Center for Water Resources Research

Annual Technical Report

FY 2000

Introduction

In FY 01, the Utah Water Research Laboratory (UWRL) expended approximately $7.3 million in water research support. USGS Section 104 funds administered through the Utah Center for Water Resources Research (UCWRR) accounted for about one percent of this total and were used for outreach, information dissemination, and strategic planning with regard to water resources and environmental quality issues in the State of Utah.

Outreach within the UCWRR continues to be a form of scholarship that is stimulated, supported, and rewarded in FY 01. Outreach activities through the UCWRR, the UWRL, and Utah State University (USU) have had an impact on the technical and economic development of the State of Utah. As part of the UCWRR outreach activities supported by USGS Section 104 funds, there continues to be a vigorous dialogue and experimentation with regard to efficiency and effectiveness of outreach activities of the UCWRR. Faculty have been involved in regular meetings with State of Utah agencies, including the Department of Environmental Quality (DEQ) and the Department of Natural Resources (DNR), to provide on-site training, non-point source (NPS) pollution assistance, technology transfer, and development of source water protection plans (SWPPs) within the context of Utah issues.

Approximately 4,000 on-site wastewater treatment systems are currently installed annually in Utah. UCWRR and UWRL faculty have teamed with the Utah local health departments and with the Utah Department of Environmental Quality to address issues including establishing criteria, testing, and monitoring for decentralized systems. A major accomplishment of the UCWWR this year was the establishment of continuing state support through passage of Utah House Bill 14 (#B-14) for the Utah On-Site Wastewater Treatment Training Center during the 2000 session of the Utah Legislature. The legislation provides a mechanism to generate funds for training and technology transfer regarding siting, designing, installation, maintenance, and monitoring of on-site systems for local health departments, designers, installers, developers, and state regulators.

Air quality issues along the Wasatch Mountains in Utah (Wasatch Front) have been identified by the Governor of Utah as a current and future concern as a result of projected increases in automobile traffic. To address these concerns, the UCWRR has appointed a faculty member (Dr. Randal Martin) during this fiscal year to work with the State of Utah DEQ Air Quality Board in the evaluation and assessment of air quality problems and in developing alternatives to meet air quality standards.

New federal source water protection plan requirements require river-basin-wide characterization, assessment, and reevaluation with regard to risks of contamination of source water from near and far sources. Both point sources and non-point sources (NPS) need to be identified. Risks to Utah’s source water include both point and non-point sources. Several UCWRR faculties are assisting the State of Utah water agencies in developing source water protection plans. The UCWRR has partnered with the Utah DEQ to assess NPS pollution as part of the Utah Source Water Protection Plan (SWPP). As part of this partnership, UCWRR is developing specific information concerning the location and status of on-site wastewater treatment systems in important watersheds in Utah. SWPPs are specifically important during periods of lower than normal precipitation that is characteristic of this fiscal year.

USGS Section 104 funds were used specifically to address the Utah SWPP during FY 2000-FY 2001.

Lake Powell is heavily used by Utah citizens, equivalent to over one million people spending one night between April and September 1999 for swimming, boating, and camping. This has resulted in increased pressure on the water quality of the beaches of Lake Powell. A Technical Advisory Committee (TAC) was formed by the Utah Department of Environmental Quality to address issues of human and non-point source animal contamination, monitoring, and management to ensure protection of human health and the environment. Two UWRL faculty members, including the Director, serve as members of the Lake Powell TAC.

With current and projected industrial growth and population trends in Utah, changing land use patterns, and transportation system expansion, the need exists in many areas of the State for evaluation of water quality issues. The Utah Water Quality Board, under the direction of the Utah Department of Environmental Quality, addresses issues and needs for the State of Utah. These include non-point sources of contaminants to Utah’s rivers, lakes, and streams, abatement or elimination of impacts, alternative treatment systems, and expansion of existing wastewater treatment systems. The UWRL Director serves as a member of the Utah Water Quality Board.

Agriculture continues to contribute significantly to the Utah economy. It is, however, vulnerable to the erratic water supply, and is a major contributor to non-point source water pollution, including salinity from irrigation return flows and pesticides in ground water. Also, agriculture will be impacted by the implementation of the state dam safety program, which is expected to require costly dam rehabilitation measures.

Alterations to natural streams now must be evaluated to ensure that adequate protection of riparian habitat and stream channel integrity will be provided. There is, however, concern about deterioration in water quality in some major reservoirs.

Prevention of continual degradation of limited surface and groundwater supplies, and remediation and renovation of soil and water resources impacted from historical and on-going industrial, mining agriculture, and military activities are high priorities. An aggressive UCWRR program for the detection and remediation of releases of fuels, agricultural chemicals, and other hazardous materials has supported the Utah Department of Environmental Quality.

Research Program

Program Goals and Priorities

The Section 104 program facilitates the important functions of linking water research programs throughout Utah, linking Utah programs with those in the region and nationally, and supporting seed projects. Utah Section 104 funds have been used in FY 99 to support information transfer, program management, and statewide regional, and national research coordination activities.

The objectives of the research, information transfer, and program management/coordination aspects of the Utah Section 104 program are discussed in Subsections 2.1 and 2.2.

Information Program

The information transfer activities of the Utah Section 104 program are limited to those managed directly by the Utah Center for Water Resources Research (UCWRR)/UWRL.

Our information transfer activities include our World Wide Web (WWW) site, the Utah Water Atlas, The Utah WaTCH (Wastewater Training Center Happenings), conferences, workshops, training for U.S. and international professionals, publications' production support and sales, general education, availability of faculty to share their expertise with users, and brochures. The UCWRR/UWRL library has been integrated with the main university library to make UCWRR/UWRL publications and holdings more widely available to users across the campus and throughout the state.

The UWRL is involved in efforts to increase the amount of water research information available to the general public. The UWRL World Wide Web (WWW) pages (http://www.engineering.usu.edu/uwrl) include information on UWRL staff and full text of major publications. It is easy for users to download and print the information they are looking for. Currently we have provided links to The Utah Water Atlas, which is a comprehensive work covering all aspects of water in the State of Utah. Users are able to quickly link to our experts and obtain information on issues of interest using our searchable database publications and reports.

Program Management/Coordination

Administration of the Section 104 program in FY 00-01 involved the UCWRR Director, Dr. Ronald C. Sims; UCWRR Acting Associate Director, Mac McKee; UCWRR Administrative Assistant, Jan Urroz; UCWRR Information Dissemination Coordinator, Ivonne Harris, and the UCWRR Business Office Supervisor, Tamara Peterson, and her staff. Coordination activities can be divided into state, regional, and national activities. At the state level, we administer the Section 104 Program, publish an annual report that summarizes UCWRR research, co-sponsor the Utah Section AWRA Annual Meeting, and keep UCWRR associates informed through various mailings.

At the regional level, the UCWRR Director participates in meetings of the Powell Consortium of Water Research Institutes in the Colorado River Basin states. The UCWRR Director also participates as a member of the Lake Powell Technical Advisory Committee composed of representatives of the State of Utah, State of Arizona, and the National Park Service.

At the national level, the UCWRR Director participates in the National Institutes for Water Resources (NIWR) Annual Meeting and either the Director or the Associate Director attends the Annual Meeting of the Universities Council on Water Resources Research (UCOWRR).

Individuals Cooperating in Program Development

Utah Water Research Laboratory and Utah Center for Water Resources Research

Ronald C. Sims, Director Upmanu Lall, Associate Director (on leave July, 2000 - June, 2001) Mac McKee, Acting Associate Director (September, 1999 - June, 2001) R. Ryan Dupont, Head, Environmental Division Judith L. Sims, Manager, Utah On-Site Wastewater Treatment Training Center David G. Tarboton, Head, Water Division Geoffrey G. Smith, Manager, International Office for Water Education

Utah State University Water Resources Research Council

A. Bruce Bishop, Dean, College of Engineering (Chair) Ronald C. Sims, Director, Utah Water Research Laboratory/ Utah Center for Water Resources Research Rodney J. Brown, Dean, College of Agriculture Fee Busby, Dean, College of Natural Resources Peter F. Gerity, Vice President for Research Donald W. Fiesinger, Interim Dean, College of Science Ann Leffler, Dean, College of Humanities, Arts, and Social Sciences H. Paul Rasmussen, Director, Agricultural Experiment Station Martyn M. Caldwell, Director, Ecology Center

Representatives from Other Utah Universities

Danny Vaughan, Weber State University Larry DeVries, University of Utah A. Woodruff Miller, Brigham Young University

Outreach Activities

To promote the application and dissemination of current, past, and related research results, the following principal activities were carried out during the fiscal year.

Formal Gatherings

Each fall, the UWRL participates in the Governor’s Banquet on Water Education that is held in Salt Lake City, Utah. To promote K-6 water education throughout the state, the UWRL and the Department of Water Resources conduct a poster contest among students at elementary schools to reinforce the statewide program of in-service training and to support water education in the elementary schools.

UWRL Faculty has conducted the following workshops:

On-Site Wastewater Treatment Training. Over 350 people in Utah received training regarding important site characterization information that is necessary to select sites, size systems, and protect public health. These training workshops were offered across the State of Utah.

Physical Habitat Simulation Model. The Institute for Natural Systems Engineering has developed a Windows-based implementation of the Physical Habitat Simulation System that includes several enhancements in addition to an expanded module for time series analysis. This advanced modeling system is supported by technical documentation and training opportunities provided by the UWRL as part of its technology transfer commitment.

Principal Outreach Publications

Principal outreach items include the Comprehensive Water Education Grades K-6 manual (several thousand copies of the manual have been distributed throughout the country), newsletters addressing the on-site wastewater issues (Utah WaTCH), and a Mineral Lease Report to the Utah Office of the Legislative Fiscal Analyst.

UWRL’s International Office for Water Education (IOWE) produced and distributed a regional water education calendar to elementary schools in Arizona, California, Colorado, Nevada, New Mexico, Wyoming, Alaska, Hawaii, Idaho, Montana, Oregon, and Washington. The calendar featured the winning posters from the K-6 poster contests conducted in the seven Colorado River and Columbia River states. It also included lessons, questions with answers, and facts about water. A separate water education calendar was produced and distributed to all elementary school classrooms in Utah.

UWRL has prepared two water education manuals for elementary school teachers. More than 20 in-service workshops were conducted. Preservice training workshops were completed at universities throughout the state. The Program is expanding into other states. More than 200 elementary school teachers received water related training through UWRL/UCWRR-sponsored credit workshops.

Professional Publications and Presentations

Technical publications in FY 00-01 that were partially supported by the cooperative program described in this report are listed below. Other publications from the Utah Water Research Laboratory appear regularly as technically reviewed project reports, professional journal articles, other publications and presentations, theses and dissertation papers presented at conferences and meetings, and project completion reports to other funding agencies.

Dent, J.L. and D.L. Sorensen (2000). Onsite Wastewater Treatment Database Development. Utah Non-Point Source Conference. Utah State University, Logan, UT. August.

Sims, J.L. (2001). The Utah WaTCH (Volume 2-1). The newsletter addressing on-site wastewater treatment issues in Utah. Utah Water Research Laboratory, Utah State University, Logan, UT.

Sims, J.L. (1998-2000). The Utah WaTCH (Volumes 1-4). The newsletter addressing on-site wastewater treatment issues in Utah. Utah Water Research Laboratory, Utah State University, Logan, UT.

Sims, J.L. and M. Cashell (2001). Basic Site Evaluation Techniques for On-Site Wastewater Treatment. Utah Water Research Laboratory, Utah State University, Logan, UT.

Sims, J.L. and M. Cashell (2001). Fundamentals of On-Site Wastewater Treatment and Disposal Systems. Utah Water Research Laboratory, Utah State University, Logan. UT.

Smith, G.G. (1999-2001). Powell States and Columbia Water Education Calendar. International Office for Water Education, Utah Water Research Laboratory, Utah State University, Logan, UT.

Smith, G.G. (2001). Substitute Teacher Handbook (Elementary IV Edition). International Office for Water Education, Utah Water Research Laboratory, Utah State University, Logan, UT.

Smith, G.G. (2001). Substitute Teacher Handbook (Secondary IV Edition). International Office for Water Education, Utah Water Research Laboratory, Utah State University, Logan, UT.

Smith, G.G. (2001). SubJournal, Best Practices in the Management of Substitute Teaching. Substitute Teaching Institute, Utah State University, Logan UT.

Sorensen, D.L., M.W. Kemblowski, J.P. Dobrowolski, R.R. Dupont, D.T. Jensen, R.D. Ramsey, R.C. Sims, D.K. Stevens, D.G. Tarboton, G.E. Urroz. (2000). Source Water Protection Assessment Tools Development. Utah Non-Point Source Conference. Utah State University, Logan, UT. August.

Utah Water Research Laboratory (2000). Mineral Lease Fund Report. Utah State University, Logan, UT.

Utah Water Research Laboratory (2001). Stewardship Through Collaboration: Research and Testing, Education Support, and Outreach for July 1996 1999. Utah State University, Logan, UT.

Cooperative Arrangements

The UCWRR maintains a List of Center Associates and distributes mailings on research opportunities to faculty on the campuses of Utah State University, the University of Utah, Brigham Young University, and Weber State University. Program coordinators have long been established on each campus.

The UCWRR/UWRL works with the regional group of Center Directors (Powell Consortium of Water Institute Directors, in Arizona, California, Colorado, Nevada, New Mexico, and Utah) in maintaining a current statement of regional research priorities and developing collaborative research of regional significance. Also UCWRR/UWRL participates in annual National Institutes for Water Resources (NIWR) and Utah State University Water Resources Research Council meetings.

The UCWRR interacts with federal (National Forest Service, U.S. EPA), and state agencies (Utah DEQ, DNR, Water Rights) involved in water resources planning and management, water quality control, and source water protection. The research response to state needs is coordinated with other universities through established interactive and iterative processes.

The UCWRR/UWRL's current cooperative studies with governmental agencies and private sector firms include: 1) a research agreement with the United States Department of Agriculture - Agricultural Research Service on Scaling up spatially distributed models of arid water sheds; 2) an agreement with U.S. Department of the Interior - Fish and Wildlife Service on Habitat and flow requirements study for the Comal Ecosystem; 3) research agreement with U.S. Department of the Interior - Bureau of Reclamation on Study of water yields on semi-arid environments under projected climate change and impact of global climate change on urban water demand; 4) joint effort with U.S. Bureau of Reclamation, State of Utah, Division of Water Quality, and Weber Basin Water Conservancy District on Weber Basin water quality study. In addition, several faculty have worked on IPAs with the Department of Defense, Hill Air Force Base, and U.S. Army Corps of Engineers.

Other cooperative arrangements were: 1) Utah State Board of Regents and various Utah school districts on Retraining Teachers in Science and Math Using Water Concepts; 2) with Utah Department of Environmental Quality on On-site Wastewater Treatment-Site Characterization; 3) with U.S. Department of the Interior - Bureau of Land Management on Seasonal Use of the Virgin River Gorge by Protected Fish; 4) with Utah Division of Water Rights on Poster Contest and Teacher Inservice/Assemblies/Classroom Demonstrations; 5) with U.S. Department of Agriculture - Agricultural Research Service on Water Quantity and Quality Analysis of Mining Areas Located Within Wasatch Plateau of Central Utah; 6) with Department of Natural Resources - Utah Division of Water Resources, U.S. Department of the Interior - Bureau of Reclamation, and Cache County Commission on Cache County Municipal Water Demand Model; and 7) with Utah local health departments and the Utah Department of Environmental Quality on Soil Percolation Testing and Evaluation.

Basic Information

Title:	Development of a GIS-Based Approach for Better Statewide Water Use Estimation
Project Number:	G-01
Start Date:	9/1/2000
End Date:	8/31/2002
Research Category:	Not Applicable
Focus Category:	Water Use, Water Supply, Models
Descriptors:	crop water use, data analysis, data storage and retrieval, information dissemination, irrigation, land use, planning, statistics, water use data
Lead Institute:	Utah State University
Principal Investigators:	Mac McKee, David Gavin Tarboton

Publication

PROBLEM

In many states, the need for detailed and accurate water use data has become critical in light of increasing water demands and limited water supplies. Water resources planning and decision-making can benefit from improved water demand forecasts, which are based in part on analyses of historic water use trends. To these ends, water use and related data are collected and compiled by various Federal, State, and local agencies.

In 1977, the recognition of the need for a single source of accurate water use information led the Congress to direct the United States Geological Survey (USGS) to establish a National Water-Use Information Program. The USGS has published reports on estimated water use in the United States at five-year intervals since 1950. The USGS has traditionally used a variety of inventory and census-type approaches to compile water use data. These approaches are generally labor intensive and expensive, and only provide water use estimates for one year out of five. Because of the infrequent sampling interval, the utility of these data is limited with respect to identifying trends and supporting water demand forecasts for planning and decision-making. Further, because of their expense, utilization of the present methods for water use estimation for annual or other more frequent sampling intervals is not cost-efficient.

RESEARCH OBJECTIVES

The purpose of the proposed project is to develop, test, and demonstrate methodologies to utilize electronically available data, GIS technology, and attendant analytic methods for more efficiently generating statewide water use estimates for many of the USGS water use categories, and forecasting future water use. The specific objectives of the work proposed here are to:

- formulate the conceptual design of a statewide water use model
- develop and implement approaches for estimating individual water use components consistent with the USGS water use categories
- estimate trends in water use in Utah in order to facilitate water use estimation for any given year
- develop a methodology for using the water use trends to forecast future water use to facilitate planning of statewide water allocation

METHODOLOGY

The statewide water use model will be a collection of methods to estimate water use for: (1) agriculture, (2) wastewater production and water supply for public, domestic, commercial, and industrial uses, (3) reservoir evaporation, and (4) wetlands and other open water evaporation. The model will use a monthly time scale in its computations, but output from this model will be a summary of the water use categories and major sub-categories at an annual time scale for a user-defined geographic area.

The estimation results for year 2000 will be compared against those obtained using standard USGS methods in Utah. As a part of each five-year cycle of water use estimation, the USGS publishes detailed guidelines for how the data collection and analysis are to be done. For example, see USGS (1996) for a discussion of the procedures recommended for the 1995 water use estimates. The exact procedures vary from state to state, depending on the details of how water resources data collection is done by local and state agencies. Methods are also recommended for addressing missing data and other problems (Schwarz, 1995).

The following sections describe the methods (and their data requirements) that will be developed to estimate statewide water use in the categories identified above.

Agricultural Water Use

Agricultural water use is defined as the potential consumptive use and is estimated as the potential evapotranspiration (ET) of actively growing crops. The irrigation water requirement is the difference between the potential ET and the portion of precipitation that is directly used by the crops. Agricultural surface water withdrawals are difficult to determine since not all the gauged flow in canals is used for irrigation. To obtain the 1995 Utah water use figures, the USGS calculated irrigation consumptive use by applying a modified Blaney-Criddle equation to estimates of the irrigated cropping pattern in the state (which were supplied by the DWR). Data on groundwater withdrawals were then subtracted from the Blaney-Criddle consumptive use numbers to obtain an estimate of surface water withdrawals. These were then compared against known surface water discharge measurements to detect any anomalies.

