SOFTWARE VALIDATION TEST PLAN AND REPORT FOR CHANNEL–HILLSLOPE INTEGRATED LANDSCAPE DEVELOPMENT (CHILD) VERSION 2.3.0

Prepared for

U.S. Nuclear Regulatory Commission
Contract NRC–02–07–006

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November 2008

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CONTENTS

FIGURES

TABLES

SOFTWARE VALIDATION TEST PLAN AND REPORT FOR CHANNEL–HILLSLOPE INTEGRATED LANDSCAPE DEVELOPMENT (CHILD) VERSION 2.3.0

This is a software validation test plan and report for acquired software Channel–Hillslope Integrated Landscape Development (CHILD) (Tucker, et al., 1999, 2001). The CHILD model simulates landscape evolution and provides information about the potential for localized channel development. CHILD was recommended to the U.S. Nuclear Regulatory Commission (NRC) staff (Walter and Dubreuilh, 2007) as a potentially useful erosion code. This recommendation was based on a review of codes that could simulate erosion of engineered closure caps installed over radioactive waste processing tanks that are planned for in-place closure under provisions of the National Defense Authorization Act (NDAA) of Fiscal Year 2005. CHILD can simulate changes in cover topography and provide information about the potential for localized channel development in a cover. CHILD can provide information about the susceptibility of engineered closure caps to long-term erosion and the style of resulting erosion features and thus should be useful for evaluating the long-term integrity of engineered closure caps. The NRC staff interest in CHILD is mainly from the standpoint of simulating the landscape evolution of engineered waste disposal covers and surrounding terrain over a period on the order of thousands of years.

Based on consideration of the possible cover designs that might be proposed for in-place tank closures, the environmental processes affecting the performance of such covers, and the information likely to be available for assessing the performance of these covers, the following features were determined to be desirable for these erosion assessment codes under as-built and future conditions:

- Physics-based models and database representation of erosion processes appropriate for future cover properties and climate

- Ability to simulate changes in cover topography due to short-term and long-term processes

Major physical processes CHILD can model include fluvial sediment transport, diffusive sediment transport (e.g., soil creep, rainsplash, and rockslide), vegetation cover effects, and the topographic and erosional effects of tectonic uplift, sediment deposition, layered stratigraphy, slope failure, and storm events (Table 1).

Table 1. Physical Processes Enabled for Each Test Case

Test Case	Sediment Transport		Vegetation Cover	Tectonic Uplift	Storm Events	Layered Stratigraphy	Sediment Deposition	Slope Failure
	Fluvial	Diffusive						
1	X				X	X		
2	X				X	X		
3	X				X	X	X	

This report conforms to the software validation requirements of Technical Operating Procedure 18 (TOP–018)—Development and Control of Scientific and Engineering Software. Software is validated to gain confidence that software successfully implements underlying theory and algorithms. Software validation test plans describe test cases that will provide evidence supporting the correct and successful implementation of software functions.

This report is organized consistent with the existing template for all such software validation exercises. Section 1 provides the scope of the software validation; Section 2 lists the report references; Section 3 describes the software and hardware environment associated with software validation testing; Section 4 describes software assumptions and any constraints; and Section 5 describes the test cases used to validate the functionalities of the software and the results of the software validation tests. Per NRC staff request, conclusions are provided in Section 6.

1 SCOPE OF SOFTWARE VALIDATION

CHILD is a finite-element landscape erosion and evolution model that simulates development of channels and erosion of hillslopes. CHILD uses a physics-based approach applied over a three-dimensional volume that allows representation of complex topography and changes to topography based on soil loss and deposition. CHILD implements a partial differential equation of the form (Tucker and Bras, 1998)

$$\frac{\partial z}{\partial t} = U - \frac{\partial Q_s}{\partial s} + H(x, y, t) \tag{1}$$

to describe the catchment elevation within a watershed where

z	—	land surface elevation at lateral location (x, y) [L]
U	—	rate of tectonic uplift [L/t]
Q_s	—	fluvial sediment transport flux in the direction, s, of surface water flow [L^2/t]
$H(x, y, t)$	—	function [L/t] describing land surface elevation changes due to diffusive transport processes, such as soil creep, rainsplash, and rockslide

The sediment flux in Eq. (1) is a nonlinear function of semiempirical parameters that relate sediment particle transport to surface water flow, land surface slope, and soil properties. The CHILD model simulates landscape evolution by tracking the passage of water and sediment across an irregular lattice of points that represents the landscape surface (Tucker, et al., 1999). Water is routed from node to node with a variable timestep, and every iteration corresponds to a storm event with rainfall intensity and duration, which later defines the hydrological model to use. CHILD has an elaborate representation of fluvial processes calculating channel depth and width within the node. CHILD can construct simple alluvial stratigraphies by entering grain sizes and regolith thicknesses and can record the age of deposits.

CHILD uses an adaptive irregular mesh instead of a regular grid, so areas where a frequent activity occurs will have more nodes (i.e., higher spatial resolution than the surrounding landscape). Nodes may be moved, deleted, or added to accommodate the meandering of channels. A mesh can be generated from

- An existing triangulated irregular network (TIN) output from a geographic information system (GIS) or a previous CHILD run

- An existing ASCII file containing *x*, *y*, *z* triplets

- A digital elevation model (DEM) in ArcInfo ASCII GRID format

CHILD output consists of a set of ASCII files, each file containing one type of information [i.e., node coordinates, edges and triangle identifiers (IDs), elevation, slope drainage area, surface flow directions, surface water discharge, surface sediment composition, layer data, and information on mesh triangulation]. CHILD has no graphic capabilities, but the output files can be processed and visualized using standard numerical mathematics software packages (e.g., Matlab®).

The CHILD code includes two simple algorithms for simulating landslides due to slope failure (Tucker and Bras, 1998). The first algorithm generates a landslide when the simulated land surface slope in a model cell exceeds a user-specified critical value. Once the critical slope is exceeded, sediment is progressively transported downslope from the cell until the slope decreases to the critical value. This takes place during a single timestep.

The second slope stability algorithm is termed “pore pressure induced” landsliding (Tucker and Bras, 1998). This algorithm uses the infinite slope stability model to identify cells with unstable slopes. Landsliding occurs when (i) the soil in the cell is calculated to be water saturated based on the user-specified precipitation rate and drained area of the cell and (ii) the slope angle exceeds the user-specified angle of friction. Although the slope stability algorithms in CHILD are mechanistically rather simple, the CHILD code could be useful for simulating complex, heterogeneous slopes that might develop on an aged soil cover.

