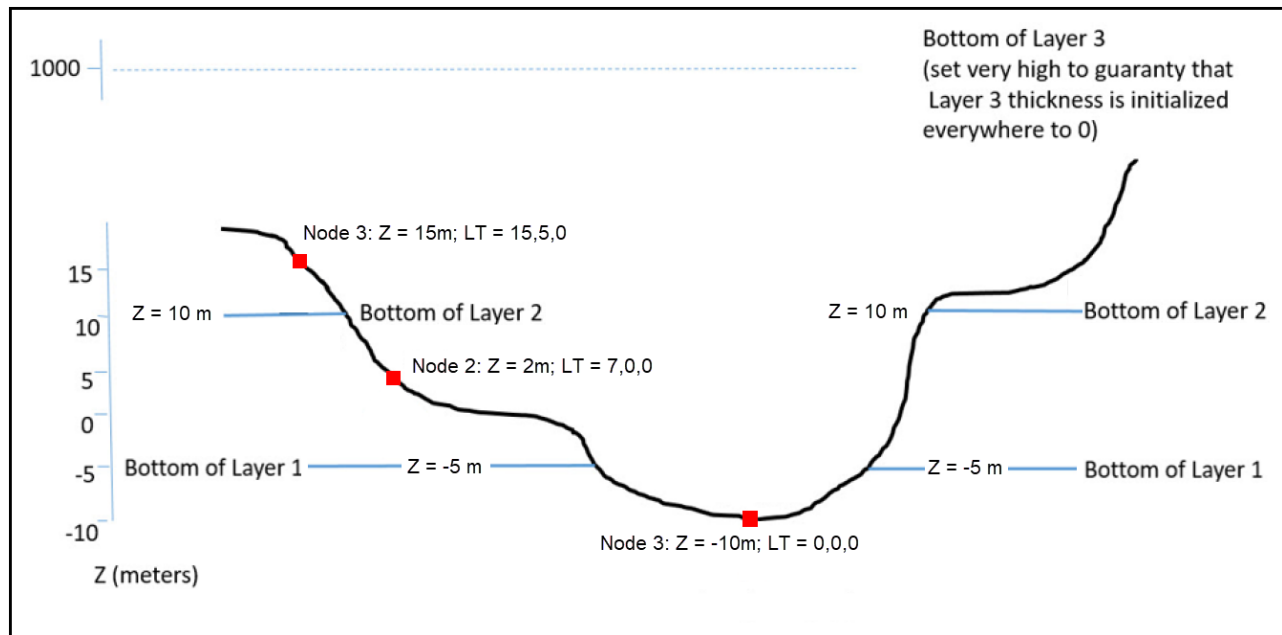
Where η is elevation.

For example, the following layers are defined (with one grain for simplicity):

MP NBL 3 1
SBA -5 1.0
SBA 10 1.0
SBA 1000 1.0

The code will then look at the z coordinate for each node and assign layer thicknesses. If node 1 has a z coordinate of -10 this elevation is below the deepest defined elevation on the cards so all three layers will have zero thicknesses. For node 2 with a z coordinate of 2, the layer thicknesses are 7, 0, and 0. For node 3 with a z coordinate of 15, the layer thicknesses are 15, 5, and 0. See Figure 1 for an illustration of the specification of nodes 1-3, where “LT” stands for “layer thickness.”

Figure 1. Illustration of layer thickness specification using bed layer thickness assignment protocol = 1



Note that, when using this layer thickness protocol, the best way to define zero thickness layers is to assign a large number (such as 1000) to the elevation horizon of the layer, such that the number chosen is large enough that no elevation in the domain exceeds it.

MP NBL

NUMBER OF SEDIMENT BED LAYERS

Field	Type	Value	Description
1	char	MP	Card type
2	char	NBL	Parameter
3	int	≥ 0	Number of bed layers for sediment transport (layer number begins with the bottom-most layer)
4	int	0 or 1	Bed layer thickness assignment protocol 0 = bed layer thickness assigned directly on SB cards 1 = bed layer thickness assigned by sediment layer bottom elevation on SB cards

The sediment layer bottom elevation option functions as follows:

For layer n , the thickness of the layer is equal to: $t_n = \text{MAX} \left[\left(\text{MIN}(\eta_{n+1}, \eta_{bed}) - \eta_n \right), 0 \right]$

Where η is elevation

Note that if the user desires to implement spatially explicit bed initialization (e.g. if the user has access to spatial data concerning bed thicknesses etc.) this can be accomplished by editing the initial hotstart file. This is discussed further in section ???.

MP SBA

SEDIMENT BED INITIALIZATION APPLIED TO ALL NODES

Field	Type	Value	Description
1	char	MP	Card type
2	char	SBA	Parameter
3	int	> 0	Bed layer ID number
4	real	≥ 0.0	Bed layer thickness or sediment layer bottom elevation
5	real	≥ 0.0	Grain class fraction for the first sediment
6	real	≥ 0.0	Grain class fraction for the second sediment
#	real	≥ 0.0	Grain class fraction for the final sediment.

MP SBM

SEDIMENT BED INITIALIZATION APPLIED BY MATERIAL

Field	Type	Value	Description
1	char	MP	Card type
2	char	SBM	Parameter
3	int	> 0	Bed layer ID number
4	int	> 0	Material type ID number
5	real	≥ 0.0	Bed layer thickness or sediment layer bottom elevation
6	real	≥ 0.0	Grain class fraction for the first sediment
7	real	≥ 0.0	Grain class fraction for the second sediment
#	real	≥ 0.0	Grain class fraction for the final sediment

MP SBN

SEDIMENT BED INITIALIZATION APPLIED TO SELECTED NODES			
Field	Type	Value	Description
1	char	MP	Card type
2	char	SBN	Parameter
3	int	> 0	Bed layer ID number
4	int	> 0	Node number from which to start
5	int	> 0	Node number at which to end
6	real	≥ 0.0	Bed layer thickness or sediment layer bottom elevation
7	real	≥ 0.0	Grain class fraction for the first sediment
8	real	≥ 0.0	Grain class fraction for the second sediment
#	real	≥ 0.0	Grain class fraction for the final sediment

4.3 Sediment Grain Characteristics Input Specifically for Coarse/Non-Cohesive Sediment (Sand, Gravel, and Cobble)

The non-cohesive nature of coarse sediment allows both the erosional and depositional characteristics of coarse sediment to be assigned or determined by grain size. AdH requires the assignment of grain diameter, specific gravity, and porosity for coarse sediment. These are supplied via the **CN SND** cards. **SND** stands for sand, although sand, gravel and cobble grain sizes are specified with this card. . Here is an example:

CN SND 1 1.0 1.E-4 2.65 0.3

CN SND 2 1.0 5.E-4 2.65 0.3

CN SND 3 1.0 1.E-3 2.65 0.3

Beginning after the **CN SND** are the constituent number, the reference concentration for this grain class, grain diameter, the specific gravity, and the porosity. Note that the reference concentration, like all sediment concentrations given in AdH, is in units of micro-mass per unit mass, or parts per million by mass (ppm). The reference concentration is commonly specified as 1 ppm, but one can also use any typical value of the suspended sediment concentration that is characteristic for the site being modeled.

CN SND

NON-COHESIVE SEDIMENT (SAND)			
Field	Type	Value	Description
1	char	CN	Card type
2	char	SND	Parameter
3	int	≥ 1	Constituent ID number
4	real	> 0	Characteristic concentration
5	real	> 0	Grain diameter

6	real	> 1	Specific gravity
7	real	> 0	porosity for newly deposited sediment

4.4 Sediment Grain and Bed Characteristics Input Specifically for Fine/Cohesive Sediment (Silts and Clays)

Since cohesive sediment has sediment transport properties that are associated with the bed as well as with the individual grains, boundary condition input cards are needed for both.

Because of the cohesive behavior of fine sediment, it is necessary to define the erosional characteristics of the existing sediment bed independently of the general characteristics of the individual fine grains.

There are also erosional characteristics assigned to the individual grains, but they serve a specific purpose. These grain-specific erosion characteristics are needed in order to define the properties of any newly deposited sediment layer: that is, the erosional characteristics of a sediment layer that is deposited only after the model simulation has commenced.

Both the depositional characteristics and the erosional characteristics of *newly deposited* cohesive sediment are given on the **CN CLA** card (**CLA** stands for clay, although both clay and silt are specified with this card). The erosional characteristics of the existing sediment bed are given on the cohesive bed (**MP CB**) cards.

The **CLA** in the **CN CLA** card stands for clay, but this card is used for both silt and clay grain diameters.

The parameters given on the **CN CLA** card are:

- Grain diameter
- Specific gravity
- Bed porosity (new deposit)
- Critical shear stress for erosion (new deposit) (τ_c)
- Erosion rate constant (new deposit) (M)
- Critical shear stress for deposition
- User-specified settling velocity

Note that cohesive sediments tend to flocculate (stick together) under certain flow and sediment conditions, and hence their effective settling velocity can vary significantly with time and space. Flocculation is, in general, a very complex process. In SEDLIB, there are currently limited methods of simulating this process.

The simplest method is just the explicit assignment of constant settling velocities on the **CN CLA** cards that are associated with floc settling rates rather than grain settling rates. The other method is invoked with the **SP CSV** card.

The erosion of cohesive sediment that either was part of the original bed or has been deposited long enough that it has become like the original bed is controlled by the **MP CB** card.

The inputs to the **MP CB** cards include the following:

- Layer number
- Bed porosity
- Critical shear stress for erosion (τ_c)
- Erosion rate constant (M)
- Erosion rate exponent (n).

The erosion properties specified on **CN CB** card and the **CN CLA** card are used to solve the erosion flux equation (Alishahi and Krone, 1964):

$$F_E = M \left(\frac{\tau}{\tau_c} - 1 \right)^n \quad (4)$$

Where F_E is the erosion flux, M is the erosion rate constant, n is the erosion rate exponent, and τ_c is the critical shear stress for erosion. Note that the erosion rate exponent (n) is assumed to be equal to 1 for newly deposited sediment (this is consistent with the observation of Parthenaides).

The erosional characteristics of the existing sediment bed are (in general) highly site specific, and ample data must be collected to define coefficients that are appropriate for a given site. While the characteristics of the grain diameter are (in general) less site specific than the characteristics of the existing sediment bed, the grain characteristics are still best determined by local observations.

The following are examples of **CLA** cards for 2 fine sediment grains.

CN CLA 1 1.0 0.000001 2.65 0.88 0.014 0.00016 0.01 0.00006
CN CLA 2 1.0 0.00001 2.65 0.75 0.02 0.00018 0.015 0.00016

The reference concentration, like all sediment concentrations given in AdH is in units of micromass per unit mass, or ppm by mass.

In addition to these grain definitions, cohesive sediment beds require a **MP CB** card for each bed layer to define the cohesive properties of the layers.

Here's an example of **MP CBA** cards for 2 bed layers:

```
MP CBA  1  0.5  0.1  0.00018  3.0
MP CBA  2  0.6  0.08  0.00016  2.0
```

As with the **SBA** card, the cohesive bed properties can be defined by all nodes (**CBA**), specific materials (**CBM**), or specific nodes (**CBN**). As with the previous bed definitions, the layer numbering begins with the bottom-most layer.