The project will employ a similar procedure, but will develop a more flexible GIS-based method to do so. In addition, alternatives to the Blaney-Criddle method (e.g., Penman) will be included in the model, as will linkages to the necessary hydroclimatic databases to supply the required meteorological data. The statewide cropping pattern will be obtained from DWR water-related land use inventories, which are carried out periodically for the state. (USU project staff will work with DWR staff to secure the necessary computer hardware and software to put these data on-line in a GIS format.) To calculate agricultural water use, precipitation and potential ET must be obtained for any user-defined area of interest.

Precipitation: Monthly precipitation data for 579 precipitation stations are available in Utah. These point measurements provide excellent temporal coverage (some go back to 1900). However, precipitation in Utah is highly spatially variable, and the point measurements provide relatively sparse coverage. In order to estimate precipitation at a non-guage location, some form of interpolation is required. Two data sets have become available that can potentially provide better ways to estimate spatially distributed precipitation. One of these data sets is based on the climatic divisions prepared for the US by the National Climate Data Center (NCDC, available at http://www.ncdc.noaa.gov/onlineprod/drought/statelist.html). Monthly divisional average temperature and total precipitation are derived using all stations reporting both precipitation and temperature within the division and are available for download from the Climate Diagnostics Center (CDC, http://www.cdc.noaa.gov/Timeseries/). The other source of spatial precipitation data is the Oregon Climate Center, which provides PRISM ("Parameter-elevation Regression on Independent Slopes Method") (Daly et al., 1994; Daly, 1994) generated gridded estimates of mean monthly precipitation maps at two-minute spatial resolution (http://www.ocs.orst.edu/prism/prism_products.html). These two spatial data sets along with point precipitation data will be used to estimate spatial precipitation fields for Utah.

Potential Crop Evapotranspiration: The potential crop evapotranspiration is defined as the rate at which actively growing crops transpire water under non-limiting water supply. The potential crop ET can be computed by adjusting the reference crop evapotranspiration by a crop coefficient:

$$ET_{crop} = k_c \; ET_0 \qquad [1]$$

where ET_0 is the reference crop evapotranspiration, k_c is a dimensionless crop coefficient, and ET_{crop} is the crop evapotranspiration. ET_0 and ET_{crop} have dimensions of length. Crop coefficient values for Utah have been estimated by the DWR and the Agricultural Experiment Station of Utah State University (Hill, 1994). Several methods for computing the reference crop ET (for example, see Jensen et. al, 1990, Chapter 4 in Maidment, 1993) will be available as user-selectable options in the model, including the modified Blaney-Criddle and Penman methods. For each, links to the required meteorological and land-use databases will be provided in a fashion transparent to the user.

Surface and Groundwater Use: In Utah, groundwater withdrawals are determined from an annual pumpage inventory and measured flows from a small number of springs. Following the current USGS procedure, but implementing it in a GIS format, groundwater withdrawals will be subtracted from the calculated irrigation water requirements and the remaining water will be compared to known surface water irrigation withdrawals on a county-by-county basis to decide which numbers are the best estimates of surface water use. The USGS does not consider this an optimum method for determining surface water withdrawals for irrigation because of the number of errors that can be introduced in the process. USGS water use personnel will work with their State Cooperators at DWR and project personnel from USU to analyze historical data on withdrawals, consumptive use, and conveyance losses to develop and streamline a better estimation method for determining surface water irrigation withdrawals. The project will attempt to automate as much of this as possible in a GIS context.

Open Water Surface Evaporation

The oldest method for estimating evaporation from lakes is the evaporation pan method, and will be used where supporting data required for other more physically realistic methods are not available. When appropriate data are available, the more physically realistic Penman-Monteith equation will be used (see section 4.2.5 in Maidment, 1993):

$$E_r = \frac{\Delta}{\Delta + \gamma}\left(R_n + A_h\right) + \frac{\gamma}{\Delta + \gamma}\,\frac{6.43\left(1 + 0.536\;\; U_2\right)}{\lambda}\;D \qquad [2]$$

where E_r is the evaporation (mm/day), Δ is the gradient of the saturated vapor pressure/temperature relationship (kPa/°C), D is the vapor pressure deficit, $R_n + A_h$ is available energy (in mm/day of evaporation equivalent) comprising net radiation and advected energy, U_2 is wind speed at a height of 2-m (m/s), γ is the psychrometric constant (kPa/^{o}C), and λ is the latent heat of vaporization of water (kJ/kg).

Municipal and Industrial Water Use and Wastewater Production

In Utah, municipal and industrial (M&I) water use studies are conducted periodically by DWR for each of the eleven major hydrologic basins in the state (for example, refer to the M&I study of the Sevier River Basin, DWR, 1998). These data are collected through the use of mail-in surveys designed to query each major public water provider about its sources of water supply. Public water systems are divided into four major categories: (1) community water systems, (2) non-community water systems, (3) self-supplied industrial water systems, and (4) private domestic water systems. The system operators provide categorized data for community systems, which include information on residential (metered), commercial (generally estimated), institutional (estimated), and industrial (metered) water use. Water use for non-community systems is estimated by personal visits by DWR staff. The DWR collects annual water use data for most of the major self-supplied industrial systems. However, these data are confidential and only county totals are reported. Private domestic systems that are not connected to any public community or non-community sources generally are supplied by individual wells. Water use for this category is estimated on the basis of population served and a reasonable per capita use rate. These procedures are consistent with USGS guidelines (USGS, 1996). The USGS procedures for estimating wastewater returns in Utah rely heavily on EPA-PCS data.

As an alternative to the survey-based methods currently used by USGS for estimating M&I use and wastewater production, the project will explore GIS-based methods following those developed by Hughes et al. (1996) and others (see USU et al., 1993). These methods calculate M&I demand in several categories from regression equations that utilize census, income, lot size, water price, meteorological, and other data. Most of the data needed for these calculations are already electronically available and could be made easily accessible in GIS form. The accuracy of the resulting calculations will be assessed against water use data available from individual water providers. A comparison of these estimates will also be made against the survey-based estimates obtained from USGS procedures.

The Water Use Model

The proposed work will develop a statewide water use model based on GIS layers to provide spatially distributed information, such as land use, cropping patterns, crop coefficients, etc. Other publicly available supporting hydro-meteorological data, including precipitation and air temperature, will also be used. Weather data will be obtained from the Utah Climate Center for all National Weather Service (NWS) stations in Utah (http://climate.usu.edu/weather/dataserv.htm). Williams (1999) recently prepared a preliminary example of the agricultural portion of the water use model. This implemented many of the components of the agricultural water use module using the GIS software ArcView, version 3.1, and S-PLUS, a statistical and computational package. An ArcView extension (plug-in functionality module) called “S-PLUS for ArcView GIS” allowed easy exchange of data between ArcView and S-PLUS, facilitating quick analysis capabilities.

The proposed work envisions developing similar modules that will use GIS data to build the other components of a statewide water use model described above. At this time, we expect to develop these modules using ArcView and S-PLUS. Wherever possible and appropriate, the equations for determining water use will include calculation options based on USGS guidelines for estimating withdrawals, consumptive use, return flows, etc. To the maximum extent possible, the system will be structured to allow options for different USGS Districts to choose the variables that will be incorporated in each estimation procedure according to the types of data available to each state.

Planning and Forecasting Statewide Water Use

One of the primary reasons for developing a statewide water use model is to give state and local agencies a tool for managing limited water resources. This objective requires us to analyze the historical water use data for each category to describe past trends in water use. Several factors may affect these trends. For example, as urban areas expand in response to population growth and economic development, the overall water use for residential, commercial, and industrial categories may increase. At the same time, agricultural use may also increase to sustain the growing population. There is also recent evidence that US water use may be growing more slowly than population because of recent above average precipitation, higher costs of supply, and improved efficiency (see Brown, 2000). We will use traditional methods for trend analysis, such as regression against a pre-selected set of independent variables at point scales (such as for a city), and also on larger spatial scales up to the whole state (if significant inter-dependence structure is found in water use trends in space). New or innovative methods may be developed as part of this analysis when warranted, such as the use of neural networks in trend analysis. We will exercise care in selecting independent variables during trend analysis so that these variables are truly representative of the water use patterns in space and time. Independence among variables is desirable, but in case significant correlations exist, we will carefully quantify the inter-dependence as far as possible. We will also estimate the uncertainty associated with these trends.

The results from the trend analysis will be used for forecasting purposes in conjunction with projections of independent variables such as population and economic growth (available for Utah from the Governor's office of Planning and Budget; see Robison, 1994). The forecasting capability will result in significant improvement in planning and management capabilities for state agencies. The uncertainty in forecasting also depends on the uncertainty in the input data, and the way in which this uncertainty propagates through the model structure. We will quantify the uncertainty in all pieces of input data as far as possible, and use this to characterize the uncertainty in forecasts. Continual assessment of the forecasts as more data become available will be done to refine some of the methods used in this analysis. This will also help reduce the uncertainty associated with forecasting. The DWR is committed to maintaining the water use database and the suite of programs comprising the statewide water use model for the foreseeable future.

In the second year of the project, USU and the USGS will collaborate in applying the IWR-MAIN water use forecasting software (Planning and Management Consultants, Ltd., 1994) to obtain representative M&I water use estimates for selected, urbanizing counties in Utah. These will be compared to the M&I forecasts obtained with the GIS-based methodologies developed by the project.

We expect the water use model and the forecasting tools to be general enough that they can be used for other states as well. The products from this project will be made accessible to other Federal and State agencies for evaluation and potential use.

Principal Findings and Significance

When completed, the research will benefit the water sector by having developed and tested a GIS-based methodology to efficiently estimate water use in the categories of municipal and industrial (M&I) supply (i.e., public, domestic, commercial, and industrial supply), wastewater production, irrigation, reservoir evaporation, and evaporation from wetlands and other open-water bodies. The methodology will take advantage of readily available, dynamic databases and forecasts, and it will be integrated into the data collection and office procedures of the Utah Division of Water Resources. The methodology will include appropriate protocols for trend analysis of demographic, economic, and water use data. It will also provide forecasting methods for predicting future water use, suitable for analysis of alternative population and economic growth scenarios. The procedures, software, and documentation developed by the project will be provided to the USGS for export and application in other states.

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Basic Information

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Project Number:	B-01
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Research Category:	Water Quality
Focus Category:	Water Supply, None, None
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Lead Institute:	Utah State University
Principal Investigators:	Darwin L. Sorensen, David G. Tarboton

Publication

Research Project Synopses

Project Number: **B-01**

Start: 03/99
End: 02/02 (expected)

Title: **Source Water Protection Assessment Tools Development**

Investigators: Darwin L. Sorensen, David Tarboton, Gilberto E. Urroz, David K. Stevens, Donald T. Jensen, R. Ryan Dupont, Nancy Mesner, Mariush Kemblowski, and Ronald C. Sims

Congressional District: UT 1

Focus Category: WS

Descriptors: Drinking water, source water, pollution sources, watershed management

Problem and Research Objectives

The present research project is focused on developing a source water assessment tool that decrease reliance on arbitrary boundary setting and improves the use of scientific information and professional experience. Diffuse sources of contamination present a major challenge to source water protection management. Nonpoint source pollution is seen as the nation's largest water quality problem (USEPA 1996) and it is a major focus of water quality management in Utah. Runoff water and infiltration water contaminated with nitrate, other nutrients, and pesticides from agricultural operations, construction site runoff, highway runoff, and urban storm water and infiltration water are nonpoint pollution sources that add to the contaminant burden of watersheds. Utah's Total Maximum Daily Load (TMDL) Program (Sec. 303(d) of the federal Clean Water Act) recognizes the difficulty in implementing controls for these kinds of sources (Utah Division of Water Quality 1998). Both public and private water quality managers are expending considerable effort and financial resources toward controlling these "traditional" nonpoint sources of pollution to surface and ground water in Utah. Source water protection assessment and management efforts may use what is being done and what has been learned from these efforts. Less has been done in inventorying and managing on-site wastewater treatment (e.g., septic tanks and drainfield) as relatively diffuse sources of contaminants to groundwater and surface water. Utah Division of Water Quality personnel have expressed concern about this source of contaminants and they have suggested that a systematic approach to management of these sources is greatly needed in the state. They have suggested that a database inventory of on-site wastewater treatment systems in the state would be an important first step in a management approach (Kiran Bhayani, personal communication, 1998).

A systematic approach to applying available, state-of-the-art scientific information, including expert understanding of contaminant transport in natural systems, to the assessment and management of potential drinking water source contamination is needed. This approach should capture the level of uncertainty in the available information and present to risk managers both an indication of the contamination risk and the uncertainty associated with that risk determination. Contaminant risk assessors and risk managers should be able to use the system to improve their understanding of information needs so that uncertainty associated with the protection of surface water supplies can be reduced in a cost effective way. A new scientific investigation methodology for analyzing complex, multi-process, stochastic systems called probabilistic networks (Castillo et al. 1997) has been developed over the past decade. We will use this methodology to develop a source water assessment approach that will have the properties and meet the needs listed above.

The principal objective of the project is to develop a method for integrating watershed information to evaluate the susceptibility of Utah drinking water sources to unacceptable contamination. The project effort is focusing principally on creating knowledge-based and computationally simple systems to connect physical (transport) and biogeochemical (fate) processes using process models. The approach recognizes the variable, stochastic and uncertain nature of watershed-scale processes and input data.

Diffuse pollution sources are more difficult to manage and present challenges to the method development. Therefore, management of on-site wastewater treatment systems has been given special emphasis. Databases for managing on-site wastewater treatment system inventories, including soils and other site characteristics, have been evaluated with emphasis on their application to Source Water Assessments.

Methodology

The Test-Case Watershed Description

The Ogden River basin near Ogden, Utah, was selected as the test-case watershed for the project. This watershed is an important source of drinking water for Ogden City. Ogden has a population of approximately 66,500 people. Ogden draws water from Pineview Reservoir at the dam and from Wheeler Creek into a 56.8 m^3 (15 million gallon) per day drinking water treatment plant. This plant is operated only during summer months to meet peak demands. On an annual basis, this plant provides Ogden City with approximately 13% of its culinary water supply.

The Ogden River basin above Pineview Reservoir Dam has an area of 832 km^2 (321 mi^2). It ranges in elevation from approximately 1450 to 2960 m (4760 to 9710 ft) above mean sea level. The mean annual discharge of the Ogden River below Pineview Reservoir is 9.95×10^7 m^3. The town of Huntsville, with a population of about 650, is located on the South shore of Pineview Reservoir. The unincorporated, populated areas of Liberty and Eden are located to the North of Pineview Reservoir.

The principal industries in the basin are agriculture and recreation. Some, relatively small, confined animal feeding operations are located in the basin. Two major ski areas, Snow Basin and Powder Mountain, are located within the basin. Other major recreational attractions include boating, waterskiing, and fishing on Pineview Reservoir.

Structure of the Tool

Figure 1 illustrates the basic components of the Source Water Protection Assessment Tool (SWPAT) that is being developed. There are four major components that make up the assessment tool: (1) a spatial database of watershed physical characteristics, (2) a pollution source inventory and characteristic database, (3) a graphical user interface that includes a computer communication interface, and (4) a geographic information system (GIS) based hydrologic and pollutant transport model called Terrain Analysis using Digital Elevation Models (TauDEM) (http://www.engineering.usu.edu/cee/faculty/dtarb). The tool helps the user integrate the information collected in the source inventory portion of the assessment with watershed physical characteristic data and produces an estimate of the concentration of contaminant that may occur at the point of drinking water supply diversion as a result of contaminant release from a source or multiple sources in the watershed. The user can then rank the source or a combination of sources so that management action can be appropriately planned and implemented.

GIS Spatial Database

A GIS spatial database is used by the SWPAT. The SWPAT requires GIS coverages of several types including digital elevation models (DEMs), river reach files (rf1 and rf3), land use and landcover shape files, major road shape files, meteorological data (climate, precipitation grids), and shape files for watershed boundaries. The SWPAT needs these coverages to run the hydrologic pollutant transport model. The SWPAT also allows for the use of other types of GIS coverages that are helpful for managing a watershed. For example, U.S. Geological Survey (USGS) quad maps may provide useful reference information.

GIS coverages are available through many sources on the World Wide Web, through state and federal agencies, and from private or commercial data companies. Some of the most common sources are the U.S. Environmental Protection Agency's (EPA's) BASINS, USGS, and state agencies with environmental missions. All coverages used in the SWPAT development were available for download online. The SWPAT uses these coverages for geographical referencing, long-term mean annual precipitation within the watershed (precipitation layer), and to determine flow paths of water and contamination movement (DEM layer).

Watershed Inventory and the Default Database

The SWPAT's has a default database to help the user identify and prioritize potential pollution sources. Itis comprised of physical and chemical properties for EPA's National Primary Drinking Water Regulation listed compounds (http://www.epa.gov/safewater/mcl.html), nutrient and coliform loading rates from the literature, and accident frequency rates for pipelines, storage tanks, and trucks from available federal and state government sources. All physical and chemical properties for the regulated compounds were found online at Syracuse Research Corporation's environmental fate database CHEMFATE (http://esc.syrres.com/efdb/Chemfate.htm). MCLs and common chemical uses were found online at EPA's Office of Water

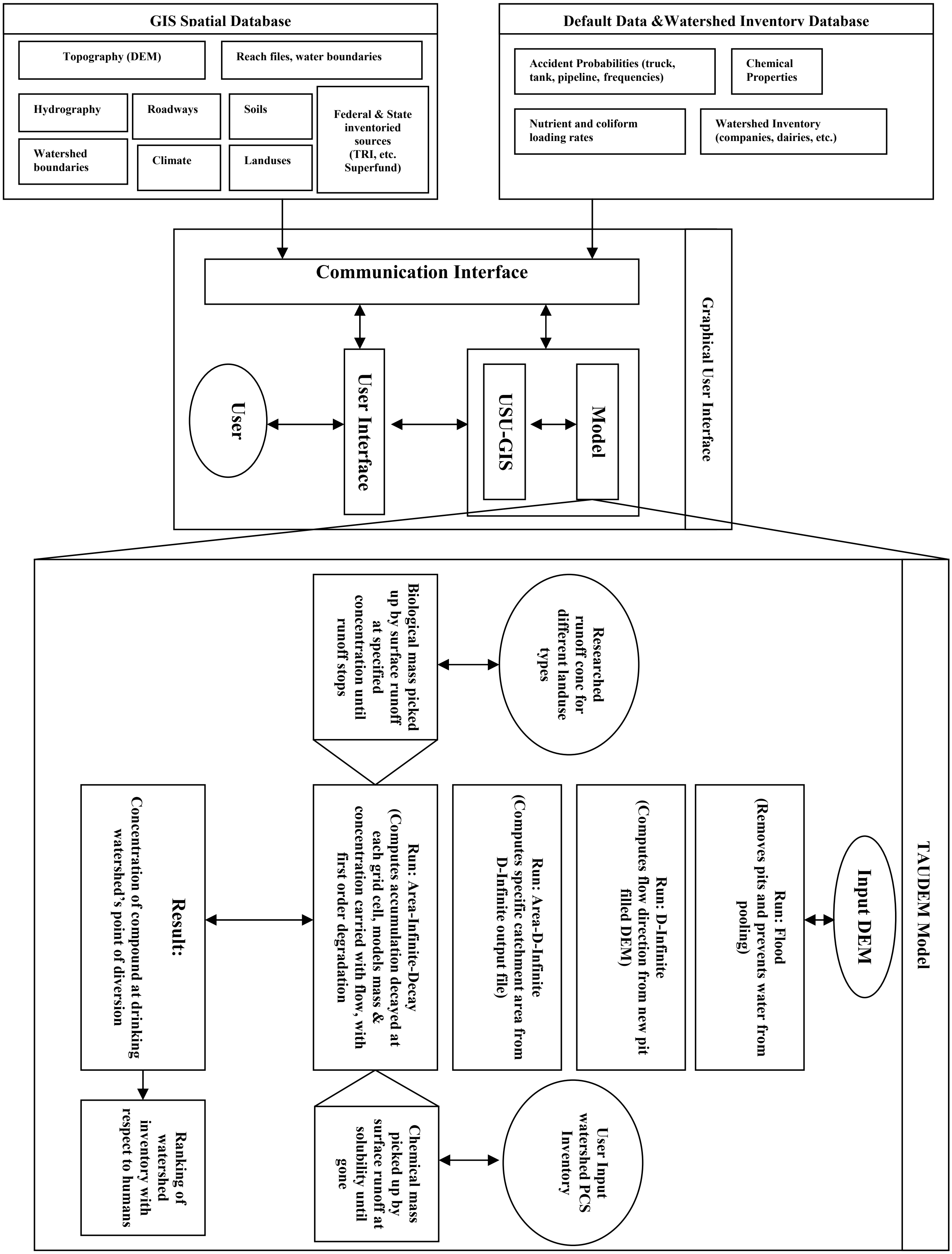


Figure 1. Conceptual Diagram of SWPAT's Structure

drinking water contaminants and Spectrum Laboratories (http://www.epa.gov/safewater/hfacts.html and http://www.speclab.com/, respectively). This information is available in the SWPAT for quick access to help in modeling and inventorying of a watershed.

