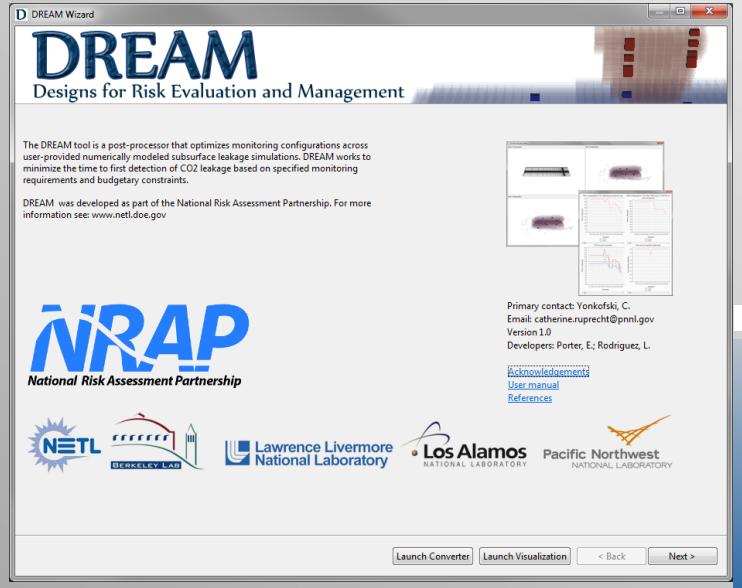

*Presenter: *Catherine Yonkofski*
NRAP monitoring workgroup

Contributors: Catherine Yonkofski[1], Ellen Porter[1], Luke Rodriguez[1], Jason Gastelum[1], Diana Bacon[1], Chris Brown[1]

NRAP Tool Webinar Series

Webinar 6

Designs for Risk Evaluation and Management (DREAM) tool: A tool for optimizing monitoring schemes based on time to CO_2 leakage detection

Monday November 16, 2015

** Presenter*
[1] Pacific Northwest National Laboratory, Richland, WA

Outline

- Welcome and Overview of NRAP – Technical Approach and Tool Development
- Introduction to the NRAP Designs for Risk Evaluation and Management tool (DREAM)
- What does DREAM do?
- User-provided input
- User Interface Workflow with a Simple Example
- Path Forward and QA/QC
- Questions and Open Discussion

National Risk Assessment Partnership (NRAP)

NRAP leverages DOE's capabilities to help quantify uncertainties and risks necessary to remove barriers to full-scale CO_2 storage deployment.

Objective: Building toolset and improving the science base to address key questions about potential impacts related to release of CO_2 or brine from the storage reservoir, and potential ground-motion impacts due to injection of CO_2

Technical Team

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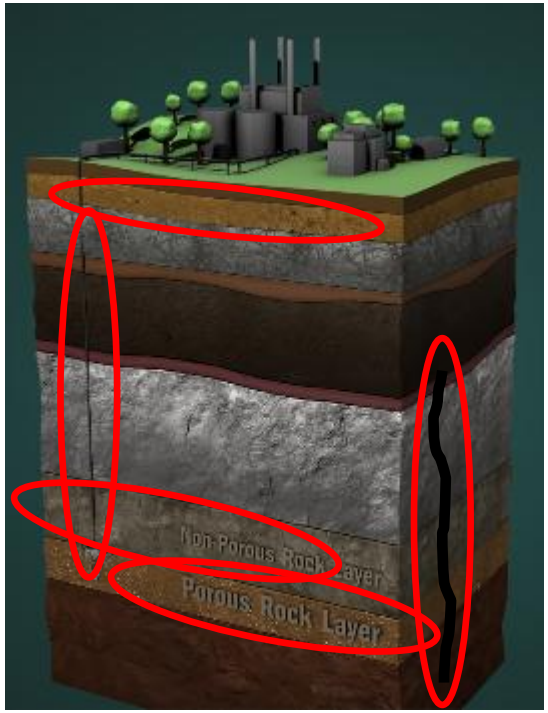
Berkeley Lab
Los Alamos National Laboratory EST. 1943
Pacific Northwest National Laboratory



Stakeholder Group

American Electric Power
Blue Source
bp
EPA United States Environmental Protection Agency
ExxonMobil
ieaghg
IEc
MIT
NRDC
Schlumberger
Southern States Energy Board
Stanford University
Texas Railroad Commission
USGS
The University of Utah
Wade, LLC
Whiting
Zurich

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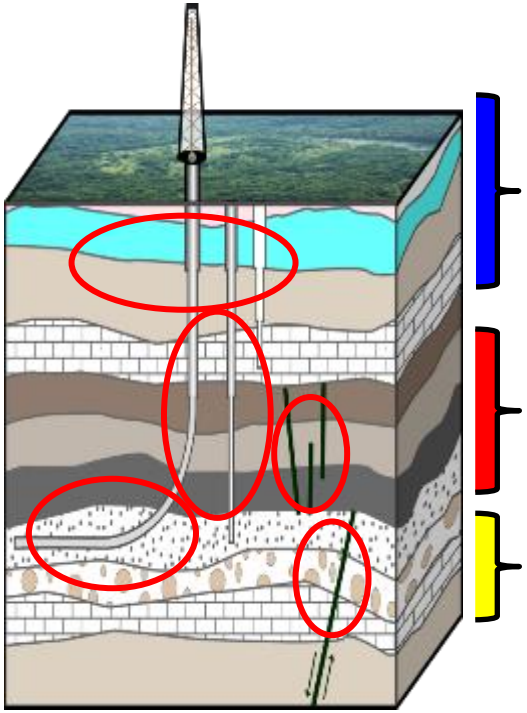
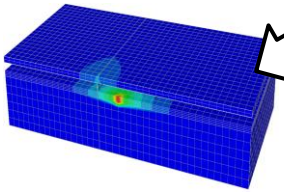
NRAP's approach to quantifying performance relies on reduced-order models to probe uncertainty in the system.

A. Divide system into discrete components



B. Develop detailed component models that are validated against lab/field data

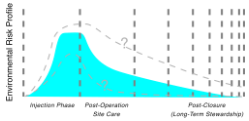


Energy Data Exchange (EDX)

Data

IAM

NRAP Integrated Assessment (System) Models



Potential Receptors or Impacted Media

Release and Transport

Storage Reservoir

C. Develop reduced-order models (ROMs) that rapidly reproduce component model predictions

D. Link ROMs via integrated assessment models (IAMs) to predict system performance & risk; calibrate using lab/field data from NRAP and other sources

E. Develop strategic monitoring protocols that allow verification of predicted system performance

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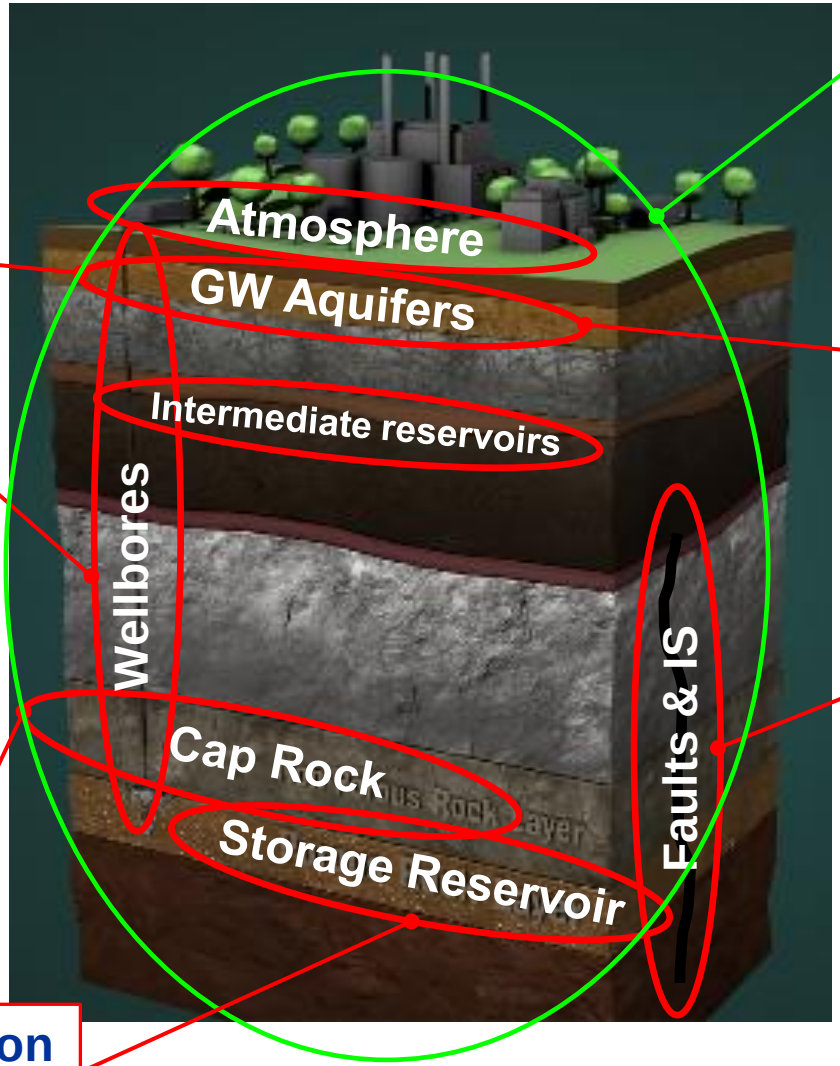
NRAP Tools

Now available for beta testing



NRAP-IAM-CS

Design for Risk Evaluation and Monitoring

Aquifer Impact Model

Wellbore Leakage Analysis Tool

Short Term Seismic Forecasting

Natural Seal ROM

Reservoir Evaluation and Visualization

www.edx.netl.doe.gov/nrap → *TOOL BETA TESTING link*

Schedule for NRAP Tool Webinar Series

Date/ Time	Tool	Presenter(s)
October 13 **Time: 1pm ET**	Integrated Assessment Model–Carbon Storage (NRAP-IAM-CS) (2.5 hours)	Rajesh Pawar
October 19 **Time: 1pm ET**	Natural Seal ROM (NSealR) (1 hour)	Nicolas Huerta, Ernest Lindner
October 26 **Time: 1pm ET**	Reservoir Evaluation and Visualization (REV) Tool (1 hour)	Seth King
November 2 **Time: 1pm ET**	Wellbore Leakage Analysis Tool (WLAT) (1.5 hour)	Nicholas Huerta
November 9 **Time: 1pm ET**	Aquifer Impact Model (AIM) (1.5 hour)	Diana Bacon
November 16 **Time: 1pm ET**	Design for Risk Evaluation and Monitoring (DREAM) (1 hour)	Catherine Ruprecht Yonkofski
November 30 **Time: 1pm ET**	Short Term Seismic Forecasting (STSF) (1 hour)	Josh White, Corinne Bachman
December 7 **Time: 1pm ET**	TBD	

Check for updates at www.edx.netl.doe.gov/nrap

What does DREAM do?

Problem statement:
In the case of CO_2 injection operations in the vicinity of abandoned wellbores, there is a need to identify diverse monitoring designs capable of efficiently detecting leakage before persistence in USDWs.

Solution:
The DREAM tool optimizes site specific monitoring schemes based on minimizing the time to leakage detection (TTD).

- Uses a simulated annealing algorithm
- Varies monitoring parameter sensor-types and quantities
- Adheres to cost constraints
- Minimizes TTD
- Outputs optimal monitoring configurations based on inputs

User-provided input

Leakage Simulations

- DREAM requires previously computed simulation output from numerically modeled leakage cases.
- To improve computational efficiency, DREAM converts this ASCII data to binary hdf5 formatted data prior to optimization.
  - Currently the data converter included with DREAM is directly compatible with NUFT and STOMP output files.
  - Developments are being made to accept a more universal text format.

