APEX-CUTE 4 User Manual

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Overview

In recent years, watershed simulation models have been conducted to replicate hydrological, sediment, and nutrient processes in providing scientific credible information for engineers, scientists, and decision makers (Arnold et al., 2015). Among different models, the Agricultural Policy Environmental eXtender (APEX) was specifically initiated and developed to resolve relevant issues associated with agricultural impact on natural environment in the field scale (Williams and Izaurralde, 2006). One the other hand, applications of APEX could be technically tedious since potentially a large number of corresponding model parameters may need to be predefined or calibrated to properly represent the area of interest. In considering this issue, the Agricultural Policy Environmental eXtender - auto-Calibration and UncerTainty Estimator (APEX-CUTE) was developed to facilitate the calibration and uncertainty analysis routines with a user-friendly interface (Wang et al., 2014). APEX-CUTE was developed by the framework of the Integrated Parameter and Uncertainty Analysis Tool (IPEAT, Yen et al. (2014)) with the primary coding platform in Python. The current revision includes Sensitivity Analysis (SA) and the Dynamically Dimensioned Search (DDS) algorithm (Tolson and Shoemaker, 2007) for APEX auto-calibration. For the DDS optimization procedure, APEX-CUTE interacts with APEX by modifying APEX input files with candidate solution, running APEX, evaluating model output by calculating performance statistics, perturbing current best solution to generate candidate solution, and iteratively repeating the process until maximum number of objective function evaluations completed. APEX-CUTE offers sensitivity analysis using the Morris method (Morris, 1991; Campolongo et al., 2007).

These SA and auto-calibration tools can be used to complement users' refinement of an APEX model. Users are responsible for conducting necessary checks for model input and initial runs before conducting SA and/or auto-calibration using APEX-CUTE to make sure that the basic APEX input and setup are correct. More applications of APEX-CUTE can also be found in Wang et al. (2015).

1. Program download

A distributable package program is available for local installation at the EPICAPEX model website. The APEX-CUTE package program is a public domain program and can be downloaded with no charge.

Program Website: http://epicapex.tamu.edu/model-executables/

Package program to download: APEX-CUTE_ver4.6_APEX1501.exe

2. Program Installation

After downloading, execute APEX-CUTE_ver4.6_APEX1501.exe to start an installation. A local directory can be selected as the destination location where the program files will be copied. It is recommended that the user install the program at the default path (C:\APEX\APEX-CUTE), though the program can be installed any local hard drive.

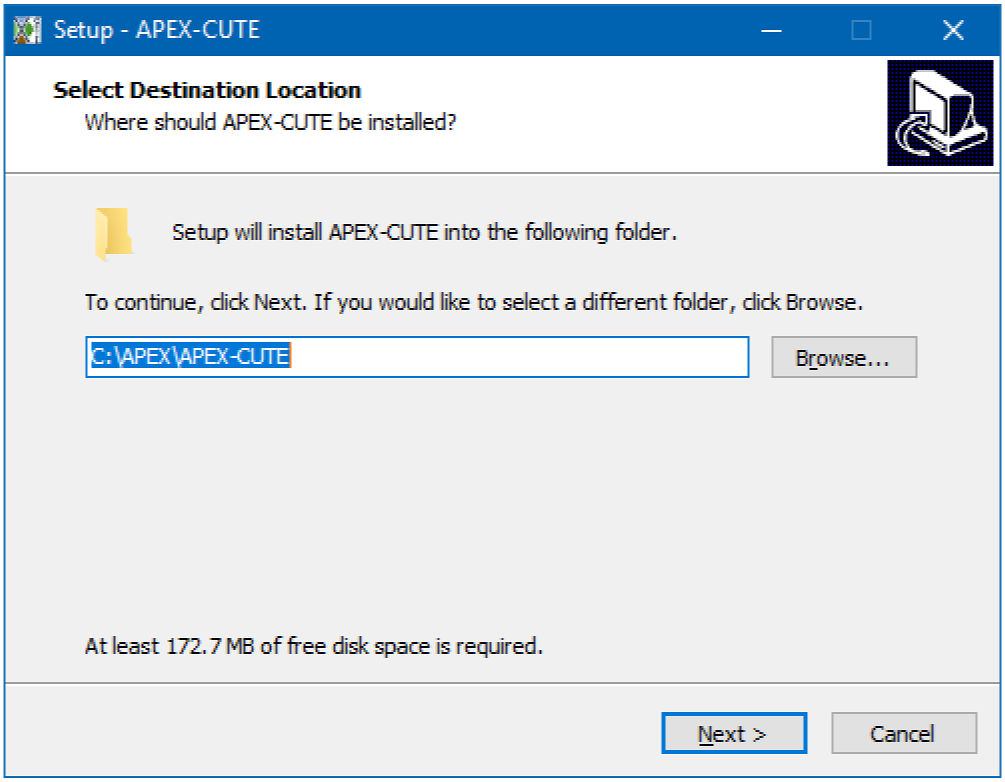


Figure 1. APEX-CUTE Installation screens

Windows Start menu can be customized, e.g., APEX-CUTE (Fig. 1b). The start menu folder will contain a shortcut to run the program and a shortcut to uninstall the program. A user can choose to place a desktop icon for the program (Fig. 1c). Follow the in-screen instruction to complete the installation, which will copy files to the local computer.

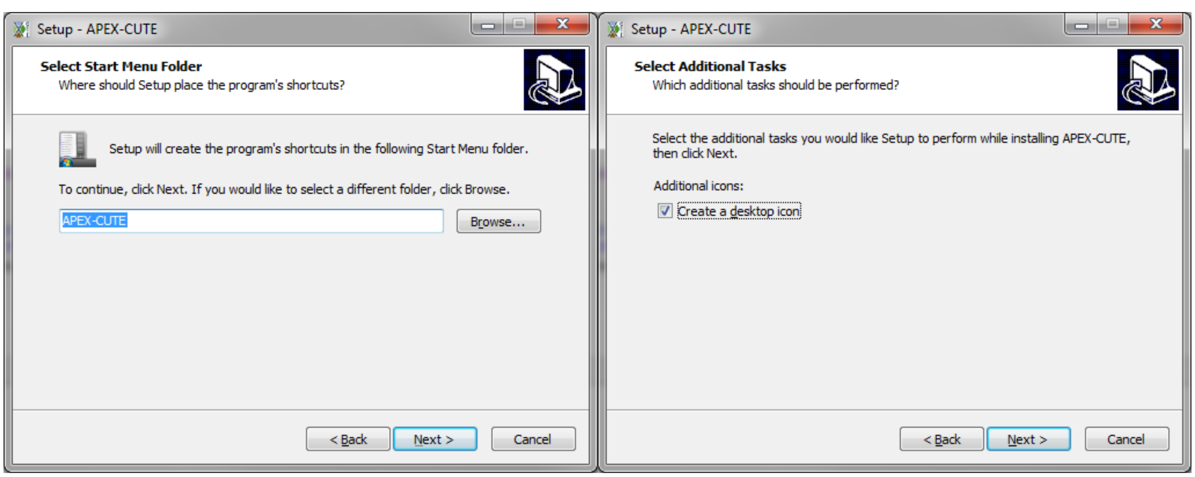


Figure 2. Options for Start menu selection and desktop icon creation

Follow steps to finish installation.