The SWPAT uses land use coverages dealing with historical urban and agricultural land use practices. The SWPAT model combines these land use types with loading rates for nutrients and coliforms. The nutrients and coliform loading rate data set, that relates different land use types with corresponding nutrient and coliform yield, has been constructed to serve as the default input data for various source water protection scenarios within the SWPAT. Emphasis was given to data sources newer than 1950, if possible, and land uses dealing with agriculture. None of the loading rate studies reviewed took into account extreme storm events and they did not encompass the same region of the United States, climate, land topography, and land management methods (farming methods). The nutrient loading rates were taken primarily from reports from EPA funded studies that compiled nutrient loadings for different land types (Athayde, 1983; Dornbush, 1974; Porcella, 1980; Reckhow, 1980). The coliform loading rates were selected from studies that measured coliform concentrations in runoff during rain or snowfall events. Unfortunately, virtually none of the studies measured storm event intensity and duration.

Accident frequency rates for truck wrecks, pipeline failures, and storage tank failures were compiled. The SWPAT uses these rates to determine the likelihood of a particular industry or activity to become a significant contamination source. These rates were tabulated in units of (accidents/year/mile of road) and (accidents/year/mile of pipeline). Storage tank accident frequencies are in units of (ruptures/year). The data were classified with respect to road class and vehicle type for truck accident rates and geographic location for pipelines. Storage tank failure frequencies are national data and not specific to any location.

Graphical Interface

The components of the graphical interface for source water protection assessment tool are: (1) the watershed GIS spatial database, (2) the point and non-point pollutant loading source database, and (3) the pollutant transport and degradation analysis model. The program developed requires that the user store these data in a project file. After processing, output data can be stored independently in different output files.

To get the program started, the user provides the watershed GIS spatial data file, a file created utilizing the *ArcView* GIS package. The files required for running the program are: a watershed DEM file, a stream network shape file, a watershed boundary shape file, a watershed precipitation grid file, a watershed land use shape file, and, a roadways and railways shape file. All of these data can be displayed graphically into the map windows of the interface. The maps can later be used as platform for the input of pollutant source and for model analysis.

The various components of the pollutant loading source database allow the user to input information regarding contaminant sources. This information includes source location, source type, size of influence area (non-point source), contaminant properties, loading rate, and release time or volume. The interface also allows the user to edit the inputted data. As indicated above, all the input data can be saved into one project file and used by the program for subsequent model analysis.

The analysis of the pollutant transport path and first order degradation is made through an internal adaptation of the TauDEM model described below. All the output files can be saved independently and displayed graphically in the interface map window.

Watershed Characterization Approach

Topography: Digital Elevation Model (DEM)

A DEM is a topographic surface arranged in a data file as a set of regularly spaced x, y, z coordinates where z represents elevation. The topographic elevation of each pixel in a grid DEM is stored in a matrix node within a matrix data structure (Tarboton 1997). The SWPAT uses grid DEMs with a 30-meter grid size to determine flow paths of water and contamination movement. DEMs based on 7.5-minute maps have 30- by 30-meter data spacing with the Universal Transverse Mercator (UTM) projection. All 7.5- by 7.5-minute grids provide the same coverage as the standard USGS 7.5-minute map and correspond to a USGS 1:24,000 and 1:25,000 scale. DEMs were downloaded from the United States Geological Survey's (USGS) Internet website (http://www.usgs.gov/) and EPA's Office of Water, BASINS Internet website (http://www.epa.gov/ostwater/BASINS/). A 30-meter resolution digital elevation model in shape file format is included in the BASINS data set for each of the USGS 8-digit hydraulic unit codes (HUCs).

Precipitation

Average annual and monthly precipitation data produced by the Parameter-elevation Regression on Independent Slopes Model (PRISM) is available for the entire conterminous US. Data sets are available for download by state or for the whole western United States in both raster and vector formats from their website http://www.ocs.orst.edu/prism/prism_new.html. The SWPAT uses PRISM data in a gridded raster format with a 30-meter grid size to get the long-term mean annual precipitation within the watershed. The PRISM are converted to a grid of the same size as the 30- by 30-meter grid DEM data, this can be done in ESRI's ArcView or ArcInfo (http://www.esri.com/).

Stream Flow

The discharge of water from the watershed was separated into base flow and quick flow, which are assumed to represent subsurface and surface flow paths, respectively. USGS's Hydrograph Separation Program (HYSEP) was used for hydrograph separation (http://water.usgs.gov/software/hysep.html). All historical stream flow was retrieved online from USGS. Base flow and quick flow were determined from representative water years and are given as one number for each gage station. Base flow and quick flow are divided by contributing catchment area to get base and surface runoff per unit area. The SWPAT uses these valves to estimate surface runoff and subsurface infiltration coefficients.

Source Inventory Approach Development

Watershed Industry and Toxic Contaminant Considerations

Regulated compounds and possible industry sources. Chemical manufacturer and supply companies may produce and store pesticides, herbicides, fertilizers, solvents, etc. within a watershed. Large amounts of these chemicals can be stored and have the potential of being spilled via either rupture of storage tanks or structures or breakage in a supply pipeline. These sources can be controlled by leak warning systems, containment basins, and emergency shut off valves. Organic chemicals stored on farmlands for fertilizer/pesticide application on agricultural land uses also pose a possible contamination source (PCS) due to possible tank rupture or leakage.

The steps taken to find point source PCSs were to retrieve the state and federal database information on companies permitted to discharge. The state databases used in development were available through the Utah Department of Environmental Quality, Drinking Water Division's Internet website by PDF file download or comma delimited text files. The local phone book and Internet yellow page sites were also used to identify local gas stations, animal feeding operations, dry cleaners, recreation providers and pesticide/fertilizer distribution companies. Some other methods used to find possible PCSs within the watershed were "windshield" surveys to look for possible sources and phone calls to city officials for personal communication about known PCSs.

Using the LEPC. The Federal Emergency Planning and Community Right-To-Know Act requires facilities using "hazardous chemicals" over established threshold amounts to submit an inventory report to: (1) their local fire department, (2) the Local Emergency Planning Committee (LEPC), and to the State Emergency Response Commission (SERC) (Utah Department of Environmental Quality 2000a). The Utah Department of Environmental Quality is designated by Utah law to receive the chemical inventory reports for the Utah SERC. The function of this chemical inventory is to (Utah Department of Environmental Quality 2000b):

1. Provide local officials with general information about chemicals present in their communities;
2. Assist local emergency planning efforts; and
3. Make facility chemical usage information more accessible to the general public.

The best way to locate facilities in a watershed using and storing "hazardous chemicals" over established threshold amounts is to contact the LEPC and local fire department and ask for this information. The Tier II Chemical Inventory Report Data Summary was examined for any reportable quantities for businesses or facilities in the study watershed. There were a total of 47 facilities reporting within Weber County, but none that were located in the Ogden River basin above Pineview Reservoir.

The Toxic Release Inventory (TRI) was also reviewed for any past releases by companies within the watershed. The TRI is a database providing information concerning releases of certain chemicals into the environment, and transfers to off-site facilities. Facilities using more than established volumes of TRI listed chemicals, report their TRI information annually to the EPA and to the state in which they are located (Utah Department of Environmental Quality 2000). Envirofacts is national information system that provides a single point of access to data extracted from seven major EPA databases (http://www.epa.gov/enviro/index_java.html). This database system along with acquired environmental state agency information can be used to determine if there were any toxic releases within a watershed. This Envirofacts system also allows for multiple queries to search several environmental databases for facility information, including toxic chemical releases, water discharge permit compliance, hazardous waste handling processes, Superfund sites (CERCLA) and standing, and air emissions.

The Envirofacts system and EPA's Region 8 superfund (http://www.epa.gov/region08/superfund/siteinfosf.html) websites were also searched for Superfund or CERCLA sites that are currently active or inactive. The state environmental agency's website was used to download a CERCLA sites list and then searched for any Superfund site within our study area. The state environmental agency's website was also used to review the landfill and closed landfill inventory reports for any current or past landfill operations in the study area. Landfills are sources of contaminated leachate and pose a threat to a drinking water supply.

The underground storage tank and leaking underground storage tank (UST and LUST respectively) lists (PDF files) were checked to find any operation that owned a UST in the study area. These lists can be obtained through a state office such as the department of environmental quality or natural resources. The possible sources in the Ogden River Basin were found using state supplied database information and listed company information from the Utah Department of Environmental Quality, Bureau of Solid & Hazardous Waste, Division of Environmental Response and Remediation. There are many other PCSs that have not been found because of lack of information about the watershed area and the inability to inventory local farmers and private properties for aboveground storage of listed chemicals. The sources that were found were all possible rapid accident or slow leakage contamination sources due to regular storage and use or disposal of gasoline, diesel, or recreation vehicle sewage. All the gas stations, state/city operations and recreation sewage dumps were tanks that are located underground. The gas stations and state/city operations have one or more underground storage tanks (USTs) some of which maybe closed due to past leakage.

Transportation Considerations And Accident Rates

General Trucking. National accident statistics are available online through the U. S. Bureau of Transportation Statistics (http://www.bts.gov/). State accident statistics are most likely available through the state's department of transportation. Accident statistics for the state of Utah were available online from the Utah Department of Transportation's website (http://www.dot.state.ut.us/). The Utah Technology Transfer (T^2) Center at Utah State University (http://www.utaht2.usu.edu/) supplied accident counts for vehicle type, state road, and road class. Accident statistics for trucks with a weight rating of one ton or higher were gathered for the state of Utah for all roads and road classifications (Thompson 2001). These statistics were further limited to the two main roads within the test watershed, state road 39 and 126 and are the most likely to support hazardous substance transportation in and out of the watershed. The Utah Department of Transportation (UDOT) classified the two roads in four different road groups:

1. Class 6: Rural Minor Arterial
2. Class 7: Rural Major Collector
3. Class 14: Urban Other Principal Arterial
4. Class 16: Urban Minor Arterial

The total length of each road in miles was measured using GIS road coverages of the study area and divided by the average truck accidents per year over a 5-year span (1995 to 1999). The accident rates for trucks on each road are in units of accidents/year/mile of road. There was no distinction made between truck cargo load and accident count.

Pipeline. Pipeline accident statistics were obtained through U. S. Department of Transportation, Office of Pipeline Safety (http://ops.dot.gov/). National accident data for pipe transport of hazardous liquids was downloaded as a tab delimited text file for the years of 1986 to present and sorted by state. This data was then divided by the total miles of pipeline in a particular state and, in the specific case of Utah, this data was acquired online through the Utah Division Of Oil, Gas And Mining (http://dogm.nr.state.ut.us/default.HTM). The accident rate for pipelines currently in the database is in units of accidents/year/mile of pipeline in Utah. There was no distinction made between above ground and below ground pipelines.

The SWPAT uses these rates to determine the likelihood of a particular industry or activity to be a significant contamination source to drinking water. These are the default accidents rates for the SWPAT and can be changed by the user to reflect more specific watershed conditions. There is no difference in the accidents rate for steep and winding terrain for both pipelines and truck wrecks, because the data covered number of accidents per state road and not specific location on that road or pipeline.

Principal Findings and Significance

The GIS Spatial Database

Figure 2 shows GIS coverages for the Ogden River Basin watershed that have been collected. Watershed boundaries, DEM, river reach files (rf1 and rf3), roads, and land use shape files are shown. The white triangles are examples of possible contamination sources within the watershed inventoried by the SWPAT user. Some examples of what these white triangles may represent are gas station’s UST, ski area’s diesel storage, or animal feedlots.

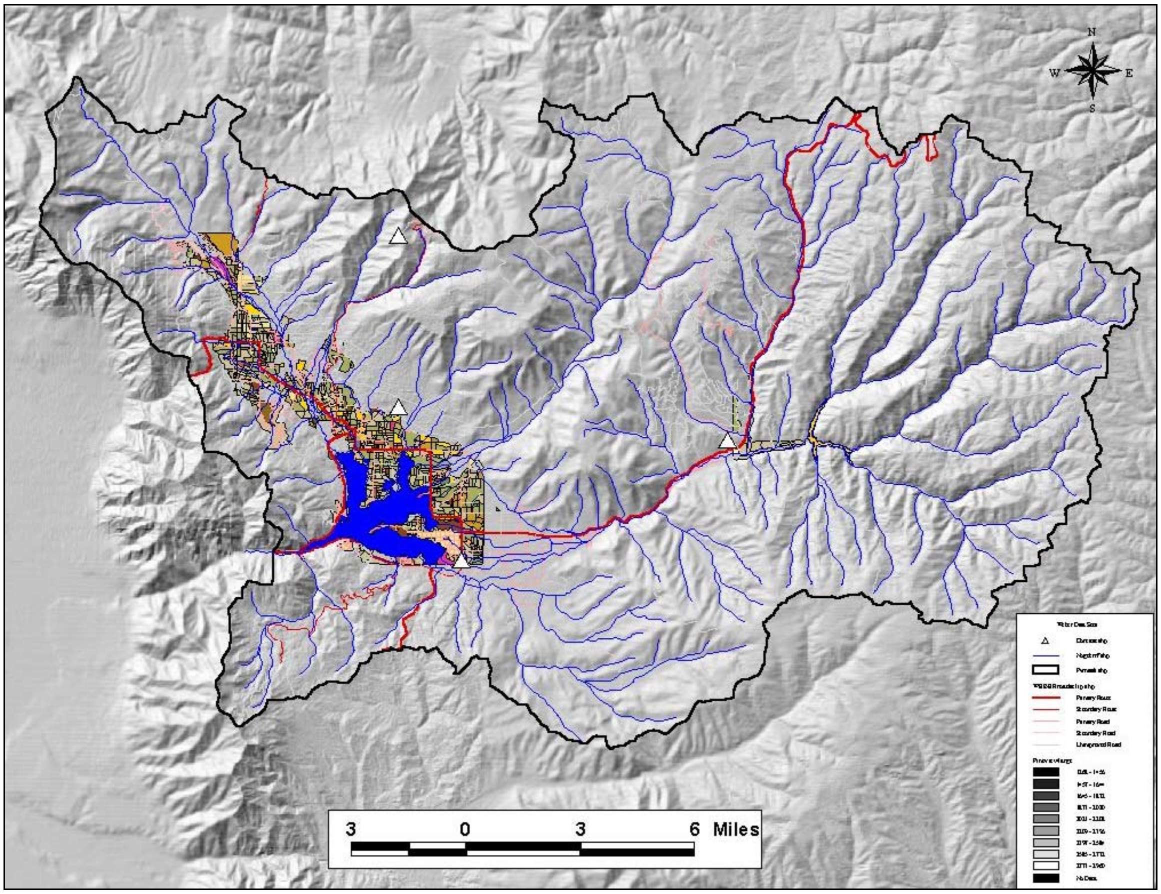


Figure 2. GIS coverages of the Ogden River Basin watershed

The Inventory Database

The default SWPAT database contains physical and chemicals properties for drinking water regulation listed compounds and nutrient and coliform loading rates as well as accident rates for truck wrecks, pipeline, and storage tanks ruptures. These values are used by the SWPAT to calculate the amount of contamination picked up from the ground by surface runoff in a simulated spill. Appendix A shows the physical/chemical properties and common uses for the synthetic organics group of the National Primary Drinking Water listed compounds. Appendix A is one of three tables created to help users of the SWPAT inventory a watershed, as well as to supply the model with contaminant property default information. Appendixes B and C are for volatile organics and inorganics, respectively, and contain the same type of information as appropriate. Table 1 shows different general land uses matched with nutrient loading rates found in the literature. These land uses have been grouped into broad land use categories for simplification.