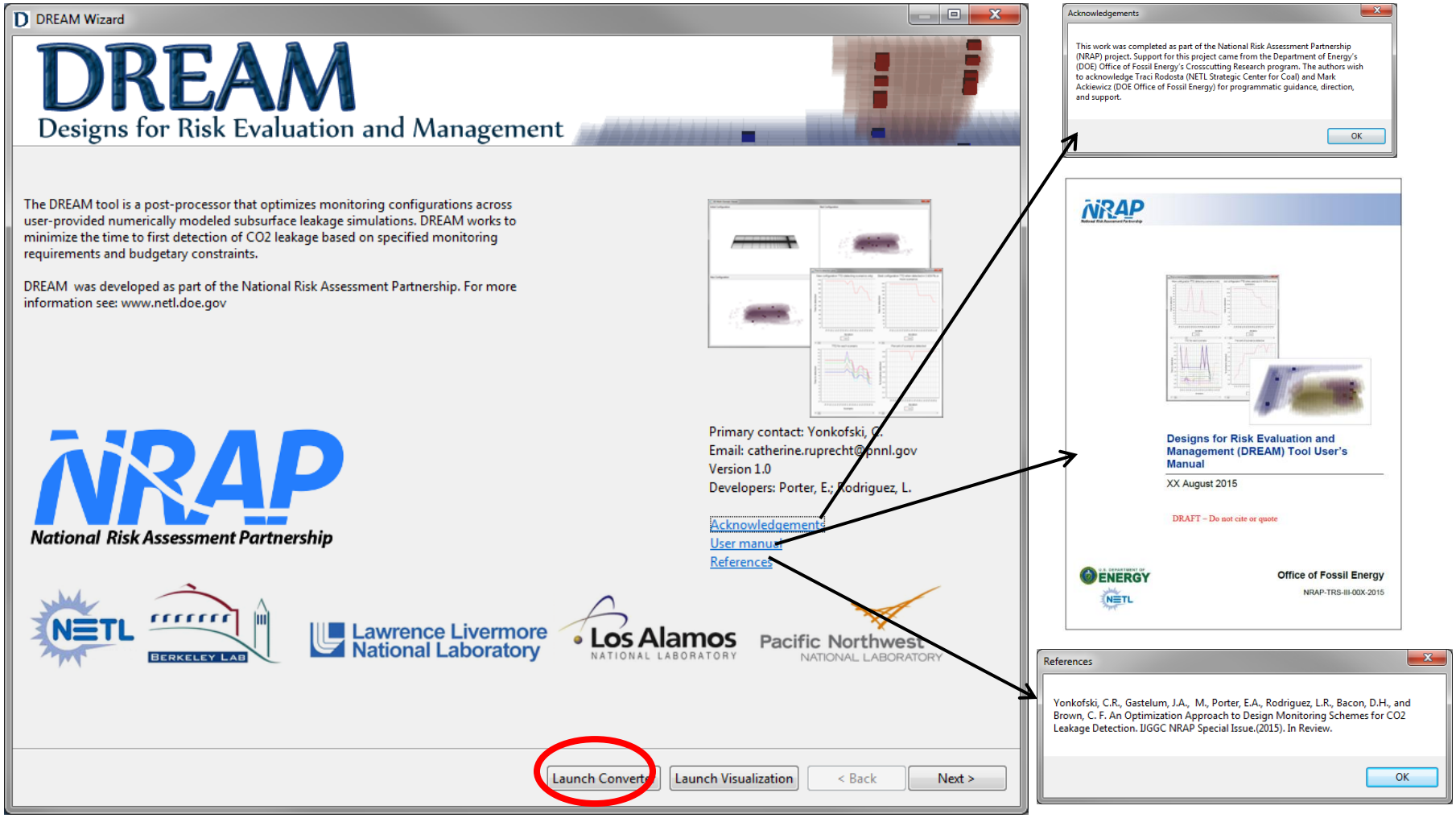
Leakage Signature

- Select monitoring parameters of interest – called “sensor-types”.
- Set threshold values.
- Specify minimum number of alarming sensors to constitute a leak.

Constraints

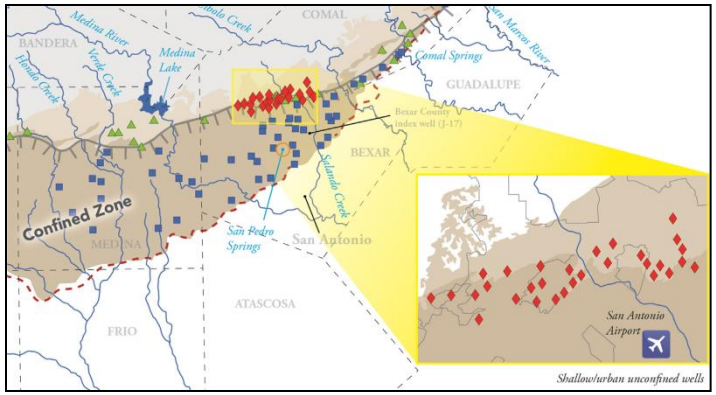
- Budget
- Number of wells
- Locations

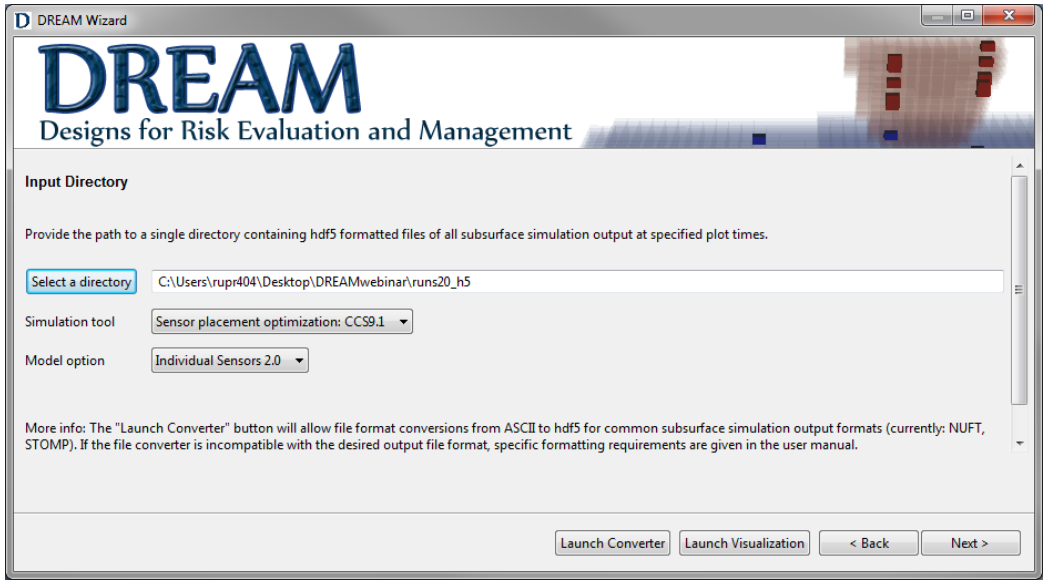
User Interface Workflow with a Simple Example

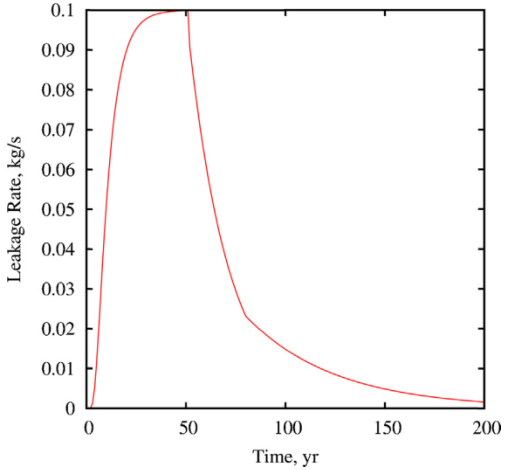


User Interface Workflow: Load Realizations

Example simulations from Hou et al. (2014) of leakage through an abandoned wellbore into an unconfined aquifer. Variable leakage rate, geochemistry, hydrogeology.







Input parameters and their ranges for uncertainty quantification.

Number	Parameter	Minimum	Maximum	Distribution
p1	Distance from injection well to leaky well, m	10	4300	Log uniform
p2	Maximum leak rate, kg/s	0.01	1	Log uniform
p3	Porosity, %	13	23	Normal
p4	Hydraulic conductivity, m/day	0.09	4.6	Log normal
p5	Calcite, solid phase, volumetric %	0.1	0.99	Normal
p6	Calcite dissolution rate at 25 °C, mol/m^2/s	1.5×10^{-7}	1.5×10^{-5}	Log normal
p7	Dolomite dissolution rate at 25 °C, mol/m^2/s	2.9×10^{-9}	2.9×10^{-7}	Log normal
p8	Surface area, cm^2/g	0.01	1	Log normal
p9	Calcite equilibrium constant at 25 °C, log	1.35	2.35	Normal
p10	Dolomite equilibrium constant at 25 °C, log	2.01	3.01	Normal

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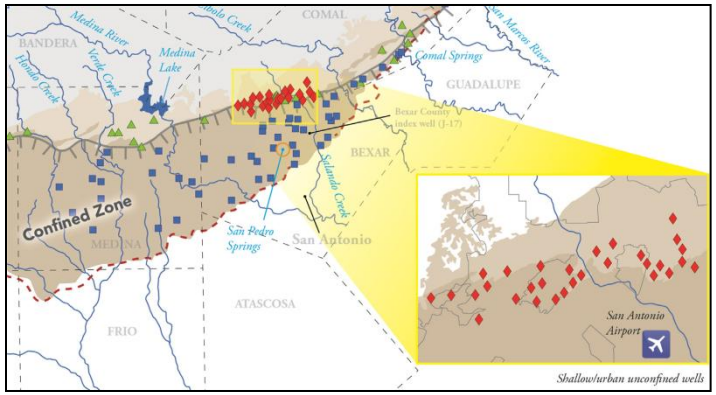

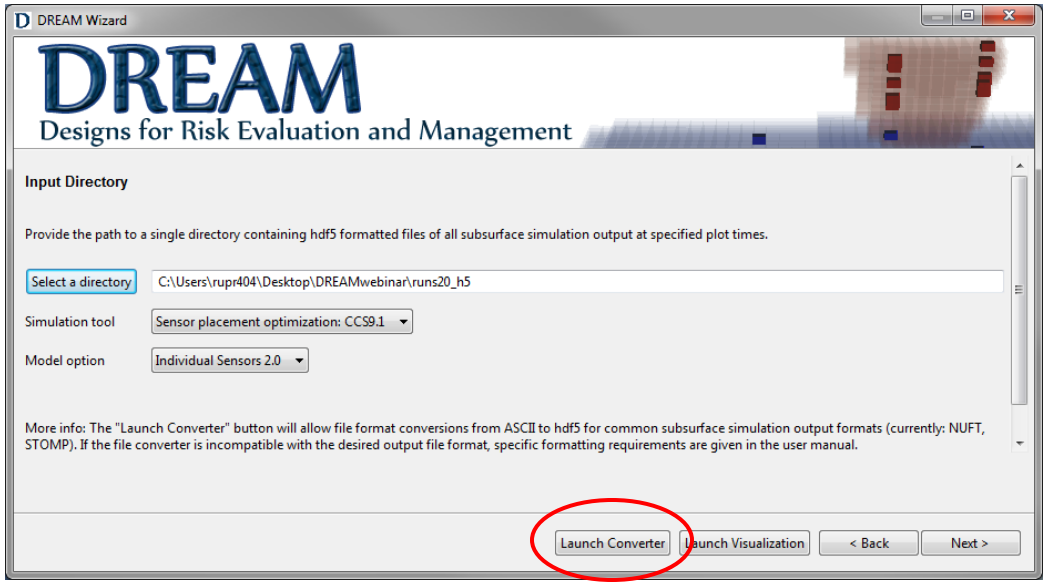

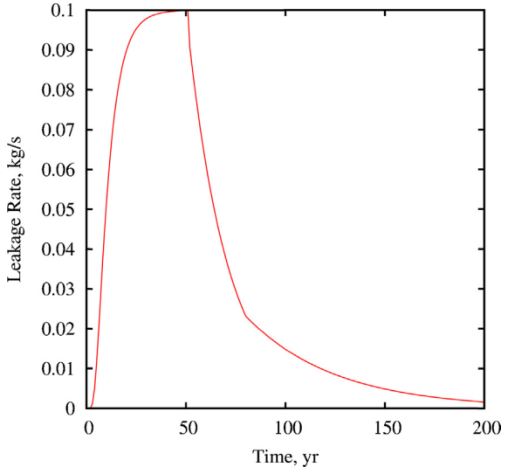

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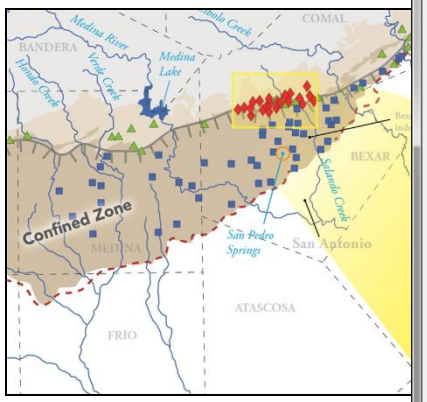

