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Application of TREECS™ to Small Arms Firing Ranges at Fort Leonard Wood, MO

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PURPOSE: This technical note (TN) documents application of the Training Range Environmental Evaluation and Characterization System (TREECS™) (*http://el.erdc.usace.army.mil/treecs/*) to small arms firing ranges (SAFRs) located at Fort Leonard Wood, MO. This application provided an opportunity to further evaluate the utility of TREECS™; it also provided forecasting information to the installation regarding the fate of lead in bullets deposited on these ranges. This TN also provides guidance about the application of TREECS™.

BACKGROUND: TREECS™ was developed by the US Army Engineer Research and Development Center (ERDC). TREECS™ has varying levels of capability to forecast the fate of munitions constituents (MC), such as high explosives and metals, within firing/training ranges. TREECS™ also evaluates the likelihood of MC transport from firing/training ranges to surface water and groundwater. The overall purpose of TREECS™ is to provide environmental specialists with tools to assess the potential for MC migration into surface water and groundwater systems and to evaluate range management strategies for protecting human health and the environment. Although TREECS™ was developed for fate of MC on firing ranges, it has applicability to many other situations requiring prediction of contaminant fate in multi-media environmental systems.

OBJECTIVE: The primary objective in this TN is to document the application of TREECS™ to predict the fate of lead from rounds fired on small arms ranges 20-22 located at Fort Leonard Wood (FLW), MO. The secondary objective of this TN is to provide guidance on the application of TREECS™ to other users of this software.

PHYSICAL DESCRIPTION OF STUDY SITE: FLW is located in South-Central Missouri, approximately 120 miles southwest of St. Louis and 85 miles northeast of Springfield, Missouri. Site information summarized below was obtained from Engineering-Environmental Management, Inc. (2008) and Malcolm Pirnie (2006). The installation is approximately 61,410 acres and most of it is located in Pulaski County, with small portions located in Texas County and Laclede County. The site is bounded by the northerly flowing Big Piney River to the east and Roubidoux Creek to the west. The climate at FLW is classified as continental and is characterized by hot, humid summers and cold winters. Annual precipitation is approximately 41 inches, with the greatest amount of precipitation occurring during September and the least occurring in January. Rain showers and thunderstorms occur from March through November and snowfall typically occurs from November through March and averages 15 to 20 inches per year. The majority of FLW is underlain by Ordovician dolomites. Dissolution along fractures in the dolostone formations that underlie FLW form karst features. Sinkholes, caves, and springs are evident throughout FLW, but are most prevalent in the cantonment area and the northern portion of the installation.

FLW is located in the Springfield-Salem Plateau and is characterized by rugged rolling hills with narrow valleys. The installation can be characterized by two regions known as the Low Plains and the High Plains. Eighty percent of FLW is located in the High Plains region, which consists of gently to moderately rolling hills with deeply dissected tributaries to the major streams. Elevations in the High Plains region range from approximately 980 to 1,260 feet above sea level. The Low Plains region of the installation is characterized by the major stream valleys. A ridge running north-south lies in the central portion of the installation. The land surface in the Low Plains region ranges from approximately 750 to 1,150 feet above sea level near the northeastern installation boundary.

The soils located at FLW are formed in the dolostone and contain a high percentage of chert. Unconsolidated deposits range from a few inches thick to greater than 30 feet thick. Three official U.S. Department of Agriculture (USDA) soil types have been identified at FLW: Clarksville Gravelly Loam, Lebanon Silt Loam, and Huntington Loam. Clarksville Gravelly Loam is a cherty loam with gravel-sized deposits found at the FLW uplands. Lebanon Silt Loam is found specifically at the eastern uplands and has a more silty composition. The Huntington Loam is deep alluvium that lines the floodplains of the Big Piney River and Roubidoux Creek. Soils at Fort Leonard Wood are well drained, with permeability ranging from roughly two to 12 feet per day.

Surface-water drainage within FLW is by small tributary streams and dry washes that direct water from the central north-south trending topographic divide. Surface water from the eastern half of the divide drains into Big Piney River and surface water from the western half of the divide drains into Roubidoux Creek. Big Piney River flows for 9.5 miles along the eastern boundary and through FLW. The main tributaries to the Big Piney River on FLW include: Dry Creek, McCourtney Hollow, and Falls Hollow. Falls Hollow (also referred to as Quarry Hollow) is a gravelly bed, shallow stream that drains Ranges 20-22. Many unnamed tributaries also drain FLW into the Big Piney River, many of which are losing streams due to permeable sub-soils and karst bedrock conditions. Big Piney River supplies most of the potable water to FLW. Oak-hickory forests are the dominant vegetation on the uplands surrounding the study site.

Small arms ranges 20, 21, and 22 of FLW (see Figures 1 and 2) are used for close combat training. The combined area of these three ranges, including firing points and impact areas, is about 36 hectares (89 acres). These ranges drain into Falls Hallow as shown in Figure 3. There is concern that lead can be transported from the firing ranges into Falls Hallow, which crosses the installation boundary about three kilometers downstream of the firing ranges. The primary ammunition fired at Ranges 20-22 consists of 5.56 and 9 mm cartridges.

INPUT DATA: Input data required by TREECS™ consist of the following general categories:

- Installation name and description and description of the area of interest (AOI)
- GIS information (optional)
- Meteorological data and soil and hydrologic parameters used in applying the Hydro-Geo-Characteristics Toolkit (HGCT) to estimate inputs for fate models (optional)
- Tier analysis selection and applicable media, such as surface water and/or groundwater
- Munitions constituents (MC) selection, such as high explosive components (e.g., RDX, TNT, etc.), propellants, other organic chemicals, and metals (e.g., lead)
- Operational inputs, such as types and numbers of munitions used and related parameters

- Target health benchmarks and associated parameters for assessing media concentrations relative to levels that are highly conservative for protection of human and ecological health
- Site-specific fate modeling inputs for each of the medium models being applied
- Uncertainty analysis parameters (optional)

Figure 1. Aerial digital imagery of small arms ranges 20 – 22, Fort Leonard Wood, MO.

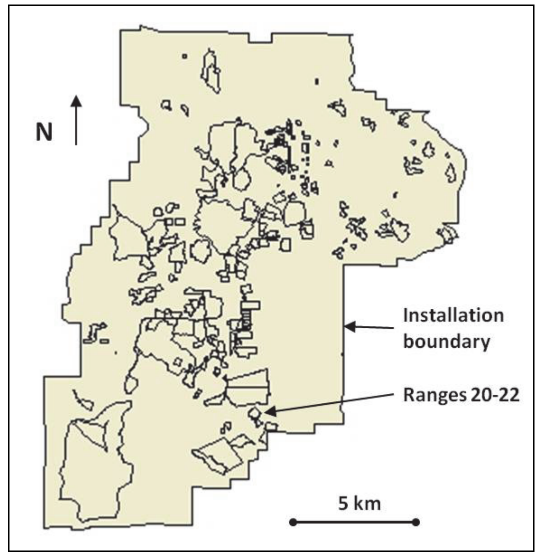


Figure 2. Map of Fort Leonard Wood, MO.

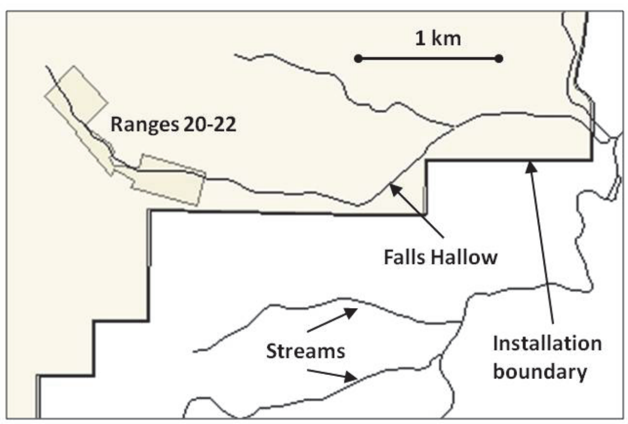


Figure 3. Drainage from Ranges 20-22.

Details regarding the above inputs are described in the sections below, except for uncertainty analysis, which was not used in this application.

Installation and Description: On the *Installation/AOI Description* screen, FLW must be entered as an installation and then selected. Brief text descriptions of the installation and AOI are entered primarily to aid the user in documenting the application.

GIS Information: GIS information is used to provide the user with: a better graphical depiction of the study site and the region surrounding it; delineation of the AOI where MC residue could accumulate; delineation of the watershed containing the AOI; and spatially explicit data that can be used within the HGCT of TREECS™ to provide improved estimates of model input parameters. This section focuses on the steps taken to transform input GIS files into grids to be used by the HGCT when it is applied in spatial mode. This section does not explain how to use the various tools and functionality within the TREECS™ GIS module; those concepts are explained in the help dialogs and within an appendix of the TREECS™ user guide, which can be found under the *help* menu of the TREECS™ main screen.

GIS Input Files Required: GIS files must be acquired from other sources to provide the information from which to build the GIS grid files that will be used within HGCT. The files that are required include:

- military range areas (shape file);
- soil classes (usually as shape file);
- land use map (usually as a grid file); and
- digital elevation map or DEM (grid file), or ground slope map (grid file) as computed from DEM with separate GIS software.

