Carcass Disposal: A Comprehensive Review

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Chapter

14

Evaluating Environmental Impacts

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Selected Abbreviations

3MRA	multimedia, multi-pathway, multi-receptor exposure and risk assessment model
ADMS	atmospheric dispersion modeling system
AGNPS	agricultural nonpoint source
ALOHA	areal locations of hazardous atmospheres
AMC	antecedent moisture condition
ANSWERS	aerial nonpoint source watershed environment response simulation
ARS	USDA Agricultural Research Service
BOD	biochemical oxygen demand
CN	curve number
CTSCREEN	complex terrain screening model
DRAINMOD	a field-scale water management simulation model

DRASTIC	a standardized system for evaluation of groundwater pollution potential using hydrogeologic settings
ERS	Economic Research Service
EPA	Environmental Protection Agency
EPIC	erosion-productivity impact calculator
EUTROMOD	a watershed-scale nutrient loading and lake response model
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FMD	foot and mouth disease
GIS	geographic information system
GLEAMS	a model to simulate the effects of different agricultural management systems on water quality
HEC	
HELP	standard model for landfill design
HSPF	
INPUFF	intergrated PUFF
K	soil erodibility screening model
L-THIA	long-term hydrological impact assessment
MULTIMED	multimedia exposure assessment model
NAPRA	national agricultural pesticide risk analysis
NEH-4	USDA SCS National Engineering Handbook
NFF	national flood frequency
NH4-N	ammonia-nitrogen
NPS	non-point source
NRCS	Natural Resources Conservation Service
OBODM	open burn/open detonation dispersion model
QUAL2E	enhanced stream water quality model
PRZM3	predicts pesticide transport and transformation
REM	register of ecological models
RUSLE/RUSLE2	revisions to the universal soil loss equation
RWEQ	revised wind erosion equation
SCS	Soil Conservation Service
SEDSPEC	sediment and erosion control planning, design and specification information and guidance tool
SWAT	soil and water assessment tools
TCLP	toxicity characteristic leaching procedure
TDS	total dissolved solids
USLE	universal soil loss equation
USDA	United States Department of Agriculture
USGS	US Geological Service
VPM	virus protection model
WEPP	water erosion prediction project
WEPS	wind erosion prediction system
WMS	watershed modeling system

Section 1 – Key Content

Carcass disposal events can result in detrimental effects on the environment. The specific impacts vary by carcass disposal technology, site-specific properties of the location, weather, type and number of carcasses, and other factors. To accurately determine the impacts of a specific carcass disposal event on the environment, environmental monitoring will be necessary. This chapter provides an overview of the monitoring that may be necessary or desirable to quantify environmental impacts for a carcass disposal event.

Environmental models can be helpful in addressing environmental concerns associated with carcass disposal, and can be used at various stages, including:

1. **Prescreening.** Sites can be prescreened using environmental models to identify locations that might be investigated further in the event of an actual disposal event. The models would likely be used with geographic information systems (GIS) to create maps of potentially suitable sites for each carcass disposal technology.
2. **Screening.** In the event of a carcass disposal incident, environmental models might be used to further screen sites and disposal technologies being considered. Such models would require more site-specific data than those used for prescreening.
3. **Real-time environmental assessment.** Models might be used to predict the environmental impact of carcass disposal at a particular location for the observed conditions (site and weather) during a carcass disposal event. These predictions would be helpful for real-time management decision-making, and would provide estimates of environmental impact.
4. **Post-disposal assessment.** Once a carcass disposal event is over, the activities at the location may continue to impact the environment. A combination of monitoring and modeling may be useful to assess the likely impacts.

Some of the most promising environmental models that might be used for the various tasks described above have been reviewed and summarized in this chapter. Models were reviewed for water (surface and ground), soil erosion, soil quality, and air. Brief summaries of the models are included.

Section 2 – Environmental Monitoring to Assess Impacts of Carcass Disposal

In the case of a natural disaster or foreign animal disease outbreak, significant numbers of animal carcasses may need to be buried or disposed of using a variety of methods or technologies. Carcass disposal methods such as burial, incineration, composting, and others could result in significant impacts on human health, water supplies, air quality, soil, and the food chain, which would need to be scientifically monitored and assessed.

Protecting public health and preventing or minimizing the possible impacts of contamination with proper environmental monitoring before and after carcass disposal is a necessity. Sampling frequency and volume should be determined based on a standard sampling method to prevent human-induced errors and provide true characteristics and variability of the pollutant(s) from carcass disposal areas. Depending on carcass types and disposal methods, various sampling protocols may be applicable before, during, and after disposal.

Important elements of an environmental monitoring program include sample locations, minimum number of sampling points, frequency of sampling, baseline data prior to disposal, equipment, and pollutant types.

Laboratories capable of providing appropriate detection limits and analyses for each pollutant should be carefully selected as a part of the monitoring program.

The environmental impacts of carcass disposal are not well documented (Freedman and Fleming, 2003; Glanville, 2000). The United Kingdom Environment Agency (2001) indicated that any environmental impacts of carcass disposal in the UK following the 2001 disposal events were short-term and localized and much smaller than the day-to-day impacts of current farming practices. However, the literature available and past experiences with burial of wastes indicate carcass disposal by burial will likely require the most extensive environmental monitoring of the carcass disposal technologies considered in this document. Literature describing the potential environmental impacts of carcass disposal technologies is briefly discussed in the paragraphs that follow.

Glanville (2000) reported on the impact of livestock burial on shallow groundwater quality, noting that proper disposal of livestock mortalities can be more difficult than manure management, because animal carcasses are not easily stored for long periods of time and cannot be spread on cropland. In order to study the characteristic types, concentrations, and duration of release of contaminants from on-farm burial, the Iowa Department of Natural Resources funded two case studies.

The first case study examined two 1.8 m deep pits containing 28,400 kg of turkey carcasses that had been buried one year prior to the initiation of the study. The site was located in poorly drained soil with moderately slow permeability with a seasonal high water at depths of 0.3 to 0.9 m. Twelve monitoring wells were used to identify contaminant movement and background water quality with samples collected monthly for a period of 15 months, and again at 20 months and 40 months.

In the second case study, two 1.2 m deep trenches were spaced 2.4 m apart in well-drained, moderately permeable soil. The seasonal high water table was at a depth greater than 1.8 m. Each trench was loaded with six 11.3-13.6 kg swine carcasses spaced evenly along the trench bottom. The mass of carcasses in each trench was considered a reasonable loading rate according to Iowa rules. One of the trenches was lined with PVC sheeting and 10 cm of pea gravel. A PVC pipe was buried vertically at one end of the trench and equipped with a sump pump so that monthly samples of leachate could be obtained. The leachate was analyzed to examine the mass, concentration, and duration of decay products. Eight monitoring wells were placed around the trenches to monitor groundwater.

In these case studies, elevated levels of biochemical oxygen demand (BOD), ammonia-nitrogen (NH_4-N), total dissolved solids (TDS), and chloride were commonly found within or very near the burial trenches. Although chloride concentrations were generally lower than the other contaminants, elevated chloride levels are generally the best indicator of burial-related groundwater contamination. Glanville (2000) concluded that localized contamination may persist for a decade or more in wet soil with a high seasonal water table and low groundwater flow velocity. Even in lightly loaded burial trenches constructed in well-drained soil, complete decay may take two years or more. Neither of these experiments showed burial-related contamination more than a meter or two from the pits. In cases where groundwater velocities are higher, however, or where vertical groundwater movement occurs, leachate from burial sites may pose a higher contamination risk to groundwater.

Ritter et al. (1988) examined the impact of dead bird disposal on groundwater quality by monitoring groundwater quality around six disposal pits in Delaware. Open-bottomed pits were used for day-to-day mortality disposal. These pits are not identical to burial pits, though there are similarities. Most of these pits were located in sandy soils with high seasonal water tables. Therefore, the potential for pollution of groundwater is high with this method of disposal. After selecting the sites, two to three monitoring wells were placed around each pit to a depth of 4.5 m. Ammonia concentrations were high in two of the wells, with three of the disposal pits causing an increase in ammonia concentrations in the groundwater. Total dissolved solids concentrations were high in all monitoring wells for most dates. Bacterial contamination of groundwater by the disposal pits was low.

Ritter and Chirnside (1995) examined the impact of dead bird disposal pits on groundwater quality on the Delmarva Peninsula in Delaware. They reported these additional discoveries:

- Nitrogen is a greater problem than bacterial contamination.
- Serious contamination may occur if large numbers of birds are added to the pit.
- Abandoned disposal pits should be pumped out and filled with soil to minimize their impact on groundwater quality.
- Subsurface disposal of dead birds should be regulated.
- Only certain types of disposal pits (i.e. concrete tanks) should be allowed.
- Permits should be issued for disposal sites meeting minimum standards (i.e. dealing with soil type, water table depth, etc.).

At the time of UK foot and mouth disease (FMD) outbreaks in 2001, on-farm burial and on-farm burning were initially the primary means of carcass disposal. However, concerns for potential groundwater contamination by on-farm burial and local community health concerns due to smoke and emissions from on-farm burning were raised (Scudamore et al., 2002). Thus, mass burial and on-farm burning are now ranked at the bottom of options in the disposal hierarchy within the UK (Scudamore et al., 2002).

The State of Wisconsin Department of Natural Resources (2002) analyzed the threat of carcass disposal of deer with chronic wasting disease. They concluded that disposal of these carcasses in municipal solid waste landfills would provide adequate levels of protection to reduce the spread of chronic wasting disease, protect the environment, and protect human health.

The environment may also be impacted in unanticipated ways due to reductions in farm incomes associated with carcass disposal events (The Productive Commission, 2002). A reduction in farm income may indirectly impact the environment, because farmers may be unwilling to spend money on soil conservation or general environmental preservation due to increased financial pressure. Quantification of the environmental impacts in such cases through monitoring would not likely be feasible due to the highly diffuse nature of such impacts and the time scales over which they would occur. In such cases, models may be helpful in estimating the possible environmental impacts.

2.1 – Monitoring of Water Supplies

Burial

Burial of carcasses is likely to have the greatest impact on water quality of the carcass disposal techniques discussed. When the carcasses are buried and undergo decomposition processes, nutrients, pathogens, and other materials may be released into the environment. These substances may be degraded, transformed, lost to air, or immobilized, posing no environmental impacts. However, some may contaminate the soil, surface water, and groundwater bodies (Freedman and Fleming, 2003). Elevated levels of BOD, NH4-N, TDS, and chloride have been found within or very near carcass burial trenches (Glanville, 2000). Elevated chloride levels are generally the best indicator of burial-related groundwater contamination (Glanville, 2000). According to the UK Environment Agency (UK Environment Agency, 2001), 212 surface and groundwater pollution incidents were reported, although minor, as a result of carcass disposal during the 2001 carcass disposal events in the UK Of these incidents, 24% were due to leachates from carcass disposal pits. This was largely because the carcasses were initially buried close to a water table, since the environmental impacts of carcass burial were not high priority concerns when selecting disposal sites.

Improper management of carcass burial sites can result in both surface water and groundwater contamination. For example, the soil cover on burial sites may have to be replenished every few weeks, because settling in the cover can cause surface runoff to flow into the site. The best soil type for covering carcass burial pits to reduce groundwater contamination is a fine-grained, heavy soil like clay.

However, clay soils increase direct runoff, possibly resulting in surface water contamination.

When carcasses are buried in pits, leachate is generated by water and other liquid percolating or passing through the carcasses, as well as the liquids released by the decaying carcasses. Leachate is contaminated water containing a number of dissolved and suspended materials Leachate from carcass disposal pits is often highly contaminated and should not be directly discharged into surface water bodies or groundwater. Scudamore et al. (2002) indicated that during the large carcass disposal effort in the UK in 2001, there were initially no proven designs for mass burial sites. However, the design and engineering features of the burial sites underwent a significant transformation during the disposal period. Initially the burial pits were large holes in the ground, but later locations were engineered with increasingly sophisticated liners and leachate collection systems to minimize risks to groundwater (Scudamore et al., 2002).

Leachate quality varies depending on the composition of materials buried, elapsed time after carcass disposal, ambient temperature, available moisture, and available oxygen. Leachate quantity varies depending on precipitation, groundwater intrusion, moisture content of waste, and final cover design. Monitoring of the quantity and quality of leachate over time (daily, seasonal, and long-term) is important (Bagchi, 1994).

Leachate quality should be assessed at an early stage to identify if the waste is hazardous, to choose a pit design, o design or gain access to a suitable leachate treatment plant, and to develop a list of analytes for the groundwater monitoring program. Leachate quality can be measured using laboratory tests, such as a water leach test, standard leach test, toxicity characteristic leaching procedure (TCLP) test, and the synthetic precipitation leachate procedure. The condition of the leachate can be judged based on the concentration of contaminants, and decisions made regarding whether further action is necessary (Bagchi, 1994).

Chloride, ammonium, nitrate, conductivity, total coliforms, and *E. coli* should be monitored in potentially contaminated water supplies. Although not definitively conclusive, increases in these contaminates may indicate leachate contamination. Other possible sources, such as manure storage and spreading, should also be investigated. Thus further monitoring may be needed to confirm sources of contamination (United Kingdom Department of Health, 2003).

An elevated concentration of nitrate in groundwater is of significant concern, because nitrates can potentially be harmful to infants if found in drinking water. Proper management of a leachate plume from carcass disposal pits is important. If the site is chemically treated to kill viruses, additional monitoring may be required to check whether the processes involved meet regulatory standards (United Kingdom Department of Health, 2003).

The concentration of pollutants generated in the first year following waste disposal by burial may be less than those in the subsequent years, and concentrations of all pollutants do not peak at the same time. While this is generally true for municipal wastes, this may not be true for carcass burial. Therefore, both short-term and long-term monitoring is necessary to identify the possible risks due to the higher concentrations of pollutants. Environmental risk assessments should be performed for all burial sites to minimize the risk to the environment, which consider local topography, soil, water, geological, and aquifer features.

Trucks and equipment used for excavation or other disposal operations can transport disease agents to off-site areas and, therefore, should be thoroughly decontaminated. Some of the agents used for decontamination can contaminate water supplies, requiring proper treatment and handling of the wash (United Kingdom Department of Health, 2003).

To detect possible environmental contamination from carcass burial sites, the following factors need to be monitored:

- Leachate head within the pit.
- Head in the dewatering system, if installed.
- Leakage through the bottom of a burial pit or landfill.
- Head and quality of leachate in the collection tank.
- Stability of the final cover.

- Groundwater around the site.
- Gas in the soil and the atmosphere around the carcass disposal pit.
- Soil quality at or near the carcass disposal site.

All of these factors will vary with time, and monitoring over time is needed to ensure carcass burial sites are performing as designed.

It may take dozens of years for carcasses to decompose, thus short-term and long-term effects of carcass disposal on the environment should be considered. Retrospective assessments are also necessary to ensure sampling locations adequately depict the environmental impact of the carcass disposal event. If carcass disposal locations cause public complaint, additional monitoring may be warranted. Following closure of carcass burial sites, the owner/operator should conduct post-closure care for a period of time. Post-closure care consists of maintaining the integrity of the final cover and groundwater, gas, and leachate collection and monitoring systems (Bagchi, 1994).

In the case of carcass burial, the migration of gas, leachate, and chemicals which may have been used for decontamination should be monitored; remedial actions are easier and less expensive when only limited areas are contaminated. It is necessary to determine if the leachate and gas from the burial sites meet regulatory standards.

Incineration

In the case of incineration, heavy metals from the contaminants in coal or fuel sources can reach water supplies and change the taste and smell of the water. If water sample data contain statistically higher levels of contaminants compared with the background data, and water supplies are considered to be at risk to the contamination, routine monitoring is necessary as is monitoring for potential impacts on public health. Generally, incineration of carcasses will not produce significant surface water and groundwater concerns.

Again, trucks and equipment used in incineration operations can transport disease agents to off-site areas and, therefore, should be thoroughly decontaminated. Some of the agents used for decontamination can potentially contaminate water supplies, requiring proper treatment and handling of the wash (United Kingdom Department of Health, 2003).

