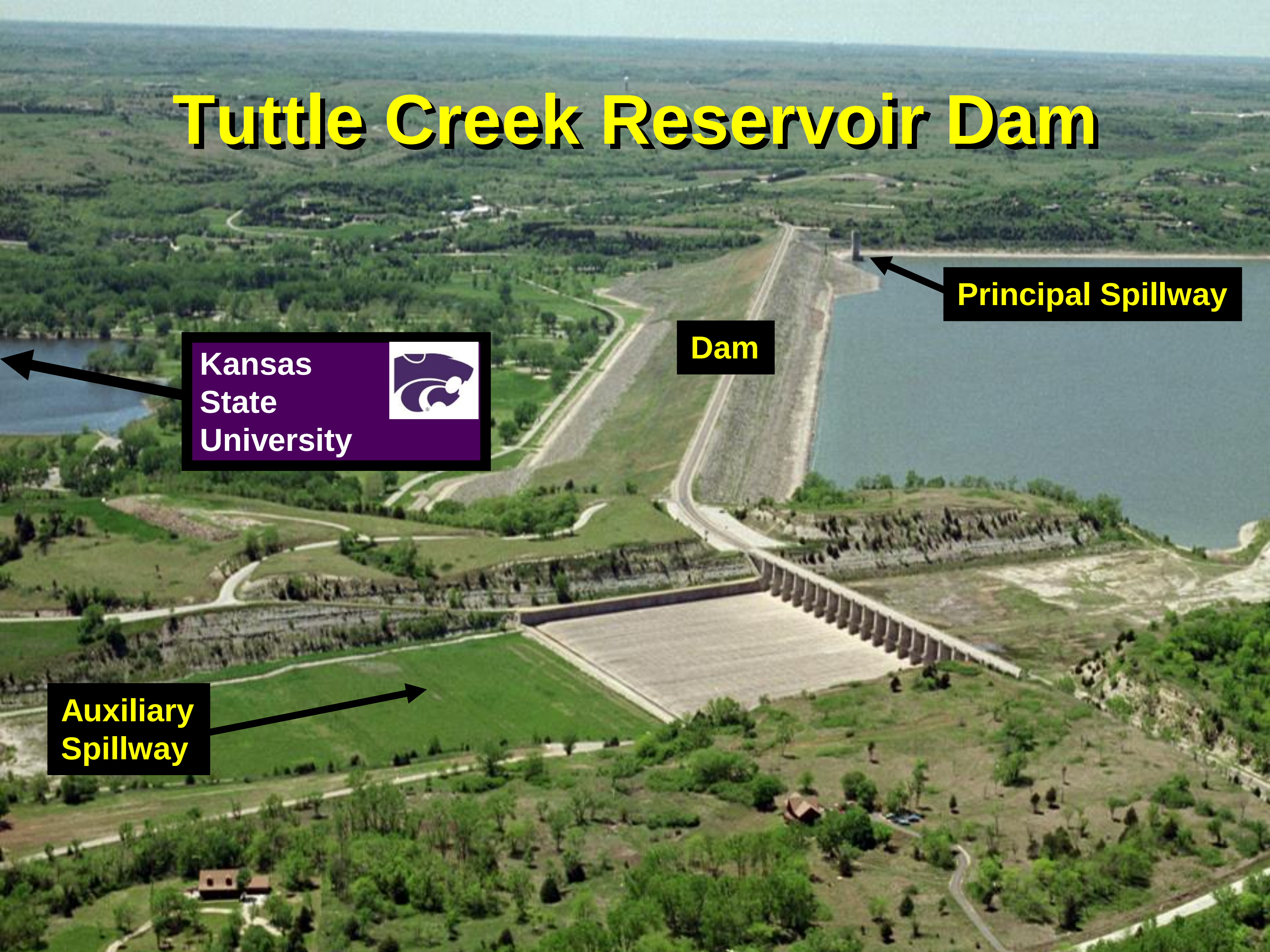
Sensitivity Analysis of Internal Erosion Models for Dam Safety

Mitchell Neilsen, Chendi Cao

Department of Computer Science
Kansas State University
Manhattan, KS, USA

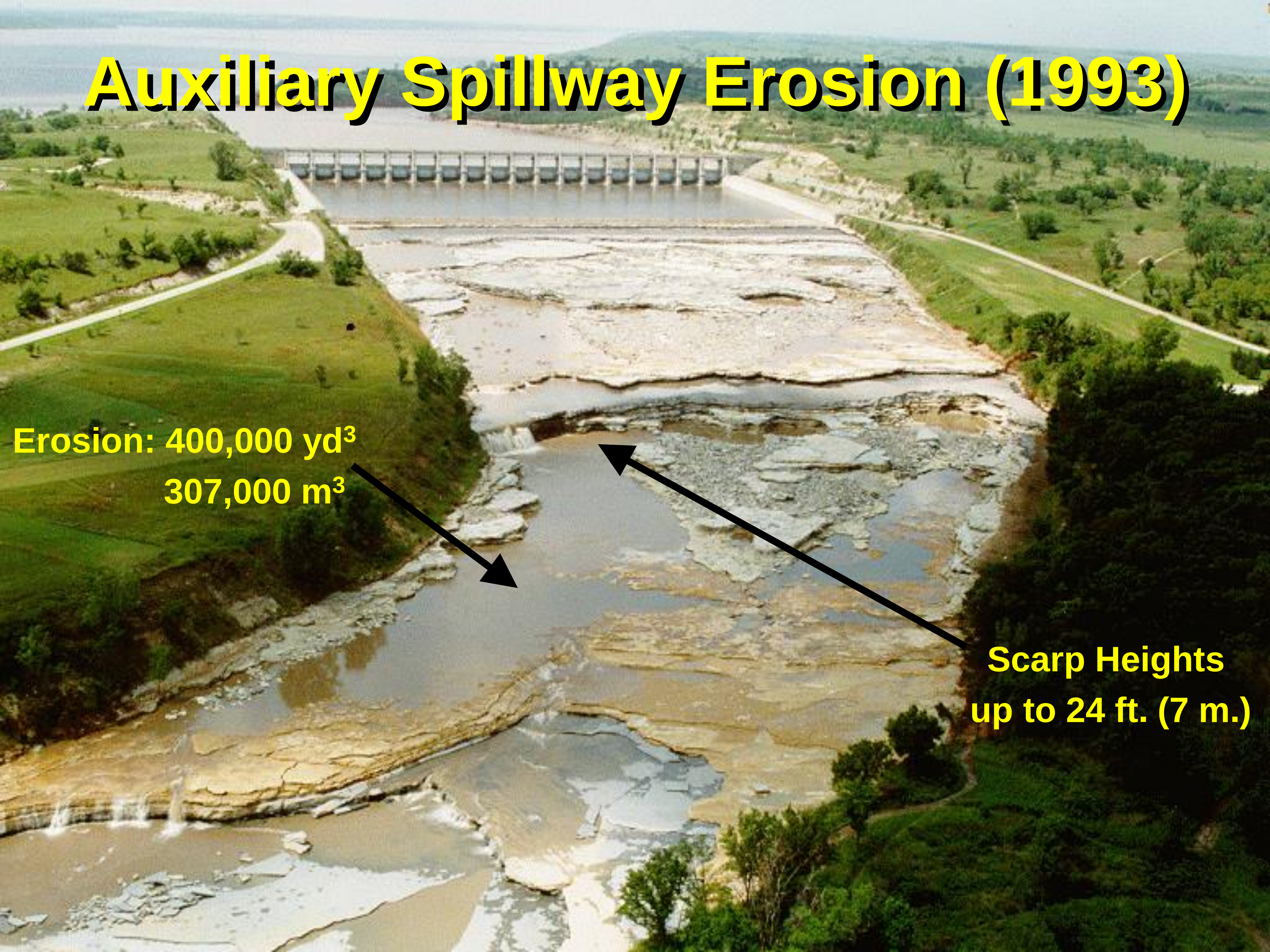
{ neilsen@ksu.edu, caocd@ksu.edu }

Tuttle Creek Reservoir Dam



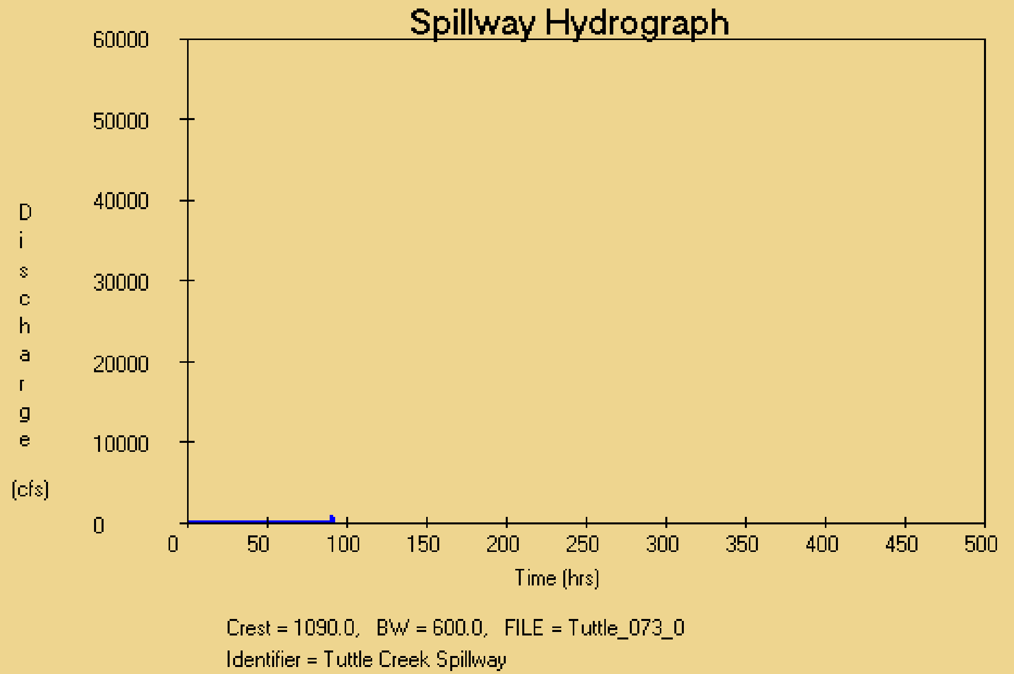
Auxiliary Spillway Discharge (1993)

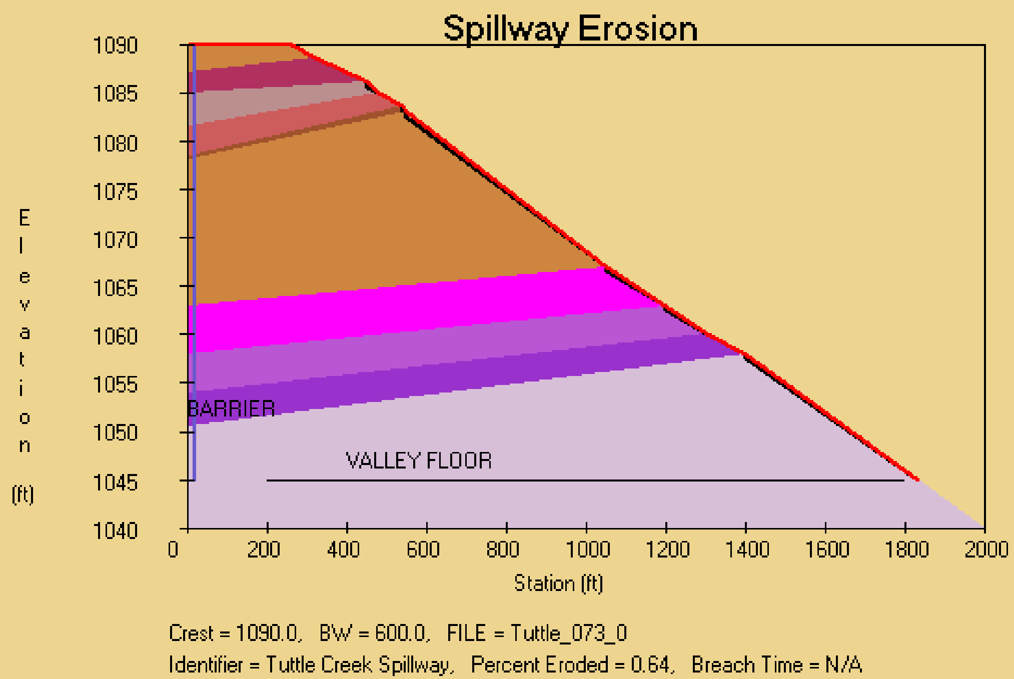
- **Peak Flow: 60,000 cfs = 1,700 cms**
- **Duration: 21 days**


Auxiliary Spillway Erosion (1993)
Erosion: 400,000 yd^3
307,000 m^3
Scarp Heights
up to 24 ft. (7 m.)

