DRAFT REPORT

The Distribution of California Landscape Variables for CalTOX™

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Prepared for:

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SUMMARY

The CalTOX™ model requires three sets of data: chemical, landscape and exposure factors. We have developed a set of landscape data for the state of California to be used as default values in the CalTOX ™ model. Mean and coefficient of variation (CV) were characterized for each landscape parameter. The default input values developed and discussed in this report are highlighted by bold print in Table 1. The purpose of this document is to report a summary of landscape data from a review of geographical resources. This summary provides regional-scale information for use in characterizing landscapes at hazardous waste sites in California.

Table 1. List of the mean and CV for landscape properties used in the CalTOX™ model.

Landscape properties	**Symbol**	**Mean**	**CV**
Contaminated area in m^2	Area	1.00E+06	0.10
Annual average precipitation (m / d)	rain	**1.48E-03**	**0.55**
Flux; surface water into landscape (m / d)	inflow	0.00E+00	0.10
Land surface runoff (m / d)	runoff	**6.40E-04**	**0.55**
Atmospheric dust load (kg / m^3)	rhob_a	**5.95E-08**	**0.64**
Deposition velocity of air particles (m / d)	v_d	**6.90E+02**	**1.50**
Plant dry mass inventory (kg[DM] / m^2)	bio_inv	**2.8E+00**	**1.05**
Plant dry-mass fraction	bio_dm	**2.20E-01**	**0.40**
Plant fresh-mass density kg / m^3	rho_p	**8.30E+02**	**0.20**
Ground-water recharge (m / d)	recharge	**8.20E-06**	**0.55**
Evaporation of water from surface wtr (m / d)	evaporate	4.38E-06	1.00
Thickness of the ground soil layer (m)	d_g	1.00E-02	1.00
Soil particle density (kg / m^3)	rhos_s	**2.65E+03**	**0.05**
Water content in surface soil (vol fraction)	beta_g	**1.31E-01**	**0.24**
Air content in the surface soil (vol frctn)	alpha_g	**2.42E-01**	**0.29**
Erosion of surface soil (kg / m^2-d)	erosion_g	3.00E-04	0.20
Thickness of the root-zone soil (m)	d_s	**8.87E-01**	**0.49**
Water content of root-zone soil (vol. Frctn.)	beta_s	**1.25E-01**	**0.30**
Air content of root-zone soil (vol. Frctn.)	alpha_s	**2.23E-01**	**0.31**
Thickness of the vadose-zone soil (m)	d_v	**3.40E+01**	**0.56**
Water content; vadose-zone soil (vol. Frctn.)	beta_v	2.80E-01	0.20
Air content of vadose-zone soil (vol. Frctn.)	alpha_v	1.70E-01	0.20
Thickness of the aquifer layer (m)	d_q	3.00E+00	0.30
Solid material density in aquifer (kg / m^3)	rhos_q	**2.65E+03**	**0.05**
Porosity of the aquifer zone	beta_q	2.00E-01	0.20
Fraction of land area in surface water	f_arw	**4.70E-02**	**1.57**
Average depth of surface waters (m)	d_w	**5.00E+00**	**1.58**
Suspended sedmnt in surface wtr (kg / m^3)	rhob_w	**8.80E-02**	**1.00**
Suspended sdmnt deposition (kg / m^2 / d)	deposit	1.05E+01	0.30
Thickness of the sediment layer (m)	d_d	5.00E-02	1.00
Solid material density in sediment (kg / m^3)	rhos_d	**2.65E+03**	**0.05**
Porosity of the sediment zone	beta_d	2.00E-01	0.20
Sediment burial rate (m / d)	bury_d	1.00E-06	5.00
Ambient environmental temperature (K)	Temp	**2.88E+02**	**0.01**
Surface water current in m / d	current_w	0.00E+00	1.00
Organic carbon fraction in root-zone soil	foc_s	**3.00E-03**	**0.37**
Organic carbon fraction in vadose-zone	foc_v	**2.70E-04**	**1.40**
Organic carbon fraction in aquifer zone	foc_q	1.00E-02	1.00
Organic carbon fraction in sediments	foc_d	**3.20E-02**	**0.84**
Bndry lyr thickness in air above soil (m)	del_ag	5.00E-03	0.20
Yearly average wind speed (m / d)	v_w	**1.50E+05**	**0.67**

INTRODUCTION

We have developed a landscape data set that is representative of the California landscape and designed for use with the CalTOX™ model. The purpose of this document is to report a summary of landscape data from a review of geographical resources. This summary provides regional-scale information for use in characterizing landscapes at hazardous waste sites in California. The information is intended to serve as a general guide on landscape properties which are necessary as inputs into the CalTOX™ model.

Because it is often impractical to develop detailed parameter sets for the landscapes surrounding a large number of facilities, we have developed average values that are representative of the California landscape. The types of data needed include meteorological data (average annual wind speed, deposition velocities, air temperature, and depth of the mixing layer), hydrological data (annual rainfall, runoff, soil infiltration, ground-water recharge, surface water depth and sediment loads), and soil properties (bulk density, porosity, water content, and root-zone depth). In Table 1, these landscape data are summarized as arithmetic means and coefficients of variation (CV).

