Improving predictive power of physically based rainfall induced shallow landslides models: a probabilistic approach with TRIGRS-P (v. 2.0)

S. Raia, M. Alvioli, M. Rossi, F. Guzzetti
CNR-IRPI, Istituto di Ricerca per la Protezione Idrogeologica via Madonna Alta 126, I-06128 Perugia (PG) Italy

R.L. Baum, J.W. Godt
US Geological Survey, P.O. Box 25046, Mail Stop 966, Denver, CO 80225-0046, USA

January 7, 2013

USER MANUAL

1 Introduction

The code TRIGRS-P is an extension of TRIGRS, the Transient Rainfall Induced and Grid-Based Regional Slope-Stability Model originally coded by the U.S. Geological Survey in FORTRAN 77/95. As such, the operation and applicability of the new code are similar to the ones of the original code. The TRIGRS code and its extended manual are available at

`http://pubs.usgs.gov/of/2008/1159/`.

We have modified and extended the Unix version of the code; since we modified version 2.0 of TRIGRS, the first version of our code is named TRIGRS-P 2.0. Using the code under Windows© or MacOS© should be straightforard but no test has been explicitly done. In the following, we will discuss the modifications with respect to the original code, pointing out the differences in the user manual, available for download at the address above. TRIGRS-P can be permanently downloaded from

`http://geomorphology.irpi.cnr.it/tools/trigrs-p`

Prerequisites for using the TRIGRS-P code are a working unix-like environment with the following utilities/programs installed: tar and gzip archive manager, a text editor, a FORTRAN compiler (we used gfortran from the GNU GCC suite version 4.5.3 both in a Ubuntu Linux box and Cygwin, a Unix environment for Windows©.)

Unpacking the archive in an empty folder, the user is presented with a new directory containing the TRIGRS-P software composed by several FORTRAN files with extensions .f, .f90 and .f95; these files must be compiled together by a FORTRAN F95 compiler, such as GNU gfortran. The ranlib library should be compiled first; this simple step is done by `cd`ing to `ranlib/src/` and running the `./make_ranlib.sh` shell script; it assumes gfortran as a compiler, but this can be changed easily by editing the script and replacing gfortran with user's compiler. Moving back to TRIGRS-P directory and typing `make` the probabilistic version of the code will be built, using GNU gfortran. A different compiler can be used by simply invoking make as follows: `make -f Makefile f90=compiler` or permanently editing the Makefile. The compiler used to build the random number generator ranlib should be the same as the one used for building TRIGRS-P. Moreover, modifying the TARGET variable in the Makefile from `pro` to `det` will result in building the deterministic version of TRIGRS instead. The next step for running the code is preparing the input grids and initialization file, described in the following.

2 Quick overview of the original TRIGRS 2.0 input file

The operation of the code is straighforward for users who already know TRIGRS initialization files; users who are not familiar with the code are invited to refer to the original manual for a detailed and clean tutorial.[1] Moreover, we do not distribute the

[1]Small portions of the following text are verbatim extracts of the original TRIGRS manual

tutorial files and the utility programs with TRIGRS-P. Please refer to the TRIGRS v. 2.0 distribution on the USGS web site.

Upon starting, TRIGRS opens a user-supplied initialization file found in the working directory, and reads a list of file names and parameters needed to compute the pore pressures and factors of safety in each cell. The program then opens and reads files of input data, computes the results, and saves the output to a series of files. The program exits automatically when it is finished. The TRIGRS program writes a brief log file that may be useful in troubleshooting or in keeping a record of successive analyses. The log file includes a record of the starting and ending time, any errors that occurred, a copy of data from the initialization file, statistics on convergence of series solutions, and other information useful in interpreting program output. The utility programs, TopoIndex, GridMatch, and UnitConvert, operate in the same manner. Successful operation of the programs requires that the initialization file and other input files be organized and formatted correctly.