CN CLA

COHESIVE SEDIMENT (CLAY AND/OR SILT)

Field	Type	Value	Description
1	char	CN	Card type
2	char	CLA	Parameter
3	int	≥ 1	Constituent ID number
4	real	> 0	Characteristic concentration
5	real	> 0	Grain diameter
6	real	> 1	Specific gravity
7	real	> 0	Porosity for newly deposited sediment
8	real	> 0	Critical shear stress for erosion for newly deposited sediment
9	real	> 0	Erosion rate constant for newly deposited sediment
10	real	> 0	Critical shear for deposition
11	real	> 0	User-specified settling velocity

MP CBN

COHESIVE BED SEDIMENT PROPERTIES APPLIED TO SELECTED NODES

Field	Type	Value	Description
1	char	MP	Card type
2	char	CBN	Parameter
3	int	> 0	Bed layer ID number
4	int	> 0	Node number from which to start
5	int	> 0	Node number at which to end
6	real	≥ 0.0	Porosity for the bed layer
7	real	≥ 0.0	Critical shear stress for erosion for the bed layer
8	real	≥ 0.0	Erosion rate constant for the bed layer
9	real	≥ 0.0	Erosion rate exponent for the bed layer

MP CBM

COHESIVE BED SEDIMENT PROPERTIES APPLIED BY MATERIAL

Field	Type	Value	Description
1	char	MP	Card type
2	char	CBM	Parameter
3	int	> 0	Bed layer ID number
4	int	> 0	Material type ID number
5	real	≥ 0.0	Porosity for the bed layer
6	real	≥ 0.0	Critical shear stress for erosion for the bed layer
7	real	≥ 0.0	Erosion rate constant for the bed layer
8	real	≥ 0.0	Erosion rate exponent for the bed layer

MP CBA

COHESIVE BED SEDIMENT PROPERTIES APPLIED TO ALL NODES

1	char	MP	Card type
2	char	CBA	Parameter
3	int	> 0	Bed layer ID number
4	real	≥ 0.0	Porosity for the bed layer
5	real	≥ 0.0	Critical shear stress for erosion for the bed layer
6	real	≥ 0.0	Erosion rate constant for the bed layer
7	real	≥ 0.0	Erosion rate exponent for the bed layer

4.5 Inflow/Outflow boundary specification for sediment transport simulations

Sediment inflow/outflow boundary conditions can be specified with **NB TRN** and **DB TRN** cards. These cards function much like the hydrodynamic boundary condition cards. The natural boundary condition will apply a sediment mass flux along a defined edge (i.e. and edge strings, which is a collection of connected element edges) and the Dirichlet boundary condition will apply a sediment concentration at a list of nodes. These boundary conditions must be defined for each grain class.

Note that, when using the **NB TRN** and **DB TRN** cards, bedload and suspended load must be input together at a boundary condition. Therefore, the mass flux (natural boundary) or sediment concentration (Dirichlet boundary) specified at a boundary condition must account for the bedload as well as the suspended load at that boundary.

At the boundary, the total load is input as suspended load. As the inflow from the boundary progresses downstream, SEDLIB determines the portion of the sediment inflow that will continue downstream as bedload and the portion of the sediment inflow that will continue downstream as suspended load.

An added (and very useful) boundary condition option is available for non-cohesive sediment transport (sand, gravel, and cobble). This is the equilibrium transport boundary condition (**EQ TRN** card). When this condition is specified, the concentration that AdH computes and applies at the boundary is the concentration that is required for a state of equilibrium to exist at the boundary. Unlike the **NB TRN** and **DB TRN** cards, the **EQ TRN** boundary condition is applied for both suspended bed material load and bedload (i.e. both suspended material load and bedload equilibrium conditions are specified). Since this boundary condition varies both in space and time, and is dependent on the local shear stress at each node, it can only be applied as a nodal boundary condition (i.e. it cannot be applied at a natural boundary condition using an edge string: it must be applied as a Dirichlet boundary condition using a node string). For such an equilibrium condition, almost no sediment will erode or deposit at the specified boundary. This condition is specified with an **EQ TRN** card followed by the node string number where it is to be applied, and the constituent number for the grain being applied.

Note that **EQ TRN** cards cannot be used for cohesive sediments. The concept of an equilibrium concentration has no physical meaning for cohesive sediments, since (in general) simultaneous erosion and deposition does not occur. The natural and Dirichlet transport boundary condition options (**NB TRN** and **DB TRN**) are used when defining suspended sediment inflow for cohesive material

NB TRN

NATURAL BOUNDARY CONDITION - TRANSPORT

Field	Type	Value	Description
1	char	NB	Card type
2	char	TRN	Parameter
3	int	≥ 1	String ID number (edge)
4	int	≥ 1	Constituent ID number
5	int	≥ 1	Series ID number that contains the sediment mass flux

DB TRN

DIRICHLET - TRANSPORT

Field	Type	Value	Description
1	char	DB	Card type
2	char	TRN	Parameter
3	int	≥ 1	String ID number (node)
4	int	≥ 1	Constituent ID number
5	int	≥ 1	Series ID number that contains the sediment concentration (units are ppm by mass)

EQ TRN

EQUILIBRIUM SAND TRANSPORT BOUNDARY CONDITION			
Field	Type	Value	Description
1	char	EQ	Card type
2	char	TRN	Parameter
3	int	≥ 1	String ID number (node)
4	int	≥ 1	Constituent ID number
5	int	≥ 0	placeholder: is not used for this option

4.6 Converting between bed porosity, wet bulk density, and dry bulk density

The versions of AdH previous to AdHv4.7 required the user to specify porosity for non-cohesive properties, and wet bulk density for cohesive properties. This was done in deference to the conventions typically used by scientists and engineers for these problems.

For AdHv4.7, this mixed convention has been abandoned. In AdHv4.7, all bed properties are assigned in terms of porosity. This has been done for 2 reasons.

1. Utilizing a single convention for all types of beds avoids confusion for users and reduces the possibility of user-error when converting between conventions.
2. Of the 3 methods typically used to specify bed properties (porosity, dry bulk density, wet bulk density), only porosity is sufficiently general to permit modeling of sediments with different specific gravity constants. Both wet bulk density and dry bulk density cannot be specified independently of the specific gravity of the grains present in the bed.

Note: if a user has a previously generated sediment hotstart file from a previous version of AdH, where the bed properties were defined in terms of wet bulk density instead of porosity, the hotstart file can still be used in AdHv4.7. AdHv4.7 will recognize that the bed properties are given in wet bulk density on the hotstart file and will convert them to porosity before using them to define the initial conditions in the model.

In order to facilitate the easy conversion between these various methods of specifying the bed conditions, Table 1 is given to provide equations that can be used to perform the conversions. Note that, in Table 1, p is porosity, s is specific gravity, and ρ is the density of fresh water ($\sim 1000 \text{ kg/m}^3$). Note also that the conversions in this table are only appropriate for sediment beds with a constant specific gravity among all grain classes. Beds consisting of grains with variable specific gravity must be first converted to a constant specific gravity value equal to the mass weighted average of the values of each grain.

Table 1: Equations to Convert Between Porosity, Dry Bulk Density, and Wet Bulk Density

	Convert from porosity (p)	Convert from dry bulk density ($\rho_{BD,D}$)	Convert from wet bulk density ($\rho_{BD,W}$)
Convert to porosity (p)		$p = \left(1 - \frac{\rho_{BD,D}}{\rho s}\right)$	$p = \left(\frac{s}{s-1}\right) \left(1 - \frac{\rho_{BD,W}}{\rho s}\right)$
Convert to dry bulk density ($\rho_{BD,D}$)	$\rho_{BD,D} = \rho s(1-p)$		$\rho_{BD,D} = \rho_{BD,W} - \rho p$
Convert to wet bulk density ($\rho_{BD,W}$)	$\rho_{BD,W} = \rho s(1-p) + \rho p$	$\rho_{BD,W} = \rho_{BD,D} + \rho p$	

4.7 Model Protocols for Mixed Sediments (coarse and fine sediments)

When non-cohesive and cohesive sediment classes are mixed together in the sediment bed, the behavior becomes even more complex than for purely non-cohesive and cohesive sediment beds.

The cohesiveness of a mixed sediment bed varies in proportion to the silt and clay fraction of the mixture. A bed consisting of both non-cohesive and cohesive sediment classes may exhibit non-cohesive and cohesive behavior, depending on the fraction of silt and clay classes that are present in the mixture.

The cohesive fraction of the sediment bed is computed with the following algorithm:

$$\beta_{CF} = \sum_{i=1}^{ngc} \beta_i \phi : \phi = \frac{d_{NCL} - d_i}{d_{NCL} - d_{CL}} : 0 < \phi < 1 \quad (5)$$

Where:

ngc= number of grain classes

β_{CF} = the cohesive fraction in the bed layer

β_i = the fraction of each grain in the bed layer
 d_i = the diameter of each grain the bed layer
 d_{CL} = Limiting diameter for cohesive grains (3.9 μm)
 d_{NCL} = Limiting diameter for non-cohesive grains (64 μm)

The fraction of cohesive material necessary for the bed layer to initiate cohesive erosional behavior ($\beta_{CF} = \beta_{CF,CI}$) has been set at 0.05 (i.e. 5%). The fraction of cohesive material necessary for the bed layer to achieve fully cohesive erosional behavior ($\beta_{CF} = \beta_{CF,CF}$) has been set at 0.1 (i.e. 10%). Sediment bed layers for which the value of β_{CF} falls between 5 and 10% exhibit erosional behavior that is linearly interpolated between fully non-cohesive and cohesive behavior, according to the value of β_{CF} for the bed layer.

Fully non-cohesive erosional behavior is defined by grain properties associated with each non-cohesive grain, as determined by the entrainment algorithms selected by the user. Full cohesive erosional behavior is determined by the cohesive layer properties, as initially defined on the **MP CBA**, **MP CBM**, or **MP CBN** cards.

Below is an example of 2 sands, 1 clay, and 1 silt. The clay is distinguished from the silt by the assigned grain size, which is less than the maximum grain size for the clay fractions i.e. (3.9 μm):

CN SND	1	1.0	0.0001	2.65	0.3					
CN SND	2	1.0	0.001	2.65	0.3					
CN CLA	3	1.0	0.000001	2.65	0.88	0.01	0.00016326	0.01	0.00006	
CN CLA	4	1.0	0.00001	2.65	0.75	0.01	0.00016326	0.01	0.00016	

4.8 Other Features

The features discussed in this section are additional to those required to model sediment transport in AdH with SEDLIB. These are optional features that users can take advantage of if they find them useful for a specific study.

4.8.1 SEDFLUME erosion rate input

SEDFLUME is a field- or laboratory-deployable flume for quantifying cohesive sediment erosion (McNeil et al. 1996). It is a device that can be used to make direct measurements of core erosion rates.

SEDFLUME erosion rate data are given as a table of values sorted by bed layer and shear stress. For a given bed layer, the erosion rate can be found by interpolating between the shear stress values to find the appropriate value for the applied bed shear stress.

If the user applies SEDFLUME data to a given material type, the erosive behavior for that material type will be governed by the parameters given on the SEDFLUME card. These parameters will override both the standard non-cohesive grain erosion rates, and any cohesive erosion rates specified on **MP CBA**, **MP CBM**, or **MP CBN** cards.

If the entire SEDFLUME layer is eroded, the erosional properties of the bed at this location revert to the default properties (i.e. standard non-cohesive grain erosion rates, and any cohesive erosion rates specified on **MP CBA**, **MP CBM**, or **MP CBN** cards.)

Note that the number of SEDFLUME shear stress intervals must be ≥ 2 .

Also note that, for good modeling practice, it is advisable to make sure the total number of bed layers is ≥ 2 plus the number of layers assigned SEDFLUME erosion rates. This is to ensure that the two extra layers (which should be the highest number: i.e. on top of the SEDFLUME layers) can be used by the model to store the active layer and any deposition. Adding these layers ensures that the SEDFLUME erosion is governed by the SEDFLUME parameters only: i.e. there is no depositional material mixed into the SEDFLUME layers.

Finally, note that SEDFLUME cards only specify erosion rates. The bed porosity and grain size distributions are still specified using the standard AdH/SEDLIB inputs.

