SLICKMOD – A spatial model of oil spill dispersal rates and extents in aquatic environments

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Model design

SLICKMOD is a raster based model to simulate the speed and extent of oil spill dispersal in terrestrial and aquatic environments. It simulates oil slick movement over land and in water on an hourly timestep according to (a) measured velocities and their relationship with slope gradient over land and (b) measured velocities and their relationship with river flow velocity (calculated using a kineamatic wave) in water. As well as the rate of transport, the model calculates the amount of oil deposited and the rates of evaporation and degradation in the environment.

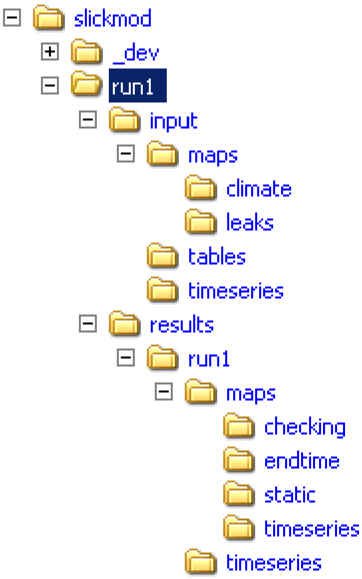
The model can be used to:

(a) simulate the extent of contamionation arising from historic leaks
(b) simulate random leaks with particular characteristics anywhere within a pipeline network so as to model the resulting speed of contamination and area contaminated and thus define the potential social and environmental consequences of leaks from a particular location
(c) to simulate particular leak events and indicate the time to contamination of particular areas so as to best locate clean-up facilities and prioritise pipeline monitoring and maintenance in pollution-critical areas

Model setup

The model runs in the PCRASTER GIS which is downloadable from www.pcraster.nl. The model script is sealed since it incorporates a series of licences for specialist PCRASTER features, which are transferred to the user for use with the script. The model consists of the model script slickmod.mod, a series of batch files for preprocessin, running, postprocessing and display of results and a bindings.mod file which contains the model parameters.

The model is distributed in a series of directories. These directories include the _dev directory which contains the model script, the input directory which contains the model input data (in a series of subdirectories named maps, tables and timeseries). **Inputs/maps** contains input maps, **input/timeseries** contains input timeseries such as the hourly rainfall record, **input/tables** contains a series of tables for model parameters which are dependent on vegetation cover or other nominal (classified) maps. The Input/maps directory also has subdirectories for climate maps (spatial rainfall) and leak maps. The results directory contains results for a series of model runs as defined in the run batch files. For each of these runs results are presented in a series of subdirectories which include **maps/checking** (maps written for model testing purposes only), **maps/endtime** (maps written at the end of a model run), **maps/static** (static maps written once) and **maps/timeseries** (maps written according to the selected interval for writing up to every hour). In addition a **timeseries/** directory contains output timeseries from the model run.

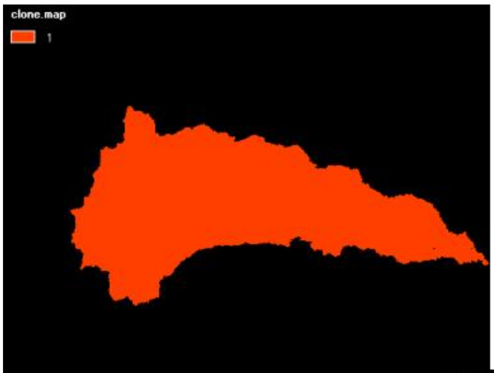


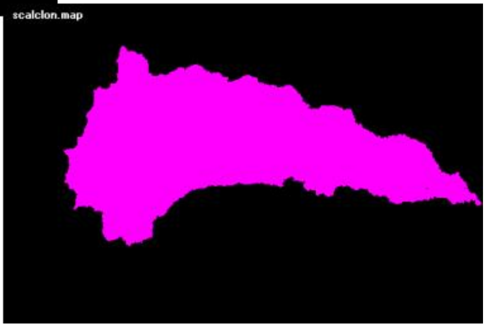
- slickmod
  - _dev
  - run1
    - input
      - maps
        - climate
        - leaks
      - tables
      - timeseries
    - results
      - run1
        - maps
          - checking
          - endtime
          - static
          - timeseries
        - timeseries

Figure 1 Directory structure for SLICKMOD

Input maps
The following input maps are required by the model. As is normal for PCRASTER models all maps must be cut to the same dimensions. In each case an example map for the Oriente of Ecuador is given.

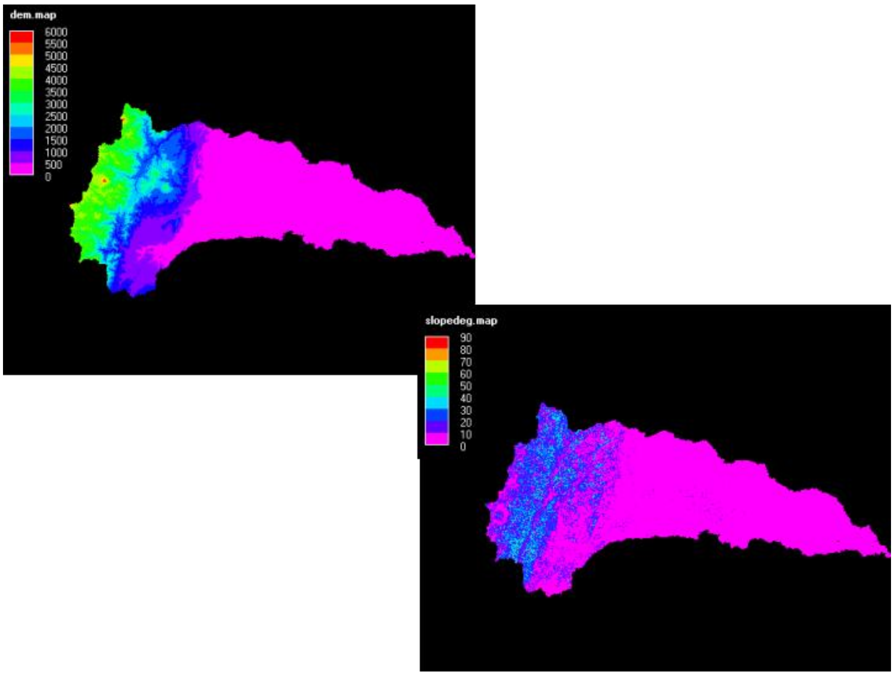
Clone.map
Scalclon.map
These two maps describe the calculation area for the model and have a 1 for areas which are part of the model catchment area and a zero elsewhere.



