Short manual on the installation of TOPOG and the use of the groundwater model in TOPOG for modelling the hydrology of the Cuieiras catchment, Brazil.

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1. How to install topog

The rainfall interception routine in the original version of TOPOG is not very good for modelling of forest. As such I included the Gash interception and regression models in the code. The original code can be obtained from the Topog Online web page at CSIRO (http://www.per.clw.csiro.au/topog/), as well as a comprehensive user manual. You should register before you can download this. In our case, I modified the program and you should therefore download the TOPOG source code and binaries (file topog.sep2001.mjw.tar.gz)from http://www.geo.vu.nl/~watm. Then use the comand:

```
tar xvfz topog.sep2001.mjw.tar.gz
```

to extract the files. This will create a directory named topog.sep2001 in your home directory. You should then "link" this directory to a topog directory by typing:

```
ln -s topog.sep2001 topog
```

You will then see a topog directory which contains all the files which are in the topog.sep2001 directory. In fact, it is just a link to this directory so you will be working in the topog.sep2001 directory. The purpose of this is that if there is a new version, you can just link the topog directory to the new version without changing everything in the configuration files.

Now you have to add the topog path to your system settings. Start xemacs (or another editor) and edit your `.bashrc` file in your home directory. At the end of the file put:

```
PATH=$PATH:$HOME/topog/bin/LINUX
export PATH
```

You also have to let the system know where the application defaults for topog are, so also put the following in the `.bashrc` file:

```
XAPPLRESDIR=$HOME/topog/app-defaults
export XAPPLRESDIR
```

Now you should be able to run topog. Open a new shell window, go to the directory where your topog data files are (type: `cd data/Brazil/Cuieiras`) and try it out by typing:

```
_display
```

If everything is OK, you should see the display program starting up and you should enter your basename (Cuieiras in our case) to display contours, etc. If _display or _chart will not start up, it is usually because the Motif libraries were not installed on the system. You can check if they are by searching your system for libXm. You may have to do this as root because of permissions.

```
find / -name libXm*
```

If Motif (commercial) or LessTif (free download) are not installed, you should install this. They are present, I think, on all Linux distributions. You can chack if it is something else (path) by typing in the name of a program that does not use graphics (e.g. `_overlay, _mkbdy, _dynamic`).

2. Installation of data files

If you have to start from scratch, please read the TOPOG user manual. In our case, the basic input files were made by me and Debora. Now let's install the data. If you have old data installed (in the Manaus directory), throw away all the Manaus files, they are really old! You can do this using the command

```
rm -rf Manaus
```

Download the data file and save it in your home directory. Then use:

```
tar xvfz Cuieiras.tar.gz
```

to create the new data directory with all the updated data files. In our case this will be $HOME/data/Brazil/Cuieiras, where $HOME stands for your home directory.

Now go to the data directory

```
cd ~/data/Brazil/Cuieiras
```

and run `_display`

The basename is Cuieiras, so type this in and then you should be able to see everything by pressing the appropriate buttons in `_display`. The _display and other programs are described in the TOPOG User Manual.

3. How to run the _dynamic model

If you want to run the topog model go to your data directory and use the command :

```
_dynamic_mjw < Cuieiras.par
```

Note _dynamic is the original program, whereas `_dynamic_mjw` has the Gash (1979) rainfall interception model, which is much better for forest vegetation! We will use `_dynamic_mjw`. You have to change the vegetation parameters file if you want to use the original model version.

Cuieiras.par is the parameter file containing the input for the _dynamic model. It is an ASCII file, which you can edit with any editor. Keywords are used for data input into topog. Each keyword starts with a # followed by at least 3 characters. For instance #cli or #climate indicate that you want to input climate data, whereas #soi or #soil indicates that you want to enter soil data.

You can also run _dynamic without a .par file. In this case just type:

```
dynamic_mjw
```

The program will ask

```
Enter #(header)                          <return=options>
```

Enter `#MYield` to start dynamic modelling

It will then ask for the basename, so enter: `Cuieiras`

You then have to enter the keywords yourself. Note, doing this is a nice way to know what input you need to give for each command when you are building the .par file. An example using the #aqu keyword is shown at the end of this document.

Note: sometimes `_dynamic` will start only to give a segmentation fault. This is most likely a memory allocation problem. Close all other programs and try again. It may be that there is too little memory available when other programs are running. If this still gives you a segmentation fault, you have to reduce the maximum elements, etc. in the source code, recompile and try again. The size of the arrays is shown when `_dynamic` starts:

```
*********************************************************************
*      Max No.Elts        =1000  Max No.Contours  =  80               *
*      Max No.Trajectories=1001  Max No.Climates  =  10               *
*      Max No.Soils       =  10  Max No.NodesFiles= 120               *
*      Max No.Nodes       =  80                                       *
*********************************************************************
```

Topog produces runoff if conditions are right. You should not need the groundwater module to produce it. In fact you only need the groundwater module to simulate a deep or regional groundwater system, which is not closely associated with the surface topography. The main problem with groundwater flow in the main part of Topog is that it flows with hydraulic gradient the same as the surface topographic gradient. That is less of a problem in steep terrain. For runoff, and groundwater flow ALWAYS use the model with an impermeable base. Ensure that

the soil column is deep enough to allow Richards eqn processes to work, and set the deep drainage off. In the ".par" file the entries are:

```
#drainage/recharge
0 0 0
```

You then get a watertable develop at the base of the soil column, sometimes the watertable is only very thin, and base flow takes place. Perching higher in the profile can happen if you have a sufficiently impermeable soil horizon to produce it. Perched water also produces runoff. There are now vertical flux traces (tflx and sflx) to allow interrogation of vertical flux at any node in the catchment. Waterlogging indices have been added to sbal dumps as well. These compute sum (depth-days: when water is less than a given distance from surface) - distances given are 0.1-0.5m) Based on Cox and McFarlane 1995, J. hydrol V167:175-194

4. How to prepare the topog groundwater Finite Element (FEM) model.

In contrast for the surface model, there is no user manual for the groundwater model in TOPOG. This section therefore provides information required to include the groundwater model. The FE groundwater mode can be turned on by inserting a #aqu or #aquifer entry in the controlling `filename.par` file. The `_simgen` programme, which you normally use to create a `filename.par` file (see Topog user manual) does not know about this so you have to edit the `filename.par` file made with `_simgen` manually to include this option.