CHILD calibrations and application validations performed by others have focused on statistical comparisons between landscapes evolved using the model and observed landscapes developed over as many as 36 years (e.g., Campo, et al., 2008). Campo, et al. (2008) evaluated the capability of CHILD to simulate gully erosion using topographic field data. This study calibrated the headcut retreat module of CHILD by adjusting the shape factor parameter to give results consistent with observed development of a single gully. Modeled headcut retreat rates and observed retreat rates for five additional gullies then differed, on average, by less than 5 cm/yr [2 in/yr] with a standard deviation of 10 cm/yr [4 in/yr].

CHILD includes a wide range of features, not all of which are addressed via this software validation. The features and options of CHILD not specifically considered in this software validation should be tested as specific modeling needs arise, and site-specific data should be used to populate any model constructed for oversight or regulatory purposes. In developing the simulation test cases for this software validation, the documentation of input parameters the code developers provided (Tucker, 1999) was found to be incomplete and, in some cases, ambiguous as to parameter usage and effect. Because this type of code is without benchmarks and in light of code documentation deficiencies, this report describes a “limited validation” of CHILD. The scope of this software validation is limited to confirmation that the software represents physically expected landscape evolution when applied to several stylized problems. Full validation of the entire suite of features offered by the code to support its use in oversight or regulatory analyses will require either more complete documentation from the code authors or detailed inspection and flow charting of the source code to clarify the input data. Various features could also be fully validated by replicating results from appropriately posed laboratory-scale physical analog models of landscape evolution.

Specific software validation simulations for engineered soil cover landscape evolution include

- Test Case 1: Comparison of Slope Angle Effect on Output Using Mounds With 10 and 20 Percent Slopes

- Test Case 2: Comparison of Surface Roughness Effect on Output

- Test Case 3: Comparison of Erosion Only to Erosion/Deposition and Effect on Output

The expected results of these three software validation test cases are that (i) more erosion should occur on a steeper slope than on a shallower slope, all other parameters held constant; (ii) multidirectional, branching channelized erosion should occur on a mound exhibiting roughness, whereas only unidirectional erosion should occur on a mound exhibiting perfectly smooth surfaces; and finally, (iii) a system that only erodes and does not deposit sediment will result in more total erosion than a system wherein both processes are active. Taken together, these three software validation exercises objectively, but nonquantitatively, indicate that the CHILD code produces physically realistic and expected landform characteristics with the passage of time. As such, this report documents the activities associated with the “limited validation” of CHILD.

2 REFERENCES

Campo, M.A., J.H. Flores-Cervantes, R.L. Bras, and J. Casalí. “Evaluation of a Gully Headcut Retreat Model with a Field Data Set.” *Geophysical Research Abstracts.* Vol. 10. EGU2008–A–10723. 2008.

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Tucker, G.E. and R.L. Bras. “Hill Slope Processes, Drainage Density, and Landscape Morphology.” *Water Resources Research*. Vol. 34. pp. 2,751–2,764. 1998.

Tucker, G.E., S.T. Lancaster, N.M. Gasparini, and R.L. Bras. *The Channel–Hillslope Integrated Landscape Development (CHILD) Model, in Landscape Erosion and Evolution Modeling.* R.S. Harmon and W.W. Doe III, eds. Norwell, Massachusetts: Kluwer Academic/Plenum Publishers. pp. 349–388. 2001.

Tucker, G.E., N.M. Gasparini, R.L. Bras, and S.L. Lancaster. "A 3D Computer Simulation Model of Drainage Basin and Floodplain Evolution: Theory and Applications." Champaign, Illinois: U.S. Army Corps of Engineers, Construction Engineering Research Laboratory. 1999.

Walter, G. and P. Dubreuilh. "Evaluation of Approaches to Simulate Engineered Cover Performance and Degradation." San Antonio, Texas: Center for Nuclear Waste Regulatory Analyses. 2007.

3 ENVIRONMENT

3.1 Software

CHILD Version 2.3.0 was obtained from Massachusetts Institute of Technology, Rafael L. Bras' Research Group. The source code was compiled on a SUN machine (SunOS v5.9), using the following command:

make –f childrx.mk

No issues were found at compilation.

Data input and postprocessing of output was performed with MATLAB 7.1, Surfer 8.04, and Microsoft® Excel® 2002 SP3.

3.2 Hardware

CHILD simulations were performed on a Sun Fire V880Z (6 x UltraSPARC-III @ 1200MHz) with 20G RAM.

4 ASSUMPTIONS AND CONSTRAINTS

Because of the incomplete documentation of the code, the assumptions behind many of the input variables and their effect on the simulation could not be evaluated within the scope of this software validation. Estimates of model parameters to be used in constitutive relationships should be derived from field experiments or appropriate literature before applying CHILD to landscape evolution of an engineered closure cap. In addition, landscape evolution changes CHILD calculated for the period starting at the end of the institutional control period are likely to be strongly dependent on initial conditions (cover topography, soil properties). For long-term engineered soil cover assessment, a very important initial condition would be the cover topography at the end of institutional control, which is unknown and would have to be assumed. The initial conditions will have some degree of uncertainty because they cannot be accurately known now for the period that follows active institutional control.

5 TEST CASES

5.1 Test Case 1: Comparison of Slope Angle Effect on Output Using Mounds With 10 and 20 Percent Slopes

5.1.1 Test Input

A 100- by 100-m [328- by 328-ft] engineered soil cover is defined, and bounding coordinates for a 10 and 20 percent soil cover slope are specified (Figure 1) as the initial rudimentary geometry for Test Case 1. Depending on whether the 10 percent side slope or the 20 percent side slope is being considered, the maximum nominal elevation of the mound is 3 or 6 m [10 or 20 ft] above a 0-m [0-ft] horizontal datum, respectively.

