Quality Assurance for Performance Assessment Modeling

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NEPTUNE AND COMPANY

Motivation for QA in PA

The overarching motivation for Performance Assessment work is defensible decision making, and that requires:

- a defensible basis for modeling,
- transparent and intelligible modeling, and
- effective communication of modeling approaches and results

These are goals shared by the CoP.

Defensibility in Modeling

Defensible decision making needs defensible modeling. This requires:

- an accepted Conceptual Site Model (CSM),
- concepts and parameters that are traceable to their source,
- a transparent analysis of parameters, and
- coherent statistics.

Without these, it may as well be Garbage IN ⇨ Garbage OUT.

Computers are not Magic

"On two occasions I have been asked, "Pray, Mr. Babbage, if you put into the machine wrong figures, will the right answers come out?"

I am not able rightly to apprehend the kind of confusion of ideas that could provoke such a question."

Charles Babbage
1791 – 1871

Passages from the Life of a Philosopher (1864), Ch. 5 "Difference Engine No. 1"

Model Evaluation

Best Practices:

- Peer Review
- Model Corroboration
- Sensitivity Analysis
- QA Project Planning – data quality assessment

Neptune's GoldSim PA QA

Neptune's Quality Assurance (QA) for GoldSim PA models includes

- development of FEPSs* and CSM,
- stochastic parameter development,
- manual QA checking of all values,
- model building, and
- model testing,
- subject to strict configuration control.

***Features, Events, Processes, and Scenarios.**

FEPSs and CSM

Features, **E**vents, **P**rocesses and **S**cenarios analysis:

- Defining and screening FEPSs assures that the PA and its model are not missing anything.

Development of a **C**onceptual **S**ite **M**odel:

- Defining a CSM helps to vet the model among stakeholders and model developers alike.

These are part of QA.

Parameter QA Process

Neptune's Process:

- *Identify and collect information* about a process or parameter, from literature, site specific studies, etc.
- Perform *manual number-by-number QA check* on that information. This is called a check print.
- Develop *statistically appropriate* stochastic *input distribution(s)*.
- Perform manual *QA check* on statistical analysis.
- Incorporate synopsis of parameter development into a topical *white paper*.
- Perform manual *QA check* on values in white paper.
- Add values to the model *Parameters Document* or Workbook.
- Perform manual *QA check* on Param Doc or Workbook.
- *Transfer values* to the GoldSim PA model.
- Perform Manual *QA check* on model values, and record in the model using GoldSim's native QA note tools.

Check Prints

Neptune's Manual QA *Check Print* Process:

- A calculation sheet, white paper, or other document is prepared by an analyst, with a copy of all cited references. This is printed to hard copy.
- An independent person, not associated with the collection and assembly of information, checks every value in the document against the value(s) in the cited references, and marks each item. For electronic transfers, every 10^{th} value is checked.
- Errors are flagged, and the checker signs and dates the check print document to the analyst.
- Errors are fixed by the analyst, and the document is resubmitted for another check print.
- This iterates until all errors have been resolved.

Distribution Development

Stochastic input distributions must be developed with care.

- Data should not be censored without cause.
- Spatial and temporal aspects must be considered.
- Distributional forms should be based on natural behavior as well as data. A natural uniform or triangular distribution is rare.

Types of Distributions

Several types of stochastic input distributions:

- independent, single value parameter
- tables of related single values
- time series
- functional forms
- environmentally-related values
- values that must sum to unity
- complex interrelated variables
- values with patterns seen collectively
- values with spatiotemporal variability

Model Configuration Control

Neptune's rules for configuration control:

- There is only One True Model File at any given time.
- No two model files ever have the same filename.
- The custodian of the True Model is always known.
- Custodianship is passed explicitly to another.
- Model file naming follows a strict convention.
- Model development may take place in branch copies, but these are never confused with the One True Model.
- Native GoldSim versioning is used.

QA in Model Building

Building a model in GoldSim requires

- appropriate distribution development,
- clarity and transparency in coding,
- clear documentation of model development, and
- enhanced communication of concepts.

- Native GoldSim QA tools are used.

Transparency in Coding

This is opaque code:

```
FUNCTION BESSI(N,X)
      PARAMETER(IACC=40,BIGNO=1.0E10,BIGNI=1.0E-10)
      IF (N.LT.2) PAUSE 'bad argument N in BESSI'
      TOX=2.0/X
      BIP=0.0
      BI=1.0
      BESSI=0.
      M=2*((N+INT(SQRT(FLOAT(IACC*N)))))
      DO 11 J=M,1,-1
        BIM=BIP+FLOAT(J)*TOX*BI
        BIP=BI
        BI=BIM
        IF (ABS(BI).GT.BIGNO) THEN
          BESSI=BESSI*BIGNI
          BI=BI*BIGNI
          BIP=BIP*BIGNI
        ENDIF
        IF (J.EQ.N) BESSI=BIP
11    CONTINUE
      BESSI=BESSI*BESSI0(X)/BI
      RETURN
      END
```

```
#include <math.h>
#define ACC 40.0
#define BIGNO 1.0e10
#define BIGNI 1.0e-10
float bessi(n,x)
int n;
float x;
{
    int j;
    float bi,bim,bip,tox,ans;
    float bessi0();
    void nrerror();
    if (n < 2) nrerror("Index n less than 2 in BESSI");
    if (x == 0.0)
        return 0.0;
    else {
        tox=2.0/fabs(x);
        bip=ans=0.0;
        bi=1.0;
        for (j=2*(n+(int) sqrt(ACC*n));j>0;j--) {
            bim=bip+j*tox*bi;
            bip=bi;
            bi=bim;
            if (fabs(bi) > BIGNO) {
                ans *= BIGNI;
                bi *= BIGNI;
                bip *= BIGNI;
            }
            if (j == n) ans=bip;
        }
        ans *= bessi0(x)/bi;
        return  x < 0.0 && n%2 == 1 ? -ans : ans;
    }
}
#undef ACC
#undef BIGNO
#undef BIGNI
```

with apologies to *Numerical Recipes*

Always a Documentation Nut

This is commented code: Remember ASCII art?

```c
{
    /* dfWinbox and dfCellSize are defined globally          */
    double dfX, dfY;             /* f.p. index to cell          */
    double dfDenominator;        /* temp variable               */
    int    iX, iY;               /* cell index number           */
    int    nxLower, nyLower;     /* index to lower bounding cell */
    int    nxUpper, nyUpper;     /* index to upper bounding cell */
    POINT  ptLower, ptUpper;     /* corner points bounding cell  */
    float  fTemp;                /* temporary variable          */


    /* I was forced to add this since for some reason nCols and nRows
     * are not consistently read properly above using PrivateWindowCols
     * and PrivateWindowCols. */
    nCols = (int)( ( Xmax( dfWinbox ) - Xmin( dfWinbox ) ) / dfCellSize );
    nRows = (int)( ( Ymax( dfWinbox ) - Ymin( dfWinbox ) ) / dfCellSize );

    /* Determine which cell contains the point ppt. */
    /* First, work with the GRID cells, to subdivide later. */

    /* Find cell index number of Lower bounding cell. */
    dfX = ( ppt->x - Xmin( dfWinbox ) ) / dfCellSize;
    iX  = (int)dfX;          /* truncation to integer */

    dfY = ( Ymax( dfWinbox ) - ppt->y ) / dfCellSize;
    iY  = (int)dfY;          /* truncation to integer */

    pcell->iX = iX;
    pcell->iY = iY;
```

some of my C code from graduate school

```
*   So for the purposes of this DarcyTrack function, the elemental
*      cell over which calculations are done must be a quarter
*      of the original GRID cells, to ensure uniform properties
*      over the cell area:
*
*         +---|---+---|---+---|---+---|---+
*         |   |   |   |   |   |   |   |   |
*         |---o---|---o---|---o---|---o---|
*         |   |   |   |   |   |   |   |   |
*         +---|---+---|---+---|---+---|---+
*         |   |   |   |   |   |   |   |   |
*         |---o---|---o---|---o---|---o---|
*         |   |   |   |   |   |   |   |   |
*         +---|---+---|---+---|---+---|---+
*
*             |-------|          |---|
*             cell size          edge size
*
*   Notes on orientation:  (This is a square GRID cell)
*
*     Ymax +------------------------+        pt.x and pt.y are in real
*          |                        |            coordinates
*          |                        |
*          |                        |        Xmin, Xmax, Ymin, Ymax are
*          |                        |            in real coordinates,
*          |                        |            and are the limits of
*     pt.y + iY        + pt         |            the grid, as stored
*          |                        |            in the global
*          |                        |            variable dfWinbox
*          |                        |
*          |                        |        iX and iY are cell column
*          |           iX           |            (left to right) and
*     Ymin +-----------+------------+            row (top to bottom)
*        Xmin         pt.x         Xmax
*
```

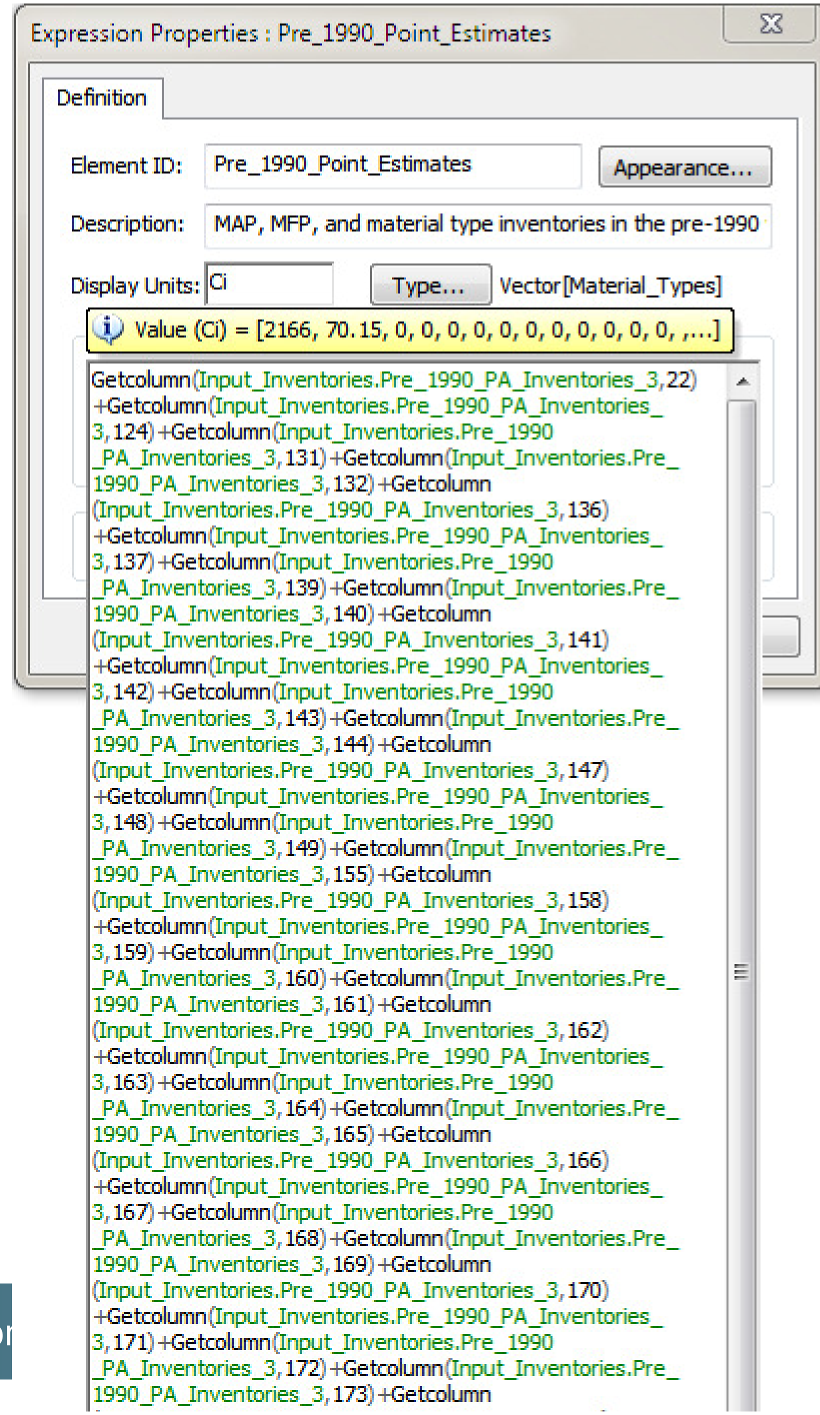
Transparency in GoldSim Coding

This is an example of sloppy GoldSim coding.

Aliases are not used, nor are sensible indices to the cited columns used by GetColumn().

The QA on this would be time-consuming and difficult.

(About ½ of this expression is shown here.)