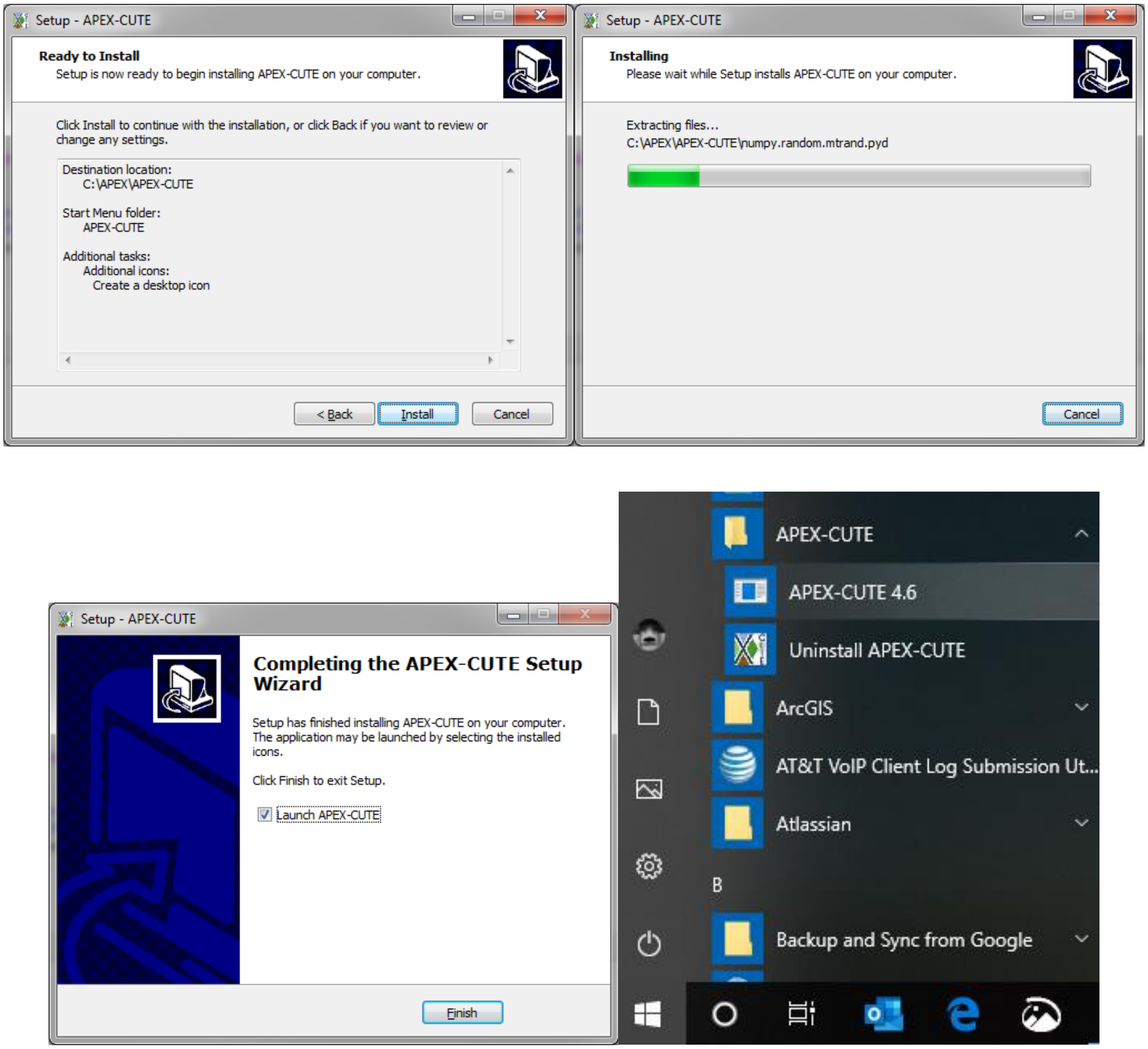


Figure 3. Installation of APEX Tool and Windows Start menu showing APEX-CUTE

At this point, the installation is completed and the user can start APEX-CUTE by either from the Windows Start menu or by double clicking the desktop icon named as APEX-CUTE 4.6.

3. Example Dataset

The installation package includes an example dataset with observed data formatted for APEX-CUTE. The example dataset is an APEX model for the USDA-ARS Riesel Y2 watershed with observed flow and water quality data formatted as daily, monthly, and annual time step data. If the user installed the program at the default path, the program files are located at C:\APEX\APEX-CUTE folder. An example dataset included in the installation package can be found in a subfolder C:\APEX\APEX-CUTE\project1501 (Figure 4). Under the project1501 folder, there are two subfolders. The folder “C:\APEX\APEX-CUTE\project1501\Obs” contains examples of observation data. The folder "C:\APEX\APEX-CUTE\project1501\TxtInOut" contains the Riesel Y2 APEX dataset.

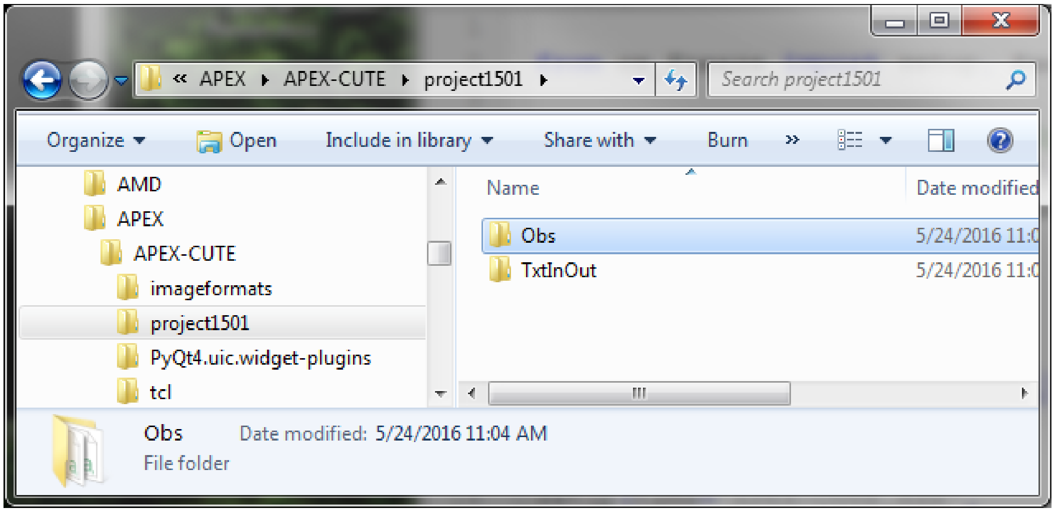


Figure 4. Example dataset

Detail description of the watershed is well described by Harmel et al. (2007). In addition, example observation data for daily, monthly, and annual monitoring data for streamflow, sediment, and crop yield are included in the "Obs" folder. Water quality monitoring data will soon be added.

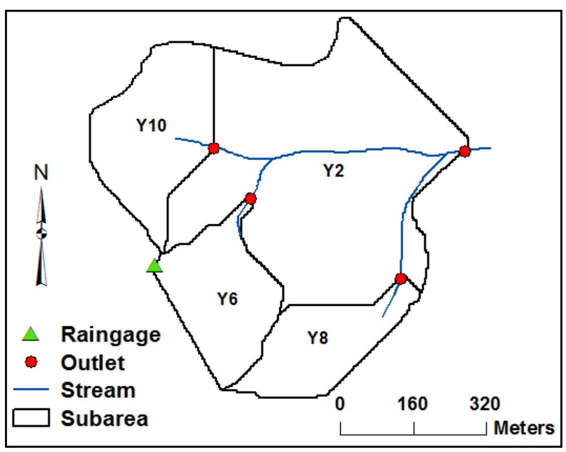


Figure 5. The Riesel Y2 watershed (adopted from Harmel et al., 2007)

4. APEX Parameters available in APEX-CUTE

APEX parameters (e.g. Table 1) that may be chosen to be included in SA and auto-calibration processes were based on previous APEX studies (Wang et al., 2006; Yin et al., 2009) and APEX developers' experience and recommendations, as summarized by Wang et al. (2012). In APEX-CUTE 4.6, there are 100 parameters in PARMS.DAT (parm1 to parm 100), 37 input parameters in APEXCONT.DAT, *.SIT, *.SUB, and *.SOL files, and 6 crop parameters in CROP.DAT. Users can select all the relevant parameters for the calibration components, or they can conduct a SA first and then decide which parameters to be included for calibration. Because water is a potential force that interacts with or drives almost all environmental processes within a watershed system, the hydrological conditions prevalent in the watershed are critical to the estimations of sediment and nutrient losses. Therefore, if the erosion/sedimentation component is to be calibrated, the hydrology-related parameters must also be selected for calibration. When sediment data are available, it is often the case that flow data are also available for calibration. For nutrient calibration, both hydrology and sediment related parameters should be involved in the calibration (Wang et al., 2014).