Other files that prove to be useful include background imagery, installation boundary (usually as shape file), watershed boundaries (shape file), and surface water features (shape file). In this study, the slope file was developed within ArcGIS using a DEM of the region surrounding FLW, but this regional DEM was also used within the TREECS™ GIS.

The FLW installation boundary and military range areas are shown in Figure 4 as mapped from input shape files. These shape files were obtained from the installation's Directorate of Public Works. The Pulaski County soil class map is shown in Figure 5 as mapped from the input shape file and zoomed in closer to installation boundaries. The soil class map was obtained from the Natural Resources Conservation Service's (NRCS) SSURGO database that was accessed through the NRCS Web Soil Survey tool (*http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx*). Web Soil Survey (WSS) is a powerful tool that can be used to find a host of soil-related properties.

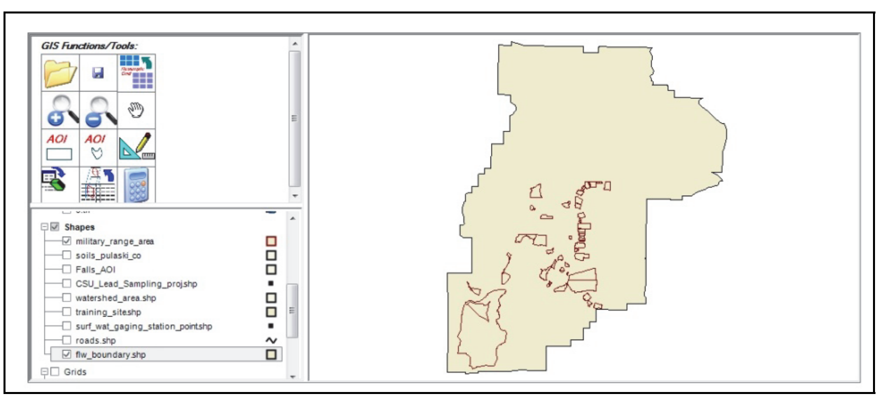


Figure 4. FLW installation boundary and ranges mapped from shape files within TREECS™ GIS.

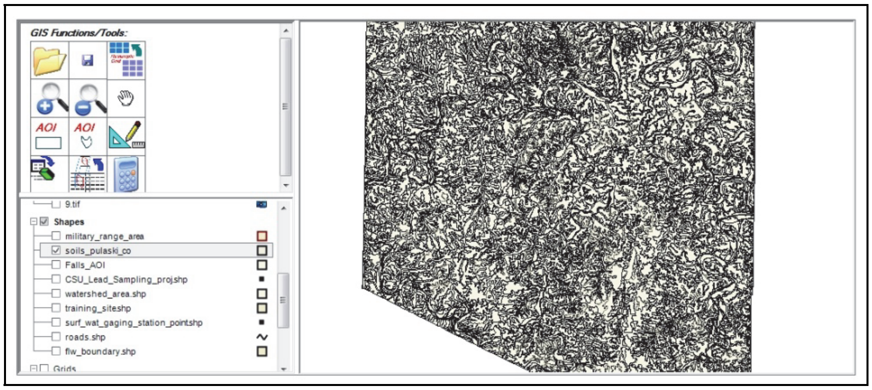


Figure 5. Pulaski County soil class map mapped from shape file within TREECS™ GIS.

The land use map is shown in Figure 6 as mapped from the input grid file, which was clipped in ArcGIS to correspond to only the region surrounding the FLW installation. The ground slope map is shown in Figure 7 as mapped from the input grid file, which was generated in ArcGIS from a DEM and clipped to correspond to only the region surrounding the FLW installation. The land use map, DEM, and digital orthoimagery were obtained from US Geological Survey National Map Viewer (http://viewer.nationalmap.gov/viewer/).

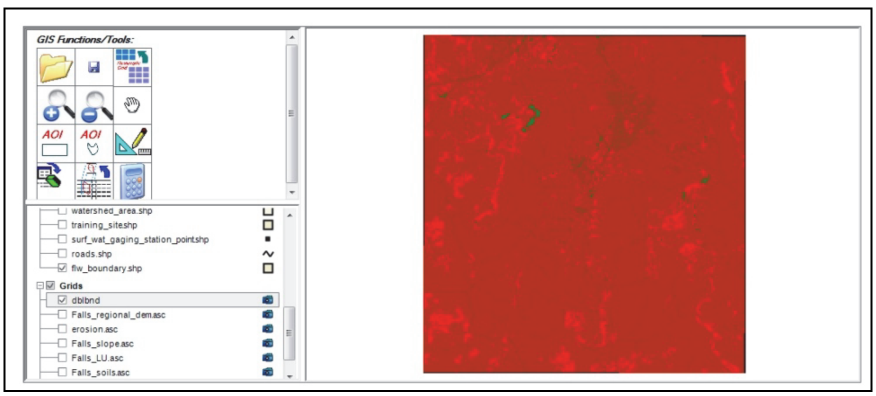


Figure 6. Land use map mapped from grid file within TREECS™ GIS.

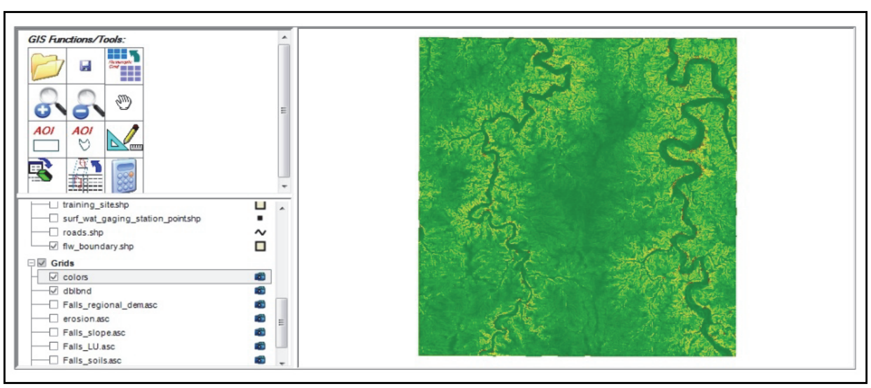


Figure 7. Ground slope map mapped from grid file within TREECS™ GIS.

AOI Shape File: The next step is to develop the area of interest (AOI) and its shape file. The AOI for this application is the impact areas of Ranges 20 – 22. These ranges are shown via digital imagery in Figure 1. The corresponding training ranges as mapped from the training range shape file look very similar to Figure 1 after zooming in. Using either the imagery or the range shapes as displayed within the TREECS™ GIS, the TREECS™ *AOI (polygon)* tool can be used to develop the AOI shape file. The use of this tool is explained within help files and the user guide, as stated previously. The resulting AOI polygon developed with this tool is mapped from the developed AOI shape file as shown in Figure 8. The default shape ID of 1 should be used when applying the AOI tool.

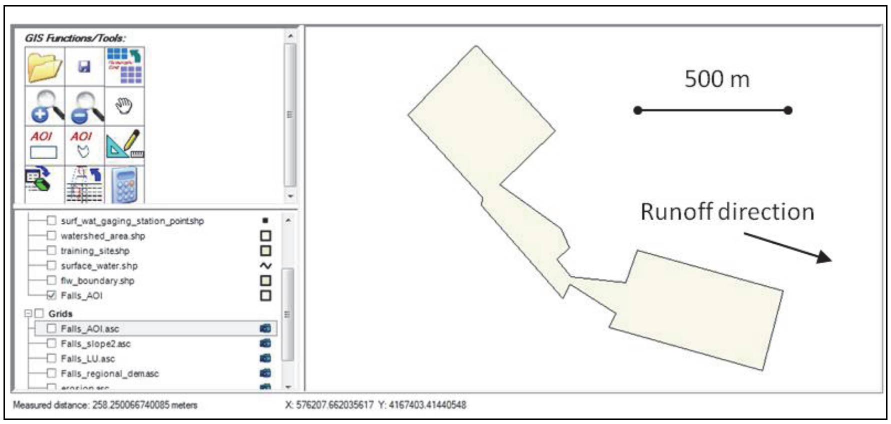


Figure 8. AOI displayed in TREECS™ GIS from shape file generated with the AOI (polygon) tool with flow direction and scale added later.

Template Grid: A template grid should be developed next. This template is a rectangular grid that is slightly larger than the AOI and encompasses all of the AOI. This template will be used to develop the AOI, soils, slope, and land use grids for the rectangular area surrounding the AOI, such that all four grids will have the same header values for the number of columns and rows and cell size, as required by the HGCT. One way to create a template grid is to first develop a template shape file using the *AOI (rectangular)* tool. The template shape file developed for this application is shown in Figure 9. The template is the orange rectangle that encloses the AOI shape as shown in Figure 9.

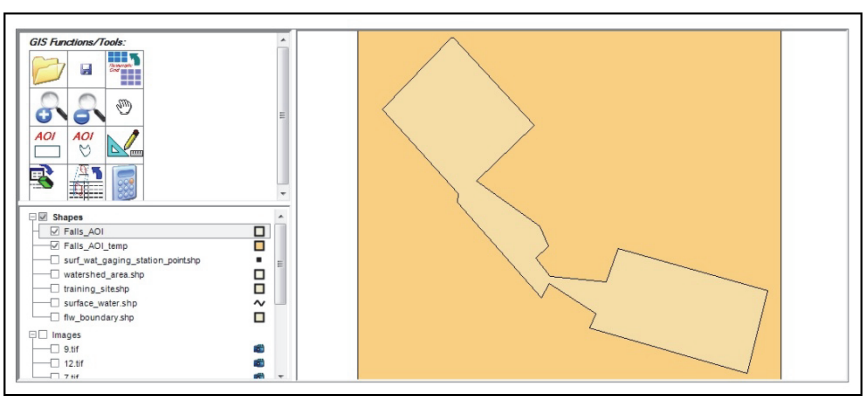


Figure 9. Template shape file (orange rectangle) for developing grids for the Falls Hollow AOI as displayed in TREECS™ GIS.