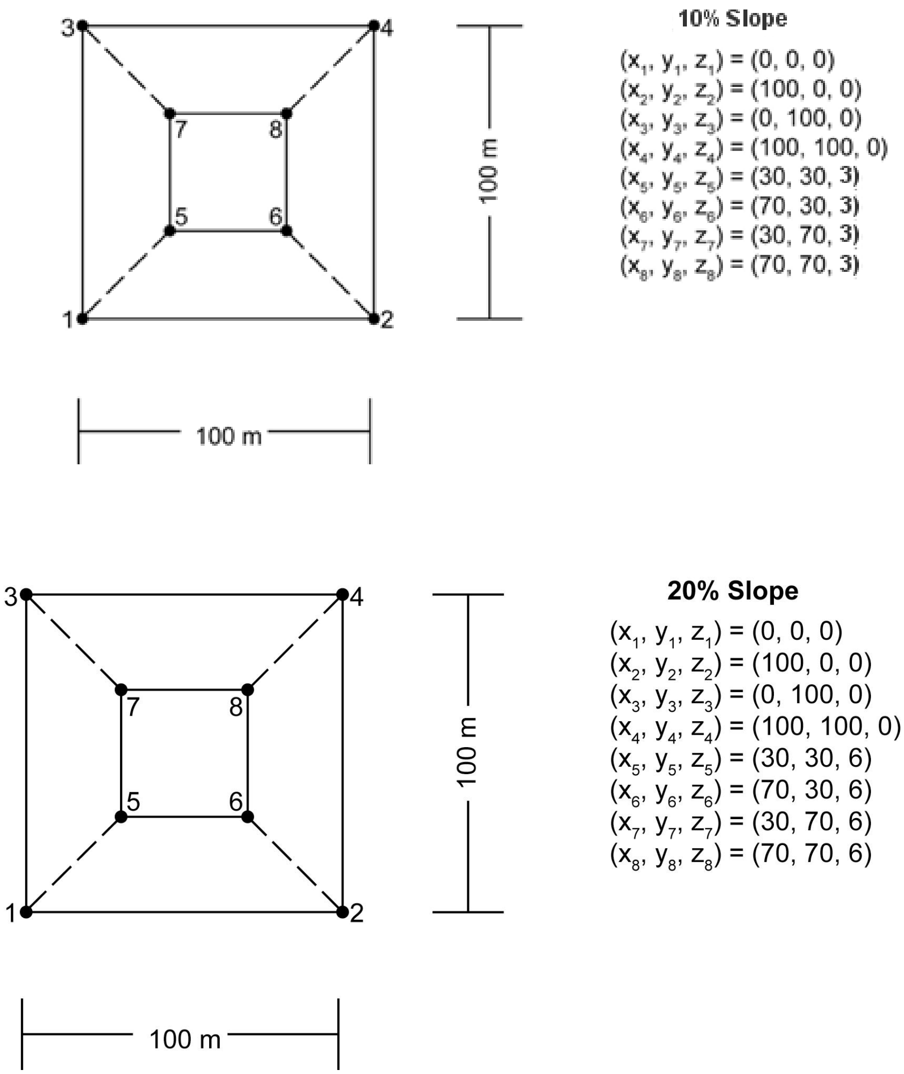


Figure 1. Test Case 1: Initial Rudimentary Topography of Simulated Engineered Soil Cover With Slopes Specified as 10 and 20 Percent

Preprocessing to produce gridded digital terrain models was performed. Otherwise planar topographic surfaces were given a Gaussian surface roughness with a mean of 0.1 m [0.3 ft] and a standard deviation of 0.1 m [0.3 ft]. Data were exported in ASCII *x,y,z* format and adapted to the format CHILD requires using Microsoft Excel. This ASCII format consists of a header line that gives the number of points, followed by a series of rows that contain the *x, y,* and *z* coordinates, and a boundary code for each point. The possible boundary codes are 1 for closed boundary, 2 for open boundary, and 0 for mesh interior. The file was saved as a space delimited file. A *dos2unix* file utility converter was used to convert the ASCII file from DOS to UNIX format. The input files were *mound_rand_3.dat* and *mound_rand_6.dat.* The selected physical parameters are summarized in Table 2.

5.1.2 Test Procedure

1. Using a text editor, modify the provided CHILD input file (*mound.in*) by setting up the parameters above. The test procedure uses a mesh constructed from an input set of (*x*,*y*,*z*) points. To create a mesh from a set of points, set the OPTREADINPUT option to 2. You will then need to specify the name of the ASCII file (parameter POINTFILENAME) containing the point data.

2. Verify that the total simulation run time (i.e., RUNTIME) is 1,000 years and output interval is 200 years. There is no need to set up SEED parameter.

3. Run the code by entering the following command:

   $ child mound.in

4. Do the above steps twice, once for the 10 percent slope (i.e., set POINTFILENAME as *mound_rand_3.dat* and OUTFILENAME as *mnd_rnd_3_1000*) and once for the 20 percent slope (set POINTFILENAME as *mound_rand_6.dat* and OUTFILENAME as *mnd_rnd_6_1000*).

5. Using Matlab: Visualize the initial and final landscapes using *mmesh.m*; difference the initial and final landscapes to visualize the elevation difference after 1,000 years using *diffmesh.m*.

6. Using calculated *z* values from *mnd_rnd_3_1000.z* and *mnd_rnd_3_1000.z*, compare the mean elevation change between these two runs.

By default, CHILD outputs several ASCII files with information written at selected intervals beginning with the initial state of run (OPINTRVL was set at 200 years). The format of each file is described in Tucker (1999). This test will analyze only four of these files containing the nodes '*.nodes*', edges '*.edges*', elevation '*.z*', and information on the mesh triangulation '*.tr*'.

Having identical input parameters, the CHILD simulation for a 20 percent side slope should produce more sediment erosion than a CHILD simulation for a 10 percent side slope.

To validate CHILD, the mean elevation (*z*) will also be examined for the 20 and 10 percent side slopes.

Table 2. Default Physical Parameters Used in Test Case 1 Simulations	
Duration of Run (yr)	1,000
Output Interval (yr)	200
Climate Parameters (OPTVAR = 0)	
Mean Rainfall Intensity (m/yr)	35.3
Mean Storm Duration (yr)	5
Mean Time Between Storms (yr)	15
Runoff Generation and Flow Routing	0
Flow Generation Option (0 = Hortonian)	0
Fill Lakes	1
Erosion and Sediment Transport Parameters	
Detachment Law – Power Law, Form 1	0
Transport Law – Wilcock Sand-Gravel SGFormula	3
Option for Detachment-Limited Erosion Only (OPTDETACHLIM)	0
Bedrock Erodibility Coefficient (dimensions in m/yr) (KB)	1×10^6
Regolith Erodibility Coefficient (dimensions same as KB) (KR)	1×10^6
Shear Stress (or Stream Power) Coefficient (m^3/yr) (KT)	987.3
Bedrock Erodibility Specific Discharge Exponent (MB)	0.66667
Bedrock Erodibility Slope Exponent (NB)	0.66667
Exponent on Excess Erosion Capacity (e.g., Excess Shear Stress) (PB)	1.5
Critical Shear Stress For Detachment-Limited-Erosion (kg/m/s^2) (TAUCD)	1
Diffusivity Coefficient (m^2/yr) (KD)	0
Diffusion Erodes and Deposits (OPTDIFFDEP)	0
Stratigraphy: Bedrock and Regolith	
Initial Depth of Bedrock (BEDROCKDEPTH) (m)	1×10^6
Initial Regolith Thickness (REGINIT) (m)	5.0
Maximum Depth of a Single Regolith Layer (MAXREGDEPTH) (m)	3.0
Grain Size Parameters	
Number of Grain Size Classes (NUMGRNSIZE)	1
Proportion of Sediments of Grain Size Diam1 in Regolith (REGPROPORTION1)	1.0
Proportion of Sediments of Grain Size Diam1 in Bedrock (BRPROPORTION1)	1.0
Representative Diameter of First Grain Size Class (m) (GRAINDIAM1)	0.0005
Hydraulic Geometry Parameters	
Option for Channel Width Closure (CHAN_GEOM_MODEL)	1
Coefficient on Downstream Hydraulic Width Relation (m/(m^3/s) (HYDR_WID_COEFF_DS)	10
Exponent on Downstream Hydraulic Width Relation (HYDR_WID_EXP_DS)	0.5
Coefficient on Downstream Hydraulic Depth Relation (HYDR_DEP_COEFF_DS) (m/(m^3/s)^exp)	1.0
Exponent on Downstream Hydraulic Depth Relation (HYDR_DEP_EXP_DS)	0
Exponent on At-A-Station Hydraulic Depth Relation (HYDR_DEP_EXP_STN)	0
Coefficient on Downstream Hydraulic Roughness Relation (Manning's *n*) (HYDR_ROUGH_COEFF_DS)	0.03
Exponent on Downstream Hydraulic Roughness (HYDR_ROUGH_EXP_DS)	0
Exponent on At-A-Station Hydraulic Roughness (HYDR_ROUGH_EXP_STN)	0
Coefficient on Downstream Bank Roughness Relation (BANK_ROUGH_COEFF)	15.0
Exp. on Discharge for Downstream Bank Roughness (BANK_ROUGH_EXP)	0.80
Precipitation Rate of a Bankfull Event, in m/s (BANKFULLEVENT)	1.268×10^{-7}