5. Observed data

For calibration purpose, observed data will also need to be prepared following the template in the default example files. They should be saved in the Obs folder under the APEX-CUTE project folder path, e.g., C:\APEX\APEX-CUTE\project1501\Obs\ in the example case (Figs 3 and 4). They should be named following the name style as in Fig. 7, where "hyd_" means flow data, "wq_" means water quality data, "yearly2" means yearly interval calibration at reach 2 and so on for the monthly or daily calibrations. Note that the number 2 should be consistent with the Subarea/Reach# selected in the "CUTE Setting" tab (Fig. 8). This way APEX-CUTE will be able to find the corresponding observation files to use. If a user calibrates outlets 1 and 2 at the same time, APEX-CUTE will know which observation file is for outlet 1 and which one is for outlet 2. If the APEX project is only for one subarea, user may use 1 as the ID#. <u>It is recommended that observation data starts January 1st and finishes December 31st for daily or monthly intervals. Days or months when no data is available must be filled with '-999'.</u>

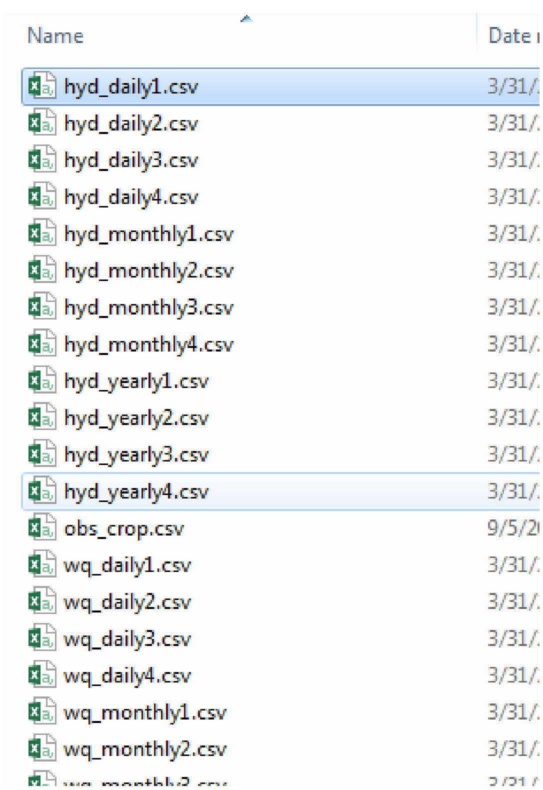


Figure 6. observed data file in the Obs folder

6.1 Daily flow data

Data is comma separated. Daily observed flow values must be written using the following format. The first line is the header line and data starts from the second line. No value must be entered as '-999'.

Year: the year that the measurement was recorded. 4-digit integer, e.g. 1998
Month: the month that the measurement was recorded. 1 or 2-digit integer, e.g. 2
Day: day of the month that the measurement was recorded. 1 or 2-digit integer, e.g. 31
Flow(mm): daily total volume of stream flow divided by drainage area. Real type, e.g. 6.23
Flow(m3/s): average daily stream flow rate. Real type, e.g.0.032
SurfaceQ(mm): daily total surface runoff volume divided by drainage area. Real type, e.g. 1.23
SurfaceQ(m3/s) : average daily surface runoff rate. Real type, e.g. 1.23

	A	B	C	D	E	F	G
1	Year	Month	Day	Flow(mm)	Flow(m3/s)	SurfaceQ(mm)	SurfaceQ(m3/s))
2	1998	1	1	0	0	-999	-999
3	1998	1	2	0	0	-999	-999
4	1998	1	3	0	0	-999	-999
5	1998	1	4	6.23	0.032	-999	-999
6	1998	1	5	58.75	0.3017	-999	-999
7	1998	1	6	25.88	0.1329	-999	-999
8	1998	1	7	13.46	0.0691	-999	-999
9	1998	1	8	0.56	0.0029	-999	-999
10	1998	1	9	0.08	0.0004	-999	-999
11	1998	1	10	0.04	0.0002	-999	-999

Example of daily flow data

6.2 Monthly flow data

Year: the year that the measurement was recorded.
Month: the month that the measurement was recorded.
Flow(mm): monthly total volume of stream flow divided by drainage area.
Flow(m3/s): average daily stream flow rate. Real type
SurfaceQ(mm): monthly total surface runoff volume divided by drainage area.
SurfaceQ(m3/s) : average daily surface runoff rate.

	A	B	C	D	E	F
1	Year	Month	Flow(mm)	Flow(m3/s)	SurfaceQ(mm)	SurfaceQ(m3/s)
2	1998	1	105.1	0.01742	-999	-999
3	1998	2	15.3	0.002804	-999	-999
4	1998	3	12.63	0.00209	-999	-999
5	1998	4	0	0	-999	-999
6	1998	5	0	0	-999	-999
7	1998	6	0	0	-999	-999
8	1998	7	0	0	-999	-999
9	1998	8	0	0	-999	-999
10	1998	9	0	0	-999	-999
11	1998	10	39.48	0.006539	-999	-999

Example of monthly flow data

6.3 Yearly flow data

Year: the year that the measurement was recorded. 4-digit integer
Flow(mm): daily total volume of stream flow divided by drainage area.
Flow(m3/s): average daily stream flow rate.
SurfaceQ(mm): daily total surface runoff volume divided by drainage area.
SurfaceQ(m3/s) : average daily surface runoff rate.

	A	B	C	D	E
1	Year	Flow(mm)	Flow(m3/s)	SurfaceQ(mm)	SurfaceQ(m3/s)
2	1998	222.8	0.003134	-999	-999
3	1999	10.45	0.0001468	-999	-999
4	2000	147.9	0.002075	-999	-999
5	2001	308.5	0.004339	-999	-999
6	2002	203.5	0.002862	-999	-999
7	2003	117.4	0.001651	-999	-999
8	2004	461	0.006468	-999	-999
9	2005	127.3	0.00179	-999	-999
10	2006	40.77	0.0005737	-999	-999
11	2007	516.6	0.007267	-999	-999

Example of yearly flow data

6.4 Daily water quality data

Year: the year that the measurement was recorded.
Month: the month that the measurement was recorded.
Day: day of the month that the measurement was recorded.
Sed(t/ha): daily total sediment yield in the stream flow divided by drainage area.
TN(kg/ha): daily TN yield in the stream flow divided by drainage area.
TP(kg/ha): daily TP yield in the stream flow divided by drainage area.
MinN(kg/ha): daily total mineral N yield in the stream flow divided by drainage area.
OrgN(kg/ha): daily total organic N yield in the stream flow divided by drainage area.
MinP(kg/ha): daily total mineral P yield in the stream flow divided by drainage area.
OrgP(kg/ha): daily total organic P yield in the stream flow divided by drainage area.
Tpest(kg/ha): daily total pesticide yield in the stream flow divided by drainage area.