After this template shape file is developed, it must be converted to a grid file using the *convert shape to grid* tool. The user must specify the name and location of the template grid. When using the *convert shape to grid* tool, be sure to select the option for “do not use a grid template.” Select a grid cell size that is desired for all the grids to be used in HGCT. A grid cell size of 30 m is typically used so that the map files will not be excessively large. Some of the input GIS data, such as land use, will be coarser than 30 m in any case. Once the template grid is set up, it can be used for developing all four grid files that are required.

Generating Supporting Grid Files: Grid files for AOI, soils, land use, and land slope are required by the HGCT. The AOI shape file must be converted to a grid file using the *convert shape to grid* tool. Select the option to “use an existing grid template” and specify the template grid as the existing template. Generally, the soil classes will be available as shape files, as was the case in this example for FLW. The soils shape file must also be converted to a grid file using the *convert shape to grid* tool with the previously generated template grid file used as the existing template grid.

In this example, the land use and land slope information were available as grid files extending over a much larger region and with a cell size greater than 30 m. The *resample grid* tool must be used to develop 30 m grids using the template grid. Thus, the option to “use existing grid as template” should be selected.

After developing the four grid files with the same grid size (30 m in this example), location, and spatial extent (numbers of rows and columns), these files can then be used within HGCT (spatial mode) to compute soil, hydrologic, and erosion inputs needed by the soil MC fate model. The soils grid file that was developed for the template region surrounding the Falls Hollow AOI is shown in Figure 10 as an example. The other three grid files have the same location, grid size, and grid extent.

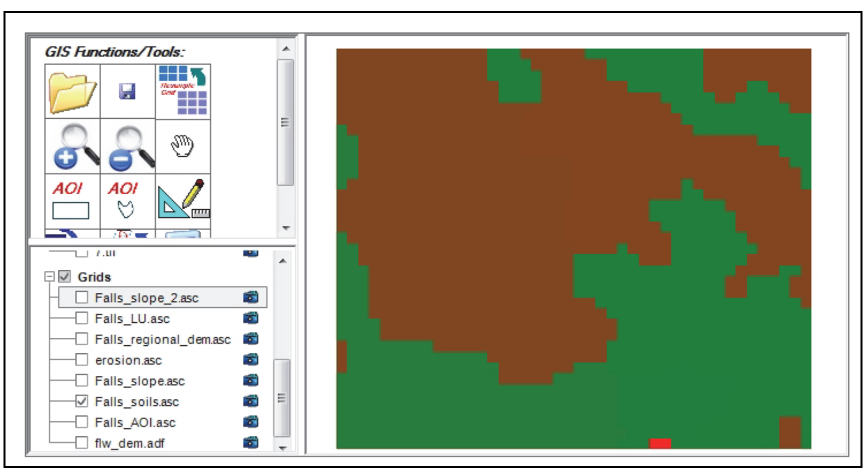
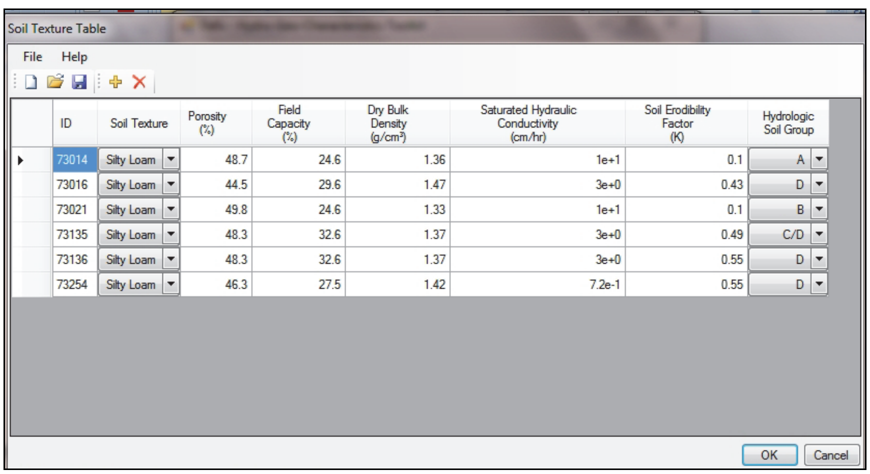


Figure 10. Soils grid for the AOI template displayed in TREECS™ GIS.

<u>**HGCT Application:**</u> Following set-up of the GIS information, the HGCT should be applied next to estimate soil and hydrologic information that will be required by the soil MC fate model. HGCT was applied in *spatial mode* to estimate AOI soil properties, soil erosion rates, and hydrology. Each is discussed below.

Soil Properties: The names of the map (i.e., grid) files must be entered for the AOI delineation (Falls_AOI.asc) and soil classes (Falls_soils.asc) that were generated within the GIS module. The specific gravity of the soil particles must be entered; a value of 2.65 is typical. The soil texture table of attributes must be opened and edited as necessary (see Figure 11). The soil names (classes) corresponding to the soil class IDs are shown in Table 1. The attributes shown in Figure 11 were specified based on soil information within ACCESS data files downloaded from WSS. Default values can be auto-filled based on soil texture selection in the absence of more detailed soils information. "Hydrologic soil group" must be selected by the user for each soil class ID. After saving the soil texture table, the *Run* button is clicked to generate the AOI-average soil properties shown in Figure 12. These soil properties can be automatically transferred to the soil fate model input screens.

Erosion: Within the *Erosion* screen of HGCT, the names of the four grid files (soils, land-use, AOI, and slope) that were generated within the GIS module must be entered for the required map file names. The land-use table must be edited as necessary. The crop management factors (*C*) of the Universal Soil Loss Equation (USLE) were adjusted based upon the land-use description and information available within the *Help* menu of the Land-use table user interface (UI). The *C* factors selected for each land-use or land-cover type surrounding the AOI are shown in Figure 13. The USLE conservation practice factors (*P*) were all set to 1.0, which is the default value within HGCT for firing ranges. The land-use table should be saved before exiting the table UI.



ID	Soil Texture	Porosity (%)	Field Capacity (%)	Dry Bulk Density (g/cm³)	Saturated Hydraulic Conductivity (cm/hr)	Soil Erodibility Factor (K)	Hydrologic Soil Group
73014	Silty Loam	48.7	24.6	1.36	1e+1	0.1	A
73016	Silty Loam	44.5	29.6	1.47	3e+0	0.43	D
73021	Silty Loam	49.8	24.6	1.33	1e+1	0.1	B
73135	Silty Loam	48.3	32.6	1.37	3e+0	0.49	C/D
73136	Silty Loam	48.3	32.6	1.37	3e+0	0.55	D
73254	Silty Loam	46.3	27.5	1.42	7.2e-1	0.55	D

Figure 11. Soil texture table of attributes within HGCT.

Table 1. Soil class ID and soil names in the AOI grid.

Soil Class ID	Soil Name
73014	Clarksville
73016	Viraton
73021	Poynor
73135	Union
73136	Union
73254	Ocie

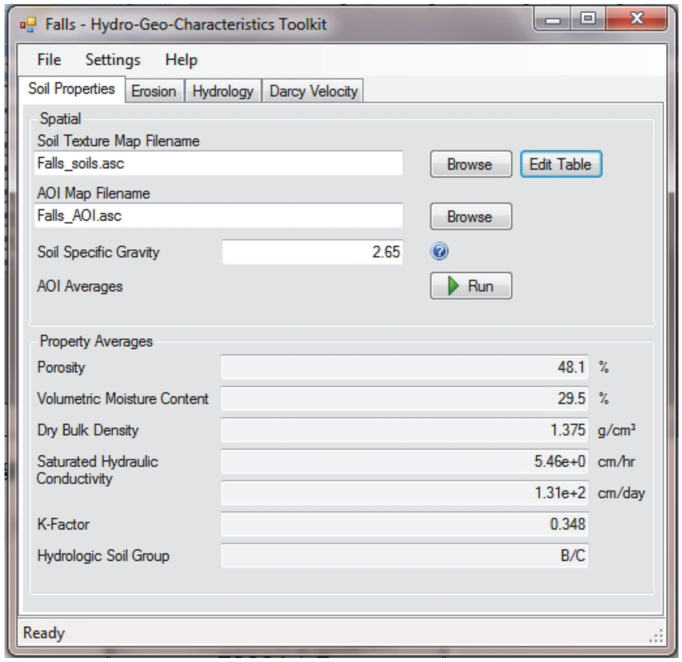


Figure 12. AOI Soil properties generated within HGCT.