If all required files are present, you can start the modelling with:

```
_dynamic_mjw < filename.par
```

The Finite Element groundwater system needs some extra files in addition to the normal Topog files. These need to be created roughly with the procedure outlined below.

4.1. Theory: linkage between groundwater system and surface water column

A simple linkage scheme (based on a potential transfer flux) has been developed to transmit water between the soil water and deep groundwater systems. The watertable within the soil profile is considered to overlie the deeper aquifer. When the underlying aquifer intersects the base of the soil column, a comparison between the intrusion height and the current day's watertable depth is made to determine the potential transfer flux required to equilibrate the two heads. When the head of the underlying aquifer differs from that of the soil watertable, there is a flux, $q^{\dagger}$, between them which depends on the direction of the head gradient. The magnitude of the flux is calculated as the harmonic mean of the available storage, S_a, within the region of overlapping heads in the soil column or aquifer, depending on which has the lower head; the available moisture, T_a, within the region of overlapping heads in the soil column or aquifer, depending on which has the higher head, divided by the timestep length, t; the soil profile conductivity, K_s, at the base of the soil column, and the saturated hydraulic conductivity of the aquifer, K_{aq}. $q^{\dagger}$ is more easily represented by its reciprocal:

$$\frac{1}{q^{\dagger}} = \frac{1}{4}\left(\frac{t}{\Theta_a} + \frac{t}{S_a} + \frac{1}{K_s} + \frac{1}{K_{aq}}\right) \tag{1}$$

S_a and T_a are calculated as follows:

if the head in the soil column is higher than that in the aquifer:

$$S_a = S\frac{\Delta h}{2} \qquad \Theta_a = \frac{1}{2}\left(\sum_i q_{i\,sat}\,\Delta z_i\right) \tag{2}$$

if the head in the soil column is lower than that in the aquifer:

$$S_a = \frac{1}{2}\left(\sum_i \left(q_{isat} - q_i\right)\Delta z_i \right) \qquad \Theta_a = S\frac{\Delta h}{2} \tag{3}$$

where S is the specific storage in the aquifer; $?h$ is the region of overlapping heads; the summations are over the soil intervals $?z_i$ within $?h$, ($?h = S?z_i$); $?_i$ and $?_{i\,sat}$ are the moisture content and saturation moisture contents, respectively, of soil interval i.

This method is chosen because it is always less than the minimum value of the four parameters which limit the flux, thus it gives a smooth transition between aquifer recharge and discharge regimes ensuring a well-behaved numerical condition.

The calculated flux is applied to the bottom node of the soil column as the drainage (or discharge) flux for inclusion in the Richards Eqn solution for the next time step.

4.2. Programs to use for setting up the FE model

These programs have not been released but were kindly made available to us by CSIRO-ACCH. Below is a short description of the FEM programs.

_aqoverlay - takes polygons and assigns values for FE mesh

_meshview - display and edit FE mesh files

_coreg – coregisters the FD elements with the FE elements

_femesh: create and edit FE mesh files. Options are:
(0) generate new data set bounded by catchment boundary
(1) generate new data set by importing an external foreign file
(2) modify existing data set by inserting new nodes
(3) modify existing data set to catchment boundary
(4) amalgamate and triangulate Topog_Meshview data
(5) amalgamate and cross-check Topog_Meshview data (no regrid)
(6) modify existing groundwater parameter file .gwp (no regrid)
(7) generate hillslope transect data set
(8) interogate transect results
(9) convert groundwater parameter file to surface network

0 Standard, make .nxy, bd1 and bd2 files from surface element file
1 Import foreign file - generally MODFLOW file, rectangular grid, raster Z's - specific to MODFLOW
2 Modify existing data insert nodes - this replaces _meshview click and Save editing
3 Modify catchment boundary. Use .sbd file as FE nodes to select subcatchment using nodes in .sbd file and original nodes to re-triangulate.
4 Amalagamate, triangulate - generates new .etn, .nxy, .gwp files. Remakes mesh and triangulation if you have modified the mesh using _meshview. Uses the _meshview multiple files to create single .gwp file.
5 Cross-check. Assumes FE grid, cross-checks element connectivity - takes .nxy and checks connectivity. Checks bdy nodes run all way around catchment boundary. Checks elements are numbered anti-clockwise - if you get a "non-anticlockwise" message press <Return> through to normal exit and rerun option (5) - it will have fixed the .etn and .nxy files. Checks there is no duplication of elements. Checks all nodes are assigned an element, and all nodes have an entry in the connectivity file (etn).
6 Modifies .gwp file. Combines options 4 and 5. Should rewrite the triangulation .etn file and .nxy as well as .gwp.
7 Generate hillslope transect - for taking a slice through the hillslope to the groundwater surface
8 I think this options looks at the results of option (7)

If you use option (6), you'll get the following questions:

```
Enter node file fmt(x,y,wlevl,base,surf)    <return=no file> wlbasesurf.txt
Number of unallocated data nodes      0   666
Enter node file fmt(x,y,bdy type,bdy val)   <return=no file>
Enter obs well node file fmt(x,y,wlevl)     <return=no file>
```

```
Enter stream node file fmt(x,y,slevl)       <return=no file>
Enter element overlay file                  <return=no file>
Enter nodal overlay file                    <return=no file>
Enter foreign external file                 <return=no file>
Enter <y> to interpolate partially filled elements (defined by 0)
```

You can also use the program `_stripgen` to generate a surface and GW mesh - you need to give the UNDOCUMENTED flag -gw to get the FE groundwater mesh:

```
_stripgen -gw
```

This will make a rectangular area with grid celles.

4.3. The basename.gwp file

The critical file is called `"basename".gwp`. It contains the initial groundwater heads and the aquifer characteristics. It is partly created by the procedure, but some editing is required as the programs are not all as they should be. It is supposed to include solute transport but last time I checked this it did not work, so I have only used it with a fixed aquifer solute concentration.

The `basename.gwp` and some other files (`basename.nxy, basename.bd1, basename.bd2`, etc.) are made with the `_femesh` program. This program does not belong to the released Topog program files and you have to get it from CSIRO. I have compiled it and added it to the binaries in the `topog/bin/LINUX/` directory, so if you use these, you are okay.