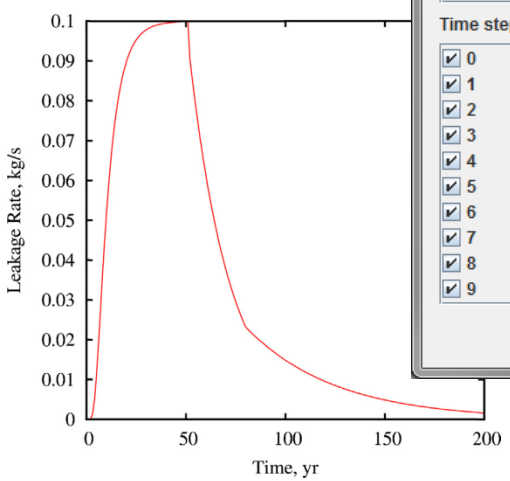

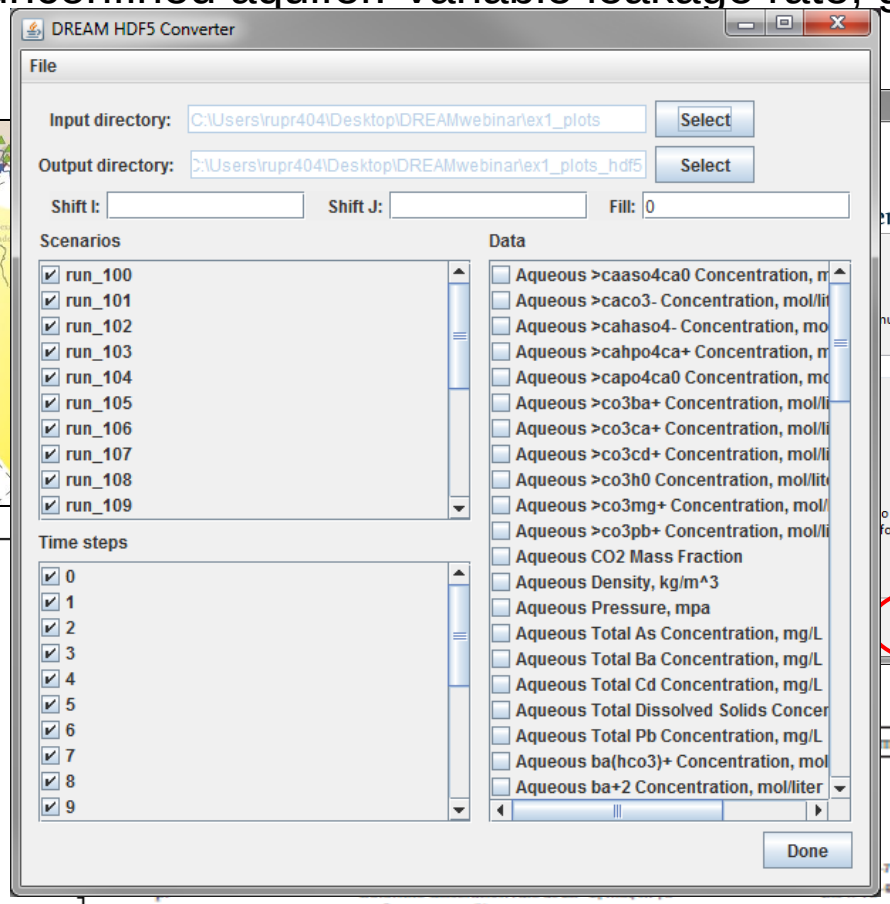

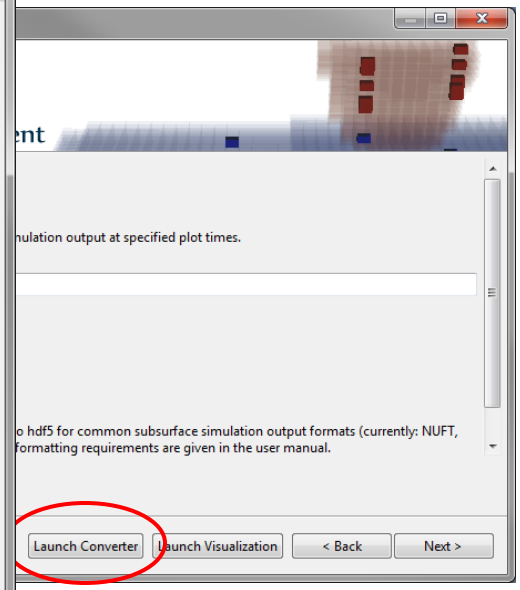

			Maximum	Distribution
			4300	Log uniform
			1	Log uniform
			23	Normal
			4.6	Log normal
			0.99	Normal
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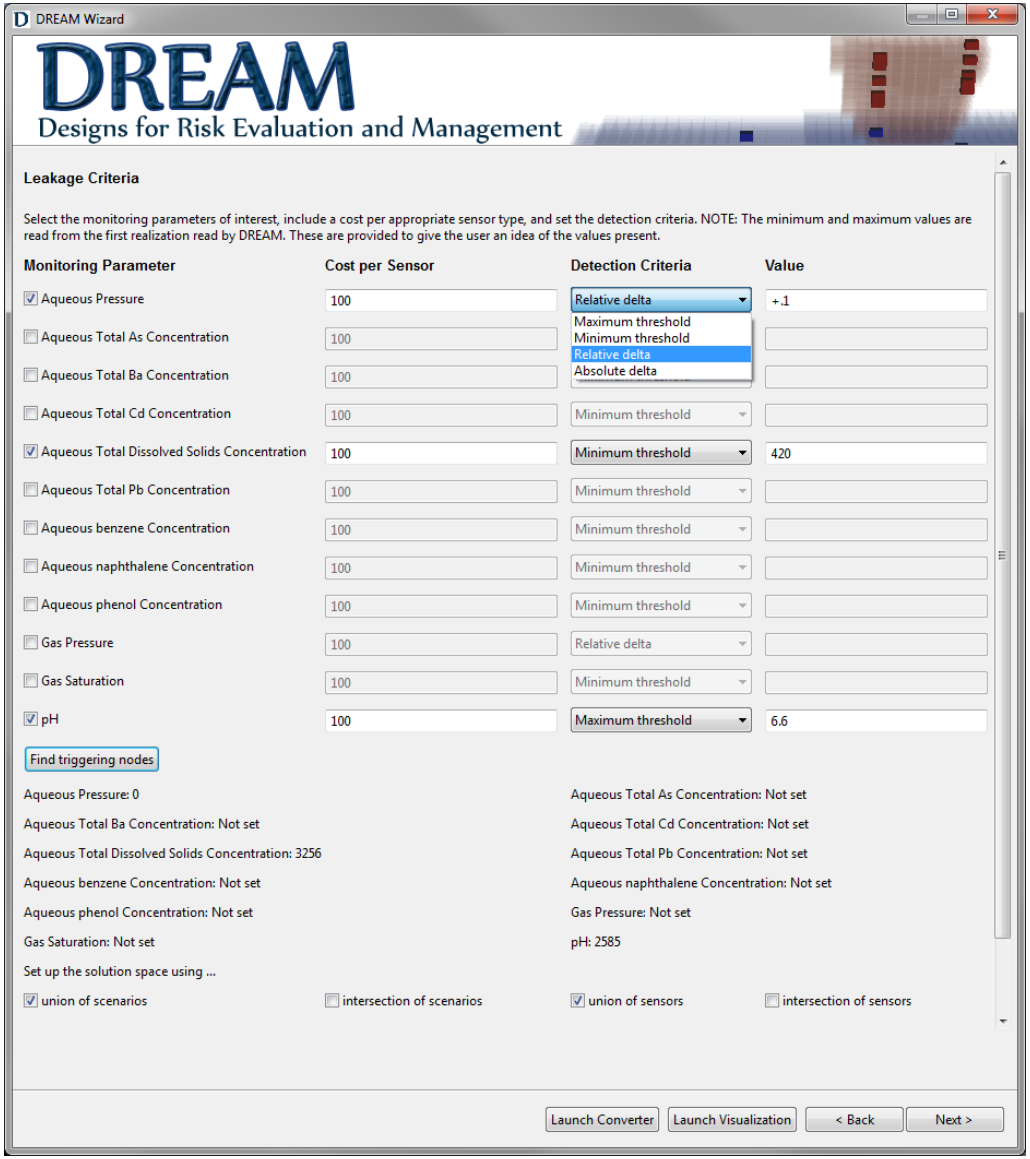