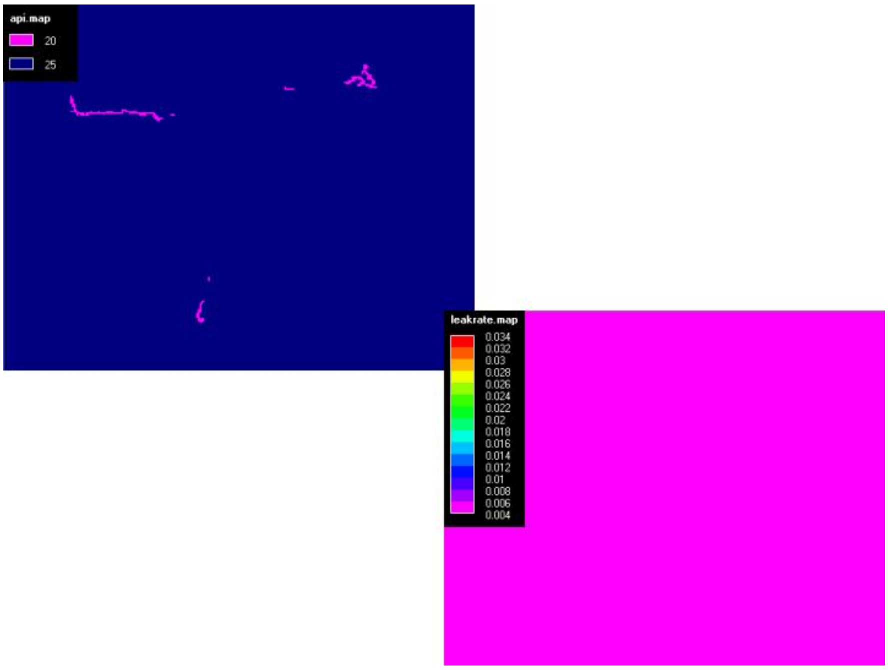


Dem.map
Slopedeg.map

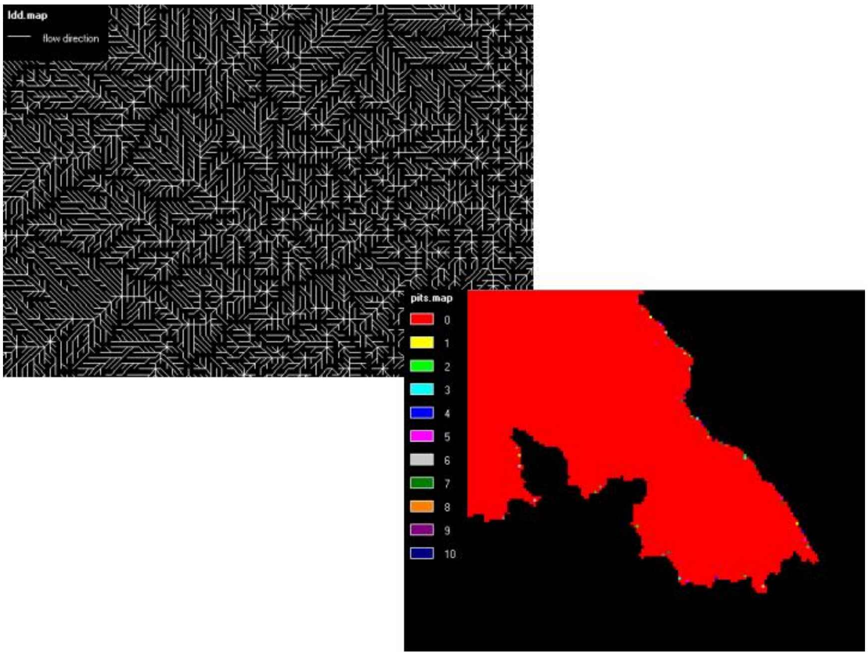
These maps are digital elevation model and slope angle for the area usually derived from the 90m SRTM digital elevation model dataset at www.ambiotek.com/topoview (www.kcl.ac.uk/geodata)



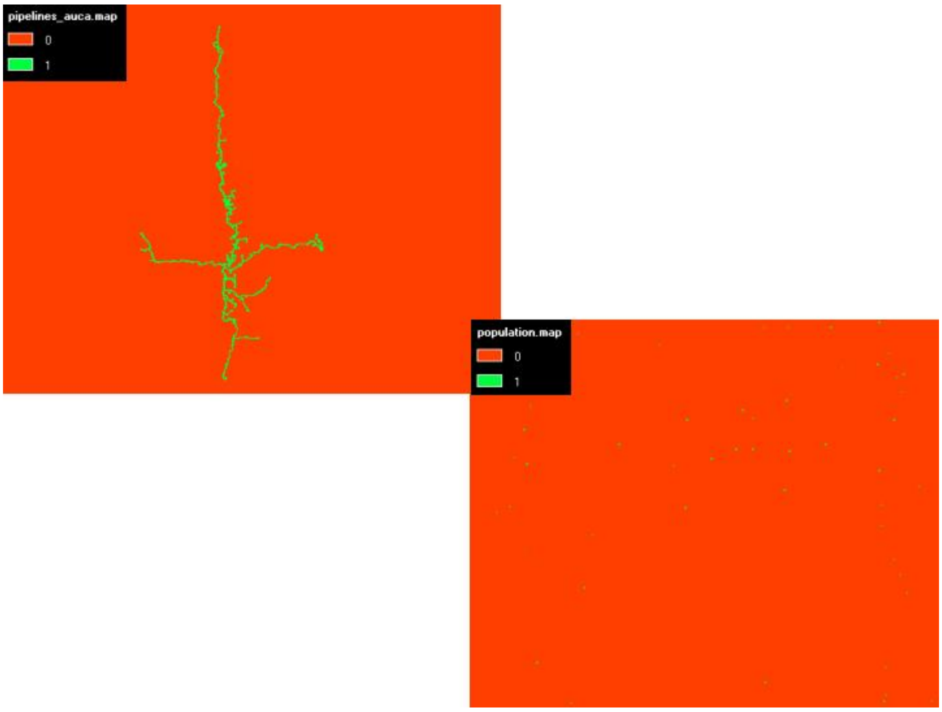
API.map
Leakrate.map
These maps present the geographical differences in API and in leak rate which can be set at a fixed value or vary between oilfields.



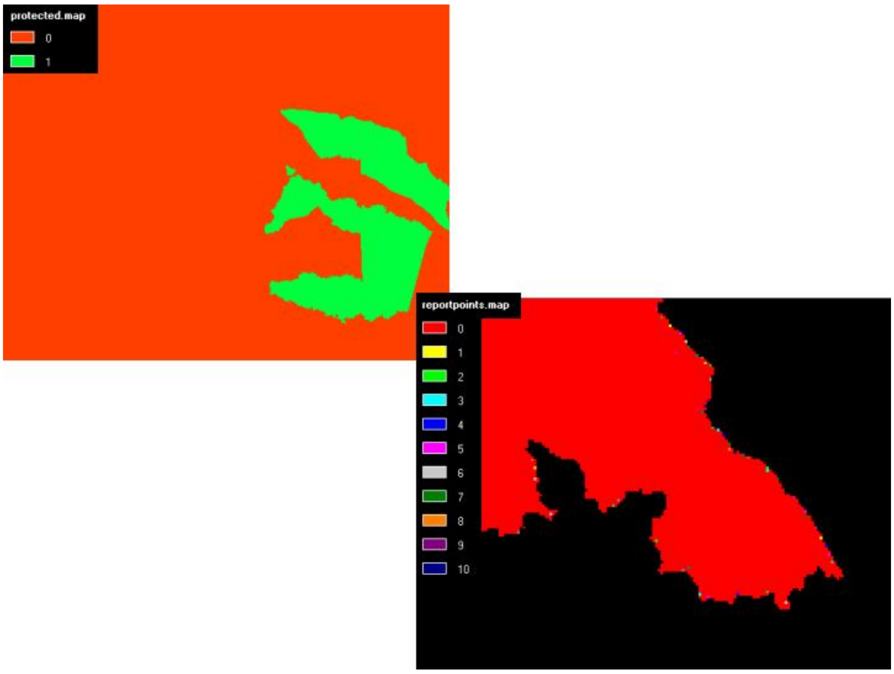
LDD.map
Order.map
Pits.map
These maps represent the local drainage directions calculated from the DEM, the stream order (not shown) and the outflow pits of the local drainage direction.