If you have the surface model set-up (elements file, trajectories file, etc.) you can start preparing the groundwater files. Run `_femesh` and use option 0 (generate new data set bounded by catchment boundary). Then insert the basename and the desired x-y distances for the FE mesh. Below is what you will see, I used a 200x200 m grid.

```
waterloo@wabuda:~/data/Brazil/Cuieiras.gw.200m > _femesh
 ****************************************************************
 *       topog.mesh : finite element triangulation program      *
 *               version 6.30 released April 1994               *
 ****************************************************************
 *                                                              *
 *                           Copyright                          *
 *   The Topog catchment modelling package has been developed   *
 *   by the Division of Water Resources,  CSIRO Australia and   *
 *   may not be used to gain income or copied for commercial    *
 *   reasons without the written permission of the authors.     *
 *                                                              *
 *                           Disclaimer                         *
 *   The Topog catchment modelling package has been written     *
 *   to provide a research tool for the simulation of water     *
 *   movement in complex terrain. Where significance is to be   *
 *   placed upon the results of simulations, the user should    *
 *   have independent methods for checking the accuracy of      *
 *   model predictions. Users are warned that significant       *
 *   errors in model predictions can arise from poor input      *
 *   data. Topog has been written in good faith but the         *
 *   authors accept no responsibility for any errors or         *
 *   omissions it may contain or any liability or damage        *
 *           that may result from its use.                      *
 *                                                              *
 ****************************************************************

Enter (0) generate new data set bounded by catchment boundary
      (1) generate new data set by importing an external foreign file
      (2) modify existing data set by inserting new nodes
      (3) modify existing data set to catchment boundary
      (4) amalgamate and triangulate Topog_Meshview data
      (5) amalgamate and cross-check Topog_Meshview data  (no regrid)
```

```
      (6) modify existing groundwater parameter file .gwp (no regrid)
      (7) generate hillslope transect data set
      (8) interogate transect results
      (9) convert groundwater parameter file to surface network      0

Enter file basename for grid generation                              Cuieiras
Enter nodal seperation x-direction  (metres)                           200
Enter nodal seperation y-direction  (metres)                           200
 deleting existing file Cuieiras.bd1
 deleting existing file Cuieiras.bd2
 deleting existing file Cuieiras.obs
Number of slender elements (angle < 4 deg) are 26
Total number of domain nodes are 287
Total number of domain triangular elements are 549

Warning - Please visually check boundary element
          connectivity using the utility program
                    Topog_Meshview.
          Modifications to the mesh using
          Topog_Meshview requires re-running this
          program selecting option <5> for
                    cross-checking.

STOP topog.mesh : normal execution and exit statement executed
```

This will generate the basename.nxy file, but not the other files. It uses a uniform grid of 200 by 200 m. If you want more detail in some locations (e.g. river valleys, slopes) you have to make a file with extra node co-ordinates (in our case this is the Cuieiras.addnodes file) and now run _femesh with option 2 (modify existing data set by inserting new nodes).

Now you have to run _femesh again using option (5) to make the basename.gwp file. Doing this will show:

```
_femesh
Enter (0) generate new data set bounded by catchment boundary
      (1) generate new data set by importing an external foreign file
      (2) modify existing data set by inserting new nodes
      (3) modify existing data set to catchment boundary
      (4) amalgamate and triangulate Topog_Meshview data
      (5) amalgamate and cross-check Topog_Meshview data  (no regrid)
      (6) modify existing groundwater parameter file .gwp (no regrid)
      (7) generate hillslope transect data set
      (8) interogate transect results
      (9) convert groundwater parameter file to surface network      5

Enter file basename for data cross-checking Cuieiras
Number of data points    287

Identifying boundary nodes ..............
Determining boundary connectivity.......
Determining element connectivity........
    17  10751.2000  11809.7000         20  10756.7000  11864.3000
48  10951.2000  11809.7000
.
.
```

Lots of number passing by on screen....

```
.
.
    1  10351.2000  11350.0000          2  10551.2000  11409.7000          4
10589.8000  11192.5000
Number of clockwise-assigned elements    227

Creating groundwater parameter file ....

Enter hydraulic conductivity type #1                            2.0
```

```
Enter specific storage type #1                                    0.25
Enter leakage coefficient type #1                                 0.0

Enter dump time and flag  (0 0 = end)
    1=printout aquifer height at end of run
    2=printout final differential aquifer height
    3=printout aquifer recharge at specified time
    4=printout cumulative aquifer recharge
    5=printout aquifer discharge at specified time
    6=printout cumulative aquifer discharge
    7=printout aquifer height at specified time
    8=printout aquifer differential height at specified time
    9=printout aquifer bedrock elevation
   10=printout aquifer surface/interface elevation
   11=printout initial aquifer height
   12=printout soil bedrock elevation
   13=printout aquifer height - surface height at specified time
   14=printout initial aquifer solute concentrations
   15=printout aquifer solute concentration at specified time
600 1
200 3
400 3
600 3
200 7
400 7
600 7
0 9
0 10
0 11
0 0
STOP topog.mesh : normal execution and exit statement executed
```

Now the Cuieiras.gwp file has been created along with some other files. The top line of thebasename.gwp file is a header line followed by a set of input flags. In what follows the symbol ??? means that this option is untested.

This is an example where the .gwp file is discussed in parts:

Part 1: Header and flags

```
  #elm  #nod #nnod  mode  link  salt  prnt  #tri  sav#  restart filename (extension .fem.fin
assumed)
  1194   666     0     0     2     0     1     3     0
```

In the explanation below, the variable name used in the program routine **feindx** is shown in parentheses.

`#elm` = No. of FE elements (nfeelm)
`#nod` = No. of FE nodes (nfepts)
`#nnod` = No. of observation wells not coincident with FE nodes (nfennw)
`mode` = Solution mode used for testing – should be 0 (itherm)
`link` = choice of groundwater linkage scheme use =2 (i/jaqtyp)
`salt` = salt groundwater diffusion flag – 0/1 untested, set =0 (ifesol)
`prnt` = Output print flag – 0 = print all input data, 1=do not print input data (ifepr)
`#tri` = Number of nodes per FE element – has always been 3 (nfenod)
`sav#` = How to save: 0 = use saved fem.fin file for node heights, 1 = use .gwp file
`restart filename` = basename of fem.fin file (fem.fin file extension is assumed – but may be included)

In the example, it lists the number of elements (#elm=1194), nodes (#nod=666) and non-node wells (#nnod), the mode (=0) that the groundwater model will be operating in and the other flags to in or exclude stuff.