5.1.3 Results

All other parameters equal, the CHILD simulation for a 20 percent side slope should produce more sediment erosion than a CHILD simulation for a 10 percent side slope.

The simulations for Test Case 1 were performed on September 3, 2008. The simulation run time was 9 min 33 sec for the 3-m [10-ft]-high mound and 14 min 17 sec for the 6-m [20-ft]-high mound. Simulation results are contained in the output files listed in Table 3 and are located on the CHILD validation CD associated with Scientific Notebook 955E (Necsoiu, 2008). Landscape evolution for the mounds with two different side slopes is shown in Figures 2 and 3.

The mean grid elevation change (i.e., mean "z") for the mounds with 10 and 20 percent side slopes over the simulation period of 1,000 years was 0.229 and 0.560 m [9.01 and 22.04 in]. Graphing the change in landscape evolution characteristics for the 10 and 20 percent side slopes over the simulation period shows that all other parameters equal, the CHILD simulation for a 20 percent side slope produces more sediment erosion than the simulation for a 10 percent side slope. This outcome is physically realistic, but computed magnitude of the erosion could not be independently evaluated.

Table 3. Output Files From Test Case 1 Simulations

3m Rough Initial Topographic Surfaces	***6m Rough Initial Topographic Surfaces***
mnd_rnd_3_1000.area	*mnd_rnd_1000.area*
mnd_rnd_3_1000.dvols	*mnd_rnd_1000.dvols*
mnd_rnd_3_1000.edges	*mnd_rnd_1000.edges*
mnd_rnd_3_1000.inputs	*mnd_rnd_1000.inputs*
mnd_rnd_3_1000.lay0	*mnd_rnd_1000.lay0*
mnd_rnd_3_1000.lay1	*mnd_rnd_1000.lay1*
mnd_rnd_3_1000.lay2	*mnd_rnd_1000.lay2*
mnd_rnd_3_1000.lay3	*mnd_rnd_1000.lay3*
mnd_rnd_3_1000.lay4	*mnd_rnd_1000.lay4*
mnd_rnd_3_1000.lay5	*mnd_rnd_1000.lay5*
mnd_rnd_3_1000.net	*mnd_rnd_1000.net*
mnd_rnd_3_1000.nodes	*mnd_rnd_1000.nodes*
mnd_rnd_3_1000.q	*mnd_rnd_1000.q*
mnd_rnd_3_1000.qs	*mnd_rnd_1000.qs*
mnd_rnd_3_1000.random	*mnd_rnd_1000.random*
mnd_rnd_3_1000.slp	*mnd_rnd_1000.slp*
mnd_rnd_3_1000.tarea	*mnd_rnd_1000.tarea*
mnd_rnd_3_1000.tau	*mnd_rnd_1000.tau*
mnd_rnd_3_1000.tri	*mnd_rnd_1000.tri*
mnd_rnd_3_1000.tx	*mnd_rnd_1000.tx*
mnd_rnd_3_1000.varea	*mnd_rnd_1000.varea*
mnd_rnd_3_1000.vols	*mnd_rnd_1000.vols*
mnd_rnd_3_1000.z	*mnd_rnd_1000.z*