	A	B	C	D	E	F	G	H	I	J	K
1	Year	Month	Day	Sed(t/ha)	TN(kg/ha)	TP(kg/ha)	MinN(kg/ha)	OrgN(kg/ha)	MinP(kg/ha)	OrgP(kg/ha)	Tpest(g/ha)
2	1998	1	1	0	-999	-999	-999	-999	-999	-999	-999
3	1998	1	2	0	-999	-999	-999	-999	-999	-999	-999
4	1998	1	3	0	-999	-999	-999	-999	-999	-999	-999
5	1998	1	4	0.0155	-999	-999	-999	-999	-999	-999	-999
6	1998	1	5	0.2385	-999	-999	-999	-999	-999	-999	-999
7	1998	1	6	0.0132	-999	-999	-999	-999	-999	-999	-999
8	1998	1	7	0.0056	-999	-999	-999	-999	-999	-999	-999
9	1998	1	8	0	-999	-999	-999	-999	-999	-999	-999
10	1998	1	9	0	-999	-999	-999	-999	-999	-999	-999
11	1998	1	10	0	-999	-999	-999	-999	-999	-999	-999

Example of daily water quality data

Monthly and yearly water quality data are formatted in the same manner the flow data are prepared for monthly and yearly interval.

6.5 Crop yield data

yyyy: the year that the measurement was recorded. Use '9999' if the observed value represents the average yield amount.
SubID: Subarea ID for which the crop yield data is recorded.
Grain Yield(t/ha): dry weight of the harvested grains.
Biomass(t/ha): dry weight of the total biomass on the field when harvested.

	A	B	C	D	E
1	yyyy	SubID	CROP	Grain Yield (t/ha)	Biomass(t/ha)
2	9999	1	CORN	7	17.17
3	9999	2	WWHT	3.01	10.5
4	9999	3	OATS	3.69	12.38

	A	B	C	D	E
1	yyyy	SubID	CROP	Grain Yield (t/ha)	Biomass(t/ha)
2	1998	1	CORN	5.65	17.17
3	1998	2	WWHT	3.01	10.5
4	1998	3	OATS	3.69	12.38
5	1998	4	RNGE	0	20.97
6	1999	1	SGHY	6.51	17.94
7	1999	1	WWHT	0	0.01
8	1999	2	SGHY	6.73	18.53

Examples of observed crop yield data

Table 1. Choice of APEX parameters available in APEX-CUTE 1.0.

Process impacted directly	Influential input or parameter	Description	Range	Default
Runoff CN method	CN2	Initial condition II curve number (CN2) or landuse number (LUN)	± 5	-
	Parm42 (if NVCN=4)	Curve Number index coefficient	0.5 - 2.5	0.5
	Parm92 (if NVCN=0)	Curve number retention parameter coefficient	0.8 – 1.5	1
	Parm20	Runoff curve number initial abstraction	0.05 – 0.4	0.2
Green & Ampt	SAT0	Saturated conductivity adjustment factor	0.1–10.0	1
Evapotranspiration (PET)	Parm34 (if Hargreaves PET)	Equation exponent	0.5 – 0.6	0.5
	Parm1 (if Penman-Monteith)	Canopy PET factor	1 - 2	2
ET	Parm12	Soil evaporation coefficient	1.5 – 2.5	1.5
	Parm17	Evaporation plant cover factor	0 – 0.5	0.1
Irrigation (if used)	EFI	Irrigation runoff ratio	0 -1	0
Tile/drainage flow	Parm83	Estimates drainage system lateral Hydraulic conductivity	0.1 - 10	4
Base flow	RFP0	Return flow ratio: (Return flow)/(Return flow + Deep percolation)	0.05 - 0.95	0.5
	Parm40	Groundwater storage threshold	0.001 - 1.0	0.25
	RFTO	Groundwater residence day	10 - 50	30
Erosion/ sedimentation	Parm46	RUSLE c factor coefficient in exponential residue function in residue factor	0.5 - 1.5	0.5
	Parm47	RUSLE c factor coefficient in exponential crop height function in biomass factor	0.01 - 3.0	1.0
	PEC (if having conservation practice)	Erosion control factor	0 - 1	1
	APM	Peak rate – EI_{30} adjustment factor	0 - 1.0	1.0
Routing	Parm18	Sediment routing exponent of water velocity function for estimating potential sediment concentration	1 - 1.5	1.5
	Parm19	Potential sediment concentration when flow velocity is 1.0 m/s	0.005 - 0.05	0.05
	RCCO or RCHC	Channel cover factor	0.001 - 1.0	0.7
	RCHK	Soil edibility factor	0.001 - 0.5	0.3
Nitrogen cycling Phosphorus cycling	Parm29	Biological mixing efficiency	0.1 – 0.5	0.1
	Parm8	Soluble P runoff coefficient	10 – 20	15
	Parm59	P upward movement by evaporation coefficient	1 – 30	1
	Parm14	Nitrate leaching ratio	0.1 – 1.0	0.2
	Parm35	Denitrification soil water threshold	0.9 – 1.1	0.99
	Parm7	N fixation coefficient	0 – 1	0.9
	Parm72	Volatilization/nitrification partitioning coefficient	0.05 – 0.5	0.15
Carbon Cycling	Parm70	Microbial decay rate coefficient	0.05 – 1.5	1
	FHP	Fraction of humus in passive pool	0.3 – 0.9	0.3
	FBM (.sol)	Fraction of organic carbon in microbial biomass pool	0.005-0.06	0.04

6. Sensitivity Analysis

6.1 In the **Directory** group, create a folder and select it as the project folder. In this tutorial, the default dataset provided with the installation package will be used. All APEX-CUTE files related to this project are saved in the current project folder. Next, provide the path where APEX dataset is located in "APEX Folder". If WinAPEX was used to create an APEX model, the dataset is located at C:\APEX\WinAPEX\apexprog. At this point, ArcAPEX is not updated for APEX1501, so APEX-CUTE 4.6 is not available for APEX models constructed with ArcAPEX.

The user provided APEX dataset will be copied to a subfolder "TxtInout" under the project folder as a backup. Click "1.Save" button to save the project path. In response, the progress bar at the bottom of the main window will briefly move to 100% before being reset to 0%.