CalTOX™ MODEL

The CalTOX™ model computes risk by relating the concentration of a chemical in environmental media with the daily dose a person would receive through inhalation, ingestion and dermal exposure routes. CalTOX™ is a spreadsheet-based model used to assist in health-risk assessments and soil remediation clean-up goals. The model includes three components--a multimedia transport and transformation model, an exposure scenario model, and output uncertainty and sensitivity analyses component. The multimedia transport and transformation model is a dynamic model that can be used to assess time-varying concentrations of contaminants. Source terms may derive from previously contaminated soil layers or be released continuously to air, surface soil, or water. This model assists the user in examining how chemical and landscape properties impact both the ultimate route and quantity of human contact.

The equations of the CalTOX™ model contain over one hundred variables. The variables are separated into three categories: chemical, landscape and exposure parameters. CalTOX™ must have estimates of each of these variables. Estimates of each input are required to compute the dose to a population. Additionally, maximum allowable soil concentrations may be estimated for a given chemical in a contaminated area using the cancer potency and reference dose provided by the responsible agency. Assuming the model equations are valid, the validity of the computed daily intakes or maximum allowable soil concentrations is directly related to the accuracy of these parameter estimates.

The document, “CalTOX™, A Multimedia Total Exposure Model for Hazardous Waste Sites”, describes the mathematical equations contained in the model. For the purpose of this report, it is assumed that the model equations are appropriate for the exposure conditions to which it is applied. The objective of the Department of Toxic Substances Control (DTSC) in developing CalTOX™ is to select a model that is adequate to predict potential exposures with sufficient precision at many of the sites regulated by the DTSC for decisions regarding regulatory action. This does not mean that the model will precisely predict the exact risk or hazard index for every individual at every point in time. Natural variability and uncertainty make precise point estimation nearly impossible and certainly impractical for most potential exposures. The CalTOX™ model will, however, provide an estimate of the range of potential risks and hazards. These estimates are just part of the risk-assessment and risk-management process performed during the oversight of clean-up of hazardous waste sites in California.

METHODOLOGY

Two techniques were used to generate values for landscape variables for the State of California. The first technique utilizes data from existing geographic information systems (GIS) to develop a mean and CV for some variables. The second technique utilizes existing tabular data from a variety of printed reports to develop the mean and CV for those variables. The criteria for selecting one method over the other was based on the availability of suitable data. If no GIS database was readily available, then the tabular method was used.

GIS Data

GIS is a computerized database that includes both spatial and other descriptive information organized to facilitate spatial analysis. The GIS software used in our analyses was ARC/INFO. This software allows geographic information, like mapped landscape features or environmental variables, to be organized into recorded tables which describe geographic features. These features are identified with points, lines, and/or polygons. Connected to these tables of spatial features are tables (or files) of descriptive data that identify and elaborate on the attributes associated with the features. For instance, a point-feature is recorded in the table with its location (longitude and latitude) and then a key identifier labels the point as a monitoring well. In separate tables, additional data is linked to the key identifier detailing other attributes of this well, like the drill depth, the drilling method, the pumping rate, or the level of atrazine contamination. A line-feature stored in the database may have data associated with it identifying it as a particular reach of the Sacramento River, with an average flow in 1994, an average level of dissolved oxygen, an average amount of copper ions, a particular ratio of ripple to pool, and a particular area of spawning gravel. A polygon-feature in the database represents a bounded area, usually on the surface of the earth. A polygon-feature could have linked data which identifies it as particular assessed parcel, with an identified owner, property value, land-use zoning, and an assessed tax rate. The quality of data stored in the GIS depends on the extent of data gathering efforts of the agency or individuals responsible for building the database. The accuracy and reliability of the data depends on the data quality objectives and protocols used by these agencies and individuals.

The main GIS source used in this report is the STATSGO database. The STATSGO database is part of a nation-wide program by the USDA Natural Resource Conservation Service (NRCS, formerly the Soil Conservation Service) which provides soils information at the regional level. The NRCS has certified this database for use at regional scales between 1:250,000 and 1:1,000,000. This database consists of polygons representing soil mapunits created at a scale of 1:250,000 for California, among others. Other data sources are available at differing scales of resolution, but mapped data at finer scales are incomplete for California. At the scale of STATSGO, the soil mapunits are composed of co-occurring soil components in recognizable landscape patterns. Soil components are contiguous geographic areas identified by a soil scientist to contain well defined set of soil characteristics (i.e. density, organic carbon content, etc.). A grouping of similar soil components makes a mapunit. For example, in the Sierra Foothill region, the pattern of ridge, slope, and basin component soils, occurring in association over particular geologic areas and climatic zones, are aggregated into a single mapunit in STATSGO. The descriptive data associated with each soil mapunit detail the percent area of each soil component. The STATSGO database also has tables describing the surface features of each component and chemical and typical physical characteristics of each layer. Although additional tables are found in this database, those described above are used in developing the data set described in this report.

STATSGO is a relational database. This means the files of tabular data have fields in each record that are related, or linked to the data in that record and to a specific soil mapunit. Soils are a three dimensional phenomenon. Some soil characteristics require a description based on the vertical layering typically found in the soil. The database, therefore, uses soil layers as the lowest common denominator from which regions are eventually described.

For all the soil components in the STATSGO database, soil scientists have developed a description of the typical soil profile. The STATSGO files organize the database by combining the topology (structured spatial relations) of the mapped soils landscape with a set of nested files. These files are used to identify the data which describe each mapunit. The structure is as follows: each set of soil layers makes up vertical column called a soil “component”. Each set of co-occuring components, in turn, make up a “mapunit”. The “mapunit” is used to define the soil characteristics of soil “polygons”, which are defined geographic areas. The data files are arranged and designated as “layer” for specific layer data, “comp” for component data, “mapunit” and “polygon attributes”, respectively.