Alkaline hydrolysis

The impacts of alkaline hydrolysis carcass disposal efforts on water should be negligible if conducted properly. The most likely impacts on water quality would likely be due to runoff from the site that might carry sediments and materials washed off equipment. If the digestate produced by alkaline hydrolysis is land applied, it may be desirable to monitor water quality (surface water and shallow groundwater) for these fields. However, if the digestate is applied at rates that are agronomically safe with respect to nutrients and trace metals, the environmental impacts should be minimal.

Trucks and equipment used in alkaline hydrolysis operations can transport disease agents to off-site areas and, therefore, should be thoroughly decontaminated. Some of the agents used for decontamination can potentially contaminate water supplies, requiring proper treatment and handling of the wash (United Kingdom Department of Health, 2003).

Composting

The impacts of carcass composting efforts on water should be negligible if conducted properly. To relieve public concern, limited groundwater and surface water runoff sampling near sites that are composting large masses of carcasses could be done. Application of the finished compost to land at agronomic rates should pose minimal threats to surface water and groundwater.

Once again, trucks and equipment used in composting operations can transport disease agents to off-site areas and, therefore, should be thoroughly decontaminated. Some of the agents used for decontamination can potentially contaminate water supplies, requiring proper treatment and handling of the wash (United Kingdom Department of Health, 2003).

2.2 – Monitoring of Air Quality and Soil Quality

Burial

While groundwater contamination may take time to occur and appear, air pollution from burial sites can cause immediate and direct impact. When carcasses are buried, anaerobic decomposition of organic materials will result in gases, such as methane, carbon dioxide, carbon monoxide, nitrogen oxides, sulphur dioxide, hydrogen chloride, hydrogen fluoride, and methane. These gases could potentially be very toxic and could violate air quality standards. For example, methane, a greenhouse gas, is potentially explosive. The diffuse gases from carcass burial sites should be monitored on a routine basis to check the potential hazard to workers and people living around the sites.

Venting of gas may be necessary if the pressure of gas generated from biodegradation or other physical/chemical processes in carcass burial sites may be high enough to rupture the disposal site cover. Thus monitoring of gas pressure is also suggested. Gas diffused through the cover can stress and potentially kill vegetation, resulting in increased erosion of the final cover. A routine monitoring program should be implemented to ensure the concentration of explosive gases from the carcass burial sites does not exceed regulatory standards in the area.

Like leachate, the quality and quantity of gas from the carcass burial sites varies with time. The quantity of gas generated depends on waste volume and time; sampling time and frequency are important as well. Spatially and temporarily unbiased sampling is needed for correct assessment.

Incineration

In the case of incineration, the prevailing wind direction should be monitored at the time of incineration to prevent unnecessary smoke and objectionable odors reaching sensitive areas. Hickman and Hughes (2002) indicated that according to the UK Department of Health, large pyres need to be built at least 3 km away from local communities and more heavily populated areas. During the FMD outbreak in the UK in 2001, pollutants from pyres were measured at various distances from the pyres with a variety of percentages of time downwind. The pollutant levels in these cases were either lower than air quality standards or within urban background levels (UK Department of Health, 2001).

Since a significant amount of fuel is often needed for complete incineration, the environmental impacts of using these fuels should be monitored and evaluated. Dioxins from pyre smoke can accumulate in soil and vegetation, ultimately entering the food chain through animal grazing. Monitoring of dioxins and dioxin-like polychlorinated biphenyls should therefore be conducted in soil, vegetation, eggs, milk, lamb, chicken, and other animal products to check whether foods produced close to these areas have higher concentration of these contaminants. Following the FMD outbreak in the UK in 2001, levels of dioxins in soil, vegetation, and food were mostly within the expected range or similar to levels at control farms (UK Department of Health, 2001). Hickman and Hughes (2002) indicated that there have been no confirmed reports of dioxins and dioxin-like products reaching the human food chain from carcass disposal activities.

One of the critical air quality pollutants from pyres is often sulphur dioxide, so use of coal with low sulphur content is highly recommended to reduce the sulphur dioxide level. In addition to sulphur, combustion products such as nitrogen oxides, particulate matter, carbon monoxide, dioxin, and polycyclic aromatic hydrocarbons should be monitored. After incineration of carcasses, ash should not be left unattended. Strong wind and heavy rainfall can cause the ash to contaminate a large area quickly, and the ash can also leach into the soil causing further contamination in surrounding areas.

It is noteworthy that the concentrations at monitoring locations selected in previous studies with carcass disposal by incineration may not represent the higher pollutant concentrations closer to the pyres, which could cause adverse impacts on human health. Fine particles carried through the air from carcass disposal sites could cause inflammation and deterioration in the heart and lungs. Carbon monoxide can lead to a significant reduction in the supply of oxygen to the heart. Air pollution can cause eye irritation and coughing, and breathing difficulties, especially for elderly people.

Concerns have been raised about the potential for diseases to be transmitted in the smoke and particles that move off site as a result of incineration of diseased carcasses. The FMD virus can be spread by the wind as well as by the movement of infected animals and aerogenous transmission to susceptible animals (Donaldson and Alexandersen, 2002). Although the wind spread of the FMD virus is not that common, its impacts on downwind areas can be very rapid and extensive, and become uncontrollable, once spread by the wind. Hickman and Hughes (2002), however, indicate that there is no evidence of the FMD virus being transmitted to humans or into the human food chain as a result of the incineration of diseased livestock in the UK

Alkaline hydrolysis

The use of alkaline hydrolysis for carcass disposal is unlikely to negatively impact air quality. Therefore, air quality monitoring would not likely be necessary. However, the spread of disease by wind from carcasses that are stockpiled at the site or that are being placed in the digester may be a concern.

Composting

The use of composting for carcass disposal is unlikely to negatively impact air quality. Therefore, air quality monitoring would not likely be necessary. However, the spread of disease by wind from carcasses that are stockpiled at the site or that are being placed in the compost material may be a concern.

Section 3 – Environmental Models for Carcass Disposal Impact Evaluation

3.1 – Introduction

Natural disasters or disease outbreaks can result in an unexpected large number of dead livestock and present a challenge in the disposal of carcasses. Catastrophic livestock deaths could also be the result of intentional attacks or introductions of disease. Quick and efficient responses are required to deal with carcass disposal. Since September 11, homeland security and public protection from biological attacks such as anthrax have become a more serious concern. The livestock industry, a significant portion of the agricultural sector in the United States, provides numerous products highly related to public health.

Animal disasters may engender massive carcass disposal or destruction of livestock. Carcass disposal should be handled correctly and quickly to minimize environmental impacts on surface water, groundwater, soil, and air. Although some situations may allow for carcasses to be safely disposed of on site, other situations may require off-site disposal. Carcass disposal and treatment sites are environmentally vulnerable due to potentially enormous numbers of dead animal bodies with associated liquids and organic material that should be isolated from the environment. The presence of pathogens in the carcasses can present even greater environmental risks.

Depending on the disposal method, water resources are often the most vulnerable aspect of the environment. Disposal sites may be located near streams, lakes, and ponds, and groundwater is likely to be present beneath sites. Water bodies can be contaminated from carcass disposal and serve as a route or delivery medium for waterborne pathogens and liquids from carcasses (Freedman and Fleming, 2003). The potential environmental impact of carcass disposal should be evaluated prior to disposal in order to minimize effects on water resources. In addition, evaluation should continue after disposal to detect any potential problems before they occur.

Soil is also vulnerable to contamination from massive carcass disposal, especially from burial. Burial methods usually expose the soil to chemical and biological interactions with carcasses. Around and under the burial site, soil may potentially be exposed to high nutrient levels, including phosphorus and nitrogen, from animal decomposition. Leachate from carcasses may also contain biological agents. Other carcass disposal technologies may also contaminate soil through contact of soil with ash and by-products, disinfectant materials, fuel sources, and other materials used by the disposal technology. Hence, the impact of the disposal technology on soil should be evaluated during site selection, operation, and post-closure. Air can also be negatively impacted by carcass disposal. Some disposal technologies potentially impact air to a much larger degree than others. For instance, open burning of carcasses can potentially have severe consequences on air quality. Air pollution can cause eye irritation, coughing, and breathing difficulties.

This section describes models that can potentially be used to assess the environmental sensitivity of surface water, groundwater, erosion/sedimentation, soil quality, and air models at or near possible carcass disposal locations. In the case of a carcass disposal event, these models can be used to screen sites during planning, evaluate potential sites during site selection, and estimate the environmental impact during and following the emergency. Itemized model information is provided in the sections that follow. The models are described in terms of category, model name, evaluation stage, specified use, model overview, applicable scale, computer system requirements, cost, model inputs, model outputs, selected references, and model Web site. The models in the list were chosen based on information gathered through the Internet, journals, and reports. Many additional models are available, so those identified as potentially most appropriate for carcass disposal issues are discussed.

3.2 – Surface Water and Groundwater Models

Various hydrologic models simulating surface water, groundwater, nutrients, and pathogen movement can play a significant role in evaluating the impact of carcass disposal. These models can be used for screening, pre-disposal site selection, real-time evaluation of possible environmental impact, and post-disposal evaluation of sites. Realistically, environmental impacts cannot be entirely avoided in large-scale carcass disposal, but they can be minimized by using appropriate tools, including hydrologic models, to improve decision making. Hydrologic models operated with readily available data from each step can provide information to assist with decision making.

Impacts on surface water and groundwater due to carcass disposal differ for each carcass disposal method. The impacts on surface water and groundwater will also be site-specific for a given carcass disposal technology. In the case of burial, the selected disposal site may be modified prior to disposal to provide more appropriate land surface conditions for slope, aspect, and roughness, potentially reducing the potential impact on water resources. After disposal, water contamination possibilities increase from decomposition of the carcasses.

Impact evaluation on surface water from carcass disposal includes several issues, such as peak runoff (storm flow), long-term runoff, and stream flow. Surface water quality issues also arise with carcass disposal. Carcasses may release materials that reach water, potentially increasing waterborne pathogens, nutrients, and oxygen consumption.

To evaluate the hydrologic impacts from carcass disposal, the following analysis steps are suggested: screening to identify potential carcass disposal sites for various carcass disposal technologies, more detailed pre-disposal assessment of sites, real-time assessment of sites during carcass disposal and post-disposal site assessment. Complex physical models typically require intensive and wide ranges of data and data preparation, so such models may be too difficult to run for large areas and in the event of a carcass disposal emergency. Therefore, choosing a hydrologic model for a carcass disposal impact evaluation for any stage of carcass disposal analysis is critical to support decision making.

Role of surface water and groundwater models

Through model application, the impact of carcass disposal on water bodies can be identified.

Fundamental questions for water body management typically include "how" and "what if" questions. For example, if a watershed is a carcass disposal site or will be altered by carcass disposal processes, then a question may be "how" the carcass disposal will affect hydrologic conditions and water quality. To answer such a question, hydrologic models are commonly used to evaluate the impact of changes.

The hydrologic models overviewed have varying capabilities as described in the further detail associated with each model. Collectively, they can simulate surface water, groundwater, nutrient movement, and pathogen movement, and may play a significant role in evaluating the impact of carcass disposal. A search of the literature did not identify any example applications of these or other hydrologic models to carcass disposal efforts, and thus the following paragraphs provide brief descriptions of how the hydrologic models have generally been used. This should be helpful for assessing the potential application of these models in carcass disposal events.

The United States Department of Agriculture (USDA) Soil Conservation Service (SCS) Curve Number (CN) Method (USDA SCS, 1986) is one of most popular direct runoff (surface runoff – excludes base flow and other forms of flow in streams) estimation methods and has been incorporated in numerous hydrologic models as a key element. SWAT (Soil and Water Assessment Tools), L-THIA (Long-Term Hydrological Impact Assessment), AGNPS (Agricultural Non-Point Source), SEDSPEC (Sediment and Erosion Control Planning, Design and SPECification Information and Guidance Tool), and the HEC series of models use the SCS CN method to estimate direct runoff. The SCS CN Method can be used for run off estimation from small areas and watersheds and thus can provide estimates of amounts of water that might runoff an area being used for carcass disposal or that might run on to such an area from the upstream or upslope area.

Since the 1990s, GIS tools have been commonly used with hydrologic and water quality models. SWAT (Arnold et al., 1998) has been integrated with the US Environmental Protection Agency's (EPA) Better Assessment Science Integrating point and Non-point Sources (BASINS, http://www.epa.gov/waterscience/basins/) effort to provide an analysis capability to meet the needs of pollution control agencies. BASINS integrates a GIS, national watershed and meteorological data, and state-of-the-art environmental assessment and modeling tools, with SWAT as a key hydrologic and non-point source pollution model. SWAT also has a broad application spectrum with ability to estimate daily stream flow, non-point source pollution loading and Total Maximum Daily Load (TMDL) levels.

There are several models that can be operated through the Internet thus reducing the level of expertise required to use the models. The Internet-based models include L-THIA, WWW NAPRA (National Agricultural Pesticide Risk Analysis) and SEDSPEC. Among them, L-THIA developed by Harbor (1994) is a screening stage model for NPS and direct runoff estimation. L-THIA uses the SCS CN method as its main core to simulate runoff based on long-term daily rainfall values, land use, and soil information. Its effectiveness as a long-term land use change analysis tool has been demonstrated by several studies (Leitch and Harbor, 1999; 2000; Grove et al., 2001). Muthukrishnan et al. (2002) used the L-THIA model to study the hydrologic impacts of land use changes using time series analysis for watersheds in northeastern Ohio, and the results were found to be very useful to the community and the watershed planners in planning for future land use zoning and development, and minimizing the impacts associated with land use conversion. Models such as L-THIA and SEDSPEC could potentially be used to quickly analyze sites being considered for carcass disposal to understand the potential for runoff from the sites.

The WWW NAPRA (Lim and Engel, 1999) model, also Internet-based, uses the GLEAMS model to simulate field scale non-point source pollution loading and fate. SEDSPEC (Tang et al., 2002) is also an Internet-based model that was developed to support peak runoff, sediment, and erosion control efforts when there are needs to design runoff, erosion, and sediment control structures. SEDSPEC might be useful for quickly assessing whether runoff and erosion control structures (vegetated and lined channels, water diversion structures, culverts, etc) are required at a carcass disposal site and providing a preliminary design for such structures.

The AGNPS model is widely used to estimate runoff and non-point source pollution loadings. Recently, AGNPS was restructured as an annualized continuous-simulation version of the model, AnnAGNPS, to provide operational flexibility. Since AGNPS was introduced, a large number of research results have been published, especially in integrating it with GIS and for agricultural watershed management. Mitchell et al. (1993) applied AGNPS to agricultural small watershed to identify areas contributing disproportionate amounts of runoff and pollutants. Such areas can then be targeted with best management practices to reduce such impacts. In carcass disposal efforts, the local watershed in which the carcass disposal location is located could be analyzed to determine the potential impact of the carcass disposal location in contributing runoff and pollutants to local streams or other waterbodies.

The DRAINMOD model may be useful in understanding shallow groundwater impacts of carcass disposal efforts. McCarthy and Skaggs (1991) applied DRAINMOD to predict drainage rates for changing boundary conditions, and Madramootoo (1990) assessed drainage benefits on a heavy clay soil in Quebec, Canada. The installation of subsurface drainage near carcass disposal sites may be desirable to prevent high water tables from interacting with the disposal site. DRAINMOD is capable of such analysis.

Model classification

Surface water and groundwater models were categorized by evaluation stage for screening, pre-disposal site selection, site analysis during a disposal emergency, and post-disposal analysis. The models were classified into these categories largely based on their complexity, data requirements, and operational requirements.

Screening and pre-disposal evaluation models

Models that evaluate hydrologic and water quality impacts of carcass disposal vary from simple empirical methods to complex physical models in terms of data requirements and model components. Screening models can be applied before or during disposal site selection to identify potentially suitable sites. Such applications require comparably simple data and are relatively easy to use. These models are recommended for preliminary site screening use, and for use in situations of limited resources (time, cost, and human resources). More detailed information is located in Appendix A. For this stage, three models were identified and are listed below:

- SEDSPEC: Sediment and Erosion Control Planning, Design and SPECification Information and Guidance Tool (estimates peak runoff and erosion).
- L-THIA, WWW LTHIA, GIS L-THIA: Long-Term Hydrological Impact Assessment (estimates average annual runoff and nonpoint source pollution).
- DRASTIC: A standardized system for evaluation of groundwater pollution potential using hydrogeologic settings (estimates groundwater vulnerability to pollutants).