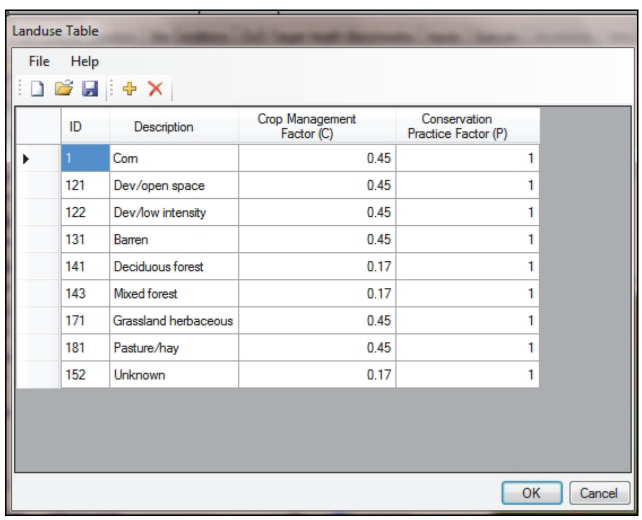


Figure 13. Land-use table of attributes within HGCT.

After editing the land-use table, the USLE rainfall factor must be entered for the region, and a value of 230 was selected, based upon the help map provided within the UI (the blue question mark). The run button is next clicked, and the erosion rates are generated and displayed as shown in Figure 14. The user can display the rates with or without applying a sediment delivery ratio (SDR), which accounts for eroded sediment trapping within the AOI before exiting. The SDR was not included in this application due to the relatively small size of the AOI.

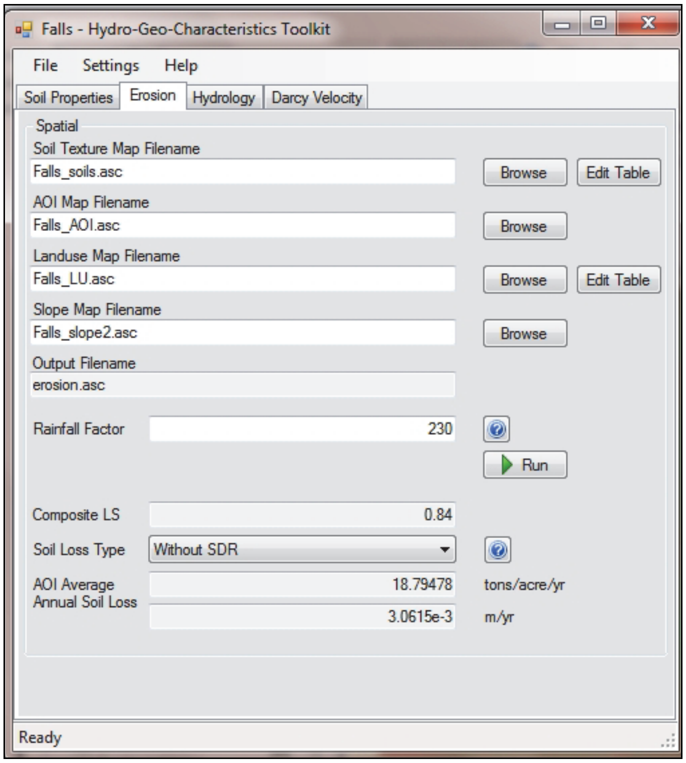
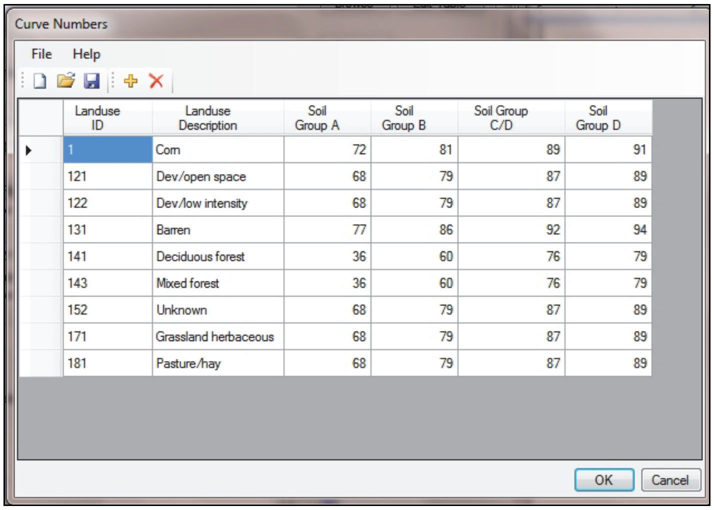


Figure 14. AOI erosion rates generated with HGCT.

Hydrology: Within the *Hydrology* screen of HGCT, the same names of three grid files (soils, land-use, and AOI) that were generated within the GIS module must be entered for the required map file names. Runoff within the hydrology module of HGCT is computed with the Soil Conservation Service curve number (CN) method. The curve number table must be edited to provide CN values for each land-use type and each hydrologic group as shown in Figure 15. The CN values were determined with the aid of information within the *Help* menu of the CN table UI. The CN table should be saved before exiting the table UI. Following exiting of the CN table, the *Compute* button should be clicked to generate the AOI-composite CN value, which is 73.7 for this application.

The filenames for the long-term precipitation and air temperature records must be entered as shown in Figure 16. These two text files contain daily precipitation and mean and maximum daily air temperatures, respectively, and are developed by the user from meteorology data obtained near the study site. Such data can usually be downloaded from the National Climatic Data Center (NCDC) of the National Oceanographic and Atmospheric Administration (NOAA) (http://www.ncdc.noaa.gov/cdo-web/), as was done in this case for station C238777 in Pulaski County, MO. After the data are downloaded from NCDC, spreadsheets can be used to import the raw data, and prepare the data for export as the required text files. The top portion of these two text files are shown in Figures 17 and 18. The records extending from January 1, 1950, through December 31, 2010, were used to develop these files. These data are used to develop long-term, average annual hydrologic inputs (precipitation, rainfall, runoff, infiltration, air temperature, annual number of days with rain, and evapotranspiration). Thus, it is not necessary that the record encompass the simulation period since the models are driven by average annual inputs; rather, it is more important that the record be long enough to develop good average annual values.



Landuse ID	Landuse Description	Soil Group A	Soil Group B	Soil Group C/D	Soil Group D
1	Corn	72	81	89	91
121	Dev/open space	68	79	87	89
122	Dev/low intensity	68	79	87	89
131	Barren	77	86	92	94
141	Deciduous forest	36	60	76	79
143	Mixed forest	36	60	76	79
152	Unknown	68	79	87	89
171	Grassland herbaceous	68	79	87	89
181	Pasture/hay	68	79	87	89

Figure 15. Curve number table within HGCT.

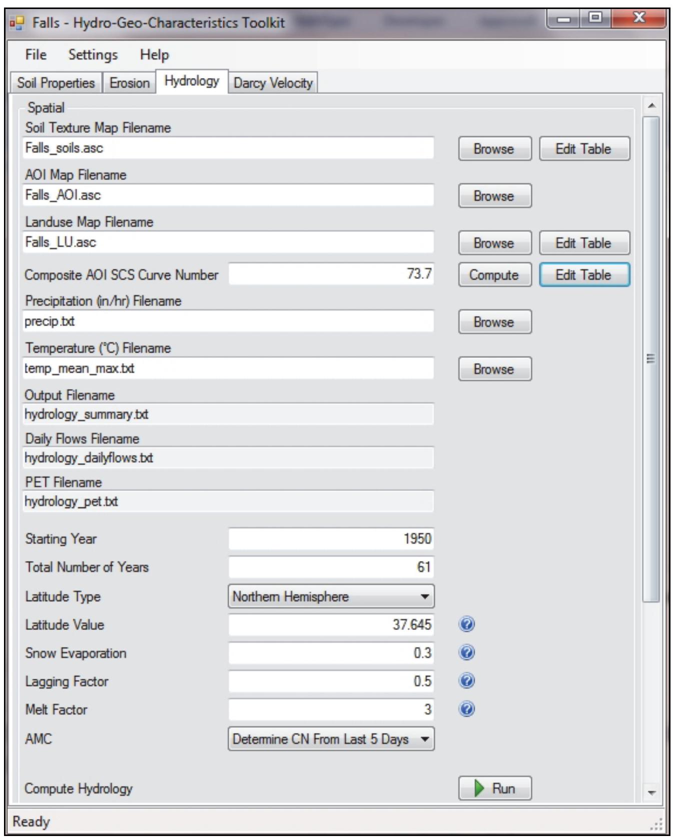
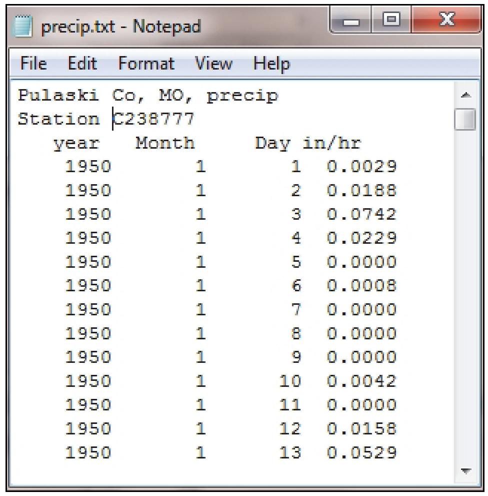
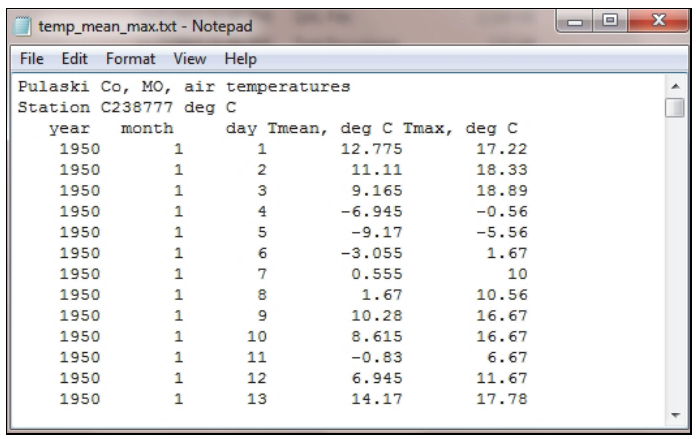


Figure 16. Hydrology inputs within HGCT.




```
Pulaski Co, MO, precip
Station C238777
   year   Month      Day in/hr
    1950       1        1  0.0029
    1950       1        2  0.0188
    1950       1        3  0.0742
    1950       1        4  0.0229
    1950       1        5  0.0000
    1950       1        6  0.0008
    1950       1        7  0.0000
    1950       1        8  0.0000
    1950       1        9  0.0000
    1950       1       10  0.0042
    1950       1       11  0.0000
    1950       1       12  0.0158
    1950       1       13  0.0529
```

Figure 17. Precipitation input file required by the hydrology module of HGCT.