Example:

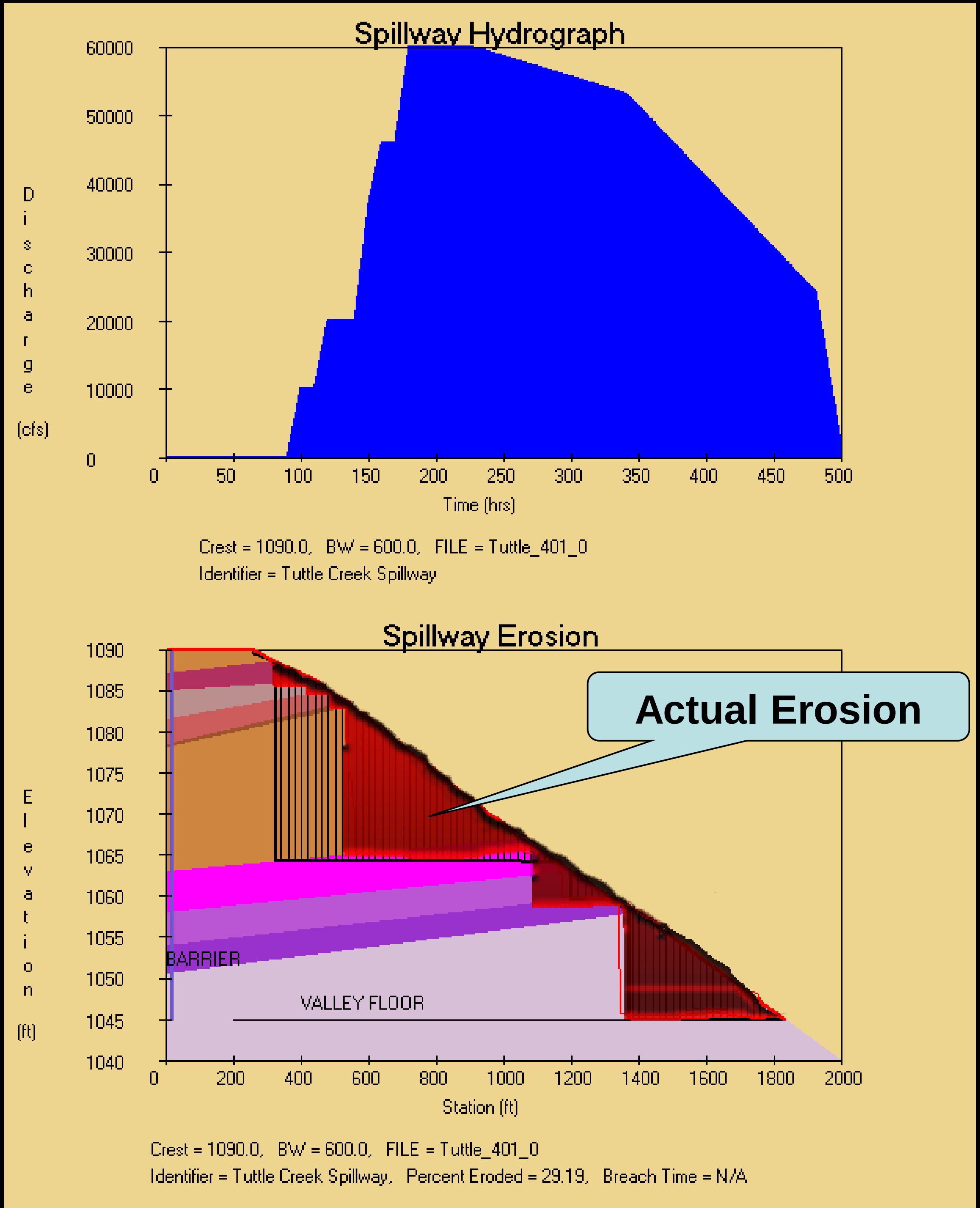
Tuttle Creek Spillway





Example:

Tuttle Creek Spillway



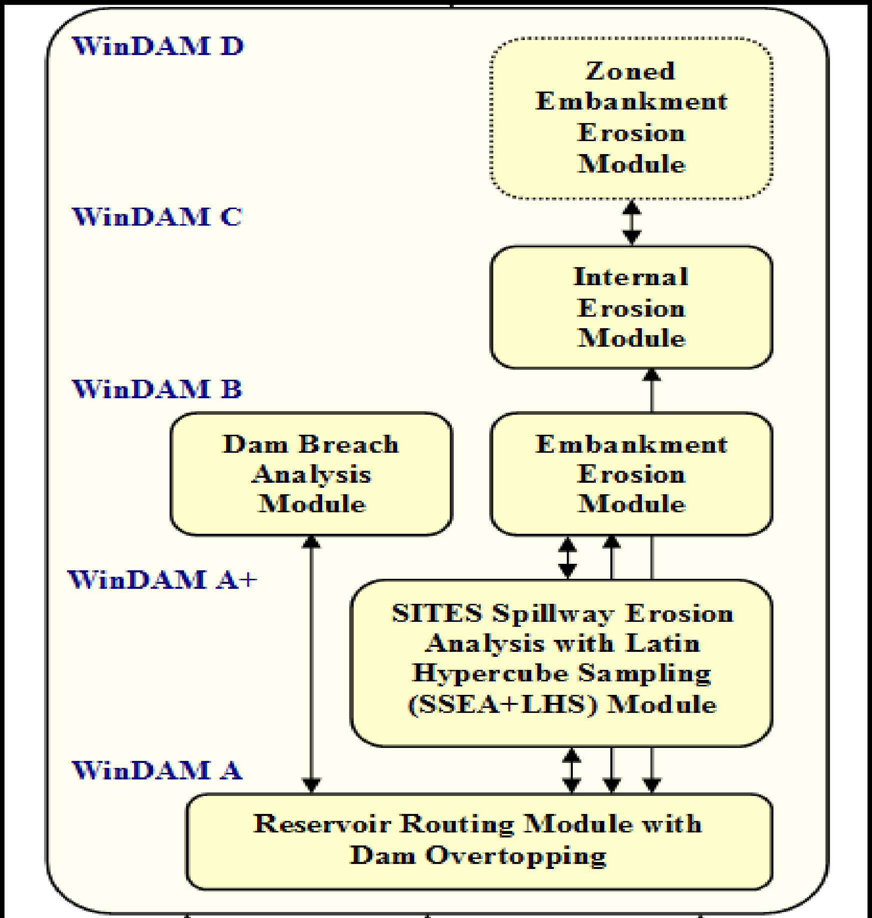
Causes of Dam Failures

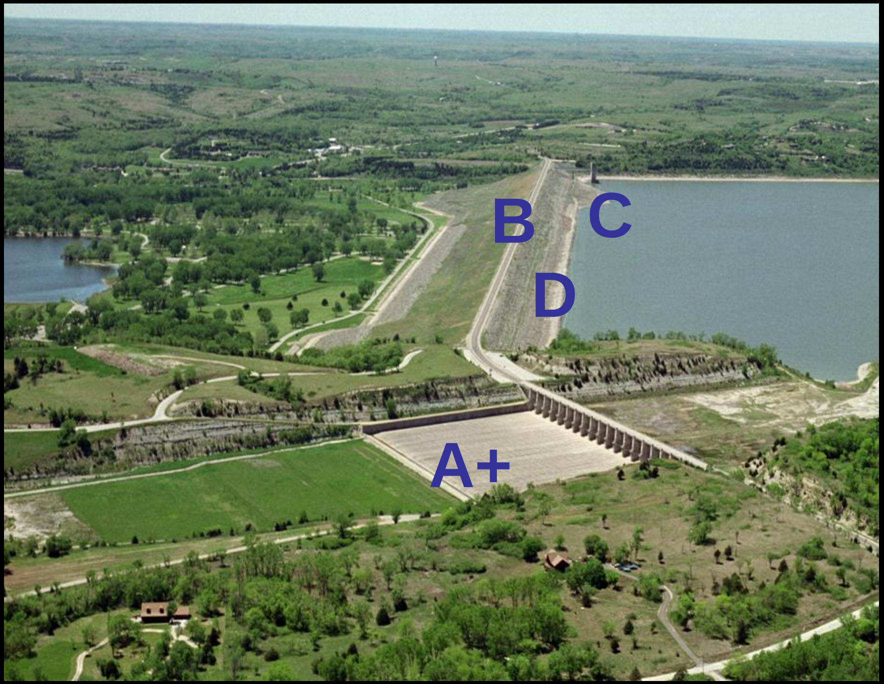
Causes of Dam Failures*	Percentage
Dam overtopping and auxiliary spillway failure	23 – 52%
Piping/seepage/internal erosion	25 – 44%
Slides	2 – 15%
Miscellaneous	9 – 40%

* V. Singh, “Dam breach modeling technology”, 1993.

Windows* Dam Analysis Modules (WinDAM)

WinDAM is a modular framework for the design and analysis of water control structures (dams).