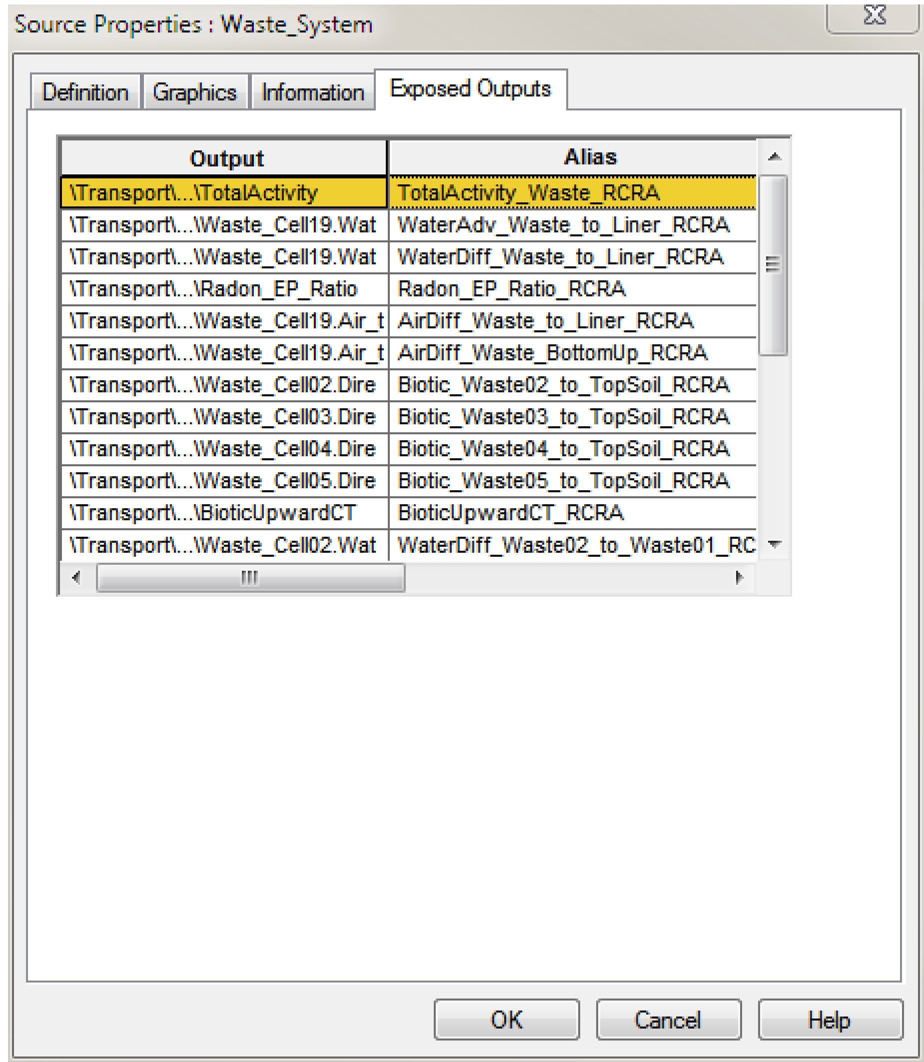


Transparency in GoldSim Coding

Tools at your disposal:

Use *aliases* for exposed outputs from Localized containers.

The aliases should be clear and have unique names.

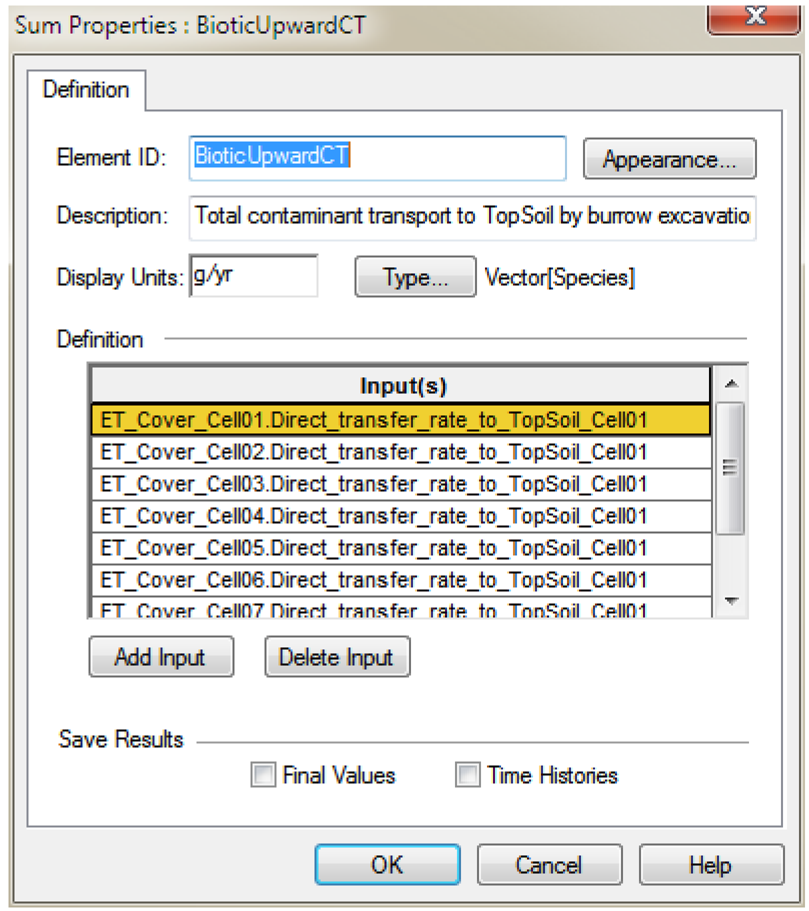


Transparency in GoldSim Coding

Tools at your disposal:

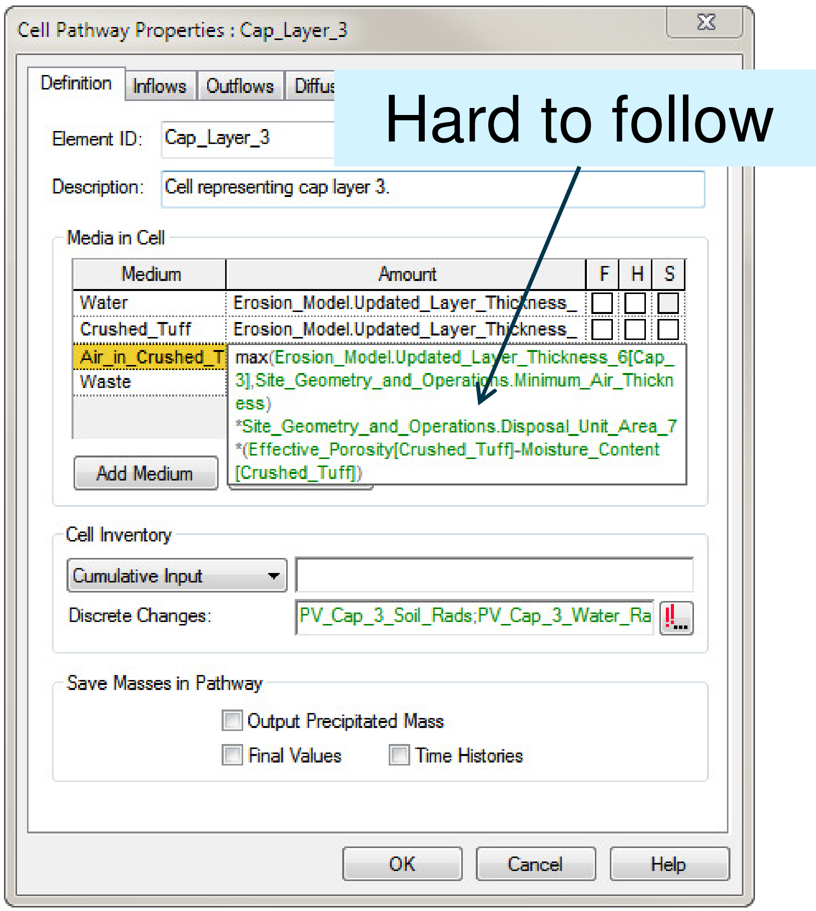
Use *Sum* elements for organizing summations.

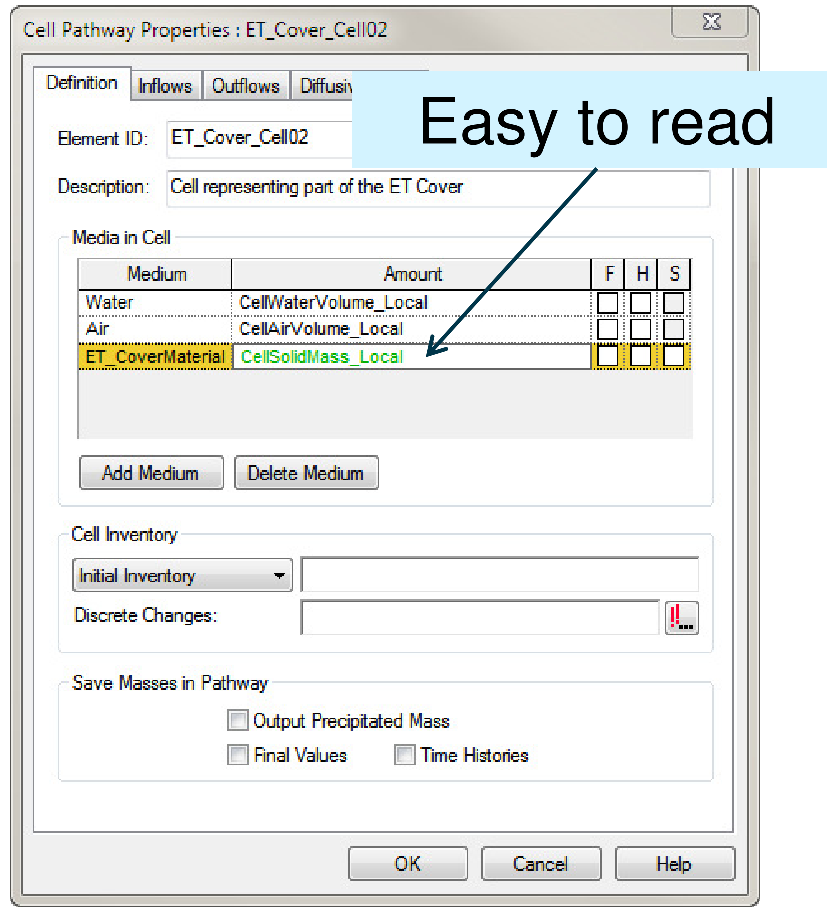
(This would have helped the earlier code example.)



Transparency in GoldSim Coding

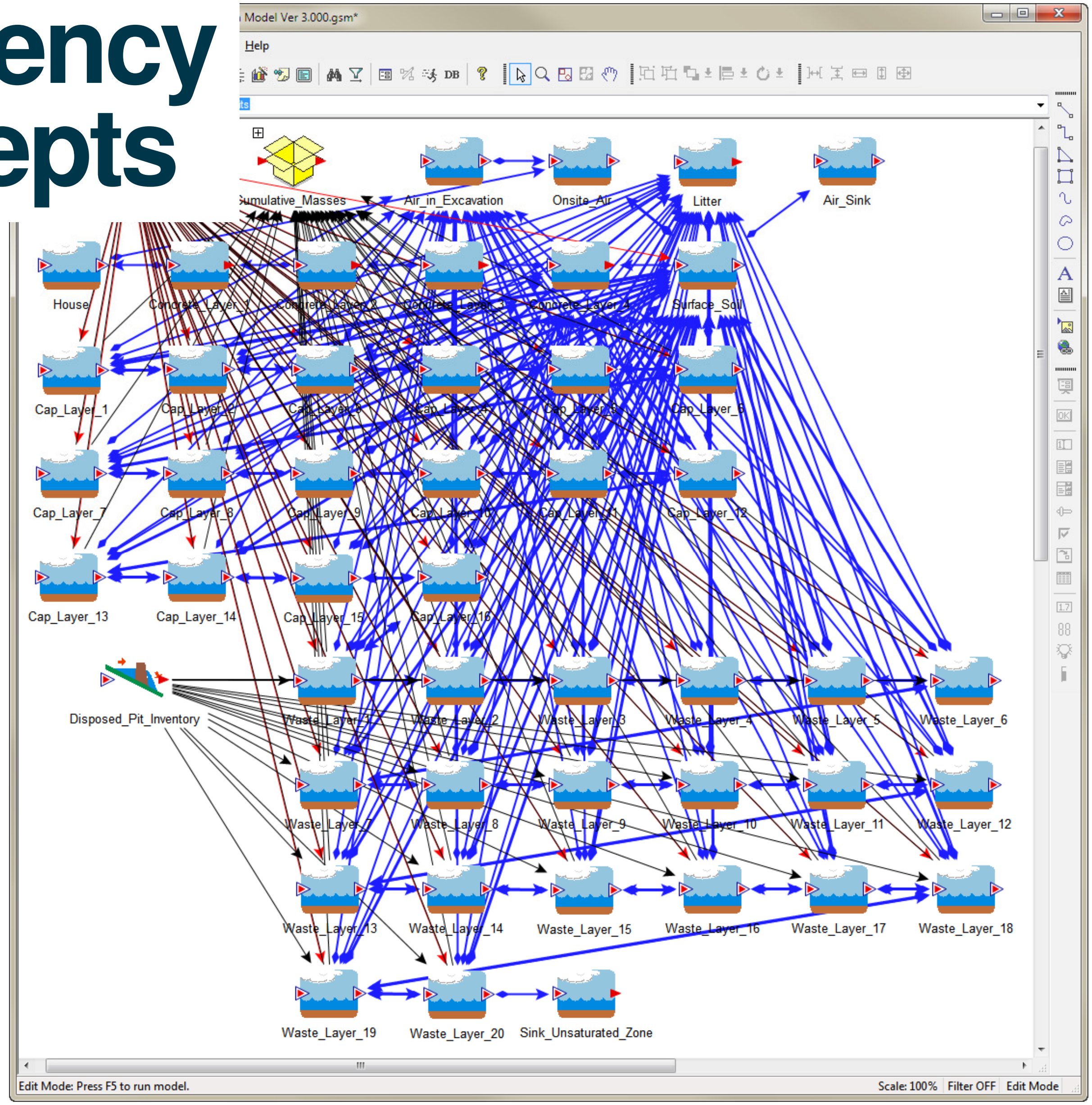
Don't cram too much into an expression or property.