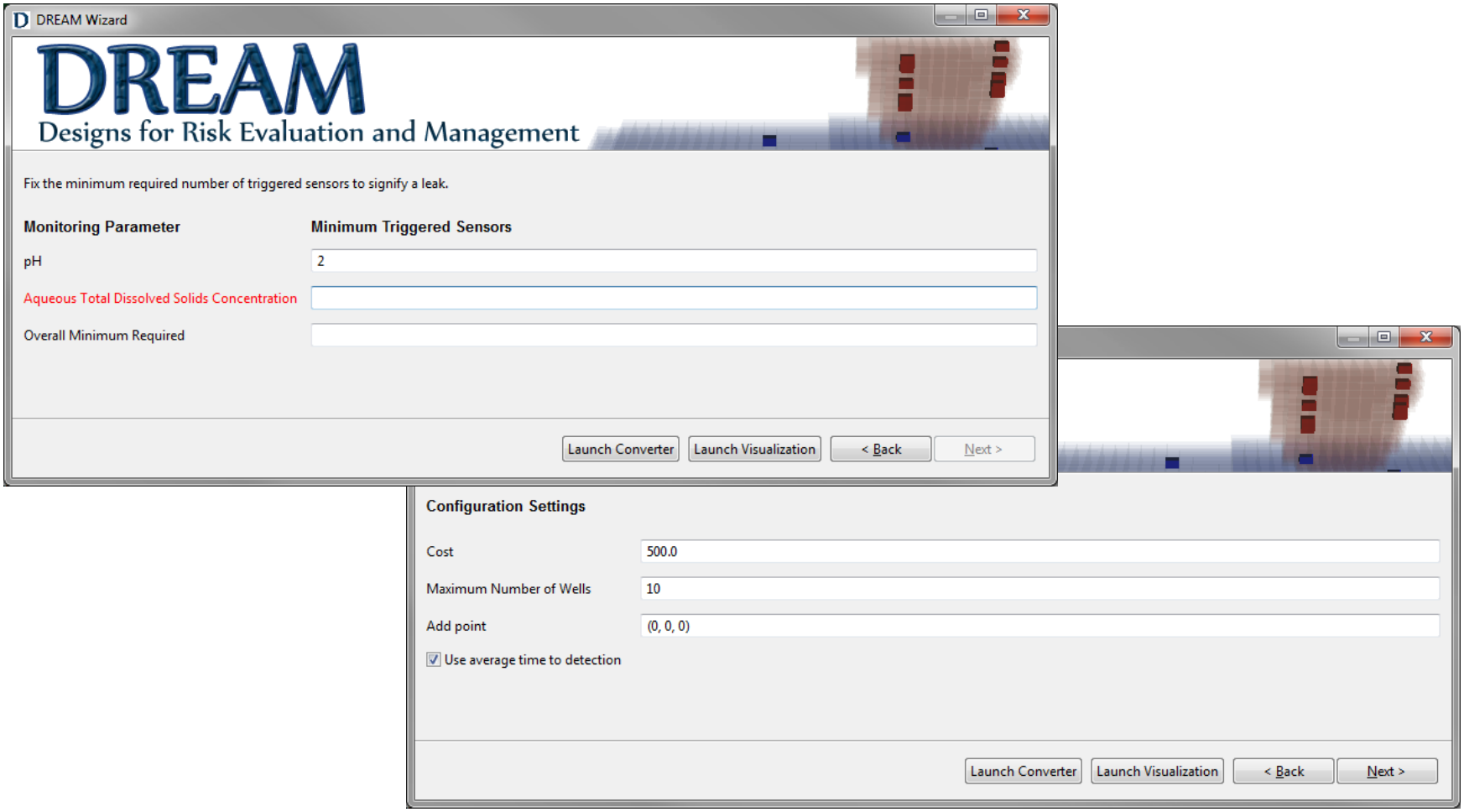
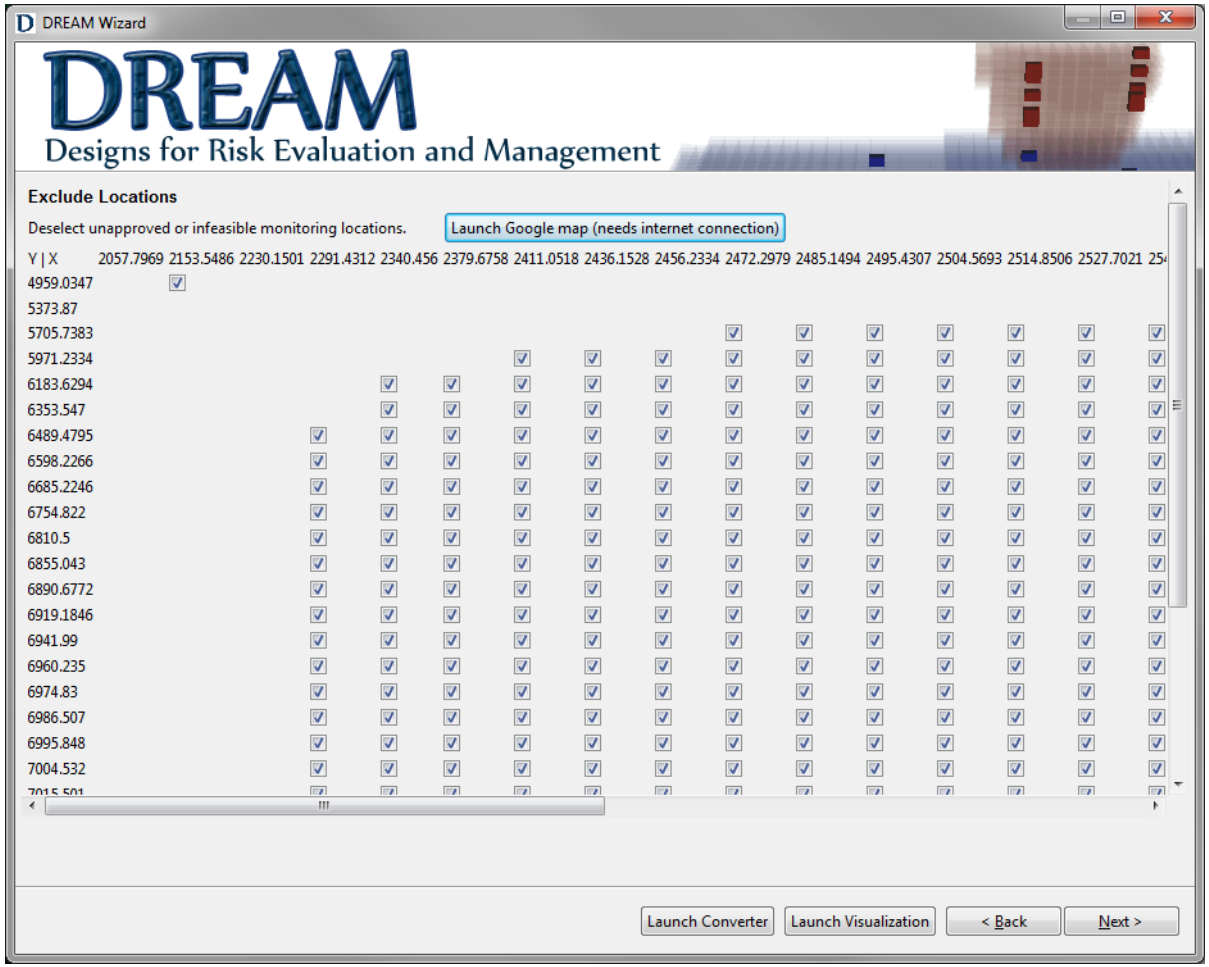
User Interface Workflow: Leakage Criteria



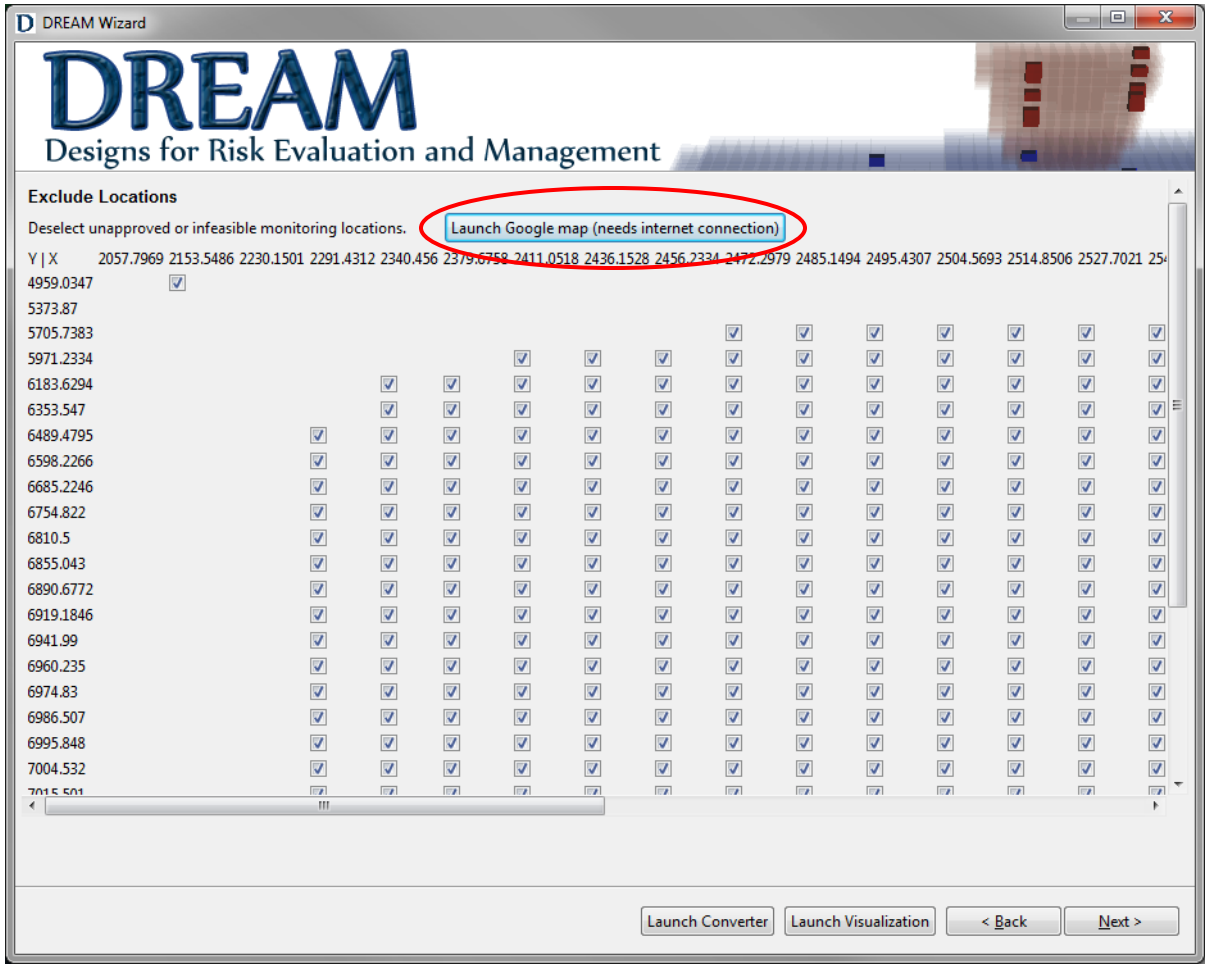
User Interface Workflow: Configuration Details



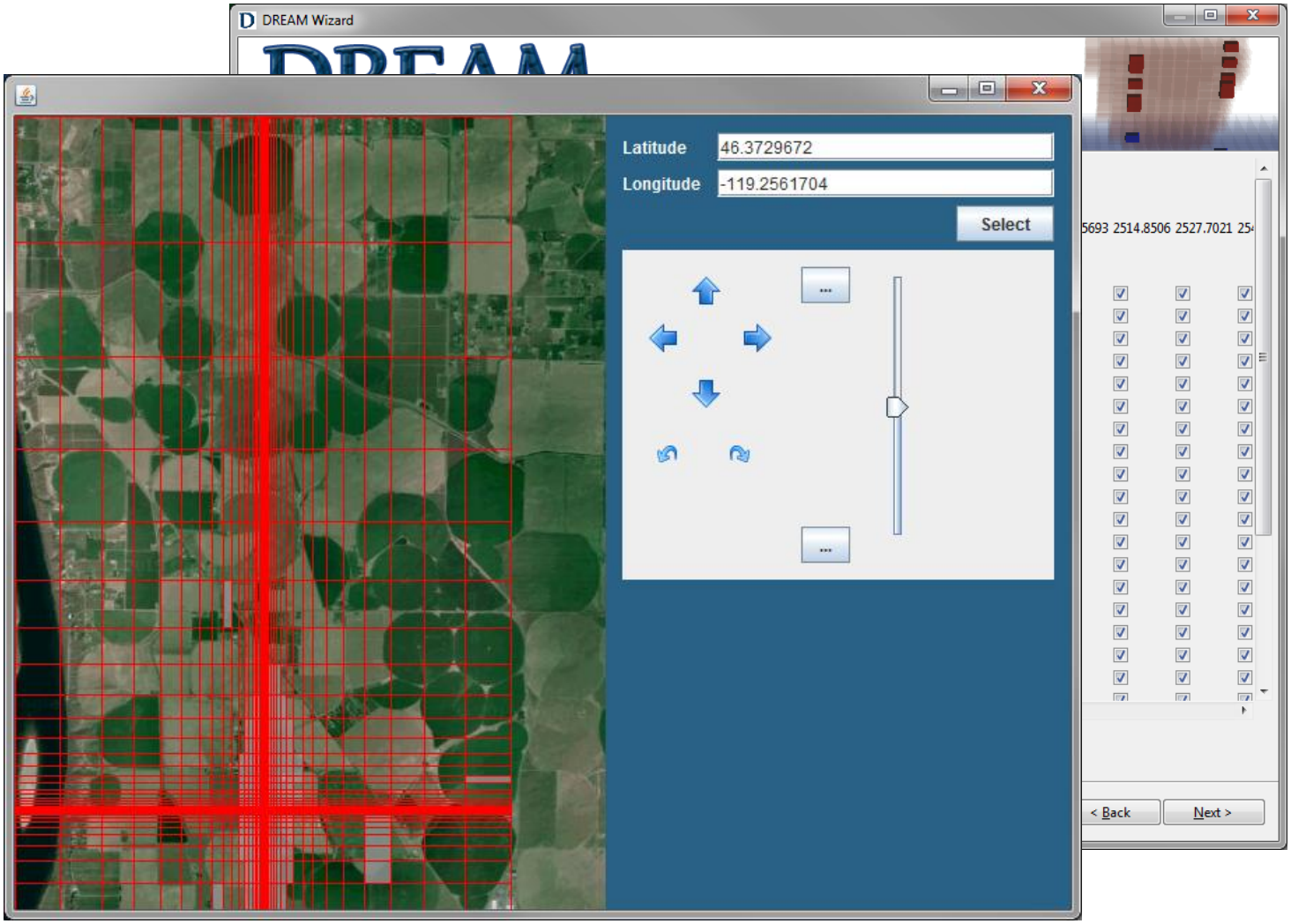
User Interface Workflow: Exclude Locations



