

Development of a GIS Based Dust Dispersion Modeling System.
F.C. Rutz, B.L. Hoopes, D.J. Crandall, K.J. Allwine
Pacific Northwest National Laboratory
Richland, Washington

Abstract

With residential areas moving closer to military training sites, the effects upon the environment and neighboring civilians due to dust generated by training exercises has become a growing concern. Under a project supported by the Strategic Environmental Research and Development Program (SERDP) of the Department of Defense, a custom application named DUSTRAN is currently under development that integrates a system of EPA atmospheric dispersion models with the ArcGIS application environment in order to simulate the dust dispersion generated by a planned training maneuver. This integration between modeling system and GIS application allows for the use of real world geospatial data such as terrain, land-use, and domain size as input by the modeling system. Output generated by the modeling system, such as air concentration and ground deposition patterns, can then be displayed upon accurate maps representing the training site. This paper discusses the development of this integration between modeling system and Arc GIS application.

Introduction

As residential areas continue to develop closer to military sites, the military has become more concerned with the possible effects this may have on civilians, the environment, and how dust dispersion may possibly impede training exercises. During 2000, Pacific Northwest National Laboratory (PNNL) began a research project for the Strategic Environmental Research and Development Program of the Department of Defense (SERDP) to develop an atmospheric dust dispersion modeling system named DUSTRAN that would aid in particulate air quality at military training and testing sites (Allwine et al. 2001). This modeling system would use historical, current and user defined data within a geographic information system (GIS) application to generate simulations for use in managing dust generating activities and developing dust mitigation strategies (Allwine et al. 2001). The finished modeling system would need to be Windows compatible, operate on a personal computer, and be site dynamic (Crandall and Rutz 2004).

Selection of the GIS application

The developed modeling system consists of three integrated units: the graphical user interface (GUI), the atmospheric modeling software, and the GIS application. The atmospheric modeling software used within the system requires user inputs that are geospatial in nature as well as inputs that are numeric or textual and as such the GUI and the GIS application need to be closely integrated in order to eliminate any possible confusion on the part of the user. For example, spatial inputs such as lines representing roads traveled during a training maneuver need to be entered using the drawing

capabilities of the GIS application while data such as the number and speed of the vehicles traveling on the road need to be entered within the GUI. The GIS application chosen for the modeling system would also need to be usable by numerous users with varying expertise in both GIS applications as well as atmospheric modeling. Due to DUSTAN's potential wide spread use, the initial decision was to use Environmental System Research Institute's (ESRI's) ArcView3.2 as the GIS application, and in 2001, a prototype of the modeling system was developed.

For the initial prototype of the modeling system a version of the ArcView 3.2 application was integrated with an existing atmospheric dispersion modeling system named APGEMS (Allwine and Bian 1995)(Glantz et. al 2000) through the use of Avenue scripts. While this integration provided the basic functionality needed by the modeling system, the GUI and the interface of the ArcView 3.2 application were still separate, forcing users to switch back and forth between the two applications in order to make changes to simulation runs or update the map display. This switching between applications proved to be confusing to users and at times caused refresh problems with the ArcView application. With the release of ArcMap8.1 came additional functionality that gave the development team the ability to closely couple the two interfaces into a single window and eliminate the need to switch between applications.

With the release of ArcMap 8.1, came the ability to add custom tools and interfaces to the interface of the ArcMap 8.1 application. Custom tools and interfaces could now be added to the ArcMap 8.1 application through the use of ActiveX DLLs (Zeiler 2001). Another benefit to using the ArcMap application was its ability to make use of geodatabase files (Zeiler 2001). Because the modeling system was intended to execute numerous simulation runs at multiple sites the storage requirements for the software could potentially become a concern in addition, the large number of files present in an installation would add an extra level of confusion for a user trying to find data files associated with a simulation run. Each site present in the modeling system would require its own set of files defining the map layers, saved source data, saved domain data, and saved simulation results. Using a geodatabase file as a repository for this data reduced the number of these files to one for each site and stored the data in a format that would be easy for a user to search and retrieve data from. The use of the geodatabase file also eliminated the need for the software to track multiple paths and load into memory multiple files for a simulation run. With the new functionality and capabilities present in ArcMap 8.1, the development team decided to change the GIS system from ArcView 3.2 to ArcMap 8.1 and development of the final modeling system was started.

Description of the Computational Model Integration

The DUSTAN modeling system uses a computation system based upon the EPA-approved CALPUFF dispersion model (Scire et al. 2000a) and the widely used CALGRID dispersion model (Scire et al. 1989). Generation of the meteorological data used by the CALPUFF and CALGRID models, such as wind fields, is handled by the CALMET meteorological model (Scire et al. 2000b) that is also integrated within the system. In order for the Calmet and Calpuff models to execute successfully within the modeling system, an automated system of processors are required to be executed in order to supply the proper data needed by the models. With the exception of the dust emission

processor, the processors and models are legacy code written in the FORTRAN programming language and as such eliminated the option of directly linking the codes.

This integration of processors with the Calmet and Calpuff models is accomplished through the use of a software model manager. Written in Visual Basic, the software model manager is code that controls the order in which the executables of the processors and models are executed as well as controlling the flow of data between the executables.