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Pulaski Co, MO, air temperatures
Station C238777 deg C
   year   month      day Tmean, deg C Tmax, deg C
    1950       1        1       12.775       17.22
    1950       1        2        11.11       18.33
    1950       1        3        9.165       18.89
    1950       1        4       -6.945       -0.56
    1950       1        5        -9.17       -5.56
    1950       1        6       -3.055        1.67
    1950       1        7        0.555          10
    1950       1        8         1.67       10.56
    1950       1        9        10.28       16.67
    1950       1       10        8.615       16.67
    1950       1       11        -0.83        6.67
    1950       1       12        6.945       11.67
    1950       1       13        14.17       17.78
```

Figure 18. Air temperature input file required by the hydrology module of HGCT.

Other input parameters for hydrology are shown in Figure 16 below the *PET filename*. The starting year (1950) of the input meteorology and the number of years in the record (61) must be entered. The proper hemisphere and the latitude of the site must be entered. There are three snow-related parameters that must be entered, and the blue question mark symbols provide assistance for setting values for these. Finally, the user can either use the average CN value or have the software adjust it based on the previous five days of rainfall. Following all entries, the *Run* button is clicked to generate the site hydrology as shown in Figure 19.

It is emphasized that all of the hydrology outputs are average annual values for the period of record. Average annual hydrology is used to drive the processes within the fate models. Alternative versions of the HGCT and fate models have been developed that operate with daily varying hydrology. The daily varying hydrology option within TREECS™ has not been released yet, but tests have shown that this option yields results very similar to those generated with average annual hydrology after averaging daily results over years. The results generated within HGCT should be saved prior to exiting HGCT and returning to the TREECS™ main screen. The *Darcy Velocity* screen of HGCT was not used in this application since groundwater was not modeled.

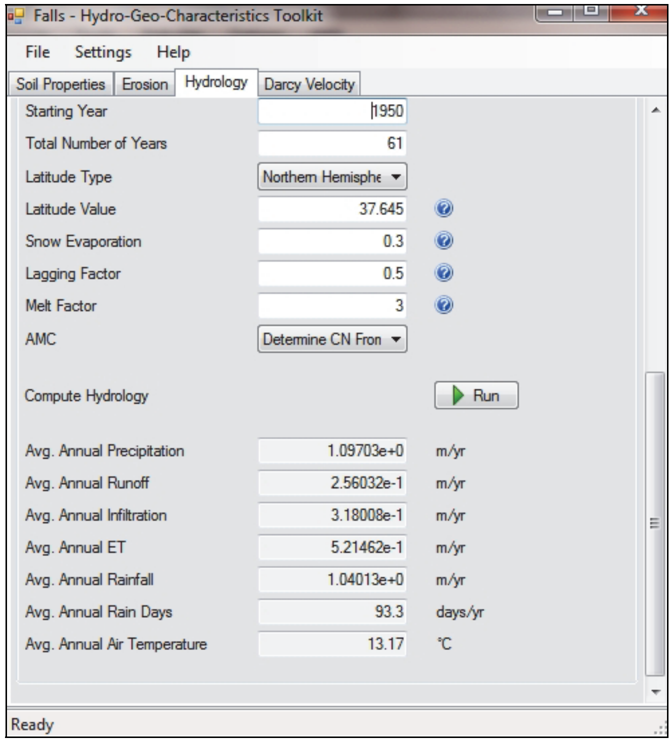

Figure 19. AOI hydrology generated with HGCT.

Tier Analysis and Applicable Media: The user must next click the *Tier Analysis Selection* tab of the main screen (see Figure 20), and select the appropriate level of analysis. Tier 1 analysis is generally used for initial screening studies, such as during or immediately following a Phase I assessment of a site during the Army's Operational Range Assessment Program (ORAP). Tier 2 analysis is generally used during and following a Phase II assessment of ORAP. Tier 2 is more involved that Tier 1, but it provides more accuracy for predicting MC fate. Tier 2 was used in this application. There is an *Advanced Tier 2* option that is object oriented and provides fairly extensive flexibility for setting up rather complex conceptual site models. On the *Tier Analysis Selection* screen, the applicable media must be chosen (see Figure 21). Only surface water was of interest in this application.

MC Selection: Munitions constituents selection is performed by clicking the *Site Conditions* tab on the main screen and then selecting the *Constituent Selection* sub-tab. Several choices of constituent databases are available, but the Army Range Constituent Database (ARCDB) was used for this application. The metal lead was selected from the list of available constituents within the ARCDB, as shown in Figure 22. Because the ARCDB has multiple values for constituent properties, when a particular constituent (such as lead) is selected, the user is prompted with another interface to choose the value for each property he or she wants to include in the analysis. The constituent properties included in this application for lead included molecular weight = 207.19 g/mole, molecular diffusivity in water = 9.45E-6 cm^2/sec, and density of 11.34 g/cm^3.

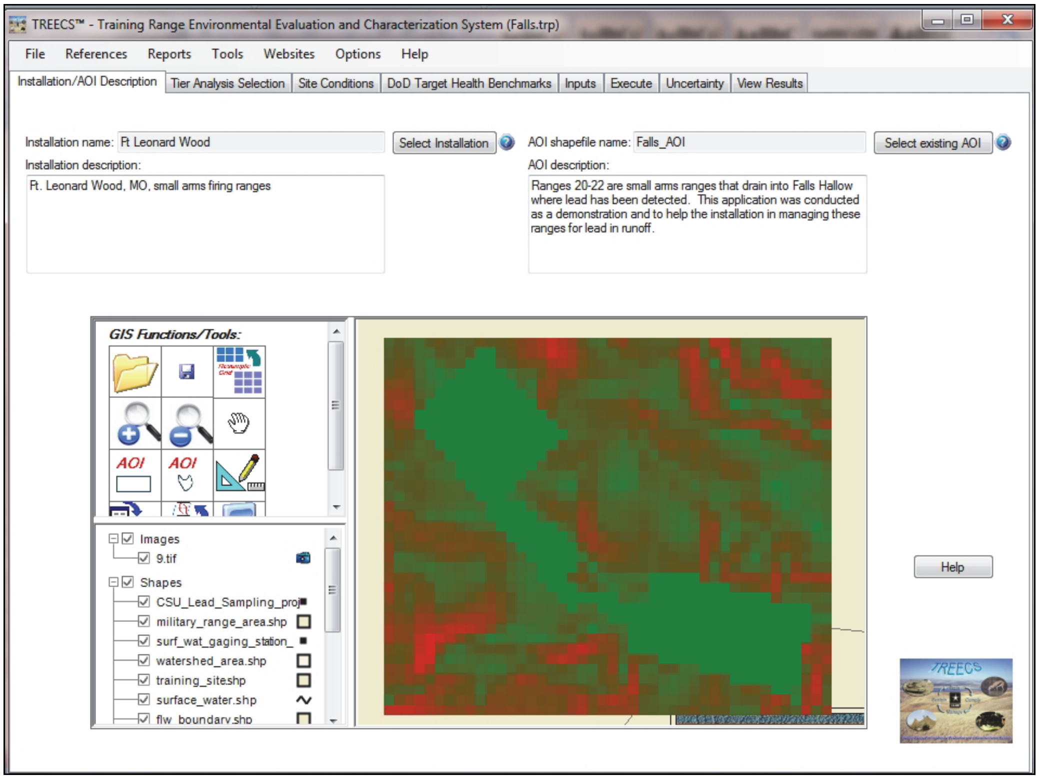

Figure 20. TREECS™ main screen for going to *Tier Analysis Selection* screen.

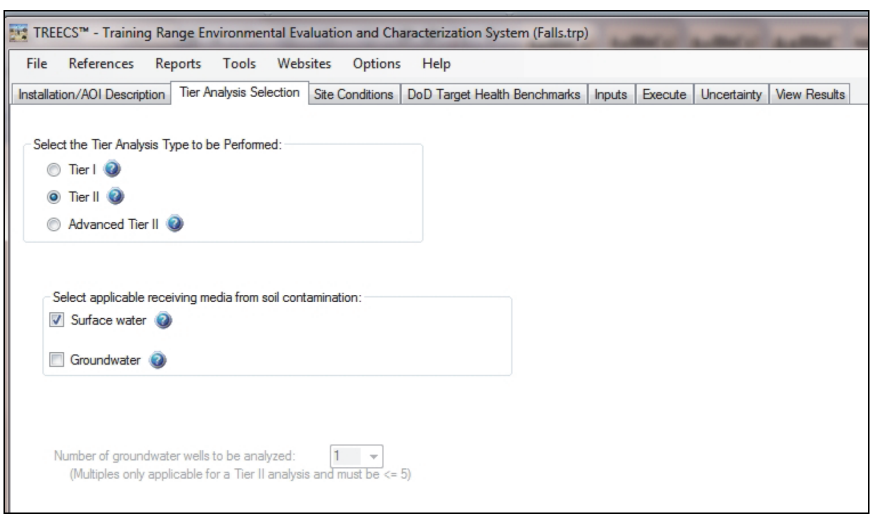

Figure 21. Tier and media selection within *Tier Analysis Selection* screen.

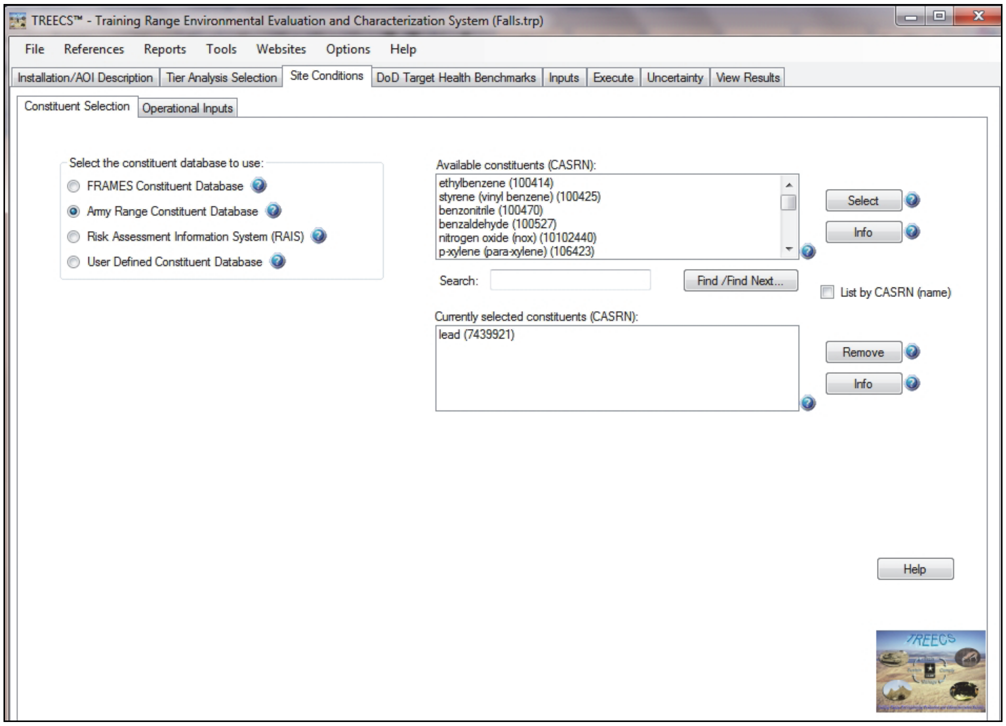

Figure 22. *Constituent Selection* screen for choosing the MC of interest.

<u>Operational Inputs:</u> Operational Inputs are also accessed from the *Site Conditions* tab. Training ammunition usage reports were provided for Ranges 20-22 by the installation. These reports were in the form of Range Facilities Management Support System (RFMSS) Excel spreadsheets. These spreadsheets were assembled by range, and included total numbers fired for the years 1999 through 2012 for each item used. Munitions items are designated by their Department of Defense Identification Code (DODIC) and the associated nomenclature or description. TREECS™ has a RFMSS filter that can be used to read the RFMSS spreadsheets and sort the priority of DODICs according to the most amount of MC mass delivered to the AOI. MC mass delivered depends on the amount of MC mass within each DODIC and the number fired for that DODIC. The highest priority items fired on Ranges 20-22 during the period 1999 through 2012 that contained lead are shown in Table 2, along with the total numbers fired and the average number fired per year for each DODIC. The total number fired per year for all four items was 2,432,568.

Table 2. Primary items fired on Ranges 20-22 during 1999-2012 containing lead.

DODIC	Description	Total fired over period	Number fired per year
A059	M855, 5.56 mm ball	23,288,744	1,663,482
A066	M193, 5.56 mm ball	2,352,634	168,045
A363	M882, 9 mm ball	8,406,554	600,468
A063	M856, 5.56 tracer	8,030	574
Total		34,055,962	2,432,568