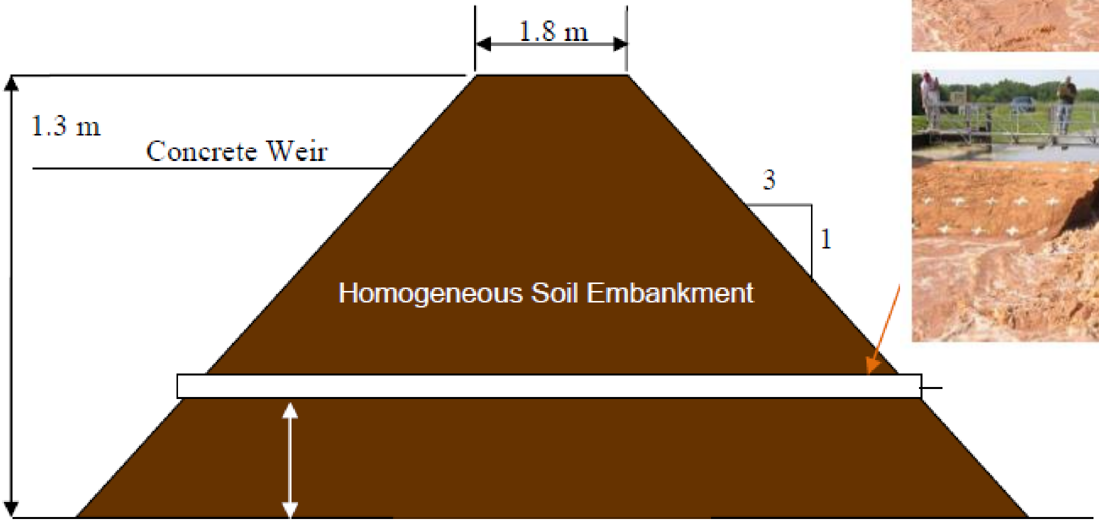
Weir Upstream of Test Embankment

USDA Hydraulic Engineering Research Unit (HERU)

Dam Overtopping Breach Analysis

Dam Overtopping Breach Analysis

Internal Erosion Analysis
(weak silty sand material - SM)

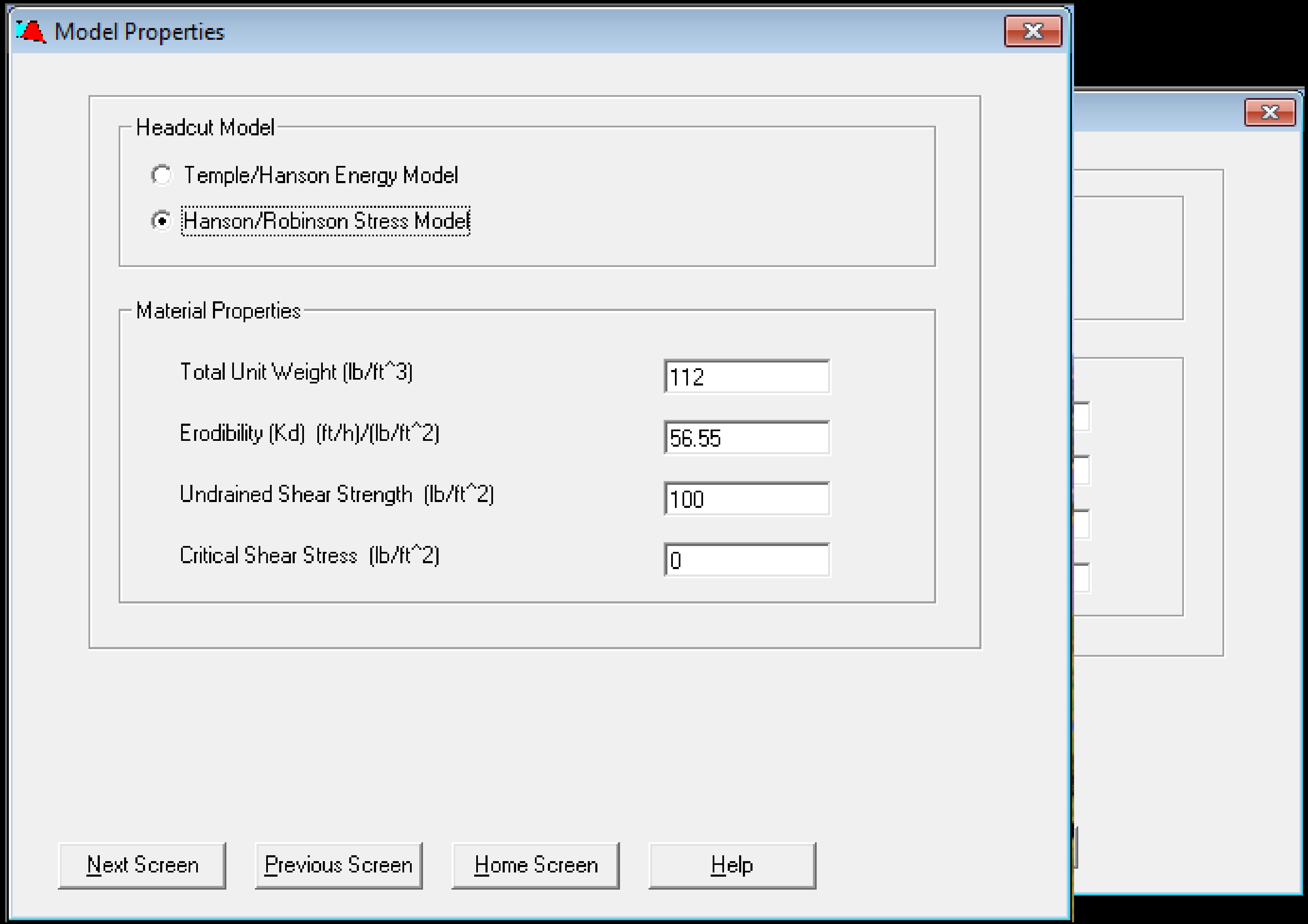


e) 13 min., f) 60 minutes.

$\tau \gg \tau_c$ Rapid Internal Erosion

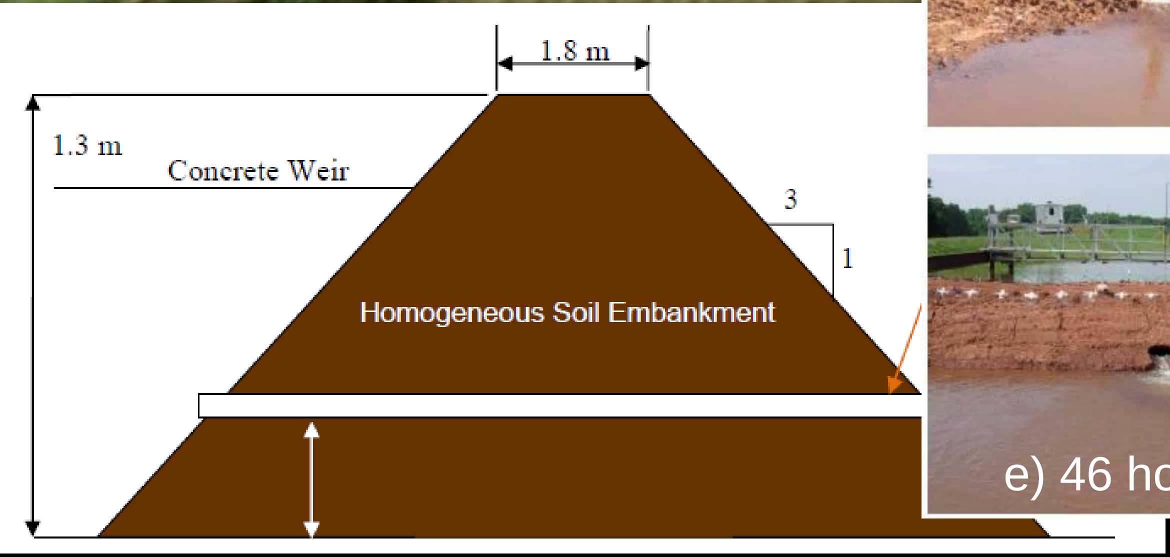
k_d ~ 57 (ft/hr)/psf
τ_c ~ 0 psf

WinDAM Headcut Model Input



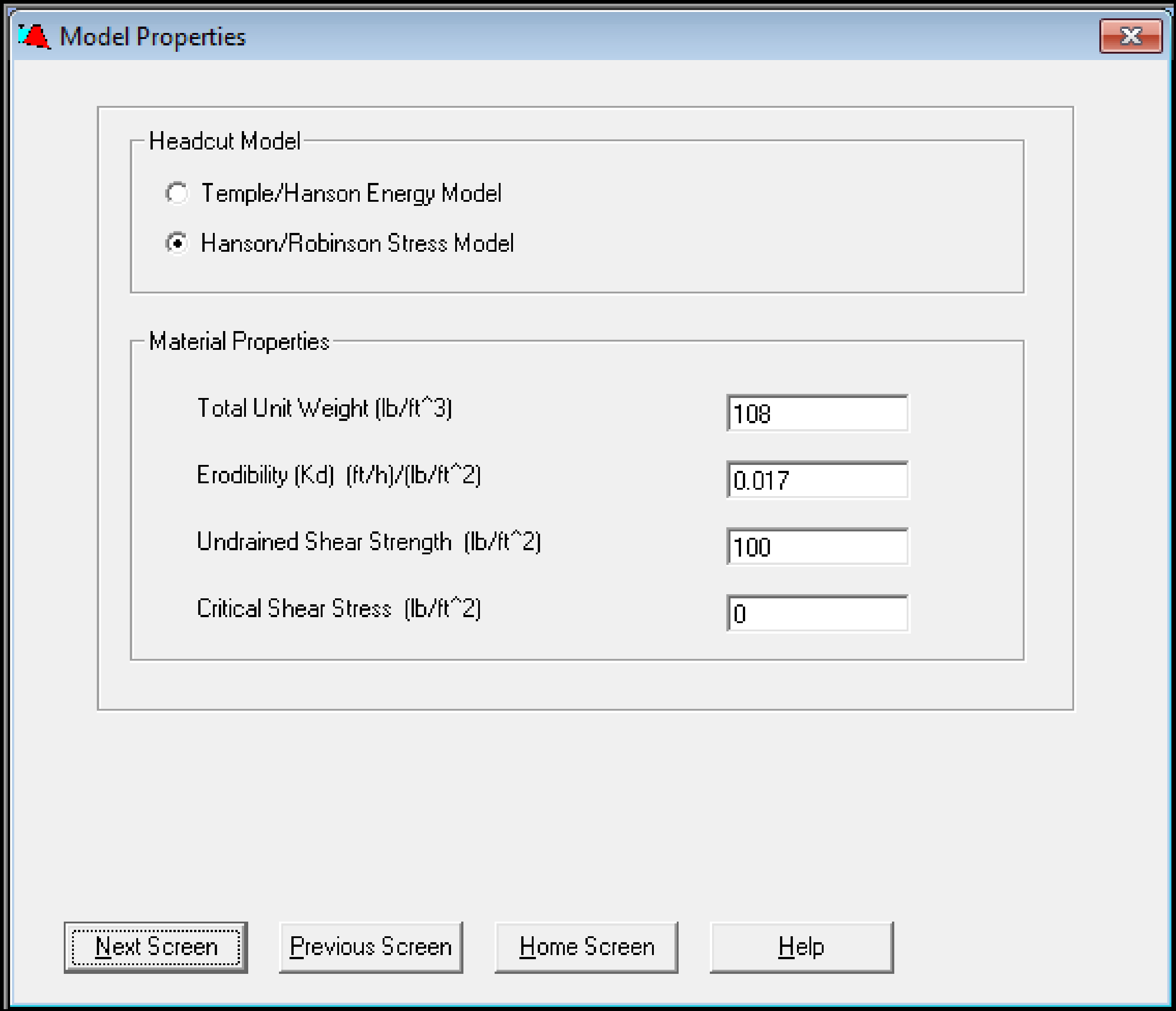
Silty sand (SM) material properties

Internal Erosion Analysis
(stronger clay material - CL)



$\tau \sim \tau_c$ Negligible Internal Erosion

WinDAM Headcut Model Input



Clay (CL) material properties

JET Field test for k_d

- Submerged jet from known orifice diameter
- Measured height above bare soil
- Erosion is measured over time→ $\mathbf{k_d}$