Each processor and model requires input data to be passed to it in files of differing formats. The model manager accomplishes this through the use of a standardized directory structure that is used for each site that is present in the modeling system. Prior to the execution of a processor or model, the software manager retrieves parameter data from the user interface, GIS interface, and default parameter files and then creates the needed input files required by the processor or model and places them into the appropriate directory used by the processor or model. The software model manager also ensures that certain parameters such as domain size, domain location, run time, and run duration are synchronized between all of the models and handles any conversions that are needed. Once the input files have been created and placed, the manager executes the model or processor that is needed at that point of the simulation using a standard Windows API call. Following the execution of a processor or model, the software model manager performs a check for a successful execution and if an error is encountered notifies the user of which model or processor produced the error and that the simulation has been stopped. Upon the successful completion of a processor or model run, the software manager relocates the output files to the appropriate input directories required by the next processor or model.

Besides the creation of input files and scheduling the execution of the processors and models, the software model manager also processes and creates input data required by the Calmet and Calpuff models. If the user selects the "Use single observation" option for meteorology, the manager calculates constant wind field data based upon input entered by the user and creates the appropriate wind files used by the Calmet file. For each individual point source selected by the user for a simulation, the manager also calculates a receptor grid based on polar coordinates and updates the input file for the Calpuff model accordingly. Figure 1.0 outlines the flow of data between the software model manager and the modeling system's processors and models.

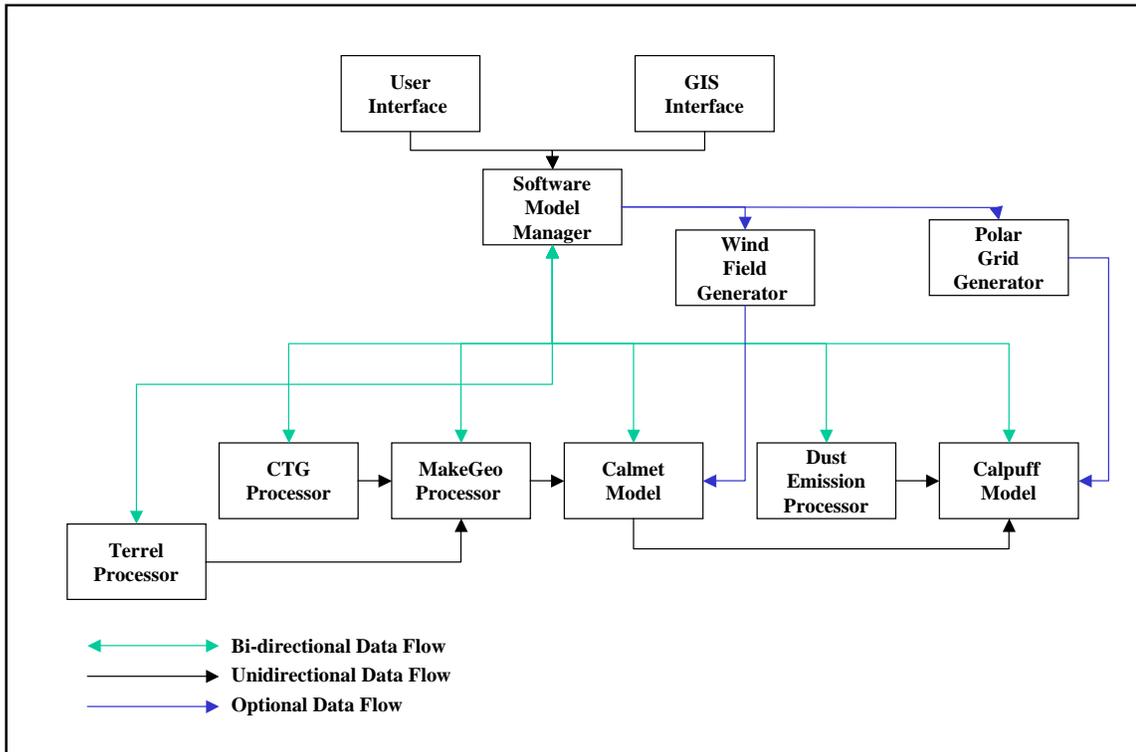


Figure 1.0 Processor and model data flow using software model manager

Development of the User Interface

In order to create the needed coupling with the GIS application and achieve the desired level of usability, the user interface was developed as an ActiveX DLL using the Visual Basic programming language. Once developed, the DUSTRAN interface was integrated with the interface of the ArcMap 8.1 application using the customize option of ArcMap 8.1 and then registering the appropriate ActiveX DLL using the Categories application supplied with the install of ArcMap 8.1. Using the Microsoft Component Object Model (COM) the interface was developed as a dockable window that could be integrated with the interface of the ArcMap 8.1 application much like the table of contents window. Designed with a main panel that would be used to enter data related to the general inputs required to run a simulation, the interface also consists of a set of dialog windows that are used for the input of data related to individual sources and the saving of data. Figure 2.0 displays an example of the DUSTRAN interface integrated with the ArcMap 8.1 application interface.