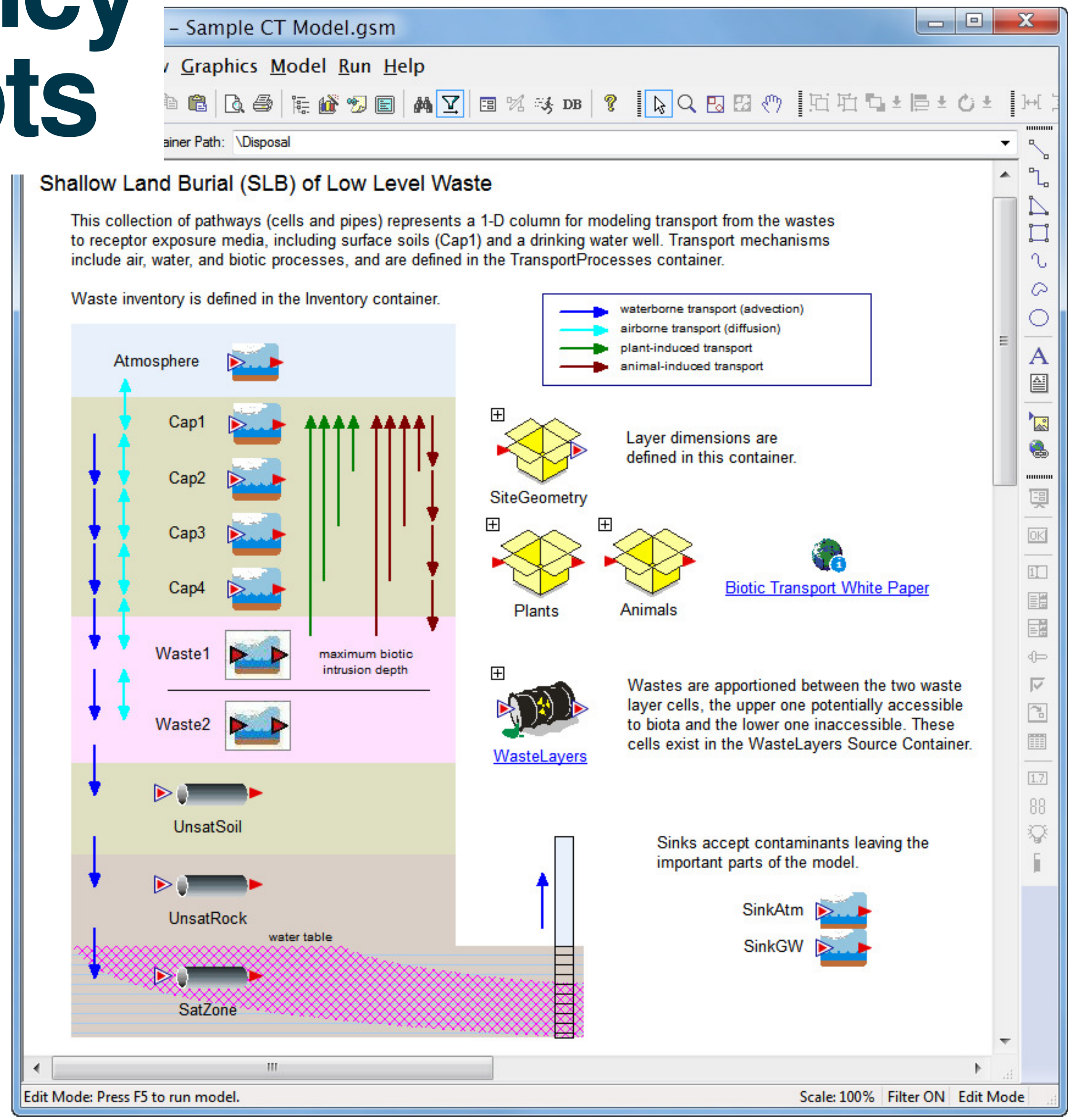
Transparency in Concepts

A mismash of elements on the page is not useful to anyone trying to understand the model.



Transparency in Concepts

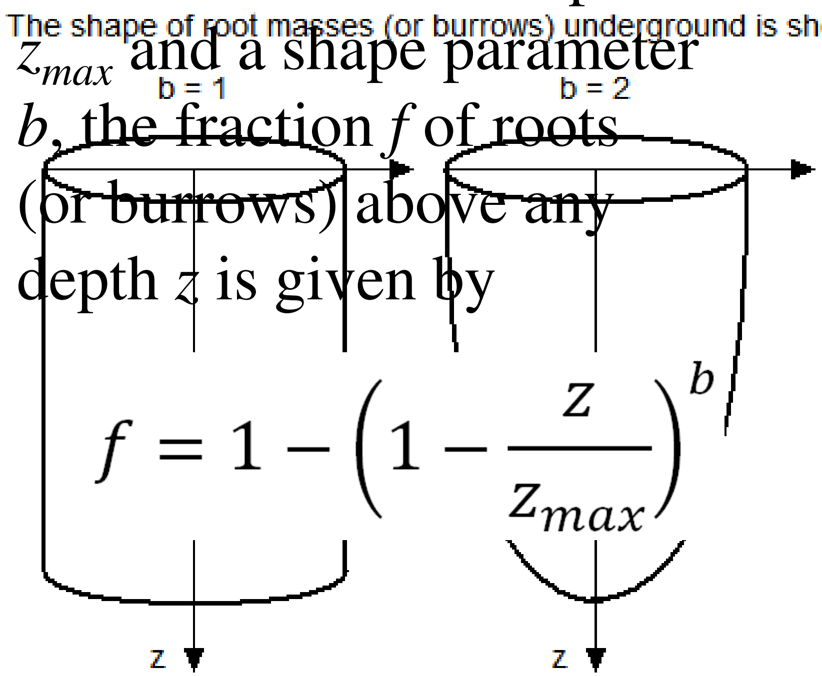
Use the drawing tools and a logical arrangement of elements shows what is going on in the model.



Transparency in Concepts

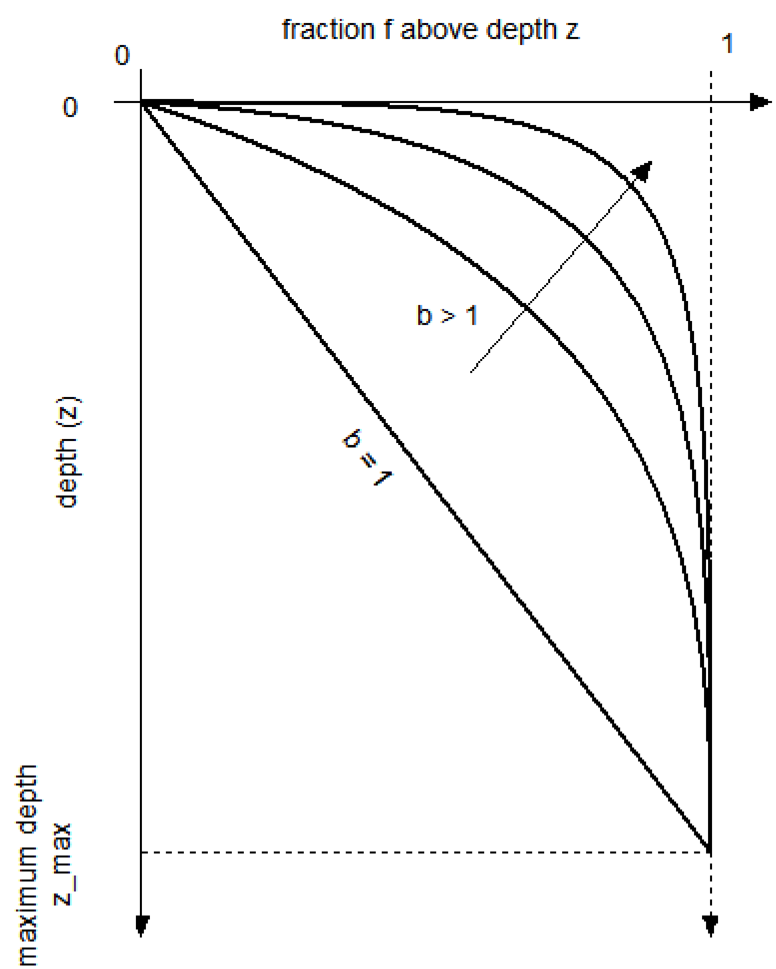
Given a maximum depth z_{max} and a shape parameter b, the fraction f of roots (or burrows) above any depth z is given by

$$f = 1 - \left(1 - \frac{z}{z_{max}}\right)^b$$



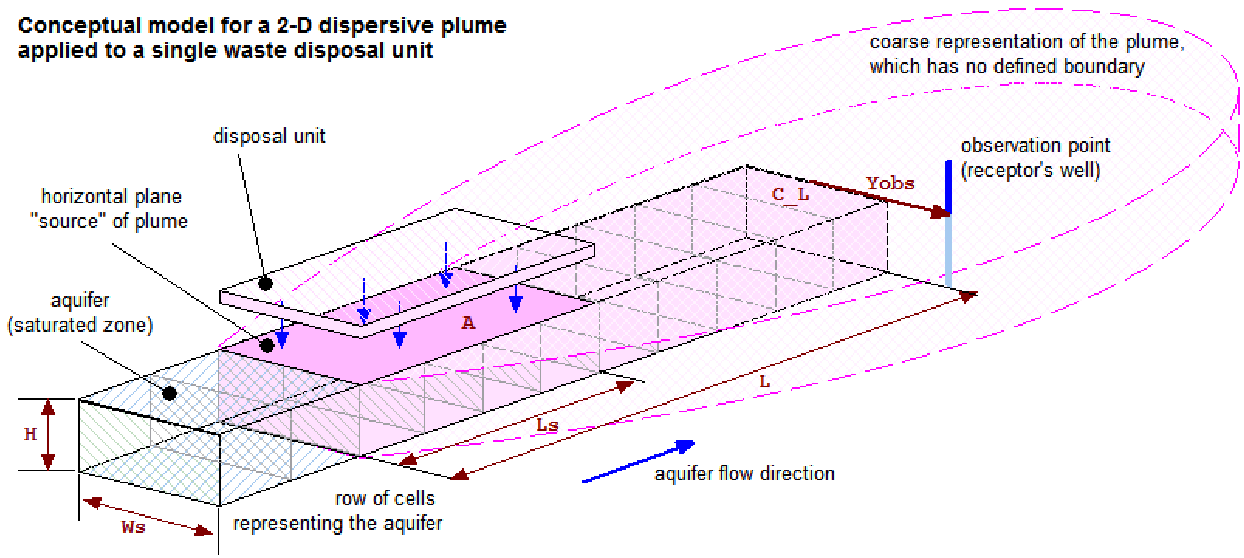
A simple illustration c

Plant root and burrow volume depth function



Transparency in Concepts

Modeling tools can be described in the model itself:

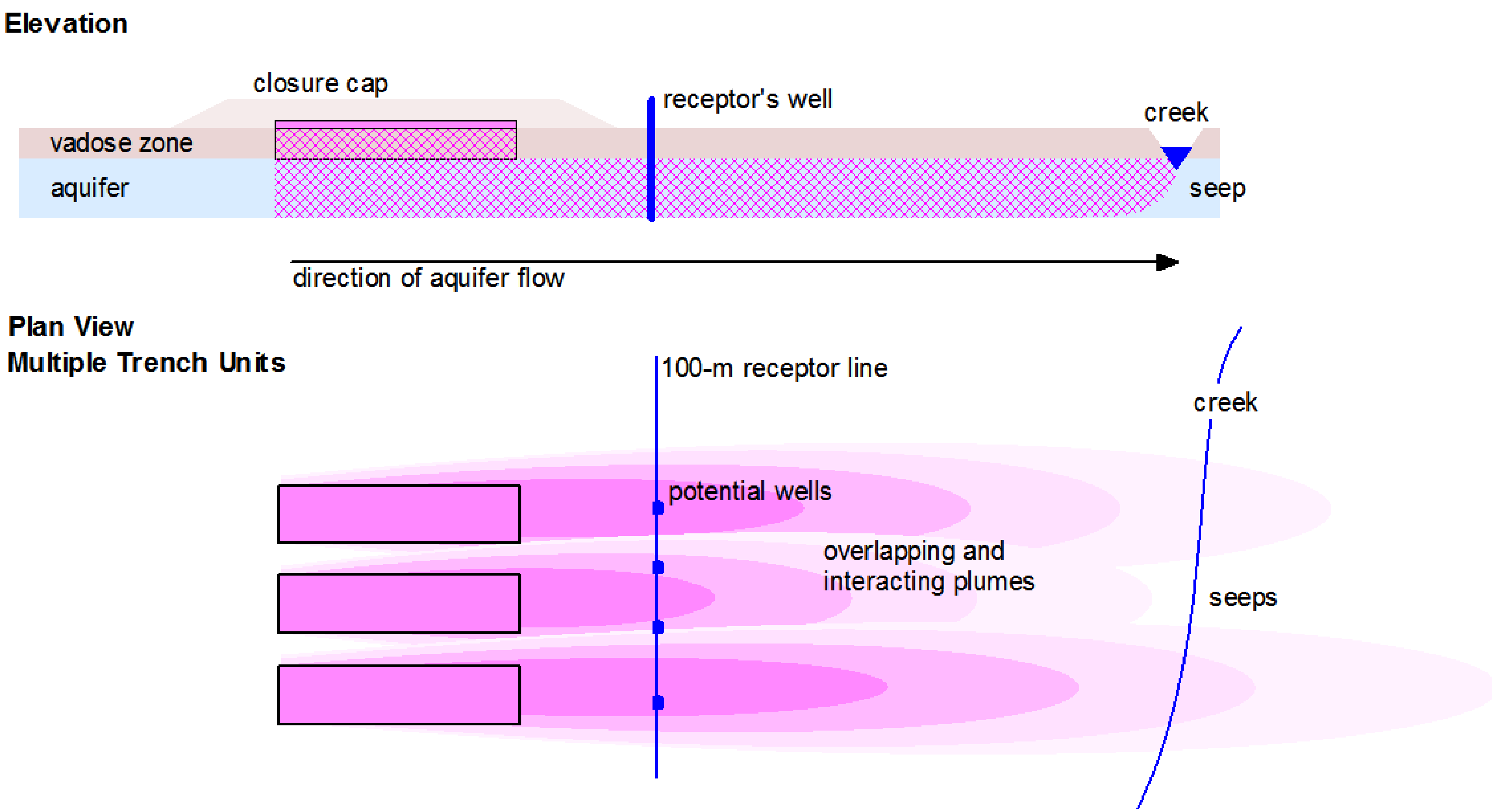


Application of the GoldSim Plume Function

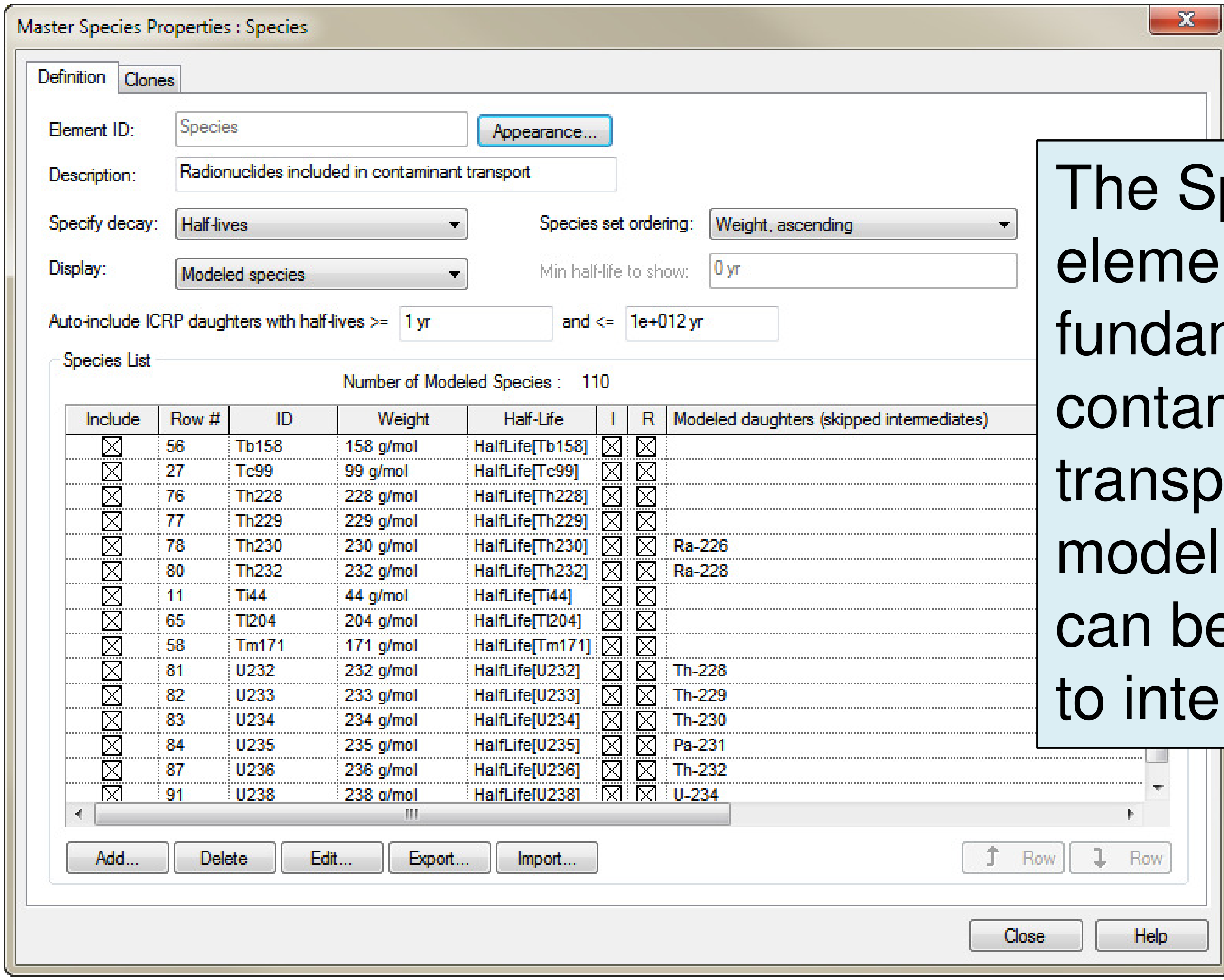
As described in the GoldSim on-line help (search for "plume"), the plume() function accepts 11 arguments. The description presented here is somewhat simplified for the case at hand. The arguments to the function are as follows, with comments following the "//". Footnotes are below.

```
plume(
      L,          // length of the Pipe or row of Cells, as measured from
                  //    the upstream end of the Source¹
      A,          // cross-sectional area of the Pipe or Cells
      Ls,         // length of the Source set equal to the length of the
                  //    overlying disposal unit, parallel to flow
      0,          // vertical offset of observation point (zero)²
```

Transparency in Concepts

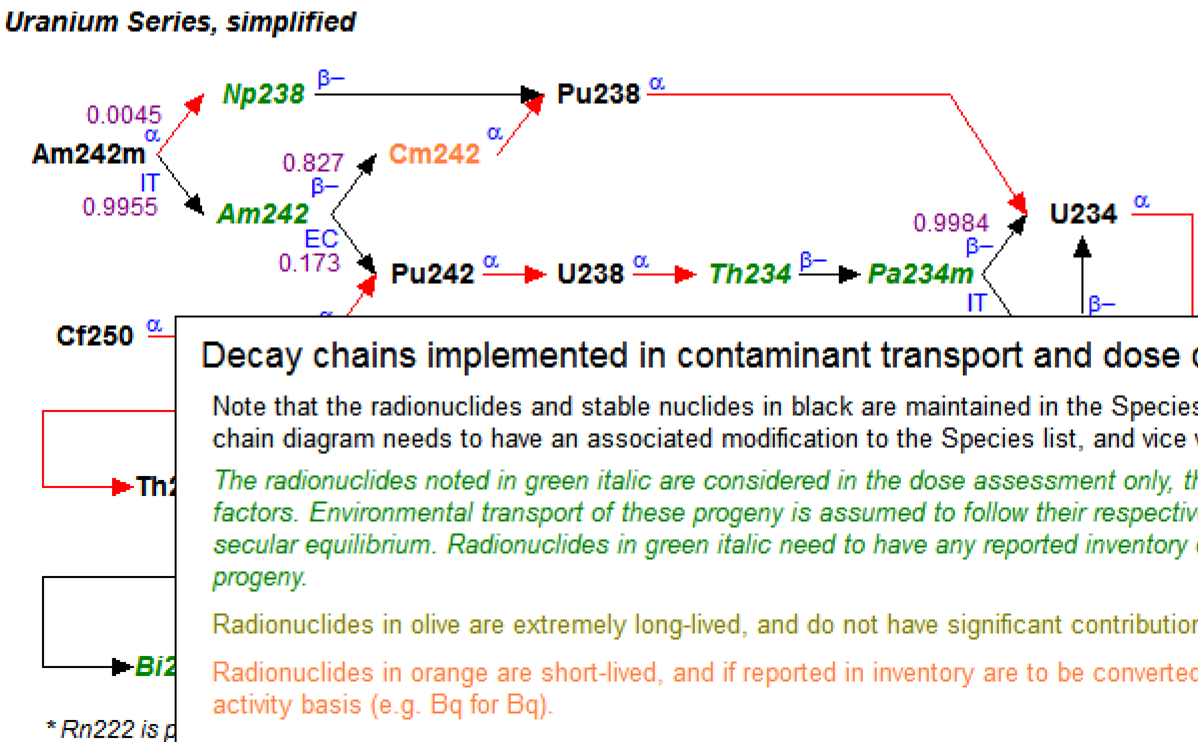


Transparency in Concepts



The Species element may be fundamental to contaminant transport modeling, but it can be a challenge to interpret.

Transparency in Concepts



The drawing tools can make this easier.

Decay chains implemented in contaminant transport and dose calculations

Note that the radionuclides and stable nuclides in black are maintained in the Species list. Any modification to the decay chain diagram needs to have an associated modification to the Species list, and vice versa.

The radionuclides noted in green italic are considered in the dose assessment only, through the "roll-up" of dose coversion factors. Environmental transport of these progeny is assumed to follow their respective parents, with which they are in secular equilibrium. Radionuclides in green italic need to have any reported inventory converted to the next long-lived progeny.

Radionuclides in olive are extremely long-lived, and do not have significant contributions to dose. These are not modeled.

Radionuclides in orange are short-lived, and if reported in inventory are to be converted to the next long-lived progeny on an activity basis (e.g. Bq for Bq).

Radionuclides, stable nuclides, and decay arrows in gray are not represented in the model, but are shown here for completeness. Details in the Actinoid_detail Container are also not modeled.

Each decay mode is shown in blue (alpha, beta, beta positron, isomeric transition, and electron capture), with modeled alpha decay arrows shown in red.

Branching fractions are shown in purple, and are assumed to be 1 unless a value is shown. Branching fractions less than 0.001 are identified as "~0" and are not modeled. Branching fractions are used in the dose roll up calculations (external to the model) and in the Stoichiometry definitions in the Species element specification. These come from Tuli's Nuclear Wallet Cards (2005).

Change Log

Change log:
(Tabs are entered as Ctrl+Tab).

JT John Tauxe
RP Ralph Perona
KC Kate Catlett

date	ver	init	description
12 Oct 11	0.001	JT	• Model-building begins, acknowledging previous work on the WCS LLW Model by Bill Dornsife (WCS), Abhishek Singh (Intera), Gary Merrell (URS Corp.), and John Tauxe (Neptune and Co.)
24 Oct 11		RP	• Work on N&Co dose model begins. Integrate CWF and FWF within a single dose container. Implement structure shown in receptor diagram_influences and well dose diagram_influences.
28 Oct 11	0.002	RP	• New model structure (including Switches for exposure conditions) and pathways have been incorporated. For this interim Dose_Assessment container, the scenarios and receptors used in the Fall 2011 PA model submitted to TCEQ have been retained.
28 Oct 11	0.003	JT	• Custodianship assumed by JT. Begin work on v0.003.
21 Nov 11	0.003	RP	• Custodianship assumed by RP. • Update dose model to include ranching and oil drilling scenarios while retaining receptors from the License Application PA model. • Restrict use of saline water from deeper aquifers (600 ft) to cattle. • Add all particulate inhalation and external DCFs. • Added a Chronology container for timed events (loss of institutional control and concrete failure for the containment system).
21 Nov 11	0.003	JT	• Custodianship assumed by JT.
28 Nov 11		JT	• Minor revision to decay chains illustration to list Sn126 in the category of non-actinide decay to short-lived progeny that are modeled in dose assessment.
19 Dec 11		JT	• Added initial structure for stochastic Kd values.
Jan/Feb 12		JT	• Extensive reorganizational revisions, including completely reorganizing the CWF and FWF containers, moving common elements out of them, and making extensive use of the UZ_Units array for storing information and for calculations

Readability

Project budget and accounting

The user can specify the funding profile, which constitutes annual increases to the project account. Costs are deducted from the project account as tasks start and complete.

Main Project Account

ProjectFundingProfile

ProjectFundingHistory

ProjectAccount

ProjectAccountHistory

The ProjectAccount has revenues added each FY, as worked out above.

It also has these deductions:

- each task deducts its estimated cost on task start
- each task reconciles its actual costs with the estimated cost, and deducts the difference on completion of the task
- penalties and fines are deducted as they occur

Funding Profile (set on Control Panel)

Budget_FY12

FY12_Funded

Budget_FY13

FY13_Funded

Control Panel

Estimated expenses and allocation priorities

EstimatedCosts

Estimated costs for each task are provided here. Each task must wait until sufficient funding is available before starting, and actual costs are reconciled with estimates on task completion.

Funding allocations are determined as annual spending rates.

Project_Alloc

The allocation of funds from the top Project level down to the individual tasks takes place hierarchically. This top level allocator takes the entire project budget (ProjectAccount) and allocates to the main activities. Each of those activities similarly allocates its share of the funds it was provided to its tasks, and so on.