JET Lab Samples

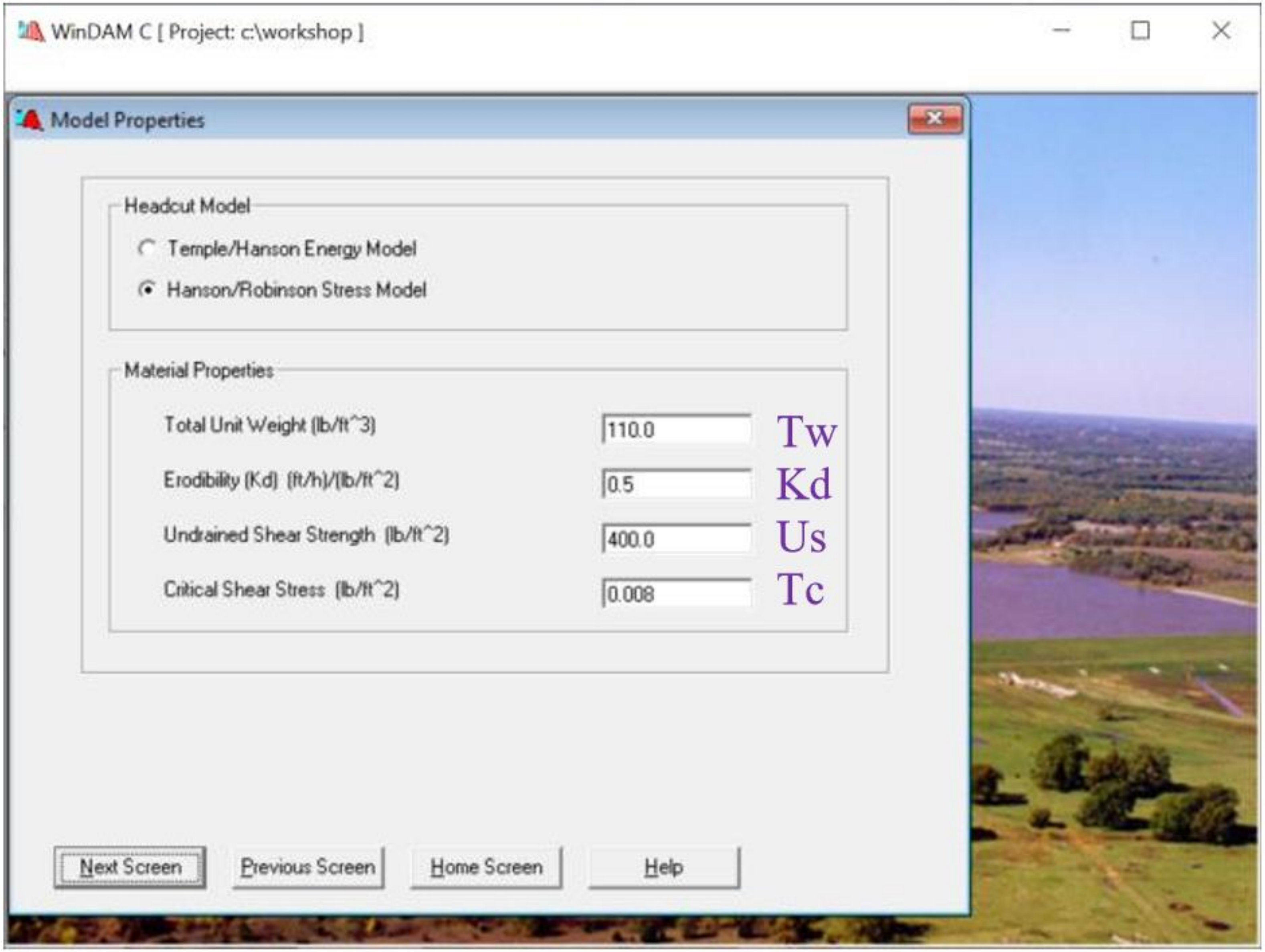
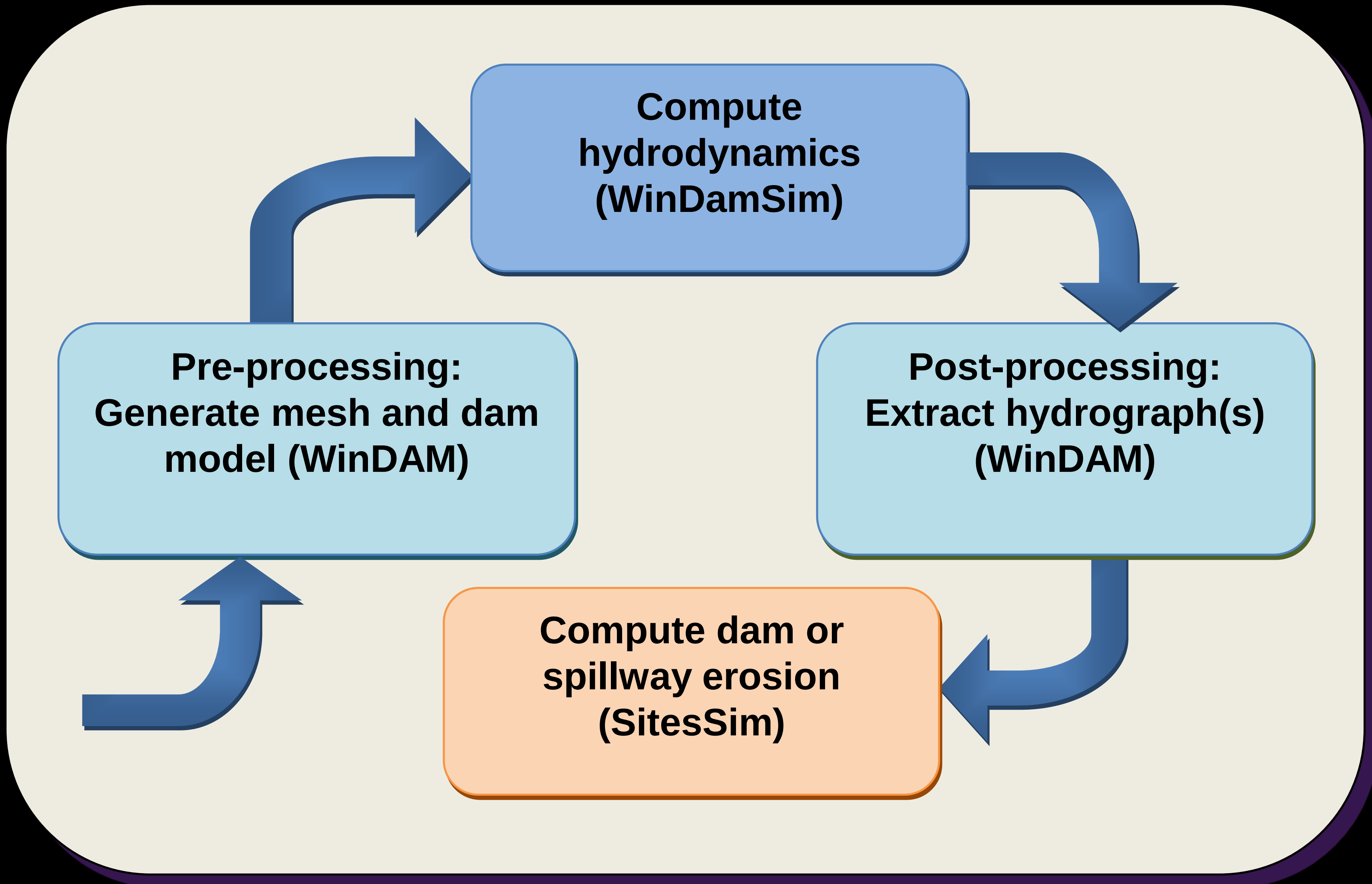