Real-time and post-disposal evaluation models

For real-time and post-carcass disposal evaluation, more intensive environmental evaluation using models that have more scientific consideration and better representation of hydrologic components is desirable. Models for these uses typically require significantly greater data, time, and human resources than screening stage models. More detailed information is located in Appendix A. The models recommended in this category are listed below:

- SCS Curve Number Method.
- ANSWERS (ANSWERS-2000): Aerial Nonpoint Source Watershed Environment Response Simulation.
- AGNPS, AnnAGNPS: Agricultural Non-Point Source (AGNPS) model.
- DRAINMOD: A field-scale water management simulation model.
- EUTROMOD: A watershed-scale nutrient loading and lake response model.
- GLEAMS: A model to simulate the effects of different agricultural management systems on the water quality.
- NAPRA WWW: Web-based National Agriculture Pesticide Risk Analysis model.
- SWAT: Soil and Water Assessment Tool.

- WMS: Watershed Modeling System.
- WEPP: Water Erosion Prediction Project.
- EPIC: The Erosion-Productivity Impact Calculator.
- QUAL2E: The Enhanced Stream Water Quality Model, recommended only for post-disposal evaluation because the model requires observed data for calibration.

3.3 – Sediment and soil transport

Significant soil disturbance at disposal sites is a likely result of many carcass disposal technologies. In most instances, burial would result in significant soil disturbances. However, incineration, composting, and alkaline hydrolysis may result in disturbances due to operation of heavy machinery and trucks. Soil disturbances typically increase the potential for erosion, and soil eroding from these sites may carry contaminants resulting in severe off-site impacts. After the closure of carcass burial sites, the gas diffused through the cover of the site can stress vegetation, potentially increasing soil erosion. The impacts of carcass disposal methods on soil erosion should be considered and minimized to avoid possible off-site contamination by pathogens and other contaminants attached to sediment.

Role of sediment and soil transport models

Computer models can be used to identify possible locations for carcass disposal, minimizing the soil erosion and soil quality degradation. These models can be used to simulate the impacts of land disturbance by the carcass disposal methods on soil erosion. Since soil erosion is also related to water movement, combined hydrologic and soil erosion models can be used for this purpose. To simulate the movement of soil particles and associated contaminants by wind, wind erosion models are also discussed.

A search of the literature did not identify any example applications of erosion models to carcass disposal efforts, and thus the following paragraphs provide brief descriptions of how some erosion models have generally been used. This should be helpful for assessing the potential application of these models in carcass disposal events.

The Water Erosion Prediction Project (WEPP) model estimates runoff and soil erosion from small watershed or field areas. Cochrane and Flanagan (1999) applied WEPP to assess water erosion in small watersheds using GIS and digital elevation models. Vining et al. (2001) applied WEPP to a watershed in Michigan to solve a water quality problem, and Laflen et al. (2001) utilized WEPP at construction sites to understand the erosion impact from unprotected soils. WEPP could be useful in assessing the potential magnitude of soil losses from carcass disposal sites and from such sites once they are "closed."

RUSLE2 (Foster et al., 2001) and RUSLE (Renard et al., 1991) are revisions of the USLE (Universal Soil Loss Equation). The USLE is the most widely used erosion model and is often embedded in other soil erosion models to estimate annual soil loss yield and erosion. Among the abundant applications of USLE, Toy et al. (1999) used RUSLE to estimate soil loss from mining, construction, and reclamation lands during periods when the soil was disturbed. Hession and Shanholtz (1988) used GIS with the USLE to compute sediment loading to streams. The USLE estimated values matched the measured values reasonably well (R2 = 0.88) for the small watersheds studied. Simanton et al. (1980) applied the USLE to four watersheds and found USLE estimated soil losses matched reasonably for two watersheds having no gullies or significant alluvial channels. Note the USLE does not estimate gully erosion, rather it provides a method for quick estimation of rill and inter-rill erosion.

Model classification

Erosion models ranging from simple screening models to complex models, which can be used to assess the impacts of carcass disposal methods on the soil erosion and sediment yield, are introduced below.

Screening models

Many water and wind erosion models can be used for the evaluation of carcass disposal sites. However, these models are complex and are difficult to operate without erosion modeling knowledge. These screening models can be used as guidance to choose a potential location for carcass disposal. Additional descriptions of these can be found in Appendix B. The erosion screening models include:

- K: Soil Erodibility.
- RWEQ: The Revised Wind Erosion Equation.
- WEPS: Wind Erosion Prediction System.
- USLE: Universal Soil Loss Equation.

Pre-disposal, real-time, and post-disposal evaluation models

The water and wind erosion models listed below can be used for pre-disposal site assessment, real-time assessment of erosion, and post-disposal evaluation. These models provide more detailed soil erosion and sediment yield results than the screening models, although input data required for these models are sometimes not readily available. Some of the following models predict the results on a daily time step, which is potentially desirable for real-time assessment and post-disposal evaluation. Additional information is located in Appendix B. These models are:

- RUSLE: Revised Universal Soil Loss Equation.
- WEPP: The Water Erosion Prediction Project.
- AGNPS: Agricultural Non-Point Source Pollution Model.
- ANSWERS: Areal Nonpoint Source Watershed Environmental Response Simulation.
- SWAT: Soil and Water Assessment Tool.
- WEPS: Wind Erosion Prediction System.

3.4 – Soil Quality and Ecology (Biological Transport)

As stated previously, significant soil disturbance at disposal sites is a likely result of many carcass disposal technologies. In particular, burial of carcasses, or ash and residue from burning or chemical digestion, can create what are, in effect, mini-landfills which may require careful design and long-term monitoring. The rationale for this comparison stems from the large volumes of leachate produced by burial of carcasses, the concentration of metals or pathogens possible from burial of ash and incineration, or biological digestion remnants.

For example, a pit intended to contain 100 carcasses at 1,000 pounds mass per carcass may not be designed to effectively handle the hundreds of liters of leachate from the decomposing carcasses. Leachate may contain biological agents or mineral constituents undesirable in underlying aquifers. Leachate will be present even if a clay cap is placed over the pit, arising from fluids in the carcasses. Technology for determining hazards represented by this leachate and for controlling, preventing, or monitoring this leachate exists and can be implemented with proper planning.

The pits intended to contain ash and residue from the burning or chemical digestion of carcasses can also suffer from poor design. The range of possible construction criteria goes from wet, aerobic composting-type pits to covered, anaerobic landfill-type excavations. The specific design style should be determined in advance for the local or regional conditions. High-water tables, shallow drinking aquifers, rocky or sandy soils, and proximity of water bodies are examples of factors that should be included in the design stage, preferably in advance of an emergency.

Role of multimedia models in soil quality

These factors suggest that using computer models intended to design and monitor landfill construction may be useful in creating a standard design for a disposal site for burying carcasses, incineration remains, or chemical digestion products. Appropriate models individually or in aggregate should account for the water balance leaving the site and carrying with it chemical and biological constituents.

Model classification

As with other technologies, models range from simple and basic to those with very detailed inputs and complex functions. This document describes models based on i) pre-implementation regional screening and risk management or ii) design standards for disposal and post-implementation monitoring.

Regional screening and pre-disposal evaluation and risk assessment

Models that can account for leachate creation and motion on a regional scale include generalizations of local physical characteristics or boundary conditions. These models can result in outputs that can be generalized across a region and can describe exposure to leached contaminants in terms of risk to the population or food chain.

Models in this section involve physical soil parameters, weather parameters, chemical constants, and time steps; and they are referred to as "multimedia" models. Several such models are available for use in risk assessment of exposure to chemicals moving off site from surface impoundments, landfills, land application units, and waste piles. Some are available as open source programs and also as enhanced versions from commercial distributors. Examples of both are included. The principal models used are discussed below. Detailed descriptions of these can be found in Appendix C.

Regional screening and risk assessment

The models most suitable for prescreening of sites, including at regional scales, include:

- PRZM3.
- MULTIMED 2.0.
- 3MRA Multimedia, Multi-pathway, Multi-receptor Exposure and Risk Assessment Model.
- MMSOILS.

Site design and monitoring

Several multimedia models are available for use in designing landfills, sludge disposal sites, manure waste lagoons, and similar features that need to account for the precise motion of water, chemicals, and biological agents through both constructed and natural features. The standard model for landfill design (HELP) is available as an open source program and also in enhanced versions from commercial distributors. Examples of both are included. Detailed descriptions of these can be found in the Appendix. The principal models that might be considered are listed below:

- HELP.
- Visual HELP.
- BIOF&T-3D.
- 3DFATMIC.
- MIGRATEv9.

3.5 –Air

The impacts of carcass disposal methods—such as burial, incineration, and composting—on air quality should be assessed to control and monitor the possible hazard to the local public. Gases generated from carcass burial could be toxic and could violate air quality standards. In the case of incineration, dioxins may be generated and travel off site with pyre smoke.

Role of air models

Computer models can be used to simulate the movement of odor, toxic gases, particulate matter, and airborne pathogens. These computer models can be used to identify the potential location for carcass disposal while minimizing off-site impacts of airborne pollutants. These simulations can be used to assess the impact of a disposal site on air quality during disposal and after a site is closed.

A search of the literature did not identify any example applications of air quality models to carcass disposal efforts. However, concerns have been raised about the potential for diseases to be transmitted in the smoke and particles that move off site as a result of incineration of diseased carcasses. The FMD virus can be spread by the wind as well as by the movement of infected animals and aerogenous transmission to susceptible animals (Donaldson and Alexandersen, 2002). A computer model called the Virus Production Model (VPM) was developed and integrated into a GIS system to simulate the airborne spread of viruses (Sorensen et al., 2000; Sorensen et al., 2001). The model generates airborne plumes that can assist decision-making processes and help in deploying personnel to contain the disease (Sorensen et al., 2001). However, the model does not consider the incineration of diseased animals but assumes live animals. The following paragraph provides a brief description of how some air quality models have generally been used. This should be helpful for assessing the potential application of such models in carcass disposal events

SCREEN3 is the model currently used by US EPA for regulatory screening of new air permit applications and new source review screening. It estimates the worst-case scenario ambient impacts from point, volume, and area sources of pollutants by incorporating general meteorological conditions. USEPA uses this model as a conservative first-run screening tool, followed by more refined modeling in areas determined by SCREEN3 to be of potential concern (US EPA, 1995). Such a model might be used for screening locations and carcass disposal situations. Those locations and situations that appear to raise potential air quality concerns could be modeled further with more complex models.

Model classification

Models ranging from simple screening models to complex that can be used to assess the impacts of carcass disposal methods on air quality are introduced in the following sections.

Screening models

Two air dispersion models were identified for potential use as screening tools. These screening models can be used to simulate/assess the immediate impacts of carcass disposal on air quality in the vicinity of the carcass disposal site. More detailed information is provided in Appendix D.

- SCREEN3
- CTSCREEN: Complex Terrain Screening Model.

Pre-disposal, real-time, and post-disposal evaluation models

Different computer models are needed to simulate the dispersion of pollutants from the different carcass disposal methods, such as burial and incineration. The air dispersion models, capable of simulating dispersion from open burning, point, line, and area sources, can be used for the evaluation of sites prior to disposal, during disposal and post-disposal. These complex computer models predict the peak concentration and time-averaged concentration of air pollutants. These models can predict the source contribution and plume characteristics at sampling locations for every hour, day, and year. More detailed information is provided in Appendix D.

- Open Burn/Open Detonation Dispersion Model (OBODM).
- Atmospheric Dispersion Modeling System (ADMS).
- Areal Locations of Hazardous Atmospheres (ALOHA).
- Integrated PUFF (INPUFF).

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Appendices

Appendix A – Surface water and groundwater models list

A1. SCS Curve Number Method

A2. ANSWERS (ANSWERS-2000)

A3. AGNPS, AnnAGNPS

A4. DRAINMOD

A5. EUTROMOD

A6. GLEAMS

A7. SEDSPEC

A8. L-THIA, WWW-LTHIA, GIS-L-THIA

A9. NAPRA WWW

A10. SWAT

A11. QUAL2E

A12. WMS

A13. DRASTIC

A14. WEPP

A15. EPIC

A16. MODFLOW

No. A1: SCS Curve Number Method

Category: Surface water/Groundwater/Air/Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Surface water (peak runoff estimation)

Model Name: NRCS Curve Number Method

Overview

The basic assumption of the SCS curve number method is that, for a single storm, the ratio of actual soil retention after runoff begins to potential maximum retention is equal to the ratio of direct runoff to available rainfall. This relationship, after algebraic manipulation and inclusion of simplifying assumptions, results in the equation found in Section 4 of the US Department of Agriculture Soil and Conservation Service *National Engineering Handbook* (NEH-4), where curve number (CN) represents a convenient representation of the potential maximum soil retention.

Although usually considered to be a model for predicting surface runoff, "direct flow" (Q) also includes subsurface flow or interflow. The method was developed to predict the initial or "quick" response of a watershed outlet to a storm event. In the case of tile-drained watersheds, total outlet response may be the sum of base flow or water flowing directly in through the sides and bottom of the ditch or stream channel, flow entering the ditch via field tile systems, and surface runoff. Quick response may be predominantly tile-flow, with any surface runoff being passed to the low-lying areas of the watershed to exit as base flow or tile flow. Conceptually, the SCS method could be applicable to such watersheds with possible modification of the following:

a) Curve number (CN) value used to estimate potential maximum soil retention (S). Values are tabulated in Chapter 9 of NEH-4 for various land covers and soil textures. These values were developed from annual flood rainfall-runoff data from the literature for a variety of watersheds generally less than one square mile in area.

b) Fraction of potential maximum retention (S) associated with initial abstractions (Ia). Initial abstractions are water losses (such as plant interception, infiltration, and surface storage) which occur prior to runoff and are thus subtracted from the total rainfall available for either soil retention or quick response. The standard assumption is that Ia = 0.2S. The "0.2" was based on watershed measurements with a large degree of variability and other researchers have reported using values ranging from 0.0 to 0.3. The original estimates of Ia were determined by subtracting rain that fell prior to the beginning of watershed outlet response from the total rainfall. Several sources of error associated with these estimates are listed in NEH-4, including the likelihood that some of the abstracted rainfall does eventually appear at the outlet. In the case of tile-drained watersheds, there is a greater chance that some of this rainfall could contribute to quick response.

c) Accounting for watershed wetness prior to the storm event of interest (antecedent moisture condition, AMC). Curve number can be adjusted to estimate less runoff under dry conditions and more runoff under wet conditions. Table 4.2 of NEH-4 provides guidance for this adjustment based on the amount of rainfall over the previous five days. The appropriateness of this guidance is likely to depend on location and size of the watershed. The table was eliminated from the 1993 edition of NEH-4.

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: DOS, Windows, UNIX

Cost: Commercial, Public domain, N/A

Input Data: Land use, Hydrologic soil group, Rainfall

Output Results: Direct Runoff

Selected References:

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No. A2: ANSWERS

Category: Surface Water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Surface water - Storm water, Nonpoint source pollution and sediment loading

Model Name: ANSWERS (ANSWERS-2000)

Overview

Beasley and Huggins (1980) developed the original ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation) model in the late 1970s. ANSWERS-2000 is a distributed parameter, physically-based, continuous simulation, farm or watershed scale, upland planning model developed for evaluating the effectiveness of agricultural and urban BMPs in reducing sediment and nutrient delivery to streams in surface runoff and leaching of nitrogen through the root zone. The model is intended for use by planners on ungaged watersheds where data for model calibration is not available. The model divides the area simulated into a uniform grid of square (1 hectare or smaller), within which all properties (surface and subsurface soil properties, vegetation, surface condition, crop management, and climate) are assumed homogeneous. The model uses breakpoint precipitation data and simulates hydrologic processes with a 30-second time step during runoff events and with a daily time step between runoff events. The model simulates interception; surface retention/detention; infiltration; percolation; sediment detachment and transport of mixed particle size classes; crop growth; plant uptake of nutrients; N and P dynamics in the soil; nitrate leaching; and losses of nitrate, ammonium, total Kjeldahl nitrogen, and P in surface runoff as affected by soil, nutrient, cover and hydrologic conditions. The model has an ArcInfo based user interface that facilitates data file creation and manipulation. The model is in the public domain and is available via ftp (Dillaha et al., 2001).