Waste Characterization Funding

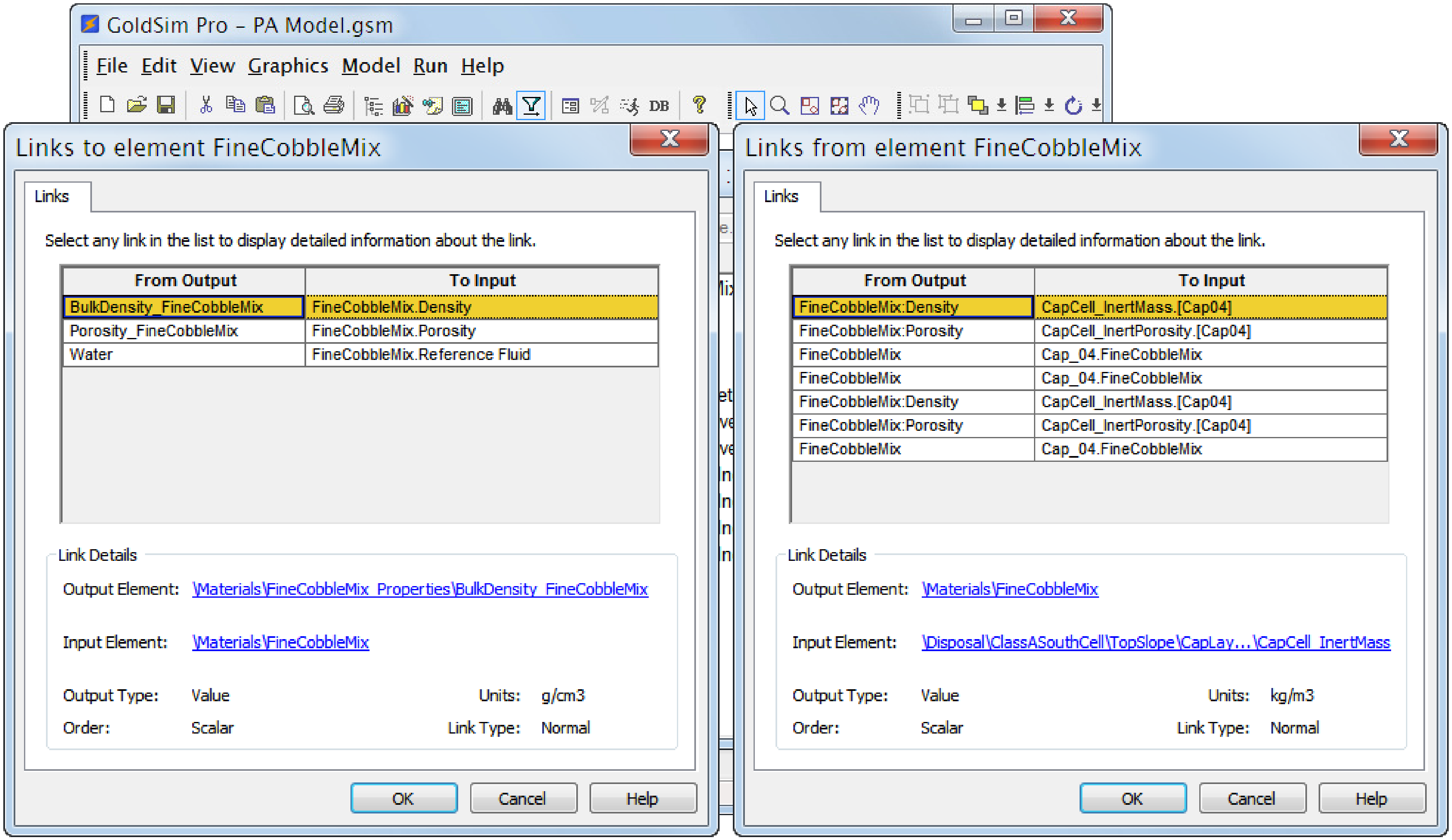
Public Involvement Funding

Operations Funding

Compliance Activities Funding

Public Involvement Activities Funding

Traceability Within the Model



Traceability Outside the Model

TABLE 7. HELP INFILTRATION MODEL LAYERS AND MATERIAL PROPERTIES

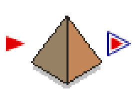
Layer	Material	Thickness (inches)	n (vol/vol)	θ_{fc} (vol/vol)	θ_{wp} (vol/vol)	Available Moisture (vol/vol)	θ_i (vol/vol)	K_s (cm/sec)	Layer Type n/a	Size Range (inches)	Material Description n/a	Notes:
Layer 1	Type-B Rip Rap	18	0.190	0.024	0.007	0.017	initialized to ss	42	vertical percolation	0.75-4.5	1.25 inches	Size is nominal diameter
Layer 2	Type-A Filter (upper)	6	0.190	0.024	0.007	0.017	initialized to ss	42	vertical percolation	0.08-6.0	Coarse Sand - Fine Cobble	
Layer 3	Sacrificial Soil	12	0.31	0.2	0.025	0.175	initialized to ss	4.00E-03	vertical percolation	<0.75	Silty Sand and Gravel	Placed at 4×10^{-4} cm/sec; freeze/thaw reduces K to 4×10^{-3} cm/sec.
Layer 4	Type-B Filter (lower)	6	0.28	0.032	0.013	0.019	initialized to ss	3.5	lateral drainage	0.2-1.5	Coarse Sand -Fine Gravel	
Layer 5	Upper Radon Barrier	12	0.430	0.390	0.28	0.11	0.43	5.00E-08	barrier soil	n/a	Clay	
Layer 6	Lower Radon Barrier	72	0.430	0.390	0.28	0.11	0.39	1.00E-06	vertical percolation	n/a	Clay	
Layer 7	Waste	100	0.437	0.062	0.024	0.038	initialized to ss	5.00E-04	vertical percolation	n/a	Sand	Unit thickness for waste. Model is insensitive to waste thickness variation.
Layer 8	Clay Liner	24	0.430	0.390	0.28	0.11	0.43	1.00E-06	barrier soil	n/a	Clay	

n = Porosity
θfc = Field Capacity
θwp = Wilting Point

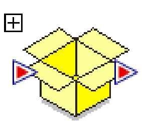
θi = Initial Moisture Content
K_s = Saturated Hydraulic Conductivity
θ_i = Value for initialized steady-state moisture content are given in the model output files.
Available Moisture: = Moisture available to be evaporated is only applicable in the upper 18 inches of the model

Engineered material properties

Engineered materials are in a variety of forms serving various purposes. These are used in the construction of the cap (top slope and side slope) and liner layers.

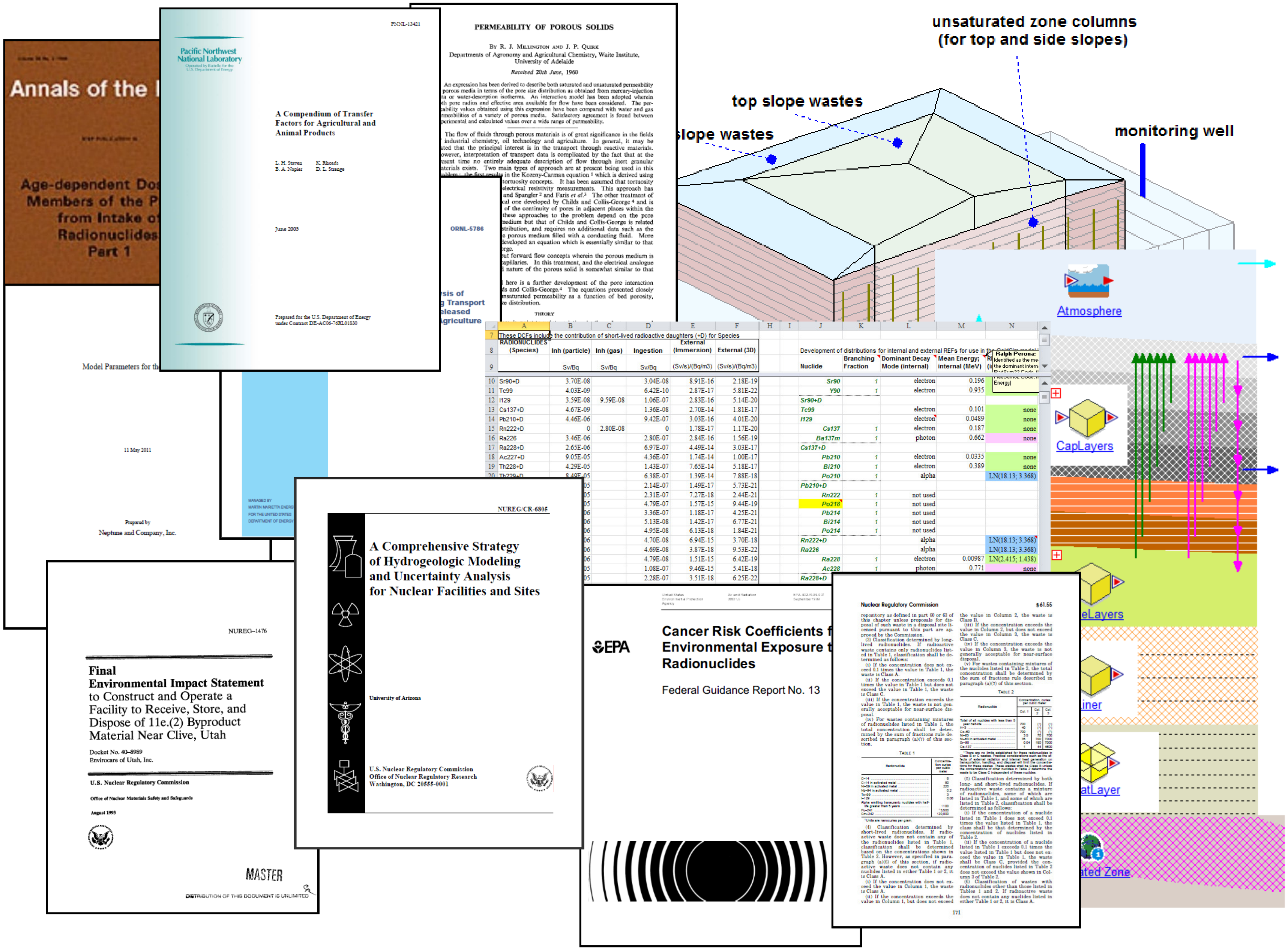


RipRap



RipRap_Properties

Rip Rap is used to construct the uppermost layer: Armor. It quickly becomes infilled with Loess. The Rip Rap itself is assumed to be an inert material.


Annals of the
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from Intake o
Radionuclides
Part 1
Pacific Northwest National Laboratory
PNNL-13421
A Compendium of Transfer Factors for Agricultural and Animal Products
June 2003
PERMEABILITY OF POROUS SOLIDS
By R. J. Millington and J. P. Quirk
ORNL-5786
Model Parameters for th
11 May 2011
Prepared by Neptune and Company, Inc.
NUREG/CR-6805
A Comprehensive Strategy of Hydrogeologic Modeling and Uncertainty Analysis for Nuclear Facilities and Sites
University of Arizona
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001
NUREG-1476
Final
Environmental Impact Statement
to Construct and Operate a Facility to Receive, Store, and Dispose of 11e.(2) Byproduct Material Near Clive, Utah
Docket No. 40-8989
Envirocare of Utah, Inc.
U.S. Nuclear Regulatory Commission
August 1993
MASTER
EPA
Cancer Risk Coefficients f
Environmental Exposure t
Radionuclides
Federal Guidance Report No. 13
Nuclear Regulatory Commission
§61.55
unsaturated zone columns
(for top and side slopes)
top slope wastes
slope wastes
monitoring well
Atmosphere
CapLayers
eLayers
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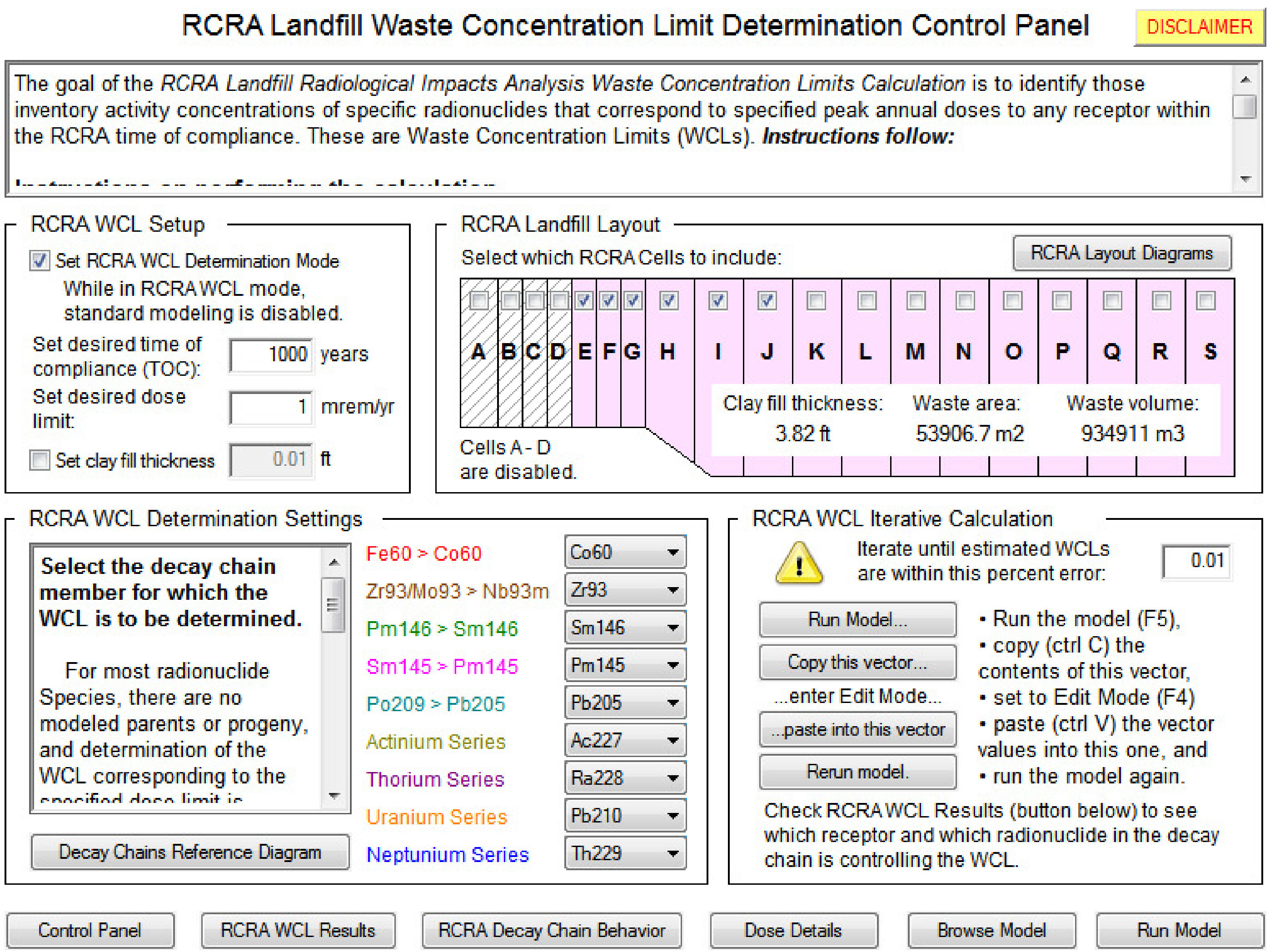
Utility: Input Dashboards



Utility: Results Dashboards

RCRA Landfill Waste Concentration Limit Determination Results

DISCLAIMER

Results of the RCRA Landfill WCL determination are organized in several tables, organized by radionuclide.