Figure 3. Breach model input

WinDAM Computational Model



Internal Erosion Flow Conditions

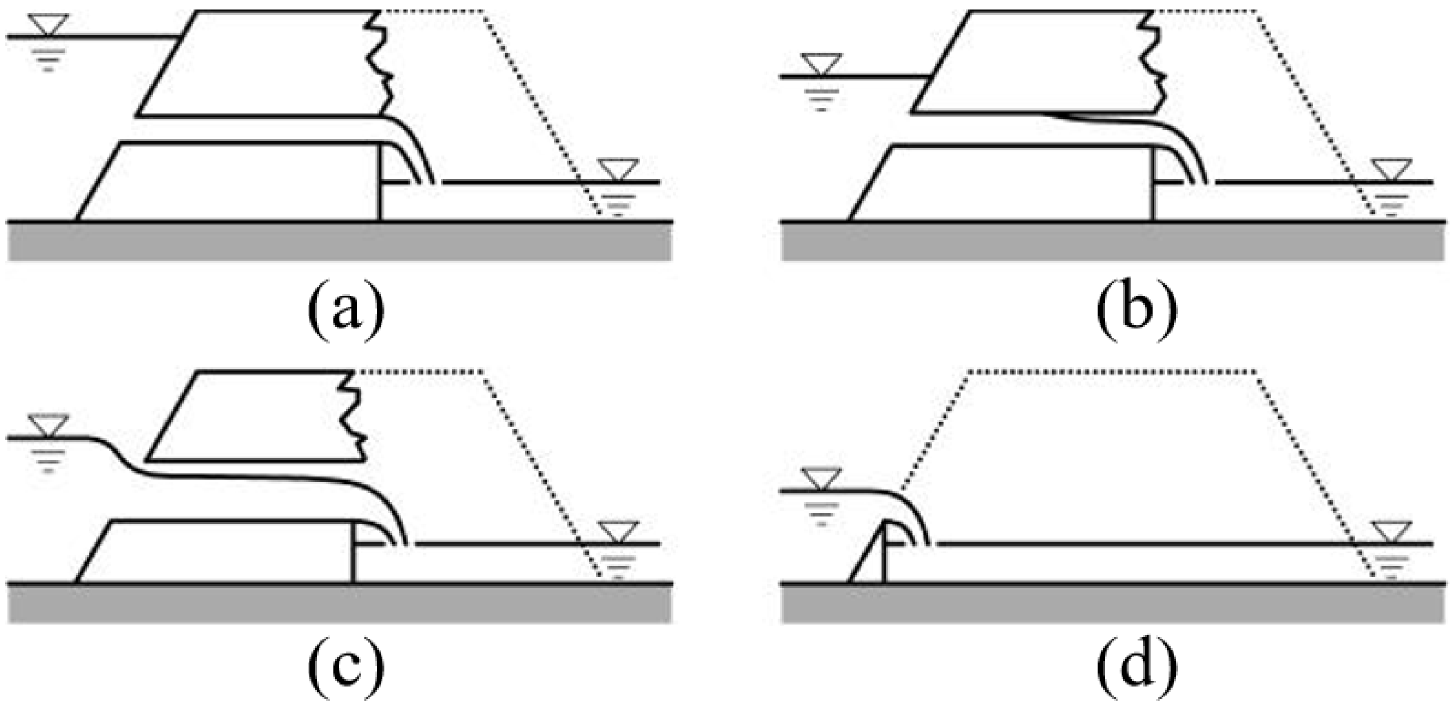
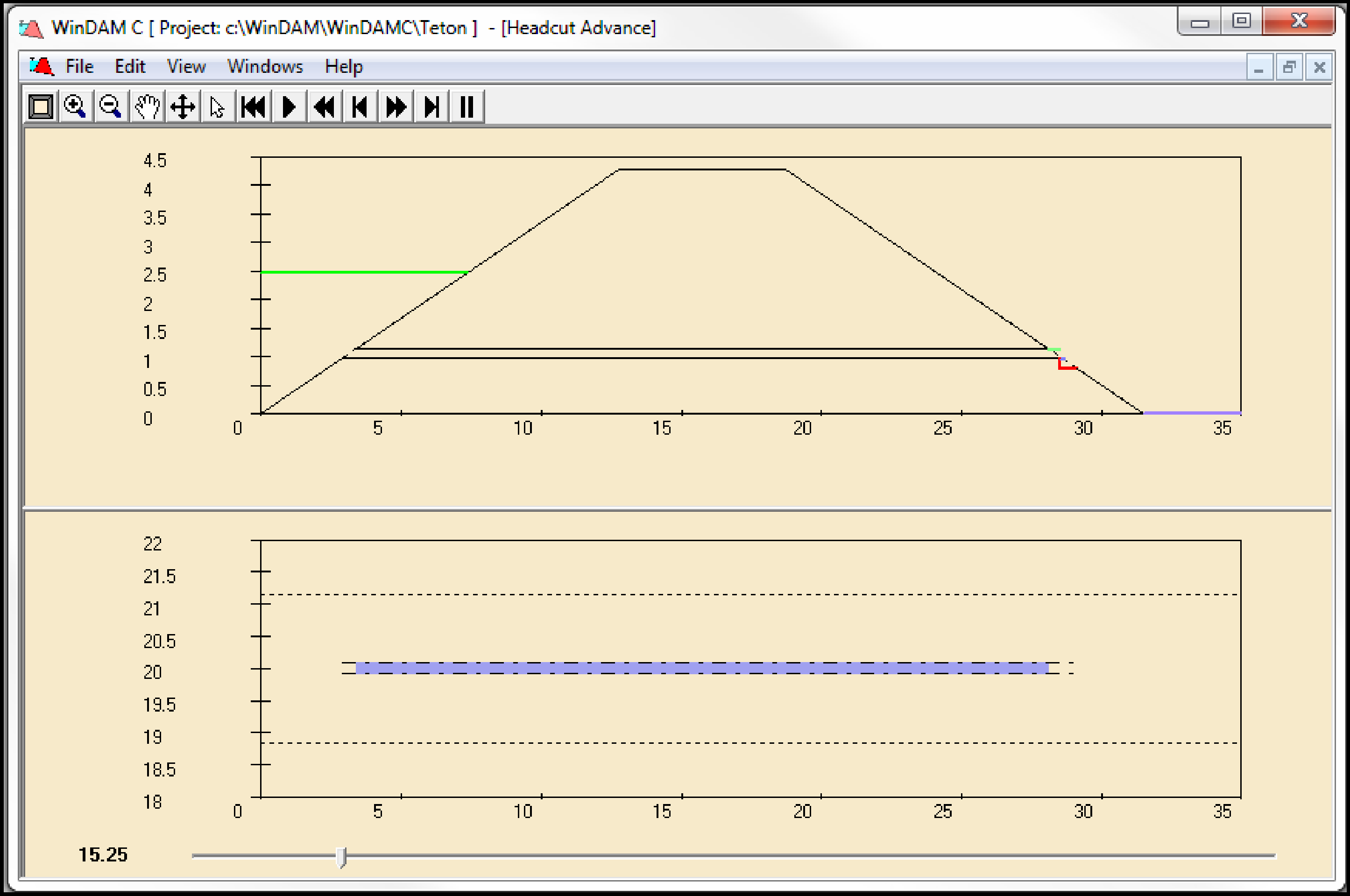
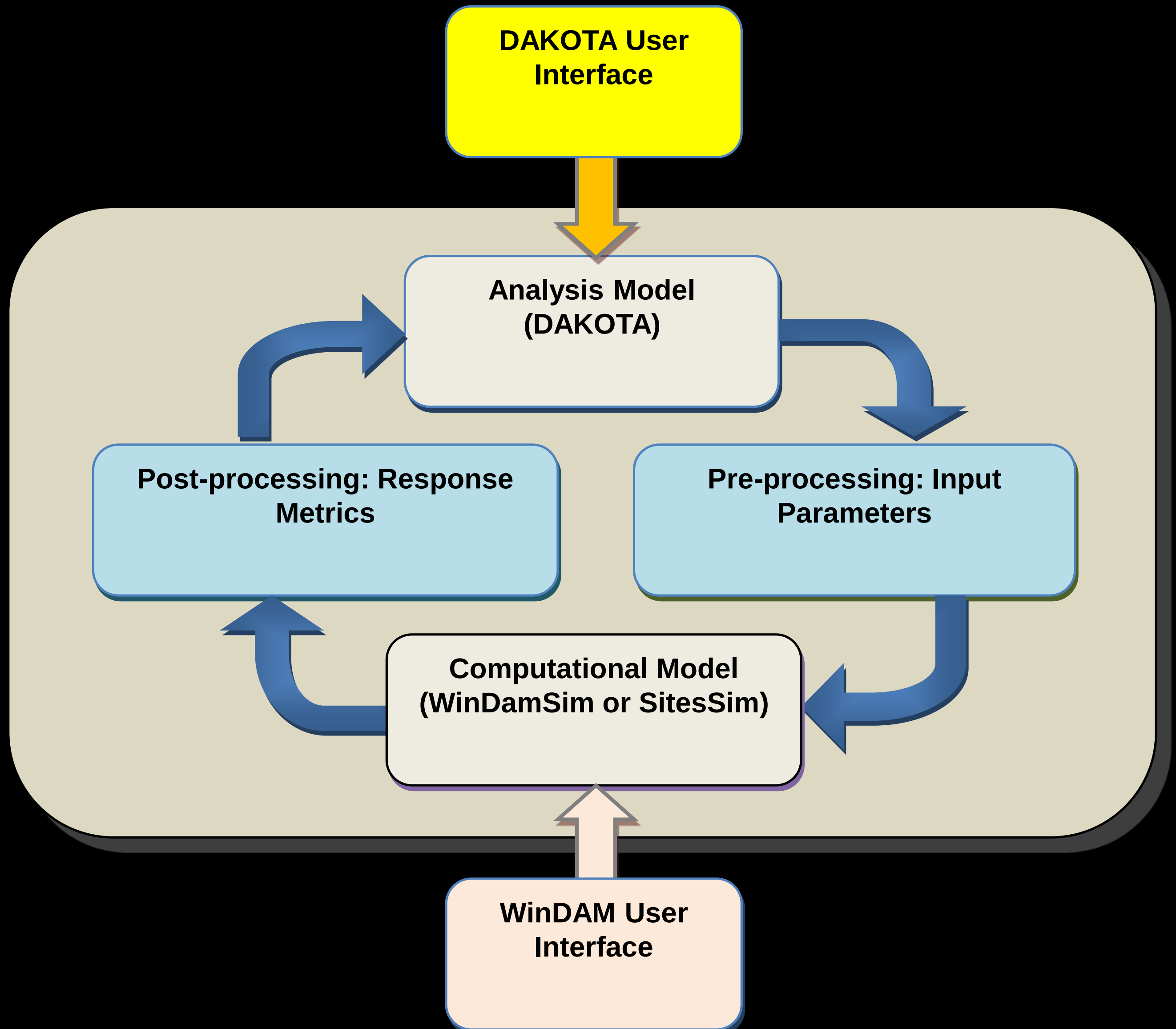


Figure 6. Internal erosion flow conditions

WinDAM Output



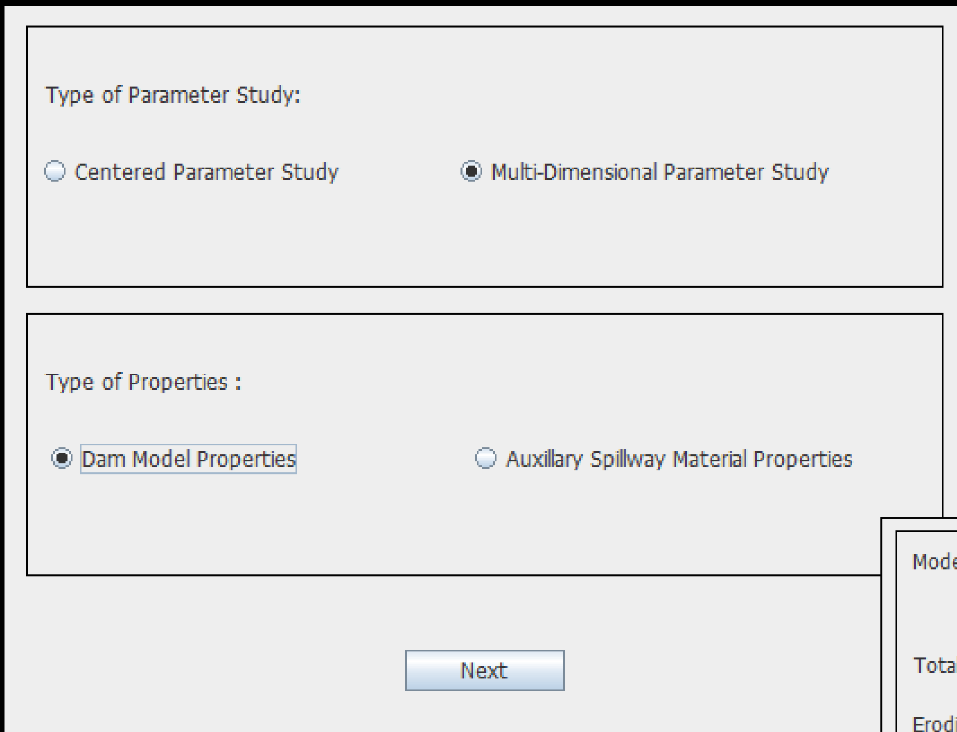
Using DAKOTA to drive the Analysis

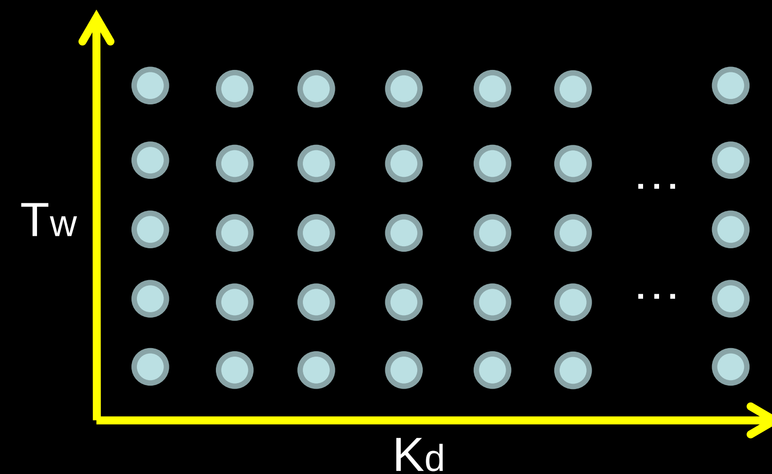


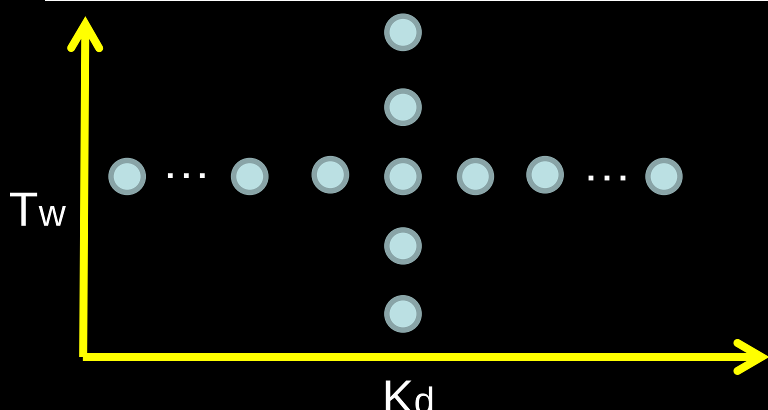
DAKOTA

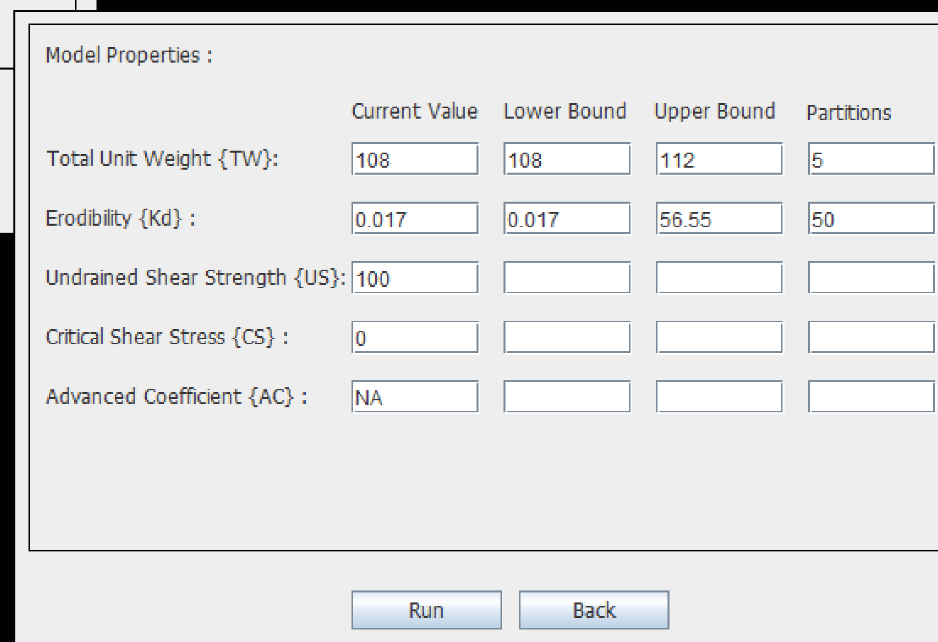
- **DAKOTA:** **D**esign and **A**nalysis too**K**it for **O**ptimization and **T**erascale **A**pplications - by Sandia National Laboratories
- DAKOTA adds value to simulation-based analysis:
  - Sensitivity - which input parameters affect performance metrics?
  - Uncertainty (quantification) - how safe, reliable, robust or variable is the system?
  - Optimization - which design performs best?
  - Calibration - which models and parameters best match empirical data?
  - Parameter studies - vary input, how does output change?
- All require iterative analysis with the computational model.