For example, the following SEDFLUME cards assign to all nodes and one bed layer (layer 1) SEDFLUME characteristics for two shear stress intervals (0.1 and 0.7 Pa) with two corresponding erosion rates (0.5 kg/m²/s and 1.0 kg/m²/s).

MP NSF 2

MP SFA 1 1 0.1 0.5

MP SFA 1 2 0.7 1.0

MP NSF

SEDFLUME NUMBER OF SHEAR STRESS INTERVALS SPECIFICATION			
1	char	MP	Card type
2	char	NSF	Parameter
3	int	≥ 2	Number of shear stress intervals on the SEDFLUME cards

MP SFN

SEDFLUME EROSION RATES BY NODE			
1	char	MP	Card type

2	char	SFN	Parameter
3	int	> 0	Sediment bed layer
4	int	> 0	Node number from which to start
5	int	> 0	Node number at which to end
6	int	> 0	Shear stress interval number
7	real	≥ 0.0	Shear stress corresponding to this interval (Pa)
8	real	≥ 0.0	Erosion rate corresponding to this interval and bed layer (kg/m ² /s)

MP SFM

SEDFLUME EROSION RATES BY MATERIAL

1	char	MP	Card type
2	char	SFM	Parameter
3	int	> 0	Sediment bed layer
4	int	> 0	Material type
5	int	> 0	Shear stress interval number
6	real	≥ 0.0	Shear stress corresponding to this interval (Pa)
7	real	≥ 0.0	Erosion rate corresponding to this interval and bed layer (kg/m ² /s)

MP SFA

SEDFLUME EROSION RATES FOR ALL NODES

1	char	MP	Card type
2	char	SFA	Parameter
3	int	> 0	Sediment bed layer
4	int	> 0	Shear stress interval number
5	real	≥ 0.0	Shear stress corresponding to this interval (Pa)
6	real	≥ 0.0	Erosion rate corresponding to this interval and bed layer (kg/m ² /s)

4.8.2 Sediment Dredging and Placement

AdHv4.7 introduces sediment dredging and placement capability. The user can define multiple dredge and/or placement events. These can occur consecutively or simultaneously. Dredging can consist of discrete events or continuous dredge production. Placement characteristics can be defined by the user, or placement can be associated with a specific dredge event (i.e. one can place the sediment dredged from one location in another location).

To invoke dredge and/or place cards, you define a dredge (**MR DRD**) or place (**MP DRP**) card for EACH dredge or place “event.” Each event can be a discrete event (consisting of a defined volume or material to be dredged or placed) or a continuous event (occurring at a

prescribed dredge or placement rate over a period of time). Dredge and placement regions are defined by material type. The syntax for these cards are given in the specific card formats later in this manual.

Dredge and placement output are written to a text file, called *Project_name_dredge_record*. The record includes total volume dredged/placed, the porosity of the dredged/placed material, and the fraction of each sediment grain in the dredged/placed material. The file can be easily read into a spreadsheet or other post-processing tool.

The following are some examples of dredge and place cards.

Dredge event 1: Material type 2: discrete event, occurring at time 7200 seconds, dredge to an elevation of -15 m

Dredge event 2: Material type 3: continuous dredging from time 0.0 seconds to time 86400 seconds, dredging rate equal to 0.08 m³/s

Place event 1: Material type 4: place the material dredged in dredge event 1 into material type 4. Do not specify cohesive bed properties (i.e. either there is no cohesive sediment being dredged and placed, or the user is allowing the cohesive properties of the existing bed layer that the material is placed into (in material type 4) to remain unchanged)

MP DRD 1 2 1 7200.0 -15.0
MP DRD 2 3 2 0.0 86400 0.08
MP DRP 1 4 3 1 0

MP DRD

DREDGE AND PLACE: DREDGE CARD

Field	Type	Value	Description
1	char	MP	Card type
2	char	DRD	Parameter
3	int	≥ 1	Dredge Event Identifier
4	int	≥ 1	Material Type to be Dredged
5	int		Type of Dredge Event
		=1	Discrete Event
		=2	Continuous Event

If Event Type = Discrete Event

6	real	any	Time at which to initiate dredge event (seconds)
---	------	-----	--

7	real	any	Elevation to which to dredge (meters)
---	------	-----	---------------------------------------

If Event Type = Continuous Event

6	real	any	Time at which to initiate dredging (seconds)
7	real	any	Time at which to stop dredging (seconds)
8	real	any	Volumetric rate of dredging (m ³ /sec)

MP DRP**DREDGE AND PLACE: PLACEMENT CARD**

Field	Type	Value	Description
1	char	MP	Card type
2	char	DRP	Parameter
3	int	≥ 1	Placement Event Identifier
4	int	≥ 1	Material Type where placement will take place
5	int		Type of Placement Event
		=1	Discrete Event
		=2	Continuous Event
		=3	Placement of an associated user-specified dredge event

If Event Type = Discrete Event

6	real	any	Time at which to initiate placement event (seconds)
7	real	any	Volume of sediment to be placed (m ³)
8	real	0 to 1	Porosity of sediment to be placed
9	int		Toggle to specify cohesive bed properties
		=0	Do not specify cohesive bed properties
		=1	Do specify cohesive bed properties

If Field 9 = 0

10	real		Grain class fraction of placement for grain 1
.			
.			
.			
NGS+ 10	real		Grain class fraction of placement for grain NGS (Number of GrainS)

If Field 9 = 1

10	real		Critical shear for erosion for placement
11	real		Erosion rate constant for placement
12	real		Erosion rate exponent for placement
13	real		Grain class fraction of placement for grain 1

.

.

.

NGS+ 13 real Grain class fraction of placement for grain NGS

If Event Type = Continuous Event

6	real	any	Time at which to initiate placement event (seconds)
7	real	any	Time at which to stop placement (seconds)
8	real	any	Volumetric rate of placement (m ³ /sec)
9	real	0 to 1	Porosity of sediment to be placed
10	int		Toggle to specify cohesive bed properties
		=0	Do not specify cohesive bed properties
		=1	Do specify cohesive bed properties

If Field 10 = 0

11	real		Grain class fraction of placement for grain 1
.			
.			
.			
NGS+ 11	real		Grain class fraction of placement for grain NGS

If Field 10 = 1

11	real		Critical shear for erosion for placement
12	real		Erosion rate constant for placement
13	real		Erosion rate exponent for placement
14	real		Grain class fraction of placement for grain 1
.			
.			
.			
NGS+ 14	real		Grain class fraction of placement for grain NGS

If Event Type = Placement of an associated user specified dredge event

6	int	≥ 1	Associated dredge event to be placed
7	int		Toggle to specify cohesive bed properties
		=0	Do not specify cohesive bed properties
		=1	Do specify cohesive bed properties

If Field 7 = 1

8	real	0 to 1	Porosity of sediment to be placed
9	real		Critical shear for erosion for placement

10	real	Erosion rate constant for placement
11	real	Erosion rate exponent for placement
12	real	Grain class fraction of placement for grain 1

4.8.3 Bed Consolidation

Cohesive beds will consolidate over time due to self-weight and the weight of the water above. AdH/SEDLIB models that include cohesive constituents can also include bed consolidation, if the user decides to do so. In SEDLIB, the rate of consolidation is specified directly by the user, with a series of parameters. These parameters are defined as a time series, with time 0 equal to the time that the sediment is initially deposited (note that the algorithm infers the age of the deposit from the local bed layer density, since these parameters are interdependent when consolidation is invoked). The parameters are specified similarly to the other bed properties, i.e. by all nodes, by materials, or by selected nodes. An **NP NCP** card is necessary to define the number of time values that will be used to define the consolidation. Then an **MP CPA** (or **CPM**, or **CPN**) card is given for each of the time values with the time in seconds that has elapsed since sediment was deposited, the porosity of the material, the critical shear for erosion, the erosion rate constant, and the erosion rate exponent for the bed material at that time. Hence, the parameters on these cards represent a time history of bed consolidation.

For example, assume we wish to specify consolidation with 3 sets of time parameters. The first parameters correspond to time 0, the second correspond to time 43200 seconds, and the third correspond to time 86400 seconds. The parameters are given below.

MP NCP 3

MP CPA 1 0.0 0.8 0.1 0.02 1

MP CPA 2 43200 0.7 0.5 0.015 1.5

MP CPA 3 86400 0.6 1.0 0.01 2

Note that these values define points in time on a piecewise continuous curve. The values of each of these parameters are interpolated from this curve to compute the appropriate values for the elapsed model time, at every time step.

Note also that the porosity grows smaller through time. This is how the consolidation occurs.

MP NCP

1	char	MP	Card type
2	char	NCP	Parameter
3	int	≥ 0	Number of time values in the consolidation time series for sediment transport

MP CPN

CONSOLIDATION TIME SERIES PROPERTIES APPLIED TO SELECTED NODES

1	char	MP	Card type
2	char	CPN	Parameter
3	int	> 0	Node number from which to start
4	int	> 0	Node number at which to end
5	int	> 0	Consolidation time value number
6	real	≥ 0.0	Elapsed time since sediment deposition (sec)
7	real	≥ 0.0	Porosity at the elapsed time
8	real	≥ 0.0	Critical shear stress for erosion at the elapsed time
9	real	≥ 0.0	Erosion rate constant at the elapsed time
10	real	≥ 0.0	Erosion rate exponent at the elapsed time

MP CPM

CONSOLIDATION TIME SERIES PROPERTIES APPLIED BY MATERIAL

1	char	MP	Card type
2	char	CPM	Parameter
3	int	> 0	Material type ID number
4	int	> 0	Consolidation time value number
5	real	≥ 0.0	Elapsed time since sediment deposition (sec)
6	real	≥ 0.0	Porosity at the elapsed time
7	real	≥ 0.0	Critical shear stress for erosion at the elapsed time
8	real	≥ 0.0	Erosion rate constant at the elapsed time
9	real	≥ 0.0	Erosion rate exponent at the elapsed time

MP CPA

CONSOLIDATION TIME SERIES PROPERTIES APPLIED FOR ALL NODES

1	char	MP	Card type
2	char	CPA	Parameter
3	int	> 0	Consolidation time value number
4	real	≥ 0.0	Elapsed time since sediment deposition (sec)
5	real	≥ 0.0	Porosity at the elapsed time
6	real	≥ 0.0	Critical shear stress for erosion at the elapsed time
7	real	≥ 0.0	Erosion rate constant at the elapsed time
8	real	≥ 0.0	Erosion rate exponent at the elapsed time

4.8.4 No Bed Displacement by Material Type

Often, it is neither necessary, nor desirable, to compute bed displacements at every point in the model domain. For example, at the inflow boundary, the inherent uncertainty in the inflowing sediment concentration can result in large perturbations of the bed displacement, which in turn can contribute to model instability (due to the feedback of these changes to the hydrodynamics).

The **MP NDM** card allows the user to turn off bed displacements for selected material types. This card requires the material number to be specified. For material types with an **NDM** card active, sediment can be eroded from the bed or deposited to the bed, but the bed elevation will not change.

There are 2 different options used to enable no bed displacement, which are specified by the user with a 0 or a 1 on the **NDM** card.

Option 0: The bed displacement at each time step is transferred from the bed surface to the bottom of the deepest bed layer. This ensures that sediment bed mass is conserved, but the elevation of the bed surface remains constant. However, this also means that the elevation of the underlying nonerodable boundary (i.e. bed surface elevation minus the total bed thickness) will change in response to erosion or deposition of the bed. This can create problems if the elevation of the nonerodable boundary is important (i.e. if the location is on top of a dike structure). Hence, option 0 is most useful for parts of the model domain where the nonerodable boundary elevation is not important (such as at an inflow boundary, or in a floodplain adjacent to a river).