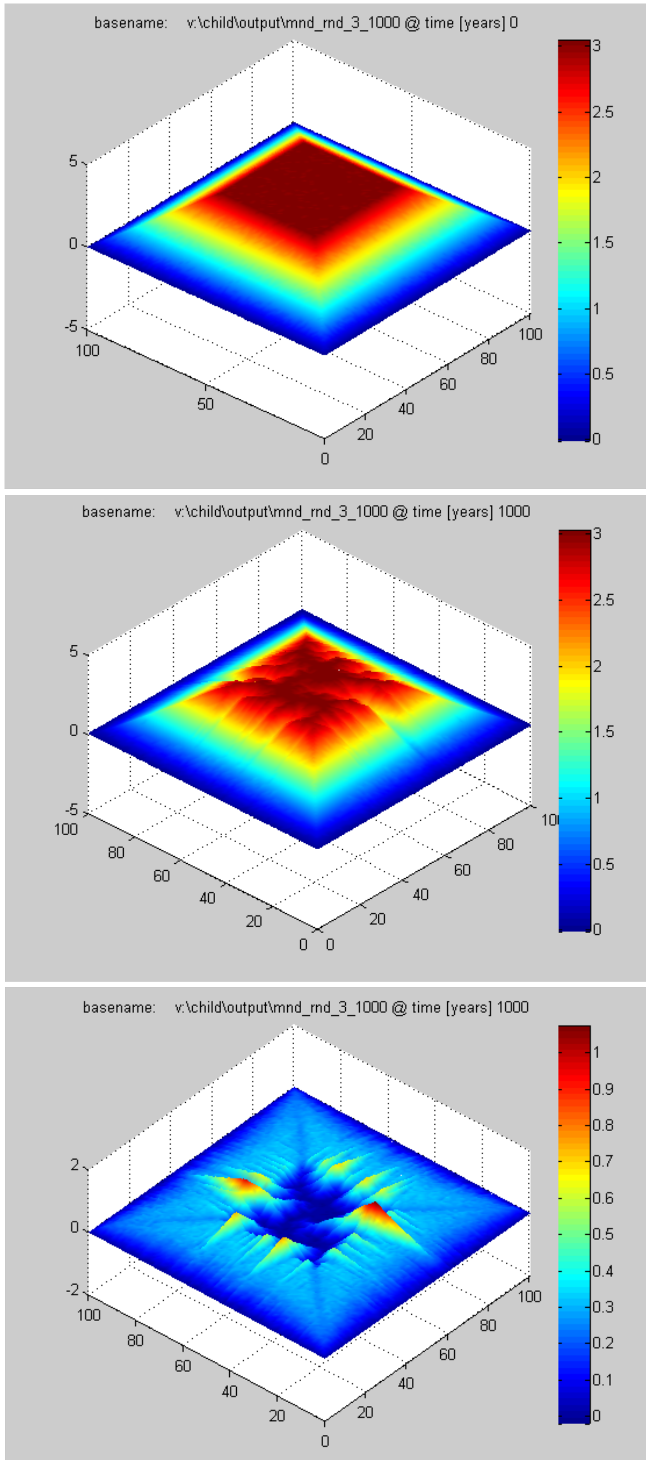
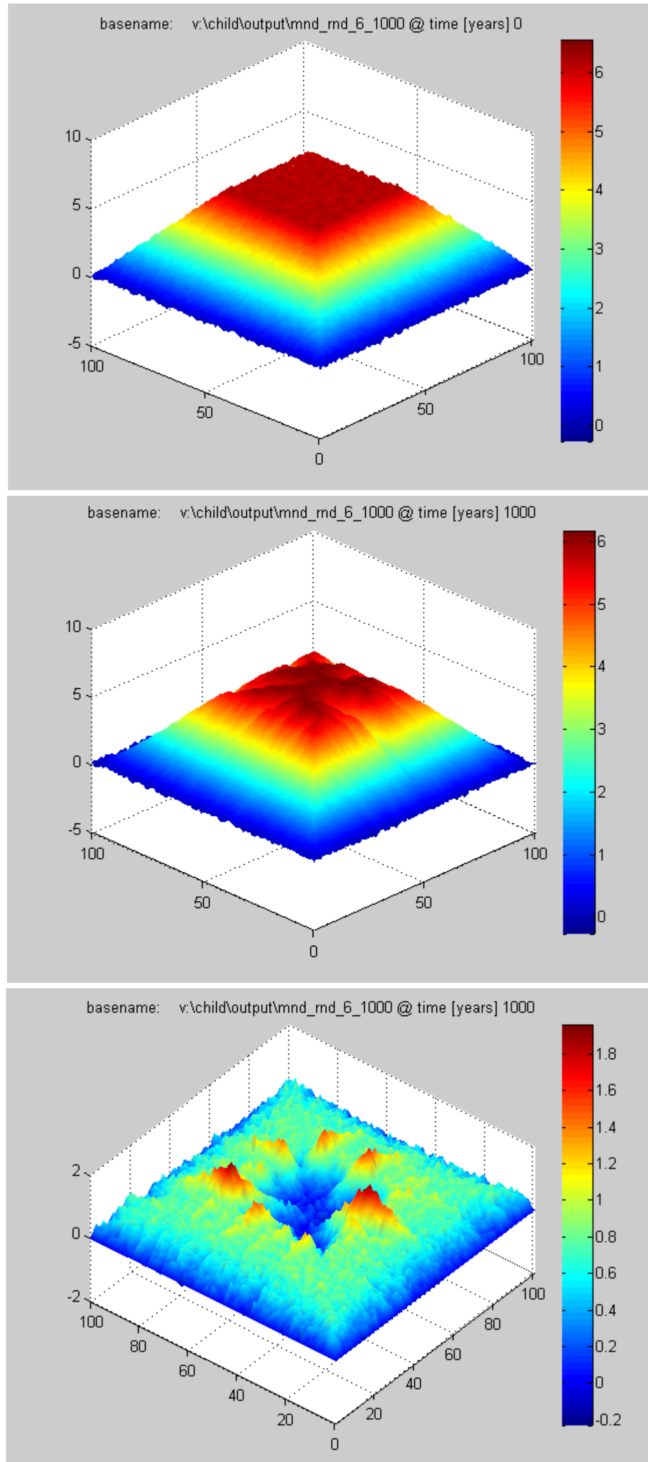


Figure 2. Test Case 1: Landscape Evolution of 3-m [10-ft]-High Mound Over 1,000 Years. (a) Initial Mound With 3-m-High Slope, (b) Eroded Mound After 1,000 Years, and (c) Total Sediment Lost in 1,000 Years.



(a)

(b)

(c)

Figure 3. Test Case 1: Landscape Evolution of 6-m [20-ft]-High Slope Over 1,000 Years. (a) Initial Mound With 6-m-High Slope, (b) Eroded Mound After 1,000 Years, and (c) Total Sediment Lost in 1,000 Years.

5.2 Test Case 2: Comparison of Surface Roughness Effect on Output

5.2.1 Test Input

A 100 by 100 m [328 by 328 ft], initially 6-m [20-ft]-high engineered soil cover is defined, and bounding coordinates for a 20 percent soil cover slope are specified (see Figure 1) as the initial rudimentary geometry for Test Case 2. The selected default dataset of physical parameters for Test Case 2 are the same as for Test Case 1 and are as summarized in Table 2. Two types of surfaces were simulated; one without any surface roughness and one with surface roughness. The rough-surfaced digital terrain model was given a Gaussian surface roughness with a mean of 0.1 m [0.3 ft] and a standard deviation of 0.1 m [0.3 ft].

5.2.2 Test Procedure

1. Using a text editor, verify that the provided CHILD input file (*mound.in*) has the input parameters set as in Table 2.

   Modify POINTFILENAME as *mound_uni_6.dat* and OUTFILENAME as *mnd_uni_6_1000* (i.e., the mound exhibiting smooth topographic surfaces).

2. Run the code by entering the following command:

   $ child mound.in

3. Repeat Steps 2 and 3 using the mound exhibiting rough topographic surfaces (POINTFILENAME as *mound_rand_6.dat* and OUTFILENAME as *mnd_rnd_6_1000*).

4. Using Matlab: Visualize the initial and final landscapes using mmesh.m; difference the initial and final landscapes to visualize the elevation difference after 1,000 years using *diffmesh.m*.