The top-level file is the polygon map of the soils as mapped by the NRCS. There are 4245 soil polygons for the state of California. In ARC/INFO, these polygons are maintained in a file also called a “coverage” that has a unique identifier for each polygon. These special record fields are sometimes called key fields, since they are so important to the structure of the relational database. The

"Polygon Attribute File" stores the polygon record identifier and a mapunit identifier.

There are 703 soil mapunit-types used to characterize the 4245 soil polygons. The "Mapunit" file has a key field for each of these classes of soil landscapes and is called the MapUnIt iDentifier or "muid", for short. Each mapunit class is a composite landscape of up to 21 soil components, contained in "comp" files.

Mapunits are aggregated soil landscapes linked to a "Comp" file which contains all the component data. These data include a "muid" along with a key field called a component SEQuence NUMber or "seqnum". The "muid" and "seqnum", together, identify each unique soil component. All together, the California database contains 9900 records of soil components in this "Comp" file, which make up the 703 mapunits.

The components are made up of a series of soil layers. The ""layer"" file contains the description of soil layer properties. It is linked to the "Comp" file through the key fields of "muid" and "seqnum". Each layer also has a unique key field for the LAYER NUMber called "layernum". There are many soil properties that are described in fields for each layer, including field capacity, bulk density, and other CalTOX™ model variables.

The important nested relationships between files in the STATSGO data structure are illustrated in Figure 1. The description of the manipulations of the data structure required to make each map will accompany the maps displayed in this report. Understanding these data manipulations is based on understanding this fundamental data structure.

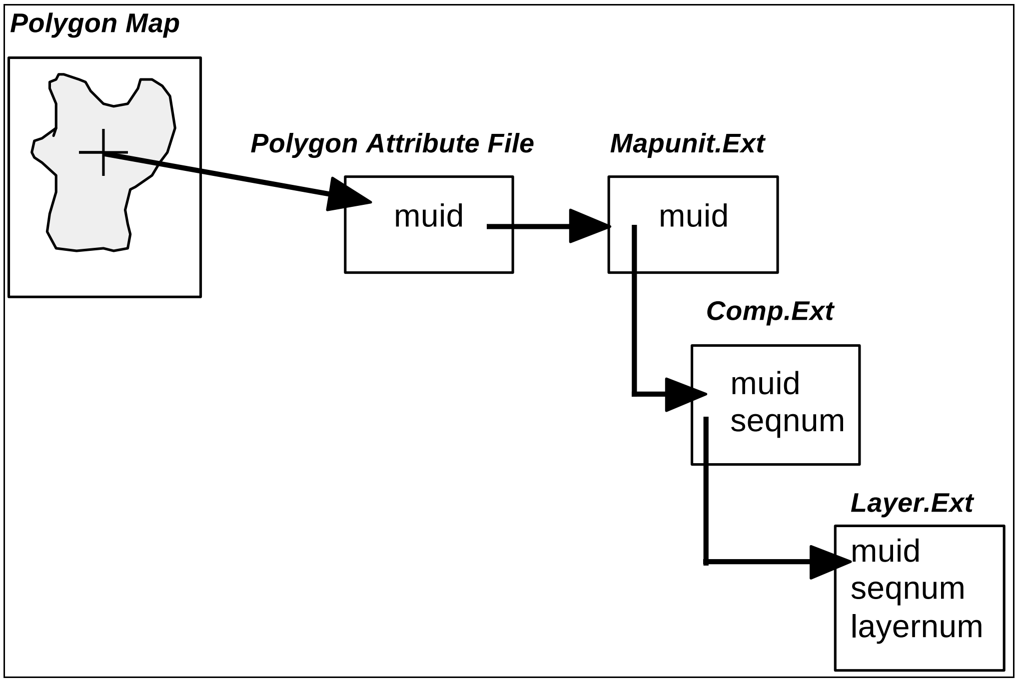

Figure 1. Structure of STATSGO database.

The data manipulations required to construct each map are detailed later in this report. In general, construction initially involved separation of soil layers into soil compartments as required for CalTOX™; surface, rooting and vadose-zone soil compartments. The layer data were weighted by layer thickness to obtain a parameter average for each component. The values for each soil component were weighted by percent mapunit area to calculate the mapunit average. The mapunit value was then assigned to the corresponding polygons. The values for each polygon were averaged to derive the state average, weighted by polygon area. A similar stepwise process was used to develop the coefficient of variation.

Tabular Data

GIS data were not readily available to calculate values for many landscape variables used in the CalTOX™ model. Documents describing the values for climatic variables, e.g. average rainfall, are needed to find the best available data source. Table 2 cites the sources used to compute averages for landscape variables for this remaining set of parameters.