DAKOTA User Interface
(for parameter studies)







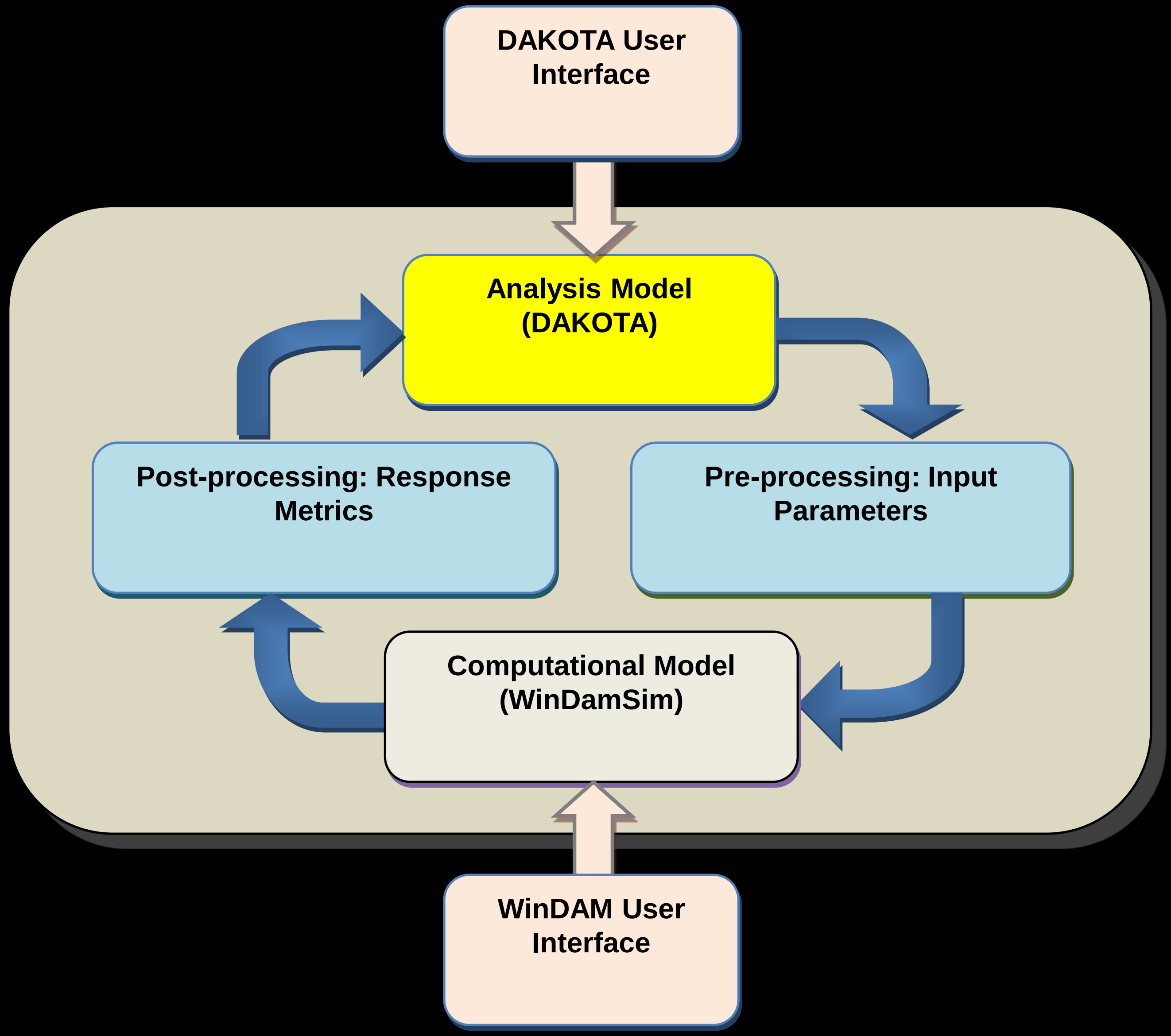


DAKOTA Input File

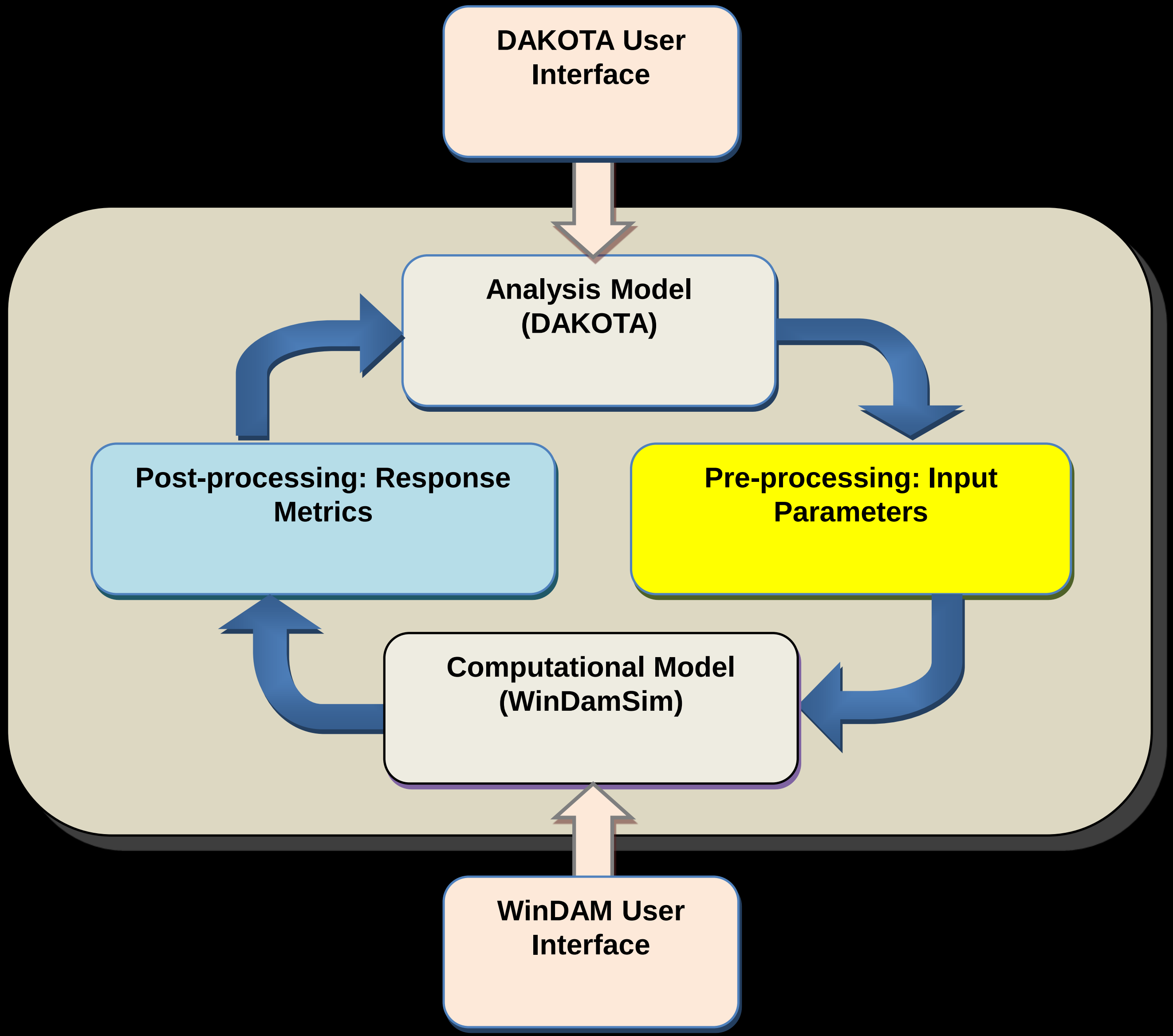
dakota_windam_multidim.in + (~\...heticInternalErosionExample) - VIM

```
# DAKOTA INPUT FILE - dakota_windam_multidim.in

environment,
          graphics,tabular_graphics_data
            tabular_graphics_file = 'dakota_multidim.dat'

method,
        multidim_parameter_study
          partitions = 5 50

model,
        single

variables,
        continuous_design = 2
          lower_bounds   108     0.017
          upper_bounds   112     56.55
          descriptors    'Tw'    'Kd'

interface,
        system
          analysis_driver = 'WinDam.bat'
          parameters_file = 'params.in'
          results_file    = 'results.out'
        file_save

responses,
        num_response_functions = 1
        no_gradients
        no_hessians
```

Using DAKOTA to drive the Analysis



Using DAKOTA to drive the Analysis



DAKOTA Analysis Driver

(WinDam.bat)

WinDAM.bat (~\Dakota\SyntheticInternalErosionExample) - VIM

```
perl parseWinDamIn params.in newParams.in
perl dprepro newParams.in example.WDT example.WDC
WinDamSim.exe example.WDC
perl parseWinDamOut example.OUT results.out
```

params.in

```
                     2 variables
1.080000000000000e+002 Tw
1.700000000000000e-002 Kd
                     1 functions
                     1 ASV_1:response_fn_1
                     2 derivative_variables
                     1 DVV_1:Tw
                     2 DVV_2:Kd
                     0 analysis_components
                     1 eval_id
```

parseWinDamIn

newParams.in

```
2 variables
    0108.0000 Tw
    0000.0170 Kd
```

DAKOTA Analysis Driver
(WinDam.bat)

WinDAM.bat (~\Dakota\SyntheticInternalErosionExample) - VIM

```
perl parseWinDamIn params.in newParams.in
perl dprepro newParams.in example.WDT example.WDC
WinDamSim.exe example.WDC
perl parseWinDamOut example.OUT results.out
```

example.WDT

example.WDT (~\Dakota\SyntheticInternalErosionExample) - VIM

```
WINDAM     01/01/2009Internal Erosion
OPTION     SIMPLE     EARTH      NOPS       INTERNAL
*
IEMODEL    2          {Tw      } {Kd      } 100        0
HYD        Constant   0.05       0          0C
                      10         10         10         10         10
                      10         10         10         10         10
                      10         10         10         10         10
```