The mode parameter can have two values:

0 to restrict soil Psi from rising above hydrostatic press.

1 to allow soil Psi to rise above hydrostat press.

Part 2: Nodes characterisation

Then you get several columns describing the nodes.

```
 node           x           y                    initial h          boundary       pumpage
observation  stream     bedrock     surface
    1  10351.2000  11350.0000      0.0000   2      0.0000 0      0.0000 0      0.0000 0
0.0000      0.0000      0.0000
```

`node` = FE node index number
`x,y` = x,y — position coordinates
`initial h` = initial value for groundwater level at each node (in m a.s.l.). – this uses same datum as surface and bedrock/basement heights (also in m a.s.l.)

Then there are 4 pairs of numbers – as integer and real value pairs.

`Boundary`
integer: 0 = non-boundary node, 1=constant head node, 2=constant flux node
real: value of constant flux, or head
`Pumpage`
integer: 0 = non-pumping node, 1= pumping node
real: value of pumped abstract from that node, to simulate pumped wells
`Observation`
Integer: 0 = non-observation node, 1 = observation node – During the model run, a file will be written with water level in this node throughout simulation
Real: The value is ignored/not used
`Stream`
Integer: value indicates this is a "stream" node – not used
real: value ignored/not used

This is followed by two real values:

`Basement`
Real: Topographic height of bedrock (m a.s.l.), Can be a negative value
`Surface`
Real: Topographic height of the surface of the FE node (m a.s.l.).

The initial waterlevel height is allowed to be above surface height, but you will get a message written.
Set the surface of FE mesh to be the same as surface of the "regular" FD Topog element mesh.

The .gwp file should not be edited manually. The `_femesh` program (option 6: modify existing groundwater parameter file .gwp (no regrid)) should be used to change these values.

Part 3: element characterisation

Then we have element type characterisation and connectivity.

```
 elem      type       evapotranspiration      stream element         connectivity
   1         1         0     0.0000E+00    0     0.0000E+00        15        36        37
```

`elem` = FE element number
`type` = FE element type (mine are all type 1)
`evapotranspiration` = index flag (0,1) followed by value of vertical flux to/from element – this may be imposed if you want to simulate ET a bit like MODFLOW – never used, because we can use the calculated ET from TOPOG
`stream element` = index flag (0,1) followed by imposed lateral flux to/from stream – never used – doubt if it is operational.
`Connectivity` = the node numbers that make up the FE element, in order

Part 4: non-node data

Not sure if implemented
If there are "non-node" data to be entered they will be done here.(this is read in fedata). In our case this remains empty.

Part 5: Aquifer paramters

If the mode flag on 2nd line of the header (see Part 1) was set to 0, (meaning salinity diffusivity and lateral transport was turned off), we read some static parameters.

```
         k              S                 leakage     dispvity-l     dispvity-t      porosity
    1.0000         0.2500         0.0000         0.0000         0.0000         0.0000
```

K = conductivity
S = specific yield
Leakage = leakage out bottom of aquifer (set to zero…)
These can be varied for every element in the FE mesh, but only laterally, there is no vertical structure in the groundwater component. Dispersivity and porosity are not read here.

If mode flag was set to 1, it means we have 2-D lateral advection-dispersion of salt and the characteristics for each element type are then read. This mode has not been tested except in very early setting up. There are two element types defined in the example below. There is a line for each element type, as defined in Part 3. "*element type characterisation and connectivity*" above.

```
         k              S                 leakage     dispvity-l     dispvity-t      porosity
    1.0000         0.2500         0.0000         0.0000         0.0000         0.0000
    0.0100         0.3000         0.0001         0.0000         0.0000         0.0000
```

Part 6: Read timestep data

```
  #dt   maxiter        tol1                tol2
    2        50     0.1000E-06     0.1000E-06
```

`#dt` = number FE iterations
`maxiter` = number of FE solver iterations
`tol1, tol2` = solution error tolerances

Not sure if implemented

```
        time        delta t
      0.0000        1.0000
    500.0000        1.0000
```

time = time of reading gwp file – need to set the second time (= 500.0000 here) after the end of the simulation – set for debugging during development and is a remnant.
delta t = gives you option to have different time steps in surface Topog and subsurface Topog – always set =1.

Part 7: Printout flags

```
     time    printout option
  #300.0      9
  300.0      13
  500.0       9
```

The # character acts to "comment out" the rest of the line, so you can leave things in or out as you choose.. The time printout options are:

Time entry gives time of spatial dump.
Enter dump time and flag (0 0 = end)
1=printout aquifer height at end of run
2=printout final differential aquifer height
3=printout aquifer recharge at specified time
4=printout cumulative aquifer recharge
5=printout aquifer discharge at specified time
6=printout cumulative aquifer discharge
7=printout aquifer height at specified time

8=printout aquifer differential height at specified time
9=printout aquifer bedrock elevation
10=printout aquifer surface/interface elevation
11=printout initial aquifer height
12=printout soil bedrock elevation
13=printout aquifer height - surface height at specified time
14=printout initial aquifer solute concentrations
15=printout aquifer solute concentration at specified time

These determine output times of spatial maps of aquifer properties - pretty well superseded by normal Topog outpout now but you can still use them.

Part 8: Groundwater update

Not sure if used
GW update time – not really used unless debugging – I always set as 1 more than the **time** used at Part 7 above

```
  update t
  501.0000
fluxbc 245 0.003
```

This option is used by routine **feupdt**. Reading it is fairly straight-forward. The format is “String” “Integer” “Value” If the first 3 characters of “string” are blank then skip, else valid strings are "headbc" "fluxbc" "infilt" "stream" "obswel" "pmpwel" "nonpmp" with the following integer being the **node** number and the value being the appropriate quantity according to the string used.

The bd1 and bd2 files are boundary node files, listing the boundary nodes of two allowable types - one is constant head the other constant flux. These are used by `_meshview` but not by `_dynamic` any more. Their function is now included in the .gwp file.

You must manually construct febdy fenode and feobs files and use `_femesh` (option 6) to incorporate them into the .gwp file.

4.4. Waterlevel, bedrock and surface level heights in the .gwp file

To enter the initial waterlevel height, the surface height and the bedrock elevation in the .gwp file prepare a file in the format (x,y,wl height, bedrock height, surface height) For the x,y columns use the x-y coordinates given in the .nxy file! Then add three columns with the r level height (m a.s.l.), bedrock height (m a.s.l., can be negative) and surface height for each node. Then use _femesh option 6 to include these data in the .gwp file.