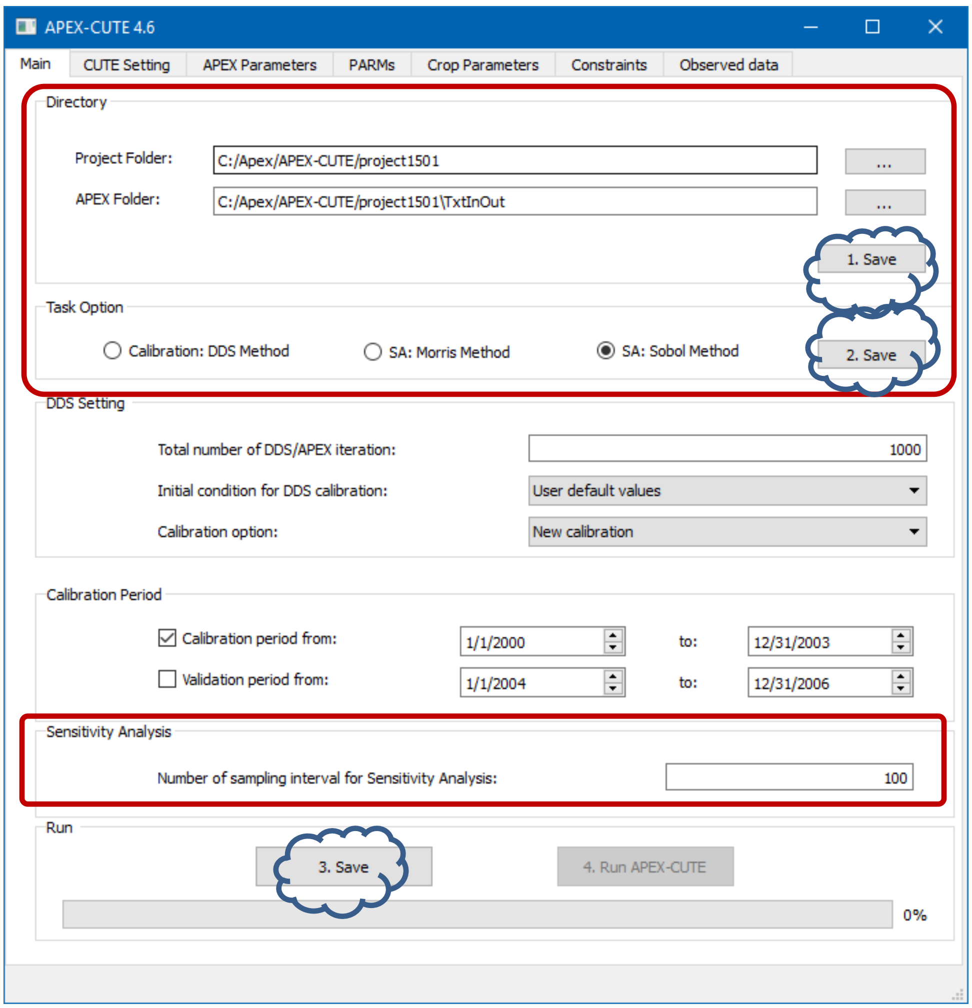


Figure 7. Main window

6.2 In the **Task Option**, select either "SA: Morris Method" or "SA: Sobol Method" and save (2. Save button). Input options under DDS Setting and Calibration Period will become disabled because they are irrelevant to sensitivity analysis.

6.3 Click open the **CUTE Setting** tab and input the following:

a. Subarea/Reach ID: Input an integer ID for an outlet where the model output will be evaluated. If the SA is to be conducted for the entire watershed, input the watershed outlet ID.
b. Time step(D/M/Y), or crop name: select APEX output time interval between daily, monthly, and annual step using letters D, M, or Y. If crop yield or total crop biomass is to be evaluated, provide a 4-letter crop name as listed in CROP.DAT (e.g. CORN, SOYB).

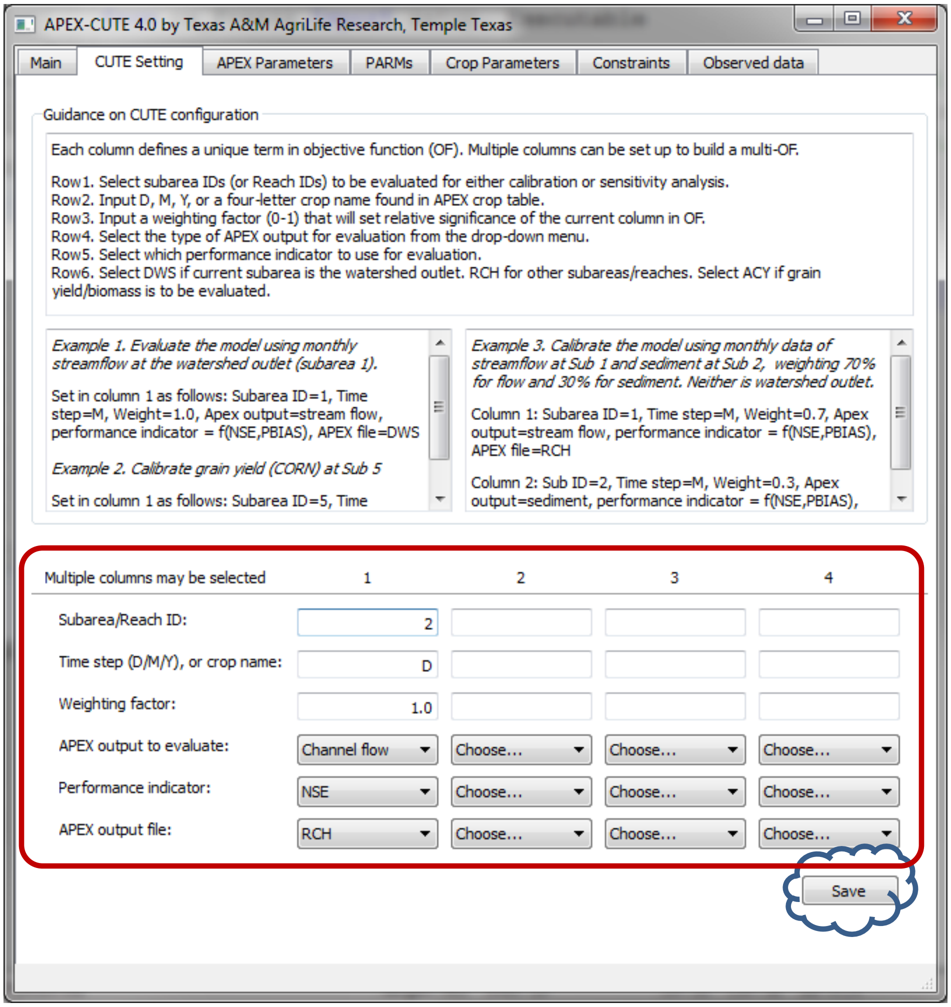


Figure 8. CUTE Setting tab for CUTE configuration

c. Weight factor: leave the default value of 1.0 for sensitivity analysis.
d. APEX output to evaluate: Choose one type of APEX output from the drop-down list among Surface runoff, Channel flow, Sediment, TN, TP, Mineral N, Organic N, Mineral P, Organic P, Total pesticide, Grain yield, and Total biomass.
e. Performance indicator: This is not used in sensitivity analysis
f. APEX output file: Choose DWS if the selected Subarea ID is the watershed outlet. Choose RCH if the selected Subarea ID is located upstream of the watershed outlet. Choose ACY if a crop is selected in the second row.
g. Add more objective function terms in column 2 to 4. Click the Save button.

6.4 Click open the **APEX Parameters** tab. Hover the mouse cursor over APEX parameters on the Name column for parameter definition and description. Reset the OnOff column value to 1 to select a parameter for evaluation. Select as many parameters as needed. Click Save button.

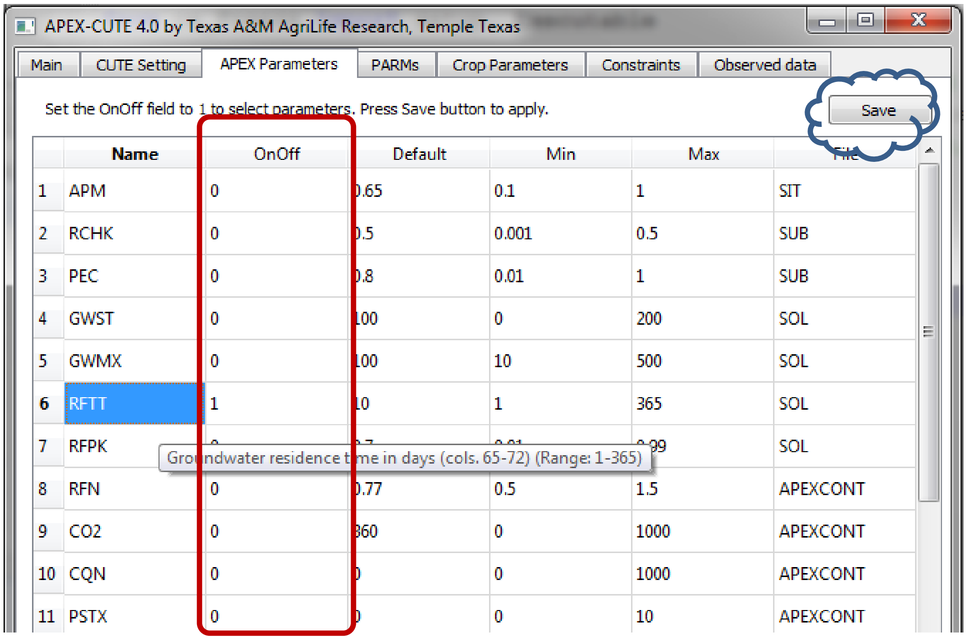


Figure 9. APEX Parameters tab

6.5 Go through **PARMs** and **Crop Parameters** tabs to select more parameters. Click the Save button on each tab to save the parameter selection.