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: UNIX, Windows

Cost: Public domain

Input Data: Land use, Topographic data, Soil, Storm rainfall

Output Results: Storm runoff, Nonpoint source pollution loading, Sediment loading

Selected References:

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ANSWERS-2000. http://dillaha.bse.vt.edu/answers/index.htm, ftp://dillaha.ageng.vt.edu/pub/models/answers

No. A3: AGNPS

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Storm runoff, Annual loading of nonpoint source pollution, Sediment loading, Pesticide

Model Name: AGNPS, AnnAGNPS

Overview

The single event Agricultural Non-Point Source (AGNPS) model was developed in the early 1980s by the Agricultural Research Service (ARS) in cooperation with the Minnesota Pollution Control Agency and the Natural Resource Conservation Service (NRCS). The model was developed to analyze and provide estimates of runoff water quality resulting from single storm events from agricultural watersheds ranging in size from a few hectares to 20,000 ha. Because of its ease of use, flexibility, and relative accuracy, AGNPS is widely applied throughout the world to investigate various water quality problems.

AGNPS is a single-event model. Early in its development, this was recognized as a serious model limitation. In the early 1990s, a cooperative team of ARS and NRCS scientists was formed to develop an annualized continuous-simulation version of the model, AnnAGNPS. Coordination of the effort was originally supervised by the ARS, North Central Soil Conservation Laboratory in Morris, Minnesota, and later was transferred to the NRCS, National Water and Climate Center, Water Science and Technology Team in Beltsville, Maryland. Research and development leadership was assumed by the ARS, National Sedimentation Laboratory in Oxford, Mississippi. NRCS in Beltsville provides technology transfer support for AnnAGNPS.

AnnAGNPS is the pollutant loading component for a suite of models referred to as AGNPS 2001. AGNPS 2001 is a tool for use in evaluating the effect of management decisions impacting a watershed system. AGNPS 2001 includes GIS routines for developing model input and analysis of model output, a synthetic weather generator (GEM), AnnAGNPS for pollutant loading, in-stream modeling routines, and routines to examine salmon development. The tool automates many of the input data preparation steps needed for use with large watershed systems (Bosch et al., 2001).

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: UNIX, DOS, Windows

Cost: Commercial or Public domain

Input Data:

- Climate: precipitation, maximum and minimum air temperature, relative humidity, sky cover, and wind speed
- Land characterization data: soil characterization, curve number, RUSLE parameters, and watershed drainage characterization

- Field operation data: tillage, planting, harvest, rotation, chemical operations, and irrigation schedules
- Feedlot operations: daily manure production rates, times of manure removal, and residual amount from previous operations.
- Output Results: storm runoff, nonpoint source pollution loading, sediment loading, pesticide

Selected References:

Bosch, D., Theurer, F., Bingner, R., Felton, G., & Chaubey, I. (2001). Evaluation of the AnnAGNPS Water Quality Model, Agricultural Non-point Source Water Quality Models: Their Use and Application. Southern Cooperative Series Bulletin #398. Southern Association of Agricultural Experiment Station Directors, 45-54.

Cronshey, R.G., & Theurer, F.D. (1998, April). AnnAGNPS - Non-point pollutant loading model. *Proceedings of the First Federal Interagency Hydrologic Modeling Conference*, Las Vegas, Nevada.

Young, R.A., Onstad, C.A., Bosch, D.D., & Anderson, W.P. (1995). AGNPS: An agricultural nonpoint source model. In Singh, V. P. (Eds.), *Computer Models of Watershed Hydrology*. Water Resources Publications. Highlands Ranch, CO, 1011-1020.

Young, R. A., Onstad, C. A., Bosch, D. D., & Anderson, W. P. (1989). AGNPS: A nonpoint-source pollution model for evaluating agricultural watersheds. *Journal of Soil and Water Conservation, 44* (2), 168-173.

USDA-ARS. National Sedimentation Laboratory. http://dillaha.bse.vt.edu/answers/index.htm

No. A4: DRAINMOD

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Surface and subsurface water flow simulation

Model Name: DRAINMOD

Overview

DRAINMOD is a field-scale water management simulation model. The model simulates surface and subsurface water flows in response to water management systems in soils with high water tables. Surface and subsurface drainage improvements along with controlled drainage and subirrigation can be considered by DRAINMOD. Simulations of 20 years or more enable system comparisons over a range of weather scenarios. The model was developed by Skaggs (1980a) and has been updated a number of times to extend the model's capabilities (Skaggs et al., 1988; Workman et al., 1994; Fernandez et al., 1998).

DRAINMOD simulates the effects of various water management systems on water tables by performing a one-dimensional water balance at the midpoint between parallel drains. The drains can be either subsurface tiles or open ditches. The water management systems can include combinations of surface drainage, subsurface drainage, controlled drainage, and subirrigation. The water balance includes routines to simulate surface and subsurface drainage, infiltration, and evapotranspiration (Parsons et al., 2001).

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: DOS, Windows, UNIX

Cost: Commercial or Public domain

Input Data: Field observations, NRCS soils databases, Long-term weather records

Output Results: Runoff, Infiltration, Evapotranspiration, Depth to the water table, Drainage volume, Number of work days based on soil air volume, Drought and wet stresses

Selected References:

Fernandez, G.P., Chescheir, G.W., & Skaggs, R.W. (1998, March). DRAINMOD 5.0: A windows version that considers crop yield, nitrogen and salinity. In Brown, L. C. (Eds.), *Drainage in the 21st Century: Food Production and the*

Environment, 220-226. Orlando, FL. ASAE, 2950 Niles Rd. St. Joseph, MI 449085-9659 USA.

Parsons, J., George, E., Sabbagh, J., Evans, R.O., & Ward, A.D. (2001). Evaluation of DRAINMOD, Agricultural Non-point Source Water Quality Models: Their Use and Application. Southern Cooperative Series Bulletin #398, 55-62. Southern Association of Agricultural Experiment Station Directors.

Skaggs, R.W. (1980a). A water management model for artificially drained soils. North Carolina Agricultural Research Service Technical Bulletin, 267:54. North Carolina State University, Raleigh, NC 27695.

Skaggs, R.W. (1980b). *DRAINMOD: Reference Report - Methods for Design and Evaluation of Drainage-Water Management Systems for Soils with High Water Tables*. Fort Worth, TX: USDA-SCS.

Skaggs, R.W., Parsons, J.E., & Konyha, K.D. (1988). DRAINMOD version 4.0 — An overview. *Proceedings of the American Society of Agricultural Engineers,* Paper No. 88-2563. St. Joseph, MI: ASAE.

Workman, S.R., Parsons, J.E., Chescheir, G.M., Skaggs, R.W., & Rice, J.F. (1994). *DRAINMOD User's Guide*. Washington, DC: NRCS, and Raleigh, NC; NC State University.

No. A5: EUTROMOD

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Watershed-scale nutrient loading and lake response

Model Name: EUTROMOD

Overview

EUTROMOD is a watershed-scale nutrient loading and lake response model. The model provides information concerning the appropriate mix of point source discharges, land use, and land management controls that result in acceptable lake water quality. EUTROMOD is intended for predicting lakewide average conditions for the growing season as a function of annual nutrient loadings. Therefore, short-term conditions (e.g., weekly or monthly), spatially-local water quality (e.g., concentrations in embayments), and dynamic response (e.g., continuous changes over time) cannot be predicted.

The model was developed by Ken Reckhow of Duke University (Reckhow et al., 1992) as a simple, spreadsheet-based collection of models with built-in uncertainty analysis. Although several updates are currently in development, this paper focuses on Version 3.0 which is actively supported and available from the North American Lake Management Society for a fee. Annual runoff, erosion, and nutrient (nitrogen and phosphorus) loadings are simulated with a simple, lumped watershed modeling procedure. Lake response is predicted by a set of nonlinear regression equations from multi-lake regional data sets in terms of lake nutrient levels, chlorophyll *a*, Secchi Disk depth, and a trophic state (Hession et al., 2001).

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Cost: Commercial or Public domain

Input Data:

- Precipitation: annual mean, coefficient of variation
- Precipitation nutrients: phosphorus, nitrogen
- Erosion factors: runoff coefficient, rainfall erosivity, soil erodibility, topographic factor, cropping factor, practice factor, area per land use
- Phosphorus loading factors: dissolved, sediment attached, phosphorus enrichment ratio, ENP ratio
- Nitrogen loading factors: dissolved, sediment attached, nitrogen enrichment ratio, ENN ratio, trapping factors
- Septic system information: number of people, phosphorus load, nitrogen load, phosphorus soil retention, nitrogen soil retention
- Point source information: waste flow, phosphorus concentration, nitrogen concentration
- Lake: surface area, mean depth, lake evaporation

Output Results: Average annual surface water runoff, Annual soil loss, Nutrient loading, Lake nutrient concentrations, Chlorophyll *a* concentrations, Trophic state index

Selected References:

Reckhow, K.H., Coffey, S., Henning, M.H., Smith, K., & Banting, R. (1992). *EUTROMOD: technical guidance and spreadsheet models for nutrient loading and lake eutrophication*. Draft report. Durham, NC: School of the Environment, Duke University.

Hession, W.C., Storm, D.E., Burks, S.L., Smolen, M.D., Lakshminarayanan, R., & Haan, C.T. (1995). Using EUTROMOD with a GIS for establishing total maximum daily loads to Wister Lake, Oklahoma, In K. Steele (Eds.), *Impact of Animal Waste on the Land-Water Interface*, 215-222. Boca Raton, FL: Lewis Publ.

Hession, W.C., McBride, M., Parsons, J.E., & Reckhow, K.H. (2001). Evaluation of the Water Quality Model EUTROMOD, Agricultural Non-point Source Water Quality Models: Their Use and Application. Southern Cooperative Series Bulletin #398, 63-68. Southern Association of Agricultural Experiment Station Directors.

No. A6: GLEAMS

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Surface water and Groundwater

Model Name: GLEAMS

Overview

The GLEAMS model is a computer program used to simulate water quality events on an agricultural field. GLEAMS has been used in the US and internationally to evaluate the hydrologic and water quality response of many different scenarios considering different cropping systems, wetland conditions, subsurface drained fields, agricultural and municipal waste applications, nutrient and pesticide applications, and different tillage systems. It has been used both as a research model and as a management model, depending upon the user's desire. (Shirmohammadi et al., 2001)

In order to simulate the many events occurring on a field, the model is divided into three separate submodels, or parameter files. These submodels include hydrology, erosion/sediment yield, and chemical transport. The chemical transport submodel is further subdivided into nutrient and pesticide components so that one, or both, may be simulated as desired by the user. The parameter files contain variables which are entered by the user in order to best simulate the management events occurring on the particular field of study. The hydrology component simulates runoff due to daily rainfall using a modification of the SCS curve number method. Hydrologic computations are determined using a daily time step (Shirmohammadi et al., 2001).

A modification of the Universal Soil Loss Equation (USLE) is used to estimate inter-rill and rill detachments, and a modification of Yalin's equation is used to estimate the sediment transport capacity. Different topographic configurations and surface flow processes may be selected to properly assess the sediment detachment and deposition on the land surface. The chemistry component of the GLEAMS is divided to pesticide and nutrient submodels. The user may select to run any or all of the specified components during each simulation (Shirmohammadi et al., 2001).

The pesticide component of the GLEAMS incorporates the surface pesticide response of CREAMS with a vertical flux component to route pesticides into, within, and through the root zone. Characteristics of pesticide adsorption to soil organic carbon are used to partition compounds between solution and soil fractions for simulating extraction into runoff, sediment, and percolation losses. Pesticide dissipation in soil and on foliage is treated as a first-order process with a different apparent half-life for each. (Shirmohammadi et al., 2001).

The nutrient component of the GLEAMS is a complex submodel and considers both nitrogen and phosphorus cycles. The nitrogen component includes: mineralization, immobilization, denitrification, ammonia volatilization, nitrogen fixation by legumes, crop N uptake, and losses of N in runoff, sediment, and percolation below the root zone. It also considers fertilizer and animal waste application. The phosphorus component includes: mineralization, immobilization, crop uptake, losses to surface runoff, sediment, and leaching, and it also includes fertilizer and animal waste application. Tillage algorithms are included in the model to account for the incorporation of crop residue, fertilizer and animal waste (Shirmohammadi et al., 2001).

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: DOS, Windows, UNIX

Cost: Commercial or Public domain

Input Data: Precipitation, Soil characteristics, Land use, Pesticide, Nutrients, Cultivation

Output Results: Water, Sediment, Nutrient, and Pesticide movement on surface and through the root zone

Selected References:

Knisel, W. G., Leonard, R. A., & Davis, F. M. (1989, July). Agricultural management alternatives: GLEAMS model simulations. *Proceedings of the 1989 Summer Computer Simulation Conference*, 701-706. Austin, TX: Society for Computer Simulation.

Shirmohammadi, A., Knisel, W. G., Bergström, L. F., Bengtson, R., Ward, A., Reyes, M., Manguerra, H., & King, K. (2001). GLEAMS Model, Agricultural Non-point Source Water Quality Models: Their Use and Application. Southern Cooperative Series Bulletin #398, 69-82. Southern Association of Agricultural Experiment Station Directors.

Southeast Watershed Research Laboratory. http://dino.wiz.uni-kassel.de/model_db/mdb/gleams.html

No. A7: SEDSPEC

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Peak runoff estimation and conservation structures design

Model Name: SEDSPEC

Overview

SEDSPEC, Sediment and Erosion Control Planning, Design and SPECification Information and Guidance Tool, is an expert system which will assist users in analyzing runoff and erosion problems on their sites. The analysis will provide information about different types of runoff and erosion control structures. Also, SEDSPEC will provide customized drawings of the structures, and there is a limited amount of interaction which allows users to determine what size structure fits their needs.

SEDSPEC designs and recommends many structures. The following lists provide some basic information and maintenance concerns for each structure. The reason SEDSPEC does not design every structure on the list is that many structures require no design, and a few structures are too complicated to design over the Web.

SEDSPEC designs the following structures: Concrete-lined channel, culvert, grass-lined channel, level terrace, low-water crossing, open channel, riprap-lined channel, runoff diversion, sediment basin, and storm water detention basin.

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: Web browser, Internet connection

Cost: Commercial or Public domain

Input Data: Land use, hydrologic soil group, area, location information

Output Results: Peak runoff, conservation structures dimension recommended

Selected References:

Tang, Z., Choi, J.Y., Sullivan, K., Lim, K.J., Engel, B.A. (2002). A Web-based DSS for watershed sediment and erosion control. *Proceedings of the American Society of Agricultural Engineers*, Chicago, IL, Paper. No. 023038, St. Joseph, Michigan: ASAE.

Purdue Research Foundation. (1994). http://pasture.ecn.purdue.edu/~sedspec

No. A8: L-THIA

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Long-term daily direct runoff estimation

Model Name: L-THIA, WWW LTHIA, GIS L-THIA

Overview

Community planners, developers, and citizens of a community should be aware of the long-term impacts of land use change on their environmental resources. L-THIA, Long-Term Hydrologic Impact Assessment, is designed to help these people to quantify the impact of land use change on the quantity and quality of their water. This tool uses the land use and a soil characteristic from the user along with thirty years of precipitation data to determine the average impact that a particular land use change or set of changes will have on both the annual runoff and the average amount of several non-point source pollutants. For those unfamiliar with the hydrologic (water-related) impacts of land use change, this tool and the supporting documents will hopefully give the user enough information to start asking questions about land use changes in their area.