4.5. Observation wells in the .gwp file

To enter the observation wells in a file: Create a file with the coordinates of the nodes (these have to be the same as listed in the .nxy file, so change this first to include the observation well locations!) and s (x,y,wl) used for observation wells. The format is 6 spaces for the node number so this could be (_ represents a space):

_____5
____14
___617
____13

5. Coregistration of surface and groundwater elements

The `_coreg` program is used to coregister the surface and groundwater elements to ensure that the triangular finite elements are correctly registered with the surface mesh elements. The procedure will create the `basename.a2y basename.y2a basename.yap`, etc. files. Coregistration may fail when elements cannot be registered properly. You then have to modify the location of one of the nodes of that FE element,

delete the .gwp file and create a new one with `_femesh` as described above. Also delete all the coregistration files and rerun `_coreg`.

6. Procedure for creating the groundwater files for Cuieiras

All the files have been prepared by M.J. Waterloo for Cuieiras but if you need to repeat the procedure for some reason (change of grid size for instance) it is detailed below.

1) To prepare the .nxy, .etn and .gwp files for Cuieiras run _femesh and use option 0, grid size 150 m x 150 m.
2) Then run _femesh and use option 2 to include extra nodes (file Cuieiras.addnodes).
3) Then run _femesh option 5 to create the Cuieiras.gwp file
4) Then run _coreg, this will give an error. Correct the error by shifting a node (change the coordinates of this node in the Cuieiras.nxy file) of the element in which the error occurred
5) Delete the Cuieiras.gwp file, the .bd files, the .mesh. files and the files created by _coreg so far.
6) Rerun _femesh, option 2
7) Rerun _femesh, option 5
8) Rerun _coreg, which should now exit normally
9) add the observation well nodes using _femesh, option 6 (file Cuieiras.obswells)
10) add the waterlevel, bedrock, surface heights using _femesh option 6 (file Cuieiras.gwpinfo)
11) Change the Cuieiras.par file to include groundwater (#aqu keyword)
12) Run dynamic_mjw < Cuieiras.par

7. Overview of how to use topog _dynamic without .par file.

There is an inconsistency between _simgen and _dynamic par files. If you use a uniform spatial soil distribution, _simgen assumes that you have only given 1 nodes file. Dynamic allows you to have given many nodes files. If you have given "uniform" as the distribution, _dynamic expects the next entry to be a nodes file index number. Simgen will have written "1" so you will always get the first nodes file as your soil. The problem arose because CSIRO changed the .par files to have a common .par file format for scenarios when CSIRO may sometimes want uniform soil and sometimes not. If you use _simgen to set up your first par file and then use an editor to modify it from then on, you should be fine. It's a good idea to run through _dynamic entries once by hand before launching your simulations to make sure the entries are as they should be.

```
waterloo@wabuda:~/data/Brazil/Cuieiras.gw.110m > _dynamic_mjw

 ************************************************************************
 *                                                                      *
 *      TOPOG_Dynamic: Catchment water balance and flux model           *
 *                     Solves water and solute transport problems       *
 *      Version 9.23 released January 2001                              *
 *      Copyright: CSIRO Australia                                      *
 *                                                                      *
 ************************************************************************
 *      Max No.Elts        =1000  Max No.Contours  =  80                *
 *      Max No.Trajectories=1001  Max No.Climates  =  10                *
 *      Max No.Soils       =  10  Max No.NodesFiles= 120                *
 *      Max No.Nodes       =  80                                        *
 ************************************************************************
 *                              Copyright                               *
 *      The Topog catchment modelling package has been developed        *
 *      by CSIRO Australia and may not be used to gain income or        *
 *      copied for commercial reasons without the written permission    *
 *      of CSIRO. Correspondence should be addressed to the Chief,      *
 *      CSIRO Land and Water, GPO Box 1666, Canberra, Australia, 2601   *
 ************************************************************************
 *                              Disclaimer                              *
 *      The Topog catchment modelling package has been written          *
 *      to provide a research tool for the simulation of water          *
 *      movement in complex terrain. Where significance is to be        *
```

```
 *      placed upon the results of simulations, the user should         *
 *      have independent methods for checking the accuracy of           *
 *      model predictions. Users are warned that significant            *
 *      errors in model predictions can arise from poor input           *
 *      data. Topog has been written in good faith but the              *
 *      authors accept no responsibility for any errors or              *
 *      omissions it may contain or any liability or damage             *
 *      that may result from its use.                                   *
 *********************************************************************
 *********************************************************************

 Enter #(header)                        <return=options>   #MYield

 Enter project basename                                    Cuieiras


 reading element attributes file .....
 reading element connections file ....
 Enter run identifier                                                 test
 Enter solution scheme (0=Richards,1=SBmodel,2=Rksmodel)               0
 Enter overland flow scheme (0=export,1=cascade,2=kinematic wave)      0
 Enter soil macropore scheme (0=inactive,1=active)                     0
 Enter sediment transport scheme (0=inactive, 1=Storm and Jorgensen,
2=Burch et al.)                                                        0
 Enter conservative solute transport scheme  (0=inactive,1=active) 0
 Enter start time  (ddmmyyyy or climate record#)                       200
 Enter finish time (ddmmyyyy or climate record#)                       300
 Enter #header keyword for next data entry (CR=end)   : #aqu
 Enter aquifer file: (CR for default:Cuieiras ): Cuieiras
 Aquifer mode: enter "isat" (default=1):
 0 to restrict soil Psi from rising above hydrostatic press.
 1 to allow soil Psi to rise above hydrostat press.
     isat ? : 1
 Enter #header keyword for next data entry (CR=end)   :
```

8. Common values/ranges for parameters in TOPOG

The following pages provide a guide to the values of Parameters used in TOPOG. These parameters were given in an Appendix to a CSIRO report.