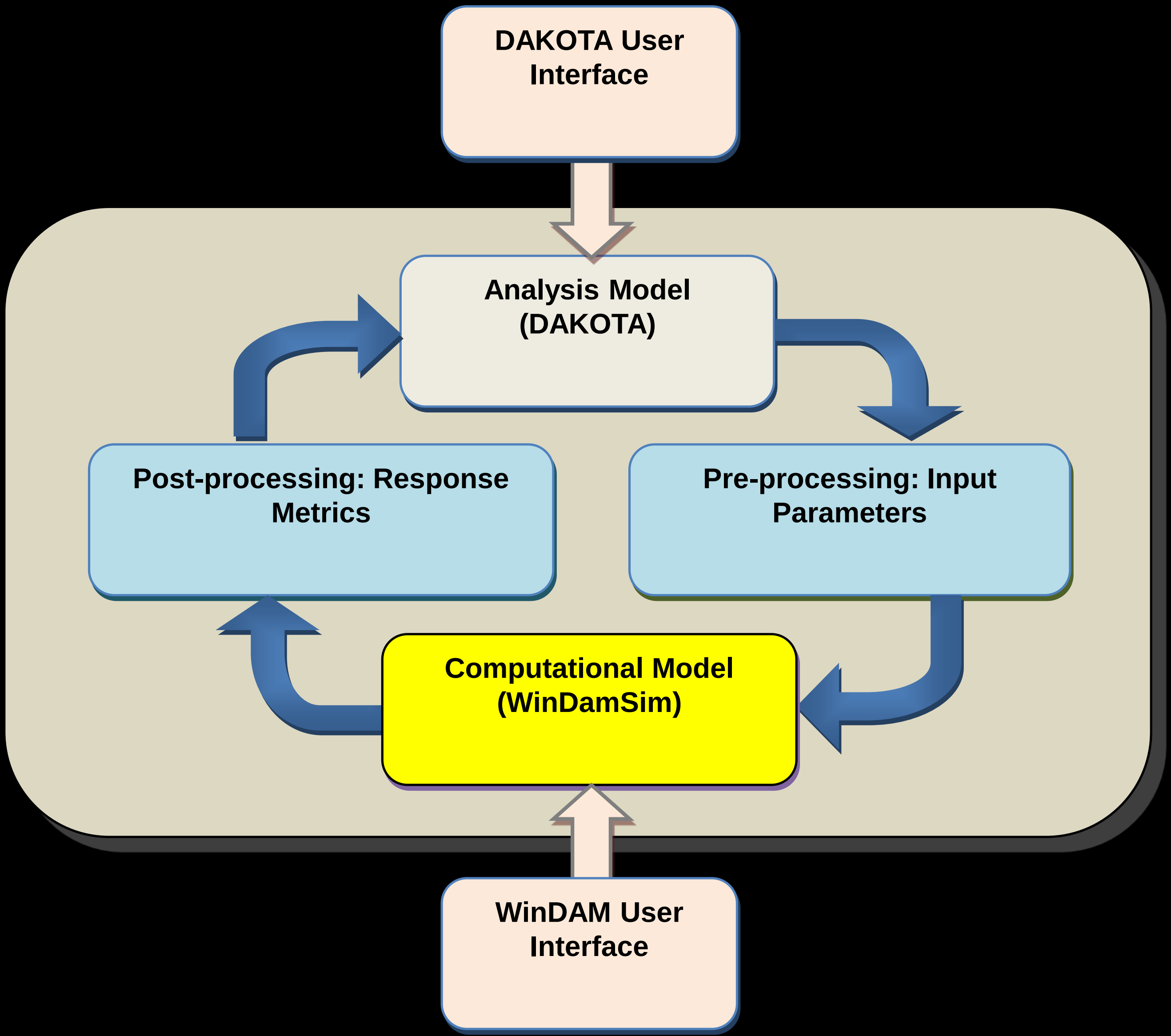
example.WDC

dprepro

example.WDC (~\Dakota\SyntheticInternalErosionExample) - VIM

```
WINDAM     01/01/2009Internal Erosion
OPTION     SIMPLE     EARTH      NOPS       INTERNAL
*
IEMODEL    2          0108.0000  0000.0170  100        0
HYD        Constant   0.05       0          0C
                      10         10         10         10         10
                      10         10         10         10         10
                      10         10         10         10         10
```

Using DAKOTA to drive the Analysis

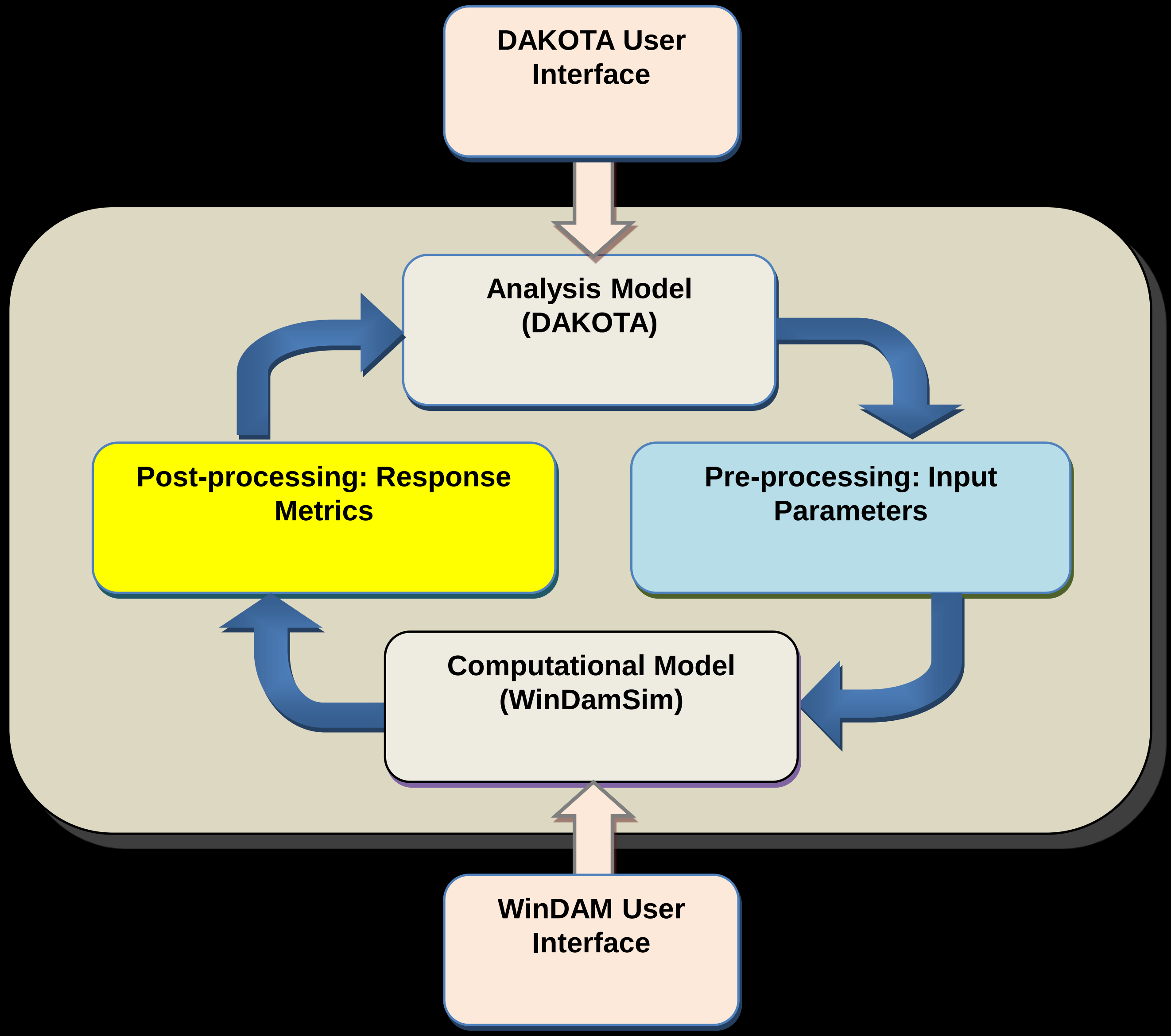


DAKOTA Analysis Driver
(WinDam.bat)

WinDAM.bat (~\Dakota\SyntheticInternalErosionExample) - VIM

```
perl parseWinDamIn params.in newParams.in
perl dprepro newParams.in example.WDT example.WDC
WinDamSim.exe example.WDC
perl parseWinDamOut example.OUT results.out
```