Table 2. Selected Landscape Variables and Reference

Landscape Variable	Reference
Annual Average Precipitation	NOAA, 1985
Plant Fresh Mass Inventory	Schulze, 1975; Calveg
Atmospheric Dust Load	CalEPA 1992
Deposition Velocity of Air Particles	McKone and Ryan, 1989
Ambient Environmental Temperature	NOAA, 1985
Yearly Average Wind Speed	CalEPA 1990
Suspended Sediment in Surface Water	USGS 1983
Land Surface Runoff	Kahrl et al., 1979; Frits et al., 1990
Ground-Water Recharge	Kahrl et al., 1979
Particle Density	SCS, 1993
Fraction of Land Area Surface Water	State of California, 1992
Organic Carbon Fraction in Sediments	USGS, 1983
Surface Water Depth	State of California, 1992; Kahrl et al. 1979
Plant Fresh Mass Density	Trapp and McFarlane, 1995
Plant Dry Mass Fraction	Mackay and Paterson,1994

CALTOX™ SOIL VARIABLES

There are three soil compartments in the CalTOX™ model: surface, rooting and vadose-zone soil. The CalTOX™ definition of surface soil is the top first few centimeters of soil. The Soil Conservation Service (SCS) defines Layer One as the first soil layer. The depth of Layer One is often larger than a few centimeters. For this report, however, the Layer One data in the “Layer” data file was considered sufficient to describe surface soil parameter values. Rooting soil is the depth of “actual” soil to a maximum depth of 60 inches (1.5 meters). This maximum of 60 inches was established by the NRCS soil scientists as the most logical soil depth maximum to use in STATSGO. Rooting depth varies between soil polygons due to the occurrence of non-soil materials, such as bedrock, at depth less than 60 inches. Soil properties are important model inputs because they are factors which influence the rate of transfer, etc. between soil and other media (see Figure 2). Soils interact with water and air, as well as deeper layers of vadose-zone material.

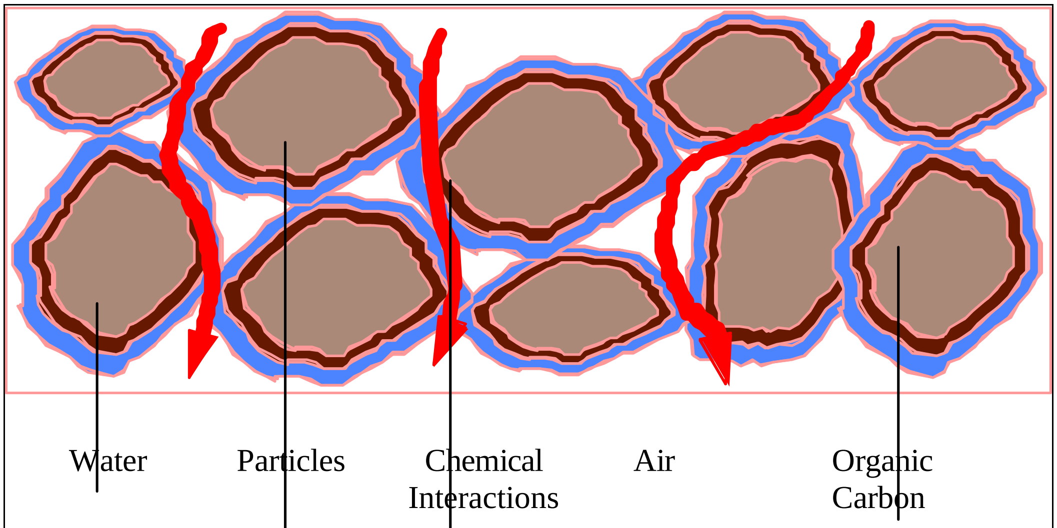

Figure 2: Chemical interactions in soil include particles, water, air and organic carbon.

California has a variable topography and climate pattern that has developed a wide variety of soils. This pattern of soil variability and diversity can be easily seen in maps generated using the STATSGO Database. Since soil scientists had to decide where the major transitions in soils occurred in the landscape, a map showing the range of sizes of soil mapunits was created. The distribution of mapunit size is a basic measure of the landscape diversity, because larger polygons encompass a similar pattern of soils over larger areas than smaller polygons (where transitions in the landscape are more abrupt).

A map was developed using the “acres”data field in the polygon attribute table for the “coverage”. A statistical summary of the distribution of acreage values for the polygons was generated (Table 3). These statistics and a frequency histogram were used to generate the classes for soil mapunit acreages.

Table 3. Area Of Mapunits (m^2)

	Area Of Mapunits (m^2)
MEAN	9.65E+07
MINIMUM	0.0
MAXIMUM	3.79E+09
STANDARD DEVIATION	2.27E+08

Since each mapunit is actually an aggregate of several soil components, the number of soil components per mapunit can also give important information about soil variability. Using a program, the number of components in the "Comp" file was calculated and retained as a data field for each record in the "Mapunit" file. In a manner similar to that performed regarding acreage, statistics were generated regarding this data field and appear in Table 4.

Table 4. Number Of Components Per Mapunit

	Components Per Mapunit
MEAN	13.25
MINIMUM	0.0
MAXIMUM	20.0
STANDARD DEVIATION	5.76

Counting the number of soil components per mapunit does not give an accurate assessment of the diversity of soils within a polygon because the spatial proportions of different soil types may vary considerably. By using an index that takes this proportion into account, a more useful measure of soil diversity within mapunits is obtained. The Diversity Index (H) is calculated as follows (p.176, Turner 1989):

$$H = \sum_{i=1}^{s} (Pk)\ln(Pk) \qquad (1)$$

where s is the number of components and Pk is the area fraction of a component in a mapunit. The statistics on the results of this calculation for each polygon can be found in the Table 5.

Table 5. Diversity Index (Unitless)

	Diversity Index
MEAN	2.06
MINIMUM	0.0
MAXIMUM	2.93
STANDARD DEVIATION	0.656

All the soil variables have statistics weighted according to the relative area of each polygon (polygon area / tot. CA surface area). California covers 10^8 acres. The following equations are the calculations for weighted means and standard deviations.

$$\text{Weighted Mean} = \sum \quad \times \qquad (2)$$

$$\text{Weighted Standard Deviation} = \sqrt{\sum(\; - \bar{\;}) \times} \qquad (3)$$

$$\text{Coefficient of Variation} = \frac{\text{Weighted Standard Deviation}}{\text{Weighted Mean}} \qquad (4)$$

where x_j is the value of parameter x in polygon j, $\bar{x}$ is the state parameter average and percentacreage_j is the relative area of polygon j.