User Interface Workflow: Exclude Locations



User Interface Workflow: Exclude Locations



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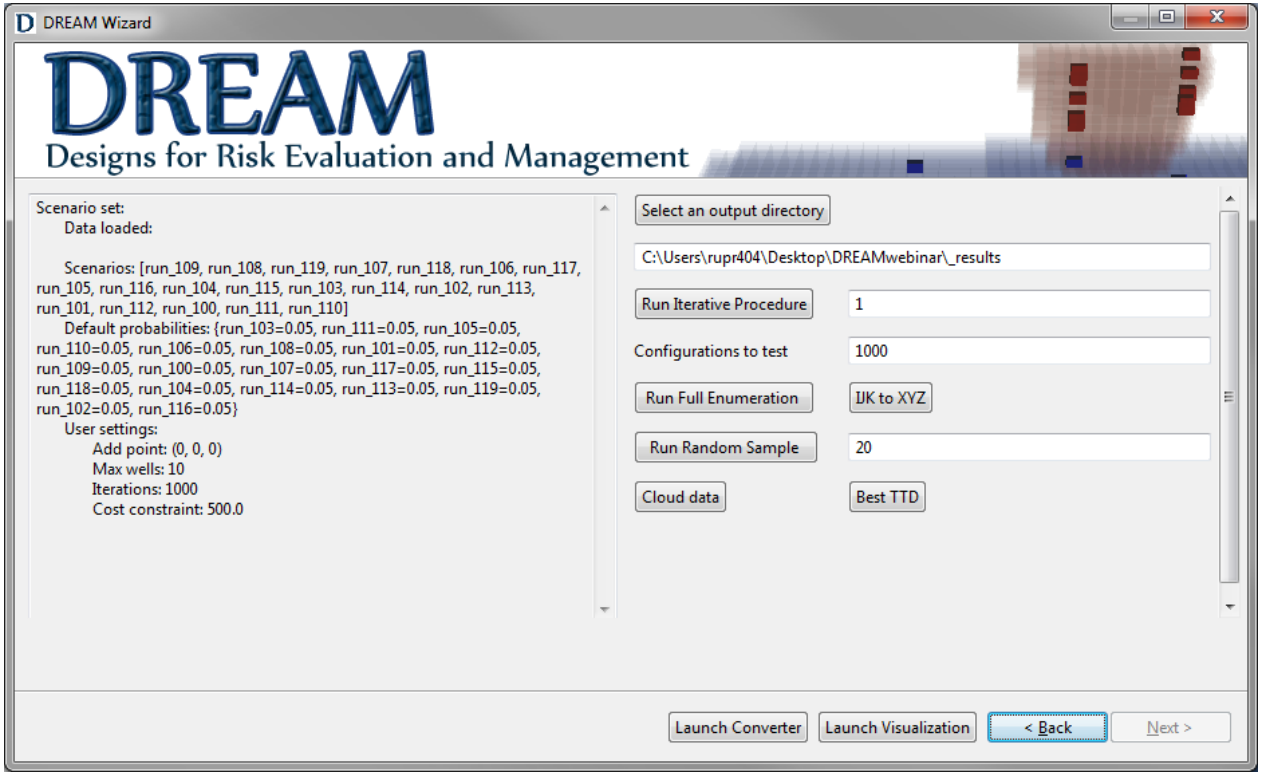
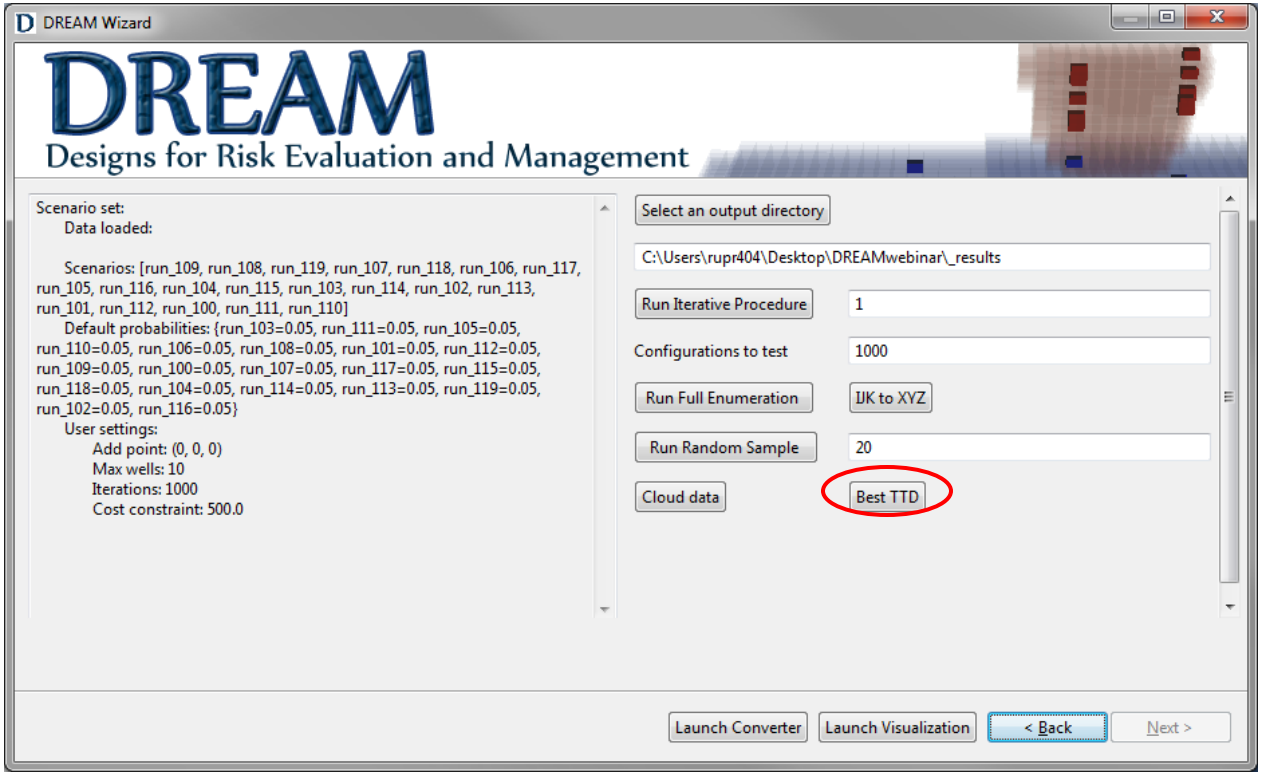
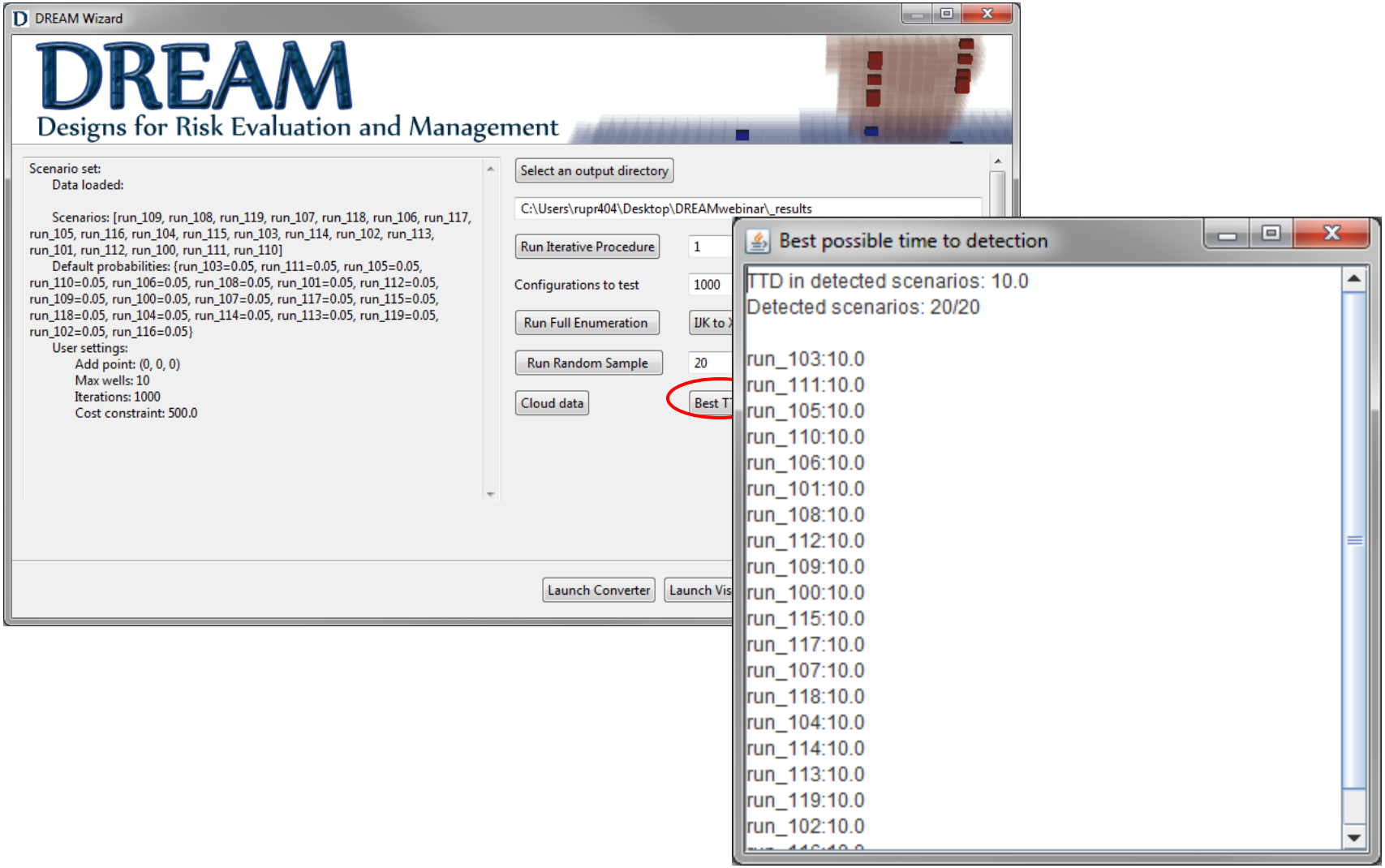
User Interface Workflow: Solution Settings