Using DAKOTA to drive the Analysis



Dakota 6.10 Input Format

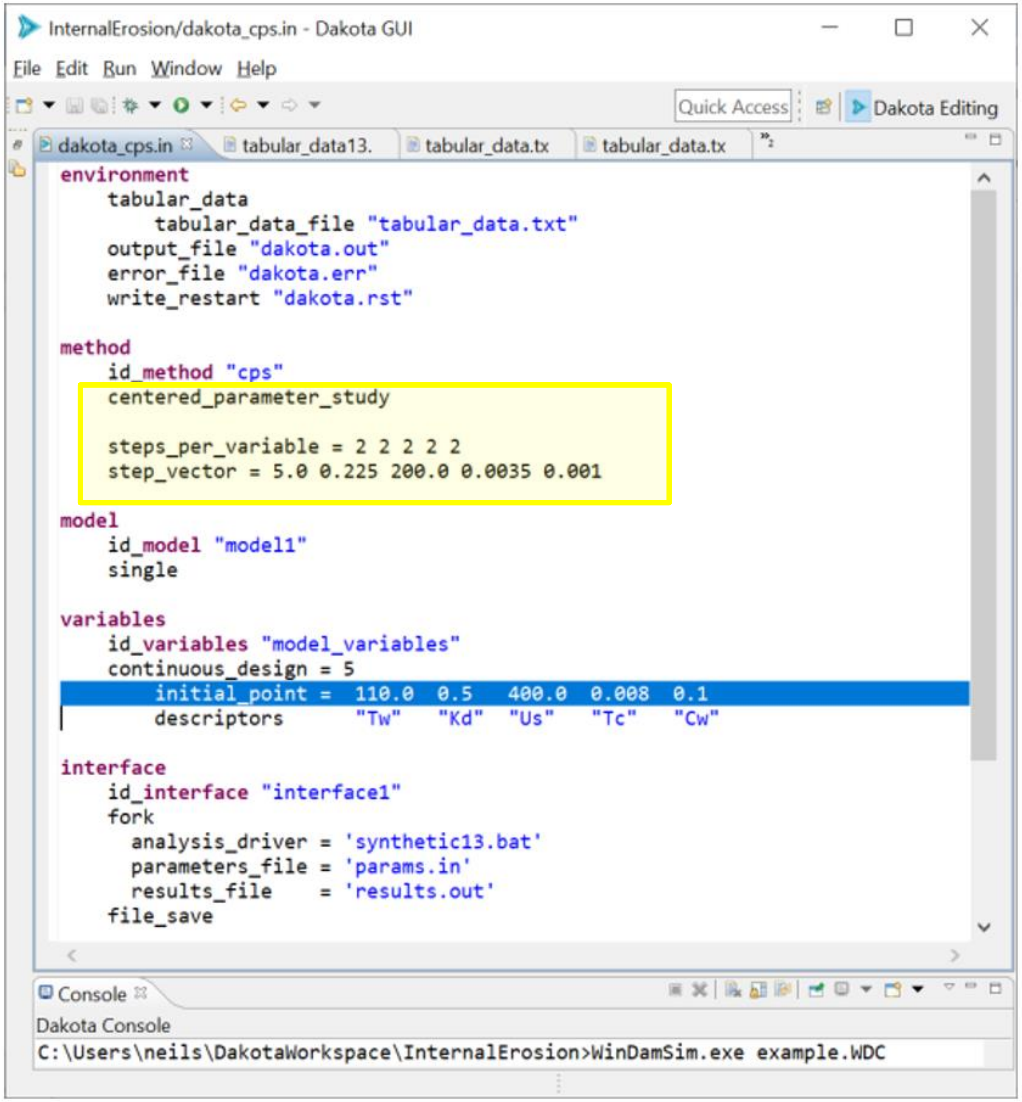


Figure 14. Dakota centered-parameter study input file

Centered Parameter Study Results

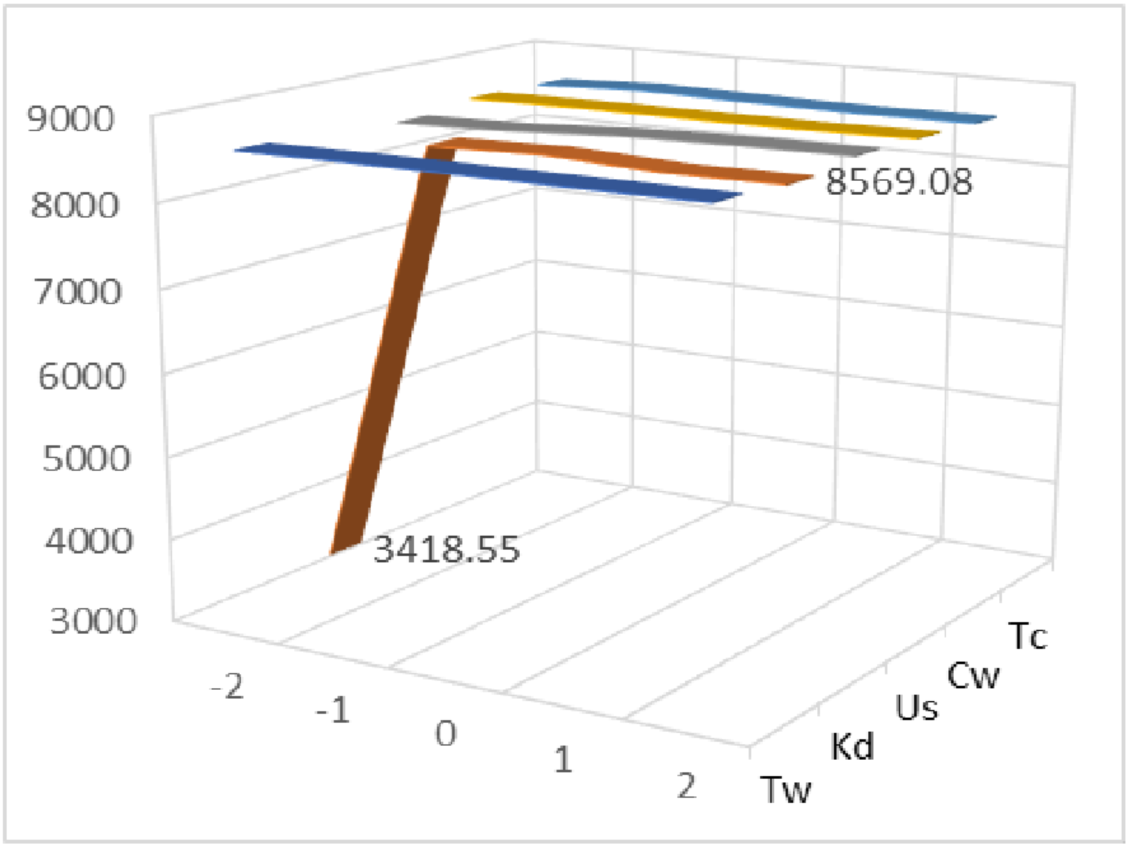


Figure 15. Centered-parameter study results

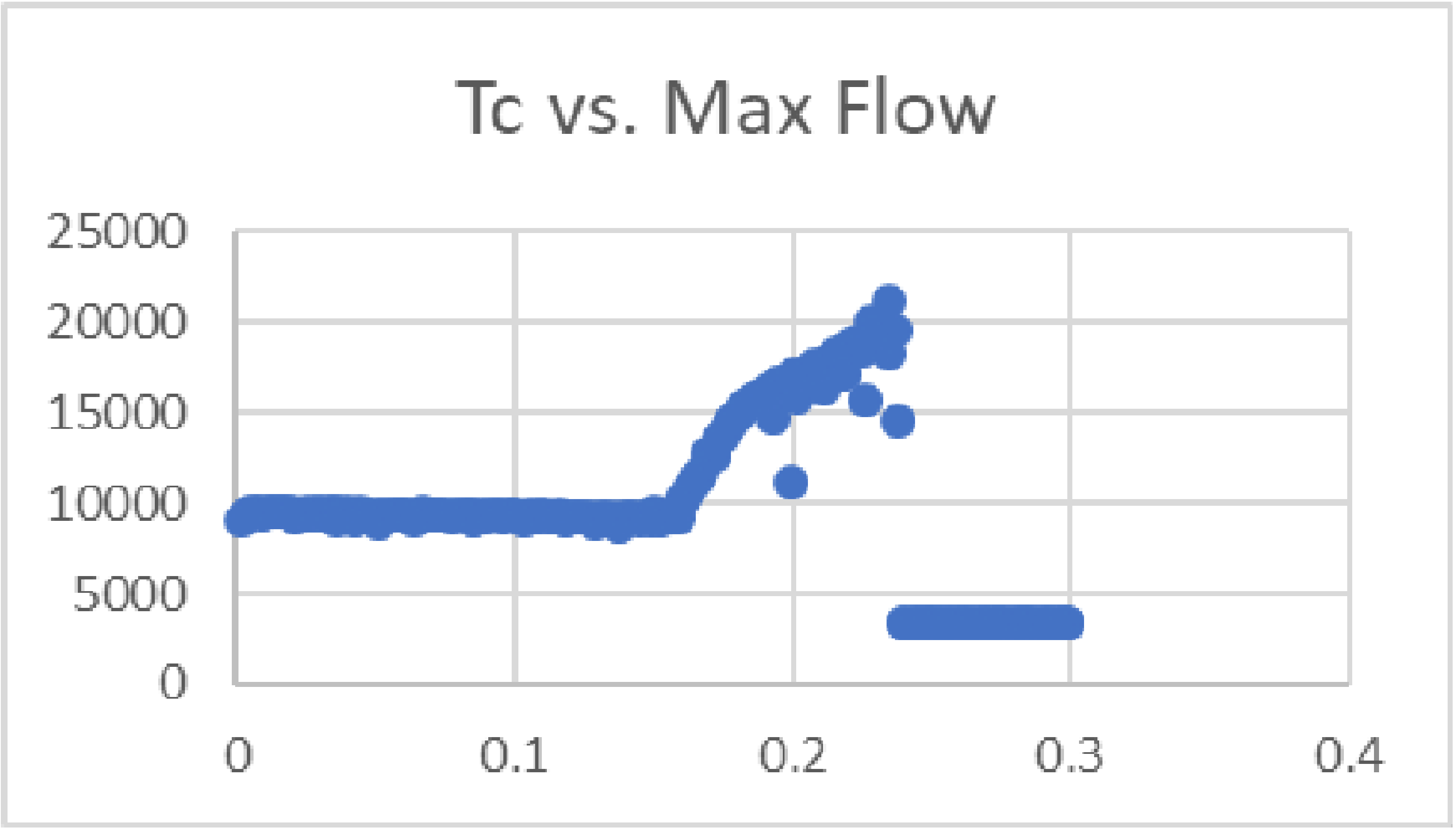
```
# DAKOTA INPUT FILE
environment
    tabular_data
        tabular_data_file "tabular_data13.txt"
    output_file "dakota.out"
    error_file "dakota.err"
    write_restart "dakota.rst"

method
    id_method "method1"
    sampling
        sample_type lhs
        samples = 100
        variance_based_decomp

model
    id_model "model1"
    single

variables
    id_variables "variables1"
    active all
    continuous_design = 5
        initial_point   110.0  0.5   400.0  0.008  0.1
        lower_bounds    100.0  0.05  100.0  0.0001 0.8
        upper_bounds    120.0  5.0   800.0  0.85   1.2
        descriptors     "Tw"   "Kd"  "Us"   "Tc"   "Cw"
```

Figure 16. Variance-based decomposition study input

Resulting Sobel Indices

Main	Total	Variable
3.6583120264e-04	6.1933580748e-04	Tw
7.9733886725e-01	**8.1438160208e-01**	**Kd**
7.5951019306e-03	2.0226039927e-03	Us
2.8293990703e-01	**4.0351278028e-01**	**Tc**
-1.7264200992e-04	2.1209241177e-03	Cw

Figure 17. Sobel indices for peak flow


Tc vs. Max Flow
25000
20000
15000
10000
5000
0
0
0.1
0.2
0.3
0.4

Summary

- WinDAM
  - Provides a framework to combine existing models and develop new models for dam erosion analysis
- Dakota
  - Provides a framework for parameters studies, uncertainty quantification, and sensitivity analysis

- Together, they provide a powerful framework for dam safety analysis

http://www.damsafety.info

United States Department of Agriculture NRCS Natural Resources Conservation Service

Agricultural Research Service

Kansas State University

WinDAM C (Ver 1.1.9) Installation Set (6/28/2019)

2011 Hunter Rouse Hydraulic Engineering Award Lecture Visuals

SITES 2005.1.8 Water Resource Site Analysis Software Installation Set

ARS Dam Breach Research

NRCS Hydrology & Hydraulics

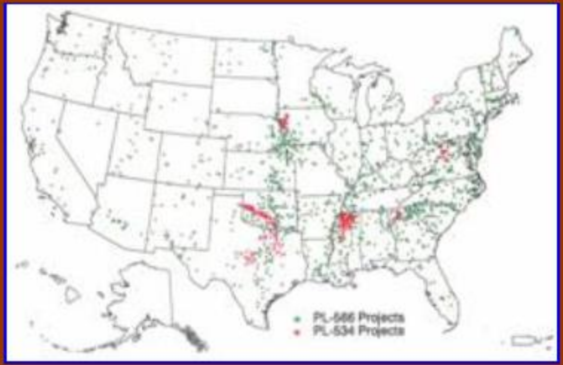
NRCS Watershed Rehabilitation Information

ARS Hydraulic Engineering Research Unit

The United States Department of Agriculture (USDA) and its partners are actively involved in providing the tools and technology for maintaining safe dams. Through the programs of the USDA, Natural Resources Conservation Service (NRCS), USDA has assisted in the construction of over 11,000 dams in 47 states since 1948. These dams provide flood control as well as water supply and recreation opportunities. The USDA, Agricultural Research Service (ARS) works closely with the NRCS to develop the technology needed for the economical design and rehabilitation of these dams. Kansas State University is partnering with the USDA to incorporate the results of research and field experience into computational tools for use in design and maintenance of safe dams. These tools provide the basis for optimal use of natural materials such as vegetation to protect embankments and spillways.

Additional information on the available resources and ongoing research is available by following the links to the left.

Watershed Project Locations



Next Steps

- International Internal Erosion Breach Model Performance Evaluation
  1. EMBREA – HR Wallingford (www.dambreach.org)
  2. WinDAM – USDA, KSU (www.damsafety.info)
  3. AREBA – EDF
  4. DL BREACH – Clarkson University
  5. RUPRO – IRSTEA

HR Wallingford
Working with water
USDA
United States Department of Agriculture
Agricultural Research Service
eDF

Next Steps

Questions?