H3 to Co60 | Ni59 to Cd113m | Sn121m to Sm151 | Eu150 to Tl204 | Pb205 to Pa231 | U232 to Pu244 | Am241 to Cf252

RCRA Landfill Inventory Concentration Results

nuclide*	activity conc.	disposed act.	max. peak dose	AR	NR	SR	OW	F	H	R	ratio of max peak dose to inventory concentration	inventory concentration for dose limit (or SA)***	
Pb205	0 pCi/g	0 Ci	1.32e-13 mrem/yr					✓			0 (mrem/yr)/(pCi/g)	0 (pCi/g)	
Pb210	0 pCi/g	0 Ci	3.28e-24 mrem/yr					✓			0 (mrem/yr)/(pCi/g)	0 (pCi/g)	
Bi207	40297 pCi/g	69677 Ci	1 mrem/yr				✓				2.482e-5 (mrem/yr)/(pCi/g)	40289 (pCi/g)	
Bi210m	21870 pCi/g	37815 Ci	1 mrem/yr				✓				4.573e-5 (mrem/yr)/(pCi/g)	21865 (pCi/g)	
Po208	5.93e14 pCi/g	1.03e15 Ci	0 mrem/yr								0 (mrem/yr)/(pCi/g)	5.93e14 (pCi/g)	✓
Po209	1 pCi/g	1.73 Ci	0 mrem/yr								1.321e-13 (mrem/yr)/(pCi/g)	7.57e12 (pCi/g)	
Rn222	0 pCi/g	0 Ci	7.5e-24 mrem/yr	✓							0 (mrem/yr)/(pCi/g)	0 (pCi/g)	
Ra226	0 pCi/g	0 Ci	3.24e-25 mrem/yr					✓			0 (mrem/yr)/(pCi/g)	0 (pCi/g)	
Ra228	0 pCi/g	0 Ci	1.83e-21 mrem/yr					✓			0 (mrem/yr)/(pCi/g)	0 (pCi/g)	
Ac227	0 pCi/g	0 Ci	5.08e-23 mrem/yr					✓			0 (mrem/yr)/(pCi/g)	0 (pCi/g)	
Th228	0 pCi/g	0 Ci	0 mrem/yr								0 (mrem/yr)/(pCi/g)	0 (pCi/g)	
Th229	0 pCi/g	0 Ci	2.81e-16 mrem/yr	✓							0 (mrem/yr)/(pCi/g)	0 (pCi/g)	
Th230	0 pCi/g	0 Ci	1.12e-24 mrem/yr	✓							0 (mrem/yr)/(pCi/g)	0 (pCi/g)	
Th232	0 pCi/g	0 Ci	1.5e-22 mrem/yr	✓							0 (mrem/yr)/(pCi/g)	0 (pCi/g)	
Pa231	0 pCi/g	0 Ci	5.41e-23 mrem/yr					✓			0 (mrem/yr)/(pCi/g)	0 (pCi/g)	

(AR–R columns: max. exposed receptor**)

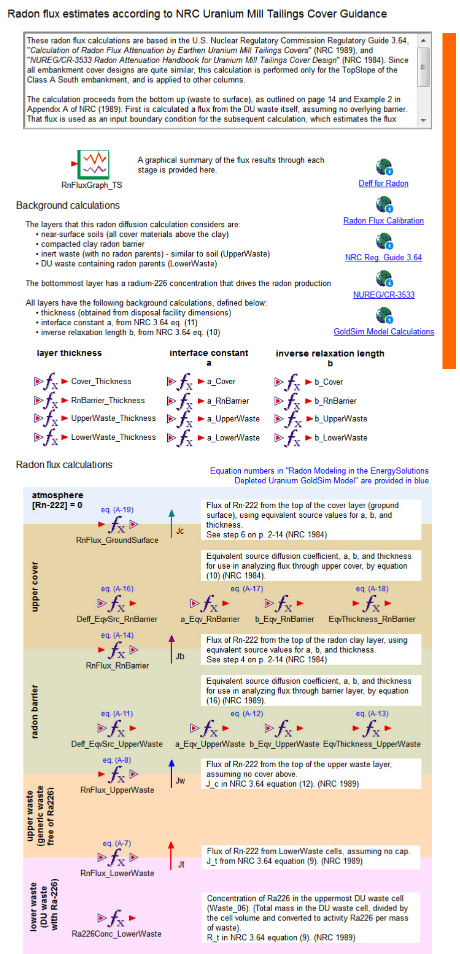
Po209 > Pb205 Actinium Series Thorium Series Uranium Series Neptunium Series

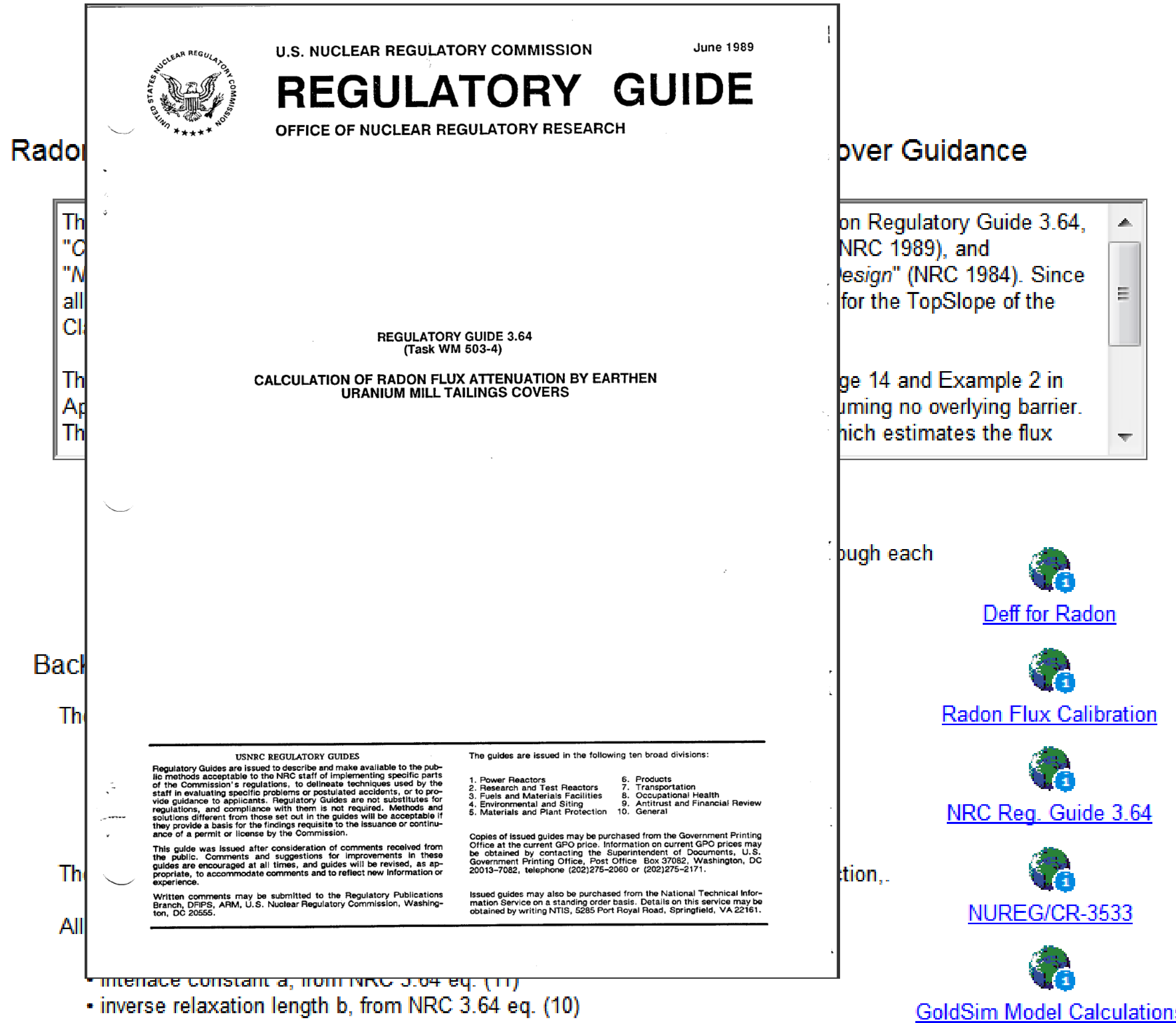
Decay Chains Diagram

* Radionuclides identified in the same color are members of a decay chain and require individual WCL development.
** Receptors: AR adjacent resident, NR nearest resident, SR on-site resident, OW oilfield worker (driller), F farmer, H hunter, R rancher
*** A value of 0 pCi/g means that the WCL for this radionuclide is not evaluated. A checkmark indicates that the WCL is from specific activity.

Control Panel | RCRA WCL Controls | Decay Chain Specific Results | Dose Details | Browse Model | Run Model

Bringing it Together





U.S. NUCLEAR REGULATORY COMMISSION

June 1989

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 3.64
(Task WM 503-4)

CALCULATION OF RADON FLUX ATTENUATION BY EARTHEN URANIUM MILL TAILINGS COVERS

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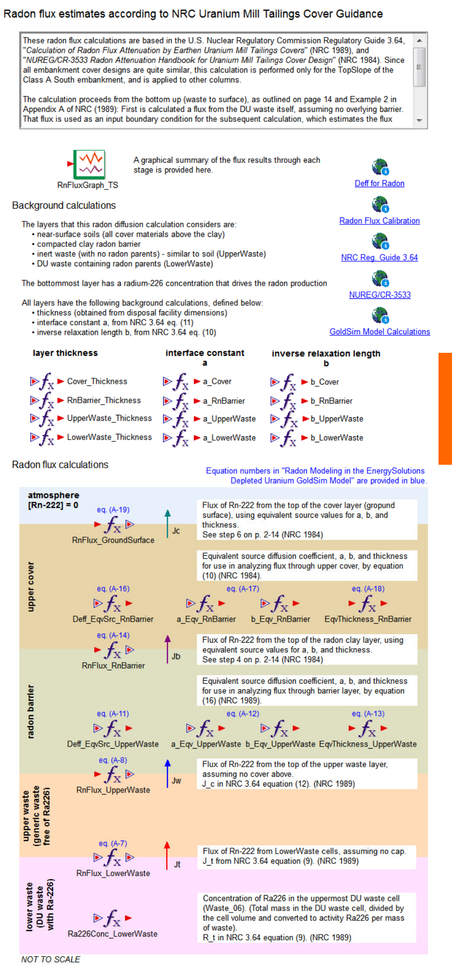
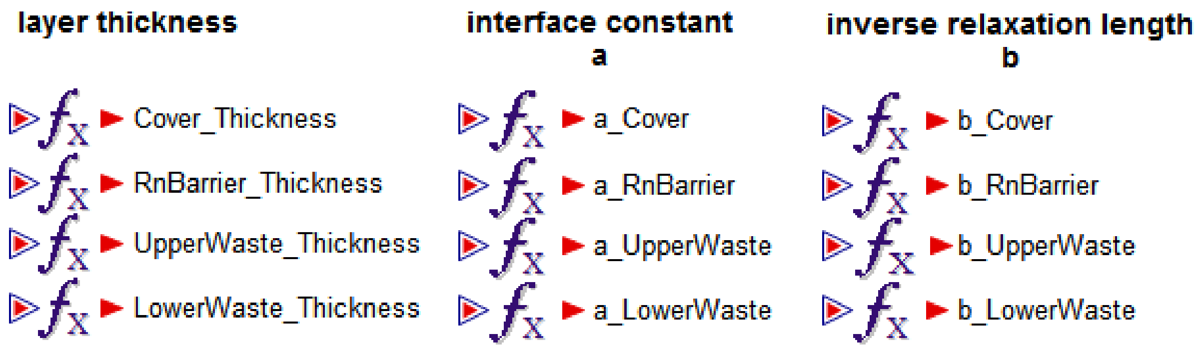
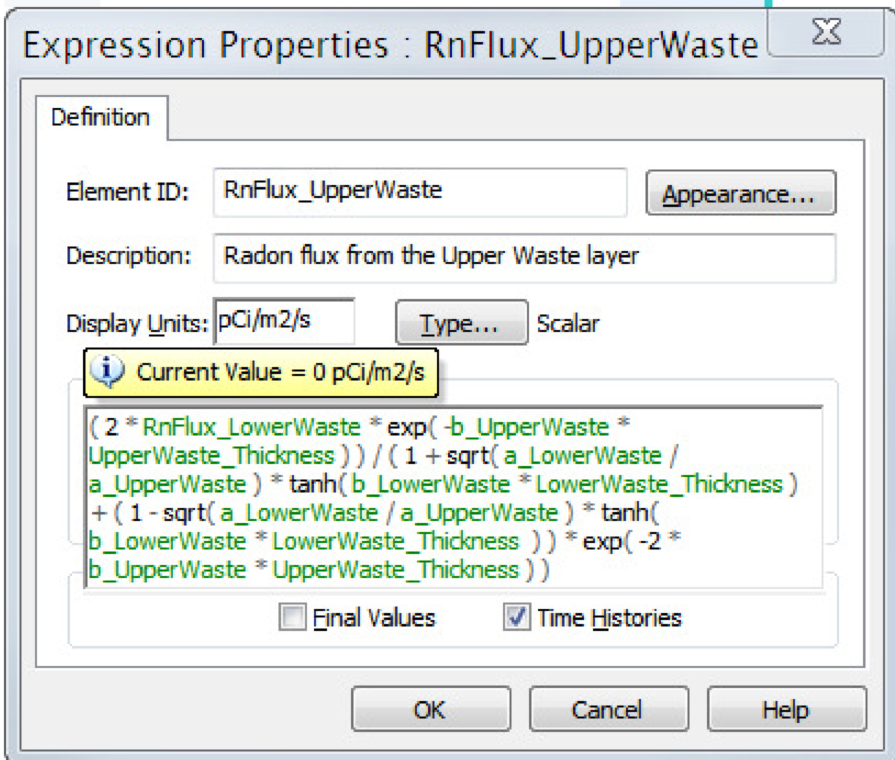
Bringing it Together