Option 1: Neither the bed surface elevation nor the nonerodable boundary elevation is allowed to change. Eroded and/or deposited sediment thickness at the surface is replaced by an equivalent thickness of sediment added to or taken away from the deepest bed layer(s). This means that neither the bed surface nor the nonerodable boundary can move during the simulation, but it also means that sediment mass is not conserved (because sediment is just added to or taken away from the bed in response to erosion and deposition at the bed surface). Because it is not mass conservative, this option is intended for *model initiation only*. It is very useful as a means to initialize the sediment bed surface gradation throughout the domain (see Appendix B).

MP NDM

TURN OFF DISPLACEMENT BY MATERIAL TYPE

1	char	MP	Card type
2	char	NDM	Parameter

3	int	> 0	Material type ID number
4	int	0 or 1	Select type of NDM implementation 0 = bed sediment mass is preserved, bed surface elevation is fixed, solid bottom changes elevation 1 = bed sediment mass is not preserved, bed surface elevation is fixed, solid bottom elevation is fixed

4.8.5 Approximation of Local Scour

Very close to structures and hard points, abrupt changes in geometry and/or bathymetry can result in locally generated vertical circulation and other non-hydrostatic flows. These can induce the formation of local scour holes.

The hydrostatic approximation associated with the shallow water version of AdH precludes direct simulation of these scour holes. Rather, the hydrostatic approximation will tend to result in a modeled flow condition that is more generally depositional than erosional. Hence, the model has a tendency to fill existing scour holes with sediment, and introduced structures have a tendency not to exhibit local scour in the model.

Since AdH is not intended to simulate local scour, but rather is intended to examine sediment transport conditions away from these local phenomena (such as the influence of existing and introduced structures on nearby and regional bathymetry) this is not a crucially significant problem. However, the tendency for AdH to fill and/or not generate local scour conditions around structures may influence the interaction of the structure with the flow, and this in turn could influence the ability of the model to simulate the influence of the structure on the nearby bathymetry.

To help address this problem, AdH has been equipped with a local scour card. The **MP LSM** card allows the user to define local scour conditions for specific material type(s). Deposition is not allowed on material types associated with the **MP LSM** card – only scour is possible. There are 2 different options, which are specified by the user with a 0 or a 1 on the **MP LSM** card.

Option 0: The local scour conditions are modeled simply as scour-only conditions: that is, no deposition is permitted for that material type. This option is independent of the applied shear stress: it does not allow deposition for any flow conditions.

Option 1: The local scour conditions are modeled by applying a scale factor that is applied to the ambient shear stress. The scale factor is provided by the user on the **LSM** card. For example, a value of 2 would cause the bed shear stress for the material type where the

LSM card is applied to be 2 times larger than that which is computed from the physics in the model.

The user is responsible for defining the geometry of the scour holes (by selecting elements to be assigned to the local scour material type(s)). Also, the user must be constantly cognizant of the fact that the local scour card is an **approximate** method. It creates scour holes where the user says they should be. It does not create them for physically correct reasons, and it does not place them where the model physics says they should go.

Hence, this method can be useful for sustaining and or creating qualitative approximate scour hole morphology, which in turn can allow for more physically realistic interaction between structures and the flow field. But care and judgement must be exercised by the modeler to ensure that the method is applied appropriately.

MP LSM

LOCAL SCOUR BY MATERIAL TYPE

1	char	MP	Card type
2	char	LSM	Parameter
3	int	> 0	Material type ID number
4	int	0 or 1	Select type of LSM implementation 0 = no deposition is permitted 1 = shear stress is scaled by the quantity given in 5
5	real	>0	(only read if quantity 4 (above) =1) scale factor for bed shear stress (e.g. 2 means that the shear stress is multiplied by 2)

4.8.6 Infiltration of Fine Sediment into Coarse Sediment Beds

For coarse sediment beds (such as gravel beds), the deposition of fine sands and silts can sometimes form a top layer and can sometimes infiltrate through the gravel bed to fill up the pore spaces within the gravel matrix. The ability to predict which of these behaviors is manifested for a given gravel bed can be important for many different considerations, including, for example, salmonid spawning.

The results of recent research by Gibson et al. (2010) established criteria for estimating the threshold for determining whether or not the deposited sediment will “bridge” (form a top layer) or “percolate” (infiltrate into the bed). These criteria have been included in SEDLIB using the following equation.

$$\frac{d_{05.Bed}}{d_{85.Deposit}} = 12\beta \quad (6)$$

Where $d_{05.Bed}$ is the 5% finer diameter of the existing bed material (i.e. diameter that 5% of the existing bed material is finer than), $d_{85.Deposit}$ is the 85% finer diameter of the newly deposited material (i.e. the diameter that 85% of the newly deposited material is finer than), and β is a user specified multiplier (default = 1.0).

If the $d_{05.Bed} / d_{85.Deposit}$ ratio is less than 12β , the deposit will “bridge” and form a new layer. If the $d_{05.Bed} / d_{85.Deposit}$ ratio is greater than 12β , the deposit will infiltrate into the existing bed and fill the pore spaces.

If the user desires to invoke this option, the **SP SIF** card must be used. The only additional information supplied by the user is the value of β , which should initially be set equal to 1, and only adjusted if site specific information is available that would justify altering it.

SP SIF

SEDIMENT PROCESS: SEDIMENT INFILTRATION FACTOR

Field	Type	Value	Description
1	char	SP	Card type
2	char	SIF	Parameter
3	real	> 0	Coefficient to adjust the sediment infiltration factor computation (default is 1)

4.8.7 Morphologic Acceleration

In order to investigate long-term (multi-annual to multi-decadal) morphological changes, it is useful to have a means whereby morphologic change can be “accelerated” within the model. This is accomplished in AdH by simply adjusting the bed porosity, such that a given mass of sediment erosion or deposition is associated with a rate of bed elevation change that is scaled by the desired (user-specified) morphologic acceleration factor.

As with all morphologic acceleration methods, application of the method is generally restricted to steady or quasi-steady flow conditions. This is because the method requires that the time-series of the hydrodynamic boundary conditions are also accelerated by the morphologic acceleration factor (e.g. a flood hydrograph “happens” much faster), but there is no way to scale the time rate of change of momentum.

To address this, a dynamic hydrograph can be approximated as series of steady flows of different magnitudes. The user can then pause sediment transport during the parts of the

hydrograph where the model is transitioning between flows (using SP NST cards), and the re-enable sediment transport when the new hydrodynamic conditions have stabilized.

Appendix C contains a detailed description of the derivation of the morphologic acceleration technique, and discussion of how it should be applied in AdH.

Note that, as with all morphologic acceleration techniques, any application of the method should be tested by comparison accelerated and non-accelerated solutions for appropriate test conditions. This is also discussed in Appendix C.

5 Sediment Processes

The sediment process cards are designed to allow the user to select among various methods of describing a specific process. SEDLIB has several process options available and intends to grow as additional options are necessary or requested. Processes included to date are:

- cohesive settling
- wind wave shear
- non-cohesive suspended entrainment
- non-cohesive bedload entrainment
- non-cohesive hiding factor
- turn off sediment transport for specified time window

These process cards all begin with **SP** and are followed by a three-letter descriptor of the specific process being specified. The third field is a flag indicating which process algorithm to use. Since some methods require additional parameters, the fields 4 and above are reserved for any parameter that may be required for a specific method.

Sediment Process cards

SP CSV

SEDIMENT PROCESS: COHESIVE SETTLING VELOCITY

Field	Type	Value	Description
1	char	SP	Card type
2	char	CSV	Parameter
3	int	= 0	0 - Free Settling
		= 1	1 - Hwang and Mehta
4...	real	≥ 0	Process specific parameter(s)

SP WWS

SEDIMENT PROCESS: WIND WAVE SHEAR

Field	Type	Value	Description
1	char	SP	Card type
2	char	WWS	Parameter
3	int	= 0	0 – No applied wind-wave stress
		= 1	1 - Grant and Madsen
		= 2	2 - Teeter
4...	real	≥ 0.0	Process specific parameter(s)

SP NSE

SEDIMENT PROCESS: NON-COHESIVE SUSPENDED ENTRAINMENT

Field	Type	Value	Description
1	char	SP	Card type
2	char	NSE	Parameter
3	int	= -1	-1 – No suspended load (bedload only)
		= 0	0 - Garcia-Parker
		= 1	1 - Wright-Parker
		= 2	2 – Van Rijn
		= 3	3– Yang (should be run with SP NBE = -1)
4...	real	≥ 0.0	Process specific parameter(s)

NOTE: See Appendix D for a more thorough description of these options

SP NBE

SEDIMENT PROCESS: NON-COHESIVE BEDLOAD ENTRAINMENT

Field	Type	Value	Description
1	char	SP	Card type
2	char	NSE	Parameter
3	int	= -1	-1 – No bedload (suspended load only)
		= 0	0 – van Rijn
		= 1	1 – Meyer Peter Mueller
		= 2	2 – Meyer Peter Mueller with Wong Parker Correction
		= 3	3 – Wilcock (should be run with SP NSE = -1)
4...	real	≥ 0.0	Process specific parameter(s)

For **Wilcock (option 3)**, there are 2 of these:

4	real	≥ 0.0	Critical shear stress for sand
5	real	≥ 0.0	Critical shear stress for gravel

NOTE: See Appendix D for a more thorough description of these options

SP HID

SEDIMENT PROCESS: NON-COHESIVE HIDING FACTOR

Field	Type	Value	Description
1	char	SP	Card type
2	char	NSE	Parameter
3	int	= 0	0 – Karim Holly Yang
		= 1	1 – Egiazaroff
		= 2	2 – Wu Wang Jia
		= 3	3 – Parker and Klingeman
4...	real	≥ 0.0	Process specific parameter(s)

For **Parker and Klingeman (option 3)**, there is 1 of these:

4 real $1 \geq X \geq 0.0$ Hiding factor exponent

SP NST

SEDIMENT PROCESS: NO SEDIMENT TRANSPORT

Field	Type	Value	Description
1	char	SP	Card type
2	char	NST	Parameter
3	int	>0	Event number (i.e. 1,2,3...etc.) Each SP NST card describes one event.
4	int	0-4	Input units. (0 = seconds; 1 = minutes; 2 = hours; 3 = days; and 4 = weeks)
5	real	time	Start time for pausing sediment transport (units consistent with field 4)
6	real	time	Stop time for pausing sediment transport (units consistent with field 4)

6 Coupled Vegetation Modeling: SEDLIB-VEG

Natural multi-year or multi-decadal cycles that are associated with riverine, lacustrine or estuarine systems include the introduction, growth, and/or loss of vegetation. This may include wetland vegetation, riparian woody vegetation (trees), or other vegetated environments.

The growth and/or loss of vegetation can have several different potential influences on the hydrodynamics and morphodynamics of these systems. These include

- Changes to hydrodynamic drag, influencing preferential flow pathways
- Changes to the erodibility of the substrate (e.g. vegetated emergent features are much more resistant to erosion than barren emergent features)
- Changes to the rate of subsidence/elevation-gain. The accumulation of refractory (residual) organics associated with vegetation senescence adds elevation to marsh surfaces. For mature marshes, this is the primary mechanism of elevation gain, and hence the primary mechanism whereby the marsh maintains planform elevation when subjected to relative sea-level rise.
- Changes to the ability for features to trap sediment. Vegetated features tend to sequester more fine sediments than barren features.
- Changes in the ability for wind-wave erosion to resuspend settled sediments. Vegetation shelters sediments from wind-wave erosion, by mitigating the propagation of wind-wave energy into the marsh interior.