6.6 Click open **Constraints** to configure constraints of the simulation. Up to 6 constraints can be used at a time. Selected constraints are used to enforce APEX-CUTE to drop any APEX output during iterations that is out of bound. For instance, rto_bf (i.e. baseflow ratio) is selected and 0.5-0.8 is provided as the enforcing range, any apex output during a SA iteration for which the estimated baseflow ratio is either smaller than 0.5 or greater than 0.8 is not selected for evaluation. This applies to the calibration process, too.

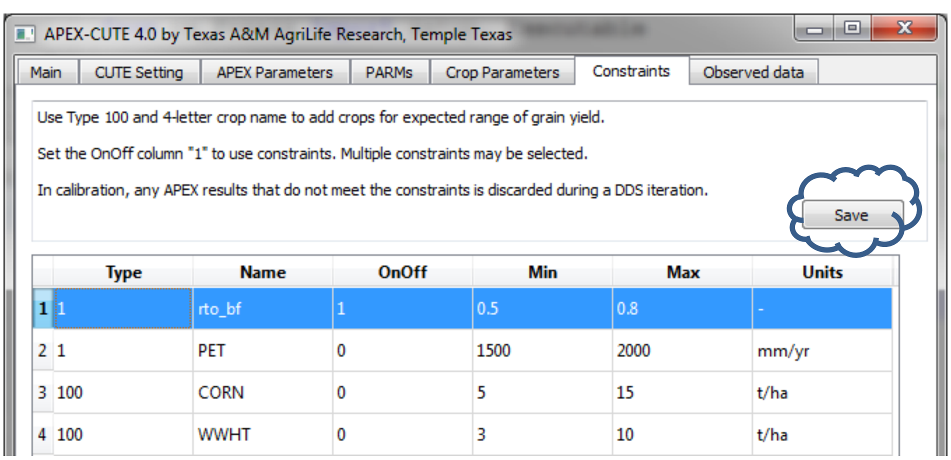


Figure 10. Constraints tab

6.7 Return to the Main tab. In the Sensitivity Analysis group, provide the number of sample interval. If the Morris Method was selected, the total number of iterations (N) for the current SA is:

$$N = I * (P + 1)$$

Where P is the number of APEX parameters (including PARMs and Crop parameters) selected and I is the number of intervals. If the Sobol Method was selected, the total number of iterations is:

$$N = 2I * (P+1)$$

In the Run group, click the 3.Save button and the button 4. Run APEX-CUTE will become enabled. Click the Run button to start the sensitivity analysis. APEX-CUTE prints out the progress of SA in a console window as shown in Figure 10. In the example run, two parameters were selected for evaluation (P=2) with I=100, so the total number of iteration was 100*(2+1)=300.

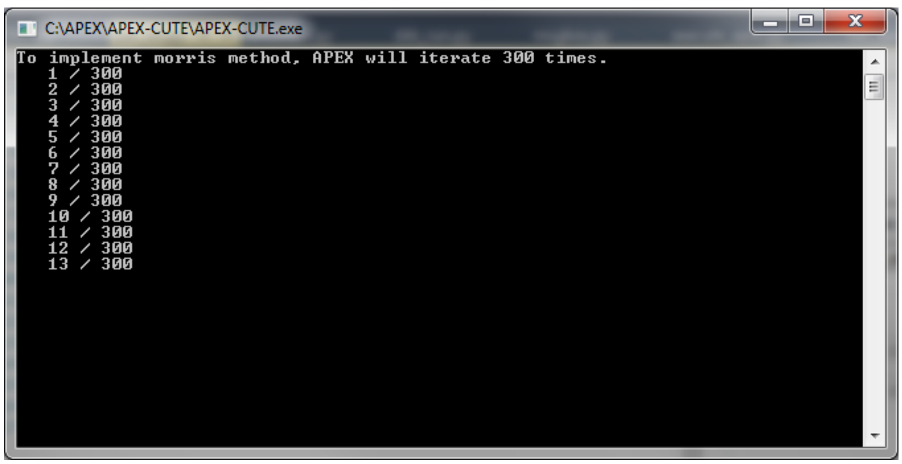
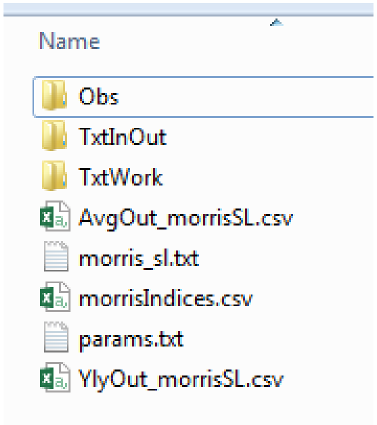


Figure 11. Console window showing the progress of Sensitivity Analysis

7. Sensitivity Analysis Output

Five output files as listed below will be generated and more detail is provided in Fig. 13.



AvgOut_morrisSL.csv/AvgOut_sobolLS.csv – average annual APEX output (e.g., flow, sediment, TN) for each iteration

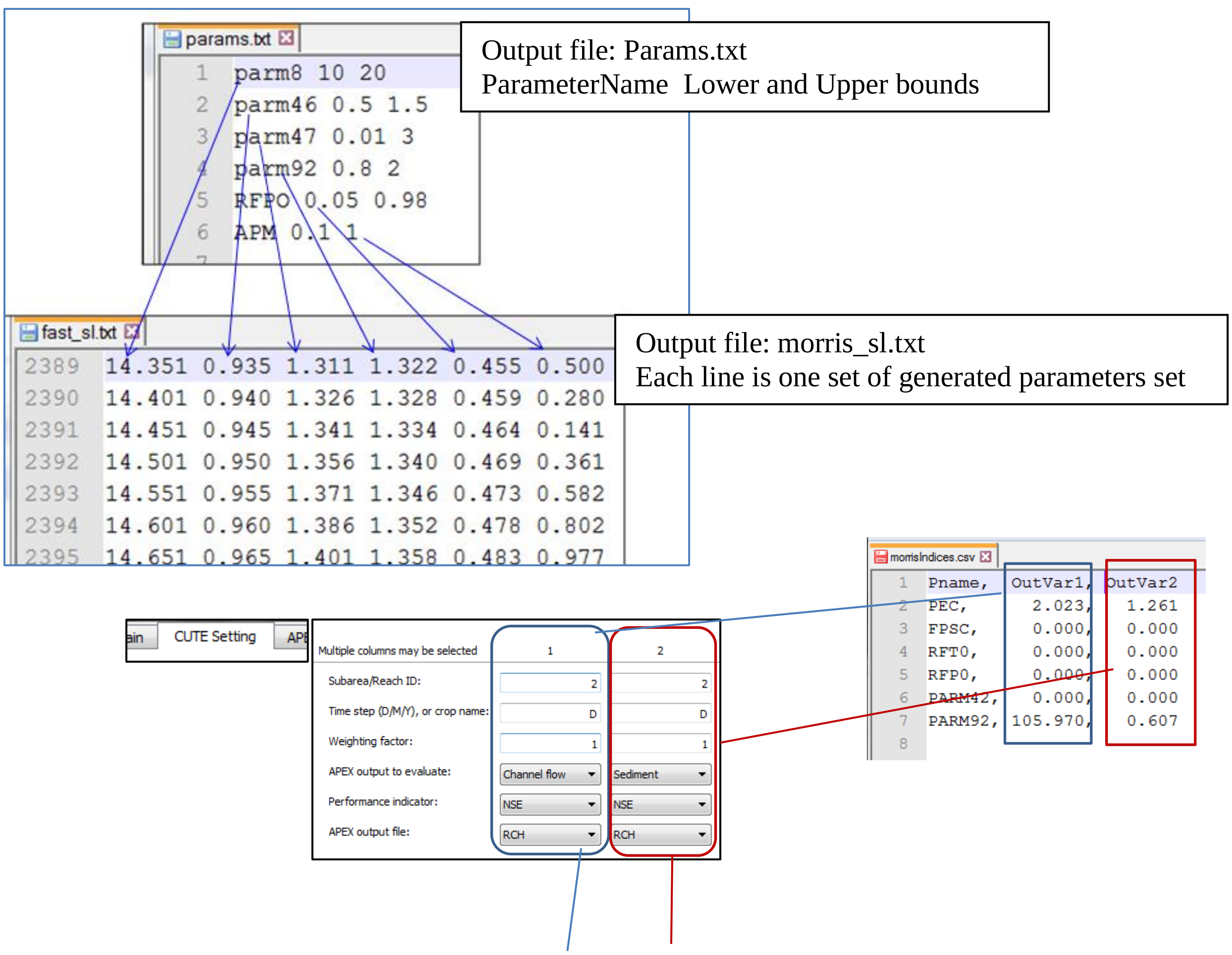
morris_sl.txt/sobol_sl.txt – this file has sampled parameters for SA