Table 1. Nutrient loading rates for general land use types

Nutrient Export Coefficient				
Land Use Activity	Total Nitrogen	NO_3-N	Total Phosphorous	Method Used or Comments
Units (kg/ha/yr) unless specified otherwise				
Forest	[1](1.38 - 6.26) [2](3 - 13) [3](*1.008)	[2](1.5 - 4.1) [3](*0.728)	[1](0.019 - 0.830) [2](0.03 - 0.9) 3(*0.369)	-Does not represent extreme storm conditions -*Stream Flow, Little cultivated land
Forested	1.46 - 3.36		0.34 - 0.9	-Does not represent extreme storm conditions -*Stream Flow, Some logging and road construction
Rangeland	[1](0.90)	[1](0.7) 2(*0.628)	[1](0.08) 2(*0.075)	-Does not represent extreme storm conditions - *Primarily grazing, no chemicals added
Agricultural Crop Land	0.1 - 13		0.06 - 2.9	Does not represent extreme storm conditions
Land Receiving Manure	4 - 13		0.8 - 2.9	Does not represent extreme storm conditions
Seepage From Stacked Manure	3			Does not represent extreme storm conditions
Grazed and Pastured Watersheds	(1.48 - 30.85) Mean: 5.19		(0.14 - 4.90) Mean: 1.50	Does not represent extreme storm conditions
Feedlot Runoff	100 - 1,600		10 - 620	Does not represent extreme storm conditions
Animal Feedlot and Manure Storage	(680.5 - 7979.9) Mean: 3110.7		(2.128 - 795.20) Mean: 300.7	Does not represent extreme storm conditions
Urban Watersheds	(1.48 - 38.47) Mean: 9.97		(0.19 - 6.23) Mean: 1.91	Does not represent extreme storm conditions
Urban Land Drainage and Storm Water	[1]('7 - 9) [1](3 - 18 mean= 8)	[1](0.01 - 1.5 mg/L) 2(<1 - 14 mg/L)	[2](1.1 - 5.6) [1](0.27 - 8.5 mean = 2.76) [1](0.63 - 1.65 mean = 1.11)	Does not represent extreme storm conditions
Farmland, Corn and Oats	9.4		7.85E-02	-Does not represent extreme storm conditions - Surface runoff, 173 acre cultivated site
Hay	4.09		0.64	
Corn	11.1		2	
Cotton	10		4.3	
Small Grains	5.3		1.5	

Nutrient Export Coefficient				
Land Use Activity	Total Nitrogen	NO_3-N	Total Phosphorous	Method Used or Comments
Units (kg/ha/yr) unless specified otherwise				
Pasture	^{1}(3.1)	^{2}(0.404)	^{1}(0.1) 2(0.25)	'-Does not represent extreme storm conditions
Alfalfa and Brome Grass		0.24	0.101	'-Does not represent extreme storm conditions
Feedlot Dairy	2900		220	
Idle	3.4		0.1	
Residential	^{1}(7.5) 2(9.98)		^{1}(1.2) 2(*0.897)	- *Soluble P
Business	13.8		30	
Industrial	4.4		3.8	
Continuous Grazing	***2.25		*4.60 **0.03	-* Total P - **Ortho P -*** NH_4^+ - NO_3^- - N
Rotational Grazing	***0.25 - 0.78		*0.3 - 1.30 **0.7 - 0.38	-* Total P - **Ortho P -*** NH_4^+ - NO_3^- - N
Grazed Pasture		*1.30 (0.14 - 3.49) mg/L **0.29 (0.04 - 1.32) mg/L *** 0.42 (0.02 - 1.57) mg/L	*1.27 (0.88 - 2.35) mg/L Soluble P *1.51 (0.95 - 2.94) mg/L Total P **0.54 (0.36 - 1.42) mg/L Soluble P **0.92 (0.57 - 1.99) mg/L Total P ***0.80 (0.62 - 2.31) mg/L Soluble P ***1.26 (1.07 - 3.76) mg/L Total P	- 106 acre fenced pasture, Average annual precipitation is 24.7 inches, pasture drains a watershed of 80.3 acres, slope ranges for 0 - 3 percent, a small 0.27 acre fenced pasture was used as the control (ungrazed), animal stocking rates were between 44 - 57 animal units per month, grazing season from April to November, -*Snowmelt, no livestock, and values are arithmetic means -** Rainfall, livestock, and values are event weighted averages -*** To Rainfall, no livestock, and values are event weighted averages
Ungrazed Pasture (or control area)		*2.57 (0.53 - 5.68) mg/L **3.31 (0.29 - 1.14) mg/L	*3.76 (0.78 - 7.47) mg/L Soluble P *4.09 (0.80 - 7.42) mg/L Total P **4.15 (1.46 - 6.09) mg/L Soluble P **4.72 (1.56 - 7.10) mg/L Total P	- 106 acre fenced pasture, Average annual precipitation is 24.7 inches, pasture drains a watershed of 80.3 acres, slope ranges for 0 - 3 percent, a small 0.27 acre fenced pasture was used as the control (ungrazed), animal stocking rates were between 44 - 57 animal units per month, grazing season from April to November -*Snowmelt, no livestock, and values are arithmetic means -** Rainfall, no livestock and values are event weighted averages

Determining coliform yield from various land uses and assembling the bacteriological data for meaningful application is difficult because of the wide and overlapping ranges of organism counts encountered in snowmelt and rainfall events (Harms, Middaugh et al. 1975). Table 2 was created by compiling coliform concentration data from reported storm or snowmelt runoff event measurements for different land use types. There is a broad range of land use types studied, geographic location, and methods used to measure coliform concentrations in runoff during storm or snowmelt events. To eliminate some of the variability among different studies and land use types, all the data collected during rainfall or snowmelt runoff were grouped into broader land use descriptions. For example, if three studies described their study areas as cornfields, agriculture, and wheat fields, respectively, then they would all be put into the broader group of non-pasture agriculture. Any farming practice that raised agricultural crops was put into this non-pasture agriculture group. Any land use considered to be urban, industrial, or commercial was put into the urban group, and so on for each general land use type seen in Table 2.

Once the broad grouping was completed, the range of coliform concentrations present in surface runoff was separated into high, medium, and low concentration ranges within each group. This was done by taking the $\log_{10}$ of each value collected and taking the lowest value in the range of values as the low level concentration. The value on the upper end of the range became the high value. The median value was the medium. If there was only a high and low value for a group, a medium value was the average of the high and low values. The values were rounded to one significant figure. Table 2 shows anticipated log coliform concentrations in runoff water from various common land uses.

The Graphical Interface

The components of the graphical interface include a main graphical interface, a watershed spatial GIS data input component, and a contaminant source input component. The main interface (Figure 3) allows the user to save his or her input data, to open existing project data files, to activate selected program menus, and to display the input and output data as table or figures.

Table 2. Log$_{10}$ Coliform Loadings Matched with General Land use

	Rainfall/Snowmelt Loading Rates (Log$_{10}$(#/100mL) or Log$_{10}$(CFU/100mL))					
	**Total Coliform			***Fecal Coliform		
Land use	High	Medium	Low	High	Medium	Low
Urban	8	5	2	8	4	2
Confined Animal Feedlot	9	8*	7	8	7*	6
Pasture	6	4	4	5	4	3
Non-Pasture Agriculture	7	4	4	5	3	2
Other (Rangeland)	6	6	4	5	4	0.3

* Calculated medium value
** Domestic Source Criterion 5000/100mL or Log$_{10}$ = 3.7 or 4
*** Domestic Source Criterion 2000/100mL or Log$_{10}$ = 3.3 or 3

After selecting the data menu in the tool bar of the main interface, the user can choose the watershed GIS data file input form from the drop down list (Figure 4). This form includes the watershed DEM file, a hydrography data file input form (Figure 5) (which includes a stream network shape file and a watershed boundary shape file), a climate data file form (which consists of a precipitation grid), a land use and land cover data file form, and a roadways and railways input form. The user can select a data file stored in the computer or a floppy disk, or get data files available in the Internet.

After selecting the input menu in the tool bar of the main interface, the user can choose the watershed contaminant source input menu (Figure 6). This menu allows the user to input their contaminant source data or transportation accident data into the project to be utilized in the scenario modeling.

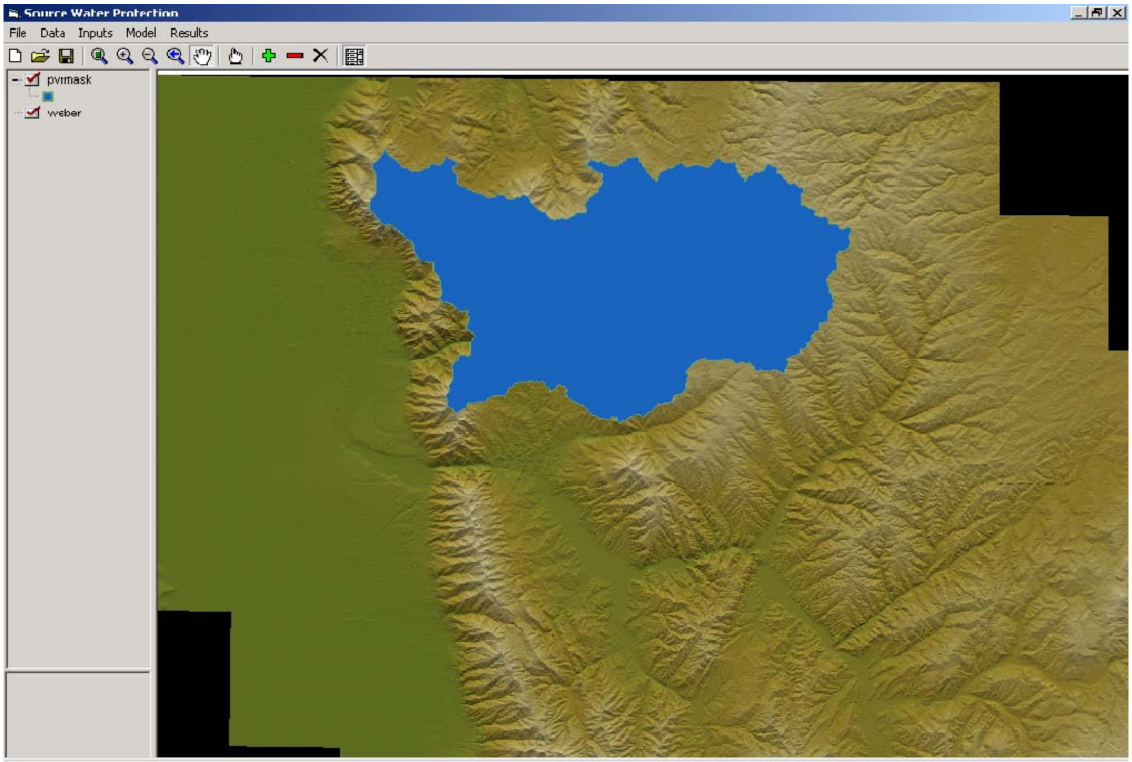


Figure 3. The first page of the main graphical interface.

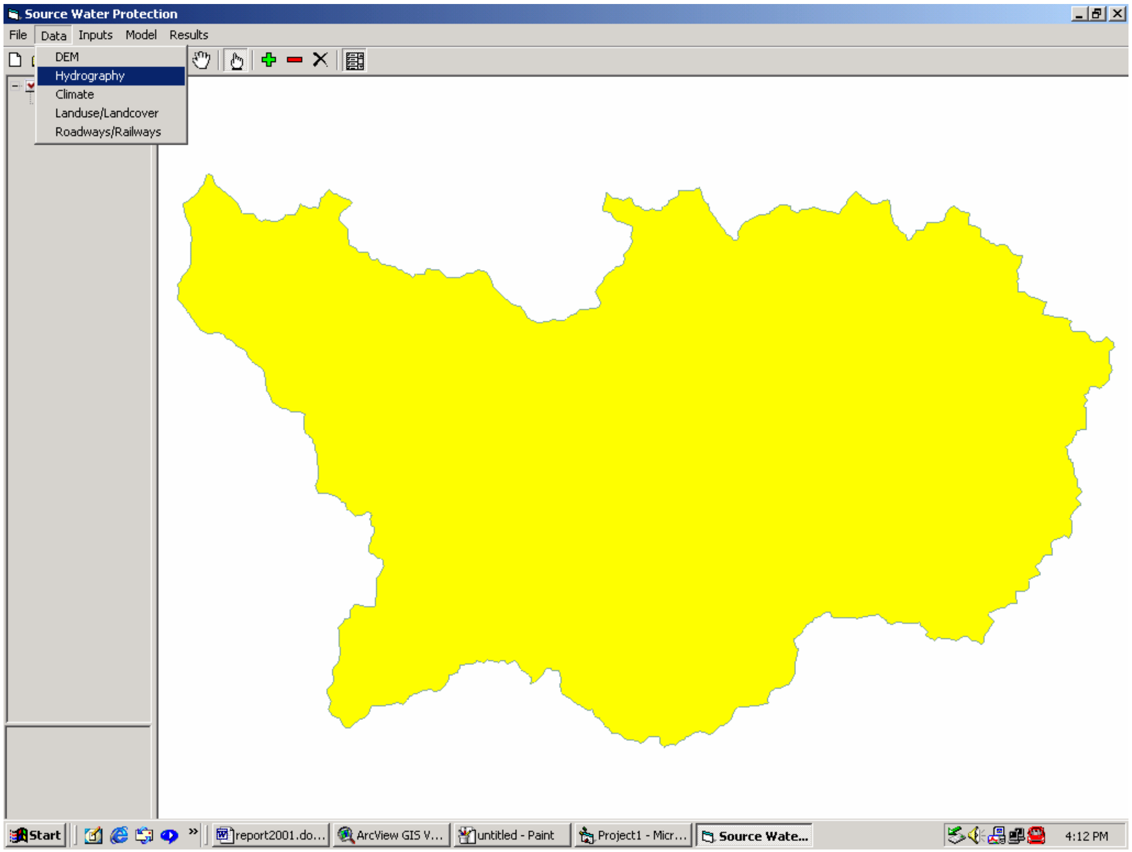
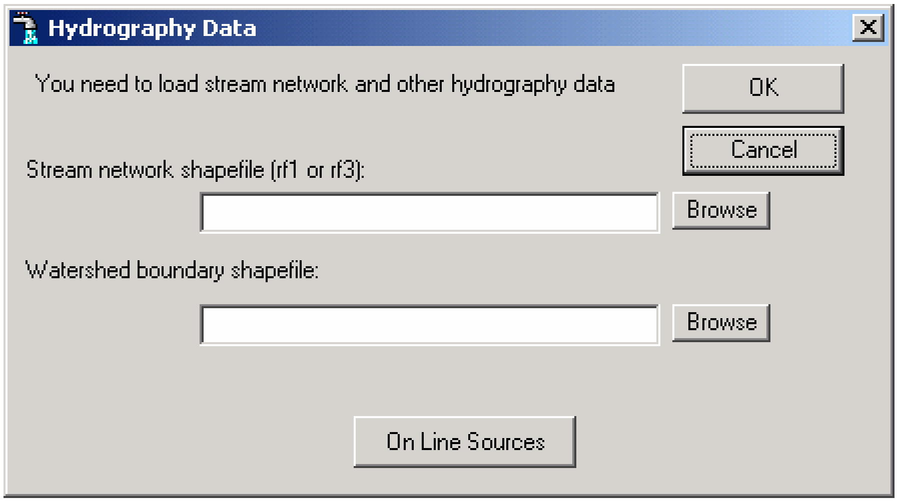


Figure 4. Watershed spatial data input menu.



You need to load stream network and other hydrography data

Stream network shapefile (rf1 or rf3):

Watershed boundary shapefile:

Figure 5. Watershed hydrography data input form

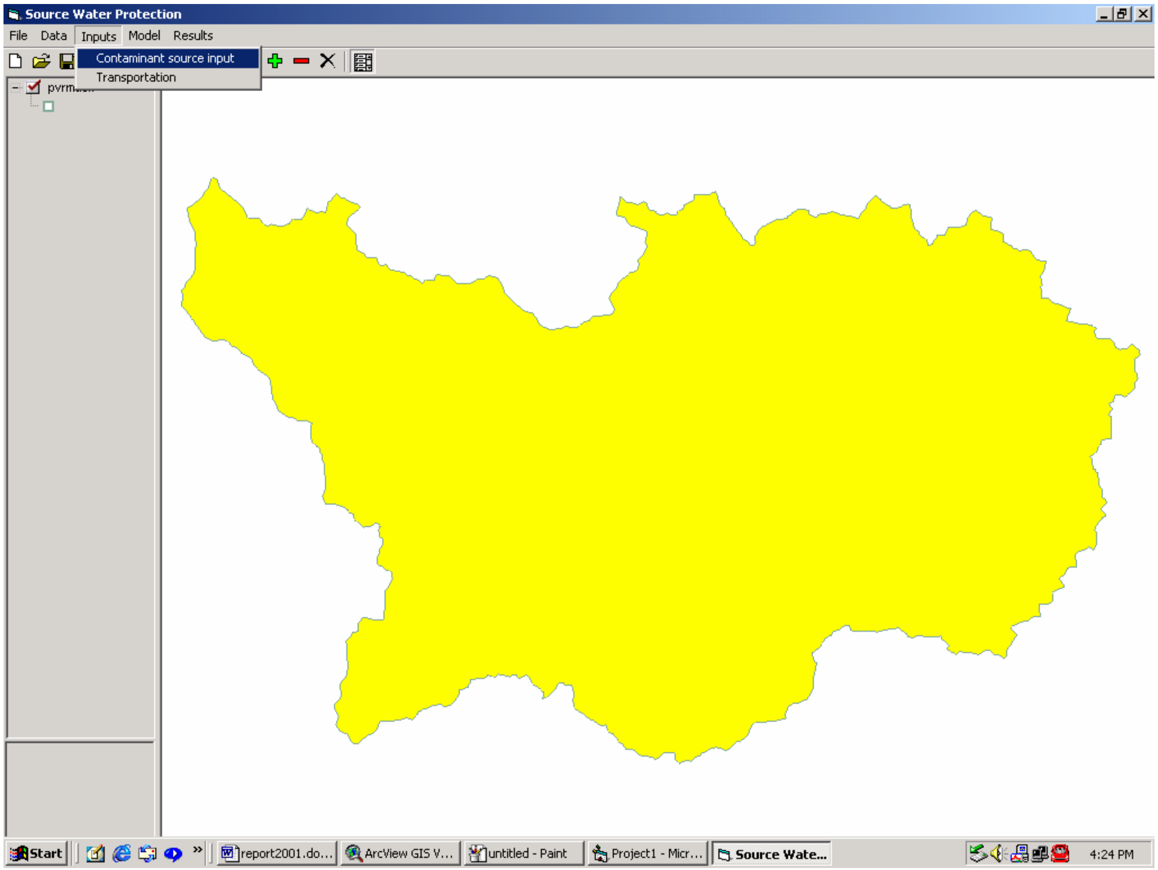
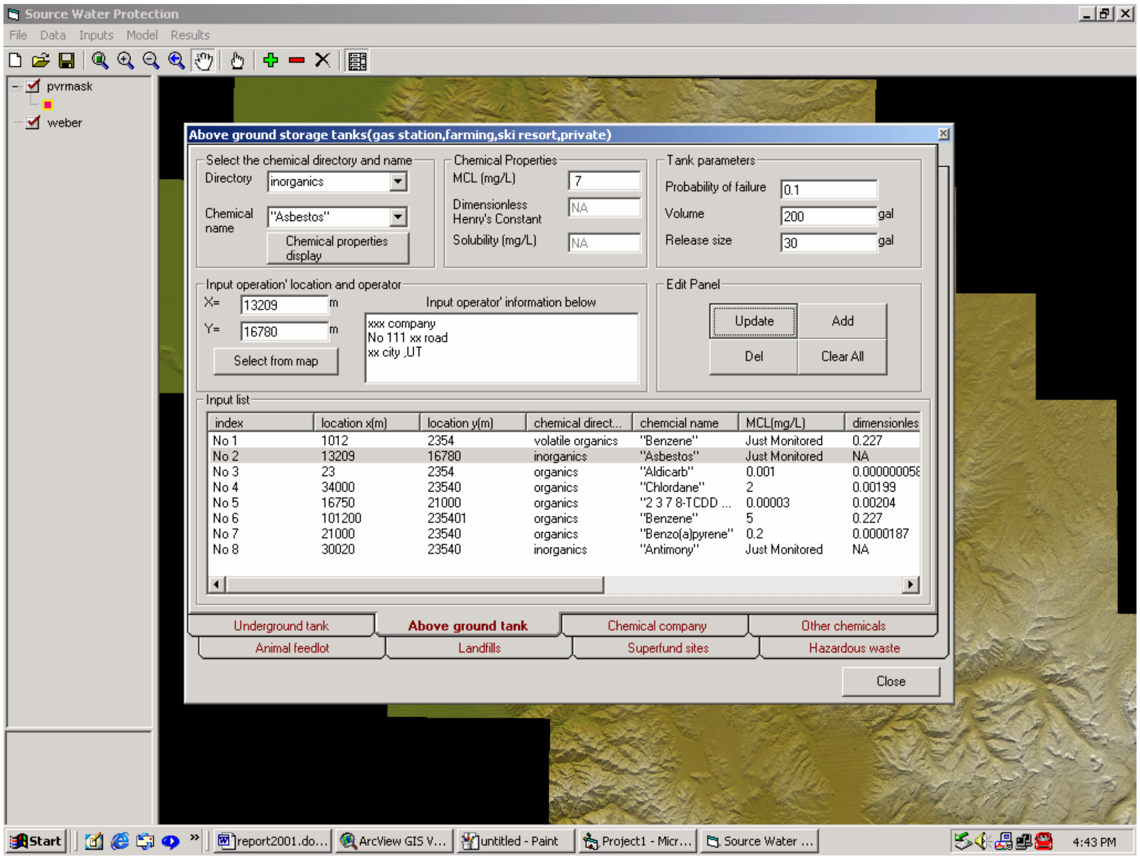


Figure 6. Contaminant source data input form.