To simulate the effects of vegetation on hydrodynamic and sediment transport simulations, a vegetation module has been added to SEDLIB. This module, called SEDLIB-VEG, was added to SEDLIB (as opposed to being developed as a separate module) so that the interactions between existing bed sediments, newly settled and/or eroded sediment, and vegetation root and refractory material can be solved simultaneously within one computational framework. This permits the effects associated with various time scales, ranging from seasonal and annual phenomena, to discrete, rapid changes associated with significant events (such as a large storm or a sediment placement), to be simulated for both inorganic sediments and for the vegetation (roots and refractory organics) simultaneously.

The model is integrated into the SEDLIB sediment module by simply adding 2 additional fine sediment classes to a given AdH simulation and assigning these fine sediment classes

to be organic classes. The first is the root class: it represents the behavior of the root material. The second is the refractory class: it represents the storage of compacted refractory material.

The root material class is assigned a very high porosity, commensurate with the porosity of the rooting zone. The refractory class is assigned a somewhat lower porosity, associated with compacted refractory organics (note that this module does not do compaction of the refractory organics: it assumes that the refractory fractions of both litterfall and root decay are immediately compacted).

The only difference between these organic “sediment” classes and the other inorganic classes is that the masses of each of these classes are modified at each time step as a result of vegetative growth and decay.

SEDLIB-VEG utilizes user-provided coefficients and local hydrodynamic conditions to generate root mass. The mass of shoots (vegetation) is computed as a function of the root mass. A fraction of the roots and shoots is lost to senescence, and a fraction of this material is retained as refractory organic material. The accumulation of root mass and refractory organics, represented by the two selected “sediment” grains, results in added elevation to the bed surface.

SEDLIB-VEG is dynamically linked to the hydrodynamics by continuously modifying the vegetative friction as a function of the computed vegetative mass. This is done as follows:

- The computed vegetation density is associated with increased vegetation drag. Typically, a **FR URV** or **FR EDO** card is used to assign vegetative friction. These cards include losses to the vegetated stems, and losses due to the undergrowth (or barren substrate).
- When SEDLIB-VEG is invoked, the vegetation density fraction at that time step is computed. This vegetation density fraction is equal to the ratio of the actual vegetation mass to the equilibrium vegetation mass provided by the user on the VEG card.
- The actual friction at that time step is then computed as the undergrowth loss (or barren substrate) value plus the vegetated stems loss value times the vegetation density fraction computed above.
- In this way, the vegetated friction is always computed as a function of the actual density of vegetation at any given time step.

More details on the theoretical basis, the basic equations, and the user-proved coefficients necessary to run SEDLIB-VEG are given in Appendix A.

To invoke SEDLIB-VEG in AdH, it is necessary to do the following.

1. Add 2 extra fine grain classes. These will be used as organic classes for SEDLIB-VEG. These also assign the physical properties and erosional characteristics of the roots and refractory sediments (note that, once eroded, the SEDLIB-VEG model assumes that the organic material disappears. There is no transport or deposition of organics modeled in SEDLIB-VEG)
2. Assign **FR URV** or **FR EDO** cards to the material types where vegetation is expected to grow.
3. Add a **VEG** card to the input deck, to assign the selected fine sediment classes to the roots and refractory organics, and the global values of the vegetation growth properties.
4. Add **MP VGM** cards if you desire to modify or turn off vegetation on selected material types.

An example is given below.

The vegetation model is to be invoked for material type 2 only, for a model that is simulating 12 inorganic sediment classes (5 cohesive classes and 7 non-cohesive classes). The model has two total material types (1 and 2) so the vegetation will be defined globally, and then turned off on material type 1 so that only material type 2 can grow vegetation.

1. Two additional grain classes are added to the model. These are used to characterize the specific gravity, porosity, and erosional characteristics of the two organic classes used to define the vegetation roots and refractory organics. The two new classes are highlighted below.

```

CN CLA 1 1 0.000003 2.65 0.68 .5 0.01 0.005 0.000009 "CLAY"
CN CLA 2 1 0.000006 2.65 0.68 .5 0.01 0.01 0.000036 "VFM"
CN CLA 3 1 0.000011 2.65 0.68 .5 0.01 0.02 0.000121 "FM"
CN CLA 4 1 0.000023 2.65 0.68 .5 0.01 0.04 0.000529 "MM"
CN CLA 5 1 0.000045 2.65 0.68 .5 0.01 0.075 0.002025 "CM"
CN SND 6 1 0.000088 2.65 0.35 "VFS"
CN SND 7 1 0.000177 2.65 0.35 "FS"
CN SND 8 1 0.000354 2.65 0.35 "MS"
CN SND 9 1 0.000707 2.65 0.35 "CS"
CN SND 10 1 0.001410 2.65 0.35 "VCS"
CN SND 11 1 0.002830 2.65 0.35 "VFG"
CN SND 12 1 0.005660 2.65 0.35 "FG"
CN CLA 13 1 0.00001 1.3 0.98 1.0 0.02 0.005 0.000036 "ROOTS"

```

CN CLA 14 1 0.00002 1.6 0.90 1.0 0.02 0.005 0.000036 "REFRACTORY"

2. An emergent vegetation roughness type (either **FR URV** or **FR EDO**) is used to define the roughness characteristics of material type 2. When no vegetation is present, the undergrowth roughness height (in this example, 0.02) defines the roughness. When vegetation is present, the drag associated with the vegetation is added, in proportion to the modeled vegetation density.

FR URV 2 0.02 0.01 50

3. A **VEG** card is added to associate grains 13 and 14 with roots and refractory sediments, respectively. It also assigns global vegetation growth properties. Note that the card invokes XY1 series 4, so that the equilibrium mass of vegetation can be entered as a time series. This permits temporal (seasonal) adjustment of vegetation growth rate. A description of this card is given at the end of this chapter.

VEG 13 14 4e-8 0.2 4 3.0 1.0 0.1

XY1 4 3 2 0

0 0.1

4344 1.6

8760 0.1

4. A **MP VGM** card is added to ensure that there is no growth for material type 1. This is easily done by setting the rate of wetland vegetation growth equal to 0. Note that one can also use the **MP VGM** card to assign different vegetation characteristics, to permit the growth of various dominant species in the same model domain. A description of this card is given at the end of this chapter.

MP VGM 1 0.0 0.2 4 3.0 1.0 0.1

Note that, since the root and refractory classes are just additional sediment classes, the standard output files associated with bed properties contain all the run-time information for these properties. For example, the total mass of root material in the bed can be found in the *_smr.dat file, in the column that corresponds to the root material (for the example above, column 13). Since the root and vegetation mass are linked by the user-specific root-to-shoot ratio, this information can also be used to investigate the vegetation coverage.

VEG

SEDLIB-VEG: GLOBAL PARAMETERS

Field	Type	Value	Description
1	char	VEG	Card type
2	int	≥ 1	Constituent assigned to represent organic root mass
3	int	≥ 1	Constituent assigned to represent refractory organic mass
4	real	≥ 0.0	Rate of wetland vegetation growth ($M L^{-2}T^{-1}$)
5	real	≥ 0.0	Limiting depth (L): the maximum water depth for which wetland vegetation will grow.
6	int	≥ 1	XY1 series used to define the equilibrium mass per unit area of vegetation (ML^{-2}): this is the mass for which vegetation mortality is equal to vegetation growth.
7	real	≥ 0.0	Root-to-shoot ratio: this is the ratio of root mass to wetland vegetation mass.
8	real	≥ 0.0	Rooting thickness limit (L): this is the maximum distance below the surface of the sediment bed where roots can be found.
9	real	≥ 0.0	Labile fraction: the fraction of dead vegetative material that decays quickly.

MP VGM

SEDLIB-VEG: PARAMETERS BY MATERIAL TYPE

Field	Type	Value	Description
1	char	MP	Card type
2	char	VGM	Card type
3	int	≥ 1	Material type
4	real	≥ 0.0	Rate of wetland vegetation growth ($M L^{-2}T^{-1}$)
5	real	≥ 0.0	Limiting depth (L): the maximum water depth for which wetland vegetation will grow.
6	int	≥ 1	XY1 series used to define the equilibrium mass per unit area of vegetation (ML^{-2}): this is the mass for which vegetation mortality is equal to vegetation growth.
7	real	≥ 0.0	Root-to-shoot ratio: this is the ratio of root mass to wetland vegetation mass.
8	real	≥ 0.0	Rooting thickness limit (L): this is the maximum distance below the surface of the sediment bed where roots can be found.
9	real	≥ 0.0	Labile fraction: the fraction of dead vegetative material that decays quickly.

7 Running AdH

Running AdH for sediment is no different than running it for hydrodynamics. Once the three required files have been created, first run `pre_AdH` to create the necessary input file for AdH. Then run AdH. The commands are:

```
pre_adh filename
adh filename
```

where *filename* is the root of the model's filenames, i.e. for a model named `pl8_AdH` the following three files would be required `pl8_AdH.3dm`, `pl8_AdH.hot` and `pl8_AdH.bc`. All three files must have the same *filename* as their root followed by one of three suffixes.

The standard output for AdH is in a tab delimited format so that it can be easily manipulated by the user. The first column of data gives the physics being solved for that iteration. For hydrodynamics the physics is listed as **HYD** and for transport it is listed as **TRN**. When modeling sediment each suspended load and bedload iteration is listed as **SLT** and **BLT**, respectively. The order of the data in the short column tabular form (**PC LVL 0**) from left to right is physics being solved, time, time step size, percent completion progress, nonlinear iteration number, linear iteration count, node number giving the maximum residual, node number giving the maximum increment norm, node count after adaption, failure flag. The order of the data in the long column tabular form (**PC LVL 1**) from left to right is physics, time, time step size, percent completion progress, nonlinear iteration number, linear iteration count, maximum residual norm, node number giving the maximum residual, x, y, and z-coordinates of this worst node, maximum increment norm, node number giving this maximum increment, x, y, and z-coordinates of this worst node, node count after adaption, failure flag. All time values in the screen output are in seconds. The maximum residual norm is used to determine convergence against the **NTL** value. The maximum increment norm is used to determine convergence against the **ITL** value, if included in the boundary conditions file. If no adaption is taking place, the node count after adaption will not change throughout the run. The failure flag is the **#** symbol and indicates that convergence did not occur, and the time step will be cut to $\frac{1}{4}$ the previous value. This column is left empty in all other instances. For transport iterations, the same information is provided but preceded by a line indicating that the data to follow is from the transport computations.

After the model is run, GMS or SMS can be used to visualize the results. The depth, velocity, and error files are the minimum output files that will be produced in any simulation. Sediment simulations will include concentration output, bed layer output, and bed displacement output. Other output files will be generated depending on the options requested in the boundary conditions file.

Output filename conventions (*.dat)

*_con#.dat	constituent concentration, # = constituent number (scalar, parts per million by mass for sediment), suspended sediment profile factor+, bedload mass per unit area
*err_con#.dat	non-normalized residual error for the transport constituent (scalar)
*_bed_dpl.dat	bed displacement (scalar, meters)
*_alt.dat	active layer thickness (scalar, meters)
*_ald.dat	active layer distribution (scalar, one column for each grain class)
*_blt#.dat	bed layer thickness, # = layer number (scalar, meters, 1 is the bottom-most layer)
*_bld#.dat	bed layer distribution, # = layer number (scalar, 1 is the bottom-most layer, one column for each grain class)
*_cbp#.dat	cohesive bed property, # = layer number (scalar, 1 is the bottom-most layer, one column for each cohesive property)
*_bsh.dat	bed shear stress magnitude (scalar, Pa)
*_smr.dat	sediment mass residual: the total mass of each sediment grain in the bed (kg/m^2 , one column for each grain class)
*_bedload.dat	bedload flux, cumulative value for all grains (vector, $\text{kg}/\text{m}/\text{s}$)
*_susload.dat	suspended load flux, cumulative value for all grains (vector, $\text{kg}/\text{m}/\text{s}$)
*_belev.dat	breach bed elevation (scalar, length)
*_conflx	concentration flux (kg/sec) across a string for each constituent is included when the FLX card is used followed by the string number. This is NOT a file that can be read by SMS. It is designed to be easily opened in a spreadsheet or other post-processor.
*_dredge_record	a record of each dredge and placement event is written if any MP DRD or MP DPR cards are present. The record includes total volume dredged/placed, the porosity of the dredged/placed material, and the fraction of each sediment grain in the dredged/placed material. This is NOT a file that can be read by SMS. It is designed to be easily opened in a spreadsheet or other post-processor.