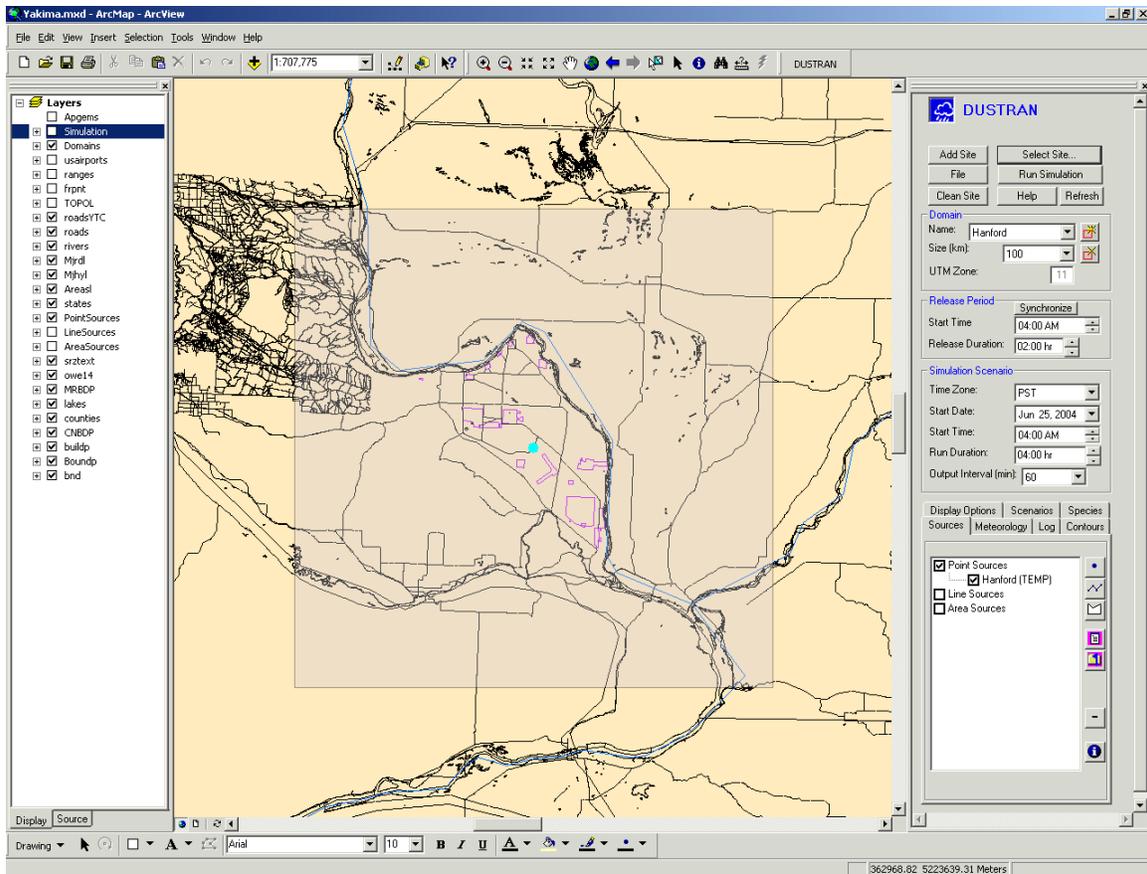


Figure 2.0 Example of the Dustran interface integrated with the ArcMap 8.1 interface.

Making use of the ArcObjects framework provided by the ArcMap 8.1 application, the user interface is able to interact directly with the map display of ArcMap 8.1. This direct interaction with the ArcMap 8.1 application allows changes entered by the user in the interface of the Dustran modeling system to be immediately reflected within the map display. The user is also able to use the built in drawing functionality found in ArcMap 8.1 to perform operations such as adding a new source or domain location to the simulation run. This integration with ArcMap also gives the Dustran interface the ability to load the processed results data automatically into the map display following the completion of a simulation run eliminating the need for any input from the user such as file locations or layer names. User inputs required by a simulation run fall into five categories: simulation time period, meteorological data, site data, source data, and domain data. The following are descriptions of how the ArcMap application can be used by the user in conjunction with the Dustran user interface to enter the required inputs for the modeling system and view the results that are generated.

Selecting or Adding a Site

The Dustran modeling system was designed to be site dynamic and as such is capable of adding a new site with very little preparation from the user. A software utility wizard is integrated within the Dustran interface that walks the user through the four

step creation process of adding a new site to the system. Besides inputs such as site name and meteorological station information the utility also requires the user to select a set of shapefiles that will be used to define the site. Once the needed data is entered by the user, the utility creates the directory structure for the site and registers it with the DUSTRAN modeling system. Along with the creation of the directory structure, the wizard will also create a new geodatabase for the site using the shapefiles selected by the user. The extent and projection of the geodatabase is automatically set by the wizard based upon the extent and projection information retrieved from the selected shapefiles. Tables in the geodatabase used by the system for storing source, domain and simulation results are also generated at this time. Following the creation of the geodatabase the user can use ArcMap to load the desired layers of the map from the tables found within the geodatabase. Once the layers of the map are organized, the user then saves the ArcMap project using the same name as the site and then places the resultant .mxd file into the appropriate site directory. Following the creation of the ArcMap project file, the user is able to use the site within the DUSTRAN modeling system.