The contaminant source input sub-menu allows the user to input 8 different types of the contaminant sources:

1. Underground tank
2. Aboveground tank
3. Chemical company
4. Animal feedlot
5. Landfills
6. Superfund sites
7. Hazardous waste
8. Other chemicals

The input form corresponding to an above-ground tank source is shown in Figure 7. Another type of contaminant input is a transportation accident that spills into a water body producing contamination. Figure 8 shows this input form.



Directory: inorganics

Chemical name: "Asbestos"

MCL (mg/L): 7

Dimensionless Henry's Constant: NA

Solubility (mg/L): NA

Probability of failure: 0.1

Volume: 200 gal

Release size: 30 gal

X= 13209 m

Y= 16780 m

Input operator' information below

xxx company
No 111 xx road
xx city ,UT

index	location x(m)	location y(m)	chemical direct...	chemcial name	MCL(mg/L)	dimensionles
No 1	1012	2354	volatile organics	"Benzene"	Just Monitored	0.227
No 2	13209	16780	inorganics	"Asbestos"	Just Monitored	NA
No 3	23	2354	organics	"Aldicarb"	0.001	0.000000058
No 4	34000	23540	organics	"Chlordane"	2	0.00199
No 5	16750	21000	organics	"2 3 7 8-TCDD ...	0.00003	0.00204
No 6	101200	235401	organics	"Benzene"	5	0.227
No 7	21000	23540	organics	"Benzo(a)pyrene"	0.2	0.0000187
No 8	30020	23540	inorganics	"Antimony"	Just Monitored	NA

Figure 7. Aboveground tank source data input form.

The TauDEM Model: Description of Concept and Programs

Dr. David Tarboton, Professor of Civil and Environmental Engineering, is developing TauDEM (http://www.engineering.usu.edu/cee/faculty/dtarb). For the purposes of the Source Water Protection Assessment project, the TauDEM routines that produce drainage patterns have been incorporated into the main Visual Basic program.

Acknowledgements

These programs have been developed though the course of Dr. Tarboton's research over the years with support from a variety of sponsors, whose support is gratefully acknowledged. Specific sponsors include:

1. Massachusetts Institute of Technology, research assistantship under Rafael Bras, for my Sc.D. research where this all got started. Some remnants of the code from this work still remain.

2. National Science Foundation grant EAR-9318977 for the development of the D¥ approach (Tarboton, D. G., 1997).

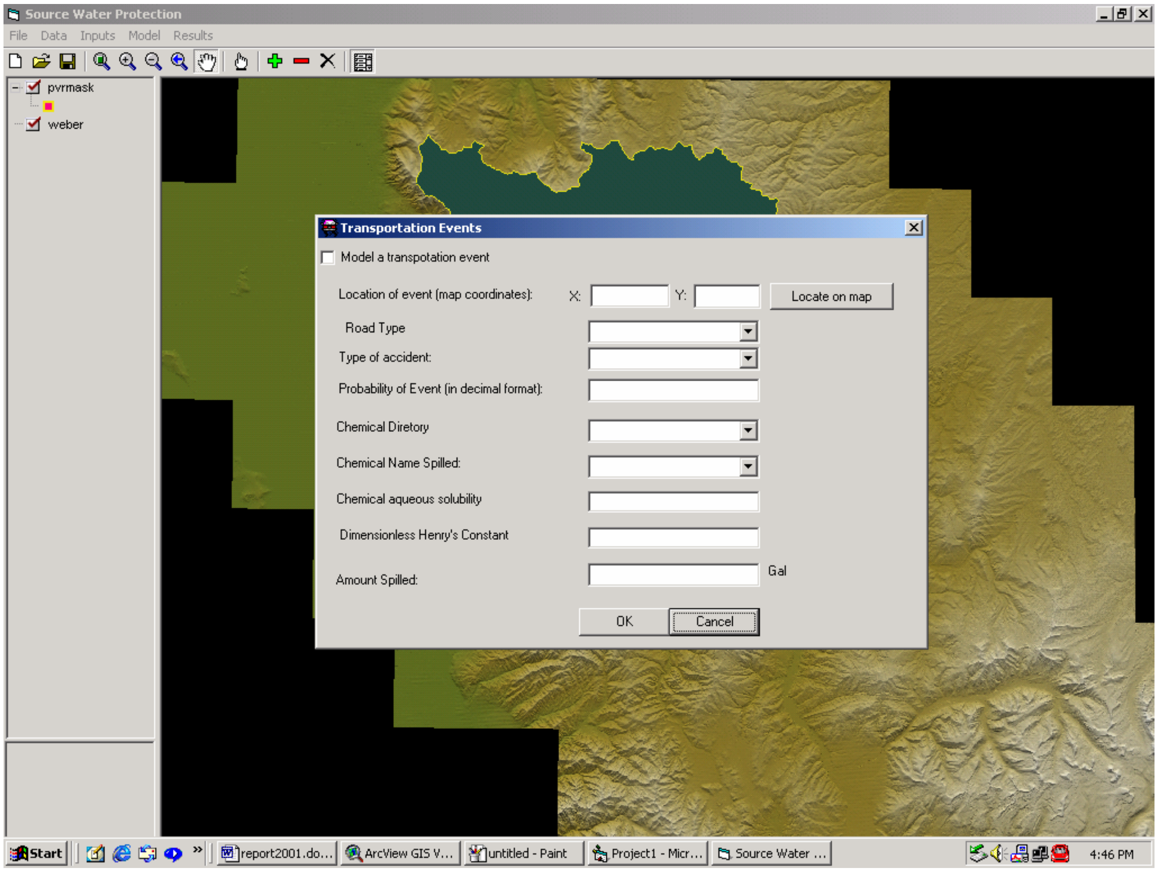


Figure 8. Transportation accident source data input form.

3. Forest Renewal of British Columbia, for the development of Terrain Stability Mapping methodology and Arcview Implementation, in a collaborative project involving Canadian Forest Products Ltd., Vancouver, British Columbia, Terratech Consulting Ltd., British Columbia (Bob Pack), and Craig Goodwin.

4. National Science Foundation grant INT-9724720 and NIWA New Zealand for the work on methods for mapping and identification of flow methods from digital elevation data.

5. Idaho National Engineering and Environmental Laboratory for work on the adaptation of these codes for use with the TMDL Toolkit, and integration of flow with existing channel networks.

Data Storage Structures

The data storage structures available to digitally encode topography in TauDEM comprise:

1. Grid Digital Elevation Models (DEMs);
2. Triangular irregular networks (TINs); and

3. Contour based storage structures.

Grid DEMs consist of a matrix data structure with the topographic elevation of each pixel stored in a matrix node. TINs store the X-Y location as well as elevation at irregularly spaced nodes. Contour based data structures store vector data along contour lines. Grid DEMs are readily available and simple to use and hence have seen widespread application to the analysis of hydrologic problems. Slope, flow directions, and contributing area are the primary hydrologic quantities derived from DEMs. Other useful quantities are derived from these three. Here grid DEM are used due to their availability and simplicity. The grid DEM processing routines used are based upon methods described by O'Callaghan and Mark (1984), Marks et al. (1984), Band (1986), Jenson and Domingue (1988), Tarboton (1989, 1997) and Garbrecht and Martz (1997). The steps involved are: (1) Pit filling corrections, (2) Computation of slopes and flow directions; (3) Computation of contributing area and specific catchment area and (4) Channel network extraction and computation of other quantities.

Pit Filling Corrections

Pits in digital elevation data are defined as grid elements or sets of grid elements surrounded by higher terrain that, in terms of the DEM, do not drain. These are rare in natural topography and generally assumed to be artifacts arising due to the discrete nature and data errors in the preparation of the DEM. They are eliminated here using a ‘flooding’ approach. This raises the elevation of each pit grid cell within the DEM to the elevation of the lowest pour point on the perimeter of the pit .

Slopes and Flow Directions

Working with grid DEMs slope may be computed as the difference in elevation between two adjacent cells divided by the distance between them. In dealing with flow this is usually done in a forward downwards direction. The slope associated with a cell is the slope from the cell to a downslope neighbor. This makes sense because it is where water will go. Radiation computations sometimes use slope based upon central finite difference methods. The earliest and simplest method for specifying flow directions is to assign flow from each grid cell to one of its eight neighbors, either adjacent or diagonally, in the direction with steepest downward slope. This method, designated D8 (8 flow directions), was introduced by O'Callaghan and Mark (1984) and has been widely used. The D8 approach has disadvantages arising from the discretization of flow into only one of eight possible directions, separated by 45°. These have motivated the development of other methods comprising multiple flow direction methods , random direction methods and grid flow tube methods . Tarboton (1997) discusses the relative merits of these.

In the D¥ method, the flow direction angle measured counter clockwise from east is represented as a continuous quantity between 0 and 2p. This angle is determined as the direction of the steepest downward slope on the eight triangular facets formed in a 3 x 3 grid cell window centered on the grid cell of interest as illustrated in Figure 9. A block-centered representation is used with each elevation value taken to represent the elevation of the center of the corresponding grid cell. Eight planar triangular facets are formed between each grid cell and its eight neighbors.

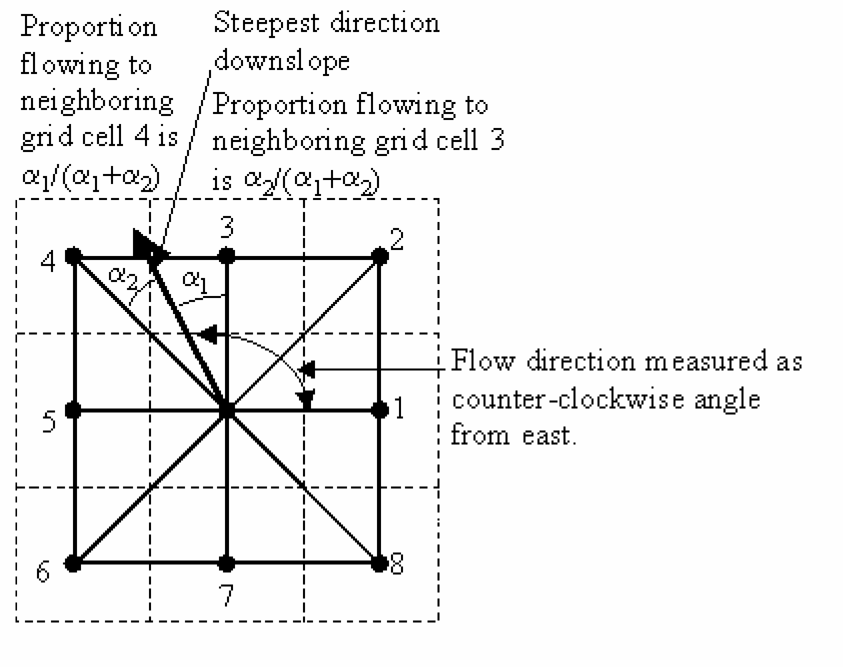


Figure 9. Flow direction defined as steepest downward slope on planar triangular facets on a block centered grid.

Each of these has a downslope vector which when drawn outwards from the center may be at an angle that lies within or outside the 45o (p/4 radian) angle range of the facet at the center point. If the slope vector angle is within the facet angle, it represents the steepest flow direction on that facet. If the slope vector angle is outside a facet, the steepest flow direction associated with that facet is taken along the steepest edge. The slope and flow direction associated with the grid cell is taken as the magnitude and direction of the steepest downslope vector from all eight facets. This is implemented using equations given in Tarboton (1997).

In the case where no slope vectors are positive (downslope), the flow direction is set using the method of Garbrecht and Martz (1997) for the determination of flow across flat areas. This makes flat areas drain away from high ground and towards low ground. The D¥ method is preferred for the computation of flow directions on hillslopes where D8 grid bias is significant the the calculation of specific catchment area. D8 is still used for the definition of channel networks because we can not (have not yet learned to) work with channel networks that bifurcate in a downwards direction

Contributing Area

Upslope area (counted in terms of the number of grid cells) is calculated for both single and multiple flow directions using a recursive procedure that is an extension of the very efficient recursive algorithm for single directions (Mark, 1988). The upslope area of each grid cell is taken as its own area (one) plus the area from upslope neighbors that have some fraction draining to it. The flow from each cell either all drains to one neighbor, if the angle falls along a cardinal

(0, p/2, p, 3p/2) or diagonal (p/4, 3p/4, 5p/4, 7p/4) direction, or is on an angle falling between the direct angle to two adjacent neighbors. In the latter case the flow is proportioned between these two neighbor pixels according to how close the flow direction angle is to the direct angle to those pixels, as illustrated in Figure 1. Specific catchment area, a, is then upslope area per unit contour length, taken here as the number of cells times grid cell size (cell area divided by cell size). This assumes that grid cell size is the effective contour length, b, in the definition of specific catchment area and does not distinguish any difference in contour length dependent upon the flow direction.

The contributing area programs check for edge contamination. This is defined as the possibility that a contributing area value may be underestimated due to grid cells outside of the domain not being counted. This occurs when drainage is inwards from the boundaries or areas with no data values for elevation. The algorithm recognizes this and reports no data for the contributing area. It is common to see streaks of no data values extending inwards from boundaries along flow paths that enter the domain at a boundary. This is the desired effect and indicates that contributing area for these grid cells is unknown due to it being dependent on terrain outside of the domain of data available. The edge contamination checking may be overridden with an option in the River Network and Watersheds/Method Options form in cases where you know this is not an issue or want to ignore these problems, if for example the DEM has been clipped along a watershed outline.

Channel Networks

When a map of contributing area is viewed using a threshold, the channel networks stand out as those cells with contributing area greater than a threshold of contributing area. It is an issue to decide the most appropriate threshold, or whether some other quantity such as slope should be part of the threshold. This is discussed at length in Tarboton et al. (1991, 1992). One approach that has some theoretical justification is to look for a break in the plot of slope versus contributing area. Once a threshold has been established the channel network can be defined (mapped) as all those grid cells with contributing area greater than the threshold.

Data Formats

Grid data. The programs are written to directly access the ESRI binary grid format accessible through the gridio application programmers interface that is part of Spatial Analyst (version 1.0a or higher) with ArcView (version 3.0a or higher). This capability is only available if you have one of these softwares installed on your computer. The programs can also access ASCII grid data files in the format used by ESRI for export of files from ArcView and Arc/Info and a direct access binary grid format we have defined. The ASCII grid data file format comprises a few lines of header data followed by lists of cell values. The header data includes the following keywords and values:

ncols – number of columns in the data set.
Nrows – number of rows in the data set.
Xllcenter or xllcorner – x-coordinate of the center or lower-left corner of the lower-left cell.
Yllcenter or yllcorner – y-coordinate of the center or lower-left corner of the lower-left cell.

Cellsize – cell size for the data set.
Nodata_value – value in the file assigned to cells whose value is unknown. This keyword and value is optional. The nodata_value defaults to –9999.

For example,

```
ncols 480
nrows 450
xllcorner 378923
yllcorner 4072345
cellsize 30
nodata_value –32768
43 3 45 7 3 56 2 5 23 65 34 6 32 etc
35 45 65 34 2 6 78 4 38 44 89 3 2 7 etc
etc
```

The first row of data is at the top of the data set, moving from left to right. Cell values should be delimited by spaces. No carriage returns are necessary at the end of each row in the data set. The number of columns in the header is used to determine when a new row begins. The number of cell values must be equal to the number of rows times the number of columns.

Grid naming convention. The following default naming convention is suggested and used by the programs with command line input. Any file names may be used with interactive input, but I suggest sticking to this convention to avoid confusion. File names are:

nnnnsss[.asc]

where *nnnn* comprises the name of the dataset. Maximum length is operating system dependent. sss comprises the suffix used to designate the data type as follows:

no suffix.	Elevation data.	
fel	Pit filled elevation data.	produced by flood
p	D8 drainage directions.	produced by D8 flow dir
sd8	D8 slopes.	produced by D8 flow dir
ad8	D8 contributing area's, units are number of grid cells.	produced by D8 drainage area
slp	Dinf slopes.	produced by Dinf flow dir
ang	Dinf flow directions.	produced by Dinf flow dir
sca	Dinf contributing area's, units are specific catchment area, i.e. number of grid cells times cell size.	produced by Dinf area
plen	Longest path length to each grid point along D8 directions.	produced by Gridnet
tlen	Total path length to each grid point along D8 directions.	produced by Gridnet

gord	Strahler order for grid network defined from D8 flow directions.	produced by Gridnet
src	Network mask based on channel source rules.	produced by RiverNetwork Raster
ord	Grid with Strahler order for mapped stream network.	produced by River Network Raster
w	Subbasins mapped using subbasinsetup.	produced by Create Network and Sub-Watersheds
fdr	Flow directions enforced to follow the existing stream network	produced by Convert Connected Reach Network to Forced Flow Direction Grid
fdrn	Flow directions enforced to follow the existing stream network after cleaning to remove any loops	produced by flood

The *.asc* extension is used if the data is ASCII. The *.bgd* extension is used for a direct access binary grid file. Otherwise it is assumed to be ESRI's proprietary grid format and accessed using the gridio library supplied with ArcView.

Vector Data. The following files are used to represent channel networks.

Network connectivity file, nnnntree.dat.

This is essentially a list of links comprising a channel network. It is text with 7 columns as follows:

1 LINK NUMBER
2 START POINT NUMBER IN COORD
3 END POINT NUMBER IN COORD
4 NEXT (DOWNSTREAM) LINK NUMBER IN CNET
5&6 PREVIOUS (UPSTREAM) LINK NUMBERS IN CNET
7 STRAHLER ORDER OF LINK IN CNET

This file is produced by the 'Create Network and Sub-Watersheds'command. The second and third columns refer to point coordinates, vectors along each link, from upstream to downstream, stored on the network coordinate, or 'coord.dat', file.

Network coordinate file, nnnncoord.dat.

This is a list of coordinates defining the points along each channel link. It is text with 5 columns of data as follows:

1 X COORDINATE (metres)
2 Y "
3 DISTANCE ALONG CHANNELS TO GAUGE (metres or whateve units grid size is in)

4 ELEVATION (metres or whateve units the DEM is in)
5 CONTRIBUTING AREA (meter2 or whatever units grid size is in)

This file is produced by the 'Create Network and Sub-Watersheds'command. The coordinates are based on the coordinate system (and projection) implicit in the header bounding box information in the raster grid file. Coordinates are the centers of grid elements (pixels) corresponding to each channel network link. This file is only useful in conjunction with the 'tree' file which gives the start and end position (line or record) in this file of each channel network link.

Shape Files. This is an open ESRI data format that stores vector data in DBF files. It is described in a white paper. TauDEM reads EPA reach files in Shape file format to enforce flow directions to follow existing streams where desired. TauDEM also outputs the delineated channel network and reach subwatersheds in Shape file format. The header information in these files is designed to be self explanatory.

Operation of the Programs Included in TauDEM

TauDEM is launched as is common from the Start/programs button, or from a shortcut.

File Menu Options. Prepare Connected Reach Network From Shape File: This launches a 'Network Builder' form that will take any polyline shape file and build a connected reach network file.