For a 3-constituent simulation (1 non-sediment constituent and 2 non-cohesive sediment constituents) of 2 grains and 3 bed layers, with constituent 2 and 3 being sediment and no breach, dredging, or FLX cards in the *.bc file, the output files would be: (information in parenthesis gives names for the hotstart file)

*_dep.dat (ioh)	Depth value
*_ovl.dat (ioy)	X_vel, Y_vel, Z_vel (Z_vel = 0 for 2D)
*_err.dat	Residual error (normalized max of hydro and constituent residual error)
*_err_hydro.dat	Hydro non-normalized residual error
*_con1.dat (icon 1)	Constituent 1 concentration (constituent 1 is non-sediment)
*_con2.dat (icon 2)	Constituent 2 concentration, Rouse factor+, bedload mass per unit area
*_con3.dat (icon 3)	Constituent 3 concentration, Rouse factor+, bedload mass per unit area
*_err_con1.dat	Constituent 1 non-normalized residual error
*_err_con2.dat	Constituent 2 non-normalized residual error
*_err_con3.dat	Constituent 3 non-normalized residual error
*_bed_dpl.dat (ibd)	Sediment bed displacement
*_alt.dat (ialt)	Active layer thickness
*_ald.dat (iald)	Constituent 2 active layer distribution, Constituent 3 active layer distribution
*_blt1.dat (iblt 1)	Bed layer 1 thickness
*_blt2.dat (iblt 2)	Bed layer 2 thickness
*_blt3.dat (iblt 3)	Bed layer 3 thickness
*_bld1.dat (ibld 1)	Bed layer 1 constituent 2 fraction, Bed layer 1 constituent 3 fraction
*_bld2.dat (ibld 2)	Bed layer 2 constituent 2 fraction, Bed layer 2 constituent 3 fraction
*_bld3.dat (ibld 3)	Bed layer 3 constituent 2 fraction, Bed layer 3 constituent 3 fraction
*_bsh.dat	Bed shear stress magnitude
*_smr.dat	Constituent 2 mass (all layers), Constituent 3 mass (all layers)
*_bedload.dat	X component of bedload flux, Y component of bedload flux, Z component of bedload flux
*_susload.dat	X component of suspended load flux, Y component of suspended load flux, Z component of suspended load flux

+Suspended sediment profile factor is the ratio of the near-bed concentration to the depth-averaged concentration.

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Appendix A: SEDLIB-VEG Theoretical Development

Introduction

This model is based largely on the work of Fagherazzi et al (2012). The primary differences between this model and the referenced model arise from the fact that this model is being incorporated into an existing sediment model (SEDLIB), so it must make computations that are dependent on local, near-instantaneous conditions (e.g. water depth).

The model is integrated into the SEDLIB sediment module by simply assigning 2 of the sediment classes to be organic classes. The first is the root class: it represents the behavior of the root material. The second is the refractory class: it represents the storage of compacted refractory material.

The root material class is assigned a very low bulk density, commensurate with the bulk density of the rooting zone. The refractory class is assigned a higher bulk density, associated with compacted refractory organics (note that this module does not do compaction: it assumes that the refractory fractions of both litterfall and root decay are immediately compacted).

The only difference between these organic “sediment” classes and the other inorganic classes is that the masses of each of these classes are modified at each time step as a result of vegetative growth and decay.

Primary Productivity Module Algorithm for Wetland Vegetation

The equation for the mass of wetland vegetation at a given time step is given as a basic implicit source/sink mass balance:

$$m_{veg} = \frac{m_{veg,o} + v_{src} \Delta t}{1 + v_{snk} \Delta t} \quad 1$$

The source term is given as a function of local, instantaneous depth:

$$v_{src} = v_{src,m} \left(1 - \frac{h}{h_{dep}} \right) : 0 \leq h \leq h_{dep} \quad 2$$

The sink term is found by setting m_{veg} and $m_{veg,o}$ equal to $m_{veg,eq}$ in (1) and solving for v_{snk} .

$$v_{snk} = \frac{v_{src,m}}{m_{veg,eq}} \quad 3$$

Once m_{veg} has been determined, m_{root} is given as a simple function of the root-to-shoot ratio. $m_{root} = m_{veg} r_{rs}$ 4

The refractory mass is a cumulative mass. It is updated at each time step with the contribution of both decaying vegetation and decaying roots, less the labile material.

$$m_{refr} = m_{refr.o} + m_{veg} (1 + r_{rs}) v_{snk} \Delta t (1 - f_{lab}) \quad 5$$

Integration of Organics into the Sediment Bed

The root mass and the refractory source term are applied in the sediment layers immediately beneath the bed surface. The root mass is assumed to decay exponentially, from a maximum value at the surface, to a (near) zero value at a user defined limiting root thickness (t_{rl}).

The mass added to each bed layer is used to adjust the bed layer thickness. The bed layer thickness of each sediment bed layer is given by the following equation:

$$T_L = \frac{m_L}{\rho s_s (1 - p_L)} \quad 6$$

Where T_L is the thickness of the layer, ρ is the density of water, s_s is the specific gravity of the sediment, and p_L is the porosity of the layer.

To add thickness, therefore, it is only necessary to add mass according to 6. i.e.;

$$\Delta T_L = \frac{\Delta m_{refr}}{\rho s_{refr} (1 - p_{refr})} \quad 7$$

Where s_s and p_L are the specific gravity and the porosity of the added refractory organics.

Figure 1 demonstrates how the addition of root mass and refractory organic mass to the bed layers results in the change in bed surface elevation.

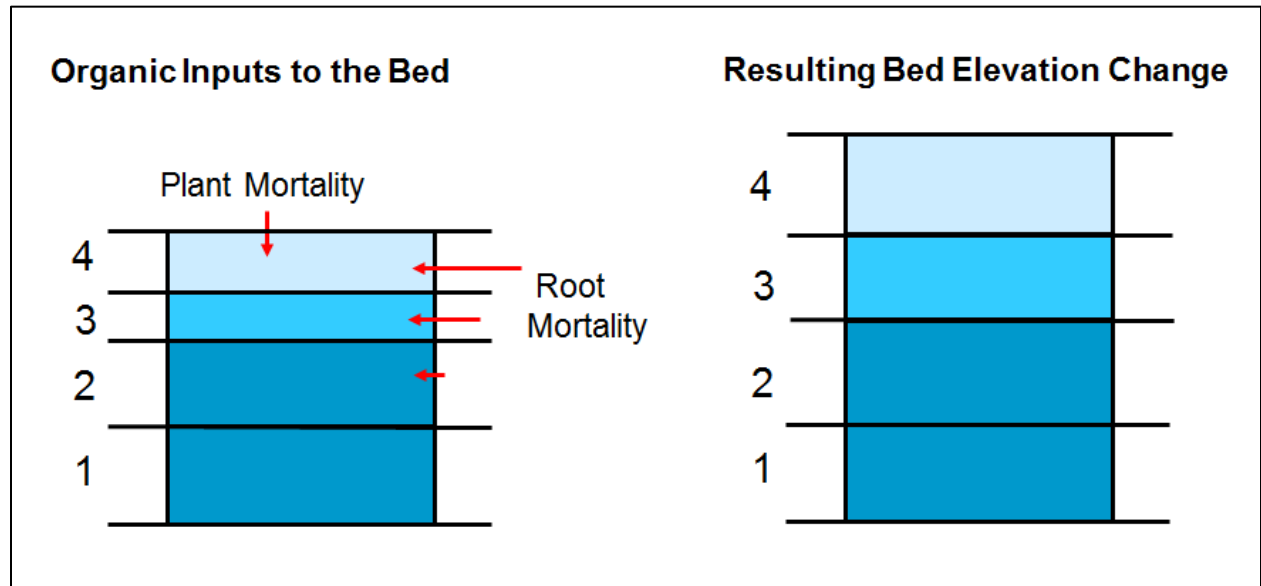


Figure 1: Demonstration of Bed Elevation Change due to Organic Mass Production Associated with Wetland Vegetation.

Each of the terms used in this development are defined below. Terms with an asterisk are user-defined terms.

f_{lab}^* = Labile fraction: the fraction of dead vegetative material that decays quickly.

h_{ldep}^* = Limiting depth (L): the maximum water depth for which wetland vegetation will grow.

m_{refr} = Mass per unit area of the refractory organic material in the sediment bed (ML^{-2})

$m_{refr,o}$ = Mass per unit area of the refractory organic material in the sediment bed at the previous time step (ML^{-2})

m_{root} = Root mass per unit area in the sediment bed (ML^{-2})

m_{veg} = Mass per unit area of wetland vegetation (ML^{-2})

$m_{veg,eq}^*$ = Equilibrium mass per unit area of vegetation (ML^{-2}): this is the mass for which vegetation mortality is equal to vegetation growth.

$m_{veg,o}$ = Mass per unit area of wetland vegetation at the previous time step (ML^{-2})

r_{rs}^* = Root-to-shoot ratio: this is the ratio of root mass to wetland vegetation mass.

t_{rl}^* = Rooting thickness limit (L): this is the maximum distance below the surface of the sediment bed where roots can be found.

Δt = Time step (T)

V_{snk} = Rate of wetland vegetation mortality ($M L^{-2}T^{-1}$)

V_{src} = Rate of wetland vegetation growth ($M L^{-2}T^{-1}$)

$V_{src,m}^*$ = Maximum rate of wetland vegetation growth ($M L^{-2}T^{-1}$)

Demonstration

Figure 2 demonstrates how the wetland vegetation model works. The sediment bed is subjected to a tidal signal, with a mean elevation that increases over time (simulating a sea

level rise rate that exceeds the maximum rate of marsh accretion). Initially, as the marsh inundates, the vegetation grows until it reaches a maximum (where growth and mortality are in balance). The root mass associated with this vegetation increases the bed elevation. Decaying vegetation is added to the refractory mass, further increasing the bed elevation over time.

As the tide range increases further, the mortality exceeds the rate of growth and the vegetation mass is reduced. Eventually, all organic production ceases as the threshold depth for growth has been exceeded for all phases of the tide.