There are two input screens for L-THIA; both are available from the side bar to the left. For those new to L-THIA and land use planning, Basic Input is a good place to start. There are eight choices for land use types which most land uses fall into. For those familiar with land use planning terms or who need to describe a custom land use, Detailed Input gives more land use options. The fourteen choices for land uses includes six lot sizes for residential housing and an option to define a custom land use. After using the Basic Input for a few analyses, a user would be able to use the Detailed Input.

Additional information about long-term impacts of land use change and L-THIA can be found in the Documentation section (click on the words in the navigation bar to the left). Along with background information about L-THIA there is information on how to interpret your results and what you can do to minimize the impacts of land use change.

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: Internet connection and Web browser

Cost: Commercial or Public domain

Input Data: Land use, Hydrologic soil group, Area, Location (state, county name)

Output Results: Daily direct runoff, Nonpoint source pollution

Selected References:

Harbor, J. (1994). A Practical Method for Estimating the Impact of Land-Use Change on Surface Runoff, Groundwater Recharge, and Wetland Hydrology. *Journal of the American Planning Association, 60* (1), 95-108.

Lim, K.J., Engel, B.A., Kim, Y., Bhaduri, B., & Harbor. J. (1999). Development of L-THIA/NPS GIS System and Web-Based L-THIA System. *Proceedings of the American Society of Agricultural Engineers*, St. Joseph, MI, Paper No. 992009, St. Joseph, MI: ASAE.

Pandey, S., Gunn, R., Lim, K.J., Engel, B.A., & Harbor, J. (2000). Developing Web-based Tool to Assess Long-term Hydrologic Impacts of Land use Change: Information Technology Issues and a Case Study. *Journal of Urban and Regional Information System Association (URISA), 12* (4), 5-17.

Pandey, S., Harbor, J., & Engel, B. (2001). *Internet Based Geographic Information Systems and Decision Support Tools*. Rak Rigde, IL: Urban and Regional Information Systems Association.

Purdue Research Foundation. (1994). www.ecn.purdue.edu/runoff

No. A9: NAPRA WWW

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Field scale pesticide and nutrient movement

Model Name: NAPRA WWW

Overview

NAPRA WWW provides a basis from which decisions on crop management practices can be made based on potential pesticide loss to the environment. The NAPRA tool recognizes that yearly variations in climate prevent the prediction of "typical" values of pesticide loss, and it therefore provides probabilities that can be used to make informed decisions to enhance farmer profitability while protecting the environment.

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: Internet connection and Web browser

Cost: Commercial or Public domain

Input Data: Land use, Hydrologic soil group, Area, Location (state, county name), Pesticide, Rainfall, Management data

Output Results: Water, Sediment, Nutrient, and Pesticide movement on surface and through the root zone

Selected References:

Knisel, W.G., Leonard, R.A., & Davis, F.M. (1994). *Groundwater Loading Effects of Agricultural Management systems. Version 2.10*. Tifton, GA: USDA-ARS. Southeast Watershed Research Laboratory.

Lim, K.J., & Engel, B.A. (2003). Extension and enhancement of national agricultural pesticide risk analysis (NAPRA) WWW decision support system to include nutrients, *Computers and Electronics in Agriculture, 38* (3), 227-236.

Manguerra, H.B., & Engel, B.A. (1997). Java-based Internet/WWW front-end for an integrated hydrologic and pesticide risk assessment model. *Proceedings of the American Society of Agricultural Engineers,* Minneapolis, MN.

Purdue Research Foundation. (1994). http://pasture.ecn.purdue.edu/~napra

No. A10: SWAT

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Daily stream flow, Pesticide, Nutrient loading

Model Name: SWAT

Overview

SWAT is the acronym for Soil and Water Assessment Tool, a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions over long periods of time. To satisfy this objective, the model is physically based. Rather than incorporating regression equations to describe the relationship between input and output variables, SWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modeled by SWAT using this input data.

SWAT is a continuous time model, i.e. a long-term yield model. The model is not designed to simulate detailed, single-event flood routing (Neitsch et al., 2002).

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

Computer System Requirements: Windows, UNIX, ArcView

Cost: Commercial or Public domain

Input Data: Daily rainfall, Geospatial data (DEM, Soil), Pesiticide, Nutrient

Output Results: Daily streamflow, Evapotranspiration, Pesticide, Nutrient

Selected References:

Neitsch S. L., Arnold, J. G., Kiniry, J. R., Williams, J. R., King, K. W. (2002). *Soil and Water Assessment Tool Theoretical Documentation 2000*. Temple, Texas: Grassland, Soil and Water Research Laboratory, Agricultural Research Service, Blackland Research Center, Texas Agricultural Experiment Station.

Srinivasan, R., Ramanarayanan, T. S., Arnold, T. G., & Bednarz, S. T. (1998). Large Area Hydrologic Modeling and Assessment - Part II: Model Application. *Journal of the American Water Resources Association, 34* (1), 91-101.

Soil and Water Assessment Tool. http://www.brc.tamus.edu/swat/

No. A11: QUAL2E

Category: Surface Water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: River water quality modeling

Model Name: QUAL2E

Overview

The Enhanced Stream Water Quality Model (QUAL2E) is a comprehensive and versatile one-dimensional stream water quality model. It simulates the major reactions of nutrient cycles, algal production, benthic and carbonaceous demand, atmospheric reaeration, and their effects on the dissolved oxygen balance. In addition, the computer program includes a heat balance for the computation of temperature and mass balances for conservative minerals, coliform bacteria, and non-conservative constituents such as radioactive substances. (F. Birgand, 2001)

The model is intended as a water quality planning tool for developing total maximum daily loads (TMDLs) and can also be used in conjunction with field sampling for identifying the magnitude and quality characteristics of nonpoint sources. QUAL2E has been explicitly developed for steady flow and steady wasteload conditions and is therefore a "steady state model" although temperature and algae functions can vary on a diurnal basis. Although the core of the model has not changed since 1987, there have been some modifications on the interfaces and other associated tools to assist the users, and the evaluation will discuss all the available versions of QUAL2E.

The conceptual representation of a stream used in the QUAL2E formulation is a stream reach that has been divided into a number of subreaches or computational elements equivalent to finite difference elements. For each computational element, a hydrologic balance in terms of flow, a heat balance in terms of temperature, and a materials balance in terms of concentration is written. Both advective and dispersive transports are considered in the materials balance. The model uses a finite-difference solution of the advective-dispersive mass transport and reaction equations and it specifically uses a special steady-state implementation of an implicit backward difference numerical scheme which gives the model an unconditional stability.

Applicable Scale: River

Cost: Commercial or Public domain

Input Data: Values and ranges for rates and constants are provided by the user's manual

Output Results:

QUAL2E produces three types of tables -- hydraulics, reaction coefficient, and water quality -- in the output file. The outputs can be easily imported into other application such as spreadsheets for analysis. The Windows™ based version (US EPA, 1995) includes some graphic analysis of the model results. State variables can be plotted at defined distances along the reaches. In addition, the user can input field observations for dissolved oxygen with minimum, average, and maximum values. The model uses those values to plot the observed data versus the estimated ones. In case of dynamic simulations, the model produces temperature and algae values on the defined time step (F. Birgand, 2001).

Selected References:

Birgand, F. (2001). Evaluation of QUAL2E, Agricultural Non-point Source Water Quality Models: Their Use and Application. Southern Cooperative Series Bulletin #398, 99-106. Southern Association of Agricultural Experiment Station Directors.

US EPA. (1995). *QUAL2E Windows interface user's guide.* (US EPA Publication No. EAP/823/B/95/003). United States Environmental Protection Agency

Environmental Protection Agency. http://www.epa.gov/OST/BASINS/bsnsdocs.html.

No. A12: WMS

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Peak runoff estimation, Surface runoff

Model Name: WMS (Watershed Modeling System)

Overview

WMS, the Watershed Modeling System, is an integrated system for watershed modeling rather than a hydrologic model. WMS is a comprehensive hydrologic modeling environment. WMS provides tools for all phases of watershed modeling including automated watershed and sub-basin delineation, geometric parameter computation, hydrologic parameter computation (CN, time of concentration, rainfall depth, etc.) and result visualization. WMS provides complete support of the industry-standard US Army Corps of Engineers HEC-1 and HEC-HMS, US Soil Conservation Service TR-20 and TR-55, and Rational Method Equation hydrologic routing programs. Also supported the National Flood Frequency (NFF) model, which was developed by the US Geologiocal Service (USGS) in cooperation with the Federal Highway Administration (FHWA) and the Federal Emergency Management Agency (FEMA). In addition, support for the EPA/USGS hydrologic water quality HSPF model is also provided (http://www.scisoftware.com/products/wms_details/wms_details.html).

This system can be used to evaluate not only hydrologic impact from carcass disposal, but also flood feasibility analysis around carcass disposal sites, because this system includes more than four different hydrologic models. One great benefit of using this system is that it has well-developed user interface and results visualization.

Applicable Scale: Field and Watershed

Computer System Requirements: Windows

Cost: Commercial or Public domain

Input Data: Input parameters vary depending on the model. Details are provided by the user's manual.

Output Results: Output parameters vary depending on the model. Details are provided by the user's manual.

Selected References:

http://www.scisoftware.com/products/wms_details/wms_details.html.

No. A13: DRASTIC

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Groundwater

Model Name: DRASTIC

Overview

DRASTIC is a groundwater quality model for evaluating the pollution potential of large areas using the hydrogeologic settings of the region (Aller et al., 1985, Aller et al., 1987, Deichert et al., 1992). This model was developed by the EPA in the 1980s. DRASTIC includes various hydrogeologic settings which influence the pollution potential of a region. A hydrogeologic setting is defined as a mappable unit with common hydrogeologic characteristics. This model employs a numerical ranking system that assigns relative weights to various parameters that help in the evaluation of relative groundwater vulnerability to contamination. The hydrogeologic settings which make up the acronym DRASTIC are:

[D] Depth to Water Table: Shallow water tables pose a greater chance for the contaminant to reach the groundwater surface as opposed to deep water tables.

[R] Recharge (Net): Net recharge is the amount of water per unit area of the soil that percolates to the aquifer. This is the principal vehicle that transports the contaminant to the groundwater. The more the recharge, the greater the chances of the contaminant to be transported to the groundwater table.

[A] Aquifer Media: The material of the aquifer determines the mobility of the contaminant through it. An increase in the time of travel of the pollutant through the aquifer results in more attenuation of the contaminant.

[S] Soil Media: Soil media is the uppermost portion of the unsaturated/vadose zone characterized by significant biological activity. This, along with the aquifer media, will determine the amount of percolating water that reaches the groundwater surface. Soils with clays and silts have larger water holding capacity and thus increase the travel time of the contaminant through the root zone.

[T] Topography (Slope): The higher the slope, the lower the pollution potential due to higher runoff and erosion rates. These include the pollutants that infiltrate into the soil.

[I] Impact of Vadose Zone: The unsaturated zone above the water table is referred to as the vadose zone. The texture of the vadose zone determines how long the contaminant will travel through it. The layer that most restricts the flow of water will be used.

[C] Conductivity (Hydraulic): Hydraulic conductivity of the soil media determines the amount of water percolating to the groundwater through the aquifer. For highly permeable soils, the pollutant travel time is decreased within the aquifer.

Applicable Scale: Watershed and Regional

Computer System Requirements: DOS and UNIX

Cost: Commercial or Public domain

Input Data: Climate, Precipitation, Soil characteristics

Output Results: Soil moisture, Groundwater quality items

Selected References:

Aller, L., Bennett, T., Lehr, J.H., & Petty, R.J. (1985). *DRASTIC: A Standardized System for Evaluation Groundwater Pollution Potential Using Hydrogeologic Settings*. (US EPA Publication No. EPA/600/2-85/0108). Robert S. Kerr Environmental Research Laboratory.

Purdue University. http://pasture.ecn.purdue.edu/~caagis/tgis/cases/gwq/drastic.html

No. A14: WEPP

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Peak runoff estimation

Model Name: WEPP

Overview

The WEPP, Water Erosion Predict Project, erosion model is a continuous simulation computer program which predicts soil loss and sediment deposition from overland flow on hill slopes, soil loss and sediment deposition from concentrated flow in small channels, and sediment deposition in impoundments. In addition to the erosion components, it also includes a climate component which uses a stochastic generator to provide daily weather information, a hydrology component which is based on a modified Green-Ampt infiltration equation and solutions of the kinematic wave equations, a daily water balance component, a plant growth and residue decomposition component, and an irrigation component. The WEPP model computes spatial and temporal distributions of soil loss and deposition, and provides explicit estimates of when and where in a watershed or on a hill slope that erosion is occurring so that conservation measures can be selected to most effectively control soil loss and sediment yield (Flanagan and Nearing, 1995).

The WEPP now has several different versions for a user's convenience. The WEPP supports a web browser interface (http://octagon.nserl.purdue.edu/weppV1/), and runs on ArcView desktop GIS environment (http://www.geog.buffalo.edu/~rensch/geowepp/).

Applicable Scale: Field, Hill slope and Watershed

Computer System Requirements: DOS, UNIX, and Windows

Cost: Commercial or Public domain

Input Data: Input parameters vary depending on the model. Details are provided by the user's manual.

Output Results: Output parameters vary depending on the model. Details are provided by the user's manual.

Selected References:

Flanagan, D.C., & Nearing, M.A. (1995). *USDA-Water Erosion Prediction Project (WEPP)-Technical Documentation*. (NSERL Report No. 10). West Lafayette, Indiana: National Soil Erosion Research Laboratory, USDA-ARS-MWA.

Purdue University. http://topsoil.nserl.purdue.edu/nserlweb/weppmain/wepp.html

No. A15: EPIC

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: Nonpoint source estimation

Model Name: EPIC

Overview

In the early 1980s teams of USDA Agricultural Research Service (ARS), Soil Conservation Service (SCS), and Economic Research Service (ERS) scientists developed EPIC, Erosion-Productivity Impact Calculator, to quantify the costs of soil erosion and benefits of soil erosion research and control in the United States. Led by Dr. Jimmy Williams, ARS scientists were responsible for model development. SCS and ERS staff collaborated on model development and took leading roles in soil and weather database development, validation, and creating interfaces with economic models. EPIC is designed to be:

1. Capable of simulating the relevant biophysical processes simultaneously, as well as realistically, using readily available inputs and, where possible, accepted Methodologies.
2. Capable of simulating cropping systems for hundreds of years because erosion can be a relatively slow process.
3. Applicable to a wide range of soils, climates, and crops.
4. Efficient, convenient to use, and capable of simulating the particular effects of management on soil erosion and productivity in specific environments.

The model uses a daily time step to simulate weather, hydrology, soil temperature, erosion-sedimentation, nutrient cycling, tillage, crop management and growth, pesticide and nutrient movement with water and sediment, and field-scale costs and returns.

(http://www.brc.tamus.edu/epic/introduction/index.html)

Applicable Scale: Field

Computer System Requirements: DOS or Windows

Cost: Commercial or Public domain

Input Data: Climate data, Precipitation, Soil characteristics, Land use

Output Results: Runoff, Soil moisture, Evapotranspiration

Selected References:

http://www.brc.tamus.edu/epic/documentation/index.html.

http://www.brc.tamus.edu/epic/introduction/index.html.

No. A16: MODFLOW

Category: Surface water, Groundwater, Air, Soil

Evaluation Stage: Screening, Pre-disposal, Post-disposal evaluation

Specified Use: 3-Dimensional groundwater flow simulation using finite-difference scheme

Model Name: MODFLOW

Overview

MODFLOW, "a three-dimensional finite-difference groundwater flow model" by Michael G. McDonald and Arlen W. Harbaugh, is the most widely used groundwater model in the world. MODFLOW is the name that has been given the USGS Modular Three-Dimensional Groundwater Flow Model. Because of its ability to simulate a wide variety of systems, its extensive publicly available documentation, and its rigorous USGS peer review, MODFLOW has become the worldwide standard groundwater flow model. MODFLOW is used to simulate systems for water supply, containment remediation, and mine dewatering. Groundwater flow within the aquifer is simulated in MODFLOW using a block-centered finite-difference approach. Layers can be simulated as confined, unconfined, or a combination of both. Flows from external stresses such as flow to wells, aerial recharge, evapotranspiration, flow to drains, and flow through riverbeds can also be simulated. (http://www.modflow.com/modflow/modflow.html).