Once the input grids for the target study area have been prepared and all the simulation parameters have been determined, the input file for TRIGRS can be modified as follows to be used as an input for TRIGRS-P. The original configuration file for TRIGRS for the tutorial prepared by USGS Authors, `tr_in.txt`, is as follows (line numbering was added for ease of presentation):

```
1.  Name of project (up to 255 characters)
2.  TRIGRS, version 2, Tutorial
3.  imax, row, col, nwf, tx, nmax
4.  100,  10,  10,  154,  1,  30
5.  nzs, mmax, nper,  zmin,  uww,     t, zones
6.  10,    100,   2,   0.001,  9.8e3,  216000,  2
7.  zmax,   depth,   rizero,  Min_Slope_Angle (degrees)
8.  -3.001,  -2.4,  -1.0e-9,       0.
9.  zone, 1
10. cohesion,phi,  uws,   diffus,   K-sat, Theta-sat,Theta-res,Alpha
11. 3.5e+03, 35., 2.2e+04,  6.0e-06, 1.0e-07,   0.45,    0.05,    -0.5
12. zone, 2
13. cohesion,phi,  uws,   diffus,   K-sat, Theta-sat,Theta-res,Alpha
14. 8.0e+03, 31., 2.2e+04,  8.0e-4, 1.0e-04,   0.45,    0.06,   -8.
15. cri(1), cri(2), ..., cri(nper)
16. 3.e-7,  9.e-5
17. capt(1), capt(2), ..., capt(n), capt(n+1)
18. 0,       172800, 216000
19. File name of slope angle grid (slofil)
20. Data\tutorial\slope.asc
21. File name of property zone grid (zonfil)
22. Data\tutorial\zones.asc
23. File name of depth grid (zfil)
24. Data\tutorial\zmax.asc
25. File name of initial depth of water table grid   (depfil)
26. Data\tutorial\depthwt.asc
27. File name of initial infiltration rate grid   (rizerofil)
```

```
28. Data\tutorial\rizero.asc
29. List of file name(s) of rainfall intensity for each period, (rifil())
30. Data\tutorial\ri1.asc
31. Data\tutorial\ri2.asc
32. File name of grid of D8 runoff receptor cell numbers (nxtfil)
33. Data\tutorial\TIdscelGrid_tutorial.asc
34. File name of list of defining runoff computation order (ndxfil)
35. Data\tutorial\TIcelindxList_tutorial.txt
36. File name of list of all runoff receptor cells  (dscfil)
37. Data\tutorial\TIdscelList_tutorial.txt
38. File name of list of runoff weighting factors  (wffil)
39. Data\tutorial\TIwfactorList_tutorial.txt
40. Folder where output grid files will be stored  (folder)
41. Data\tutorial\
42. Identification code to be added to names of output files (suffix)
43. tutorial
44. Save grid files of runoff?
45. T
46. Save grid of minimum factor of safety? T or F
47. T
48. Save grid of depth of minimum factor of safety? T or F
49. T
50. Save grid of pore pressure at depth of minimum factor of safety? T or F
51. T
52. Save grid files of actual infiltration rate? T or F
53. T
54. Save grid files of unsaturated zone basal flux? T or F
55. F
56. Save listing of pr. head and Fs ("flag")? -2 detailed, -1 normal, 0 none
57. -2
58. Number of times to save output grids
59. 1
60. Times of output grids
61. 216000.
62. Skip other timesteps? T or F
63. F
64. Use analytic solution for fillable porosity?  T or F
65. T
66. Estimate pr. head>0 in rising water table (lower part of unsat zone) T or F
67. T
68. Use psi0=-1/alpha? T or F (False selects the defaults, psi0=0)
69. F
70. Log mass balance results?   Enter T (.true.) or F (.false.)
71. T
72. Flow direction (enter "gener", "slope", or "hydro")
73. gener
74. Add steady backgr flux to transient inf. rate to prevent drying beyond  ...
75. T
```

The initialization file is in ASCII text format and contains a list of header lines, input file names, and constants needed to complete the analysis. To change problem parameters, the user edits the initialization file using a text editor. Consequently, most runtime errors result from mistakes in editing the initialization file or errors in the input grids. To reduce errors in editing the file, a descriptive or explanatory heading precedes each line (or in one case a group of related lines) of data in the initialization file. The first line of data contains a project title, followed by several lines of numeric data including program parameters, properties for each zone, rainfall infiltration rates and times; the second group of lines contains names of input files; and the third group of lines specifies which output files will be saved, as well as the directory where they will be stored. The fourth and final group contains user options that affect how the analysis is performed.

1. *Numeric data.* The file contains several lines of numeric data needed to determine array sizes, model parameters, precipitation history, initial conditions, and physical properties. An explanatory heading precedes each line of data. The file is organized with a project title and heading on the first two lines, numerical input data and headings on the next six lines, followed by two lines of headings, one line of data for each property zone, and two more lines each for rainfall rate, corresponding times, and their respective headings. The user may set physical parameters, such as soil and water table depths, background flux, and rainfall (infiltration) rates to a constant value over the entire grid by specifying a positive value. A negative value for any of these parameters prompts the program to read an input grid for spatially variable data. The user determines the number of property zones and assigns physical properties (soil strength parameters and hydraulic properties) to each zone (one line per zone). A single property-zone grid maps all these properties to the model.

2. *Input files.* The user must specify a file name for each input file. The TRIGRS program automatically reads a name for each potential input file; therefore the user must provide a placeholder for any input file that either does not exist or will not be used for a given simulation. The TRIGRS program can accept either full or partial path names. Path names of input files are on the next group of lines after the numeric data described previously. Each file name occupies a single line in the file. The total number of lines in the file depends on the number of property zones and number of periods of different rainfall intensity. Be sure to include a file path name, `rifil()`, for each period, but only one heading for this group of file names. In this example, the rainfall rates during the storm are set constant over the grid. Two storm periods are specified, so two lines are needed for the rainfall rate input file names (placeholders in this case) as long as 255 characters; however, the rules for specifying path names vary between operating systems. If the paths are typed incorrectly, the program will report an error. To minimize errors in specifying file path names, the user may place all the input data files needed for a given simulation into a specific folder. On Windows systems, placing a copy of the executable program (TRIGRS.exe) and initialization file into the folder where

the data reside will further simplify operation. By doing so, the user needs only to specify the file names and does not need to worry about the paths.