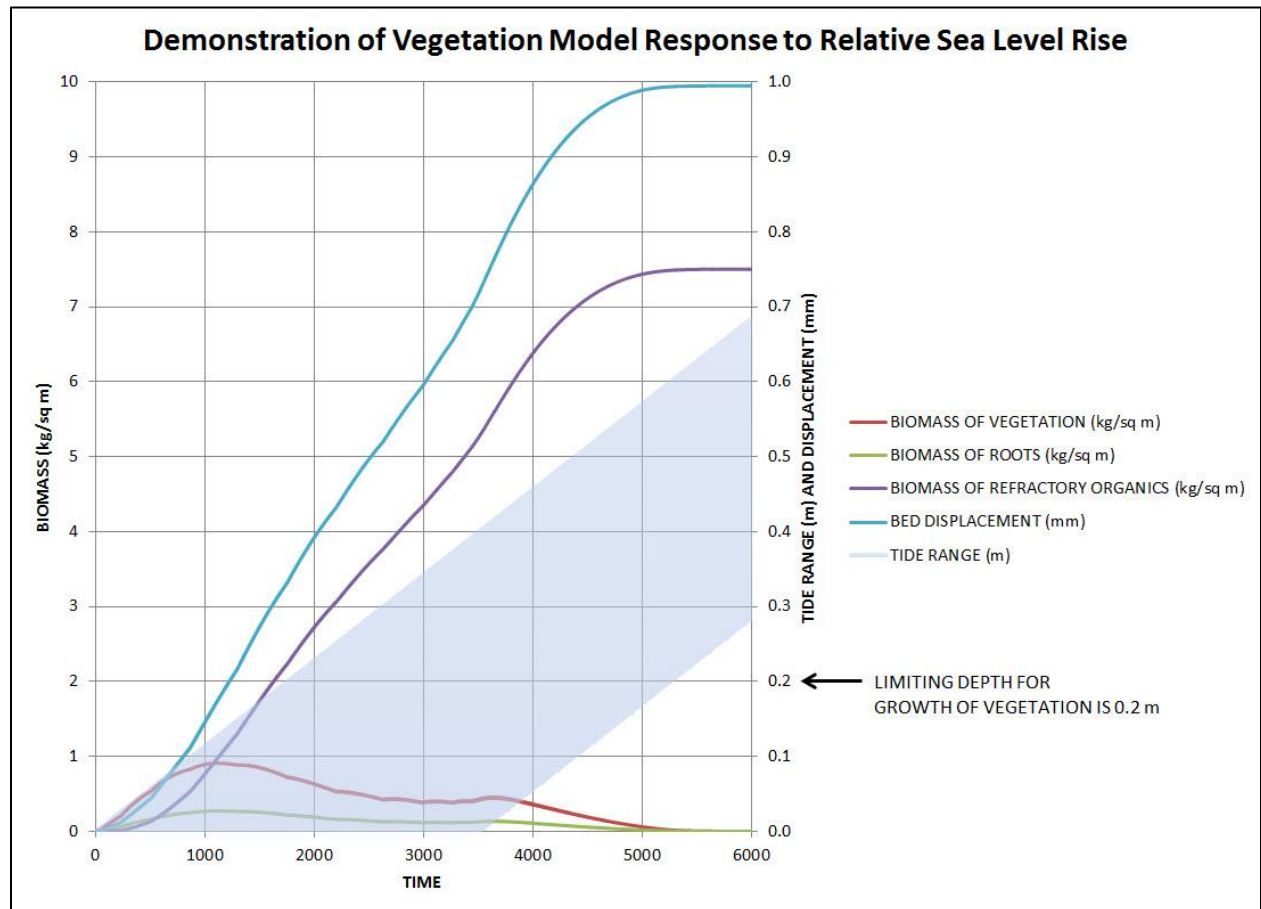


Figure 2: Demonstration of Wetland Vegetation Model

Reference

Fagherazzi, S., et al. (2012), Numerical models of salt marsh evolution: Ecological, geomorphic, and climatic factors, *Rev. Geophys.*, 50, RG1002, doi:10.1029/2011RG000359.

Appendix B: AdH/SEDLIB Boundary Condition and Bed Initialization Tips

Sediment Boundary Condition Development and Bed initialization are always challenging, but crucial, parts of sediment modeling. Ill-considered sediment boundary conditions can result in errant, and potentially unstable, model results. The sediment bed represents the history of the river, so initializing it precisely would require a very long model simulation (on the order of decades) to replicate the spatial characteristics of the strata thicknesses and composition.

Here are some helpful tips to allow the model to approximate the correct boundary and bed conditions, without having to perform decadal simulations.

Non-cohesive Sediment.

Boundary conditions can be applied using observed data, but if the observed concentrations are not consistent with the concentration that the model predicts, the model will quickly correct the concentrations by eroding or depositing the necessary sediment. Hence, it is often better to allow the model to determine the inflowing sand and gravel concentrations. This can be done, for example, as follows:

- Include at least one meander length of river upstream of the area of modeling interest. This is to be used as a boundary condition adjustment zone.
- Use the NDM card to ensure that bed displacement is turned off in this reach. This allows gradational adjustments to the bed without altering the bed elevations.
 - If NDM option 0 is used, the sediment supply is limited to what is present in the bed.
 - If NDM option 1 is used, the sediment supply is unlimited, but the sediment mass is not conserved (i.e. the reach is essentially a boundary condition reach).
- Apply an EQ TRN card to the upstream boundary for each of the sand or gravel classes. This card provides the model with the equilibrium values at the boundary (i.e. that value for which each sediment class is in equilibrium with respect to the bed: there is no net erosion or deposition).
 - Note that EQ TRN cards are not restricted to the model boundary. A node string can be placed anywhere in the mesh, and the EQ TRN card can be assigned there (this is because EQ TRN is applied as a Dirichlet boundary, where the concentration is specified explicitly, as opposed to Natural (Neumann) boundaries, where the flux is specified). So, for some models, it is advantageous to apply the EQ TRN at some short distance downstream of the inflow boundary, so that the model has some

ability to adjust the inflowing velocity distribution to a realistic condition before the sediment boundary is imposed.

Bed initialization is best accomplished by first approximating the bed with initial bed layer conditions, and then allowing the model to run through an initialization period to adjust this estimated bed such that armoring and winnowing in the high energy areas can occur (and fining in the low energy areas).

- Using observed bed gradational data, initialize the sediment bed thicknesses and gradation. Bed thickness can be applied in one of two ways.
 - Thickness by layer (NBL option 0). This is the default method and is straightforward.
 - Thickness by bottom elevation threshold (NBL Option 1). In this method, an elevation horizon is given for the bottom of each bed layer. See the documentation for more details. This method allows horizontal strata to be defined, rather than constant thicknesses.
- Once the sediment bed has been approximated, the model should be simulated through a representative hydrologic event (such as a flood hydrograph) to generate spatially varying initial bed conditions. This is best done using NDM (no bed displacement) cards with option 1 (i.e. sediment mass is not conserved, but the bed elevation and the solid boundary elevation are held constant).
- Once this spin-up simulation is completed, build a full sediment hotstart file from this run, and then run the model using this hotstart file with the NDM cards that were used for initialization either turned off (disabled) and/or converted to NDM option 0 cards (that are mass conservative).

Cohesive Sediment

Boundary conditions should be applied using observed data. Rating curves can be used, but cohesive sediment tends to be poorly correlated to river discharge, since the first flush of a hydrograph tends to have much higher concentrations than other parts of the hydrograph.

Bed conditions are highly dependent on observed data. For simulations where erosion is not of great concern (e.g. reservoir deposition, or floodplain deposition), it is possible to get good modeling results using nominal (literature) values to populate the erosion characteristics. For this case, it is only important to have data concerning the settling characteristics of the sediments. (i.e. are they flocculated, what is their size breakdown?)

If, however, erosional characteristics are important (such as reservoir scour under very high flow), it is crucial to have observed data from some type of erosion testing apparatus (e.g. SEDFLUME). Properly characterizing fine sediment erosion characteristics will require a significant investment if sufficient data are to be collected to support the modeling. The model is only as good as the input data, and the erosion characteristics of cohesive beds tend to be spatially heterogeneous and vary over orders of magnitude. Good erosion data are necessary to develop a good model.

Some typical values of these parameters are given below. These are loosely based on values taken from The USBR Erosion and Sedimentation Manual (2006). These are approximate. Local observational data are always preferable to approximated values.

- *Settling Velocity* - .01 mm/sec (free settling of fines) to 10 mm/sec (large flocs)
- *Critical Shear for Deposition* – 0.06 Pa to 0.15 Pa
- *Critical Shear for Erosion* - .05 Pa to 1.0 Pa
- *Erosion Rate Constant* - .001 kg/m²/s to 0.1 kg/m²/s
- *Erosion Rate Exponent* – 1 to 3

Appendix C: Morphologic Time-Scaling with Modified Porosity

Theoretical Foundation of Modified Porosity Scaling

In order to investigate long-term (multi-annual to multi-decadal) morphological changes, it is useful to develop a means whereby morphologic change can be “accelerated” within the model. For quasi-steady conditions (i.e. slowly-varying conditions) a simple and straightforward method of estimating this acceleration is to scale the porosity of the sediment. Consider the basic equation of mass conservation for a sediment bed (for simplicity, this is shown for a bed consisting of one grain class only, but the same principles apply for a multi-grain class sediment bed).

$$D - E = \rho s (1 - p) \frac{\partial \eta}{\partial t} \quad 1$$

That is, the deposition flux minus the erosion flux is equal to the density of sediment, times one minus the porosity, times the time rate of change of the bed elevation.

If we wish to accelerate the rate at which the same net flux (deposition minus erosion) will change the bed elevation by some acceleration factor β , we can substitute into Equation 1 and solve for the porosity necessary to achieve this acceleration (p_β).

$$D - E = \rho s (1 - p) \frac{\partial \eta}{\partial t} = \rho s (1 - p_\beta) \beta \frac{\partial \eta}{\partial t} \quad 2$$

$$\boxed{p_\beta = 1 - \frac{1}{\beta} (1 - p)} \quad 3$$

Where ρ is the density of water and s is the specific gravity of the sediment.

Figure 1 demonstrates how porosity scaling works for a wetland formed under steady inflow conditions.

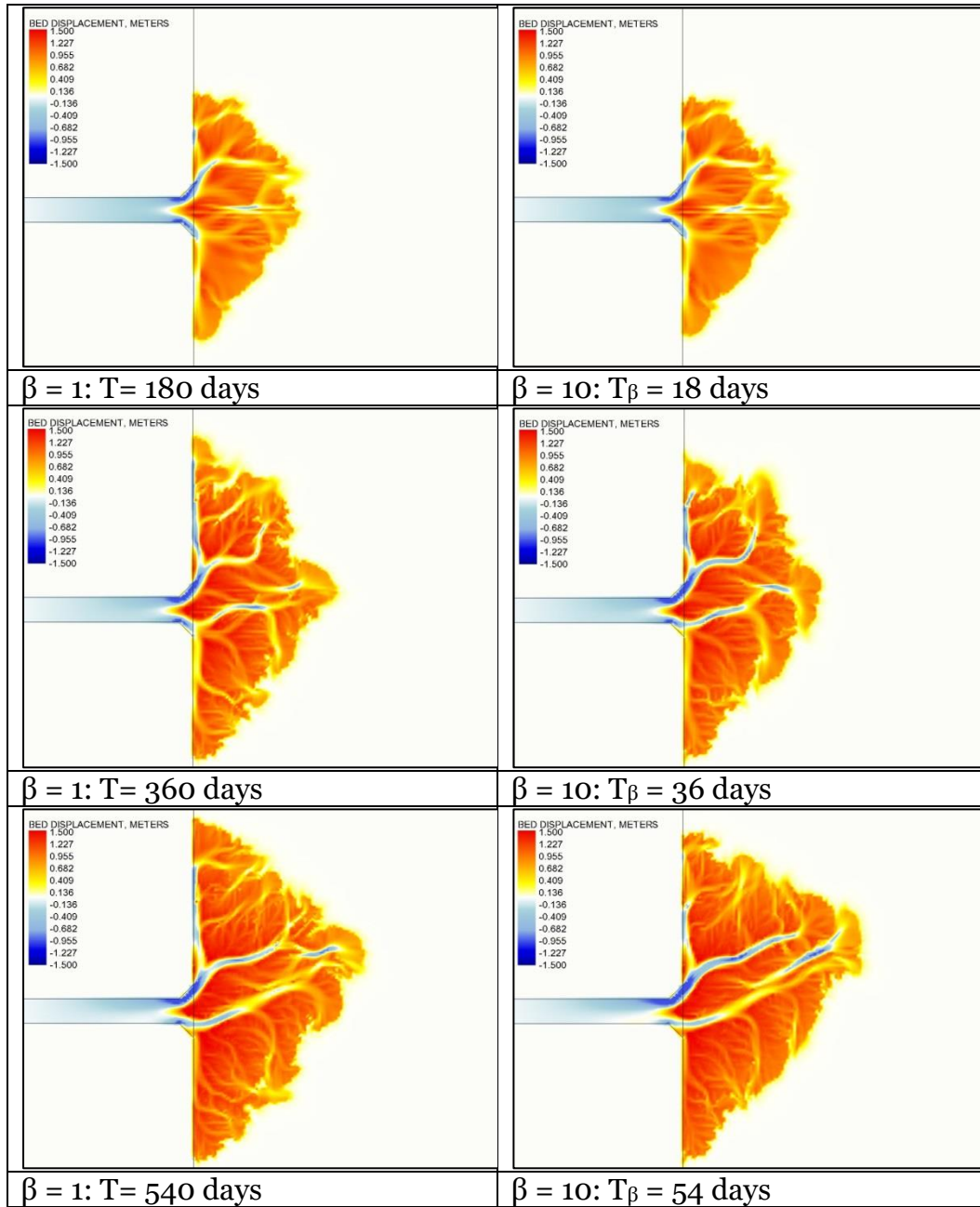


Figure 1: Demonstration of Porosity Scaling for a Wetland Formed by a Steady Inflow of Water and Sediment

Practical Limits of Modified Porosity Scaling

Note that porosity scaling is only strictly valid for steady flow conditions. When unsteady conditions are present, time scaling will scale the relative magnitude of the temporal terms in the mass and momentum equations by the same scale factor (β).