Applicable Scale: Site/Field, Watershed/Sub-regional, Region

UNIX-based computers and DOS-based 386 or greater computers having a math coprocessor and 4 MB of memory. For more enhanced version with graphical user interface, refer to the Web site, http://www.modflow.com/modflow/modflow.html.

Cost: Public domain

Input Data:

A large amount of information and a complete description of the flow system is required to make the most efficient use of MODFLOW. In situations where only rough estimates of the flow system are needed, the input requirements of MODFLOW may not justify its use. To use MODFLOW, the region to be simulated must be divided into cells with a rectilinear grid resulting in layers, rows, and columns. Files must then be prepared that contain hydraulic parameters (hydraulic conductivity, transmissivity, specific yield, etc.), boundary conditions (location of impermeable boundaries and constant heads), and stresses (pumping wells, recharge from precipitation, rivers, drains, etc.) (http://www.modflow.com/modflow/modflow.html).

Output Results:

MODFLOW can result for groundwater flow for confined, unconfined, or a combination of both aquifers, flows from external stresses such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through riverbeds. Primary output is head, which can be written to the listing file or into a separate file. Other output includes the complete listing of all input data, drawdown, and budget data. Budget data are printed as a summary in the listing file, and detailed budget data for all model cells can be written into a separate file.

Selected References:

Anderman, E.R., & Hill, M.C. (2001). MODFLOW-2000, the US Geological Survey modular ground-water model - documentation of the ADVective-transport observation (ADV2) package, version 2. (US Geological Survey Open-File Report 01-54), US Geological Survey.

Harbaugh, A.W., Banta, E.R., Hill, M.C., & McDonald, M.G. (2000). MODFLOW-2000, the US Geological Survey modular ground-water model -- User guide to modularization concepts and the Ground-Water Flow Process. (US Geological Survey Open-File Report 00-92), US Geological Survey.

Harbaugh, A.W., & McDonald, M.G. (1996). User's documentation for MODFLOW-96, an update to the US Geological Survey modular finite-difference ground-water flow model. (US Geological Survey Open-File Report 96-485), US Geological Survey.

http://water.usgs.gov/nrp/gwsoftware/modflow.html

http://www.modflow.com/modflow/modflow.html

Appendix B – Sediment and soil transport models list

B1. USLE

B2. RUSLE

B3. Soil Erodibility (K)

B4. WEPP

B5. AGNPS

B6. ANSWERS

B7. SWAT

B8. RWEQ

B9. WEPS

No. B1: USLE

Category: Soil erosion

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Screening

Model Name: Universal Soil Loss Equation (USLE)

Overview

The Universal Soil Loss Equation (USLE), developed by W. Wischmeier and D. Smith, has been the most widely used soil loss equation. It estimates the annual soil loss potential by sheet and rill erosion. It cannot be used to estimate the soil erosion for a single storm event or for a certain period of time. The USLE estimates annual soil erosion based on six factors, such as R, K, L, S, C, and P factors. It can be used to find the least soil erosion impact areas for a carcass disposal site.

Applicable Scale: Field scale

Computer System Requirements: DOS

Cost: Public domain

Input Data:

R = Rainfall-runoff erosivity factor (isoerodent map is available)

K = Soil erodibility factor (available in STATSGO soil database)

L = Slope length factor (can be derived from DEM)

S = Slope steepness factor (can be derived from DEM)

C = Covert-management factor (can be obtained from literature)

P = Support practice factor (can be obtained from literature)

Output Results: Annual average soil loss per unit area (tons/acre/year)

Selected References:

Wischmeier, W.H., & Smith, D.D. (1978). *Predicting Rainfall Erosion Losses – A Guide to Conservation Planning*. USDA Agric. Handbook No. 537, 85p.

http://topsoil.nserl.purdue.edu/usle/

No. B2: RUSLE

Category: Soil erosion

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Estimate water erosion potential

Model Name: Revised Universal Soil Loss Equation (RUSLE)

Overview

The Revised Universal Soil Loss Equation (RUSLE) is a widely and easily used computer program to estimate soil erosion rates – especially rill and inter-rill erosion – caused by rainfall and overland flow. It is an index-based method to compute the soil erosion in mass per unit area. The RUSLE can be used to develop conservation plants to control erosion. It can be applied to disturbed lands, landfills, construction sites, reclaimed lands, and land disposal of waste. The RUSLE can be used to evaluate the impacts of soil disturbance due to burial or burn by modifying K, LS, and/or? C input parameter values.

Applicable Scale: Field scale

Computer System Requirements: DOS, Windows

Cost: Public domain

Input Data:

R = Rainfall-runoff erosivity factor (Isoerodent map is available)

K = Soil erodibility factor (available in STATSGO soil database)

L = Slope length factor (can be derived from DEM)

S = Slope steepness factor (can be derived from DEM)

C = Covert-management factor (can be obtained from literature/RUSLE)

P = Support practice factor (can be obtained from literature/RUSLE)

Output Results: Annual average soil loss per unit area (tons/acre/year)

Selected References:

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., & Yoder, D.C. (1997). *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Soil Loss Equation (RUSLE).* USDA Agric. Handbook No. 703.

http://www.sedlab.olemiss.edu/rusle/

No. B3: Soil Erodibility (K)

Category: Soil erosion

Evaluation State: Screening

Specified Use: Estimate water erosion potential

Model Name: Soil Erodibility (K)

Overview

The soil erodibility (K) represents: (1) susceptibility of soil or surface material to erosion, (2) transportability of the sediment, and (3) the amount and rate of runoff given a particular rainfall input. Fine-textured soils, such as clay, have low K values because of higher resistance to detachment. Coarse-textured soils, such as sandy soil, also have low K value because of high infiltration though these soils are easily detached. Medium-textured soils, such as a silt loam, have moderate K values because of moderate susceptibility to particle detachment and moderate runoff. The soil erodibility can be used as a guidance to choose a potential location for carcass disposal.

Applicable Scale: Field scale

Computer System Requirements: DOS (Using RUSLE K Module)

Cost: Public domain

Input Data: Values of K for undisturbed soils should be selected from soil-survey information published by the NRCS. Values of K for disturbed soils should be computed using the soil-erodibility nomograph.

Output Results: Soil erodibility value between 0 to 1. (Higher K value indicates higher soil erodibility and lower K value indicates lower soil erodibility.)

Selected References:

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., & Yoder, D.C. (1997). *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Soil Loss Equation (RUSLE).* USDA Agric. Handbook No. 703.

http://www.sedlab.olemiss.edu/rusle/

No. B4: WEPP

Category: Soil erosion

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Estimates soil erosion and sediment yield by water

Model Name: The Water Erosion Prediction Project (WEPP)

Overview

A continuous simulation model used to predict soil erosion for conservation planning and assessment of environmental impacts. This model updates the soil and crop conditions that affect soil erosion. When rainfall occurs, the plant and soil characteristics are used to determine if surface runoff will occur. If predicted, then it computes estimated sheet and rill detachment and deposition, and channel detachment and deposition. It can be used for pre- and post-evaluation of carcass disposal.

Applicable Scale: Hill slope or Field-sized watershed

Computer System Requirements: MS DOS or Windows

Cost: Public domain

Input Data: Climate from either simulated or measured data, Crop and tillage, Rill/inter-rill erodibility, Texture, Organic matter, Rocks. Over 200 input parameters.

Output Results: Daily runoff volumes and peak runoff, plant-canopy, biomass, residue cover, roots, buried residue, soil detachment along hill slope and channel, deposition, sediment yield, soil water by layer, snow melt/frost lenses, and sediment size distribution.

Selected References:

Flanagan, D.C., & Nearing, M.A. (1995). *USDA-Water Erosion Prediction Project (WEPP)-Technical Documentation.* (NSERL Report No. 10). West Lafayette, Indiana: National Soil Erosion Research Laboratory, USDA-ARS-MWA.

http://topsoil.nserl.purdue.edu/nserlweb/weppmain/wepp.html

No. B5: AGNPS

Category: Soil erosion

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Calculates sediment yield for a basin from a single storm event

Model Name: Agricultural Non-Point Source Pollution Model (AGNPS)

Overview

AGNPS is a tool for use in evaluating the effect of management decisions impacting a watershed system. The capabilities of RUSLE were incorporated into AGNPS. This provides a watershed scale aspect to conservation planning. With the routing capability in this model, it allows modeling of the sediment yield changes at the downstream areas before and after soil disturbance due to carcass disposal methods.

Applicable Scale: Watershed scale

Computer System Requirements: UNIX/Windows

Cost: Public Ddomain

Input Data: SCS Curve Number, land slope, slope shape factor, field slope length, channel sideslope, Manning's roughness, soil erodibility factor, cover and management factor, support practice factor, surface condition constant, aspect (direction to drainage), soil texture, fertilization level, fertilization availability factor, point source indicator, gully source level, impoundment factor, channel indicator.

Output Results: Watershed description, area, characteristic storm precipitation, storm energy-intensity (EI) value, runoff volume, peak runoff rate, fraction of runoff generated within the cell, sediment yield and concentration, sediment particle distribution, upload erosion, channel erosion, amount of deposition, sediment generated within the cell, enrichment ratio, delivery ratio.

Selected References:

Young, R.A., Bosch, D.D., & Anderson, W.P. (1987). *AGNPS, Agricultural Non-Point Source Pollution Model; A Large Watershed Analysis Tool.* Report 35. Washington, DC: USDA.

http://www.sedlab.olemiss.edu/agnps.html

No. B6: ANSWERS

Category: Soil erosion

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Calculates sediment loading

Model Name: Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWERS)

Overview

ANSWERS is a distributed parameter, physically-based, continuous simulation, farm or watershed scale, upland planning model developed for evaluating the effectiveness of agricultural and urban BMPs in reducing sediment and nutrient delivery to streams in surface runoff and leaching of nitrogen through the root zone. It allows modeling of sediment yield changes at the downstream areas before and after soil disturbance due to carcass disposal methods.

Applicable Scale: Field and Watershed scale

Computer System Requirements: UNIX/Windows

Cost: Public domain

Input Data: Land use, Topographical data, Soil, Storm rainfall

Output Results: Storm runoff, Pollutant loading, Sediment loading

Selected References:

Beasley, B.B., Huggins, L.F., & Monke, E.J. (1980). ANSWERS: A Model for Watershed Planning. *Transactions of the ASAE*, *23* (4), 938-944.

http://dillaha.bse.vt.edu/answers/index.htm

No. B7: SWAT

Category: Soil erosion

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Calculates soil erosion and sediment loading

Model Name: Soil and Water Assessment Tool (SWAT)

Overview

SWAT is a watershed scale, continuous daily time step model to predict the impacts of different agricultural management systems on hydrology, sediment, pesticides, and nutrients in large complex watersheds with varying soils, land use, and management conditions over long periods of time. SWAT simulates the crop growth, pesticide and nutrient cycles, and water and sediment movements on a daily time step.

Applicable Scale: Watershed scale

Computer System Requirements: UNIX, Windows

Cost: Public domain

Input Data: Soil, Land use, DEM, Weather data, Pesticide and nutrient application data, Tillage, Cropping

Output Results: Hydrology, sediment, Pesticide, and Nutrient

Selected References:

Neitsch S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., & King, K.W. (2002). *Soil and Water Assessment Tool Theoretical Documentation 2000*. Temple, Texas: Grassland, Soil and Water Research Laboratory, Agricultural Research Service, Blackland Research Center, Texas Agricultural Experiment Station.

http://www.brc.tamus.edu/swat

No. B8: RWEQ

Category: Soil erosion

Evaluation State: Screening

Specified Use: Calculates average annual soil loss by wind

Model Name: The Revised Wind Erosion Equation (RWEQ)

Overview

The RWEQ model predicts the soil loss between the soil surface and a height of two meters due to wind erosion with information on weather, soils, plants, and land management. It estimates annual or period of wind erosion based on a single event wind erosion model. It can be applied to simulate the movement of airborne pathogen - some pathogens may be easily attached to the fine soil particle - due to wind erosion after carcass disposal on the ground.

Applicable Scale: Field

Computer System Requirements: DOS

Cost: Public domain

Input Data: Monthly weather data, soil and field data, cropping system, tillage and operation dates, wind barrier description, irrigation information.

Output Results: Total erosion by periods in either tabular format or graphical format.

Selected References:

Fryrear, D.W., Saleh, A., Bilbro, J.D., Schomberg, H.M., Stout, J.E., & Zobeck, T.M. (1998). *Revised Wind Erosion Equation.* Agricultural Research Service, Southern Plains Area Cropping Systems Research Laboratory. Wind Erosion and Water Conservation Research Unit. US Department of Agriculture. Technical Bulletin No. 1. June, 1998.

http://www.csrl.ars.usda.gov/wewc/rweq/rweq.htm

No. B9: WEPS

Category: Soil erosion

Evaluation State: Screening, Pre-disposal, and Post-disposal evaluation

Specified Use: Estimate wind erosion potential

Model Name: Wind Erosion Prediction System (WEPS)

Overview

A process-based, continuous, daily time step model that simulates weather, field conditions, and erosion. It is capable of simulating spatial and temporal variability of field conditions and soil loss/deposition within a field. WEPS can simulate complex field shapes, barriers not on the field boundaries, and complex topographies. It can simulate not only the basic wind erosion processes, but also the processes that modify a soil's susceptibility to wind erosion. It can be applied to simulate the movement of airborne pathogen - some pathogens may be easily attached to the fine soil particle - due to wind erosion after carcass disposal on the ground.

Applicable Scale: Field scale

Computer System Requirements: DOS

Cost: Public domain

Input Data: Climate statistics, parameters for management such as tillage tool parameters, soil data, crop growth and decomposition parameters. Model input data source: Climate database, SCS soils database.

Output Results: Average soil loss and deposition (including asuspension, saltation, and surface creep components), water balance, and crop biomass.

Selected References:

Hagen, L.J., Wagner, L.E., & Tatarko, J. (1996). *Wind Erosion Prediction System (WEPS) Technical Documentation.* Beta Release 95-08. http://www.weru.ksu.edu/weps/docs/weps_tech.pdf

http://www.weru.ksu.edu/weps.html

Glossary

- Rill erosion: Rill erosion is the removal of soil by concentrated water running through little streamlets, or headcuts. Detachment in a rill occurs if the sediment in the flow is below the amount the load can transport and if the flow exceeds the soil's resistance to detachment. As detachment continues or flow increases, rills will become wider and deeper.
- Inter-rill erosion: The removal of a fairly uniform layer of soil on a multitude of relatively small areas by splash due to raindrop impact and by sheet flow.
- Overland flow: Overland flow is water that runs across the land after rainfall, either before it enters a watercourse or after it overflows from river banks as flood water.
- Sediment yield: The amount of sediment moved out of the watershed in a given time.
- Enrichment ratio: The ratio of a compound's concentration in the eroded soil to the noneroded soil.
- Delivery ratio: The ratio of the sediment yield to the gross erosion per unit area above a measuring point.

Appendix C – Soil Quality and Ecology Models List

C1. PRZM3

C2. MULTIMED 2.0

C3. 3MRA Multimedia, Multi-pathway, Multi-receptor Exposure and Risk Assessment Model

C4. MMSOILS

C5. HELP v.3

C6. Visual HELP

C7. BIOF&T – 3D

C8. 3DFATMIC

C9. MIGRATEv9

No. C1: PRZM3

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening

Specified Use: PRZM3 is the most recent version of a modeling system that links two subordinate models--PRZM and VADOFT--in order to predict pesticide transport and transformation down through the crop root and unsaturated zone. Source: Register of Ecological Models

Model Name: PRZM3

Overview

PRZM is a one-dimensional, finite-difference model that accounts for pesticide and nitrogen fate in the crop root zone. PRZM-3 includes modeling capabilities for such phenomena as soil temperature simulation, volatilization, and vapor phase transport in soils, irrigation simulation, microbial transformation, and a method of characteristics (MOC) algorithm to eliminate numerical dispersion. PRZM is capable of simulating transport and transformation of the parent compound and as many as two daughter species.