Appendix 1. Typical parameter values for selected vegetation types

		Summer annual pasture (C_4)				Winter annual pasture (C_3)		
No.	**Parameter**	**Unit**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**
1	1 minus albedo of the canopy	—	0.85	0.90	0.75	0.85	0.90	0.8
2	1 minus albedo of the soil	—	0.85	0.90	0.80	0.85	0.90	0.8
3	Rainfall interception coefficient	$m\ d^{-1}\ LAI^{-1}$	0.0005	0.001	0.0001	0.0005	0.001	0.0001
4	Light extinction coefficient	—	-0.65	-0.70	-0.45	-0.65	-0.7	-0.5
5	Maximum carbon simulation rate	$kg\ C^{-2}\ d^{-1}$	0.02	0.04	0.01	0.025	0.04	0.01
6	Slope parameter for the conductance model	—	0.9	1.0	0.8	0.90	1.0	0.8
7	Maximum plant available soil water potential	m	-200	-250	-150	-150	-200	-100
8	IRM weighting of water	—	1.50	2.5	1.0	2.0	2.5	1.5
9	IRM weighting of nutrients	—	0.5	1.0	0.2	0.5	1.0	0.2
10	Ratio of stomatal to mesophyll conductance	—	0.8	0.8	0.8	0.2	0.2	0.2
11	Temperature when the growth is 1/2 of optimum	ºC	20	25	5	7	12	5
12	Temperature when the growth is optimum	ºC	25	30	15	12	15	10
13	Year day of germination	d	330	340	320	120	100	150
14	Degree-daylight hours for growth	ºC hr	30000	35000	25000	16000	12000	20000
15	Saturation light intensity	$\mu moles\ m^{-2}\ d^{-1}$	1500	1800	1200	1000	1500	800
16	Maximum rooting depth	m	1.0	1.5	0.5	1.0	1.5	0.5
17	Specific leaf area	$LAI\ kg\ C^{-1}$	48	54	24	24	30	20
18	Leaf respiration coefficient	$kg\ C\ kg\ C^{-1}$	0.002	0.003	0.001	0.001	0.002	0.0005
19	Stem respiration coefficient	$kg\ C\ kg\ C^{-1}$	-1	-1	-1	-1	-1	-1
20	Root respiration coefficient	$kg\ C\ kg\ C^{-1}$	0.0002	0.0003	0.0001	0.0002	0.0005	0.0001
21	Leaf mortality rate	$fraction\ of\ C\ d^{-1}$	0.001	0.0003	0.0001	0.001	0.01	0.0001
22	Above-ground partitioning factor	—	0.4	0.65	0.3	0.40	0.6	0.3
23	Salt sensitivity factor	—	1.0	10.0	0.5	1.0	10.0	0.5
24	Aerodynamic resistance	$s\ d^{-1}$	30	40	20	30	40	20
25	Crop harvest index	—	0.00	0.00	0.00	0.00	0.00	0.00
26	Crop harvest factor	—	0.00	0.00	0.00	0.00	0.00	0.00
		C_3 perennial pasture				**C_4 perennial pasture**		

No.	Parameter	Unit	Medium	High	Low	Medium	High	Low
1	1 minus albedo of the canopy	—	0.85	0.90	0.8	0.85	0.90	0.8
2	1 minus albedo of the soil	—	0.85	0.90	0.8	0.85	0.9	0.8
3	Rainfall interception coefficient	$m\ d^{-1}\ LAI^{-1}$	0.001	0.001	0.0001	0.001	0.001	0.0001
4	Light extinction coefficient	—	-0.65	-0.70	-0.50	-0.85	-0.90	-0.6
5	Maximum carbon simulation rate	$kg\ C^{-2}\ d^{-1}$	0.02	0.04	0.01	0.03	0.04	0.02
6	Slope parameter for the conductance model	—	0.90	1.0	0.8	1.0	1.1	0.9
7	Maximum plant available soil water potential	m	-150	-200	-100	-200	-250	-150
8	IRM weighting of water	—	2.0	2.5	1.5	2.0	2.5	1.5
9	IRM weighting of nutrients	—	0.5	1.0	0.2	0.5	1.0	0.2
10	Ratio of stomatal to mesophyll conductance	—	0.2	0.2	0.2	0.8	0.8	0.8
11	Temperature when the growth is 1/2 of optimum	ºC	7	12	5	15	20	10
12	Temperature when the growth is optimum	ºC	12	15	10	20	25	15
13	Year day of germination	d	-1	-1	-1	-1	-1	-1
14	Degree-daylight hours for growth	ºC hr	-1	-1	-1	-1	-1	-1
15	Saturation light intensity	$\mu moles\ m^{-2}\ d^{-1}$	1000	1500	800	1800	2000	1500
16	Maximum rooting depth	m	1.0	1.5	0.5	1.5	3.0	1.0
17	Specific leaf area	$LAI\ kg\ C^{-1}$	24	30	20	24	30	20
18	Leaf respiration coefficient	$kg\ C\ kg\ C^{-1}$	0.001	0.002	0.0005	0.0002	0.001	0.0001
19	Stem respiration coefficient	$kg\ C\ kg\ C^{-1}$	-1	-1	-1	-1	-1	-1
20	Root respiration coefficient	$kg\ C\ kg\ C^{-1}$	0.001	0.002	0.0001	0.0002	0.002	-
21	Leaf mortality rate	$fraction\ of\ C\ d^{-1}$	0.001	0.01	0.0001	0.001	0.01	0.0001
22	Above-ground partitioning factor	—	0.4	0.6	0.3	0.4	0.6	0.3
23	Salt sensitivity factor	—	1.0	10.0	0.5	1.0	10.0	0.5
24	Aerodynamic resistance	$s\ d^{-1}$	30	40	20	30	40	20
25	Crop harvest index	—	0.00	0.00	0.00	0.00	0.00	0.00
26	crop harvest factor	—	0.00	0.00	0.00	0.00	0.00	0.00
		Winter wheat				**Corn**		
No.	**Parameter**	**Unit**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**