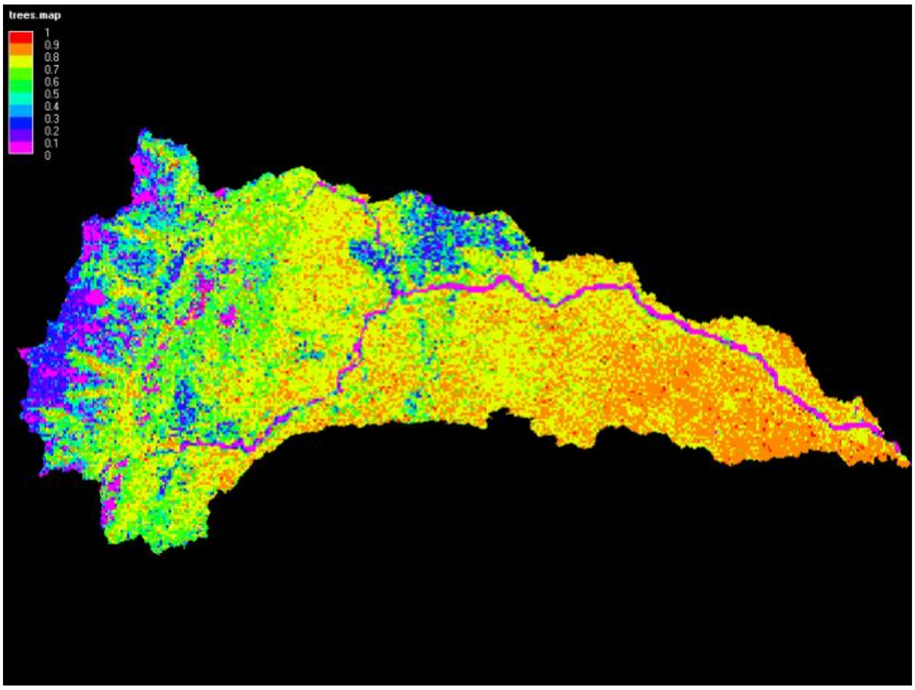
Pipelines_Auca.map
Population.map
These maps show the pipeline network and the distribution of populated pixels.



Protected.map
Reportpoints.map
These maps show the distribution of protected areas and the distribution of points at which pixel timeseries (eg runoff are written).

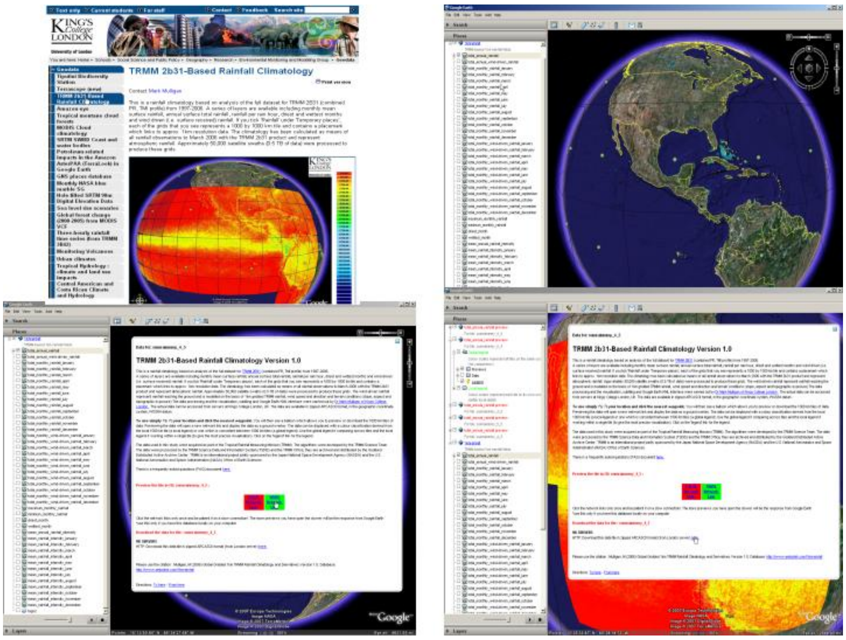


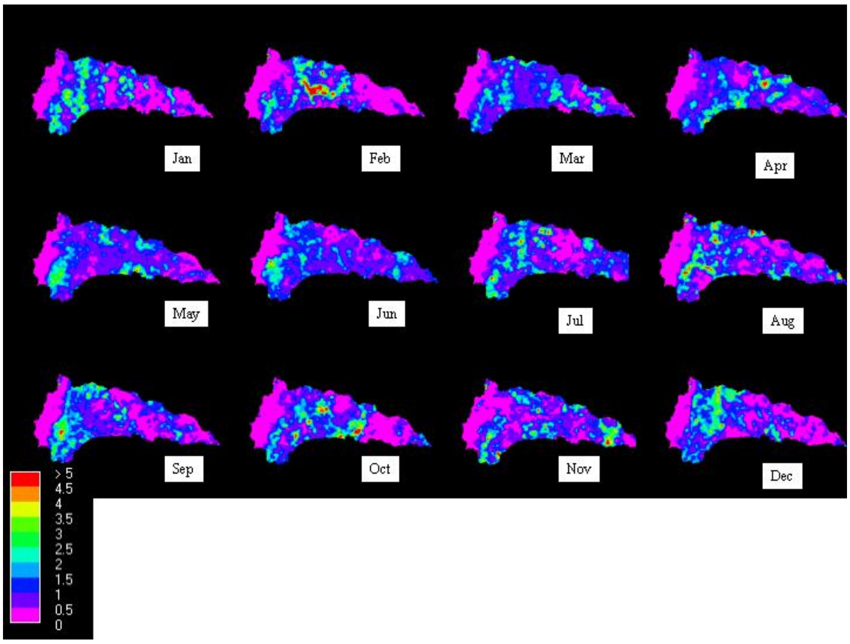
Trees.map
This is a map of tree fractional cover derived from the MODIS VCF data.



All other maps in this directory are temporary and generated by the model.

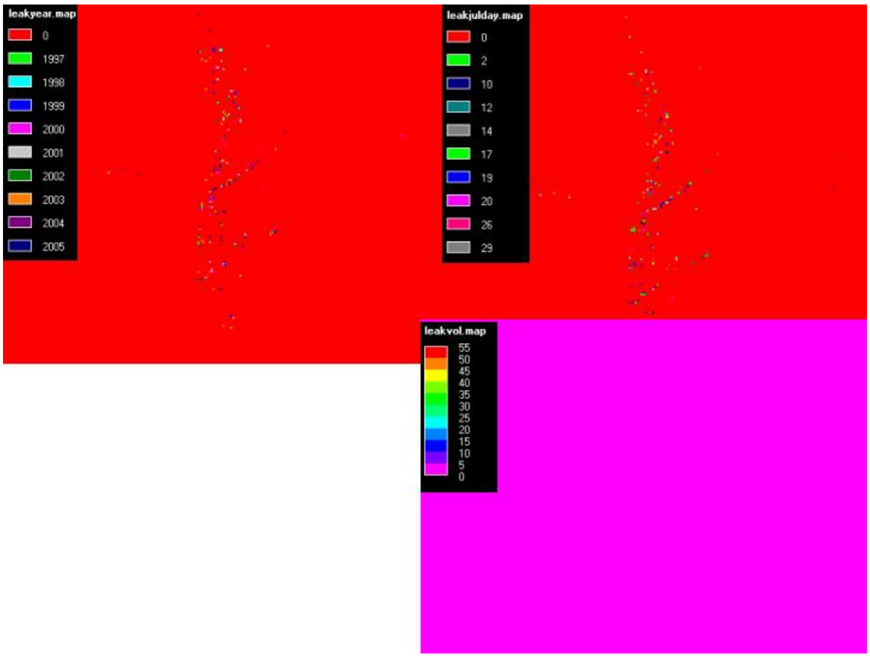
Under the **/climate** subdirectory a series of monthly spatial rainfall correction factors are given calculated from the TRMM 1km rainfall climatology at **http://www.ambiotek.com/1kmrainfall** and **http://www.cl.ac.uk/geodata**. The data are downloaded as tiled ARCASCII files for each month as below and then converted to PCRASTER format. Correction factors (rainfall in each pixel divided the mean rainfall for the entire catchment) are then calculated and the correction factor maps are used by the model to confirm the areal average input rainfall data from TRMM 3B42 to spatially distributed values for each month.