Rooting depth

Rooting depth was obtained by subtracting the surface soil depth from the depth to non-soil or 60 inches, whichever was less. Soils that were identified as weathered bedrock, unweathered bedrock, ice, cinders or cemented soil were considered to be non-soil. Rooting soil depth was recorded for each soil component. The area-weighted rooting depth for the soil mapunit was obtained by averaging the component rooting depth. Rooting depth was weighted by the area percentage for each component. The average rooting depth was calculated to be 0.89 meters with a standard deviation of 0.44 meters and a range of 0 to 1.52 meters (Table 6).

Table 6. Rooting Depth (m)

	Rooting Depth (m)
MEAN	0.89
MINIMUM	0.0
MAXIMUM	1.52
STANDARD DEVIATION	0.44

The rooting depth is the first of several data elements derived from the Layer.ext file. The evaluation of data quality for this file is based on the process by which this file was developed. NRCS soil scientists, examining the soils being classed as components of map units, did not always perform full analyses of soil profiles to develop the data for the layer file. A proportion of the layer data for components was developed by soil scientists making a professional judgment regarding the expected layer profile. They then matched the expected layer description to a description from a pre-existing database on soil profiles of similar fully studied soil components. These layer descriptions were pulled and used to describe the profiles for some unknown proportion of unexamined soil components. This process of estimation of some unknown proportion of these soil profiles has introduced an equally unknown amount of uncertainty to the calculations of layer data elements. This is because of the high degree of influence these subjective decisions may have had in determining what otherwise appear as directly measured variables, such as rooting depth or amount of organic carbon. No quality check has been performed to verify the reliability of these data elements. However, the STATSGO database remains the best source of regional soils information for the State of California, in digital or any other format.

Soil Organic Carbon Content

The soil organic carbon (OC) values were derived from the reported organic matter (OM) values in the STATSGO database. The OM field represents the percent organic matter in the fraction of soil particles less than 2mm in size. However, CalTOX requires the input of percent OC by weight and not the total OM by weight. Hence, these values were converted to represent organic carbon in total soil from organic matter in the <2mm size fraction. The factor which converts organic matter to organic carbon was taken from the *Soil Conservation*

Service's Guide to Entering Soil Properties into the National Cooperative Soil Survey Database (SCS 1993):

$$OC_{unadj} = \text{——} \qquad (5)$$

The database also provides the weight percent of soil that is less than 2mm. This value is adjusted to represent the weight percent of carbon in the entire soil profile. We used the following equation for the conversion:

$$\%OC = \frac{\%OC < 2mm}{wt.\% < 2mm} \qquad (6)$$

where %OC is the percent organic carbon, and wt.%OC is the weight percent organic carbon. Organic Carbon content was calculated this way for the surface, root-zone, and vadose-zone soils. The mean fraction OC and standard deviation is 0.0074 and 0.0040 for the surface, 0.0030 and 0.0011 for the root, and 0.00027 and 0.00038 for the vadose-zone soil. In addition the ranges are 0.00043-0.0840, 0.000-0.0746 and 0.000-0.07, respectively (Table 7).

Table 7. Organic Carbon Fraction

	SURFACE	**ROOT**	**VADOSE-ZONE**
MEAN	0.0074	0.0030	0.00027
MINIMUM	0.00043	0.00	0.00
MAXIMUM	0.0840	0.0746	0.0700
STANDARD DEVIATION	0.0040	0.0011	0.00038

The data quality for organic carbon has been described to some extent by the discussion of soil layer data elements. The numeric values given for organic carbon are thus based on some degree of subjective judgment by NRCS soil scientists. In addition, the soil surface organic carbon numbers, where these were directly measured, were determined by the soil scientist brushing the top layer of debris from the soil surface and then taking representative samples from the remainder. This reduces the organic carbon measures for some soils with a lot of surface detritus. It is impossible to quantify the amount of uncertainty in this data element without a comparative study of existing database values and soils in the field.

Soil Water Content

Water Content at field capacity was obtained by applying a linear regression formula based on the clay content of the soil, with a correction for rock fragments, developed by Bowers et al., 1989. The formula was derived using a least squares regression of data (Bower et al 1989). The equation based on clay content is:

$$F = (0.4381 + 0.2788C - 0.005679C^2 + 0.00003889C^3) + 12 \qquad (7)$$

where F is the field capacity in inches water per inch soil and C is the percent clay.

A correction is applied to the results of this formula for the rock fragments using:

$$F_C = F(1 - \frac{BxR}{265}) \qquad (8)$$

where F_C is the corrected field capacity, F is the uncorrected field capacity, B is the bulk density of the soil in g/cm^3, and R is the percentage rock fragments by weight.

The corrected field capacity was calculated for every layer in the “layer” data file. The surface soil water content is equivalent to the water content at field capacity of the first layer of soil. The surface soil water content at field capacity for each mapunit was then calculated as a weighted average for all the components in the “comp” data file. To calculate the soil water content of the root-zone soil, the soil water content at field capacity was weighted by depth for each layer in the root-zone. This was done using a percent of total depth as a weighting factor. Once again, the surface water at field capacity was calculated as a weighted average for all the components in the “comp” data file for each mapunit. The mean soil water content in percent and standard deviation is 0.131 and 0.031 for the surface and 0.125 and 0.037 for the root-zone. In addition the ranges are 0.0-0.17 and 0.0-0.173, respectively (Table 8).