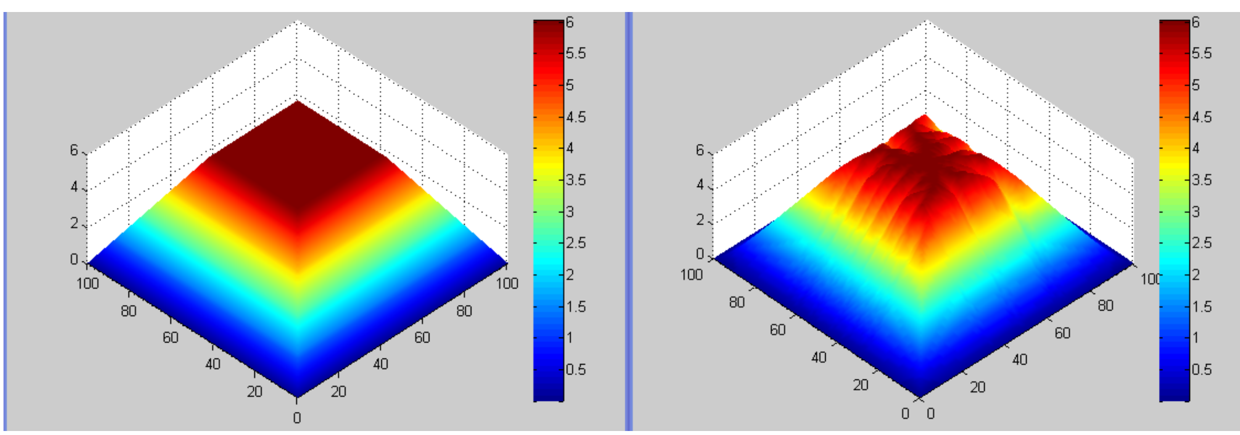
5.2.3 Results

All other parameters equal, the CHILD simulation for a waste disposal mound exhibiting perfectly flat topographic surfaces should result in mainly unidirectional channelized erosion, whereas the CHILD simulation for a waste disposal mound exhibiting Gaussian surface roughness with mean 0.1 m [0.3 ft] and standard deviation 0.1 m [0.3 ft] should result in a more tortuous, multidirectional channelized erosion.

Simulation results are contained in the output files listed in Table 4 and are located on the CHILD validation CD associated with Scientific Notebook 955E (Necsoiu, 2008). Landscape evolution for the initially smooth and initially rough waste disposal mounds is shown in Figures 4, 5, and 6.

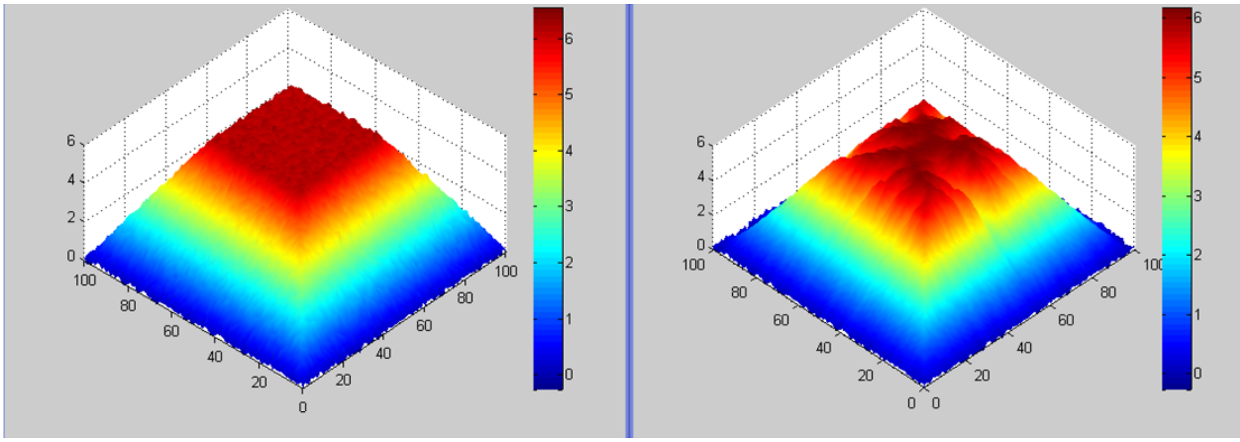
The essentially unidirectional orientation of channels developed over a 1,000-year period when starting with a perfectly flat-surfaced mound is shown by Figure 4(b). In contrast, the multidirectional orientations of channels developed over a 1,000-year period when starting with a rough-surfaced mound are shown by Figure 5(b). Development of channels on the mound with smooth surfaces was similar to results obtained for the SIBERIA software validation (Dinwiddie and Walter, 2008). The difference in channel development for the smooth and rough

Table 4. Output Files From Test Case 2 Simulations	
Smooth Initial Topographic Surfaces	***Rough Initial Topographic Surfaces***
mnd_rnd_1000.area	*mnd_uni_1000.area*
mnd_rnd_1000.dvols	*mnd_uni_1000.dvols*
mnd_rnd_1000.edges	*mnd_uni_1000.edges*
mnd_rnd_1000.inputs	*mnd_uni_1000.inputs*
mnd_rnd_1000.lay0	*mnd_uni_1000.lay0*
mnd_rnd_1000.lay1	*mnd_uni_1000.lay1*
mnd_rnd_1000.lay2	*mnd_uni_1000.lay2*
mnd_rnd_1000.lay3	*mnd_uni_1000.lay3*
mnd_rnd_1000.lay4	*mnd_uni_1000.lay4*
mnd_rnd_1000.lay5	*mnd_uni_1000.lay5*
mnd_rnd_1000.net	*mnd_uni_1000.net*
mnd_rnd_1000.nodes	*mnd_uni_1000.nodes*
mnd_rnd_1000.q	*mnd_uni_1000.q*
mnd_rnd_1000.qs	*mnd_uni_1000.qs*
mnd_rnd_1000.random	*mnd_uni_1000.random*
mnd_rnd_1000.slp	*mnd_uni_1000.slp*
mnd_rnd_1000.tarea	*mnd_uni_1000.tarea*
mnd_rnd_1000.tau	*mnd_uni_1000.tau*
mnd_rnd_1000.tri	*mnd_uni_1000.tri*
mnd_rnd_1000.tx	*mnd_uni_1000.tx*
mnd_rnd_1000.varea	*mnd_uni_1000.varea*
mnd_rnd_1000.vols	*mnd_uni_1000.vols*
mnd_rnd_1000.z	*mnd_uni_1000.z*



(a) (b)

Figure 4. Test Case 2: Landscape Evolution Over 1,000 Years: 6-m [20-ft]-High Mound With Smooth Initial Surfaces. (a) Initial Mound and (b) Eroded Mound After 1,000 Years.