Under the **/leaks** subdirectory are a series of directories which give the characteristics of leaks to be simulated. The following maps are required :

Leakyear – the year of each leak
LeakJulday – the julian day of each leak
LeakVol – the volume (m^3) of each leak [note that 1 barrel = 42 gallons = 0.158987296 m^3]

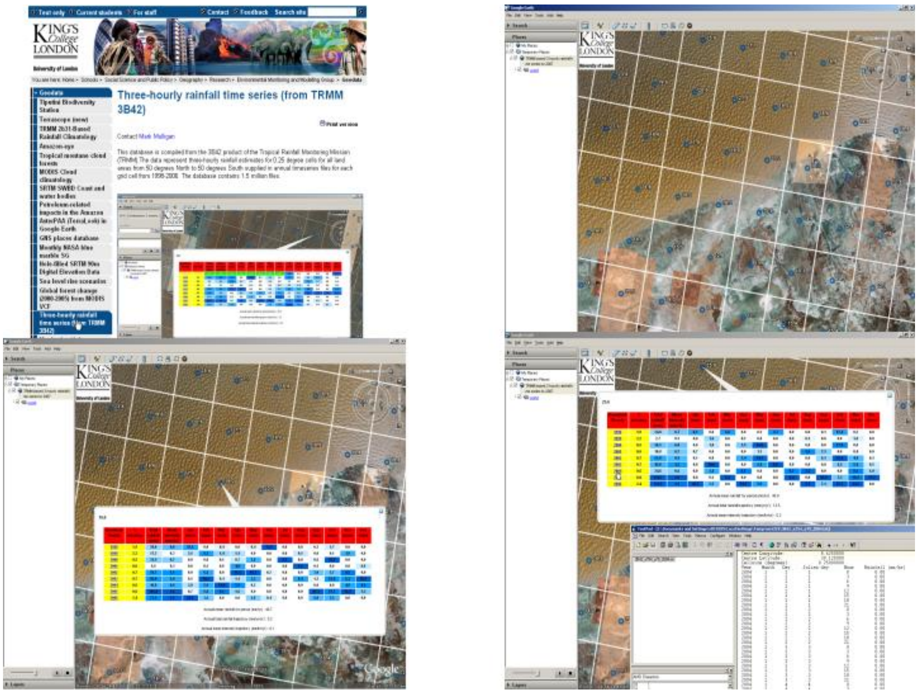


Input timeseries

The **/timeseries** input directory includes a file which contains the hourly rainfall data that is used to generate the rivers flows at the simulation time. The format of the file should be as follows:

```
Rainfall generated from TRMM 3B42 (2005) uncalibrated
5
Timestep
Month
Julian Day
Hour
Rainfall     (mm/hr)
1            1            1            0            0
2            1            1            1            0
3            1            1            2            0
4            1            1            3            0
5            1            1            4            0
6            1            1            5            0
7            1            1            6            0
8            1            1            7            0
9            1            1            8            0
10           1            1            9            0
11           1            1            10           0
12           1            1            11           0
13           1            1            12           0
14           1            1            13           0
15           1            1            14           0
16           1            1            15           0
17           1            1            16           0
18           1            1            17           0
19           1            1            18           1.02
20           1            1            19           1.02
21           1            1            20           1.02
```

This file is generated from the TRMM 3 hourly rainfall totals at http://www.ambiotek.com/trmmtimeseries (http://www.kcl.ac.uk/geodata). The relevant files are downloaded per year from the interface below and then converted to the appropriate format for PCRASTER.

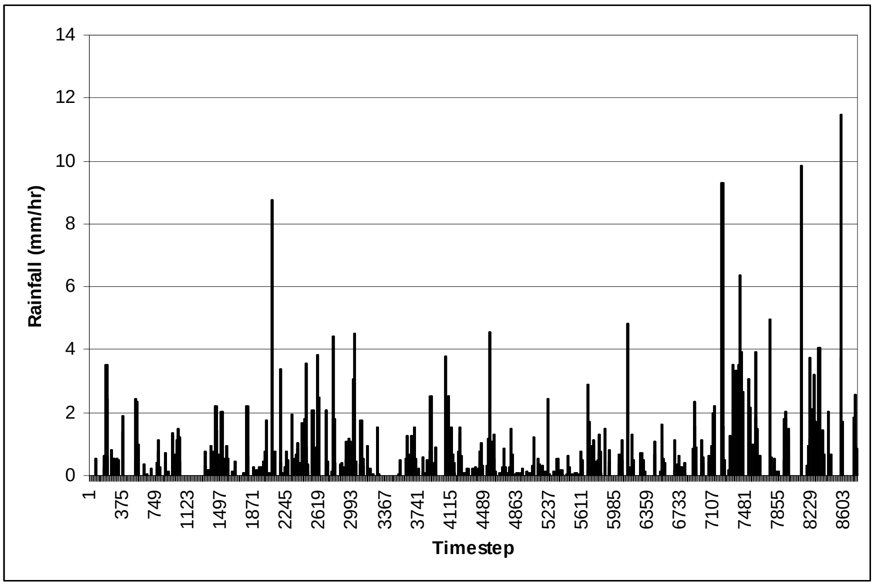


Three-hourly rainfall time series (from TRMM 3B42)

Contact Mark Mulligan

This database is compiled from the 3B42 product of the Tropical Rainfall Monitoring Mission (TRMM). The data represent three-hourly rainfall estimates for 0.25 degree cells for all land areas from 50 degrees North to 50 degrees South supplied in annual timeseries files for each grid cell from 1998-2008. The database contains 1.5 million files.

The resulting time series of rainfall may look something like this (for the oriente, 1998).



Input tables

The **/tables** directory contains a series of lookup tables to parameterise the relationships between oil velcoity, surface retention and slope gradient for each oil viscosity (API) for both vegetated and bare soils. The following tables are required :

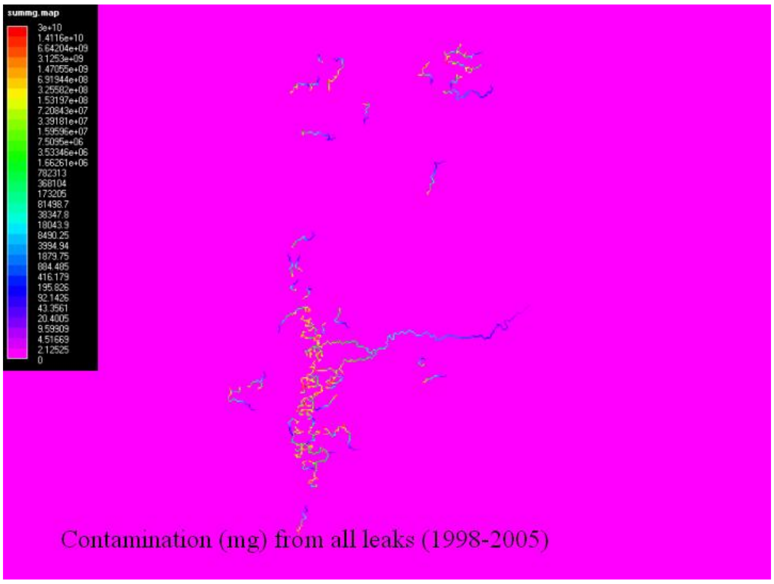
RetSlopeIntercBare.tbl – The intercept of the oil retention versus slope gradient relationship for each API for flow over bare soil
RetSlopeIntercVeg.tbl - The intercept of the oil retention versus slope gradient relationship for each API for flow over vegetated soil
RetSlopeSlopeBare.tbl - The slope of the oil retention versus slope gradient relationship for each API for flow over bare soil
RetSlopeSlopeVeg.tbl - The slope of the oil retention versus slope gradient relationship for each API for flow over vegetated soil
VelSlopeIntercBare.tbl - The intercept of the oil velocity versus slope gradient relationship for each API for flow over bare soil
VelSlopeIntercVeg.tbl - The intercept of the oil velocity versus slope gradient relationship for each API for flow over vegetated soil
VelSlopeSlopeBare.tbl - The slope of the oil velocity versus slope gradient relationship for each API for flow over bare soil
VelSlopeSlopeVeg.tbl - The slope of the oil velocity versus slope gradient relationship for each API for flow over vegetated soil