For a typical river hydrograph, using a value of β that is too large will result in significant changes in the velocities, due to rapid rise and fall of the hydrograph in the scaled condition. These changes will alter the erosion and deposition patterns of the river, and hence the porosity scaling method of time acceleration would yield invalid results.

If there are short period variations in the time series data for the inflow boundary and/or the stage boundary, it may be useful to filter these data to smooth these variations. Note, however, that this filtering should only be done if the short period variations are not significant factors in the morphologic evolution of the system.

There is no systematic way to determine what the maximum allowable value of β is for any given project. Therefore, for each project, it is important to perform a numerical test (such as the one demonstrated in Figure 1) to ensure that the selected value of β yields morphologic results that are sufficiently similar to the unscaled results to permit the use of porosity scaling for the project. The results of this test should be included in the project reporting.

The time series associated with the hydrograph data should be scaled by the inverse of β . For example, if $\beta = 10$ and the total elapsed time of the hydrograph (T) is 10 years, then the total elapsed time of the scaled hydrograph (T_β) should be $10/10 = 1$ year. This is how model performance is improved: since the model time step is unchanged, the model will run 10 times faster than it would have without the porosity scaling.

Regardless of the results of the sensitivity analysis, it is recommended that the value of β never exceed 10. This is because values larger than 10 result in very large values of scaled porosity, which in turn can result in asymptotic errors associated with the projection of bed change (note that Equation 1 is a function of $(1 - p)$, which asymptotically approaches 0 for large values of p).

Morphologic Acceleration of Dynamic Conditions using the Quasi-Steady Approximation.

If a user wishes to apply morphologic acceleration to a hydrograph with significant variations in river stage, it is necessary to introduce an additional approximation. The dynamic hydrograph must be approximated as series of steady flows of different magnitudes. The user can then pause sediment transport during the parts of the hydrograph where the model is transitioning between flows (in AdH, this done by applying SP NST cards), and the re-enable sediment transport when the new hydrodynamic conditions have stabilized.

Figure 2 illustrates how this methodology can be applied. The observed hydrograph is approximated as a series of quasi steady flows, and sediment transport is only active when the flows are steady.

Note that the utilization of this technique introduces an additional approximation into the morphologic acceleration methodology. Therefore, it is important to include the application of this technique when developing the numerical tests use to validate the accelerated model against the unscaled solution.

Note also that the time scaling must factor in the gaps in time between the regions where sediment simulation is occurring. For example, if the selected scale factor is 10, but only 70% of the duration of the hydrograph is included in the sediment simulation time (i.e. only 80% of the hydrograph is shaded yellow in Figure 2), then the true scale factor is $\sim 0.7 \times 10 = 7$. The adjustment is not exact, because the quasi-steady hydrograph is also an approximation that influences the result.

All of these additional considerations are a consequence of the use of the quasi-steady hydrograph to perform morphologic acceleration.

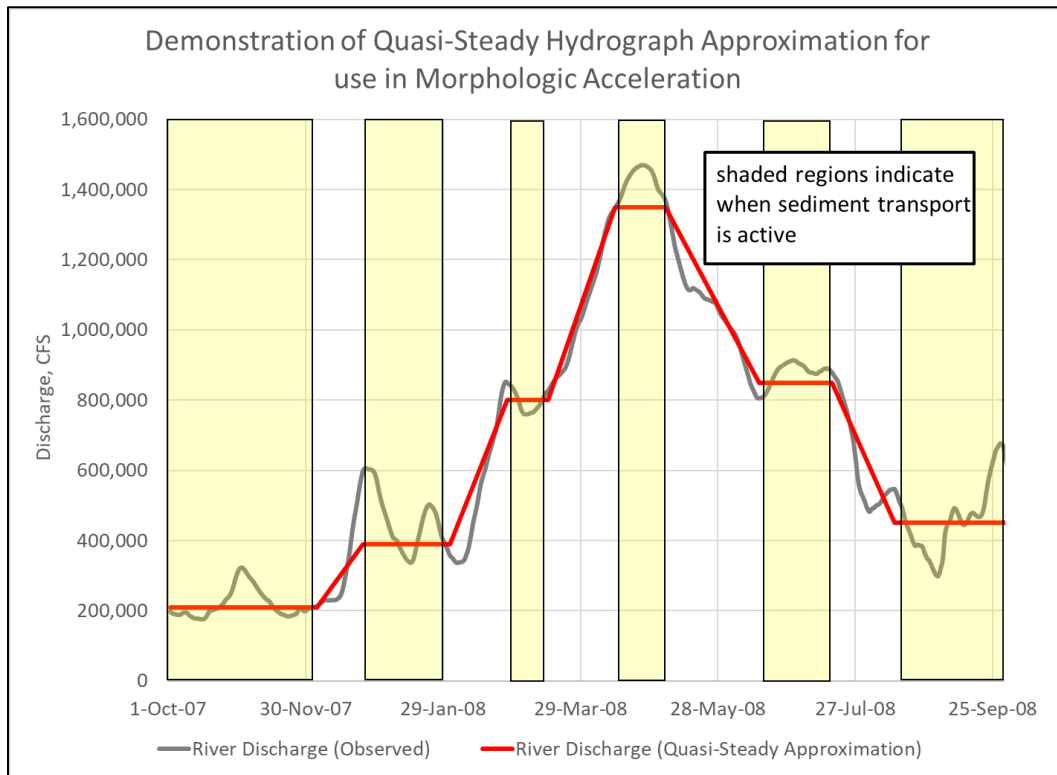


Figure 2: Demonstration of Quasi-Steady Hydrograph Approximation for use in Morphologic Acceleration

Inclusion of High Frequency Periodic Forcings (e.g. tides).

It has been noted that this scaling cannot be applied to high frequency variations, such as tidal conditions, because scaling this high frequency signal would dramatically alter the resulting velocities. However, if it is assumed that the influence of the high frequency signal is largely periodic, the signal can be modeled without scaling if the *number* of cycles within a simulation is scaled. For example, if $\beta=10$, $T=10$ years, and there are 360 cycles in 1 year (e.g. a 24hr tidal signal), the river and tide can be modeled within the same model as follows:

- River: $\beta=10$, $T_\beta=1$ year
- Tide: $\beta=1$, $T_\beta=1$ year, total number of tides modeled = 36.

Again, testing of these methods should be performed for any specific application before they are used to assess scenarios.

Appendix D: Table of Non-cohesive Sediment Entrainment Options

Suspended Load

Name	Description	Validity	Reference
Garcia-Parker	Semi-empirical model: dimensional analysis used to develop theoretical basis, laboratory data used to calibrate coefficients	Single grain size, tested against laboratory data, Range of conditions tested: u^*/w_s : 0.7 – 7.5: u^*d/v : 3.5-37	Garcia, M., and Parker, G. (1991). "Entrainment of bed sediment into suspension," <i>Journal of Hydraulic Engineering</i> , 117(4),414.
Wright Parker	This expression is an improvement of the Garcia-Parker method, offering corrections for the interaction of multiple-grain sized sediments and introducing an energy slope term that renders the method useful in large rivers. Tested against data from several large rivers including the Mississippi, Atchafalaya, and Red Rivers.	The same range of testing as Garcia-Parker, but extended to lower slope conditions (large rivers)	Wright, S., and Parker, G. (2004). "Flow resistance and suspended load in sand-bed rivers: simplified stratification model," <i>Journal of Hydraulic Engineering</i> , 130(8),796.
Van Rijn	Theoretical formulation from 1984, modified for multiple grain classes and sloping beds by Kleinhans and van Rijn. To estimate the near-bed distance, which is defined as half the bedform height, the the bedform height is estimated from van Rijn (1984).	Tested against field and observed data. Initial testing range for sand-size was 0.18 to 0.7 mm.	van Rijn ,L.C. 1984, Sediment Transport, Part II: Suspended Load Transport, <i>J. Hydr. Engrg.</i> Vol. 110, no. 11 van Rijn ,L.C. 1984, Sediment Transport, Part III: Bedforms and Alluvial Roughnesses, <i>J. Hydr. Engrg.</i> Vol. 110, no. 12
Yang	Semi-empirical formulation based on stream power. The equation was calibrated against multiple flume data sets, and validated against multiple observed suspended sediment samples in rivers.	NOTE: this is a TOTAL load equation; the user should set bedload to -1. For sand sizes < 2mm.	Yang, C. T.: 1973, 'Incipient Motion and Sediment Transport,' <i>J. Hydraulics Div., ASCE</i> 99, 1679.

Bed Load

Name	Description	Validity	Reference
Van Rijn	Theoretical formulation from 1984, modified for multiple grain classes and sloping beds by Kleinhans and van Rijn (2002).	Tested against field and observed data. Initial testing range for sand-size was 0.3 to 1.5 mm.	van Rijn, L.C. 1984, Sediment Transport, Part I: Bedload Load Transport, J. Hydr. Engrg. Vol. 110, no. 10 Kleinhans, M.G. and van Rijn, L.C., 2002, "Stochastic Prediction of Sediment Transport in Sand-Gravel Bed Rivers", <i>Journal of Hydraulic Engineering</i> , Vol. 128, No. 4, April 2002.
Meyer-Peter Mueller	Semi-empirical expression that computes bedload as a linear function of stream power.	Tested against laboratory data, mostly gravels (3 mm to 28 mm) with some sand.	Meyer-Peter, E., and Müller, R. (1948). "Formulas for bed-load transport." <i>Proc., 2nd Meeting, IAHR</i> , Stockholm, Sweden, 39-64.
Meyer-Peter Mueller with Wong-Parker Correction	Results of a reanalysis of Meyer-Peter/ Mueller. Provides better prediction for plane-bed conditions	Same data as MPM	Wong, M. and Parker, G. (2006). "Reanalysis and Correction of Bed-Load Relation of Meyer-Peter and Müller Using Their Own Database." <i>J. Hydraul. Eng.</i> , 132(11), 1159–1168.
Wilcock	Empirical method for sand and gravel bed streams. Relies on local data to parameterize critical shear for sand and gravel independently.	NOTE: this is a TOTAL load equation; the user should set suspended load to -1.	Wilcock, P. R. 2001. Toward a practical method for estimating sediment-transport rates in gravelbed rivers. <i>Earth Surface Processes and Landforms</i> . 26: 1395-1408.