VADOFT is a one-dimensional, finite-element code that solves the Richard's equation for flow in the unsaturated zone. The user may make use of constitutive relationships between pressure, water content, and hydraulic conductivity to solve the flow equations. VADOFT may also simulate the fate of two parent and two daughter products. The PRZM and VADOFT codes are linked together with the aid of a flexible execution supervisor that allows the user to build loading models that are tailored to site-specific situations. In order to perform probability-based exposure assessments, the code is also equipped with a Monte Carlo pre- and post-processor.

The PRZM3 model system with documentation is available for microcomputer (DOS) systems. Enhancements to Release 3.0 include algorithms that enable modeling of nitrogen cycle soil kinetic processes with the ability to track nitrogen discharges from a septic tank into the soil environment and movement to groundwater. Additional enhancements enable better simulation of physiochemical processes, increased flexibility in representing agronomic practices, and improved post-processing and data interpretation aids. Source: http://www.epa.gov/ceampubl/gwater/przm3/

Applicable Scale: Regional to site

Computer System Requirements: 32-bit MS-DOS

Cost: Public domain (DOS version)

Input Data: Exhaustive set of physical data on chemical and field soil characteristics and weather data for local region.

Output Results: Predicts pesticide and daughter product concentrations; can be run for daily, monthly or annual output. Model allows dynamic simulations including pulse loads, peak events, and time-varying emission or concentration profiles in layered soils.

Selected References:

Register of Ecological Models. PRZM3 Review by Carsel, R. F., Smith, C. N., Mulkey, L. A., & Dean,

J. D. from World Wide Web: http://lupo.wiz.uni-kassel.de/model_db/mdb/przm3.html.

http://www.epa.gov/ceampubl/gwater/przm3/

No. C2: MULTIMED 2.0

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening, Pre-disposal evaluation

Specified Use: Exposure assessment

Model Name: MULTIMED 2.0

Overview

The Multimedia Exposure Assessment Model (MULTIMED) simulates the movement of contaminants leaching from a waste disposal facility for exposure assessment. The model consists of modules which predict concentrations at a receptor produced by transport in soil subsurface, surface air, or air. Separate interactive pre- (PREMED) and post-processing (POSTMED) programs allow user to create and edit input and plot model output.

Flow and transport through the unsaturated zone and transport in saturated zone can be considered. A one-dimensional, semi-analytical module simulates flow in the unsaturated zone. The output from this module, water saturation as a function of depth, is used as input to the unsaturated zone transport module. The latter simulates transient, one-dimensional (vertical) transport in the unsaturated zone using either an analytical model that includes the effects of longitudinal dispersion, linear adsorption, and first-order decay or a numerical model that includes the effects of longitudinal dispersion, non-linear adsorption, first-order decay, time variable infiltration rates, and arbitrary initial conditions of chemical concentration in the unsaturated zone.

The unsaturated zone transport module calculates steady-state or transient contaminant concentrations. Output from both unsaturated zone modules is used to couple the unsaturated zone transport module with the steady-state or transient, semi-analytical saturated zone transport module. The latter includes one-dimensional uniform flow, three-dimensional dispersion, linear adsorption, first-order decay, and dilution due to direct infiltration into the groundwater plume.

The fate of contaminants in the various media depends on the chemical properties of the contaminants as well as a number of media- and environment-specific parameters. The uncertainty in these parameters can be quantified in MULTIMED using the Monte Carlo simulation technique. Source: EPA documentation,

(http://www.epa.gov/ceampubl/mmedia/multim2/ABSTRACT.TXT)

Applicable Scale: Regional to site

Computer System Requirements: DOS

Cost: Public domain

Input Data: The operation of each module requires specific input, which is organized into data groups. The General Data Group, which is required for all simulations, contains flags and data which describe the scenario being modeled. The input parameters needed for the Saturated Zone Transport Model are arranged in three additional data groups: the Chemical Data Group, the Source Data Group, and the Aquifer Data Group. Use of the Unsaturated Zone Modules requires input found in the above data groups, as well as data from the Unsaturated Zone Flow Data Group and the Unsaturated Zone Transport Data Group.

Output Results: The POSTMED postprocessor can be used to generate three types of plots: concentration vs. time at a groundwater receptor, cumulative frequency, and frequency or probability density. The cumulative frequency and frequency plots are related to model parameters that are randomly varied within the context of a Monte Carlo simulation. Source: The Register of Ecological Models (REM.) REM is a cooperative service of the University of Kassel and the GSF - National Research Center for Environment and Health. http://lupo.wiz.uni-kassel.de/model_db/mdb/multimed.html by Tobias Gabele.

Selected References:

Salhotra, A.M., Mineart, P., Sharp-Hansen, S., Allison, T., Johns, R., & Mills, W.B. (1995). *Multimedia*

Exposure Assessment Model (MULTIMED 2.0) for Evaluating the Land Disposal of Wastes-- Model Theory. Athens, GA: US EPA Environmental Protection Agency. Unpublished Report.

Sharp-Hansen, S., Travers, C., Hummel, P., Allison, T., Johns, R., & Mills, W.B. (1995). *A Subtitle D Landfill Application Manual for the Multimedia Exposure Assessment Model (MULTIMED 2.0).* Athens, GA: US EPA Environmental Protection Agency. Unpublished Report.

US EPA. (1995). *Revised Verification Testing of the Enhancements, MULTIMED Model (2.0).* Athens, GA: US EPA Environmental Protection Agency. Unpublished Report.

http://www.epa.gov/ceampubl/mmedia/multim2/index.htm

No. C3: 3MRA Multimedia, Multi-pathway, Multi-receptor Exposure and Risk Assessment

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening, Pre-disposal, and Post-disposal evaluation

Specified Use: Exposure and risk assessment: The Vadose Zone and Aquifer Modules simulate the subsurface movement of contaminants in leachate from surface impoundments, landfills, land application units (LAUs), and waste piles through the soil to downgradient drinking water wells and waterbodies.

Model Name: 3MRA Multimedia, Multi-pathway, Multi-receptor Exposure and Risk Assessment (Vadose Zone and aquifer modules)

Overview

The Vadose Zone and Aquifer Modules simulate the fate and transport of dissolved contaminants from a point of release at the base of a waste management unit (WMU), through the underlying soil, and through a surficial aquifer (or groundwater source). Module outputs include groundwater contaminant concentrations in wells, which are used by the Human Exposure Module to estimate exposures through drinking water and showering, and by the Farm Food Chain Module to estimate contaminant concentrations in beef and milk from farm well use; and contaminant fluxes into waterbodies, which are used by the Surface Water Module, along with contaminant fluxes from atmospheric deposition and overland flow, to estimate contaminant concentrations in streams, lakes, and wetlands.

The Multimedia, Multi-pathway, Multi-receptor Exposure and Risk Assessment (3MRA) technology provides the ability to conduct screening-level risk-based assessment of potential human and ecological health risks resulting from long term (chronic) exposure to HWIR chemicals released from land-based WMUs containing currently listed waste streams. The 3MRA system consists of a series of components within a system framework. The new modeling system, dubbed 3MRA technology, is envisioned as the foundation for eventually integrating other regulatory support decision tool needs anticipated in the future.

The HWIR assessment is a screening-level risk-based assessment of potential human and ecological health risks resulting from long-term (chronic) exposure to HWIR chemicals released from land-based waste management units (WMUs) containing currently 'listed' waste streams. The assessment of potential human and ecological health risks is site-based and include, for each site statistically sampled from a national database of WMUs, the simultaneous release of chemicals from the WMU to each environmental medium, the fate and transport of the chemical through a multimedia environment, and the receptor-specific exposures that result. The assessment includes an estimation of the potential exposures, per exposure pathway/receptor, and an estimation of the resulting carcinogenic and non-carcinogenic health effects. The end point of the assessment is the establishment of chemical-specific exit levels representing threshold waste concentrations below which the associated waste stream is not considered hazardous and therefore does not require Subtitle C type disposal. The exit levels are applicable to all waste streams and all locations, i.e., nationally. Source: EPA model documentation.

Applicable Scale: Regional to site

Computer System Requirements: Windows 98, NT, 2000, XP

Cost: Public domain

Input Data: Physical site databases and chemical properties databases. Physical properties such as infiltration rate, chemical flux, and soil properties such as Koc.

Output Results: The Vadose Zone and Aquifer Modules perform the following functions:

1. Model vadose zone flow and transport. The one-dimensional (1-D) Vadose Zone Module simulates infiltration and dissolved contaminant transport, by advection and dispersion, leaching from the bottom of a WMU through the soil above the water table (i.e., the vadose zone) to estimate the contaminant and water flux to the underlying groundwater.

2. Model groundwater flow and transport. The pseudo-3-D Aquifer Module simulates groundwater flow and contaminant transport, by advection and dispersion, from the base of the vadose zone to estimate contaminant concentrations in drinking water wells and contaminant discharge fluxes to intercepted waterbodies.

3. Model subsurface chemical reactions. Both the Vadose Zone and Aquifer Modules simulate sorption to soil or aquifer materials and biological and chemical degradation, which can reduce contaminant concentrations as they move through soil and groundwater. In cases where degradation of a contaminant yields other contaminants that are of concern, the modules can account for the formation and transport of up to six different daughter and granddaughter degradation products. For metals, the modules use sorption isotherms that allow adjustment of sorption behavior to account for varying metal concentrations and geochemical conditions. Source : http://www.epa.gov/epaoswer/hazwaste/id/hwirwste/sab03/vol1/1_09_vadose.pdf

The assessment of potential human and ecological health risks is site-based and include, for each site statistically sampled from a national database of WMUs, the simultaneous release of chemicals from the WMU to each environmental medium, the fate and transport of the chemical through a multimedia environment, and the receptor-specific exposures that result. The assessment includes an estimation of the potential exposures, per exposure pathway/receptor, and an estimation of the resulting carcinogenic and non-carcinogenic health effects. The end point of the assessment is the establishment of chemical-specific exit levels representing threshold waste concentrations below which the associated waste stream is not considered hazardous and therefore does not require Subtitle C type disposal. The exit levels are applicable to all waste streams and all locations, i.e., nationally. Source: EPA model documentation.

Selected References:

US EPA. (1999). The Vadose and Saturated Zone Modules. Extracted from EPACMTP for HWIR99. Office of Solid Waste, Washington, DC.

http://www.epa.gov/athens/research/projects/3mra/index.html

No. C4: MMSOILS

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening and Risk assessment

Specified Use: "The methodology consists of a multimedia model that addresses the transport of a chemical in groundwater, surface water, soil erosion, the atmosphere, and accumulation in the food chain. The methodology can be used to provide an estimate of health risks for a specific site. Since the uncertainty of the estimated risk may be quite large (depending on the site characteristics and available data), MMSOILS addresses these uncertainties via Monte Carlo analysis. Source: http://www.epa.gov/ceampubl/mmedia/mmsoils/ABSTRACT.TXT

Model Name: MMSOILS

Overview

The Multimedia Contaminant Fate, Transport, and Exposure Model (MMSOILS) estimates the human exposure and health risk associated with releases of contamination from hazardous waste sites. The methodology consists of a multimedia model that addresses the transport of a chemical in groundwater, surface water, soil erosion, the atmosphere, and accumulation in the food chain. The human exposure pathways considered in the methodology include: soil ingestion, air inhalation of volatiles and particulates, dermal contact, ingestion of drinking water, consumption of fish, consumption of plants grown in contaminated soil, and consumption of animals grazing on contaminated pasture. For multimedia exposures, the methodology provides estimates of human exposure through individual pathways and combined exposure through all pathways considered. The risk associated with the total exposure dose is calculated based on chemical-specific toxicity data.

The methodology is intended for use as a screening tool. It is critical that the results are interpreted in the appropriate framework. The intended use of the exposure assessment tool is for screening and relative comparison of different waste sites, remediation activities, and hazard evaluation. The methodology can be used to provide an estimate of health risks for a specific site. Since the uncertainty of the estimated risk may be quite large (depending on the site characteristics and available data), MMSOILS addresses these uncertainties via Monte Carlo analysis. Source: http://www.epa.gov/ceampubl/mmedia/mmsoils/index.htm

Applicable Scale: Regional to site

Computer System Requirements: DOS

Cost: Public Ddomain

Input Data: Modeling incorporates information on cover soils, waste cells, lateral drain layers, low permeability barrier soils, synthetic geomembrane liners, and weather.

Output Results: Results are expressed as daily, monthly, annual, and long-term water budgets.

Selected References:

http://www.epa.gov/ceampubl/mmedia/mmsoils/index.htm

No. C5: HELP v.3

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening, Pre-disposal, and Post-disposal evaluation

Specified Use: The HELP model is a quasi-two-dimensional, deterministic, water-routing model for determining water balances for municipal landfills, RCRA and CERCLA facilities, and other land disposal systems, including disposal of dredged material.

Model Name: HELP v.3 (Hydrologic Evaluation of Landfill Performance)

Overview

The Hydrologic Evaluation of Landfill Performance (HELP) model was developed to help hazardous waste landfill designers and regulators evaluate the hydrologic performance of proposed landfill designs. The model accepts weather, soil, and design data and uses solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane, or composite liners. Landfill systems including various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils, and synthetic geomembrane liners may be modeled. Results are expressed as daily, monthly, annual, and long-term average water budgets.

Version 3 of the HELP model has been greatly enhanced beyond versions 1 and 2. The number of layers that can be modeled has been increased. The default soil/material texture list has been expanded to contain additional waste material, geomembranes, geosynthetic drainage nets and compacted soils. The model also permits the use of a user-built library of soil textures. Computations of leachate recirculation and groundwater drainage into the landfill have been added. HELP Version 3 also accounts for leakage through geomembranes due to manufacturing defects (pinholes) and installation defects (punctures, tears, and seaming flaws) and by vapor diffusion through the liner. The estimation of runoff from the surface of the landfill has been improved to account for large landfill surface slopes and slope lengths. Source: (international groundwater modeling center, Review Authors: R. Lee Payton (Univ. Of Missouri-Columbia) and Paul Schroeder (US Army Corps of Engineers) http--typhoon.mines.edu-software-igwmcsoft-help.htm

A Spanish version is available from the US Army Corps of Engineers at the Web site below.

Applicable Scale: Site design

Computer System Requirements: MS-DOS

Cost: Public domain

Input Data: Weather, soil, and design data.

Output Results: Detailed water balance for comparison of design alternatives.

Selected References:

http://www.wes.army.mil/el/elmodels/helpinfo.html.

http://www.wes.army.mil/el/elmodels/index.html.

No. C6: Visual HELP

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening, Pre-disposal, and Post-disposal evaluation

Specified Use:

- Simulate multiple landfill profiles to find the most suitable design.
- Evaluate leachate mounding or leakage problems with current landfills.
- Determine the effectiveness of landfill caps for reducing leachate mounding.
- Design and optimize leachate collection systems.

Model Name: Visual HELP

Overview

This is one of several commercialized versions of the HELP model. This example provides a "hydrological modeling environment available for designing landfills, predicting leachate mounding and evaluating potential leachate contamination. Visual HELP combines the latest version of the HELP model (v.3.07) with an easy-to-use interface and powerful graphical features for designing the model and evaluating the modeling results. This latest version of the HELP model addresses many of the limitations and bugs of earlier versions and also includes several new analysis features.

Visual HELP's user-friendly interface and flexible data handling procedures provide you with convenient access to both the basic and advanced features of the HELP model. This completely-integrated HELP modeling environment allows the user to:

- Graphically create several profiles representing different parts of a landfill,
- Automatically generate statistically-reliable weather data (or create your own),
- Run complex model simulations,
- Visualize full-color, high-resolution results, and
- Prepare graphical and document materials for your report.