Model Outputs

The model writes a series of outputs maps and timeseries.

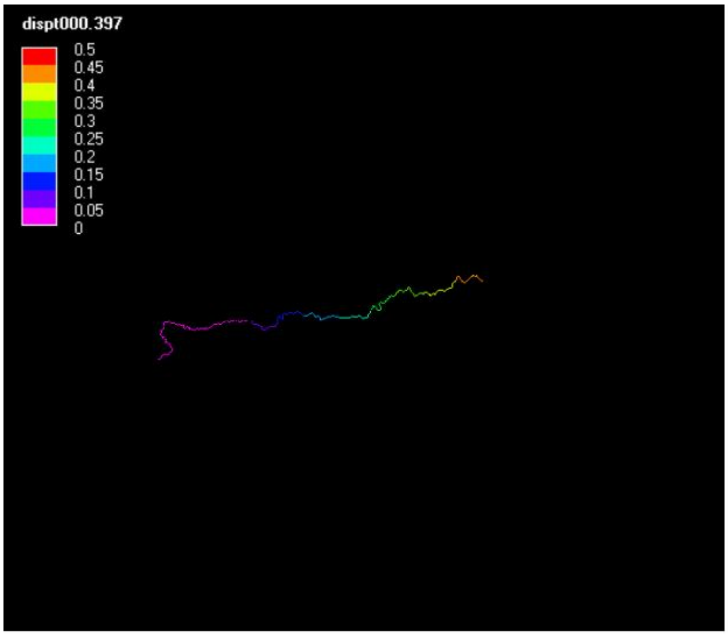
Maps

The two most significant maps written each required timestep are the dispersal time map and the contamination map. The contamination map is a summary of the oil contamination in each pixel in mg of oil. It is only calculated for levels above the predefined critical value for a cell to be considered contaminated. The diagram below shows the distribution of contamination from multiple leaks for 1998-2005.



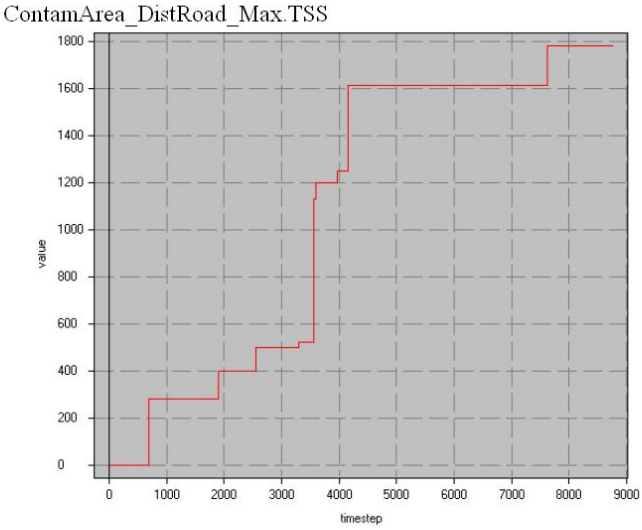
Contamination (mg) from all leaks (1998-2005)

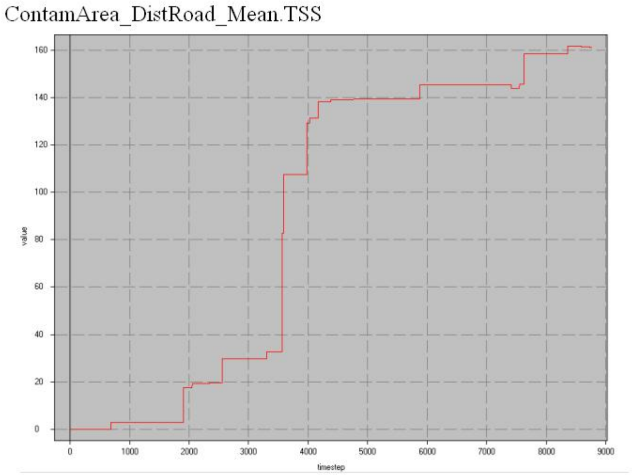
The dispersal time map is a calculation of the hours taken for oil to reach all parts downstream of the leak location. The diagram below shows this for a single leak and indicates that the oil takes a max of 0.5 hours to disperse until it falls below the predefined concentration to be considered contaminated.



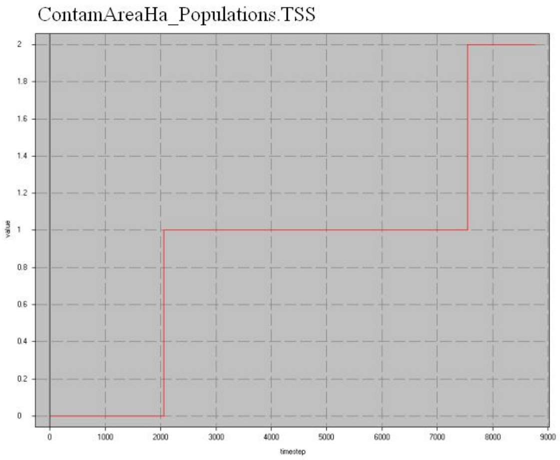
Timeseries

A series of timeseries files are written which combine the model results with some of the input maps to assess the impacts of leak dispersal. The first of these shown is the maximum distance from a road of the contaminated area. This is important since it determines the accessibility of the contamination and thus the potential for cleanup. It is clear from the annual timeseries shown below that a few major leaks cause significant increases in this maximum distance. The patterns given for mean distance of contamination from the nearest road shows similar patterns.

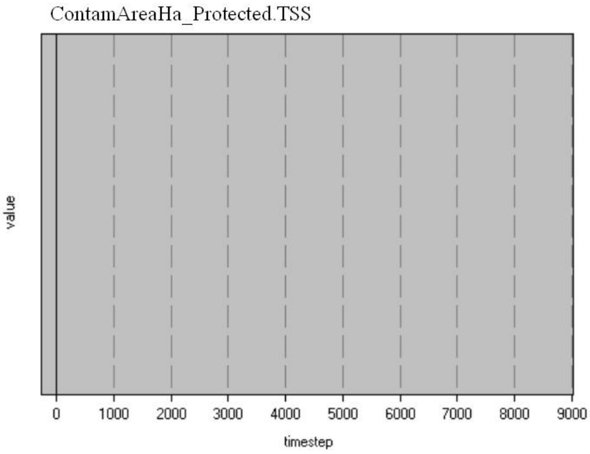

ContamArea_DistRoad_Max.TSS


ContamArea_DistRoad_Mean.TSS

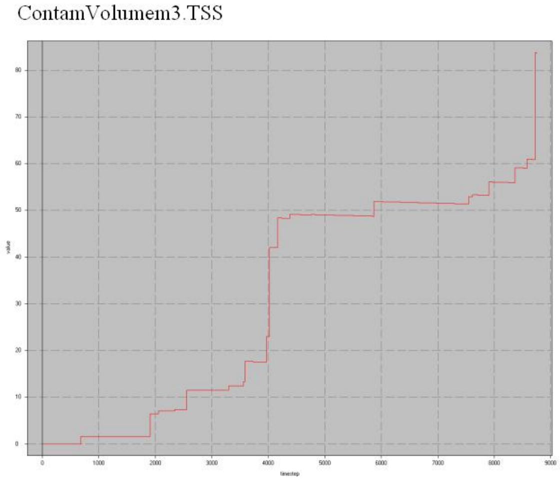
The following example shows the contaminated populations timeseries and indicated that in 1998 two populated pixels were hit by leaks.