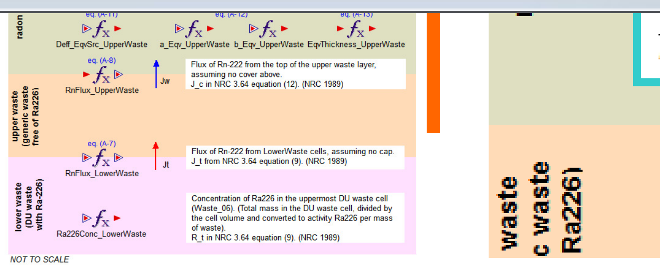


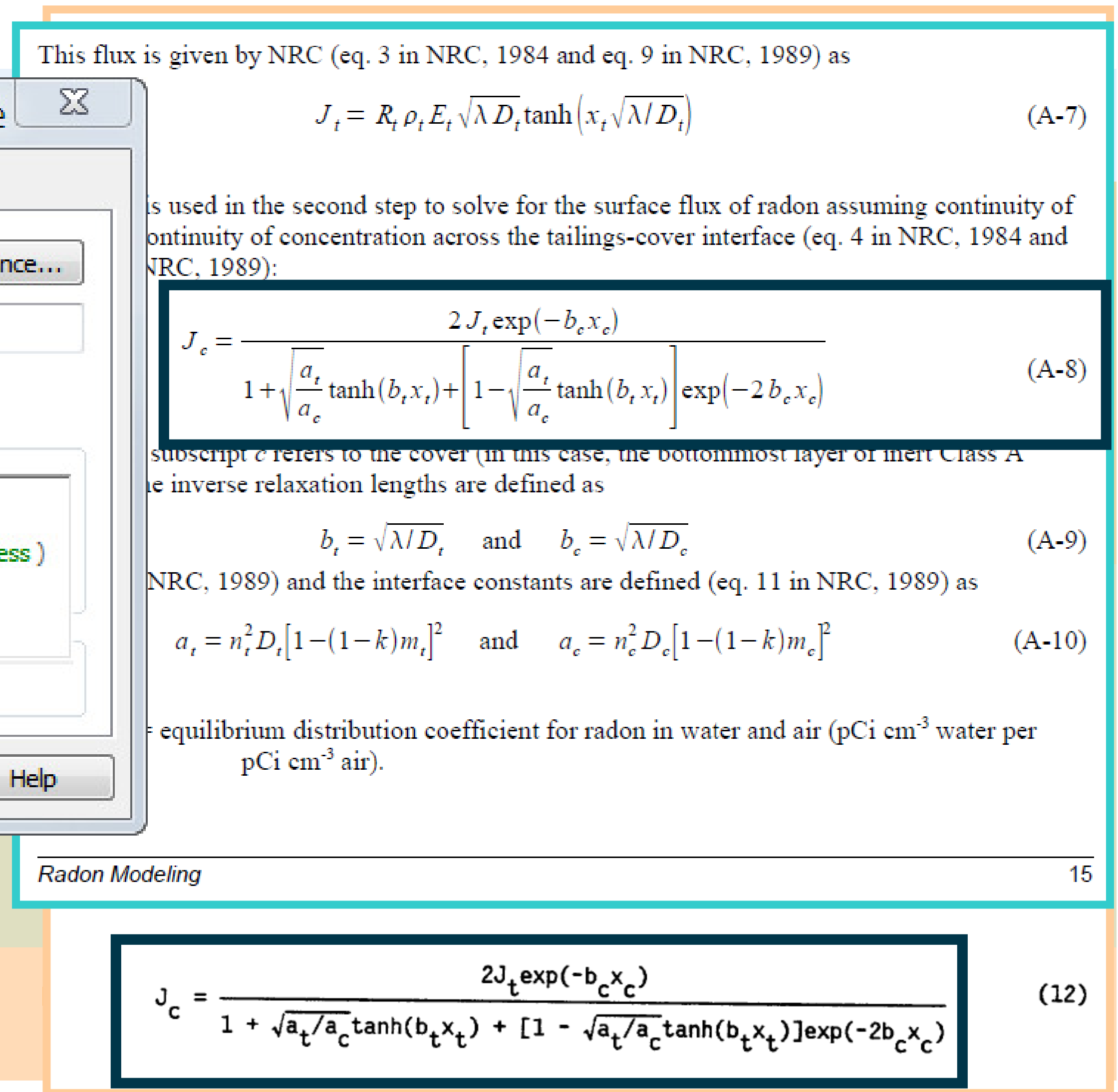


Sometimes simply organizing the appearance of calculations can help in communicating their role.

Bringing it Together







This flux is given by NRC (eq. 3 in NRC, 1984 and eq. 9 in NRC, 1989) as

$$J_t = R_t \rho_t E_t \sqrt{\lambda D_t} \tanh\left(x_t \sqrt{\lambda / D_t}\right) \quad \text{(A-7)}$$

is used in the second step to solve for the surface flux of radon assuming continuity of ontinuity of concentration across the tailings-cover interface (eq. 4 in NRC, 1984 and NRC, 1989):

$$J_c = \frac{2 J_t \exp(-b_c x_c)}{1 + \sqrt{\frac{a_t}{a_c}} \tanh(b_t x_t) + \left[1 - \sqrt{\frac{a_t}{a_c}} \tanh(b_t x_t)\right] \exp(-2 b_c x_c)} \quad \text{(A-8)}$$

subscript c refers to the cover (in this case, the bottommost layer of inert Class A e inverse relaxation lengths are defined as

$$b_t = \sqrt{\lambda / D_t} \quad \text{and} \quad b_c = \sqrt{\lambda / D_c} \quad \text{(A-9)}$$

NRC, 1989) and the interface constants are defined (eq. 11 in NRC, 1989) as

$$a_t = n_t^2 D_t \left[1 - (1-k) m_t\right]^2 \quad \text{and} \quad a_c = n_c^2 D_c \left[1 - (1-k) m_c\right]^2 \quad \text{(A-10)}$$

equilibrium distribution coefficient for radon in water and air (pCi cm^{-3} water per pCi cm^{-3} air).

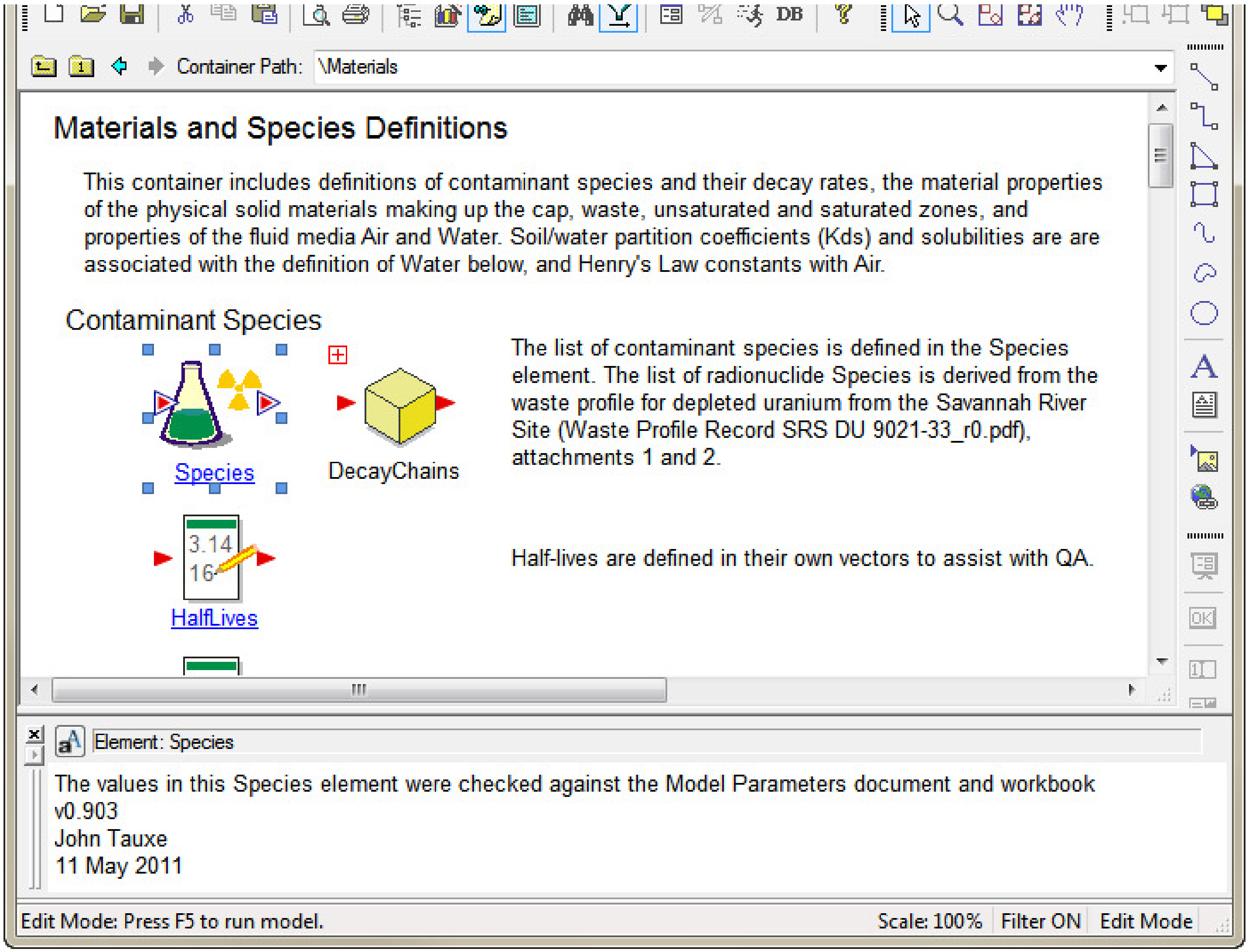
Radon Modeling 15

$$J_c = \frac{2J_t \exp(-b_c x_c)}{1 + \sqrt{a_t/a_c} \tanh(b_t x_t) + [1 - \sqrt{a_t/a_c} \tanh(b_t x_t)] \exp(-2b_c x_c)} \quad (12)$$

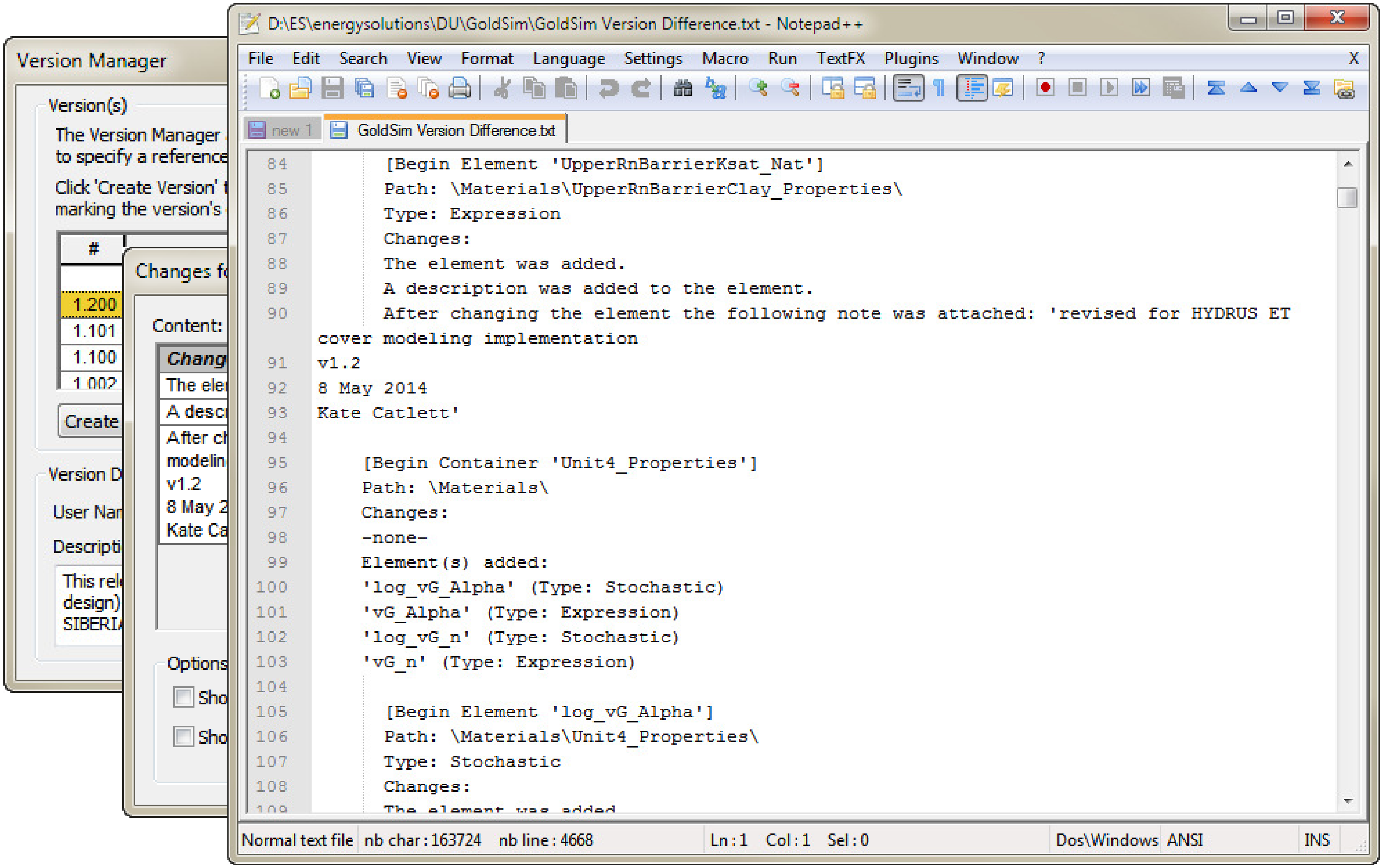
QA Tools in GoldSim

- Use the tools provided within GoldSim for QA:
- Note Panes
- Versioning
- Version change notes