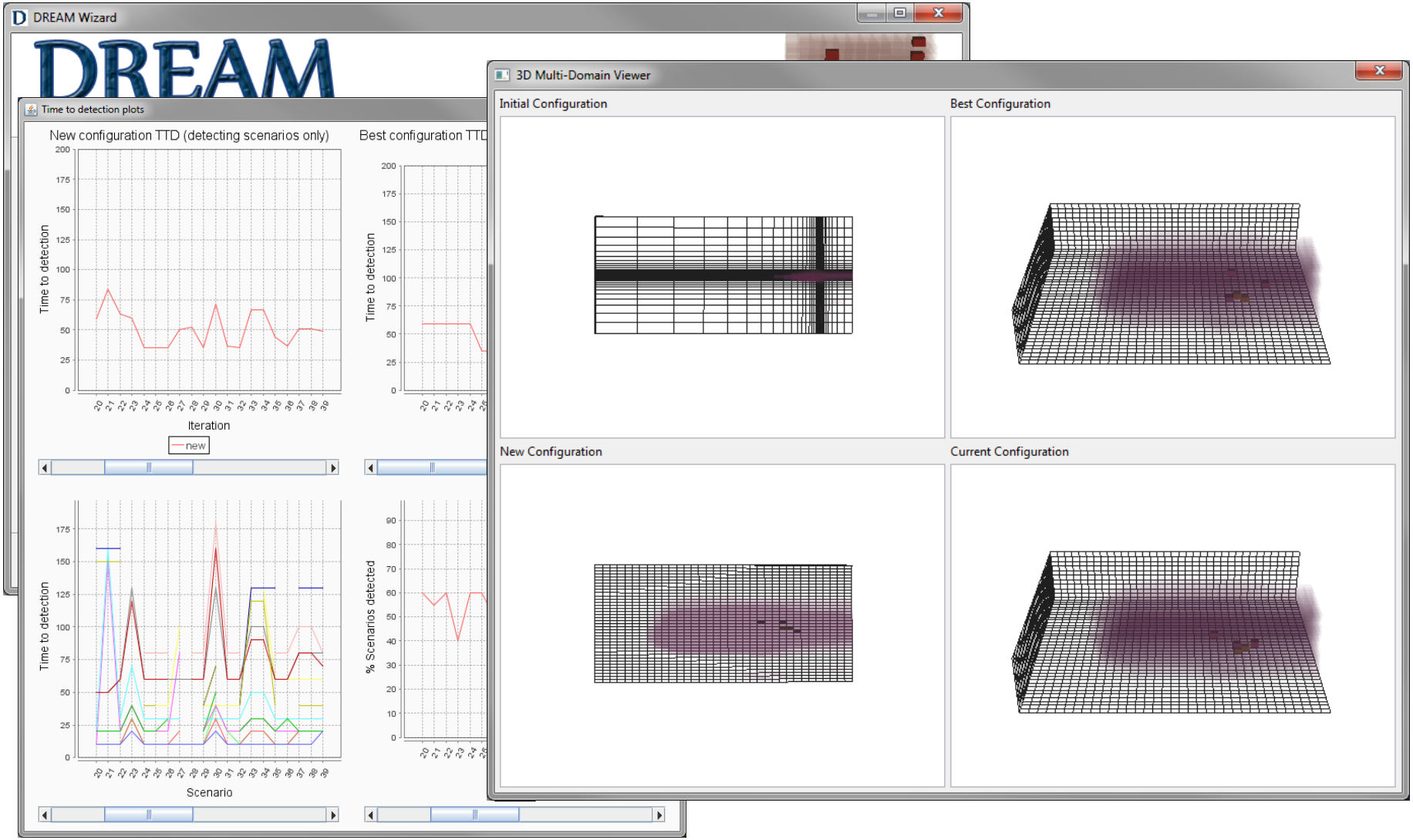
User Interface Workflow: Solution Settings



User Interface Workflow: Solution Settings



User Interface Workflow: Solution Settings



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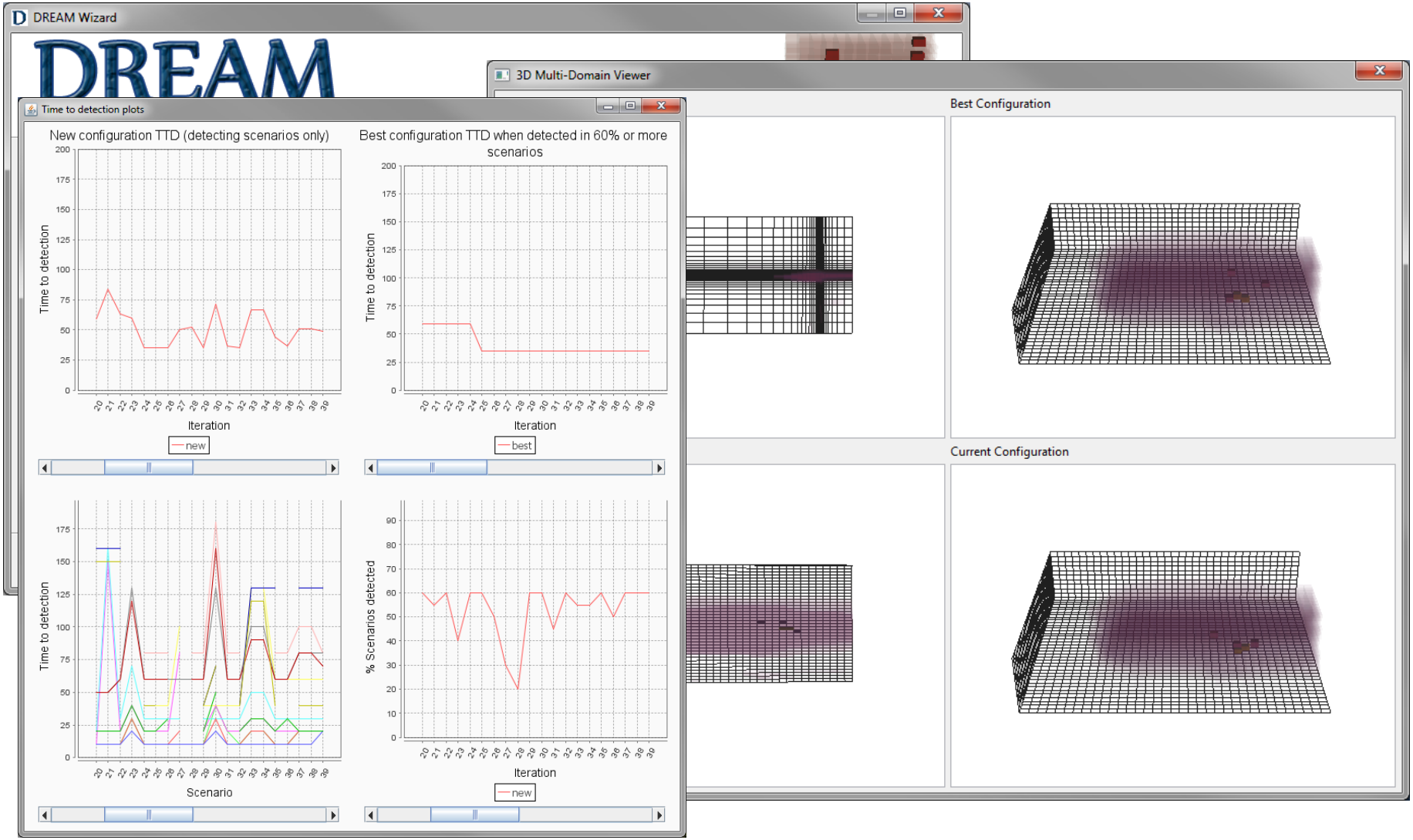
User Interface Workflow: Solution Settings



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User Interface Workflow: Output

DREAMwebinar ▸ _results

Search _results

Organize ▾ Include in library ▾ Share with ▾ Burn New folder

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objective_summary_current.csv	11/9/2015 5:46 PM	Microsoft Excel C...	18 KB
objective_summary_new.csv	11/9/2015 5:46 PM	Microsoft Excel C...	19 KB
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34 items

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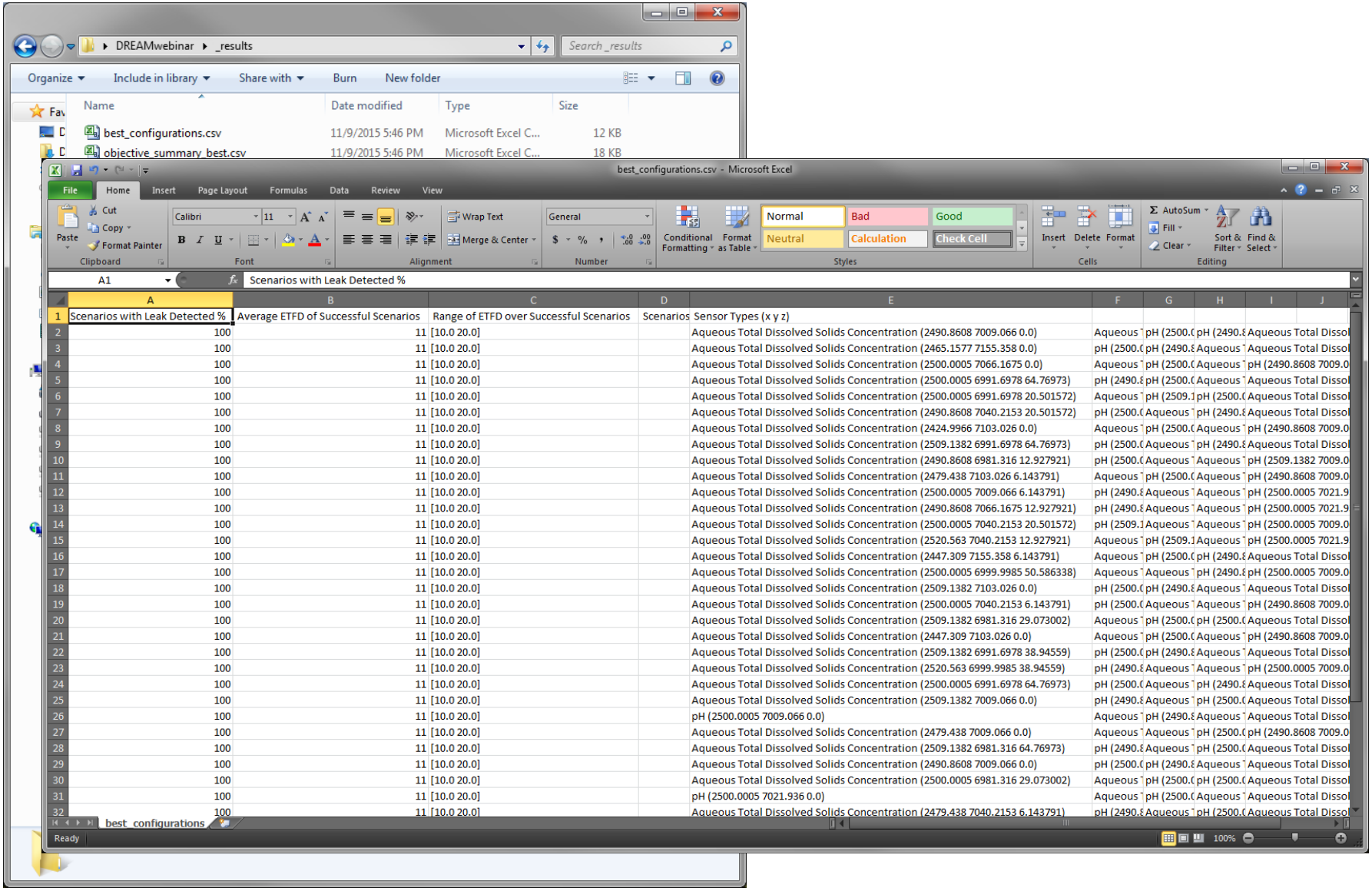
User Interface Workflow: Output