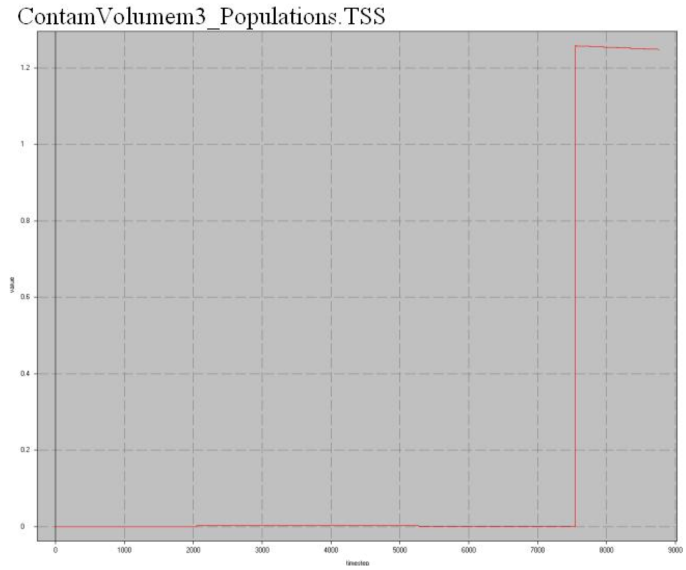
The following example represents the protected area contaminated and indicates that for 1998 no protected areas was contaimated by leak dispersion.

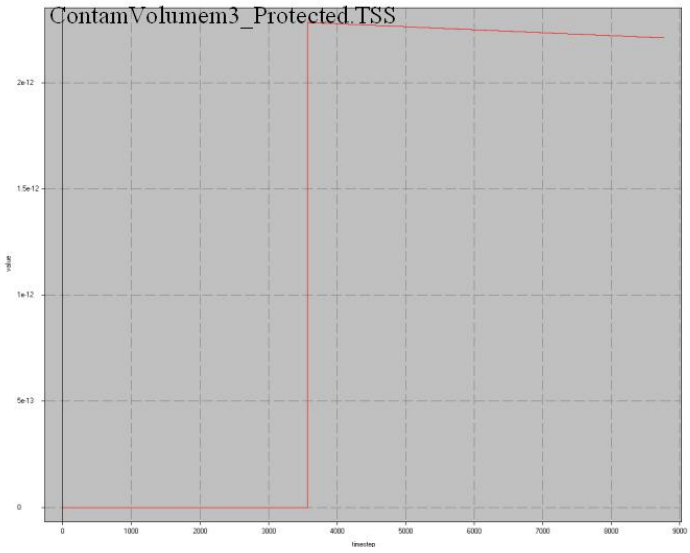


The next example shows the change in contamination total (in m^3) for the entire simulation area and indicates a progressive increase as leaks occur, particularly the two biggest leaks in the middle and at the end of the year. There is also slight decline between events, reflecting degradation and evaporation of oil.

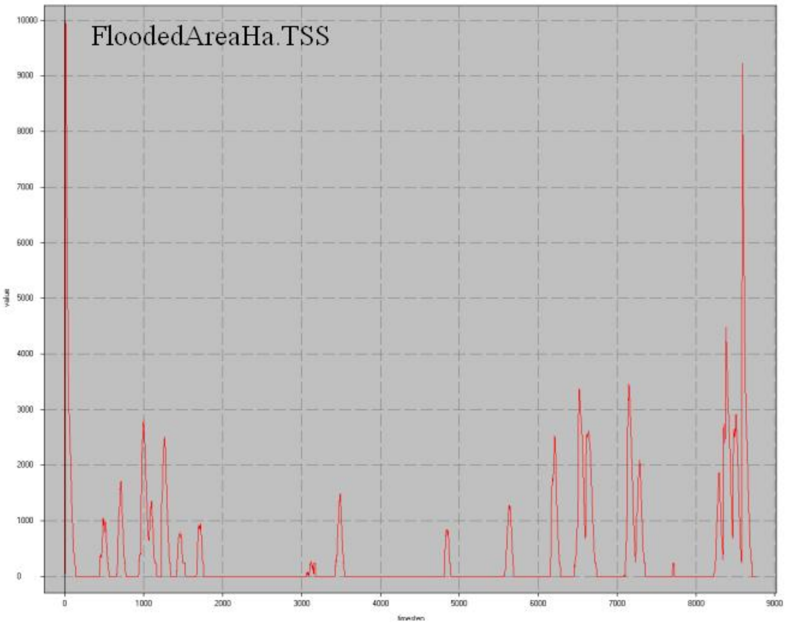


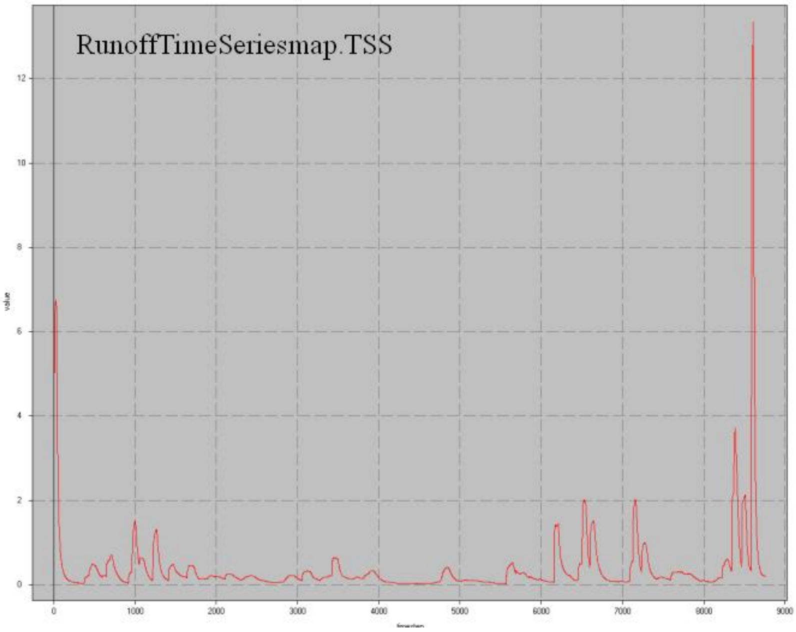
The following two examples show the contaminated volumes for populations and protected areas and indicate that the first population pixel hit received very low volumes of oil but the second one received a large contamination event. Moreover, although not sufficient oil ingressed a protected area for any cell to be considered as contaminated, a small amount of oil contamination had entered protected areas at very diffuse concentrations.





The final timeseries examples provide data on the changing flooded area (Ha) and river discharge.