(a) (b)

Figure 5. Test Case 2: Landscape Evolution Over 1,000 Years: 6-m [20-ft]-High Mound With Rough Initial Surfaces. (a) Initial Mound and (b) Eroded Mound After 1,000 Years.

surface mounds is qualitatively reasonable, but the magnitude of channel development cannot be independently evaluated.

5.3 Test Case 3: Comparison of Erosion Only to Erosion/Deposition and Effect on Output

5.3.1 Test Input

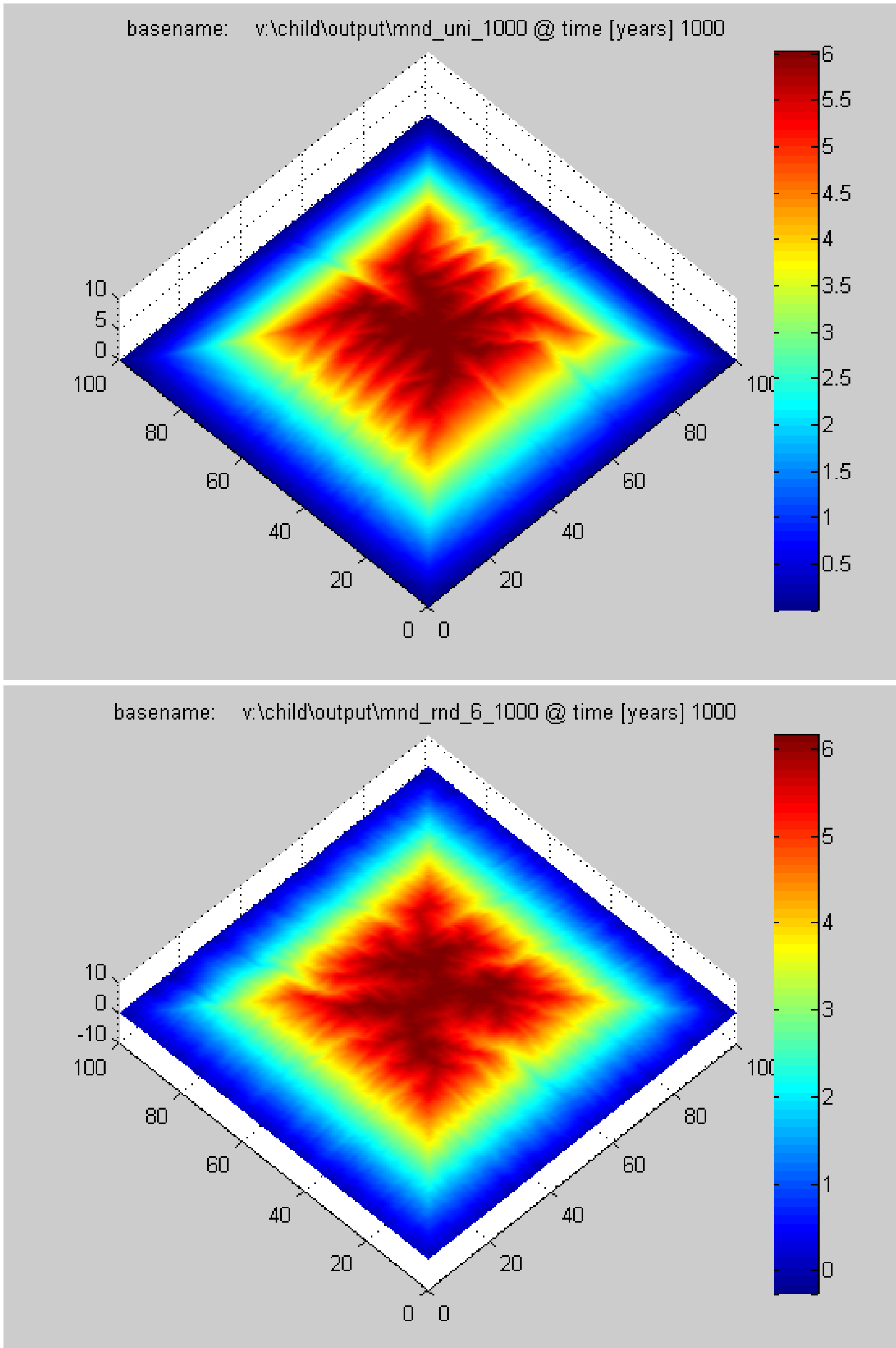
The nominally 6-m [20-ft]-high mound with 20 percent engineered soil cover slope from Test Case 1 serves as the initial geometry for Test Case 3. As before, this surface was given a Gaussian surface roughness with a mean of 0.1 m [0.3 ft] and a standard deviation of 0.1 m [0.3 ft].

Input data files include the Test Case 1 gridded digital terrain model named *mound_rand_6.dat* and the parameter file *mound.in*. Test Case 3 compares the output from the Test Case 1 simulation that included both erosion and deposition processes with new output obtained when repeating the simulation with deposition processes turned off. Specifically, this test assumes that diffusion only erodes and never deposits.

5.3.2 Test Procedure

1. Using a text editor, modify the *mound.in* input file by setting up OPTDIFFDEP = 1 and the diffusivity coefficient (m^2/yr) KD= 0.01.

2. Run the code by entering the following command:
   child mound.in



(a)

(b)

Figure 6. Test Case 2: Overhead Perspective Views of Eroded Landscapes After 1,000 Years. (a) Initially Smooth Mound and (b) Initially Rough Mound.

3. Using Matlab: Visualize the initial and final landscapes using *mmesh.m*; difference the initial and final landscapes to visualize the elevation difference after 1,000 years using *diffmesh.m*.