The information in Table 2 was used to fill out the *Munitions usage information* as shown in Figure 23. The years of usage were set between 1941 and 2012. Since all of the items fired are small arms rifles and pistols, the dud, low order, and sympathetic occurrence percentages were set to zero, and all yields were set to zero. With a high order occurrence of 100 % and high order yield of zero, all of the lead mass delivered to the impact areas is deposited there without any loss. These inputs, as well as the number fired per year, were entered for each of the four DODICs. The firing rates per year were assumed to be constant from year to year for all years and all DODICs. This usage results in a metallic lead total loading rate to the AOI of 7,723,678 g/yr.

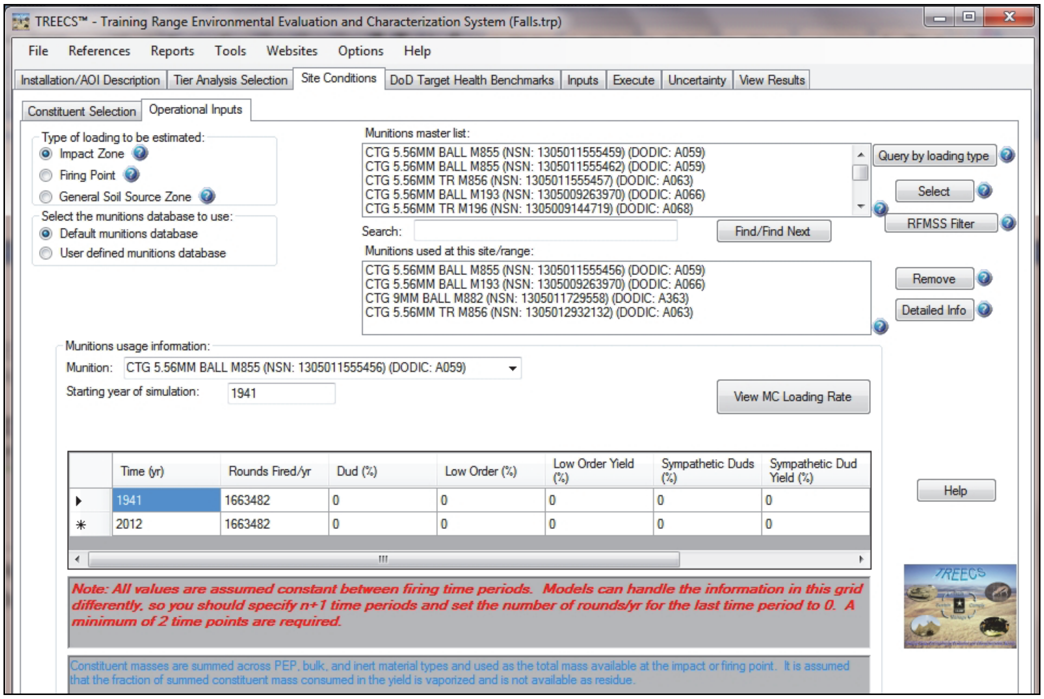

Figure 23. Operational Inputs screen for entering munitions usage.

Target Health Benchmarks: Target health benchmarks must be set up for lead. The Department of Defense (DoD) protective health benchmarks database within TREECS™ is used for this. The benchmarks within this database were established by a tri-service panel for highly conservative (overly protective) media (water, sediment, and groundwater) concentrations for both humans and ecological receptors. There are only a few entries required for this screen, as shown in Figure 24. The surface water is fresh water, so the checkbox for marine water/sediment is not checked. The fraction of total organic sediment (TOC) of the Falls Hollow sediments was not known, so it was assumed to be 0.02, which is a reasonable, typical value. Water quality data were downloaded from the United States Geological Service (USGS) National Water Information System (NWIS) Web site (*http://waterdata.usgs.gov/nwis/*) for station USGS 06930000, Big Piney River near Big Piney, MO for the years 1994 – 2002. These data included water hardness on five different dates. The average value of these five values is 153 mg/L as calcium carbonate. This value was entered within the *DoD Target Health Benchmarks* input screen as shown in Figure 24. The hardness is used to adjust the ecological surface water benchmark for lead. Benchmark values are used for comparing predicted fate model concentrations in media to see if those concentrations pose any potential health concerns.

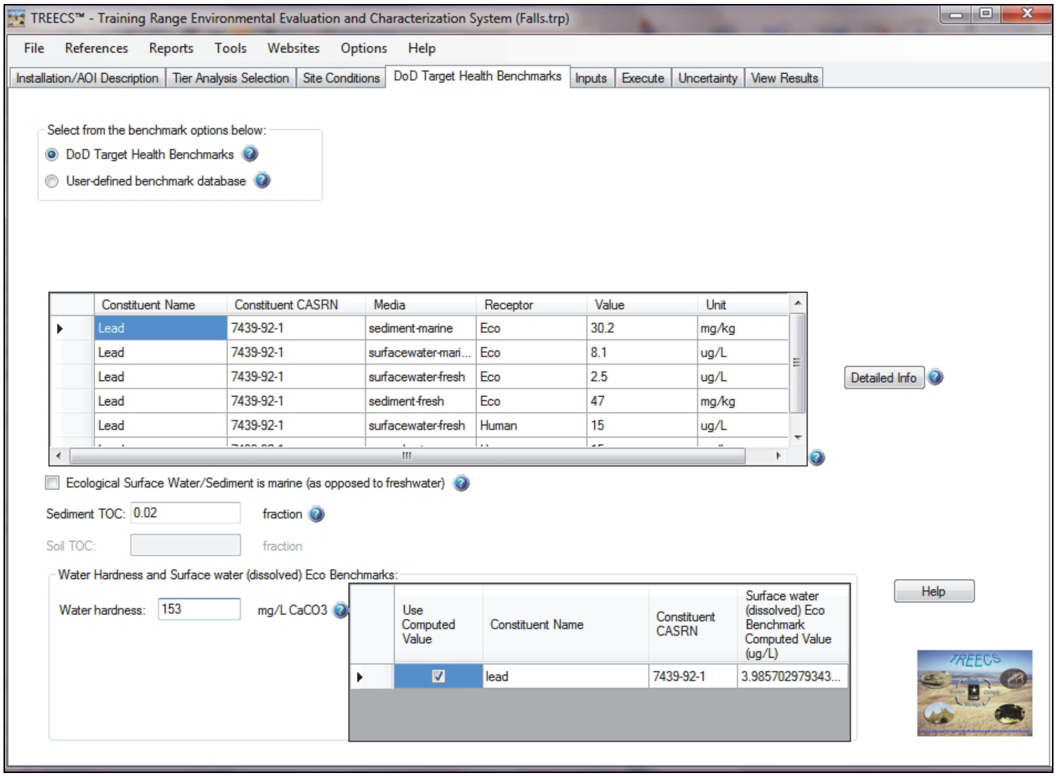

Figure 24. DoD Target Health Benchmarks input screen.

Site-Specific Fate Modeling Inputs: Two fate models were used in this application: 1) the Tier 2 soil model to compute export of lead from the AOI soil to Falls Hollow, and 2) the Contaminant Model for Streams (CMS) to compute water and sediment concentrations within Falls Hallow. The inputs for these two models are described below.

Soil Model Inputs: The AOI geometric data consist of the lengths of the AOI that are parallel and perpendicular to the runoff direction, and which are approximately 1350 and 275 m, respectively. The area of the AOI polygon (see Figure 8) is approximately 294,000 m^2. The soil properties, including average annual temperature and hydrology, were transferred from the HGCT application previously discussed by clicking *Load/Reload HGCT Data* option under the *File* menu in the soil model UI. Two of the chemical-specific properties were transferred from the constituent database information previously discussed. Table 3 lists the soil model input parameters, their values, and the source of their values. The most sensitive input parameters that are not well known are the solubility of lead and the initial particle size of lead fragments. These two inputs are discussed further below. The sorption partitioning coefficient of soluble lead (Pb^{2+}) to soil can also be highly variable and site-specific, but an order of magnitude increase had virtually no effect on model results.

Metal solubility can be quite complicated since it depends on the chemical form of the weathered metal product and the ambient soil chemistry. Visual MINTEQ (VM) (*http://www2.lwr.kth.se/English/OurSoftware/vminteq/*) was applied to gain an improved understanding of the lead solubility for this site. The discussion of the VM applications are beyond the scope of this TN, but the approach taken is like that discussed by Dortch (2012). The USGS water quality data for Big Piney River were used to get an estimate of anions in the local water, and cations were adjusted for fixed pH and free CO_2 to get a charge balance. With the adjustments for cations, VM was applied with free pH and CO_2 and infinite cerussite ($PbCO_3$) as the weathered lead product, which has a density of 6.6 g/cm^3. This yielded a good charge balance, soil pH = 6.5, and dissolved lead concentration of 3.85 mg/L.

Table 3. Tier 2 soil model inputs for the Falls Hollow application.

Input parameter	Value	Units	Data source
AOI length	1350	m	GIS measure
AOI width	275	m	GIS measure
AOI surface area	294,000	m^2	GIS measure
Active soil layer thickness	0.4	m	default
Soil-water matrix temperature	14.17	Deg C	transferred from HGCT
Annual MC residue mass loading rate of lead	7,723,678	g/yr	transferred from operational inputs
Initial concentrations of lead	0	mg/kg	assumed initial conditions
Volumetric soil moisture content	29.5	percent	transferred from HGCT
Soil dry bulk density	1.375	g/cm^3	transferred from HGCT
Soil porosity	48.1	percent	transferred from HGCT
Average annual precipitation	1.097	m	transferred from HGCT
Average annual rainfall	1.040	m	transferred from HGCT
Average annual runoff	0.256	m	transferred from HGCT
Average annual infiltration	0.318	m	transferred from HGCT
Average number of rainfall events per year	93	Unit-less	transferred from HGCT
Average annual soil erosion rate	3.06E-3	m/yr	transferred from HGCT
Vadose zone saturated hydraulic conductivity	478	m/yr	based on HGCT; this was used to estimate soil interflow of zero
Soil-water K_d for soluble lead (Pb^{+2})	597	L/kg	from K_d estimator in soil model UI based on pH of 6.5, and silty loam with 3% organic matter from WSS info
Degradation half lives	1.0E20	years	no degradation for metals
Average particle diameter of lead fragments	1000	µm	based on help file for Loess silt
Lead fragment particle shape	spherical	Unit-less	assumed
Volatilization rate	0	m/yr	lead does not volatilize