Opening a site that has been added to the modeling system is started by accessing the “Select Site” option of the DUSTRAN main interface. Once the option has been selected, a dialog window will be displayed presenting a list of available sites that the user can select from. Selecting a site name from the list will result in the software automatically loading the appropriate ArcMap project file for the selected site name. Once the project file is loaded, the first domain will be selected by the software and the map display extent will be set to the domain’s location and a default size of one hundred kilometers.

Selecting or Adding a Domain

By taking advantage of the functionality found within the ArcObjects framework, adding a new domain to the modeling system is as easy as using the mouse to select a point on the map display and then entering a name for the new domain. The process is started by selecting the “Add Domain” option found on the DUSTRAN interface. Once the option has been selected, the system will prompt the user to select the location of the new domain’s center point by clicking on the map display using the computer’s mouse. Clicking a point on the map display will then result in a dialog window being displayed asking for the name of the new domain. After the name has been entered, the system creates ten default square polygons corresponding to the default domain sizes used by the modeling system and then stores them in the Domain table of the geodatabase. Default domain sizes within the range of 20 to 400 kilometers are available within the modeling system. Figure 3.0 displays the possible domain sizes for a selected domain.

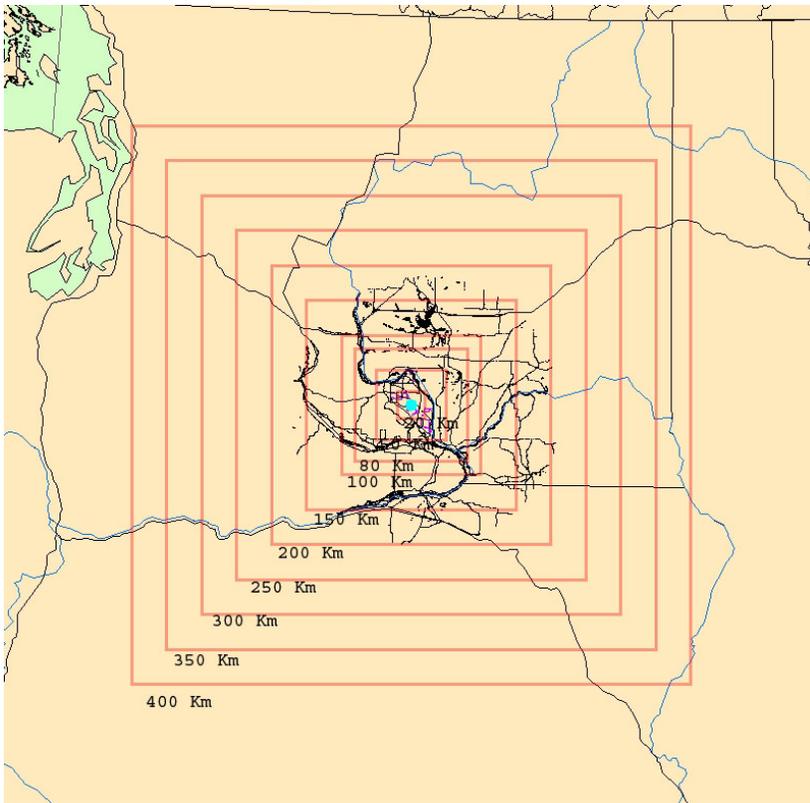


Figure 3.0 Possible Domain Size Choices Available within DUSTRAN.

Following the creation of the new domain, the software adds the name of the new domain to the domain list found in the main interface and then changes the extent of the map display to correspond with the location of the domain with a default size of 100 kilometers. To change the location or size of the currently displayed domain the user only needs to make the appropriate selections in the DUSTRAN interface and the view within the map display will be automatically adjusted to the extent of the selected domain.

Selecting or Adding a Source

The modeling system is capable of using multiple sources as well as differing source types. The computational models that are used to perform the simulation are able to accept point, line, and area sources for input and as such, the modeling system was developed to allow the user to make use of the drawing functionality found within ArcMap to add new sources by drawing the shape of the source directly onto the map display.

To add a new source to the current simulation the user first selects the appropriate “Add Source” button located on the “Sources” tab of the DUSTRAN interface. Following the selection of the source type, the user can add the source to the map display through the use of map clicks. Once the user has drawn the desired source onto the map, dialog windows are displayed prompting the user for the name of the source and additional information concerning the characteristics of the source. For point sources this information includes emission rates for the different species selected for the simulation as

well as information concerning characteristics of the source such as elevation, velocity, and temperature. For the purpose of simulating a training maneuver, line and area sources are used to represent wheeled vehicle movement. As such, the user can elect to enter the emission rates through the interface or allow the emission model of the system to generate them based upon vehicle information selected by the user. Figure 4.0 shows the line source input window used to enter emission values and Figure 5.0 shows the input window used to enter vehicle information for the line source.