3. *Output files.* A series of eight logical values (true or false) determines which output grid files are saved to disk. These are listed directly after the input file names. A numeric flag at the end of the list of output file choices determines whether the cell-by-cell list file is saved and whether it contains optional data. Note that this file can become very large, particularly if the analysis includes multiple time steps. This option should be reserved for use with small test grids to prevent filling the disk drive. The user may specify an identification code to group files from a particular simulation. Users may also specify a separate folder where the output files can be saved. Certain output grids can be saved at selected times during the simulated storm.

4. *Model options.* The last few lines of the initialization file allow the user to select options that control how the model performs certain functions in the unsaturated zone. These options allow the user to compute the fillable porosity either analytically or numerically, compute positive pressures above the original water table as water accumulates at the base of the unsaturated zone, and determine how the capillary fringe is treated. The final option allows the user to select the slope of the beta line, which determines maximum pore pressure at each depth. On start-up, TRIGRS will look for the default initialization file, `tr_in.txt`, in the same folder where the program file resides. If it is not present, then TRIGRS prompts the user to enter the name of the initialization file. TopoIndex, GridMatch, and UnitConvert follow a similar convention.

Please refer to the original manual for detailed information on input and output file formats.

3 Additions in TRIGRS-P 2.0

The use of TopoIndex, GridMatch and UnitConvert tools contained in the software suite is the same as in the original version provided by USGS. The modifications needed to run our probabilistic extension TRIGRS-P of TRIGRS are the following. The user must specify the *pdf* type from which the random number generator will sample to generate the probabilistic input for each run. This can be chosen by specifying the keword `uniform` or *gaussian* in the portion of `tr_in.txt` right before the geotechnical parameters, divided by zones, portion of the file, *i.e.* after line 8 in the listing above. Then, the mean values and the range of variation of the parameters must be specified for each parameter and for each lithological zone, whose number is specified by the parameter `zones` in line 6. The line containing the values of the parameters is replaced with a few lines containing the following information. When the uniform distribution is selected, the user must supply two lines containing, for each of the parameters, the minimum (first line) and the maximum (second line) values the parameter can assume; the program samples randomly

between these two values with uniform probability. When the gaussian distribution is selected, the user must supply the average value (first line), the standard deviation of the gaussian distribution (second line), the maximum (third) and minimum (fourth) values the parameter can assume. If the uniform distribution is selected and four lines are supplied, the last two lines are ignored. A sample of the modified configuration file is as follows; the added lines are those highlighted in red. We have discarded the final part of the file, which needs no further modification.

```
1.  Name of project (up to 255 characters)
2.  TRIGRS, version 2, Tutorial
3.  imax, row, col, nwf, tx, nmax
4.  100,  10,  10,  154,  1,  30
5.  nzs, mmax, nper,  zmin,  uww,     t, zones
6.  10,    100,   2,   0.001,  9.8e3,  216000,  2
7.  zmax,   depth,   rizero,  Min_Slope_Angle (degrees)
8.  -3.001,  -2.4,  -1.0e-9,       0.
9.  (line distr): Distribution (Possible values: gaussian, uniform)
10. gaussian
11.  zone, 1
12. cohesion, phi,   uws,     diffus,   K-sat, Theta-sat,Theta-res,Alpha
13. 3.5e+03,  35.,  2.2e+04,  6.0e-06, 1.0e-07,   0.45,    0.05,    -0.5
14. 3.5e+03,  35.,  2.2e+04,  6.0e-06, 1.0e-07,   0.45,    0.05,    -0.5
15. 2.0e+03,  30.0, 1.5e+04,  5.0e-06, 0.8e-08,   0.40,    0.04,    -0.5
16. 3.5e+03,  40.0, 2.9e+04,  7.0e-06, 1.2e-07,   0.50,    0.06,    -0.5
17. zone, 2
18. cohesion, phi,   uws,     diffus,   K-sat, Theta-sat,Theta-res,Alpha
19. 8.0e+03, 31.,   2.2e+04,  8.0e-4,  1.0e-04,   0.45,    0.06,   -8.
20. -1.0,    -1.0, -1.0,     -1.0,    -1.0,      -1.0,    -1.0,    -1.0
21. cri(1), cri(2), ..., cri(nper)
22. 3.e-7,  9.e-5
23. capt(1), capt(2), ..., capt(n), capt(n+1)
24. 0,       172800, 216000
25. File name of slope angle grid (slofil)
.....................................
```

It should be noted that the results of the original, deterministic TRIGRS approach can be recovered by providing two lines of values for the parameters; specifying a negative or null value in the second line for a given parameter, no random number generation will be performed and the parameter assumes the value specified in the first line. In this case, the following two lines (lines no. 21 and 22) should be present anyway, but they will just be discarded.