Select Existing Connected Reach Network File. This MUST have as input a reach file created previously by the 'Network Builder".

DEM Menu Options. Do all preprocessing. This runs the commands given below in sequence:

<u>*Convert Connected Reach Network to Forced Flow Direction Grid*</u>. This takes as input a network river reach file from the network builder and outputs a grid of flow directions along the rivers to enforce drainage along delineated river channels. These flow directions are in a file with suffix 'fdr' and are used by Flood if the option to use them under River Network and Watersheds/Method Options is set.

<u>*Flood*</u>: This takes as input an elevation data grid and outputs a grid file 'fel' with pits filled, using the flooding algorithm. The river flow enforcement direction grid is an optional input, and if input, pits will be filled consistent with drainage along existing streams.

<u>*D8 flow dir*</u>: This takes as input pit filled elevation data file 'fel' and outputs D8 flow directions 'p' and slopes 'sd8' for each grid cell. The following coding is used for direction of flow from a pixel to ONE of its eight neighbors:

4	3	2
5		1
6	7	8

In flat areas flow directions are assigned away from higher ground and towards lower ground using the method of Garbrecht and Martz (1997). The river flow enforcement direction grid is an optional input, and if input, directions will be set consistent with drainage along existing streams.

Dinf flow dir: The Dinf approach assigns a flow direction based on steepest slope on a triangular facet (Tarboton, 1997). This is saved as an angle ‘ang’ in radians anti-clockwise from east. In flat areas the D8 flow directions are converted to angles and used. The river flow enforcement direction grid is an optional input, and if input, directions will be set consistent with drainage along existing streams.

D8 drainage area: This takes as input a D8 flow directions file ‘p’ and outputs the contributing area. The result is the number of grid cells draining through each grid cell. By default the program checks for edge contamination. The edge contamination checking may be overridden with an option in the River Network and Watersheds/Method Options form.

Dinf drainage area: This takes as input a Dinf angle file ‘ang’ and outputs the specific catchment area. Specific catchment area is defined as contributing area per unit contour length. Here the contour length is taken as the grid cell size. The result has length units the same as grid cell size. By default the program checks for edge contamination. The edge contamination checking may be overridden with an option in the River Network and Watersheds/Method Options form.

Gridnet: This takes as input a D8 flow directions file 'p' and outputs three grid files:

'*plen*' Each grid cell contains the path length from the furthest cell that drains to each cell.

'*tlen*' Each grid cell contains the total length of all paths draining to each cell.

'*gord*' Each grid cell contains the Strahler order associated with that cell for a flow network defined using the D8 flow directions and including each grid cell. Strahler order is defined as follows. Cells that don't have any other grid cells draining in to them are order 1. When two (or more) flow paths of different order join the order of the downstream flow path is the order of the highest incoming flow path. When two (or more) flow paths of equal order join the downstream flow path is increased by 1. Algorithmically this is implemented as:

Order = Max(Highest incoming flow path order, Second highest incoming flow path order + 1)

These outputs are used by netsetup in some of the options for mapping channel networks.

River Networks and Watersheds Menu Options

Do all watershed delineation steps: This runs the commands given below in the correct sequence.

Specify outlets: Brings up a form that allows you to click on the map to identify outlets.

Method Options: This brings up a form to toggle various method options and control network delineation methods.

River Network Raster (Full): This uses the network delineation parameters to define a grid of the river network, useful for identifying outlets. Valid outlet points are only those on the 'src' grid produced here.

River Network Raster (Upstream of Outlets): This uses the network delineation parameters to define a grid of the river network, upstream of the outlets. This is necessary for the creation of networks and subwatersheds.

Create Network and Sub-Watersheds: This converts the grid of river network cells into a shapefile with attributed for each reach. Local watersheds draining to each reach are also delineated as a grid and shape file.

Drop Analysis: This brings up a table of stream drops useful for identifying the correct channel network identification threshold.

Plans for Project Completion

GIS based contaminant fate and transport models will continue to be developed. Models will simulate the movement of distributed, non-point source contaminants (e.g., coliforms, nitrate) under "average" steady state conditions. Contaminant transport from spills or releases will be simulated under both average and reasonable worst case hydrologic conditions. Spills or releases from transportation accidents, industrial accidents, agricultural sources, and construction sources will be considered. Some specific goals to be accomplished are listed below:

- Integration of TuaDEM COM function within the SWPAT
- Coding and conversion of Areadinfdecay, Dependence, and Dsaccum to COM functions
- Continued development of the Visual Basic user interface including an online data source function for the water shed spatial data.
- Continued development of USU GIS map-objects window and graphical functionality
- Ranking of EPA's National Primary Drinking Water Regulation listed compounds with respect to human toxicity and carcinogenicity
- Development of SWPAT sediment and groundwater transport modeling capabilities
- Development of surfacewater/groundwater (conjunctive source) interactions as a source on pollution transport

On-Site Wastewater Treatment Database Evaluation

Drainfields and other systems used to treat and dispose of septic tank effluents may discharge into ground water. The effectiveness of these treatment systems in removing pathogens, nitrate, and other chemical contaminants sufficiently to allow other beneficial uses including drinking water, is highly variable. Effective treatment depends on appropriate design and installation of the system relative to site and soil properties including depth to ground water. The number and distribution (density) of these systems in watersheds supplying drinking water is critical to source water protection. With few exceptions, there is little information available about on-site wastewater treatment system density in Utah watersheds. Information about relatively recent installations of these systems has been collected by local health departments but is not available to environmental managers in formats, such as GIS maps, that are readily usable. Records do not exist for many older systems. Appropriate source water protection management requires information about on-site wastewater systems including their location, size, and functionality.

Commercially available on-site wastewater treatment management software (e.g., Septic Information Management System (SIMS), Stone Environmental, Inc., Montpelier, VT; Septic System Tracking Lite, Groundwater Database, Inc., Belleville, Ontario) provide an opportunity to capture on-site wastewater treatment information in a GIS compatible format making it readily usable and easy to interpret by environmental managers. Available database programs have been evaluated for cost effective use in Utah. Special attention is being paid to evaluating the use of these database programs in source water assessments and how they might be incorporated into the Bayesian network system.

On-Site Wastewater Database Evaluation

The need for a current and efficient means of inventorying current on-site wastewater treatment (i.e., septic) systems has been recognized in Utah. Each health department is the source of data for those required to submit reports for the Source Water Assessment.

A database was determined the best means to an efficient and up-to-data inventory of Utah's on-site wastewater treatment systems. The initial criteria determined for a database were:

- Appropriate for the users' needs,
- Sufficient working and storage capacity,
- User friendly,
- Ability to download data from existing electronic files,
- Ability to link to other databases,
- Ability for the software to be upgraded,
- Ability to have one central database manager, and
- Ability for regular-interval input of new data.

Questions that arose during this investigation were:

- What economic resources are available for this?
- How do we know that each health department will "buy" into this?
- How much can each health department afford?
- Should a central system be implemented with all the health departments linked to it, or
- Should each health department be autonomous with their data?
- If each health department is autonomous, how will the data be accessible to potential users outside of the health department? Will it be accessible on the Internet?
- Should commercial software be purchased or should an in-house program be written using available software (e.g., Oracle or Access)?

- What will be the health department's future needs?
- What database will best suit their needs 15 (and more) years from now?

Several health departments in Utah were interviewed to determine their needs. A prototype database has been constructed and that database will be presented to each health department for its evaluation. The evaluations will be summarized and the needs of the health departments will be prioritized.

The procedure for locating existing databases was via the Internet and through the National Small Flows Clearinghouse (www.nsfc.wvu.edu). Several databases were recognized as potential inventory systems. The septic system database programs considered include:

- Septic Information Management System (SIMS) by Stone Environmental, Inc., Montpelier, VT.
- Computer Aided Septic System Tracking (CASST) by AppliTech, Inc., Dallas, TX.
- SS Tracking Lite by WaterWeb Database, Inc. by Waterweb Groundwater Database, Inc., Belleville, Ontario, Canada.
- The Teton Survey for the Idaho National Engineering and Environmental Laboratory (INEEL) which is an Excel spreadsheet, and
- CAMEO by the U.S. EPA National Service Center for Environmental Publications, Cincinnati, OH.
- An database program written in Access by the Whatcom County Health and Human Services, Bellingham, Washington

Contact information for current users of the available database systems were obtained. With the exception of the Whatcom County database, no users were currently applying the database they owned to their needs. Insufficient information from users was available to make an evaluation. The CASST software was eliminated because of non-Utah specific data fields that would be costly to tailor to the Utah users' needs. The SIMS software was not in use in North America to evaluate its performance. The Teton Survey for the INEEL was solely an inventory and not a database for the purpose of conducting an inventory. CAMEO was did not fit the Utah user's needs. SS Tracking Lite may have been a candidate were it not for the uncertainty of the potential costs to the user.

Finally, it was determined to write an Access-based database inventory program for the Utah user, similar to the Whatcom County database program. A prototype of that program is now functional. The next step for the application of this program is to present it to the health departments for their respective input.

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APPENDIX A

Synthetic Organic Contaminants Pesticides/PCB/SOC
Common Uses & Chemical Properties

<table>
<tr><th colspan="12">Synthetic Organic Contaminants Pesticides/PCB/SOC Common Uses & Physical Properties</th></tr>
<tr><th>Compound (organic)</th><th>MCL (mg/L)</th><th>MW (g/gmol)</th><th>VP (mmHg)</th><th>Solubility (mg/L)</th><th>H (atm m^3/mol)</th><th>Air/Water = H/RT (@25°C)</th><th>Log K_{ow}</th><th>K_d</th><th>K_{oc} (mL/g)</th><th>Aerobic Soil Half Life (days)</th></tr>
<tr><td rowspan="2">Alachlor</td><td>2</td><td>269.77</td><td>2.20E-05</td><td>240</td><td>8.32E-09</td><td>3.40E-07</td><td>2.9</td><td>0.88</td><td>130</td><td>21</td></tr>
<tr><td colspan="10">Herbicide for grasses & broadleaf weeds on corn & sorghum, soybeans, peanuts, cotton, vegetables, forage crops. It is a selective pre and early post emergence herbicide for annual broadleaf control in crops such as beans, beets, cabbage, corn, cotton, ornamentals, peanuts, peas, potatoes, sorghum, soybeans, sugarcane, sunflowers, and tobacco. Selective systemic herbicide for control of most annual grasses and many broad leaved weeds in maize, sorghum, groundnuts, soya beans, lima beans, oilseed rape, brassicas, radish, oil radish, cotton, sunflowers, sugar cane, potatoes, peas, tobacco, some ornamentals.
1. Manufacture and use as a herbicide</td></tr>
<tr><td rowspan="2">Aldicarb</td><td>0.001</td><td>190.25</td><td>3.47E-05</td><td>6030</td><td>1.44E-09</td><td>5.89E-08</td><td>1.13</td><td>0.15</td><td>19</td><td></td></tr>
<tr><td colspan="10">Soil application for control of chewing & sucking insects (esp aphids, whiteflies, leaf miners, & soil-dwelling insects), spider mites, & nematodes in glasshouse & outdoor ornamentals, sugar beet, fodder beet, strawberries, potatoes, onions, hops, vine nurseries, tree nurseries, groudnuts, soya beans, citrus fruit, bananas, coffee, sorghum, pecans cotton, sweet potatoes & other crops. Temik is used only as soil application to control certain insects, mites, and nematodes on citrus (grapefruit, lemons, limes, oranges only), cotton, dry beans; pecans (southeast only); sugarcane (Louisiana only). Aldicarb is effective in reducing the foraging of skylarks in sugar-beet fields in the United Kingdom. Terrestrial Non-Food Uses with Rates (l lb active ingredient): Birch, 5.0-10.0; dahlias, 5.0-8.0; holly, 5.0-10.0; lilies (bulbs), 5.0-7.0; and roses, 7.0-10.0. Commercial Greenhouse Uses with Rates (l lb active ingredient): Carnations, 7.5-10.0; chrysanthemum, 7.5-10.0; easter lilies, 5.0-7.5; gernera. 5.0-10.0; orchids, 7.5-10.0; poinsettia, 7.5-10.0; roses, 5.0-10.0; snapdragons, 5.0-10.0.
1. Used as an insecticide, acaricide, and nematocide. Release of aldicarb to the environment will occur due to its manufacture and use as a systemic insecticide, ascaricide and nematocide for soil use.</td></tr>
<tr><td>Aldicarb Sulfoxide</td><td>0.001</td><td>206.25</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Synthetic Organic Contaminants Pesticides/PCB/SOC Common Uses & Physical Properties

Compound (organic)	MCL (mg/L)	MW (g/gmol)	VP (mmHg)	Solubility (mg/L)	H (atm m^3/mol)	Air/Water = H/RT (@25°C)	Log K_{ow}	K_d	K_{oc} (mL/g)	Aerobic Soil Half Life (days)
	Aldicarb is applied to the soil for control of chewing & sucking insects (aphids, whiteflies, leaf miners, soil-dwelling insects), spider mites, and nematodes. It is used in glasshouse & outdoor ornamentals, and on the following crops; cotton, sugar beet, fodder beet, strawberries, potatoes, onions, hops, vine nurseries, tree nurseries, groundnuts, soya beans, citrus fruit, bananas, coffee, sorghum, pecans, sweet potatoes & other crops. Cotton crops account for 83% of aldicarb use. 1. Release of aldicarb to the environment will occur due to its manufacture and use as a systemic insecticide, acaricide and nematocide for soil use.									
Aldicarb Sulfone	0.001	222.3	9.00E-05	1.00E+04	3.37E-09	1.38E-07	-0.57		3	
	Effective against nematode, insect, and mite pest of tobacco, cotton, and peanuts. Containerized honey locust trees (Commercial Use Only) to control honey locust gall midge 1. Used as a soil application by banding and incorporating , in transplant water (tobacco) or as a seed treatment (cotton).									
Atrazine	3	215.68	2.89E-07	34.7	2.36E-09	9.65E-08	2.61	0.75	70	146
	Atrazine is a widely used selective herbicide for control of broadleaf & grassy weeds in corn, sorghum, rangeland, sugarcane, macadamia orchards, pineapple, & turf grass sod. It is used also in some areas for selective weed control in conifer reforestation & christmas tree plantation as well as for nonselective control of vegetation in chemical fallow. Atrazine also is used as a nonselective herbicide for vegetation control in non-crop land. Selective pre- & post-emergence herbicide used in asparagus, forestry, grasslands, grass crops, roses. Crisazina pre and early postemergence on african oil palm, bananas, citrus groves, coffee, corn, pineapples, sorghum, sugarcane. 1. Used herbicide for control of broadleaf and grassy weeds. Atrazine may be released to the environment in wastewater from manufacturing facilities and through its use as a herbicide.									
Benzo(a)pyrene	0.2	252.31	5.49E-09	0.00162	4.57E-07	1.87E-05	6.13		5.07E+06	

Synthetic Organic Contaminants Pesticides/PCB/SOC Common Uses & Physical Properties										
Compound (organic)	**MCL (mg/L)**	**MW (g/gmol)**	**VP (mmHg)**	**Solubility (mg/L)**	**H (atm m^3/mol)**	**Air/Water = H/RT (@25^{o}C)**	**Log K_{ow}**	**K_d**	**K_{oc} (mL/g)**	**Aerobic Soil Half Life (days)**
	Benzo(a)pyrene, or BaP, is one of a group of compounds called polycyclic aromatic hydrocarbons (PAHs). They are not produced or used commercially but are very commonly found since they are formed as a result of incomplete combustion of organic materials. Used extensively as a positive control in a variety of laboratory mutagenicity & carcinogenicity short-term tests. RESEARCH CHEMICAL NOT USED COMMERCIALLY IN USA. PAHs are found in exhaust from motor vehicles and other gasoline and diesel engines, emission from coal-, oil-, and wood-burning stoves and furnaces, cigarette smoke; general soot and smoke of industrial, municipal, and domestic origin, and cooked foods, especially charcoal-broiled; in incinerators, coke ovens, and asphalt processing and use. 1. There are two major sources of PAHs in drinking water: 1) contamination of raw wate supplies from natural and man-made sources, and 2) leachate from coal tar and asphalt linings in water storage tanks and distribution lines.									
Carbofuran	40	221.25	4.85E-06	320	3.09E-09	1.26E-07	2.32	0.31	13	11
	Broad spectrum insecticide, nematocide, miticide systemic acaricide furadan controls corn rootworm in field corn; most soil & foliar pests; alfalfa weevil, aphids & lygus bugs; nematodes, soil, foliage feeding insects in tobacco; nematodes, thrips in peanuts; rice water weevil; nematodes, wireworms, sugarcane borer in sugarcane; greenbug in sorghum; colorado potato beetle, leafhoppers, flea beetles in potatoes; nematodes, mexican bean beetle in soybeans; soil, foliar feeding insects, nematodes in sweet corn; thrips in cotton; nematodes, phylloxera in grapes; grasshoppers, cereal leaf beetle in small grains; nematodes in cucurbits; grasshoppers, stem weevils, sunflower beetles in sunflowers carbofuran is effective against a number of mites with the exception of some tetranychus outside usa: overseas uses include bananas, coffee and sugar beets. Granules are used in lowland rice against leafhoppers, stemborers, & certain other insects. 1. Broad spectrum insecticide is sprayed directly onto soil and plants just after emergence to control beetles, nematodes and rootworm mustly on alfalfa and rice. Carbofuran enters surface water as a result of runoff from treated fields and enters ground water by leaching of treated crops.									
Chlordane	2	409.8	9.80E-06	0.056	4.86E-05	1.99E-03	6	200	1.22E+03	
	It was used on corn, citrus, deciduous fruits and nuts, vegetables; for home, garden and ornamentals; lawns, turf, ditchbanks and roadsides. It was applied directly to soil or foliage to control a variety of insect pests including parasitic roundworms and other nematodes, termites, cutworms, chiggers, leafhoppers 1. Used as a pesticide on crops, on lawns and gardens, and to control termites in houses. Chlordane has been released into the environment primarily from its application as an insecticide.									