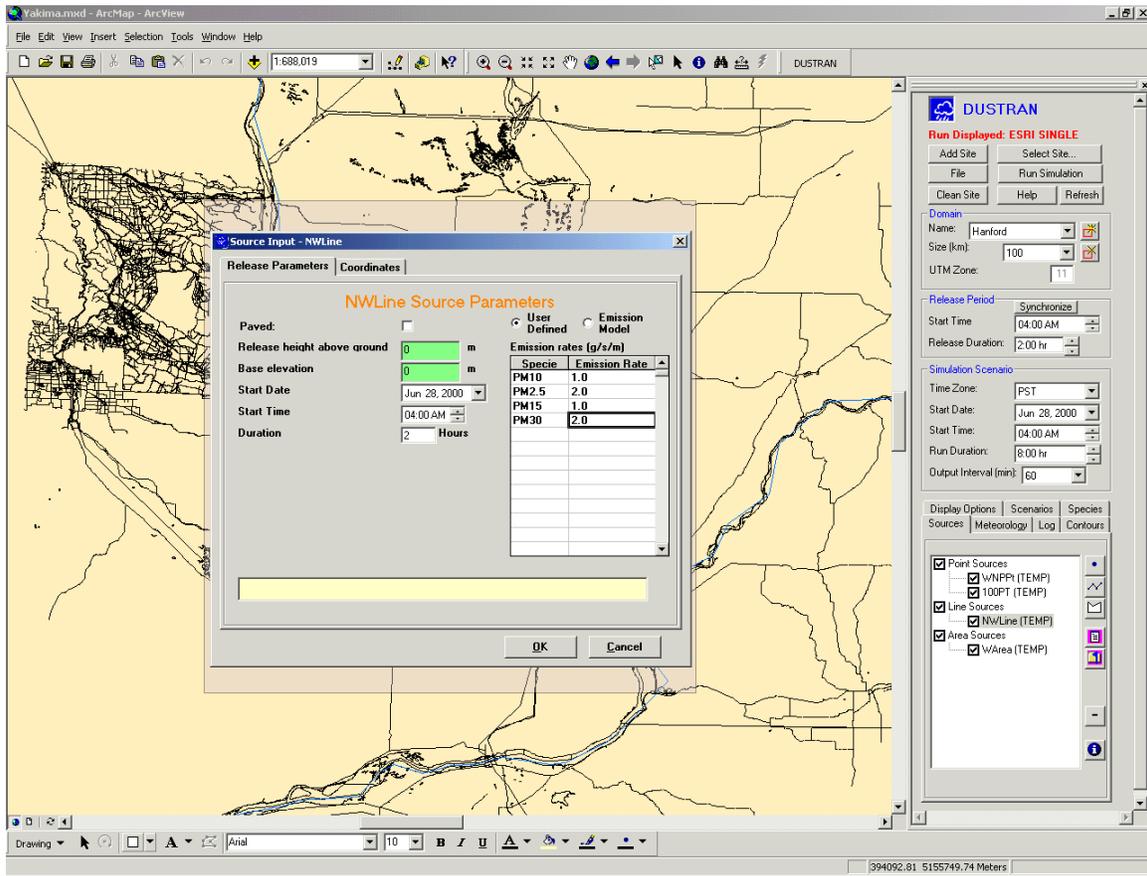


Figure 4.0 Example Line Source Input Screen.

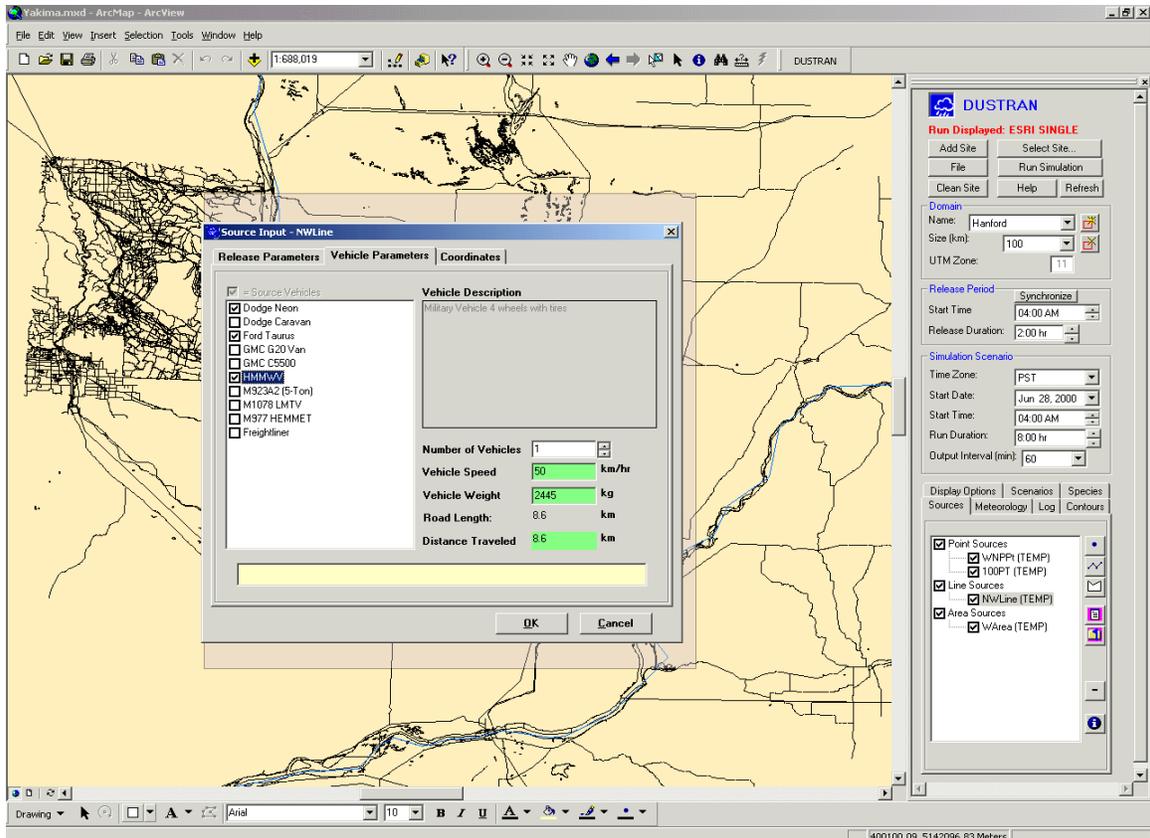


Figure 5.0 Example Vehicle Information Screen for a Line Source.