morrisIndices.csv/sobolIndices.csv – this file saves sensitivity indices

params.txt – APEX parameters selected in the SA

YldOut_morrisSL.csv/YldOut_sobolLS.csv – average annual values and annual values of APEX output for each iteration

Figure 12. Output files after completing the sensitivity analysis.



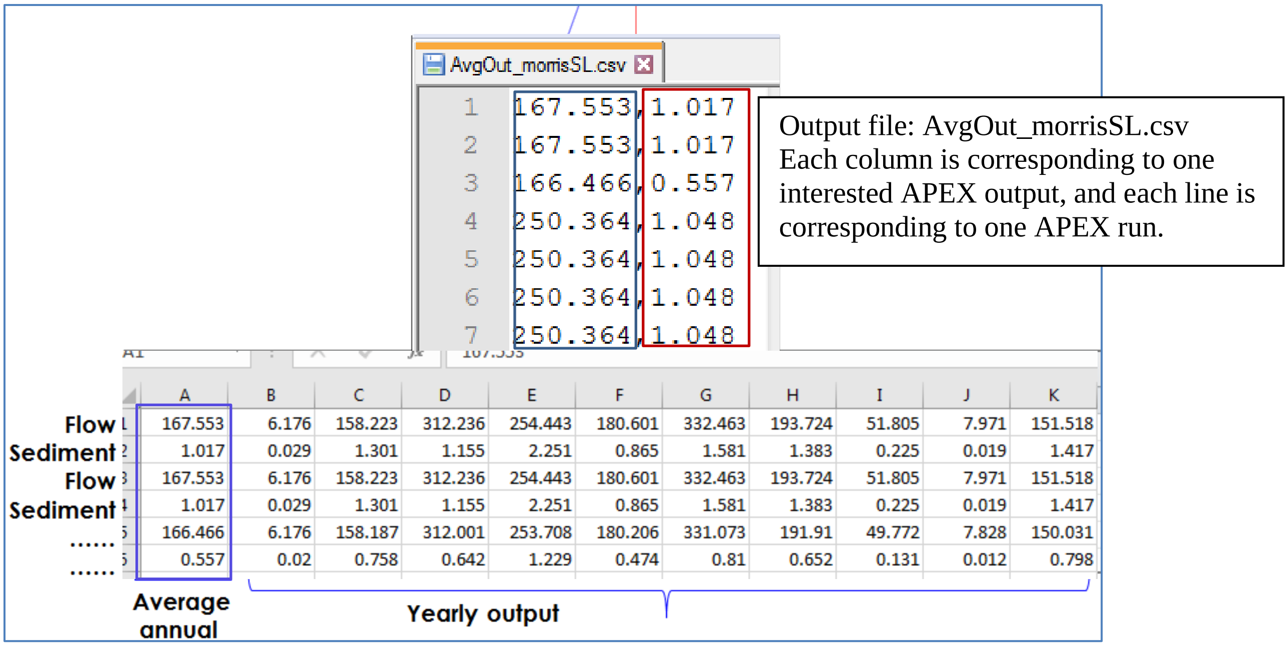


Figure 13. Example sensitivity output files.

8. Calibration

9.1 Repeat the procedures described in chapter 7, but select "Calibration" in the "Task Option" instead of "Sensitivity Analysis". Configure calibration details in the CUTE Setting tab and select parameters to calibrate in APEX Parameters/PARMs tabs. Set constraints in the Constraints tab if applies.

9.2 Set the total number of APEX iterations. It is recommended that this value be set between 500 and 5000.

9.3 Initial parameter values are important in DDS calibration because DDS uses sampled parameters values and the model responses in previous runs to determine new parameters for the next iteration during a calibration. Two options are available as for "Initial condition for DDS calibration"

a. **User default values**: The first APEX run will be made using the parameter values set in "Default" column in PARMs/APEX Parameters tabs.

b. **Random Sampling**: APEX-CUTE makes five APEX runs using randomly selected parameter values. The set of parameters that gives the best result among the five runs is selected as the first APEX run.