The Note Pane



Model Versioning



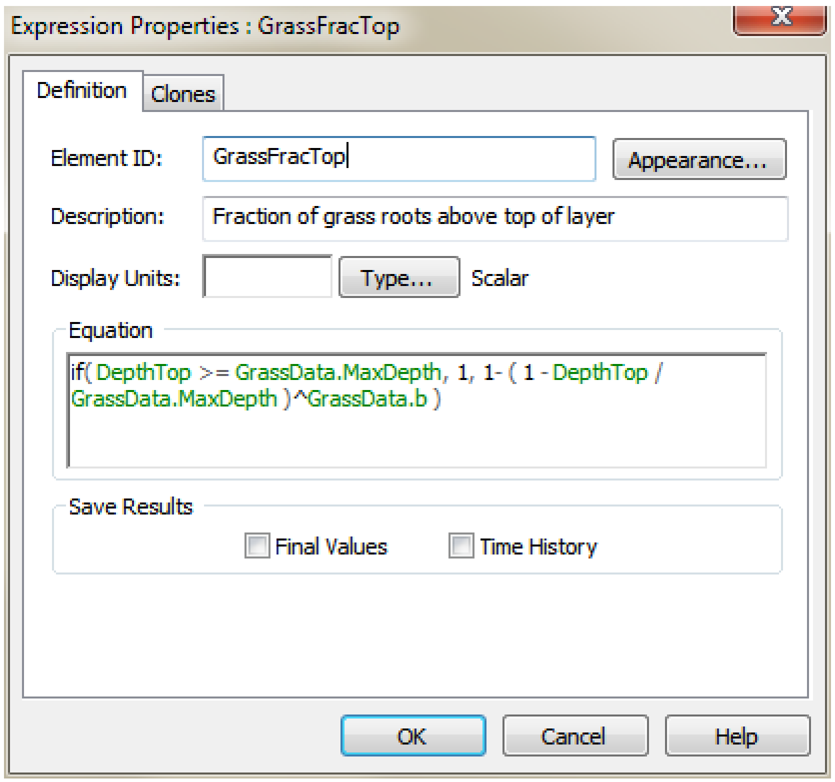
More GoldSim QA Tricks

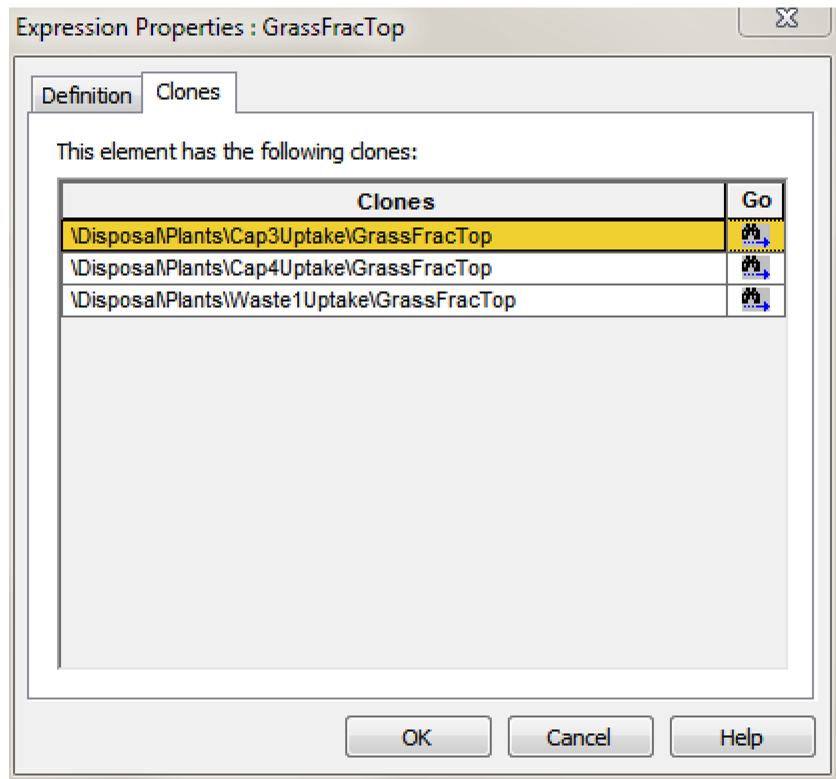
Additional QA tricks:

- Cloned elements
- Referenced units
- Graph footer information

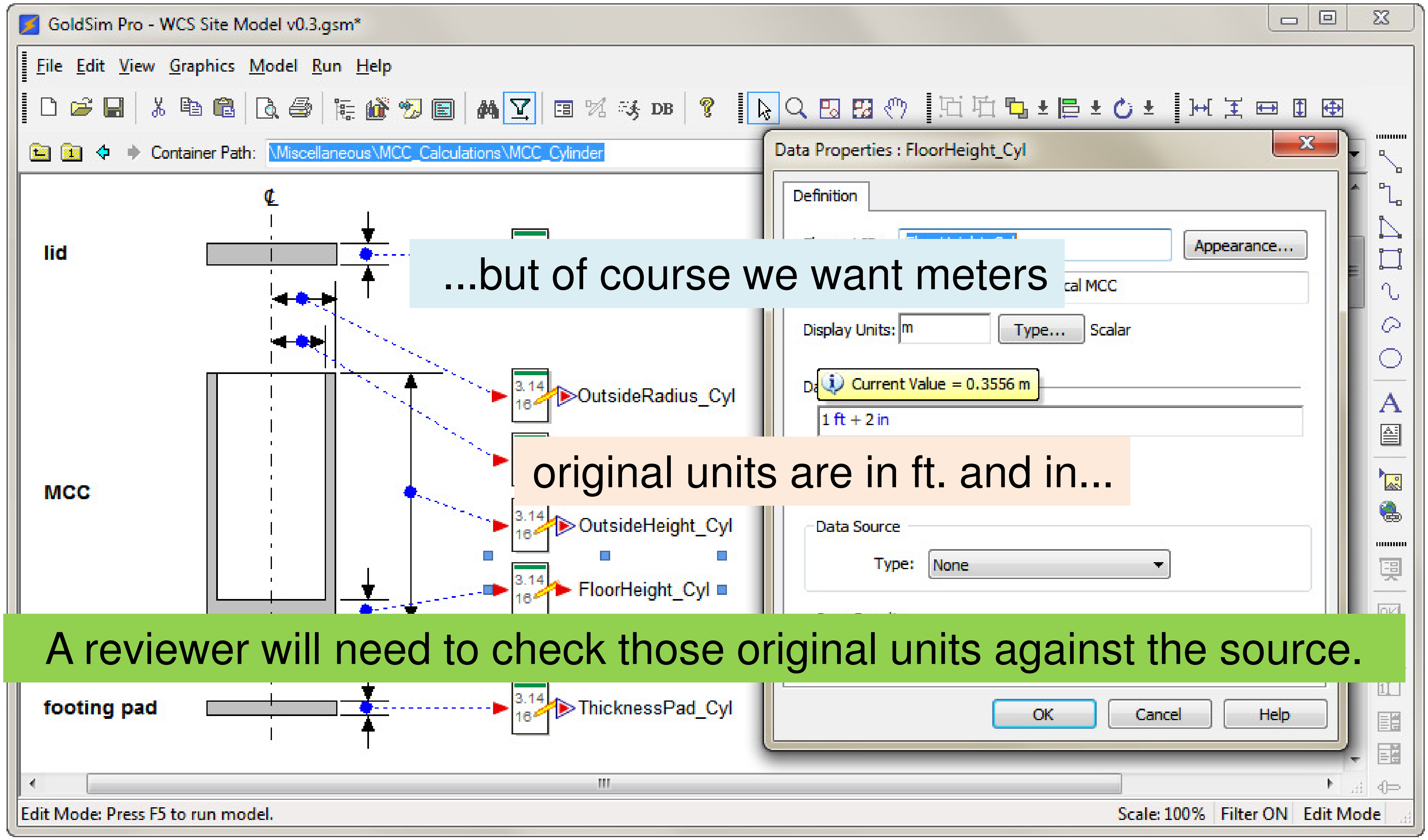
Clones for QA

If an equation is used in more than one place, cloning it guarantees that it will be the same for all clones.
That makes QA easier.





Units from References

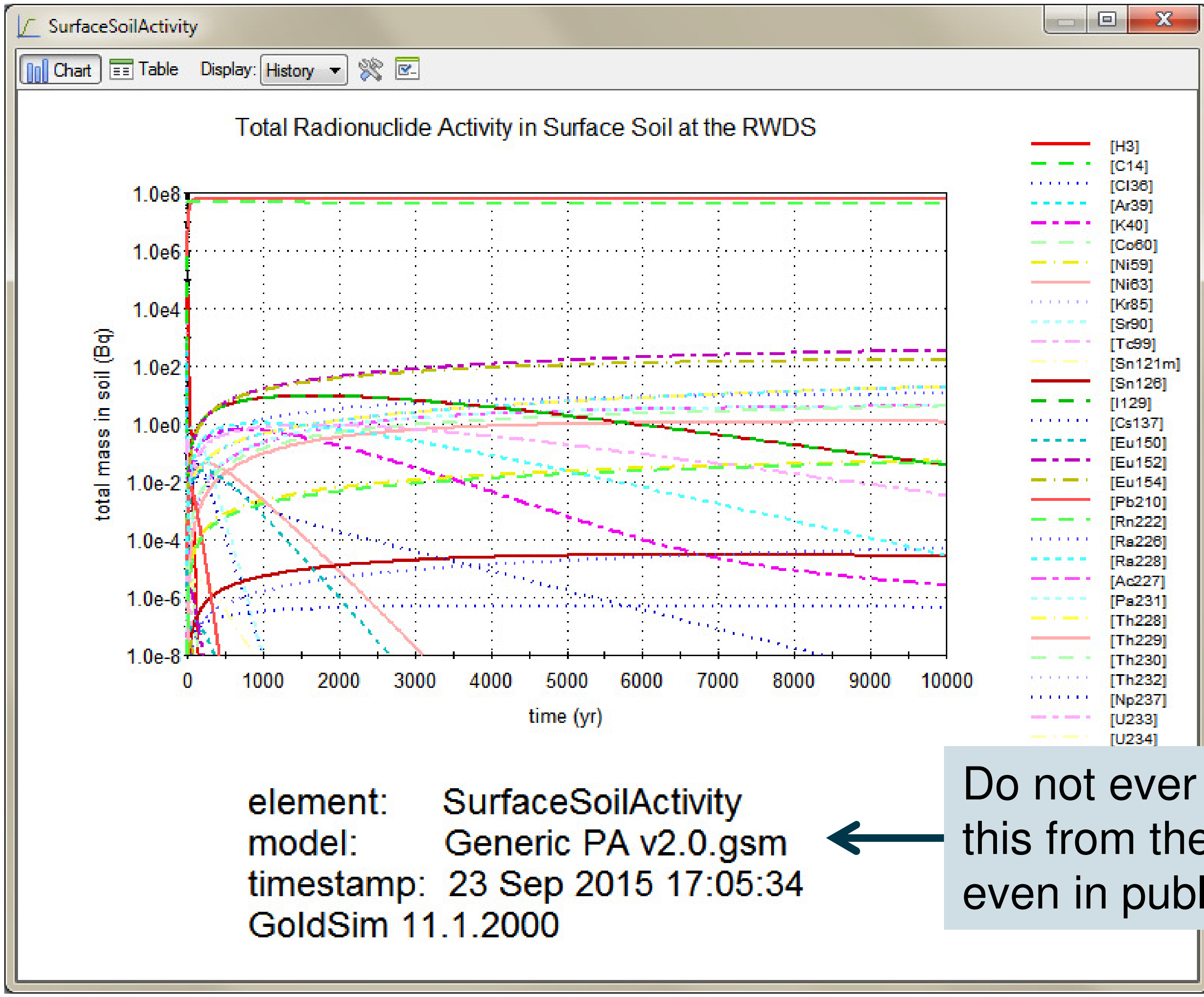


...but of course we want meters

original units are in ft. and in...

A reviewer will need to check those original units against the source.

Run Stamps for Traceability



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