Once the required source information has been entered by the user, the source name is added to the source list in the “Sources” tab and the source shape and associated data are stored within the appropriate table of the geodatabase. Sources displayed in the source list of the “Sources” tab are automatically updated depending upon the location and size of the domain used for the simulation. Using the ability to execute spatial queries within the ArcObjects framework, only the sources that lie within the boundary of the selected domain are displayed and available for use in a simulation run. To include a source in a simulation run the user selects the names of the desired sources listed in the source list by clicking on the check box located next to each source name. Once selected, sources are highlighted in the map display of ArcMap 8.1 showing which sources will be included in the simulation run. By default, sources entered for a simulation are only stored temporarily within the geodatabase and are removed whenever a new simulation is started or the simulation site is changed. To save sources long term within the geodatabase, the user has the option of saving the sources displayed in the source list as a scenario. Once this option has been selected, dialog windows will be displayed prompting the user for the name of the scenario as well as any comments they would like to add to the window. Following the saving of a scenario it is added to the list of scenarios in the “Scenario” tab and the sources will be available for other simulation runs. Source scenarios can be loaded into a simulation run by selecting the desired scenario name and clicking upon the “Add Scenario” button. Sources contained within a scenario are viewable by the user by clicking upon the scenario name in the list and the sources will

be displayed within the map display as highlighted features. Figure 6.0 displays an example of the map display with a scenario selected.

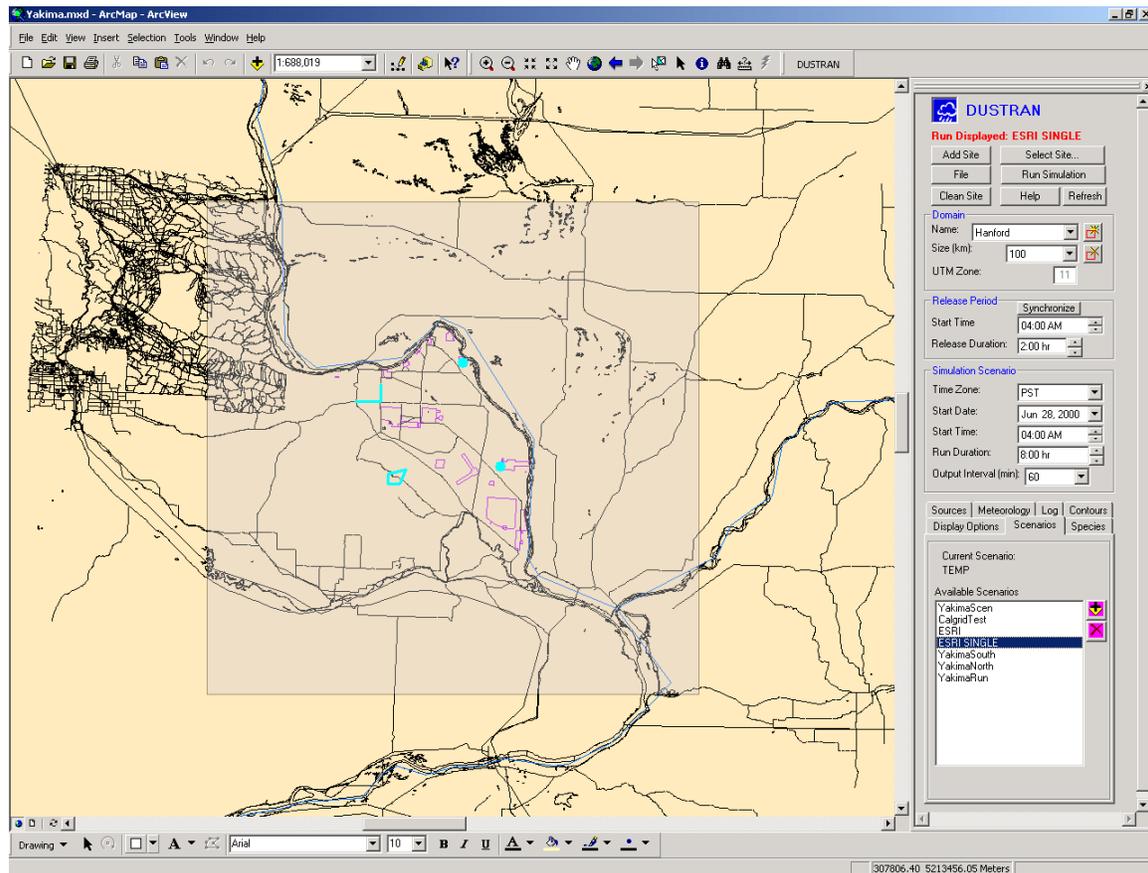


Figure 6.0 Example of a Selected Source Scenario.