1	1 minus albedo of the canopy	—	0.80	0.85	0.75	0.8	0.85	0.75
2	1 minus albedo of the soil	—	0.80	0.85	0.75	0.80	0.85	0.75
3	Rainfall interception coefficient	$m\ d^{-1}\ LAI^{-1}$	0.0003	0.001	0.0001	0.0003	0.001	0.0001
4	Light extinction coefficient	—	-0.52	-0.65	-0.45	-0.7	-0.75	-0.45
5	Maximum carbon simulation rate	$kg\ C^{-2}\ d^{-1}$	0.02	0.03	0.015	0.03	0.04	0.02
6	Slope parameter for the conductance model	—	0.9	1.0	0.8	1.0	1.1	0.8
7	Maximum plant available soil water potential	m	-100	-200	-150	-300	-350	-150
8	IRM weighting of water	—	2.2	2.5	1.5	1.5	2.0	1.0
9	IRM weighting of nutrients	—	1.0	1.0	0.5	0.5	1.0	0.2
10	Ratio of stomatal to mesophyll conductance	—	0.2	0.2	0.2	0.8	0.8	0.8
11	Temperature when the growth is 1/2 of optimum	ºC	10	20	5	20	25	15
12	Temperature when the growth is optimum	ºC	15	30	10	25	30	15
13	Year day of germination	d	150	120	180	330	340	320
14	Degree-daylight hours for growth	ºC hr	15000	20000	12000	30000	35000	25000
15	Saturation light intensity	$\mu moles\ m^{-2}\ d^{-1}$	10000	15000	8000	1800	2000	1000
16	Maximum rooting depth	m	1.0	1.5	0.3	1.0	1.5	0.5
17	Specific leaf area	$LAI\ kg\ C^{-1}$	24	30	18	24	30	18
18	Leaf respiration coefficient	$kg\ C\ kg\ C^{-1}$	0.0025	0.0030	0.0005	0.0015	0.0025	0.0005
19	Stem respiration coefficient	$kg\ C\ kg\ C^{-1}$	-1	-1	-1	-1	-1	-1
20	Root respiration coefficient	$kg\ C\ kg\ C^{-1}$	0.0001	0.00015	0.00005	0.0002	0.0005	0.0001
21	Leaf mortality rate	$fraction\ of\ C\ d^{-1}$	0.001	0.01	0.0001	0.001	0.005	0.0005
22	Above-ground partitioning factor	—	0.4	0.65	0.3	0.4	0.65	0.3
23	Salt sensitivity factor	—	0.75	10	0.5	1.0	10	0.5
24	Aerodynamic resistance	$s\ d^{-1}$	30.0	40	20	20.0	30	10
25	Crop harvest index	—	0.00	0.00	0.00	0.00	0.00	0.00
26	crop harvest factor	—	0.00	0.00	0.00	0.00	0.00	0.00

			Irrigated lucerne			**Gum trees (eucalypts)**		
No.	**Parameter**	**Unit**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**
1	1 minus albedo of the canopy	—	0.80	0.85	0.75	0.80	0.85	0.75

2	1 minus albedo of the soil	—	0.85	0.90	0.80	0.85	0.90	0.80
3	Rainfall interception coefficient	m d^{-1} LAI^{-1}	0.001	0.003	0.0001	0.0003	0.001	0.0001
4	Light extinction coefficient	—	-0.65	-0.85	-0.45	-0.45	-0.50	-0.40
5	Maximum carbon simulation rate	kg C^{-2} d^{-1}	0.025	0.04	0.02	0.02	0.03	0.01
6	Slope parameter for the conductance model	—	1.0	1.1	0.8	0.90	1.0	0.80
7	Maximum plant available soil water potential	m	-150	-200	-100	-200	-400	-150
8	IRM weighting of water	—	2.0	2.5	1.0	2.1	2.5	1.0
9	IRM weighting of nutrients	—	0.5	0.8	0.2	0.3	0.5	0.2
10	Ratio of stomatal to mesophyll conductance	—	0.2	0.2	0.2	0.2	0.2	0.2
11	Temperature when the growth is 1/2 of optimum	ºC	10	15	5	15	20	10
12	Temperature when the growth is optimum	ºC	15	20	10	20	25	15
13	Year day of germination	d	-1	-1	-1	-1	-1	-1
14	Degree-daylight hours for growth	ºC hr	-1	-1	-1	-1	-1	-1
15	Saturation light intensity	µmoles m^{-2} d^{-1}	1000	1500	800	1000	1500	800
16	Maximum rooting depth	m	2.5	3.5	1.5	20	40	10
17	Specific leaf area	LAI kg C^{-1}	54	60	48	12	10	15
18	Leaf respiration coefficient	kg C kg C^{-1}	0.0002	0.00025	0.0001	0.001	0.0015	0.0005
19	Stem respiration coefficient	kg C kg C^{-1}	0.0002	0.00025	0.0001	0.0006	0.0015	0.0001
20	Root respiration coefficient	kg C kg C^{-1}	0.0002	0.00025	0.0001	0.0001	0.0015	0.0001
21	Leaf mortality rate	fraction of C d^{-1}	0.01	0.015	0.005	0.0001	0.0015	0.0001
22	Above-ground partitioning factor	—	0.7	0.8	0.5	0.25	0.40	0.20
23	Salt sensitivity factor	—	1.0	10.0	0.5	1.0	10.0	0.50
24	Aerodynamic resistance	s d^{-1}	30	40	20	10	20	5
25	Crop harvest index	—	0.00	0.00	0.00	0.00	0.00	0.00
26	crop harvest factor	—	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 2 : Typical Values of Soil Hydraulic Parameters

Soil Type	K_s (m d^{-1})	θ_s (m^3 m^{-3})	θ_r (cm^3 cm^{-3})	λ_c (m)	C
Sand	≥ 1.0	0.30 - 0.40	0.05 - 0.10	0.01 - 0.05	1.01 - 1.02
Loamy Sand	≥ 1.0	0.35 - 0.45	0.05 - 0.10	0.01 - 0.05	1.02 - 1.05
Sandy Loam	≥ 0.5	0.40 - 0.50	0.05 - 0.15	0.05 - 0.10	1.02 - 1.05
Silt Loam	≥ 0.5	0.45 - 0.50	0.10 - 0.20	0.25 - 0.50	1.05 - 1.20
Loam	0.1 - 1.0	0.40 - 0.50	0.10 - 0.20	0.10 - 0.20	1.40 - 1.50
Sandy Clay Loam	0.1 - 1.0	0.35 - 0.45	0.10 - 0.20	0.10 - 0.20	1.40 - 1.50
Silt Clay Loam	0.1 - 0.5	0.40 - 0.50	0.15 - 0.25	0.10 - 0.20	1.20 - 1.30
Clay Loam	0.1 - 0.5	0.45 - 0.55	0.20 - 0.30	0.25 - 0.50	1.20 - 1.40
Sandy Clay	0.1 - 0.5	0.40 - 0.50	0.15 - 0.25	0.05 - 0.10	1.10 - 1.20
Silt Clay	0.01 - 0.1	0.45 - 0.55	0.25 - 0.35	0.20 - 0.50	1.05 - 1.20
Clay	0.01 - 0.1	0.45 - 0.55	0.25 - 0.35	0.20 - 0.50	1.30 - 1.50
Heavy Clay	0.001-0.01	0.40 - 0.60	0.05 - 0.20	0.50 - 2.00	1.50 - 2.00

Table A2.1 : Typical values of the five BW soil parameters, for generic soil texture.