Synthetic Organic Contaminants Pesticides/PCB/SOC Common Uses & Physical Properties

Compound (organic)	MCL (mg/L)	MW (g/gmol)	VP (mmHg)	Solubility (mg/L)	H (atm m^3/mol)	Air/Water = H/RT (@25°C)	Log K_{ow}	K_d	K_{oc} (mL/g)	Aerobic Soil Half Life (days)
	2. Chlordane was also used as a pesticide on agricultural crops, lawns, and gardens and as a fumigating agent.									
Dibromochlorpropane (DBCP)	0.2	236.36	0.900074	1000	2.76E-04	1.13E-02	2.63		88	
	DBCP was once used as an unclassified nematocide for soil fumigation of cucumbers, summer squash, cabbage, cauliflower, carrots, snap beans, okra, aster, shasta daisy, ornamental turf (lawns), bermudagrass, centipedegrass, St Augustine grass, zoysia grass, ardisia, azalea, camellia, forsythia, gardenia, hibiscus, roses, and arborvitae. Large amounts of 1,2-dibromo-3-chloropropane were used in the past on certain farms to kill pests that harmed crops. 1. Though it is also used as a chemical intermediate in the production of a flame-retardant, essentially all of its present use is as a soil fumigant. In the past, release of DBCP to the environment occurred primarily from its fumigant and nematocide uses mainly on grapes and tomatoes.									
2, 4-D	70	221.04	8.25E-05	677	3.54E-08	1.45E-06	2.81	0.94	42	4
	2,4-D is a herbicide for the control of broad-leaf weeds in agriculture, and for control of woody plants along roadsides, railways, and utilities rights of way. It has been most widely used on such crops as wheat and corn, and on pasture and rangelands. Herbicide used on grasses, wheat, barley, oats, sorghum, corn, sugarcane, & noncrop areas pasture and range land; lawns & turf/ for post-emergent control of canada thistle, dandelion, annual mustards, ragweed, lambsquarters & others. Some formulations for pine release, water hyacinth control & prevention of seed formation; double-gee, wild radish, turnip & other broadleaf weeds in cereals. 1. Used as a plant growth regulator to control fruit drop, such as on tomatoes to cause all fruits to ripen at the same time for machine harvesting. Major environmental releases of 2,4-D are due to agricultural applications of systemic herbicides. It is also released as a result of the production or disposal of 2,4-D or its by-products.									
Ethylene dibromide	0.05	187.9	11.2	4150	6.67E-04	2.73E-02	1.76		1.96	
	SRP: Former use: to some extent as chem intermediate & in gauge fluids catalyst for the initiation of reaction in the preparation of grignard reagents. chem intermediate for vinyl bromide used as a solvent for resins, gums, and waxes and as a chemical intermediate in the synthesis of dyes and pharmaceuticals. Fumigant, insecticide, nematicide. Former uses scavenger for lead in gasoline, general solvent, waterproofing preparations, organic synthesis in antiknock gasolines.									

Synthetic Organic Contaminants Pesticides/PCB/SOC Common Uses & Physical Properties

Compound (organic)	MCL (mg/L)	MW (g/gmol)	VP (mmHg)	Solubility (mg/L)	H (atm m^3/mol)	Air/Water = H/RT (@25°C)	Log K_{ow}	K_d	K_{oc} (mL/g)	Aerobic Soil Half Life (days)
	1. Used for mill, warehouse or household fumigation. EDB is released during the use, storage, and transport of leaded gasoline, as well as during any spills; from its former use as a pesticide; wastewater and emissions from processes and waste waters of the chemical industries that use it primarily from petroleum refineries.									
Heptachlor	0.4	373.3	0.0004	0.18	2.94E-04	1.20E-02	6.1		3475	
	Used as a non-agricultural insecticide. Insecticide for control of cotton boll weevil former use insecticide for termite control (former use) insecticide for certain field crops-eg, corn (former use) insecticide for citrus crops (former use) insecticide for foliar & seed treatment (former use) insecticide for pest control operators (former use) insecticide for pineapples & cereal (former use) insecticide for vegetables & sugar beets (former use) insecticide for certain nut crops (former use) usually added to soil to control white grubs, root weevils, & wireworms to prevent girdling of seedlings by reproduction of weevils. Material is either sprayed on planted trees or trees are dipped in water emulsions of active compound prior to planting. srp: former use in USA vet: as premise spray against flies, fleas, mosquitoes, & their larvae by use of residual sprays (0.125-0.5%). Former use Formulation of pesticides supplied as an emulsifiable concentrate, wettable powder, dust or granular material; Used formerly as an insecticide in seed treatment, preplanting soil application, dipping tops of plants and roots for control of insects, flies and mosquitoes; Used formerly on household plots and on fruits; Used formerly in termite control. 1. The only permitted commercial use of heptachlor products is for fire ant control in buried, pad-mounted electric power transformers, and in underground cable television and telephone cable boxes.									
Heptachlor epoxide	0.2	389.31	1.95E-05	0.2	2.10E-05	8.58E-04	4.98		10.58	
	The epoxide is formed from heptachlor in the environment 1. Not avail as commercial product in USA, & it is not normally present in commercial heptachlor. Heptachlor Epoxide is formed from heptachlor in the environment									
Lindane	0.2	290.85	4.20E-05	7.3	5.14E-06	2.10E-04	3.72		1355	

Synthetic Organic Contaminants Pesticides/PCB/SOC Common Uses & Physical Properties

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	Insecticide for field crops corn, wheat insecticide for ornamentals, pasture, & forage crops insecticide for forestry, timber protection, & livestock insecticide for soil & seed treatment & viticulture medication (human: pediculicide, scabicide; vet: ectoparasiticide) used in baits & seed treatments for rodent control. It is also used as a dip for fleas and lice on pets, and livestock, for soil treatment, on the foliage of fruit and nut trees, vegetables, timber, ornamentals and for wood protection. 1. Most uses being restricted in 1983, lindane is currently used primarily for treating wood-inhabiting beetles and seeds.									
Methoxychlor	40	345.65	2.58E-06	0.1	2.03E-07	8.30E-06	5.08		76000	
	For use as insecticide on beef cattle, dairy cattle, goats, sheep, & swine & for spray treatment of barns, grain bins, mushroom houses, & other agric premises. Methoxychlor has been utilized extensively for the control of biting flies AS A PREMISE SPRAY Insecticide effective against mosquito larvae and houseflies. A contact & stomach insecticide effective against a wide range of pests, but not aphids, in field & forage, fruit & vegetable crops. 1. It is an insecticide preferred to DDT for use on animals, in animal feed, and on DDT-sensitive crops such as squash, melons, etc.									
Polychlorinated biphenyls	0.5					0.00E+00				
	They were formerly used in the USA as hydraulic fluids, plasticizers, adhesives, fire retardants, way extenders, de-dusting agents, pesticide extenders, inks, lubricants, cutting oils, in heat transfer systems, carbonless reproducing paper. 1. PCBs are also currently released from landfills, incineration of municipal refuse and sewage sludge, and improper (or illegal) disposal of PCB materials, such as waste transformer fluid, to open areas.									
Pentachlorophenol	1	266.3	0.00011	14	2.45E-08	1.00E-06	5.12		20000	

Synthetic Organic Contaminants Pesticides/PCB/SOC Common Uses & Physical Properties

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	Has been recommended for use in the preservation of starches, dextrins, glues as a molluscicide to inhibit fermentation in various materials registered homeowner uses incl maintenance of boats, trailers, station wagons, siding, fences, outdoor furniture & similar articles. There are a large number of registered industrial uses, such as construction of boats and buildings, mold control in petroleum drilling & prodn, & in treatment of cable coverings, canvas belting, nets, construction lumber & poles. Other uses incl incorporation in paints, pulp stock, in pulp & paper, cooling tower water, hardboard & particleboard. Wood preservative (fungicide) chem int for sodium pentachlorophenate soil fumigant for termites herbicide for weeds & preharvest defoliant for seed crops srp: former use seed treating agent for beans herbicide for control of moss-eg, on lawns & roofs fungicide-eg, for use on prunes preservative-eg, for paints, leather, textiles & inks slimicide & algaecide in indust applications antibacterial agent in disinfectants & cleaners. Use In various products, pentachlorophenol has been used as a herbicide, algacide, defoliant, wood preservative, germicide, fungicide, and molluscicide. 1. The greatest use of pentachlorophenol is as a wood preservative (fungicide). It may be released to the environment as a result of its manufacture, storage, transport, or use as an industrial wood preservative.									
Toxaphene (chlor. Camphenes)	3	414	9.80E-07	0.74	6.00E-06	2.45E-04	4.82		2.10E+05	
	It is a non-systemic contact & stomach insecticide with some acaricidal action insecticide for cotton, peas, soybeans, peanut, corn, wheat & other small grains, eg, rice (former use), alfalfa, sorghum (former use), cattle, sheep, goats, swine, & horses (former use), fruits & nuts (former use), ornamentals, forage, & turf (former use), & certain agricultural premises. Toxaphene is released into the environment primarily from its application as an insecticide for the protection of cotton, mostly in southern states. 1. Toxaphene was used as an insecticide for cotton and vegetables, and on livestock and poultry. These uses have been restricted, and toxaphene is now used only for special needs									
2, 4, 5-TP (silvex)	50	269.53	9.97E-06	71	9.06E-09	3.70E-07	3.8		2600	

Synthetic Organic Contaminants Pesticides/PCB/SOC Common Uses & Physical Properties

Compound (organic)	**MCL (mg/L)**	**MW (g/gmol)**	**VP (mmHg)**	**Solubility (mg/L)**	**H (atm m^3/mol)**	**Air/Water = H/RT (@25°C)**	**Log K_{ow}**	**K_d**	**K_{oc} (mL/g)**	**Aerobic Soil Half Life (days)**
	Aquatic uses included control of weeds in ditches and riverbanks, on floodways, along canals, reservoirs, streams, and along southern waterways. Plant hormone former use used on phreatophytes on floodways, along canals, reservoirs, & streams as liq spray in ester form. Used on floating & emersed weeds in southern waterways as a liq spray. From table; former use for control of woody plants, broadleaf herbaceous weeds, & aquatic weeds. It is also useful as selective postemergence herbicide in rice & bluegrass turf. in sugarcane, it is used to control wild lettuce, chicory, nightshade, tievine & other weeds not susceptible to 2,4-d. for brush control in rangeland improvement programs, especially post, blackjack, sand shinnery oaks, yucca, & salt cedar. Former use controls alligator weed in ditches & riverbanks. controls 2,4-d tolerant weeds such as chickweeds, spurges, & black medic in turf. (former uses) herbicide for industrial/commercial uses (former use) herbicide for pasture & rangeland (former use) herbicide for lawns, turf, & aquatic use 1. The greatest use of 2,4,5-TP was as a postemergence herbicide for control of woody plants, and broadleaf herbaceous weeds in rice and bluegrass turf, in sugarcane, in rangeland improvement programs, on lawns. Former releases were from spraying on rangelands, runoff from fields, and direct release to water for control of aquatic weeds.									
Dalapon (Na salt)	200	142.96	1.90E-01	9.00E+05	6.43E-08	2.63E-06	0.76		2.3	
	In non-crop areas such as roadsides, railways, ditches. Also in certain established crops such as alfalfa, asparagus, flax, potatoes, rape seed, sugar beets. For quackgrass, bermudagrass, johnsongrass, other perennial and annual grasses, cattails, rushes. Often preplant for established perennial grasses in cropland, noncropland areas, irrigation ditch banks. Translocates to the roots of most species as a growth regulator. Selective herbicide; growth regulator herbicide sodium salt. Dalapon is a herbicide used to control grasses in a wide variety of crops, including fruit trees, beans, coffee, corn, cotton and peas. It is also registered for use in a number of non-crop applications such as lawns, drainage ditches, along railroad tracks, and in industrial areas. 1. Dalapon is released directly to the environment in its use as a herbicide for the control of annual and perennial grasses.									
Di(2-ethylhexyl) adipate	400	370.57	2.35E-06	1.00E-01	2.13E-05	8.71E-04	4.2		15500	

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	Plasticizer, commonly blended with general purpose plasticizers, such as DOP and DIOP in processing polyvinyl and other polymers; solvent; aircraft lubes Functional (hydraulic) fluid Plasticizer or solvent in the following cosmetics: bath oils, eye shadow, cologne, foundations, rouge, blusher, nail-polish remover, moisturizers and indoor tanning preparations PVC film now used in meat wrapping operations contains bis(2-ethyl hexyl) adipate (DOA) as its major plasticizer. 1. It is used in making plastics. Adipate is released in fly ash from municipal waste incineration, wastewater effluent from sewage treatment plants and chemical manufacturing plants. Since adipates are known to leach from plumbing made of PVC plastic, they have been recognized as a potential drinking water contaminant.									
Di (2-ethylhexyl) phthalate (DEHP)	6	390.57	1.42E-07	2.70E-01	2.70E-07	1.10E-05	7.6			
	In plasticizing a variety of polymeric materials: natural rubber, synthetic rubber cellulose acetate butyrate, ethyl cellulose, nitrocellulose, polymethyl methacrylate, polyvinyl butyral, polystyrene, & polyvinylidine chloride. Plasticizer manufacture; plastics manufacture & recycling, processing; organic pump fluid organic pump fluid plasticizer for polyvinyl chloride resins plasticizer for vinyl chloride copolymer resins plasticizer for other resins & synthetic rubbers component of dielectric fluids in electrical capacitators solvent-eg, for erasable ink acaricide for use in orchards inert ingredient in pesticide formulations vacuum pump oil testing agent for air filtration systems plasticizer for chlorinated rubber used widely in insect repellant formulations cosmetics, rubbing alcohol, liquid soap, detergents, decorative inks, lacquers, munitions, industrial and lubricating oils, defoaming agents during paper and paperboard manufactures, and as pesticide carriers. Phthalic esters photographic film, wire and cable, adhesives in vacuum pumps.									
	1. The greatest use of DEHP is as a plasticizer for polyvinylchloride (PVC) and other polymers including rubber, cellulose and styrene. Disposal of polyvinyl chloride and other DEHP-containing materials by incineration, landfill, etc., will result in the release of DEHP into the environment. DEHP has been detected in the effluent of numerous industrial plants. Releases were primarily from rubber and plastic hose industries.									
Dinoseb	7	240.2	7.50E-05	5.20E+01	4.56E-07	1.86E-05	3.56		30	
	Miticide Former use Insecticide or ovicide but must be used in the dormant growth season or as a salt form to reduce toxicity. Herbicide for preemergence treatment. Former use 1. Its greatest use is as a contact herbicide for post-emergence weed control in cereals, undersown cereals, seedling lucerne and peas. Dinoseb is also used as a corn yield enhancer and an insecticide and miticide. Used primarily on soybeans and vegetables. Release of dinoseb has resulted primarily from its use as an herbicide on a variety of weeds.									

<table>
<tr><th colspan="11">Synthetic Organic Contaminants Pesticides/PCB/SOC Common Uses & Physical Properties</th></tr>
<tr><th>Compound (organic)</th><th>MCL (mg/L)</th><th>MW (g/gmol)</th><th>VP (mmHg)</th><th>Solubility (mg/L)</th><th>H (atm m^3/mol)</th><th>Air/Water = H/RT (@25°C)</th><th>Log K_{ow}</th><th>K_d</th><th>K_{oc} (mL/g)</th><th>Aerobic Soil Half Life (days)</th></tr>
<tr><td rowspan="2">Diquat dibromide</td><td>20</td><td>344.06</td><td>Non-volatile</td><td>7.18E+05</td><td>0.00E+00</td><td>0.00E+00</td><td>-4.6</td><td></td><td>500</td><td></td></tr>
<tr><td colspan="10">Contact herbicide used also to produce desiccation & defoliation. Its uses incl potato haulm destruction (420-840 g diquat/ha) used as desiccants to aid harvesting (on cotton, rape, & other oil seed crops, cereals, lucerne, etc) & to assist in the conservation of forage (prewilting for silage, prepn of standing hay, etc). Herbicide for industrial, commercial, & aquatic uses. Sugarcane-flowering suppressant plant growth regulator. It is used on potatoes; as an aid in harvesting cotton, rapeseed and other oil seed crops; to wilt and dry out silage, standing hay, etc. for storage; a plant growth regulator and sugar cane-flowering suppressant.
1. Diquat is a herbicide that has been used extensively in the US since the late 1950s to control both crop and aquatic weeds. Diquat is released into the environment during its use as a contact herbicide, aquatic weed control agent, harvesting aid, or plant growth regulator. It may also be released into wastewater or in spills during its manufacture, transport and storage.</td></tr>
<tr><td rowspan="2">Endothall</td><td>100</td><td>186.2</td><td>1.57E-10</td><td>1.00E+05</td><td>3.85E-16</td><td>1.57E-14</td><td>1.91</td><td></td><td>85</td><td></td></tr>
<tr><td colspan="10">It is used as a desiccant on lucerne and on potato, for the defoliation of cotton and to control algae and aquatic weeds. Pre- and post-emergence herbicide, defoliant, desiccant, aquatic algicide growth regulator. For sugar beets, turf, hops sucker suppression; alfalfa, clover desiccants; cotton harvest aids; potato vine killers. Endothall is used as a defoliant for a wide range of crops and as a herbicide for both terrestrial and aquatic weeds. It is used as a desiccant on lucerne and on potato, for the defoliation of cotton, to control aquatic weeds and as an aquatic algicide growth regulator. It has been used for: sugar beets, turf, hops sucker suppression; alfalfa, clover desiccants; potato vine killers.
1. Release of endothall to the environment is expected to occur primarily during its use as a pre-emergence, post-emergence, turf and aquatic herbicide and harvest aid. Other sources of release include loss during manufacturing, formulation, packaging or disposal of this herbicide.</td></tr>
<tr><td rowspan="2">Endrin</td><td>2</td><td>380.91</td><td>3.00E-06</td><td>2.50E-01</td><td>6.36E-06</td><td>2.60E-04</td><td>5.2</td><td></td><td>11420</td><td></td></tr>
<tr><td colspan="10">Endrin is an insecticide which has been used mainly on field crops such as cotton, maize, sugarcane, rice, cereals, ornamentals, and other crops. It has also been used for grasshoppers in non-cropland and to control voles and mice in orchards.
1. Endrin's former source in the environment is from use as an insect, bird and rat-killer. It has been used on agricultural crops, cottonseeds, control of birds on buildings and mice in orchards. Its major use has been on cotton crops. The EPA presently considers the pesticide canceled.</td></tr>
</table>

<table>
<tr><th colspan="12">Synthetic Organic Contaminants Pesticides/PCB/SOC Common Uses & Physical Properties</th></tr>
<tr><th>Compound (organic)</th><th>MCL (mg/L)</th><th>MW (g/gmol)</th><th>VP (mmHg)</th><th>Solubility (mg/L)</th><th>H (atm m^3/mol)</th><th>Air/Water = H/RT (@25°C)</th><th>Log K_{ow}</th><th>K_d</th><th>K_{oc} (mL/g)</th><th>Aerobic Soil Half Life (days)</th></tr>
<tr><td rowspan="2">Glyphosate</td><td>700</td><td>169.1</td><td>Non-volatile</td><td>1.20E+04</td><td><1.4E-07</td><td>5.72E-06</td><td>-1.6</td><td></td><td>2100</td><td>0.9</td></tr>
<tr><td colspan="10">Non-selective, non-residual post-emergence herbicide. Very effective on deep-rooted perennial species. Non-selective systemic herbicide, for control of a great variety of annual, biennial, and perennial grasses, sedges, broad-leaved weeds, and woody shrubs. Used in fruit orchards, vineyards, conifer plantations, and many plantation crops (eg coffee, tea, bananas, rubber, coconut, palms, cocoa, mangoes); post-weed emergence but pre-crop-emergence in a wide range of crops (including vegetables, beet, lucerne, okra, soya beans, figs, kiwi fruit, olives, cucurbits, cereals, cotton, etc); on non crop areas; immediately pre-harvest in ripened cereals; in cereal stubble; and in pasture renovation. Also used for pre-harvest desiccation of cotton, cereals, peas, beans, etc; for destruction of rye sown to prevent wind erosion of the soil; for control of suckers on fruit trees; and for aquatic weed control.
1. The most common uses include control of broadleaf weeds and grasses in: hay/pasture, soybeans, field corn; ornamentals, lawns, turf, forest plantings, greenhouses, rights-of-way. Glyphosate is released to the environment in its use as a herbicide for controlling woody and herbaceous weeds on forestry, right-of-way, cropped and non-cropped sites. These sites may be around water and in wetlands. It may also be released to the environment during its manufacture, formulation, transport, storage, disposal and cleanup, and from spills. Glyphosate is among the most widely used pesticides by volume.</td></tr>
<tr><td rowspan="2">Hexachlorobenzene</td><td>1</td><td>284.8</td><td>1.80E-05</td><td>0.0062</td><td>1.70E-03</td><td>6.95E-02</td><td>5.31</td><td>463</td><td>14100</td><td></td></tr>
<tr><td colspan="10">*In organic syntheses as a raw material for synthetic rubber; plasticizer for polyvinyl chloride; as a rubber peptizing agent in the manufacture of nitroso and styrene-type rubbers additive for pyrotechnic compositions for the military, porosity controller in manufacture of electrodes; intermediate in dye manufacture. A selective fungicide suggested for seed treatment of wheat against bunt (tilletia tritici) found effective for control of dwarf bunt. Attribute control to inhibitory action of vapor on spore germination. fungicide for control of smut on grain, esp wheat chem intermediate. eg, for dyes & hexafluorobenzene Manufacture of pentachlorophenol, wood preservative; used in the production of aromatic fluorocarbons; used to impregnate paper Fungicide on sunflowers (seed treatment), seedborne diseases, insects; safflower (seed treatment), seed and seedling diseases, and wireworms
1. Used to make fireworks and ammunition
2. Used to manufacture synthetic rubber
3. Used as a fungicide to protect wheat and other seeds</td></tr>
<tr><td rowspan="2">Hexachlorocyclopentadiene</td><td>50</td><td>272.77</td><td>0.06</td><td>1.8</td><td>2.70E-02</td><td>1.10</td><td>5.04</td><td></td><td>2000</td><td></td></tr>
<tr><td colspan="10">Intermediate for many insecticides, polyester resins, and flame retardants. Intermediate for resins, dyes, pharmaceuticals. /Used to make shock proof plastics, acids, esters, ketones, and fluorocarbons.</td></tr>
</table>