Displaying Simulation Results

Results generated by the modeling system include concentration time series, deposition time series, and wind vector field data. Concentration and deposition values are generated for each of the species selected for the simulation run. These values are then processed into polylines representing contour levels by a contouring processor. The resultant contour lines are then stored within the geodatabase and displayed within the map display of the ArcMap application. The contour lines displayed upon the map display represent the simulated dust plume as it moves over time across the surface of the simulation site. Once displayed, the user has a variety of ways in which to view the contour lines. Contours are displayed based upon hour increments and the differing values of the data being contoured. Within the DUSTRAN interface users can select the individual contour levels, result types (e.g. air concentration, ground deposition), time periods, and species they wish to view in the map display. These selections are then displayed as graphics on top of the map layers representing the simulation site. The user also has the option to animate the contours over time for selected contour levels and species. Processed contours are by default stored within the geodatabase temporarily and

will be deleted with the start of a new simulation run. Users are able to save simulation run results long term in the geodatabase by using the “Save Run” option and entering a name for the run and any comments they wish to attach to the run data. Once a run has been saved, input data entered for the run is loaded into the DUSTRAN interface and results are loaded into the map display of the ArcMap application. Figure 7.0 is an example of the contour levels displayed for a single time step.

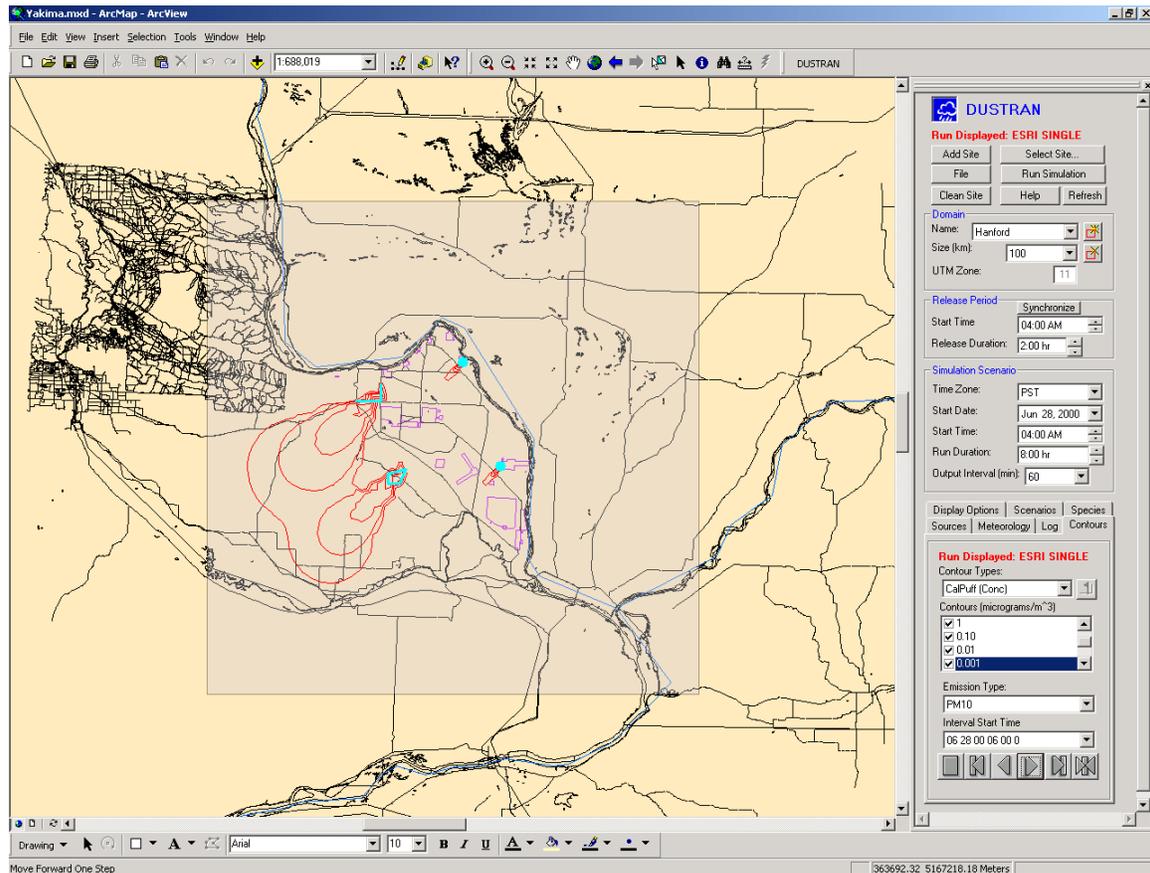


Figure 7.0 Contour Levels Displayed for a Single Time Step.

Besides the display of concentration and deposition values, the modeling system is also capable of displaying the hourly wind vector fields generated by the CALMET model. The wind vector fields are displayed by time interval as well as height and are represented by scaled vectors on the map display that automatically update with the time step of the contours being displayed. Figure 8.0 shows an example wind vector field generated by the CALMET model using historical meteorological data.