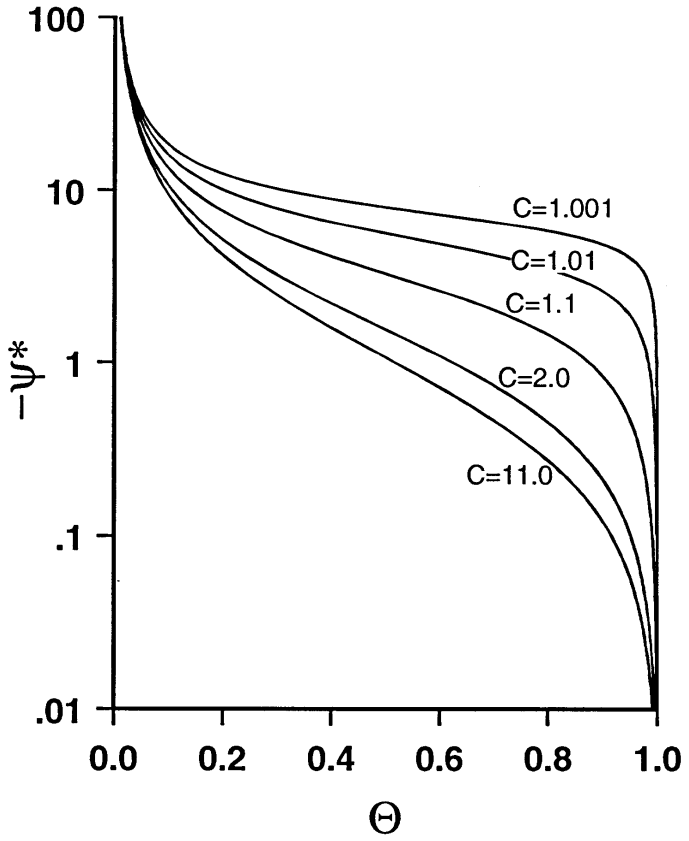

Figure A2.1 : BW soil moisture retention curves. Note that ψ^* is $-\psi/\lambda_c$, and Θ is θ scaled between 0 at air-dry to 1 at saturation.

Soil Type	K_s (m d^{-1})	θ_s (m^3 m^{-3})	$-\psi_a$ (m)	b
Sand	≥ 1.0	0.30 - 0.40	0.10 - 0.15	4.0
Loamy Sand	≥ 1.0	0.35 - 0.45	0.05 - 0.10	4.4
Sandy Loam	≥ 0.5	0.40 - 0.50	0.20 - 0.25	4.9
Silt Loam	≥ 0.5	0.45 - 0.50	0.70 - 0.80	5.3
Loam	0.1 - 1.0	0.40 - 0.50	0.40 - 0.50	5.4
Sandy Clay Loam	0.1 - 1.0	0.35 - 0.45	0.25 - 0.35	7.1
Silt Clay Loam	0.1 - 0.5	0.40 - 0.50	0.30 - 0.40	7.8
Clay Loam	0.1 - 0.5	0.45 - 0.55	0.60 - 0.70	8.5
Sandy Clay	0.1 - 0.5	0.40 - 0.50	0.10 - 0.20	10.4
Silt Clay	0.01 - 0.1	0.45 - 0.55	0.45 - 0.55	10.4
Clay	0.01 - 0.1	0.45 - 0.55	0.35 - 0.45	11.4
Heavy Clay	0.001-0.01	0.40 - 0.60	0.40 - 0.50	12.0

Table A2.2 : Typical values of the five Campbell soil parameters, for generic soil texture.
This is a generalisation of the data presented in Clapp and Hornberger (1978).

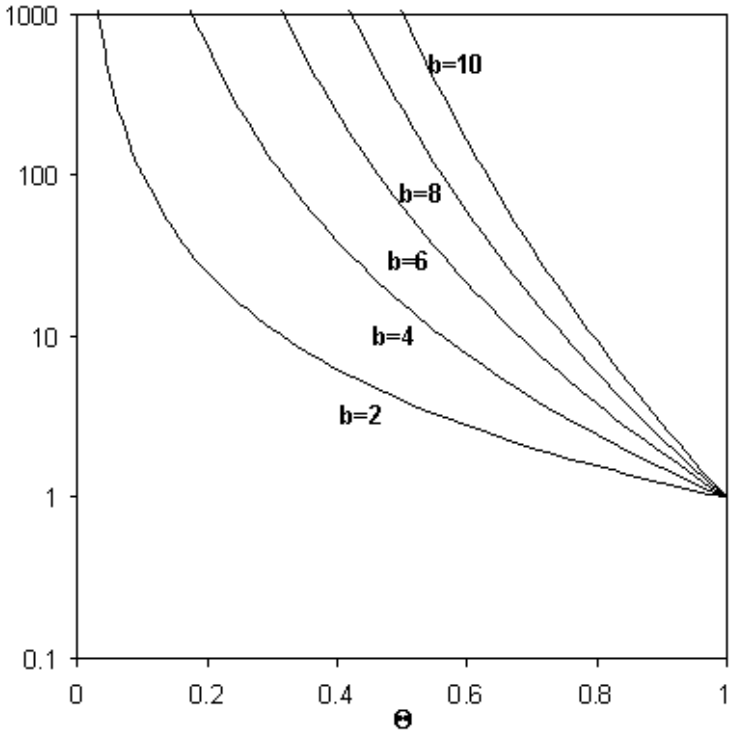

Figure A2.2 : Campbell soil moisture retention curves.
Note that ψ^* is ψ/ψ_a, and Θ is θ/θ_s.

Tables A2.1 and A2.2 present values which are typical and can be used when the user has no measured information, or other sources of data. It is not envisaged that all measurements made will fit exactly within the ranges presented here, because there is wide variation of parameters within the same apparent texture class. These values, and any measurements, make up a starting point for the user to fit some measured response, and should not be viewed as absolute numbers, or a replacement for data gathering.