4. Compare the output with the one from Test Case 1 {i.e., the nominally 6-m [20-ft]-high mound}.

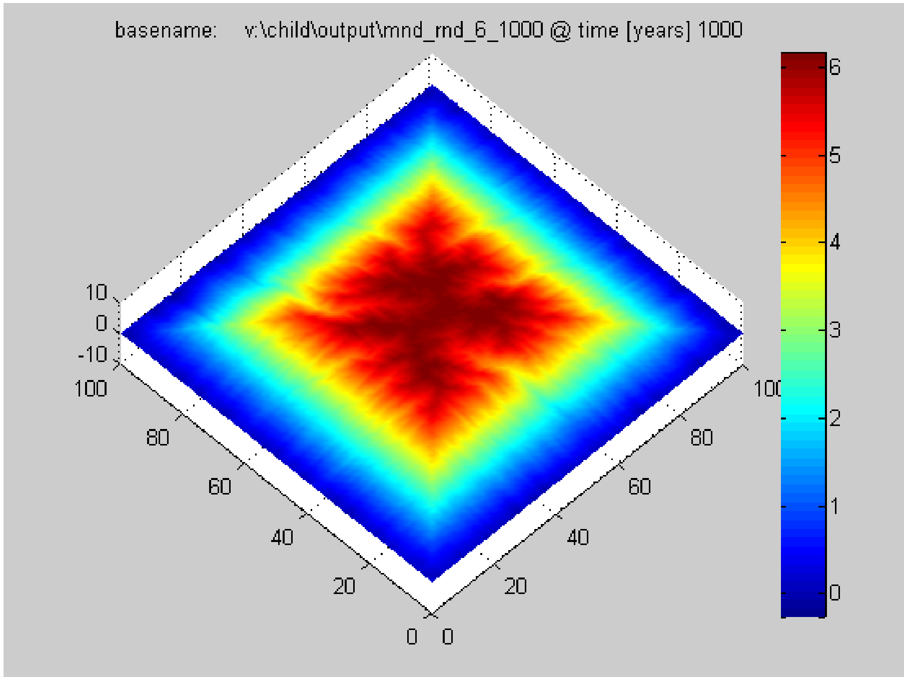
5.3.3 Results

All other parameters equal, the Test Case 3 simulation without deposition should result in more sediment erosion than the Test Case 1 simulation that had included both erosion and deposition as active processes.

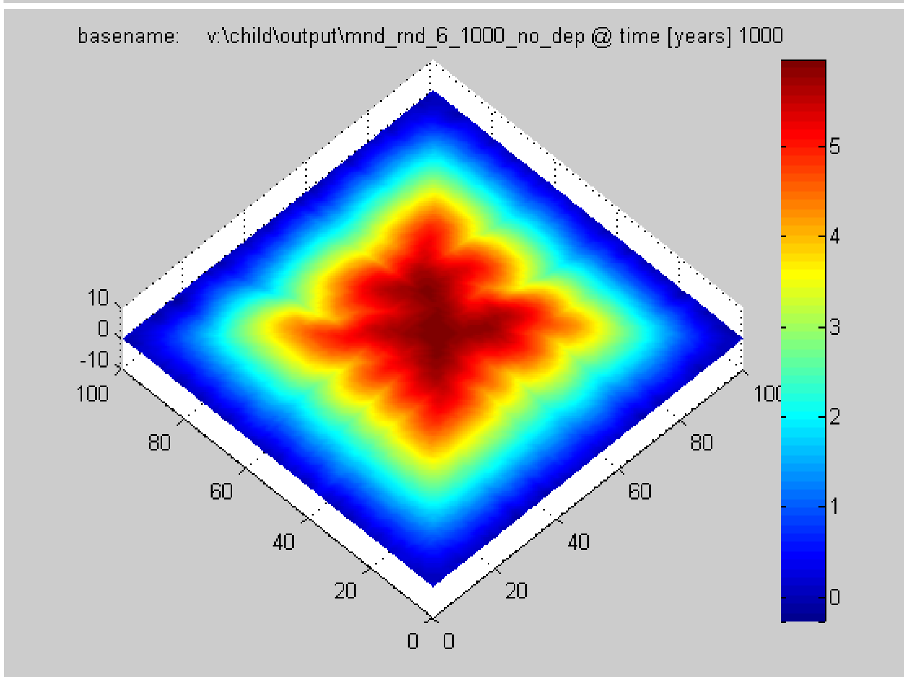
The simulations for Test Case 3 were performed on September 3, 2008. The run time for this simulation was 11 min 16 sec. Simulation results are contained in the output files listed in Table 5 and are located on the CHILD validation CD associated with Scientific Notebook 955E (Necsoiu, 2008). Landscape evolution for the mound is shown in Figure 7.

The simulation without deposition resulted in more total erosion than the simulation with both erosion and deposition. The results of this software validation test are physically reasonable but cannot be independently evaluated.

Table 5. Output Files From Test Case 3 Simulations
6 m [20 ft] Rough Initial Topographic Surfaces
mnd_rnd_6_1000 _no_dep.area
mnd_rnd_6_1000_ no_dep.dvols
mnd_rnd_6_1000 _no_dep.edges
mnd_rnd_6_1000 _no_dep.inputs
mnd_rnd_6_1000 _no_dep.lay0
mnd_rnd_6_1000 _no_dep.lay1
mnd_rnd_6_1000 _no_dep.lay2
mnd_rnd_6_1000 _no_dep.lay3
mnd_rnd_6_1000 _no_dep.lay4
mnd_rnd_6_1000 _no_dep.lay5
mnd_rnd_6_1000 _no_dep.net
mnd_rnd_6_1000 _no_dep.nodes
mnd_rnd_6_1000 _no_dep.q
mnd_rnd_6_1000 _no_dep.qs
mnd_rnd_6_1000 _no_dep.random
mnd_rnd_6_1000 _no_dep.slp
mnd_rnd_6_1000_no_dep.tarea
mnd_rnd_6_1000_no_dep.tau
mnd_rnd_6_1000 _no_dep.tri
mnd_rnd_6_1000_no_dep.tx
mnd_rnd_6_1000_no_dep.varea
mnd_rnd_6_1000 _no_dep.vols
mnd_rnd_6_1000_no_dep.z



(a)



(b)

Figure 7. Test Case 3: Landscape Evolution of 6-m [20-ft]-High Slope Over 1,000 Years: (a) the Eroded Mound Assuming That Diffusion Erodes and Deposits and (b) the Eroded Mound Assuming That Diffusion Erodes but Does Not Deposit

6 CONCLUSIONS

This software validation has determined that the functionalities of the CHILD software addressed in Test Cases 1–3 have undergone limited validation, consistent with TOP–018. Not every functionality of CHILD was tested herein.

CHILD has good potential to model cover degradation and performance for radioactive waste disposal performance assessments. The code can simulate changes in engineered closure cap topography. Calculated changes are likely to be strongly dependent on initial conditions (cover topography, soil properties) that will not be accurately known after the period of institutional control. Nevertheless, CHILD may indicate the susceptibility of an engineered cover to long-term erosion and provide information about the anticipated style of erosion features, and thus be useful for evaluating the long-term integrity of engineered soil covers.

The CHILD code is primarily designed to simulate landscape evolution. It does, however, incorporate two simple algorithms for simulating landslides: one using the critical slope concept and the other using the infinite slope concept. The CHILD code could be useful for simulating slope failures on aged soil covers.

We recommend (i) acquisition of better software documentation, possibly in the form of peer-reviewed literature focused on CHILD or the algorithms employed by CHILD, or else by internally developing such software documentation after detailed examination of the code; (ii) additional test case runs for limited validation of the tectonic uplift, diffusive sediment transport, stream meandering, overbank and aeolian deposition, and vegetation cover capabilities; and (iii) parametric sensitivity evaluations of parameters thought to be important to NDAA-site cover degradation.