Visual HELP has also proven to be an extremely valuable tool for accurately predicting seasonal groundwater recharge for periods of up to 100 years for use in MODFLOW models. This seasonal recharge data has proven to significantly influence the vertical migration of contaminants through the unsaturated zone. Source: Scientific Software Group.

Applicable Scale: Site design

Computer System Requirements: Windows 95/98/2000/NT

Cost: Proprietary software from Scientific Software Group, P.O Box 708188, Sandy, Utah 84070

Input Data: Weather, soil, and design data.

Output Results: Detailed water balance for comparison of design alternatives.

Selected References:

Source: Scientific Software Group.

No. C7: BIOF&T – 3D

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening, Pre-disposal, and Post-disposal evaluation

Model Name: BIOF&T -3D

Overview

BIOF&T -3D models flow and transport in the saturated and unsaturated zones in two or three dimensions in heterogeneous, anisotropic porous media, or fractured media. Package will model convection, dispersion, diffusion, adsorption, desorption, and microbial processes based on oxygen limited, anaerobic, first order, or Monod type biodegradation kinetics. Includes anaerobic or first order sequential degradation involving multiple daughter species. Source: http://www.hydrology-software.com/issubsrf.htm

Applicable Scale: Site

Computer System Requirements: Microsoft Windows ™

Cost: Proprietary software from Scientific Software Group, P.O Box 708188, Sandy, Utah 84070

Input Data:

- Mesh discretization data.
- Initial conditions for flow: water.
- Boundary conditions for flow: specified head boundaries, flux boundaries, and sources and sinks.
- Soil hydraulic properties: van Genuchten parameters, hydraulic conductivity distribution and porosity.
- Initial conditions for transport: species concentration.
- Boundary conditions for transport: specified concentration boundary, specified mass flux, and spatial distribution of contaminant loading.
- Dispersivities.
- Mass transfer rate coefficient between oil and water phase.
- Distribution coefficient.
- Bulk density.
- Diffusion coefficient for species.
- Biodegradation parameters for each species.
- Fraction of the mobile phase.

Output Results:

Flow

- Spatial distribution of water pressure with time
- Spatial distribution of water saturation with time
- Velocity distribution with time
- Pumping/injection rates and volume vs. time

Transport (for each species):

- Spatial distribution of concentration with time
- Mass dissolved in water vs. time
- Mass remaining in NAPL phase vs. time
- Mass adsorbed on the solid phase vs. time

Selected References:

http://www.scisoftware.com/products/bioft_details/bioft_details.html.

http://www.scisoftware.com/products/bioft_overview/bioft_overview.html

No. C8: 3DFATMIC

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening, Pre-disposal, and Post-disposal evaluation

Specified Use: 3DFATMIC is designed to simulate transient and/or steady-state density-dependent flow field and transient and/or steady-state distribution of a substrate, a nutrient, an aerobic electron acceptor (e.g., the oxygen), an anaerobic electron acceptor (e.g., the nitrate), and three types of microbes in a three-dimensional domain of subsurface media. Examples include saltwater intrusion models, virus transport models.

Model Name: 3DFATMIC

Overview

3DFATMIC computes and predicts the distribution of pressure head, moisture content, flow velocity, and total head over a three-dimensional region in either completely saturated, or completely unsaturated, or partially unsaturated or partially saturated subsurface media. It also computes and predicts the spatial-temporal distribution of microbes and multi-chemical components. The media may consist of as many types of soils and geologic units as desired with different material properties. Each soil type may be isotropic or anisotropic. The processes governing the distribution of chemical and microbe concentration and temperature include: (1) reversible sorption, (2) microbe-chemical interaction, and (3) hydrological transport by flow advection/convection, dispersion/diffusion, and effect of unsaturation. Source: Scientific Software Group:

Applicable Scale: Site design

Computer System Requirements: Pentium class with 16 MB RAM and FORTRAN Compiler. Any Workstation, e.g., IBM RS6000, DEC Alpha, Silicon Graphics, Sun SparcStation, and HP 9000 Series.

Cost: Proprietary software from Scientific Software Group, P.O Box 708188, Sandy, Utah 84070

Input Data:

- Geometry in terms of nodes and elements, and boundaries in terms of nodes and segments.
- Soil properties including:
  - Saturated hydraulic conductivities or permeabilities.
  - Compressibility of water and the media, respectively.
  - Bulk density.
  - Three soil characteristic curves for each type of soil or geologic unit which are the retention curve, relative conductivity vs. head curve, and water capacity curve.
  - Effective porosity.
  - Dispersivities and effective molecular diffusion coefficient for each soil type or geologic unit.
- Enitial distribution of pressure head over the region of interest.
- Net precipitation, allowed ponding depth, potential evaporation, and allowed minimum pressure head in the soil.
- Prescribed pressure head on Dirichlet boundaries.
- Prescribed fluxes of chemicals and heat on Cauchy and/or Neumann boundaries.
- Artificial withdrawals or injections of water.
- Number of chemical components as well as microbes and microbe-chemical interaction parameters such as specific yields, utilization coefficients, saturation constants, etc.
- Artificial source/sink of water and all chemical components, heat and microbes.
- Prescribed concentrations of all chemical components and microbes as well as temperature on Dirichlet boundaries.
- Prescribed fluxes of all chemical components and heat on variable boundaries.
- Initial distribution of all chemical component and microbe concentrations and temperature. All inputs in items 4 through 11 can be time-dependent or constant with time. Source: Scientific Software Group.

Output Results:

- Pressure head, total head, moisture content, and flow velocity over two-dimensional grid at any desired time.
- Water fluxes through all types of boundaries and amount of water accumulated in the media at any desired time.
- Distribution of chemical concentrations, microbes, and temperature over a three-dimensional grid at any desired time.
- Amount of chemical and heat fluxes through all boundary segments. Source: Scientific Software Group.

Selected References:

http://www.scisoftware.com/products/3dfatmic_details/3dfatmic.PDF.

Web site:

http://www.scisoftware.com/products/3dfatmic_overview/3dfatmic_overview.html

No. C9: MIGRATEv9

Category: Soil quality and ecology (multimedia modeling)

Evaluation State: Screening, Pre-disposal, and Post-disposal evaluation

Specified Use: For modeling landfills, buried waste deposits, spills and disposal ponds. Model contaminant sources as surface boundary conditions or as a physically buried layer to generate time-distance-concentration output.

Model Name: MIGRATEv9

Overview

Using the MIGRATEv9 software, contaminant transport from multiple sources, either at the surface or buried, can be modeled quickly and accurately in two dimensions. Unlike finite-element and finite-difference formulations, MIGRATEv9 does not require the use of a time-marching procedure. MIGRATEv9 uses a finite-layer technique that provides numerically accurate and stable results while requiring relatively little computational and data entry effort.

In addition to advective-dispersive transport, MIGRATEv9 can consider sorption, radioactive and biological decay, and transport through fractures. One or more landfills, buried waste deposits, spills, or disposal ponds can be modeled. These contaminant sources may be adjacent or offset from each other. Model properties may be either constant or transient, with the concentrations calculated at specified times, depths, and distances. (Source: Scientific Software Group)

Applicable Scale: Site

Computer System Requirements: Microsoft Windows ™

Cost: Proprietary software from Scientific Software Group, P.O Box 708188, Sandy, Utah 84070

Input Data: Each constant properties dataset is composed of: general data (e.g., number of landfills, layers), top and bottom boundary conditions (e.g., finite mass), and layer data (e.g., porosity and diffusion coefficient).

Boundary conditions, layer data and time-varying conditions can be set. Predefined models include Subtitle C and Subtitle D landfills. Geomembranes, clay layers and aquifers can be specified.

Output Results: The concentration of the contaminant is calculated at variable specific times and distances.

Selected References:

http://www.scisoftware.com/products/migratev9_description/migratev9_description.html

http://www.scisoftware.com/products/migratev9_details/migratev9_details.html

Appendix D – Air quality models list

No. D1: OBODM

Category: Air quality

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Calculate pollutant concentration from open burn

Model Name: Open Burn/Open Detonation Dispersion Model (OBODM)

Overview

The Open Burn/Open Detonation Dispersion Model (OBODM) was developed to evaluate the impacts of open burning on potential air quality problems. The OBODM model first determines the total amounts of pollutants released from an open burn using either theoretical or empirical emission factors. The OBODM uses plume rise and dispersion model algorithms to simulate downwind transport, dispersion, and deposition of pollutants from short-term quasi-continuous, such as an open burn, sources – point/volume and/or line sources. The OBODM model can be used to calculate peak concentration, time-mean concentration, time-integrated concentration, and particulate deposition from open burn sources. The movement of odor, toxic gases, particulate matter, and airborne pathogens from open burning can be simulated with this model.

Applicable Scale: Field scale

Computer System Requirements: DOS and Windows

Cost: Public domain

Input Data: Receptor locations and heights, meteorological data, wind speed and direction, air humidify, temperature, and either Pasquill stability category or the Net Radiation Index (NRI), half-life or the pollutant if pollutant decays with time.

Output Results: Peak concentration, dosage, concentration time-averaged concentration.

Selected References:

Bjorklund, J.R., Bowers, J.F., Dodd, G.C., & White, J.M. (1998). *Open Burn/Open Detonation Dispersion Model (OBODM) User's Guide*. (DPG Document No. DPG-TR-96-008a). Dugway, Utah: West Desert Test Center, US Army Dugway Proving Ground.

http://www.epa.gov/scram001/tt22.htm#obodm

No. D2: CTSCREEN

Category: Air quality

Evaluation State: Screening

Specified Use: Assess plume impaction in complex terrain

Model Name: Complex Terrain Screening Model (CTSCREEN)

Overview

CTSCREEN model was developed to calculate a worst-case 1-hour concentration in complex terrain with predetermined meteorological conditions.

When meteorological data are not available, CTSCREEN can be used to obtain conservative, yet realistic, impact estimates for particular sources. These estimates can provide conservative emission-limit estimates. The movement of odor, toxic gases, particulate matter, and airborne pathogens from burial, incineration, and composting can be simulated with this model.

Applicable Scale: Field scale

Computer System Requirements: DOS

Cost: Public domain

Input Data: Source location, height, stack diameter and exit velocity, stack exit temperature and emission rate, receptor, and terrain (contour) information.

Output Results: Source-receptor location, geometrical relationships between the source and the hill, plume characteristics at each receptor, summary table of up to 4 concentrations at each receptor, source contribution at each receptor, estimated 3-hour, 24-hour, and annual concentrations.

Selected References:

Perry, S.G., Burns, D.J., & Cimorelli, A.J. (1990). *User's Guide to CTDMPLUS: Volume 2, The Screening Model (CTSCREEN).* Abridgement of EPA-600/8-90-087. Atmospheric Research and Exposure Assessment Laboratory. US Environmental Protection Agency.

http://www.epa.gov/scram001/tt22.htm#ctscreen

No. D3: SCREEN3

Category: Air quality

Evaluation State: Screening

Specified Use: Ground-level concentrations for point, Area, Flare, and Volume sources.

Model Name: SCREEN3

Overview

The SCREEN3 model is the US EPA's current regulatory screening model for many air permitting applications and the New Source Review. The SCREEN3 model is based on steady-state Gaussian plume algorithms and is applicable for estimating ambient impacts from point, area, and volume sources out to a distance of about 50 kilometers. In addition, SCREEN3 can be used to model flares. The SCREEN3 model utilizes a matrix of meteorological conditions covering a range of wind speed and stability categories. The model is designed to estimate the worst-case impact based on the meteorological matrix for use as a conservative screening technique.

Applicable Scale: Field scale

Computer System Requirements: DOS or Windows

Cost: Public domain for DOS version and Commercial for Windows version

Input Data: Source type – point, flare, volume, or area source, urban or rural terrain, emission rate, physical stack height, stack gas exit velocity, and stack gas temperature.

Output Results: A dispersion curve showing the change in chemical concentration vs. distance from source.

Selected References:

US EPA. (1995). *SCREEN3 Model User's Guide* (US EPA Publication No. EPA-454/B-95-004). Office of Air Quality Planning and Standards Emissions, Monitoring, and Analysis Division Research Triangle Park, North Carolina 27711.

http://www.epa.gov/scram001/tt22.htm#screen3

No. D4: ADMS

Category: Air quality

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Concentrations of pollutants emitted both continuously from point, line, volume, and area sources

Model Name: Atmospheric Dispersion Modeling System (ADMS)

Overview

ADMS is an advanced model for calculating concentrations of pollutants emitted either continuously from point, line, volume, and area sources, or discretely from point sources. The model takes account of the following: effects of main site building; complex terrain; wet deposition, gravitational settling, and dry deposition; short-term fluctuations in concentration; chemical reactions;

radioactive decay; plume rise as a function of distance; averaging time ranging from very short to annual; condensed plume visibility; and meteorological preprocessor.

Applicable Scale: Field scale

Computer System Requirements: Windows

Cost: Public domain in selected circumstances

Input Data: Source location, emission rate, stack height, elevation, particle size distribution with corresponding settling velocities, hourly meteorological data.

Output Results: Concentration for specified averaging times at receptor points or on an output grid: averages of concentration over a specified period and percentiles of these averages. Short- and long-term average of wet, dry, and total deposition and radioactive activity.

Selected References:

Carruthers, D.J., Holroyd, R.J., Hunt, J.C.R., Weng, W.S., Robins, A.G., Apsley, D.D., Thompson, D.J., & Smith, F.B. (1994). UK-ADMS: A new approach to modeling dispersion in the earth's atmospheric boundary layer. *Journal of Wind Engineering and Industrial Aerodynamics*, *52*, 139-153. Elsevier Science B. V.

http://www.cerc.co.uk/software/adms3.htm

No. D5: ALOHA

Category: Air quality - 5

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Evaluate releases of hazardous chemical vapors

Model Name: Areal Locations of Hazardous Atmospheres (ALOHA)

Overview

ALOHA is an atmospheric dispersion model used for evaluating gas transport and dispersion in atmosphere in emergency conditions. It takes into account both the toxicological and physical properties of the pollutant and the characteristics of the site, such as the atmospheric conditions and the release conditions. ALOHA predicts how a hazardous gas cloud might disperse in the atmosphere after an accidental pollutant release. ALOHA can be used for emergency management and remediation planning.

Applicable Scale: Field scale

Computer System Requirements: Windows or Macintosh

Cost: Free

Input Data: Geographic location, time and date, site and chemical definition, atmospheric data, source definition.

Output Results: Footprint showing the affected area with uncertainty in footprint location, which results from uncertainty in wind direction. Plot showing the pollutant concentration in the air at ground level at a location specified by the user. Also plots showing dose vs. time and source strength vs. time.

Selected References:

ALOHA User's Manual from World Wide Web: http://www.epa.gov/ceppo/cameo/pubs/aloha.pdf.

http://response.restoration.noaa.gov/cameo/cameo.html

No. D6: INPUFF

Category: Air quality

Evaluation State: Pre-disposal and Post-disposal evaluation

Specified Use: Simulate dispersion from semi-instantaneous or continuous point sources over a spatially and temporarily variable wind field.

Model Name: Integrated PUFF (INPUFF)

Overview

INPUFF is an air quality model which uses the Gaussian equation to evaluate the diffusion of a puff generated by a single point source. It may be used also with multiple point sources and deals with nonreactive pollutants, but may include deposition and sedimentation. The user may choose among different algorithms to simulate the puff behavior and may also enter its own routines to evaluate the plume effective height and puff dispersion. It works on flat terrains within few tens of kilometers of distance.

Applicable Scale: Field scale

Cost: Public domain

Input Data: Wind speed and direction, dispersion coefficient option, receptor location, fraction of crosswind dispersion, elevation, azimuth angle, air temperature, minimum distance to receptor, deposition velocity, settling velocity.

Output Results: Simulation period, time, and puff type. Intermediate source concentrations. Table of average concentration for each receptor for all meteorological periods. Average concentrations for all sources.

Selected References:

Perersen W.B., & Lavdas, L.G. (1986, August). INPUFF 2.0 A Multiple Source Gaussian Puff Dispersion Algorithm – User's Guide (US EPA Publication No. EPA/600/8-86-024).

http://www.epa.gov/ttn/nsr/psds1/sup6_21.html