Lead water solubility	3.85	mg/L	based on estimates from applying Visual MINTEQ
Lead Henry's constant	0	Atm-m^3/mol	Assumed since lead does not volatilize
Lead molecular weight	207.19	g/mol	transferred from constituent database
Density of lead weathered product $PbCO_3$	6.6	g/cm^3	web search
Length of simulation	100	years	user choice

There is a help file within the Tier 2 soil model for estimating the average initial particle size of metal fragments associated with the impact of small arms projectiles. This help file contains metal particle size distributions for six different soil types that were obtained experimentally (Larson et al. 2005) from firing M855 rounds (5.56 mm rounds) into catch boxes. However, none of the six types correspond well to the silty loam soils of the Falls site. The closest match of the six to the Falls site soils is the Loess silt soil. The mean particle size for lead fragments in the Loess silt was about 1,000 µm, which is the value used in this application. Other factors besides soil type, such as distance between firing point and impact, can affect metal fragment size.

CMS Inputs: The point of interest along the Falls Hollow stream is where the stream crosses a county road near the installation boundary; the point of interest is a sampling location. The approximate flow distance from Range 22 (the AOI exit) and the sampling location is 3.2 km. This distance was divided into 20 equally spaced computational segments. The model time step was set to 1.0 year, but this input parameter is relatively unimportant since the model has an automated time-stepping feature. All model input values are shown in Table 4 along with the source of the values.

Some of the values in Table 4 need further explanation. The hydraulic parameters in Table 4 are particularly important since they affect MC dilution, travel time to point of interest, and MC concentration. A USGS stage gage became operational in March 2013 at the highway bridge noted above. About five and a half months of data for this gage were obtained from the USGS Web site (*http://waterdata.usgs.gov/mo/nwis/uv/?site_no=06929900&PARAmeter_cd=00065,63*) and were analyzed to estimate average flow and stage. The average reported flow for the period was 3.4 ft^3/sec (cfs) with a corresponding stage of 0.787 feet. The zero flow datum for the USGS gage is 0.65 feet. This flow rate agrees fairly well with an estimated average annual flow rate of 2.8 cfs, which is the estimated average annual runoff flow rate of 1.8 cfs, plus an estimated base flow rate (due to groundwater discharge) of about 1.0 cfs. The average annual runoff flow rate was obtained by multiplying the HGCT-computed runoff depth by the Falls Hollow watershed area upstream of the gage — information which was obtained from GIS — and accounting for proper units. An average annual stream flow rate of 3.4 cfs and corresponding stage of 0.787 feet translates into an annual flow rate of 3.0E6 m^3/yr with a stream depth 0.042 m; these last two values are used in the model. An approximate stream width of 3.0 m was used based on visual observation. This width resulted in a flow velocity of 2.5 ft/sec for the average annual flow rate and flow depth; a rectangular channel was assumed. This velocity agrees well with that computed from Manning's equation of 2.3 ft/sec using a Manning's *n* value of 0.025, the average annual flow depth, and the channel slope estimated from GIS.

The value for TSS was obtained from an average of the USGS data reported for Big Piney River. TSS measurements were started during 2013 on Falls Hollow, but the data available to date is provisional and was obtained during a major storm event on April 10, 2013, that resulted in discharges up to 102 cfs with TSS values as high as 115 mg/L. These data were used to develop a linear fit of TSS versus discharge with an intercept of zero. This fit was extrapolated to yield TSS = 2.8 mg/L for an annual average flow of 3.4 cfs. With such a large extrapolation from flood to low flows, it seemed more prudent for now to use the average of the TSS data from the Big Piney River. This input can be adjusted when additional TSS data become available from Falls Hollow for low flow conditions.

Table 4. CMS inputs for the Falls Hollow application.

Input parameter	Value	Units	Data source
Number of computational segments	20	Unit-less	user choice
Time step	1.0	yr	user choice
Total simulation time	99	yr	One less than soil model
Longitudinal dispersion coefficient	1.0	m^2/sec	typical value for streams
TSS concentration in stream	9.0	mg/L	Average of USGS data for Big Piney River
Depth of active sediment layer	0.1	m	typical value
Dry sediment particle specific gravity	2.65	Unit-less	typical value for inorganic sediments
Sediment porosity	0.7	Unit-less	typical value
Fraction organic carbon in water column TSS	0.02	Unit-less	typical value and agrees with USGS Piney Creek data
Fraction organic carbon in bed sediment	0.02		typical value
Average annual water temperature	14	Deg C	set to same value as used for soil
Average annual wind speed	5	m/sec	assumed (not used for lead)
Distance from entry point to usage location	3200	m	measured from GIS
Stream average width	3.0	m	based on site visit observation
Stream average depth	0.042	m	based on gage readings and other considerations
Stream average annual flow rate	3.0E6	m^3/yr	based on gage readings and other considerations
Background and initial stream concentrations	0	mg/L	assumed
Decay rates for various phases	0	per day	most metals do not decay
Partitioning distribution coefficient for adsorption of lead to water column TSS	500,000	L/kg	based on help file in TREECS™
Partitioning distribution coefficient for adsorption of lead to bed sediment	40,000	L/kg	based on help file in TREECS™
Volatilization rate	0	m/day	lead is not volatile
Mass transfer rate between sediment pore water and water column	0.0038	m/day	computed within model UI
Molecular weight of lead	207.19	g/mole	transferred from constituent database
Molecular diffusivity of lead in water at 25 deg C	9.45E-6	cm^2/sec	transferred from constituent database