FloodedAreaHa.TSS
value
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
timestep


RunoffTimeSeriesmap.TSS
value
12
10
8
6
4
2
0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
timestep

Model parameters

The model parameters are set in the **bindings.mod** file as below

```
#input variables
FractionalChannelWidthPerOrder=0.125;#******
ChanneldepthPerUnitOrder=0.5;#m #******

ConstVelBareRegrIntercept=0;#0.486666667 m/s/ degree of slope use 0 to read data from tables or any other value to specify data here
ConstVelVegRegrIntercept=0;#0.137 m/s at slope=0 use 0 to read data from tables or any other value to specify data here
ConstVelBareRegrSlope=0;#0.486666667 m/s/degree of slope use 0 to read data from tables or any other value to specify data here
ConstVelVegRegrSlope=0;#0.137 m/s at slope=0 use 0 to read data from tables or any other value to specify data here
ConstRetBareRegrIntercept=0;#8.168688  %age retained at slope=0 use 0 to read data from tables or any other value to specify data here
ConstRetVegRegrIntercept=0;# 16.86175673%age retained at slope=0 use 0 to read data from tables or any other value to specify data here
ConstRetBareRegrSlope=0;# 8.168688 %age per degree of slope, use 0 to read data from tables or any other value to specify data here
ConstRetVegRegrSlope=0;# 16.86175673 %age per degree of slope, use 0 to read data from tables or any other value to specify data here

RiverRelVelVsFlowInterc=0.263;# with discharge units in m3/s
RiverRelVelVsFlowSlope=-5.4;

RiverDeposVsFlowInterc=0.313;# fraction river discharge in cumecs
RiverDeposVsFlowSlope=-0.323;

LandOilEvapFrac=6.24879e-6 ;#fraction of oil evaporated per hour

ConstRainfall=0;#mm set to value for constant rainfall, if 0 the metinput file is read for rainfall
Infil=5;
RiverEvapm=0.00001;

RandomLeaks=0;#1 for random leaks 0 for read leaks from map time series
ProbLeakage=1;#0.004109;#0.004109589;#probability of leakage per hour, based on recorded leaks 1997-2006, could also be a map of
#differing probabailities, or set to 1 for simultaneous leaks everywhere (sensitivity analysis)
MeanLeakSize=3.83;#95.39;#3;#95.39;#3.82;#m3 Auca 1997-2005

#constants
DTsecs=scalar(3600); # time of one timestep (s)
N=scalar(0.1); # manning's n
Beta=scalar(0.6); # Wave param
QIni=10.0;#scalar(0.000000000001); # initial streamflow (m3/s)
HIni=4.0;#scalar(0.000000001); # initial waterheight (m)
ContaminationThreshold=1.28205E-07;#m3 100mg threshold below which area is not considered 'contaminated'
#input maps
#output
#1 US gallon = 0.0037854118 cubic meters, 1 barrel = 42 gallons = 0.158987296 m3
```

FractionalChannelWidthPerOrder – the proportion of a cell occupied by channel per unit streamorder (used to calculate the proportion of cell which remains land). There is no reason to change this parameter.

ChanneldepthPerUnitOrder – as for width – used to calculate depth of channel for kinematic wave. There is no reason to change this parameter.

The following parameters are used to set constant values for velocities and oil retention relationships with slope gradient rather than use the API dependent ones that are represented in the input tables. Set these to zero to read from the input lookup tables instead.
ConstVelBareRegrIntercept – the intercept of the velocity, slope gradient relationship for bare soils
ConstVelVegRegrIntercept - the intercept of the velocity, slope gradient relationship for vegetated soils
ConstVelBareRegrSlope - the slope of the velocity, slope gradient relationship for bare soils

ConstVelVegRegrSlope - the slope of the velocity, slope gradient relationship for vegetated soils
ConstRetBareRegrIntercept - the intercept of the oil retention, slope gradient relationship for bare soils
ConstRetVegRegrIntercept - the intercept of the oil retention, slope gradient relationship for vegetated soils
ConstRetBareRegrSlope - the slope of the oil retention, slope gradient relationship for bare soils
ConstRetVegRegrSlope – the slope of the oil retention, slope gradient relationship for vegetated soils

The following parameters express the relationships between the rate of oil flow and retention in rivers and the velocity of the water in the same rivers.
RiverRelVelVsFlowInterc – the intercept of the relative velocity of oil to water versus river flow rate relationship
RiverRelVelVsFlowSlope – the slope of the relative velocity of oil to water versus river flow rate relationship
RiverDeposVsFlowInterc - the intercept of the oil deposition rate versus river flow rate relationship with units of fraction of discharge in cumecs
RiverDeposVsFlowSlope - - the slope of the oil deposition rate versus river flow rate relationship

LandOilEvapFrac – the fraction of an oil volume evaporated per hour (assumes the rate of evaporation is proportional to oil volume since greater oil volumes will cover a greater proportion of a cells surface area)

ConstRainfall – set this parameter to a non zero poistive value in order to ignore the TRMM 3b42 rainfall data and instead use a constant rainfall rate (mm/hr)
Infil – constant infiltration rate for water (mm/hr)
RiverEvapm – constant rate of evaporation from river surfaces (mm/hr)
RandomLeaks – set this value to 1 in order to simulate leaks throughout the pipeline network in random locations according to the probability of leakage (defined next)
ProbLeakage – a value from 0 to 1 which defines the probability of leakage in any particular section of pipeline for each timestep (set to 1 to simulate the entire pipeline network leaking in a timestep for pipeline sensitivity studies)
MeanLeakSize – the mean leak size used for randomleaks (in m^3)
Dtsecs – the timestep of the model in seconds
N – Manning’s N
Beta – The kinematic wave wave parameter
Qini - The kinematic wave initial streamflow (m3/s)
Hini - The kinematic wave initial waterheight (m)
ContaminationThreshold - threshold oil volume below which area is not considered 'contaminated' (used in assessment of areas contaminated)

Run controls

The model is run using a batch file which sets a series of run-control parameters. The batch file is passed a parameter which defines the directory for writing output e.g.
C:\>run1 run1

```
TIME /T
rem use runx.bat runx
call remove_all e:\slickmod\%1\results\%1\
pcrcalc --matrixtable   -b bindings_%1.mod -mpf _dev\slickmod.mod e:\slickmod\run1 1 8760 1 270 8760 100 1997 %1
TIME /T
```

The runtime parameters following the model call (_dev\slickmod.mod) are as follows :

Parameter 1=dataset directory (where the data are to be found)
Parameter 2=timestart (the start time for the run)
Parameter 3=time end (the end time for the run)
Parameter 4=report start (the start time for reporting output maps)
Parameter 5=report interval (the time interval for reporting output maps)
Parameter 6=report end (the end time for reporting output maps)
Parameter 7=cellsize (the model cellsize in metres)
Parameter 8=year (the year of the model run – used to assign the correct rainfall and leak data)
Parameter 9=the run directory for results
Parameter 10=use a # to report no timeseries data (faster)

SLICKMOD

The SLICKMOD model simulates leaks along a raster map which represents a pipeline network and/or oil installations. These leaks propagate downslope and downstream according to measured relationships between rates of oil flow and (spatially varying) characteristics of the land and rivers. On land the slope gradient and vegetation cover affect the rate of oil movement and the retention of oil by land (along with the API and volume of oil leaked). In rivers the API and volume of oil leaked combine with the rate of discharge in the river to determine the relative velocity and thus rate of oil transport and deposition within the river.