Scenarios with Leak Detected %	Average ETFD of Successful Scenarios	Range of ETFD over Successful Scenarios	Scenarios	Sensor Types (x y z)					
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2490.8608 7009.066 0.0)	Aqueous	pH (2500.(	pH (2490.8	Aqueous	Total Dissol
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2465.1577 7155.358 0.0)	pH (2500.(	pH (2490.8	Aqueous	Aqueous	Total Dissol
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2500.0005 7066.1675 0.0)	Aqueous	pH (2500.(	Aqueous	pH (2490.8608	7009.0
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2500.0005 6991.6978 64.76973)	pH (2490.8	pH (2500.(	Aqueous	Aqueous	Total Dissol
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2500.0005 6991.6978 20.501572)	Aqueous	pH (2509.1	pH (2500.(	Aqueous	Total Dissol
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2490.8608 7040.2153 20.501572)	pH (2500.(	Aqueous	pH (2490.8	Aqueous	Total Dissol
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2424.9966 7103.026 0.0)	Aqueous	pH (2500.(	Aqueous	pH (2490.8608	7009.0
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2509.1382 6991.6978 64.76973)	pH (2500.(	pH (2490.8	Aqueous	Aqueous	Total Dissol
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2490.8608 6981.316 12.927921)	pH (2500.(	Aqueous	Aqueous	pH (2509.1382	7009.0
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2479.438 7103.026 6.143791)	Aqueous	pH (2500.(	Aqueous	pH (2490.8608	7009.0
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2500.0005 7009.066 6.143791)	pH (2490.8	Aqueous	Aqueous	pH (2500.0005	7021.9
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2490.8608 7066.1675 12.927921)	pH (2490.8	Aqueous	Aqueous	pH (2500.0005	7021.9
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2500.0005 7040.2153 20.501572)	pH (2509.1	Aqueous	Aqueous	pH (2500.0005	7009.0
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2520.563 7040.2153 12.927921)	Aqueous	pH (2509.1	Aqueous	pH (2500.0005	7021.9
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2447.309 7155.358 6.143791)	Aqueous	pH (2500.(	pH (2490.8	Aqueous	Total Dissol
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2500.0005 6999.9985 50.586338)	Aqueous	Aqueous	pH (2490.8	pH (2500.0005	7009.0
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2509.1382 7103.026 0.0)	pH (2500.(	pH (2490.8	Aqueous	Aqueous	Total Dissol
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2500.0005 7040.2153 6.143791)	pH (2500.(	Aqueous	Aqueous	pH (2490.8608	7009.0
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2509.1382 6981.316 29.073002)	Aqueous	pH (2500.(	pH (2500.(	Aqueous	Total Dissol
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2447.309 7103.026 0.0)	Aqueous	pH (2500.(	Aqueous	pH (2490.8608	7009.0
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2509.1382 6991.6978 38.94559)	pH (2500.(	pH (2490.8	Aqueous	Aqueous	Total Dissol
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2520.563 6999.9985 38.94559)	pH (2490.8	Aqueous	Aqueous	pH (2500.0005	7009.0
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2500.0005 6991.6978 64.76973)	pH (2500.(	Aqueous	pH (2490.8	Aqueous	Total Dissol
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2509.1382 7009.066 0.0)	pH (2490.8	Aqueous	pH (2500.(	Aqueous	Total Dissol
100	11	[10.0 20.0]		pH (2500.0005 7009.066 0.0)	Aqueous	pH (2490.8	Aqueous	Aqueous	Total Dissol
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2479.438 7009.066 0.0)	Aqueous	Aqueous	pH (2500.(	pH (2490.8608	7009.0
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2509.1382 6981.316 64.76973)	pH (2490.8	Aqueous	pH (2500.(	Aqueous	Total Dissol
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2490.8608 7009.066 0.0)	pH (2500.(	pH (2490.8	Aqueous	Aqueous	Total Dissol
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2500.0005 6981.316 29.073002)	Aqueous	pH (2500.(	pH (2500.(	Aqueous	Total Dissol
100	11	[10.0 20.0]		pH (2500.0005 7021.936 0.0)	Aqueous	pH (2500.(	Aqueous	Aqueous	Total Dissol
100	11	[10.0 20.0]		Aqueous Total Dissolved Solids Concentration (2479.438 7040.2153 6.143791)	pH (2490.8	Aqueous	pH (2500.(	Aqueous	Total Dissol

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User Interface Workflow: Output

DREAMwebinar ▸ _results

Search _results

Organize ▾ Include in library ▾ Share with ▾ Burn New folder

Name	Date modified	Type	Size
best_configurations.csv	11/9/2015 5:46 PM	Microsoft Excel C...	12 KB
objective_summary_best.csv	11/9/2015 5:46 PM	Microsoft Excel C...	18 KB
objective_summary_current.csv	11/9/2015 5:46 PM	Microsoft Excel C...	18 KB
objective_summary_new.csv	11/9/2015 5:46 PM	Microsoft Excel C...	19 KB
run_0_best.csv	11/9/2015 5:43 PM	Microsoft Excel C...	159 KB
run_0_current.csv	11/9/2015 5:43 PM	Microsoft Excel C...	167 KB
run_0_new.csv	11/9/2015 5:43 PM	Microsoft Excel C...	168 KB
run_1_best.csv	11/9/2015 5:43 PM	Microsoft Excel C...	180 KB
run_1_current.csv	11/9/2015 5:43 PM	Microsoft Excel C...	189 KB
run_1_new.csv	11/9/2015 5:43 PM	Microsoft Excel C...	188 KB
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run_4_new.csv	11/9/2015 5:43 PM	Microsoft Excel C...	173 KB
run_5_best.csv	11/9/2015 5:43 PM	Microsoft Excel C...	165 KB
run_5_current.csv	11/9/2015 5:43 PM	Microsoft Excel C...	162 KB
run_5_new.csv	11/9/2015 5:43 PM	Microsoft Excel C...	163 KB
run_6_best.csv	11/9/2015 5:43 PM	Microsoft Excel C...	151 KB
run_6_current.csv	11/9/2015 5:43 PM	Microsoft Excel C...	152 KB
run_6_new.csv	11/9/2015 5:43 PM	Microsoft Excel C...	152 KB
run_7_best.csv	11/9/2015 5:43 PM	Microsoft Excel C...	156 KB
run_7_current.csv	11/9/2015 5:43 PM	Microsoft Excel C...	165 KB
run_7_new.csv	11/9/2015 5:43 PM	Microsoft Excel C...	165 KB
run_8_best.csv	11/9/2015 5:43 PM	Microsoft Excel C...	166 KB
run_8_current.csv	11/9/2015 5:43 PM	Microsoft Excel C...	168 KB
run_8_new.csv	11/9/2015 5:43 PM	Microsoft Excel C...	169 KB
run_9_best.csv	11/9/2015 5:46 PM	Microsoft Excel C...	171 KB
run_9_current.csv	11/9/2015 5:46 PM	Microsoft Excel C...	173 KB
run_9_new.csv	11/9/2015 5:46 PM	Microsoft Excel C...	174 KB

34 items

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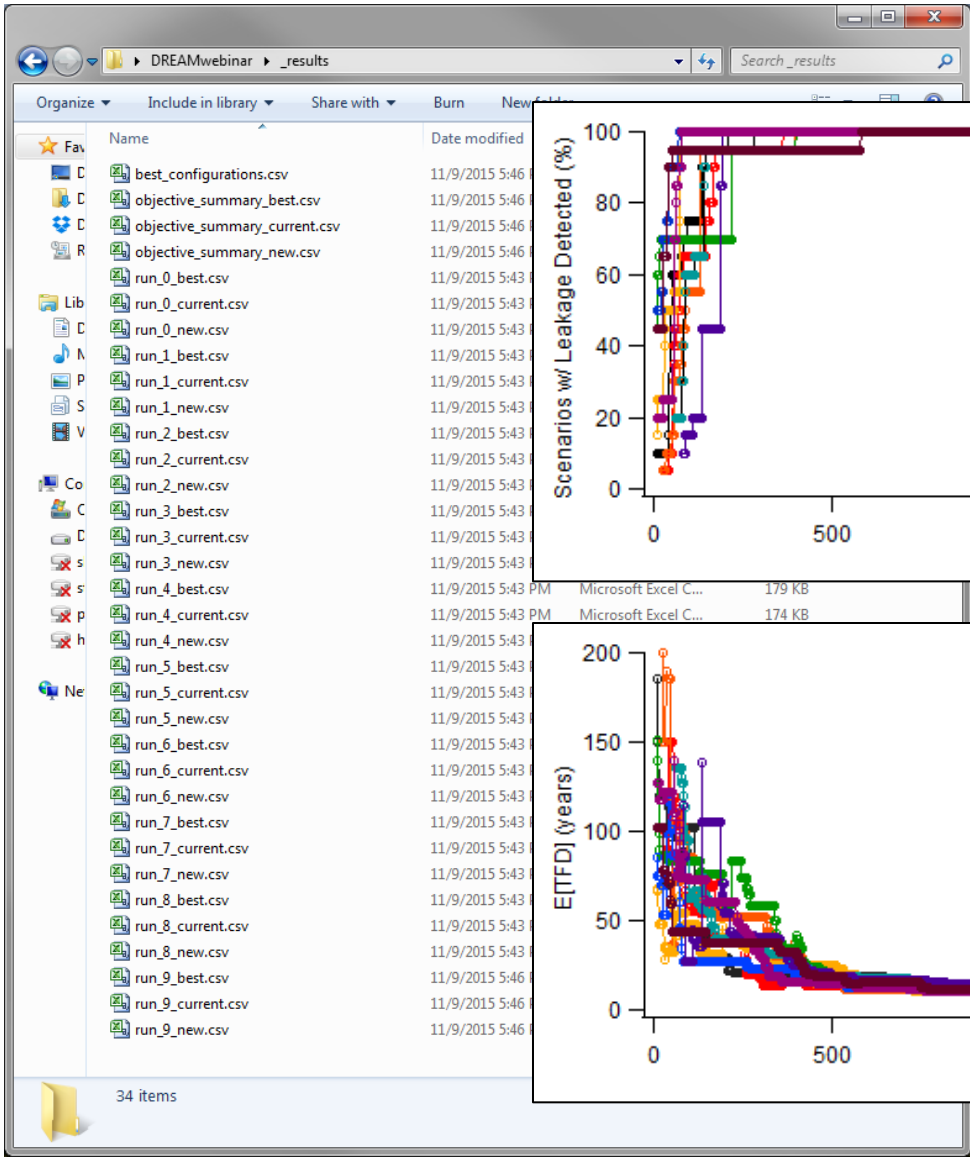
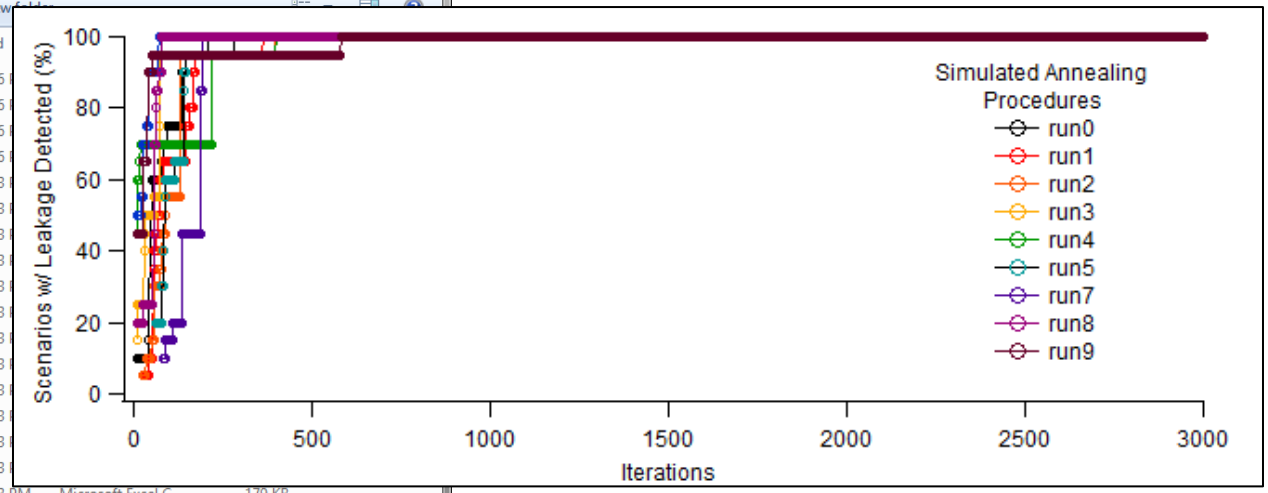
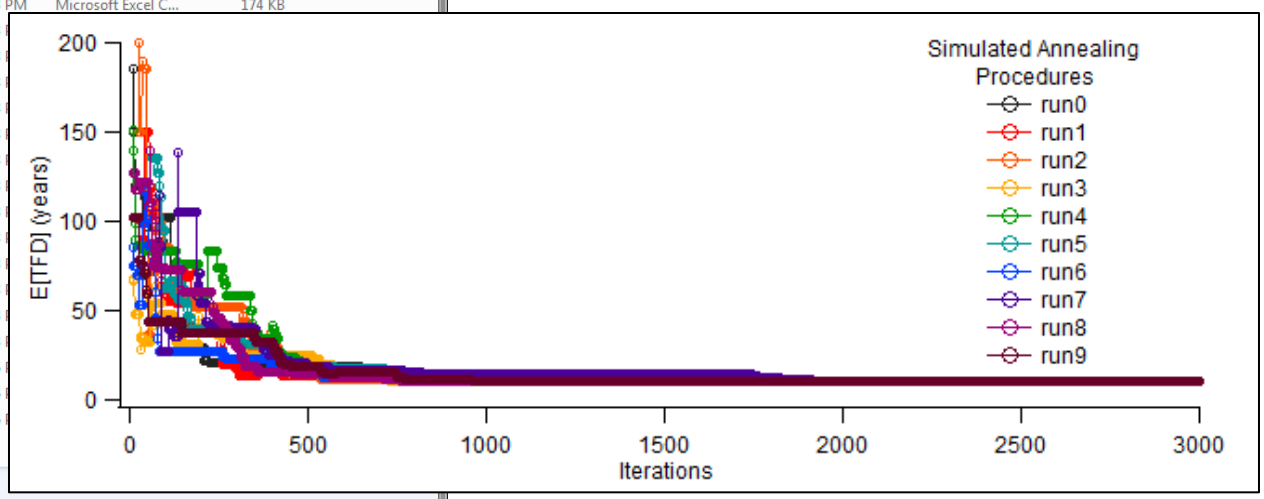
User Interface Workflow: Output