Table 8. Water Content At Field Capacity In Percent

	SURFACE LAYER	**ROOT-ZONE**
MEAN	0.131	0.125
MINIMUM	0.0	0.0
MAXIMUM	0.17	0.173
STANDARD DEVIATION	0.031	0.037

The data quality for soil water content has been described to some extent by the discussion of soil layer data elements. The numeric values given for soil water content are thus based on some degree of subjective judgment by NRCS soil scientists. Soil scientists estimated bulk density and percentage of rock fragments using standard monographs.

Soil Air Content

Soil air content was also calculated at field capacity. For each layer in the "layer" data file the overall porosity was calculated using the formula (SCS 1993):

$$P = 1 - \frac{BD}{2.65} \quad (9)$$

where P is the soil porosity and BD is the soil bulk density including the rock fraction in g/cm^3 and 2.65 is the default value for soil particle density (g/cm^3).

Once the percent pore space is known, the percent water content can be subtracted from this to obtain percent air content. The calculation of air content is made for surface soil from the data in Layer One. For rooting depth soil, air content is calculated as the depth-weighted average air content. For both surface and rooting depth air content, a weighted average is calculated for all the components in the "comp" data file for each mapunit. The mean and standard deviation percent soil air content is 0.242 and 0.071 for the surface and 0.223 and 0.070 for the root-zone. In addition the ranges are 0.0-0.608 and 0.0-0.0546, respectively (Table 9).

Table 9. Percent Surface Soil Air Content At Field Capacity

	SURFACE LAYER	ROOT-ZONE
MEAN	0.242	0.223
MINIMUM	0.0	0.0
MAXIMUM	0.608	0.546
STANDARD DEVIATION	0.071	0.070

The data quality for soil air content has been described to some extent by the discussion of soil layer data elements. The numeric values given for soil air content are thus based on some degree of subjective judgment by NRCS soil scientists. Soil scientists estimated bulk density and percentage of rock fragments using standard monographs. Since the soil air content was determined from the soil water content, these data elements were influential on the uncertainty of soil air content.

CLIMATE, HYDROLOGIC AND OTHER LANDSCAPE VARIABLES

The following variables were derived from non-GIS data sources. The sources of data and specific method of calculation are described for each variable. Once spatial data can be obtained for these landscape variables, the preliminary calculations of the mean and variance may be reanalyzed using a spatially explicit format.

Thickness of the Vadose-zone Soil

Vadose-zone soil thickness was calculated as the difference between the bottom root-zone soil and the depth to ground water. The values for depth to ground water were taken from the United States Geologic Survey (USGS) annual summary of water resources data (USGS, 1993). The depth to ground water was calculated from data for 680 California sites. The value obtained from the analysis of the STATSGO database was used for the depth of the root-zone soil. The average vadose-zone thickness was determined to be 34 meters with a standard deviation of 19 and a range from 0 to 147 meters (Table 10).

Table 10. Thickness of the vadose-zone soil.

	Thickness(m)
MEAN	34
MINIMUM	0
MAXIMUM	147
STANDARD DEVIATION	19

The data quality for the depth of the root-zone was discussed previously in its corresponding section. The depth to ground water data are limited by temporal and spatial scales. The measurements do represent limited annual variation, but data for long-term year to year variation were not available. In addition, the ground water data account for 18 counties in the state.

Annual Average Precipitation

The annual average precipitation for the State of California was calculated from the *Climatography of the United States No. 85* . "Division Normals and Standard Deviations of Temperature and Precipitation 1931-80."(NOAA, 1985). The variance was calculated based on region to region variance, weighted by region size. The average and standard deviation were calculated to be 1.48×10^{-3} and 8.10×10^{-4} meters / day (m / d), respectively, with a range from 1.24×10^{-4} to 5.59×10^{-3} m / d (Table 11).

Table 11. Annual Average Precipitation (m / d).

	Precipitation(m/d)
MEAN	1.48×10^{-3}
MINIMUM	1.24×10^{-4}
MAXIMUM	5.59×10^{-3}
STANDARD DEVIATION	8.10×10^{-4}

The precipitation data used are based on a large dataset of rainfall measurements. Therefore, long-term data were available for calculating the state average. The weather data represented the major regions of California. This was valuable in determining the region to region variance in the state, which is more significant than the year to year variance at given location.

Plant Dry Mass Inventory

The plant dry mass inventory was based on data from CALVEG (Matyas and Parker, 1980 and Parker and Matyas, 1981), which gave plant types and percent area cover in California. This information was combined with fresh mass densities taken from E.-D. Schulze, Encyclopedia of Plant Physiology, Vol. 18. *Plant Life Forms and Their Carbon, Water and Nutrient Relations* (Schulze, 1975). The fresh mass densities calculated from both data sets were converted to plant dry mass using the dry mass fraction values listed in Table 25.. The mean and standard deviations were calculated using area as a weighting factor and the variance also based on variance from type to type. The mean and standard deviation for plant area-mass inventory in California were calculated to be 2.8 and 2.9 kg/m^2 respectively, with a range of 0-16.1 kg/m^2 (Table 12).

Table 12. Plant Dry Mass Inventory in kilograms per square meter.