Henry's law constant	1.0e-20	atm-m^3/g-mole	should be zero but zero is not accepted, so a very small value is entered
TSS settling rate	1.0	m/day	assumed for silts and coarse clays
Sediment burial rate	1e-20	m/yr	assumed to be very small (bed in equilibrium for deposition and resuspension)
Computed sediment resuspension rate	3.77E-5	m/yr	computed by model from steady-state solids balance

MODEL OUTPUT

The soil and stream models were executed within TREECS™. The AOI export mass fluxes computed by the soil model are automatically supplied as input loadings to the CMS model of Falls Hollow. The results of this application are shown in Figures 25 and 26 as total (particulate and dissolved) and dissolved lead water concentrations, respectively, versus time at the Falls Hollow bridge (3.2 km downstream of the AOI or firing ranges).

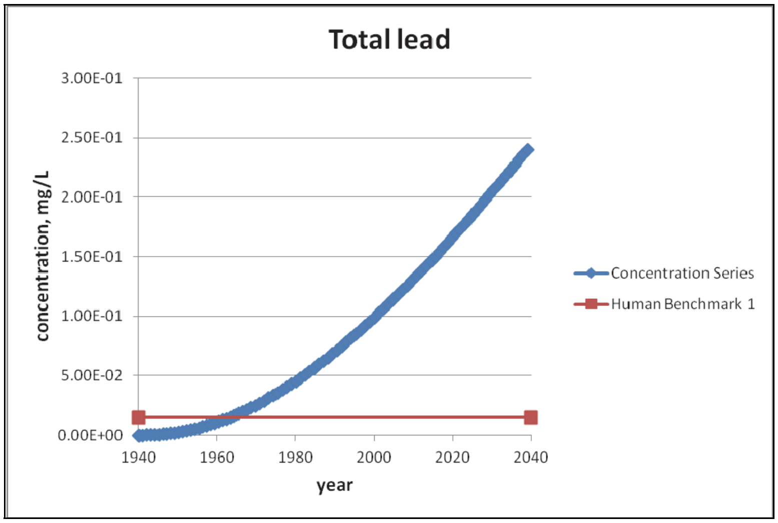

Figure 25. Model-computed concentration of total lead versus time for Falls Hollow at the bridge.

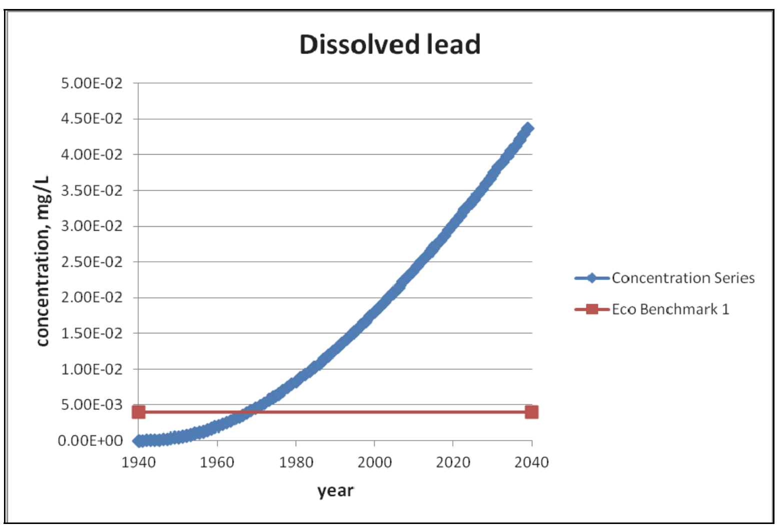

Figure 26. Model-computed concentration of dissolved lead versus time for Falls Hollow at the bridge.

Examination of Figures 25 and 26 reveals that the total concentration of lead is about an order of magnitude greater than the dissolved concentration, or that most of the water concentration of lead is in particulate form (i.e., adsorbed to TSS). If the TSS lead partitioning coefficient is reduced two orders of magnitude, the total concentration does not change noticeably, but the dissolved concentration comprises nearly all of the total concentration. The human and ecological protective health benchmarks are also shown on the two figures for reference purposes.

There was one grab sample obtained from Falls Hollow on January 31, 2012, that was analyzed for a total lead concentration of 0.027 mg/L or 27 parts per billion (ppb) (Kelly 2013). The model-computed total lead concentration during 2012 is 0.14 mg/L (140 ppb) or about five times greater than the observed value. However, it is noted that the model-computed value represents roughly an average annual value, whereas the observed value is a snap-shot in time for a particular flow condition. Flow conditions can have a major effect on stream concentrations. It is expected that during base flow conditions, stream water column concentrations of lead would be very low due to lack of any lead loading from the AOI. During high flow conditions, there could be substantial lead loadings to the stream from the AOI, but high watershed runoff will also dilute stream concentrations. Medium-size storms could potentially cause higher stream concentrations of lead than those associated with large storms or low, base flows. There was rainfall of 1.15 inches between January 25 and 28, 2012, but it is not known what the stream flow was then or on January 31, or how that flow could have impacted stream lead concentrations.

There is also considerable uncertainty associated with several model inputs, the most important being the solubility and the fragment particle size of lead. A fivefold increase in the initial, mean particle size of lead (from 1,000 to 5,000 μm) causes about a fivefold decrease in computed stream total lead concentration. Solid phase particle size affects the particle dissolution rate and thus the AOI export rate of MC. The distance between firing point and impact affects lead bullet fragmentation and associated particle size. The firing distance for the experimental catch box studies of Larson et al. (2005) was about 100 m. Targets on Ranges 20-22 vary from 50 to 300 m. Training qualification requirements for these ranges indicate that the median target distance is 150 m. It is expected that the greater firing distance of 150 m (compared with 100 m) would result in larger lead fragments, which reduces the dissolution rate and AOI export rates.

There are good firing records for these ranges over the past fourteen years, but prior to that period, there are no records. Thus, the number of rounds fired each year during previous decades is not known and assumed to equal the firing for the past 14 years. Stream concentrations are directly proportional to range firing rates.

CONCLUSIONS: This TN documents the application of TREECS™ to SAFRs 20 – 22. These SAFRs drain into Falls Hollow, a small tributary to the Big Piney River, near Fort Leonard Wood, Missouri's eastern border. This application of TREECS™ demonstrates how relatively available information and data can be used to readily assess the fate of MC (in this case lead) deposited on firing/training ranges. Given that there were limited site-specific measurements to aid in establishing model input parameters affecting fate processes, other techniques were employed, including the use of model help files, default values for input parameters, standard assumptions, and typical values based on other studies. Model results were within an order of magnitude of one observed grab sample analyzed for total lead in Falls Hollow. This level of agreement is relatively good given the uncertainty of several model inputs, particularly range firing rates prior to 1999 and mean particle size of lead fragments. More observations of stream lead concentrations for a range of flow conditions are required to provide a better understanding of lead fate at this site and the ability of the model to represent that fate. An option is being added to TREECS™ to allow computations with daily varying hydrology and stream transport. This option will be useful for comparison to observations for varying flow conditions.

POINT OF CONTACT AND ACKNOWLEDGEMENT: For additional information, contact Dr. Mark Dortch (601) 634-3517, *Mark.S.Dortch@usace.army.mil*. This study was funded under the U.S. Army Environmental Quality and Installations (EQI) Research Program of the US Army Engineer Research and Development Center. This technical note should be cited as follows:

> Dortch, M.S. 2013. *Application of TREECS™ to small arms firing ranges at Fort Leonard, MO*. ERDC TN-EQT-13-2. Vicksburg, MS: US Army Engineer Research and Development Center.

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