Path Forward and QA/QC

Development Stage

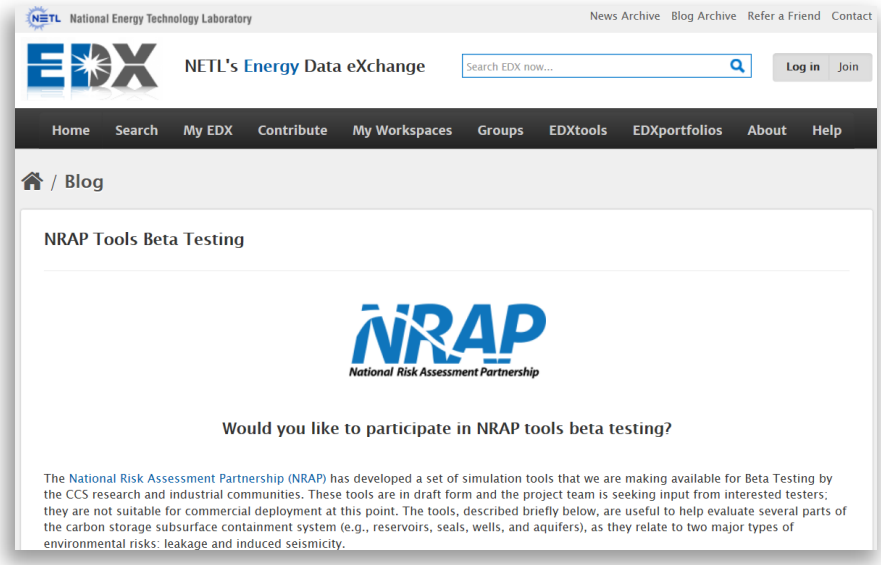
- Decision support to rank identified configurations
- Merge “like” configurations, where sensor locations and types are neighbors

Quality Assurance

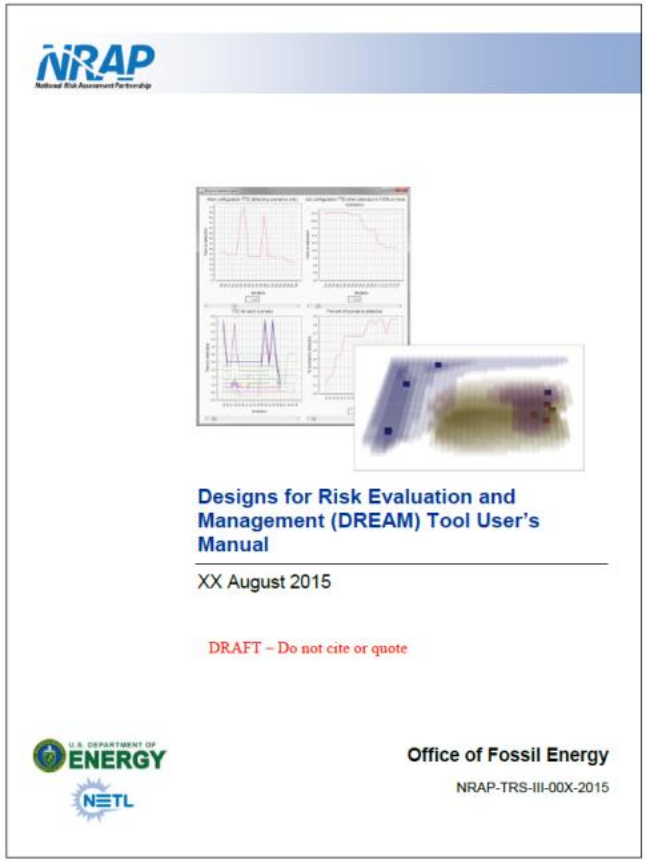
- Lack of real-world data to verify/validate against
- Internal and external reviews of DREAM application problems

Beta Tool and User Manual Available on EDX

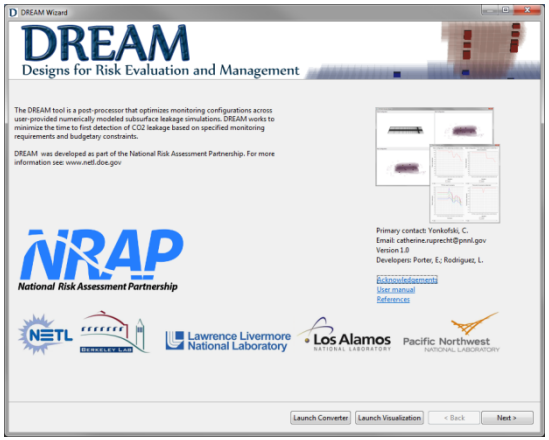
NRAP Tool Beta-Testing Portal



DREAM tool User's Manual



DREAM tool for PC and Mac



www.edx.netl.doe.gov/nrap → TOOL BETA TESTING link

Related Articles

Special Issue

Yonkofski, C.R., Gastelum, J.A., Porter, E.A., Rodriguez, L.R., Bacon, D.H., and Brown, C.F., 2015. An Optimization Approach to Design Monitoring Schemes for CO2 Leakage Detection. IJGGC NRAP Special Issue. In Review.

Thresholds

Last, G.V., Murray, C.J., Brown, C.F., Jordan,P.D., Sharma, M., 2013. No-Impact Threshold Values for NRAP's Reduced Order Models. Pacific Northwest National Laboratory. PNNL-22077. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22077.pdf

Example

Hou, Z., Bacon, D. H., Engel, D. W., Lin, G. , Fang, Y. , Ren, H. , Fang, Z. 2014. Uncertainty analyses of CO2 plume expansion subsequent to wellbore CO2 leakage into aquifers. International Journal of Greenhouse Gas Control. 27: 69-80.

Schedule for NRAP Tool Webinar Series

Date/ Time	Tool	Presenter(s)
October 13 **Time: 1pm ET**	Integrated Assessment Model–Carbon Storage (NRAP-IAM-CS) (2.5 hours)	Rajesh Pawar
October 19 **Time: 1pm ET**	Natural Seal ROM (NSealR) (1 hour)	Nicolas Huerta, Ernest Lindner
October 26 **Time: 1pm ET**	Reservoir Evaluation and Visualization (REV) Tool (1 hour)	Seth King
November 2 **Time: 1pm ET**	Wellbore Leakage Analysis Tool (WLAT) (1.5 hour)	Nicholas Huerta
November 9 **Time: 1pm ET**	Aquifer Impact Model (AIM) (1.5 hour)	Diana Bacon
November 16 **Time: 1pm ET**	Design for Risk Evaluation and Monitoring (DREAM) (1 hour)	Catherine Ruprecht Yonkofski
November 30 **Time: 1pm ET**	Short Term Seismic Forecasting (STSF) (1 hour)	Josh White, Corinne Bachman
December 7 **Time: 1pm ET**	TBD	

Check for updates at www.edx.netl.doe.gov/nrap

Questions?

Designs for Risk Evaluation and Management (DREAM) tool

Questions/comments not addressed during the scheduled meeting time can be addressed to NRAP@netl.doe.gov

Acknowledgements

This technical effort was performed in support of the National Energy Technology Laboratory's research under the RES contract DE-FE-0004000.

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Support Slides

Simulated annealing algorithm pseudo-code

```
Set x_b = x_c = x_n = x_i
Set k = 1
Set T = 100
While (k ≤ the total number of iterations to be performed)
        If Z(x_n) < Z(x_c) then
                Set x_c = x_n
                If Z(x_c) ≤ Z(x_b)
                        Set x_b = x_c
        Else
                T = T * 0.99
                Set r = U(0,1)
                If r ≤ e^(-(Z(x_n) - Z(x_c))/T)
                        Set x_c = x_n
        Set x_n to be a mutation of x_c
        k = k + 1
End while
Return x_b
```

Support Slides

```
For each time step t in realization ω
        For each sensor s in configuration x
                If simulated value at location of s
exceeds alarm signature of s
                        s_alarm = true
        Next s
        If inference signature is satisfied by x

                Return t
Next t
Return 1,000,000
```

Inference model pseudo-code to calculate time to first detection for a specified configuration.