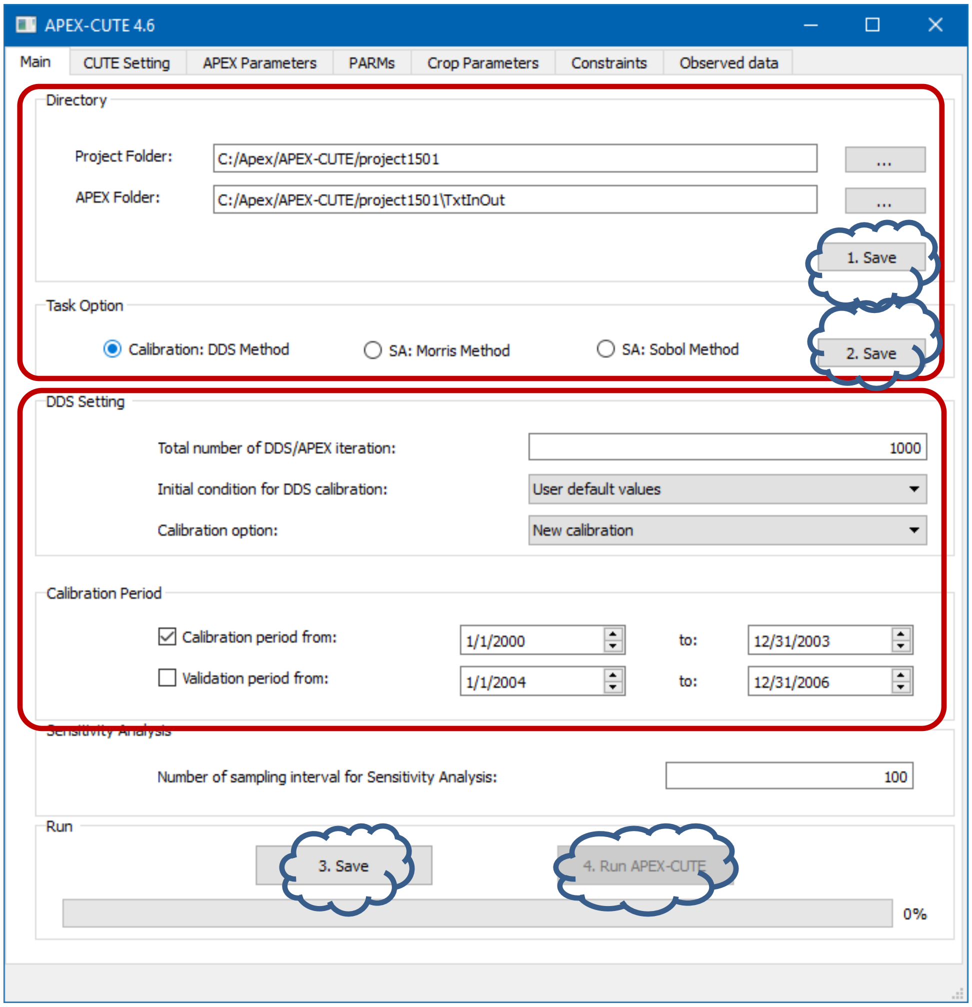


Figure 14 APEX-CUTE main window configuration for calibration

9.3 Two options are available "Calibration option" in the DDS Setting group

a. **New calibration**: this option sets up a fresh new calibration and APEX-CUTE deletes any existing calibration data and starts a new calibration. As shown in Fig.15, APEX-CUTE shows calibration progresses with values showing current objective function and the best objective function up to the point.
b. **Continuing from previous run**: APEX-CUTE collects calibration log in "DDS.out" and continue the previous calibration from where it stopped. This is optional but useful to complete a large calibration run that is stopped incompletely for a reason.

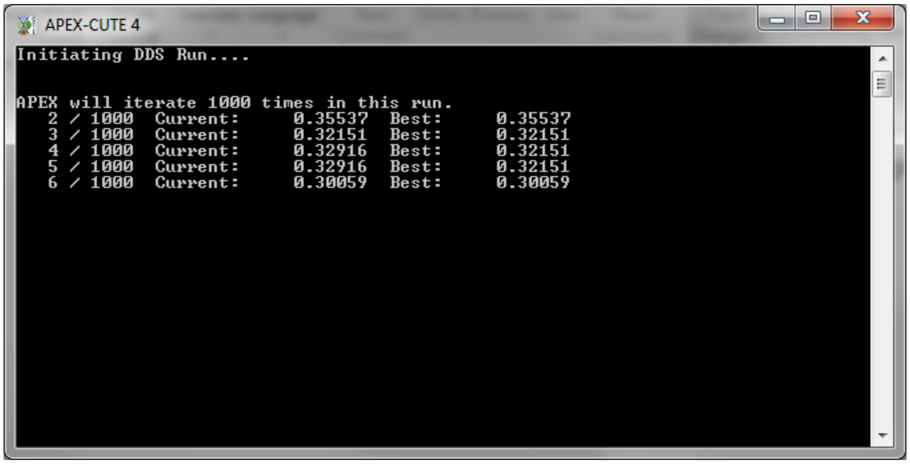


Figure 15. Screenshot of an APEX-CUTE processing window during calibration

9.4 Select starting/end date for calibration. Optionally, the user can also set a validation period and APEX-CUTE output will include performance statistics for both evaluation periods. It is advised that the APEX model is allowed to spin up for the first one or a few years before being evaluated. The calibration/validation period must NOT be out of APEX simulation period as set in APEXCONT.DAT.

9. Calibration Output

After the calibration is successfully completed, APEX-CUTE generates three output files in the project folder (Fig. 16).

a. The dds.out (Fig. 16a) contains:
   - Iteration run number (Run#);
   - Corresponding parameter set values (e.g., parm12, parm18, etc.);
   - Calculated objective function value (Test_OF) for this run; and
   - The best objective function value (Best_OF) identified so far.

b. The apex.out (Fig. 16b) saves:
   - Iteration run number (Run#);
   - Outlet ID
   - Output variable ID (VarID) where “1” represents flow, “2” represents sediment, etc. as described in the config.dat file line 4;
   - Objective function value of the run (Test_OF); and
   - The corresponding predicted output variable values (by day, month, or year depending on user’s choice of calibration time step as indicated in config.dat file line 8).

c. The modPerf.out (Fig. 16c) provides:
   - Iteration run number (Run#);
   - Outlet ID

- Output variable ID (VarID) where “1” represents flow, “2” represents sediment, etc. as described in the config.dat file line 5;
- Model performance statistics for each calibration output (e.g., flow and/or sediment) in each APEX iteration.

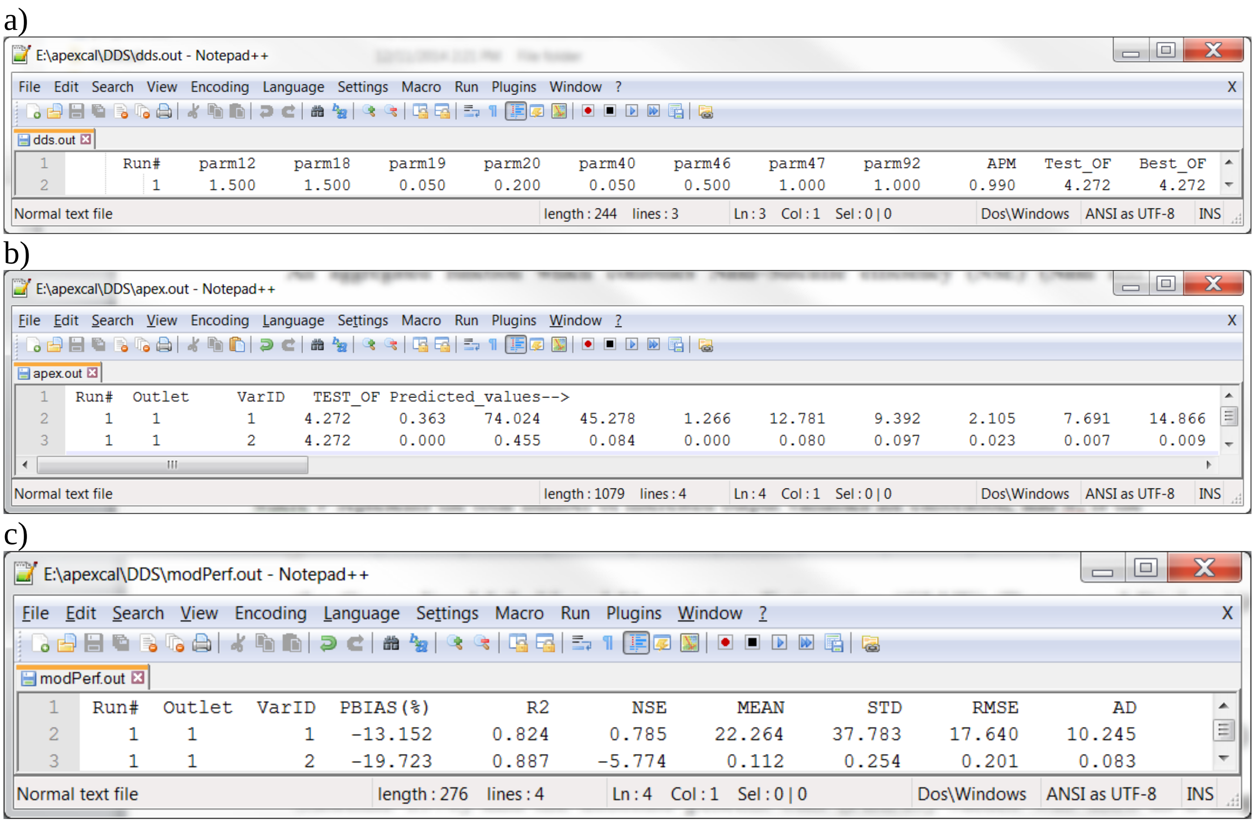


Figure 16. Calibration output files: a) dds.out; b) apex.out; and c) modPerf.out.

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