	DryMass (kg/m^2)
MEAN	2.8
MINIMUM	0
MAXIMUM	16.1
STANDARD DEVIATION	2.9

The CALVEG data were used to obtain a spatial average of the densities obtained from Schulze, 1975. It is a state wide survey of vegetation and is intended for broad scale resource assessments, which serves the purpose of this dataset. The CALVEG mapping was done between 1979 and 1980 and, thus, is not current to 1996. The data presented by Schulze represent a limited number of plant species of plant types that are obtained from the CALVEG database. The ability to obtain variability within plant types was therefore limited.

Atmospheric Dust Load

The atmospheric dust load average is based on 24-hour average measurements of total suspended particulate matter at 42 California atmospheric monitoring stations during 1992. The data are listed in the report entitled California Air Quality Data: Summary of 1992 Air Quality Data; Gaseous and Particulate Pollutants by the California Environmental Protection Agency, Air Resources Board (CalEPA 1992). The average and standard deviation were calculated to be 5.95×10^{-8} and 3.8×10^{-8} kg/m^3 respectively with a range of 9.59×10^{-7}-1.00×10^{-9} kg/m^3 (Table 13).

Table 13. Atmospheric Dust Load in kilograms per cubic meter.

	Dust Load (kg/m³)
MEAN	5.95×10^{-8}
MINIMUM	9.59×10^{-7}
MAXIMUM	1.00×10^{-9}
STANDARD DEVIATION	3.8×10^{-8}

The air quality dataset was useful for evaluating variation in atmospheric dust from region to region in the state. The report, however, was limited to one year of data. Analyses on annual average variations was not available.

Deposition Velocity of Air Particles

The estimate for air particle deposition velocity is taken from McKone and Ryan, 1989. They estimate the total deposition velocity to be 6.9×10^{2} with a standard deviation of 1.0×10^{3} m / d (Table 14). This was based on an average from a review of reported measurements that ranged from 0.86 to 155,000 m / d for air particle deposition velocity. The values reviewed give an estimate of the variation of deposition velocity due to the numerous factors which influence it. Relevant measurements to reflect deposition velocities in specific regions in California, along with long term values were not available .

Table 14. Deposition Velocity of Air Particles.

	Deposition Velocity (m/d)
MEAN	6.9×10^{2}
STANDARD DEVIATION	1.0×10^{3}

Ambient Environmental Temperature

The annual average temperature for the state of California was calculated from the *Climatography of the United States No. 85* . “Division Normals and Standard Deviations of Temperature and Precipitation 1931-80.” (NOAA, 1985). The variance was calculated to include region to region variance, weighted again by region size. The average and standard deviation were calculated to be 288.1 and 2.53 degrees Kelvin respectively, with a range of 2.77×10^{2}-2.98×10^{2} K (Table 15).

Table 15. Annual Average Temperature in degrees Kelvin.

	Temperature (K)
MEAN	2.88×10^{2}
MINIMUM	2.77×10^{2}
MAXIMUM	2.98×10^{2}
STANDARD DEVIATION	2.53×10^{0}

The temperature dataset used is based on a large dataset of temperature measurements. Therefore, long term data was available for calculating the state average. The dataset represented the major regions of California. This was valuable in determining the region to region variance in the state.

Yearly Average Wind Speed

The average wind speed for California was calculated from the yearly average station scalar wind speeds for 22 stations in California. Station averages reflected data collected from 1929 to 1978. Not all stations had data for those years. The data are listed in the report "Summary of California Upper Air Meteorological Data" by the California Environmental Protection Agency, Air Resources Board (CalEPA 1990). The average was calculated using the average wind speed from surface and 1000 ft. elevation. The average and standard deviation were calculated to be 3.2×10^{5} and 1.2×10^{5} m / d respectively (Table 16).

Table 16. Yearly Average Wind Speeds in meters per day.

	Wind Speed (m/d)
MEAN	1.5×10^{5}
MINIMUM	8.9×10^{3}
MAXIMUM	4.3×10^{5}
STANDARD DEVIATION	1.0×10^{5}

The dataset was very useful for evaluating variation in annual average wind speed from region to region in the state. The data represented actual measurements and are not subjective estimates. The report, however, was limited to one year of data. Analyses on annual average variations was not available.

Suspended Sediment in Surface Water

Average suspended sediment values from 14 California water quality surveying stations were evaluated in the U.S. Geologic Survey Investigation Report 83-533 "A Statistical Summary of Data from the U.S. Geologic Survey's National Water Quality Networks" (USGS 1983). The average and standard deviation were calculated to be 8.8×10^{-2} and 8.8×10^{-2} kg / m^3 respectively (Table 17).

Table 17. Suspended sediment in surface water.

	Suspended Sediment (kg/m^3)
MEAN	8.8×10^{-2}
MINIMUM	1.8×10^{-3}
MAXIMUM	2.6×10^{-1}
STANDARD DEVIATION	8.8×10^{-2}

Data were not available to represent the whole state. However, data are from 13 monitoring stations throughout the state of California. The data included annual variation. Report 83-533 lists statistical summaries for each station's data from the period of 1974 - 1981.

Land Surface Runoff

The land surface runoff was calculated as a percentage of the annual precipitation. The California Water Atlas (Kahrl et al., 1979) and the Water Encyclopedia (Frits et al., 1990) estimated California's runoff to be 36% and 50%, respectively, of annual precipitation. A mean fraction of rainfall was calculated to be 43%, which is equivalent to 6.4×10^{-4} m / day of runoff. The variance between the two runoff estimates and in the annual precipitation were combined to yield a CV of 0.55 or a standard deviation of 3.5×10^{-4} m / d with a range of 4.5×10^{-5} - 2.8×10^{-3} (Table 18).