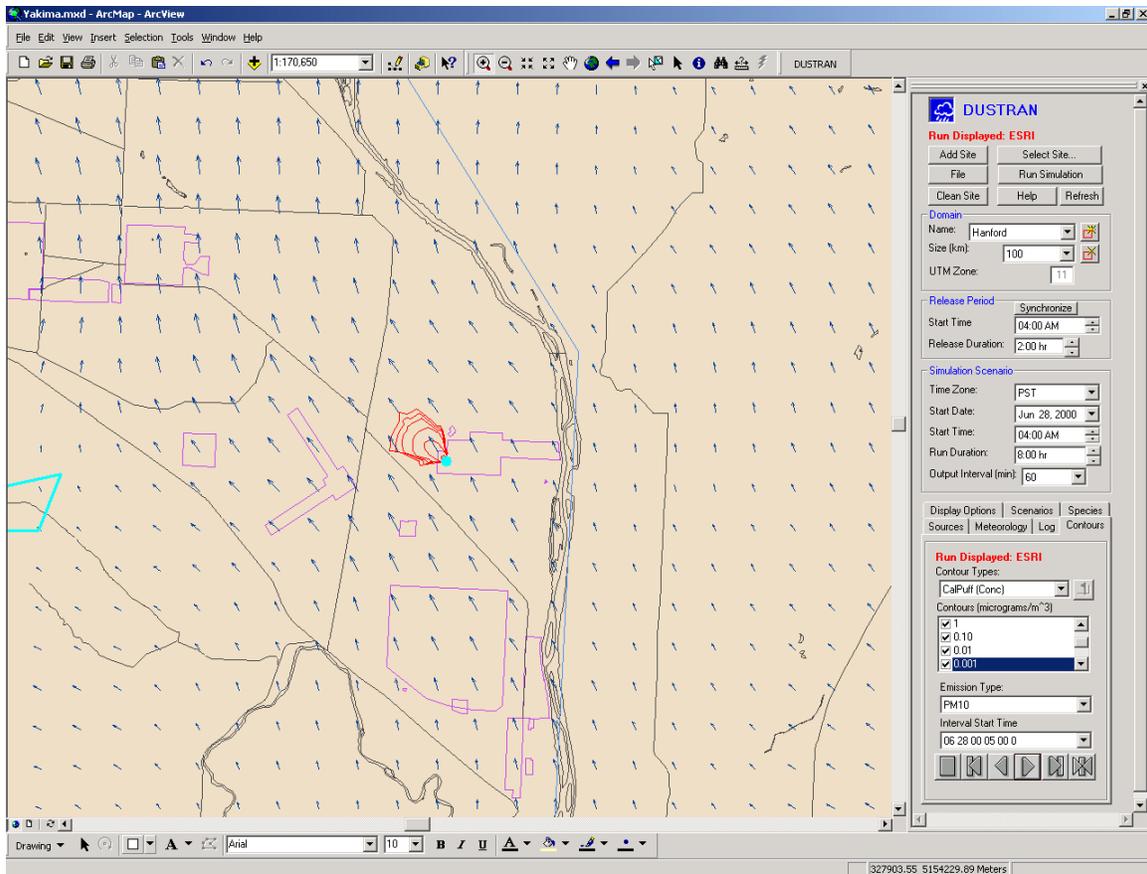


Figure 8.0 Example Wind Vector Field.

Conclusion

Development of the DUSTRAN dust dispersion modeling system is in its final year (Allwine et al. 2004) and testing is currently in progress on the functionality of the user interface and its integration with the ArcMap GIS application. This integration between atmospheric modeling and the ArcMap GIS application has proved to very successful. Initial comments from a diverse group of users including atmospheric scientists and high school students have been extremely favorable concerning the integration and the ease in which a simulation run can be setup and executed. Output generated by the modeling system has also been compared against existing field data and has been well within the desired range of accuracy expected for the modeling system. While the main focus of this development has been the simulation of dust dispersion caused by wheeled vehicles during a training maneuver, future development planned for the system includes the addition of helicopter and fixed wing aircraft sources as well as adapting the system for use in simulation potential overspray during crop dusting runs.

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Author Information:

Frederick C. Rutz
Development Engineer
Pacific Northwest National Laboratory
902 Battelle Boulevard
Richland, WA 99352
Phone: (509) 372 - 4057
Fax: (509) 372 - 4995
Email: Frederick.Rutz@pnl.gov

Bonnie L. Hoopes
Technologist
Pacific Northwest National Laboratory
902 Battelle Boulevard
Richland, WA 99352
Phone: (509) (509) 372 - 6550
Fax: (509) 372 - 4995
Email: Bonnie.Hoopes@pnl.gov

Duard J. Crandall
Undergraduate Fellow
Pacific Northwest National Laboratory
902 Battelle Boulevard
Richland, WA 99352
Phone: (509) 372 - 4057
Fax: (509) 372 - 4995
Email: Duard.Crandall@pnl.gov

Kenneth J. Allwine PhD.
Engineer
Pacific Northwest National Laboratory
902 Battelle Boulevard
Richland, WA 99352
Phone: (509) 372 - 6741
Fax: (509) 372 - 6328
Email: Duard.Crandall@pnl.gov