Since the model contains a kinematic wave for the representation of river flow it must be run for an entire hydrological catchment. It is run on an hourly basis such that (spatially variable inputs of rainfall are routed down hillslopes and into the river channel sections of those slopes. The kinematic wave carries these volumes through the channel network at an appropriate velocity and discharge which then defines the depth of river and the flooded area. Oil is thus carried downslopes and then once in the river, downriver. Throughout its journey some of the oil is deposited on the ground or in the channel and begins to evaporate and degrade over time. The volume of oil remaining in a particular cell is the balance of oil inputs from upstream, oil remaining in the cell from previous timesteps and oil losses from the cell to its downstream neighbour. Over time if oil inputs are greater than outputs, contamination builds up in the cell.

The rate of oil transport from a leak location to any given point downslope or downstream is calculated independently of the oil retention or deposition according to the appropriate combination of oil velocity on land and in the river in accordance with the proportion of land and river for each cell. The velocities are cumulated downstream in order to arrive that the time taken for oil to travel from a leak site to any location downstream. Dispersal times are ignored for cells which no oil has reached.

Finally a series of equations calculate the extent of contamination of protected or populated areas.

Model processes

The model carries out the following procedures in order to simulate the processes.

Setting up initial conditions

Calculate cleared (bare ground) fraction of each cell as 1-fraction covered by trees.

Calculate the fraction of each cell occupied by river water as :

```
OrderFrac=FractionalChannelWidthPerOrder*(scalar(Order));
RiverFrac=min(OrderFrac,1)
```

Calculate river bed width as :

```
Bw=Cellsize*RiverFrac
```

Calculate channel depth as :

```
ChannelDepth=ChanneldepthPerUnitOrder*scalar(Order)
```

Calculate fraction of cell not covered by rivers as :

```
OneMinRiverFrac=1-RiverFrac;
```

Calculate the initial conditions for the kinematic wave model :

```
# distance to downstream cell (m)
DCL=max(downstreamdist(Ldd),Cellsize);
# slope (m/m), must be larger than 0
Slope=max(0.001,slope(Dem));
# initial streamflow (m3/s)
Q=QIni*RiverFrac;
# initial water height (m)
H=HIni*RiverFrac;
# term for Alpha
AlpTerm=(N/(sqrt(Slope)))**Beta;
# power for Alpha
AlpPow=(2/3)*Beta;
# initial approximation for Alpha
P=Bw+2*H;
Alpha=AlpTerm*(P**AlpPow);
CellArea=sqr(Cellsize);
```

The slope and intercept of the relationships between oil transport velocity and ground slope gradient for different APIs and leak rates are then read for bare and for vegetated areas.

The slope and intercept of the relationships between oil retention and ground slope gradient for different APIs and leak rates are then read for bare and for vegetated areas.

The dynamic (hourly) model

The month, julian day and hour are then read along with the hourly rainfall total.

Rainfall is then multiplied by the rainfall correction factor map for the relevant month.

Hillslope runoff is then calculated as :

```
InfilExcess=max((Rainfall-Infil)*OneMinRiverFrac,0);#mm/hr
SideFlow=(InfilExcess/1000);#m
HillslQ=(CellArea*OneMinRiverFrac*SideFlow)/DTsecs;#m3/s
HillslCSA=DCL*SideFlow;#m2
HillslVel=if((OneMinRiverFrac gt 0) and (HillslQ gt 0) then (HillslQ/HillslCSA) else 0);#m/s, currently water takes max velocity possible, i.e. sheds all water within an hour (reasonable given the drainage density)
```

River runoff is then calculated from direct channel precipitation minus channel evaporation plus the sideflow from the hillslopes using the Kinematic wave approach.

Flooded areas are calculated according to the relationshiop between water depth and channel depth:

```
FloodDepth=max((H-ChannelDepth),0);
Flooded=scalar(if(FloodDepth gt 0 then 1 else 0));
NotFlooded=if(Flooded eq 1 then 0 else 1);
```

Leaks are generated as follows :

```
Leaking=if((RandomLeaks eq 0) and (Year eq LeakYear) and (JulDay eq LeakJulday) and (Hour eq 12) then 1 else 0);#considered to be an error if not on a pipeline
Leaking=if((RandomLeaks eq 1) and (Pipeline eq 1) and (RandomMap lt ProbLeakage) then 1 else Leaking);# random leakage
```

The size of leakage is then calculated as :

```
LeakSize=if((RandomLeaks eq 0)  then LeakVol*scalar(Leaking) else MeanLeakSize*scalar(Leaking));# (m3)
```

Oil velocity over land then depends upon the read parameters, slope and vegetation cover as :

```
VOilBare=max(VelBareRegrIntercept+(VelBareRegrSlope*SlopeDeg),0);
VOilVeg=max(VelVegRegrIntercept+(VelVegRegrSlope*SlopeDeg),0);
VOilLand=(ClearedFrac*VOilBare)+(TreeFrac*VOilVeg);#m/s
```

Oil retention over land is then calculated as :

```
# Uses fractions on the basis that the larger the leak the further its within cell spread will be
RetOilB=max(RetBareRegrIntercept+(RetBareRegrSlope*SlopeDeg),0)/100;
RetOilB=min(RetOilB,1);
RetOilV=max(RetVegRegrIntercept+(RetVegRegrSlope*SlopeDeg),0)/100;
RetOilV=min(RetOilV,1);
```

The potential for oil retention on land is reduced according to the presence of rainfall as :

```
# this corrects retention for rainfall wash assuming that 10mm of rainfall is enough to reduce retention to 20% on land
RetOilLand=if(Rainfall eq 0 then (ClearedFrac*RetOilB)+(TreeFrac*RetOilV) else ((ClearedFrac*RetOilB)+(TreeFrac*RetOilV))*max(1-(Rainfall/10),0.2));
```

Oil retention on rivers is then calculated as a function of the flow discharge:

```
RetOilRiver=min(max((RiverDeposVsFlowInterc+(RiverDeposVsFlowSlope*Q)),0),1);
```

Total oil retention is the sum of retention on land and in rivers:

```
PotRetOil=(min(OneMinRiverFrac,NotFlooded)*RetOilLand)+(max(RiverFrac,Flooded)*RetOilRiver);#fraction
```

Given this oil retention, the following commands calculate how much oil is left in each cell and how much is carried downstream to the next cell :

```
#accu approximation of where the oil goes (not how quickly)
OilDeposition=accufractionstate(Ldd,LeakSize,1-PotRetOil);#m3/hr, hr is irrelevant really
OilRunoff=accufractionflux(Ldd,LeakSize,1-PotRetOil);#m3/hr
OilRunon=upstream(Ldd,OilRunoff);#m3/hr
```

The velocity of oil transport through the hillslope and river system is then calculated as:

```
RelativeVelocity=max(min((RiverRelVelVsFlowInterc+(RiverRelVelVsFlowSlope*Q)),2),0);
VOilWater=RelativeVelocity*V;#m/s
VLand=if(Rainfall gt 0 then HillslVel else VOilLand);#allows hillslope wash of oil
VOil=(min(OneMinRiverFrac,NotFlooded)*VLand)+(max(RiverFrac,Flooded)*VOilWater);
```

The balance of oil remaining in each cell is calculated per timestep as :

```
LandOilEvaporation=LandOilEvapFrac*LandOilBudget;#m3/hr, again uses fraction on the basis that more oil spreads further on the ground
LandOilBudget=LandOilBudget+(OilDeposition+OilRunon)-(LandOilEvaporation+OilRunoff+LandOilDegradation) ;#m3
LandOilBudget=max(LandOilBudget,0);
```

Finally the travel time for oil is calculated for each cell and all maps and time series are written :

```
DispersalTime=spreadldd(Ldd,Leaking,0,DCL*VOil)/3600;
DispersalTime=if(LandOilBudget gt 0 then DispersalTime);#for all contamination not just that above threshold
```

The end.