Table 18. Land Surface Runoff.

	Runoff (m/d)
MEAN	6.4×10^{-4}
MINIMUM	4.5×10^{-5}
MAXIMUM	2.8×10^{-3}
STANDARD DEVIATION	3.5×10^{-4}

Measurement data were not readily available for the state of California to calculate the average runoff for the state. Therefore, the value is estimated based on state wide water budgets. Estimates to represent different regions of California were not available. In addition, the estimates are limited for analysis of annual variations.

Ground-Water Recharge

The ground-water recharge was calculated in a similar way as the land surface runoff. The California Water Atlas (Kahrl et al., 1979) estimated California's recharge to be 0.6% of annual precipitation. This was used to calculate mean recharge of 8.2×10^{-6} m / d of ground-water recharge. Again the variance from the annual precipitation was carried over to yield a CV of 0.55 or a standard deviation of 4.5×10^{-6} m / d with a range of 6.8×10^{-7}-1.1×10^{-6} (Table 19).

Table 19. Ground-Water Recharge.

	Recharge (m/d)
MEAN	8.2×10^{-6}
MINIMUM	6.8×10^{-7}
MAXIMUM	1.1×10^{-6}
STANDARD DEVIATION	4.5×10^{-6}

Similar to the value for runoff, this value is an estimate based on the water budget provided by Kahrl et. al. Its limitations on spatial and temporal analysis are similar to that of land surface runoff.

Particle Density

The solid particle density was taken from the SCS Soils Guide (SCS, 1993). It lists a default mean particle density of 2600 kg / m^3. This value is used as the default particle density for the soils, aquifer and sediment along with a default CV of 0.05 or a standard deviation of 130 kg / m^3 (Table 20).

Information based on measurements of this value is limited. This value is taken from the SCS Soils Guide. The value is their recommendation for average particle density. In addition, little information was found to indicate the variability in this value.

Table 20. Particle Density.

	Particle Density (kg/m^3)
MEAN	2.65×10^{3}
STANDARD DEVIATION	1.3×10^{2}

Fraction Of Land Area Surface Water

This value was calculated as the mean and standard deviation of surface water fraction from all 58 counties. The values were obtained from the California Statistical Abstract (State of California, 1992). The average and standard deviation were calculated to be 0.047 and 0.074 respectively (Table 21).

Table 21. Fraction of Land Area Surface Water.

	Fraction of Area
MEAN	4.7×10^{-2}
STANDARD DEVIATION	7.4×10^{-2}

The variance represents the inter-county variance for fraction land area that is surface water. Temporal variation was not taken into account.

Organic Carbon Fraction In Sediments

Average organic carbon fraction in sediment particles was derived from the values in the U.S. Geologic Survey Investigation Report 83-533 (USGS, 1983). The average and standard deviation were calculated to be 3.2×10^{-2} and 2.7×10^{-2} respectively (Table 22).

Table 22. Organic Carbon Fraction In Sediments.

	Organic Carbon Fraction
MEAN	3.2×10^{-2}
MINIMUM	6.0×10^{-3}
MAXIMUM	1.0×10^{-1}
STANDARD DEVIATION	2.7×10^{-2}

The value for average organic carbon fraction in sediments is based on actual measurements of surface water sediments. The data are from 13 monitoring stations throughout the state of California. Report 83-533 lists statistical summaries for each station’s data from the period of 1974 - 1981. The number of stations at which the measurements are made from limit accuracy of spatial analysis.

Surface Water Depth

Surface water depth where surface water occurs was calculated given surface water area (State of California 1992) and total volume of surface water (Kahrl et al. 1979). The average was calculated to be 5 meters with a standard deviation of 7.9 meters (Table 23).

Table 23. Surface Water Depth.

	Surface Water Depth (m)
MEAN	5
STANDARD DEVIATION	7.9

Once again this was calculated by an estimation method. It is not based from actual measurements but from other estimates (State of California 1992 and Kahrl et al. 1979). In addition, the method by which the value was obtained allows for very little spatial and temporal analysis, similar to land surface runoff and ground-water recharge.

Plant Fresh Mass Density

The average plant fresh mass density was based on values describing a plant in *Plant Contamination* by Trapp and McFarlane (Trapp and McFarlane, 1995). They based the typical plant values from barley and wheat plants. They listed densities for different plant parts which were used to obtain the average fresh mass density. The average was calculated to be 8.3×10^{2} kg / m^3 with a standard deviation of 1.7×10^{2} kg / m^3 (Table 24).

Table 24. Plant Fresh Mass Density.

	Plant Fresh Mass Density (kg/m^3)
MEAN	8.3×10^{2}
STANDARD DEVIATION	1.7×10^{2}

This value only reflects one variety of plants and is not wholly representative of the state. Values, however, could not be found for other varieties. Therefore, an analyses similar to that of plant mass inventory could not be made.

Plant Dry Mass Fraction

This value is based on the values used as a defaults by Mackay and Paterson,1994. From their values we obtained a mean of 0.22 and a standard deviation of 0.087 (Table 25).

Table 25. Plant Dry Mass Fraction.

	Plant Dry Mass Fraction
MEAN	2.2×10^{-1}
STANDARD DEVIATION	8.7×10^{-2}

Once again the values for wholly representative California plants were unavailable. It was chosen as a default because of its recommendation as a default in multi-media models.

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