Synthetic Organic Contaminants Pesticides/PCB/SOC Common Uses & Physical Properties										
Compound (organic)	**MCL (mg/L)**	**MW (g/gmol)**	**VP (mmHg)**	**Solubility (mg/L)**	**H (atm m^3/mol)**	**Air/Water = H/RT (@25^{o}C)**	**Log K_{ow}**	**K_d**	**K_{oc} (mL/g)**	**Aerobic Soil Half Life (days)**
	1. Its greatest use is as a raw material in manufacturing other chemicals, including pesticides, flame retardants, resins, dyes, pharmaceuticals, plastics, etc. HEX has no end uses of its own. Major sources of its release are emissions and contaminated wastewater from facilities which manufacture or use this compound as a chemical intermediate, and from the application of pesticides where it may remain as an impurity.									
Oxamyl (Vydate)	200	219.4	0.00023	2.80E+05	2.37E-10	9.69E-09	-0.48	0.05	9	15
	Insecticide, nematicide, acaricide 1. It is widely used for control of insects, mites and nematodes on field crops, fruits and ornamentals. The majority of oxamyl is applied to apples, potatoes, and tomatoes. Oxamyl is released directly to the environment in its use as an insecticide and during its manufacture, handling and storage.									
Picloram	500	241.48	4.50E-07	4.30E+05	3.33E-10	1.36E-08	-0.05	29	29	150
	It is used in salt form as a systemic herbicide for controlling annual weeds on crops, and in combination with 2,4-D or 2,4,5-T against perennials on non-croplands for brush control. Picloram is used to control bitterweed, knapweed, leafy spurge, locoweed, larkspur, mesquite, prickly pear, and snakeweed on rangeland in the western states.									
Simazine	4	201.66	2.21E-08	6.20E+00	9.42E-10	3.85E-08	2.18	1.27	114	91
	Used as a pre-emergence herbicide used for control of broad-leaved and grassy weeds on a variety of deep-rooted crops such as artichokes, asparagus, berry crops, broad beans, citrus, etc., and on non-crop areas such as farm ponds and fish hatcheries. Other herbicides with which simazine is combined include: paraquat, on apples, peaches; Roundup or Oust for noncrop use; Surflan on Christmas trees; Dual on corn and ornamentals.									
	1. Its major use is on corn where it is often combined with AAtrex. Simazine may be released into the environment via effluent at manufacturing sites and at points of application where it is employed as a herbicide.									
2,3,7,8-TCDD (Dioxin)	0.00003	321.98	1.50E-09	2.00E-04	5.00E-05	2.04E-03	6.8			
	Research chemical TCDD has been tested for use in flame proofing polymers, eg, polyesters, & against insects & wood-destroying fungi. It is hoped that these uses have never been exploited commercially. Not used commercially in USA. Dioxin is not produced or used commercially in the US. It is a contaminant formed in the production of some chlorinated organic compounds, including a few herbicides such as silvex. It may also be formed during combustion of a variety of chlorinated organic compounds.									

<table>
<tr><th colspan="11">Synthetic Organic Contaminants Pesticides/PCB/SOC Common Uses & Physical Properties</th></tr>
<tr><th>Compound (organic)</th><th>MCL (mg/L)</th><th>MW (g/gmol)</th><th>VP (mmHg)</th><th>Solubility (mg/L)</th><th>H (atm m^3/mol)</th><th>Air/Water = H/RT (@25°C)</th><th>Log K_{ow}</th><th>K_d</th><th>K_{oc} (mL/g)</th><th>Aerobic Soil Half Life (days)</th></tr>
<tr><td></td><td colspan="10">1. Dioxin is released to the environment in emissions from the incineration of municipal refuse and certain chemical wastes, in exhaust from automobiles powered by leaded gasoline, in emissions from wood burning in the presence of chlorine, in accidental fires involving transformers containing PCBs and chlorinated benzenes, and from the improper disposal of certain chlorinated chemical wastes. It has been released to the environment as a low level impurity in various pesticides.</td></tr>
<tr><td colspan="11">**References:**
http://esc.syrres.com (Physical Properties)
http://www.epa.gov/safewater/hfacts.html (MCL's & Common Uses)
http://www.speclab.com/ (Common Uses)</td></tr>
</table>

APPENDIX B

Volatile Organic Contaminants Common Uses & Chemical Properties

Volatile Organic Contaminants Common Uses & Physical Properties										
Vol-Organic Compound	**MCL (μg/L)**	**MW (g/gmol)**	**VP (mmHg)**	**Solubility (mg/L)**	**H (atm m^3/mol)**	**K_{oc} (mL/g)**	**Air/Water = 'H**	**Air/Soil = H'/K_{oc}**	**Water/Soil = 1/K_{oc}**	**R (0.5% oc, r = 1.8, q = 0.3)**
Acrylamide	Treatment Technique	71.08	0.007	6.40E+04	1.00E-09	50	4.09E-08	8.17E-10	0.0200	
	The greatest use of acrylamide is as a coagulant aid in drinking water treatment. Other uses of include: to improve production from oil wells; in making organic chemicals and dyes; in the sizing of paper and textiles; in ore processing; in the construction of dam foundations and tunnels. 1. Releases are primarily from plastics industries.									
Vinyl Chloride	2	62.5	2300	1100	0.695	8.1283	2.84E+01	0.0855	0.123	1.24
	It is used in the manufacture of numerous products in building and construction, automotive industry, electrical wire insulation and cables, piping, industrial and household equipment, medical supplies, and is depended upon heavily by the rubber, paper, and glass industries. Its major release to the environment will be as emissions and wastewater at polyvinyl chloride (PVC) plastics production and manufacturing facilities. Small quantities of vinyl chloride can be released to food since it is used to make many food wrappings and containers. 1. Releases are primarily from plastics materials and resins industries.									
1,1-Dichloroethylene	7	96.94	500	400	1.54E-01	64.565	6.29E+00	0.0024	0.015	2.94
	Virtually all of it is used in making adhesives, synthetic fibers, refrigerants, food packaging and coating resins such as the saran types. It may be released by evaporation or in wastewater during its production and use in the manufacture of plastic wrap, adhesives, and synthetic fiber. It may also form in groundwater that has been contaminated by similar solvents. 1. Releases were primarily from facilities which make plastics materials/resins.									
Dichloromethane	5	84.93	350	13200	2.57E-03	8.7096	1.05E-01	0.0003	0.115	1.26
	Virtually all of it is used in making adhesives, synthetic fibers, refrigerants, food packaging and coating resins such as the saran types. It may be released by evaporation or in wastewater during its production and use in the manufacture of plastic wrap, adhesives, and synthetic fiber. It may also form in groundwater that has been contaminated by similar solvents. 1. Releases were primarily from facilities which make plastics materials/resins.									
cis-1,2-Dichloroethylene	70	96.94	200	3500	7.50E-03	31.623	3.07E-01	0.00024	0.032	1.95

Volatile Organic Contaminants Common Uses & Physical Properties

Vol-Organic Compound	MCL (µg/L)	MW (g/gmol)	VP (mmHg)	Solubility (mg/L)	H (atm m^3/mol)	K_{oc} (mL/g)	Air/Water = 'H	Air/Soil = H'/K_{oc}	Water/Soil = 1/K_{oc}	R (0.5% oc, r = 1.8, q = 0.3)
	Both the cis and trans forms - usually as a mixture - are used as a solvent for waxes and resins; in the extraction of rubber; as a refrigerant; in the manufacture of pharmaceuticals and artificial pearls; in the extraction of oils and fats from fish and meat; and in making other organics. 1. Trans-1,2-dichloroethylene may be released to the environment in air emissions and wastewater during its production and use as a solvent and extractant, in organic synthesis, and in the manufacture of perfumes, lacquers, and thermoplastics. Releases to the environment are expected to be limited to manufacturing plants in the Gulf Region of the United States.									
trans-1,2-Dichloroethylene	70	96.94	265	3500	6.60E-03	58.884	2.70E-01	0.00011	0.017	2.77
	1,2-Dichloroethylene (1,2-DCE) is an odorless organic liquid that has two slightly different forms, a "cis" form and a "trans" form. Both the cis and trans forms - usually as a mixture - are used as a solvent for waxes and resins; in the extraction of rubber; as a refrigerant; in the manufacture of pharmaceuticals and artificial pearls; in the extraction of oils and fats from fish and meat; and in making other organics. 1. Trans-1,2-dichloroethylene may be released to the environment in air emissions and wastewater during its production and use as a solvent and extractant, in organic synthesis, and in the manufacture of perfumes, lacquers, and thermoplastics.									
Benzene	5	78.1	76	1780	5.55E-03	64.565	2.27E-01	0.0001	0.015	2.94
	The greatest use of benzene is as a building block for making plastics, rubber, resins and synthetic fabrics like nylon and polyester. Other uses include: as a solvent in printing, paints, dry cleaning, etc. Benzene is released to air primarily from fumes and exhaust connected with its use in gasoline. Other sources are fumes from its production and use in manufacturing other chemicals. In addition, there are discharges into water from industrial effluents and losses during spills. 1. Releases are primarily from petroleum refining industries.									
1,2-Dichloroethane	5	98.96	63.7	8690	1.10E-03	14.125	4.50E-02	0.0001	0.071	1.42
	Manufacture of acetyl cellulose, tobacco extract. In paint, varnish and finish removers; soaps & scouring compounds; wetting and penetrating agents; ore flotation; lead scavenger in antiknock gasoline; prodn of vinyl chloride, trichloroethylene, vinylidene chloride & trichloroethane. Fumigant for grain, upholstery & carpets; registered for agric use in the usa for postharvest fumigation of grain & for use in orchards, agric premises and mushroom houses. In leather cleaning, rubber goods fabrication, drum filling, and metal cleaning industries. In degreaser compounds, rubber cement, and acrylic adhesives. Catalyst in production of hexachlorophene. Solvent for processing pharmaceutical products. Chem int for tetrachloroethylene. Manufacture of ethylenediamine, succinonitrile, glycol ethers & esters. Chem int for ethyleneimine. Chem int for polysulfide elastomers. Manufacture of ethylene glycol, diaminoethylene, polyvinyl chloride, nylon, viscose rayon, styrene-butadiene rubber, and various plastics; solvent for resins, asphalt, bitumen, rubber; used as pickling agent and a dry clean agent; in photography, xerography, water softening & in production of cosmetics. Use in extracting spices such as annatto, paprika & turmeric. 1. These releases were primarily from facilities which make industrial organic chemicals, alkalis and chlorine									
Trichloroethylene	5	131.39	58.7	1000	8.92E-03	125.89	3.65E-01	0.00007	0.0079	4.78

Volatile Organic Contaminants Common Uses & Physical Properties										
Vol-Organic Compound	**MCL (µg/L)**	**MW (g/gmol)**	**VP (mmHg)**	**Solubility (mg/L)**	**H (atm m^3/mol)**	**K_{oc} (mL/g)**	**Air/Water = 'H**	**Air/Soil = H'/K_{oc}**	**Water/Soil = 1/K_{oc}**	**R (0.5% oc, r = 1.8, q = 0.3)**
	Its greatest use is in the textile industry, and as a component of aerosol dry-cleaning products. Major releases of tetrachloroethylene to air and water are from dry cleaning and industrial metal cleaning or finishing. Water pollution can occur from tetrachloroethylene leaching from vinyl liners in some types of pipelines used for water distribution, and during chlorination water treatment. 1. Releases are primarily from alkali and chlorine industries which use it to make other chemicals.									
1,2-Dichloropropane	5	112.98	39.5	2700	3.60E-03	51.286	1.47E-01	0.00007	0.019	2.54
	Livestock (in dd mixt); solvent in plastics, resins, & metals indust, int in rubber processing oil & fat solvent; in dry cleaning fluids; in degreasing, in insecticidal fumigant mixtures. Intermediate for perchloroethylene & carbon tetrachloride; lead scavenger for antiknock fluids; solvents for waxes, gums; solvent mixtures for cellulose esters & ethers; scouring cmpd; spotting agent; metal degreasing agents; soil fumigant for nematodes. The greatest use of 1,2-dichloropropane is in making other organic chemicals. It is also used in making lead-free gasoline, paper coating, soil fumigant for nematodes, and insecticide for stored grain. It may be released into the atmosphere or in wastewater during its production or use as an intermediate in chemical manufacture. There were also significant releases during its former use as a soil fumigant. It may also leach from municipal landfills. 1. Releases are primarily from chemical industries.									
Carbon Tetrachloride	5	153.82	91.3	800	2.00E-02	436.52	8.17E-01	0.00005	0.0023	14.1
	Recovery of tin in tin plating waste in formulation of petrol additives in refrigerants; metal degreasing; prodn of semiconductors used to reduce fire hazard in combinations with either carbon disulfide or ethylene dichloride intended as grain fumigants. These mixtures are not approved for fumigation of dry beans, peanuts or peas. Former uses solvent for rubber cement; cleaning agent for machinery and electrical equipment; in synthesis of nylon-7 and other organic chlorination processes. Use in polymer technology as reaction medium, catalyst; in organic synthesis for chlorination of organic compounds; in soap perfumery and insecticides. Industrial solvent for cable and semiconductor manufacture. As solvent for oils, fats, lacquers, varnishes, rubber waxes, resins; starting material in manuf of organic cmpd; grain fumigant. Pharmaceutic aid (solvent). Formerly used as dry cleaning agent and fire extinguisher. Most of it is used to make chlorofluorocarbon propellants and refrigerants, though this has been declining steadily. Other uses have included: as dry cleaning agent and fire extinguisher, in making nylon, as a solvent for rubber cement, soaps, insecticides, etc. 1. Carbon tetrachloride is released to land and water from landfills, in wastewater from industries, from agricultural activities. Releases are primarily from chemical manufacturing industries.									
Perchloroethylene	5	165.83	14	150	2.27E-02	660.69	9.28E-01	0.00003	0.002	20.82

Volatile Organic Contaminants Common Uses & Physical Properties										
Vol-Organic Compound	**MCL (µg/L)**	**MW (g/gmol)**	**VP (mmHg)**	**Solubility (mg/L)**	**H (atm m^3/mol)**	**K_{oc} (mL/g)**	**Air/Water = 'H**	**Air/Soil = H'/K_{oc}**	**Water/Soil = 1/K_{oc}**	**R (0.5% oc, r = 1.8, q = 0.3)**
	Used in the textile industry for dry-cleaning & for processing & finishing; used in both cold cleaning & vapor degreasing of metals; it is used as a chemical intermediate in the synthesis of fluorocarbon 113, 114, 115, & 116; it is used as a heat-exchange fluid scouring, sizing & desizing agent in textile manufacture component of aerosol laundry-treatment products solvent, eg, for silicones insulating fluid & cooling gas in electric transformers in typewriter correction fluids (eg, liquid paper, wite-out, snopake, etc) medication vet: use in small animals as a ruminant anthelmintic (vermifuge) has been largely replaced by drugs that are less toxic & easier to admin formerly used, but no longer approved, in mixtures with grain protectants and certain liquid grain fumigants. 1. Its greatest use is in the textile industry, and as a component of aerosol dry-cleaning products. Major releases of tetrachloroethylene to air and water are from dry cleaning and industrial metal cleaning or finishing. Water pollution can occur from tetrachloroethylene leaching from vinyl liners in some types of pipelines used for water distribution, and during chlorination water treatment. Releases are primarily from alkali and chlorine industries which use it to make other chemicals.									
Toluene	2000	92.14	22	515	6.61E-03	257.04	2.70E-01	0.00003	0.004	8.71
	In manufacture benzoic acid, benzaldehyde, explosives, dyes, and many other organic compounds; as a solvent for paints, lacquers, gums, resins, in the extraction of various principles from plants; as gasoline additive. diluent for photogravure inks in fabric & paper coating, mfr artificial leather Used in cements, solvents, spot removers, cosmetics, antifreezes, and inks. Asphalt and naphtha constituent. Detergent manufacture. Mfg caprolactam, saccharin, medicines, and perfumes; diluent and thinner in nitrocellulose lacquers, adhesive solvent in plastic toys and model airplanes. Fuel blending DENATURANT The largest chemical use for toluene is the production of benzene and urethane via hydrodealkylation. 1. The largest chemical use for toluene is to make benzene and urethane. It is released into the atmosphere principally from the volatilization of petroleum fuels and toluene-based solvents and thinners and from motor vehicle exhaust. It is also released in wastewaters or by spills on land during the storage, transport and disposal of fuels and oils. Releases primarily from petroleum refining industries.									
Chlorobenzene	100	112.56	8.8	490	3.46E-03	158.49	1.41E-01	0.00002	0.006	5.75
	Solvent for paints sometimes used in dry-cleaning chem int for phenol, o- & p-chloronitrobenzene, ddt, & aniline used in mfr of insecticides & as int in mfr of dyestuffs solvent carrier for methylene diisocyanate used as a fiber swelling agent and dye carrier in textile processing, a tar and grease remover in cleaning and degreasing operations, a solvent in surface coating and surface coating removers. Used as a solvent in the manufacture of adhesives, paints, polishes, waxes, diisocyanates, pharmaceuticals, and natural rubber. The greatest use of chlorobenzene is in the manufacture of other organic chemicals, dyestuffs and insecticides. It is also a solvent for adhesives, drugs, rubber, paints and dry-cleaning, and as a fiber-swelling agent in textile processing. 1. Major environmental releases of chlorobenzene are due to its use as a solvent in pesticides. These releases were primarily from alkali and chlorine industries which use chlorobenzene in chlorination processes.									
1,1,1-Trichloroethane	200	133.4	100	950	2.76E-03	151.36	1.13E-01	0	0.007	5.54

<table>
<tr><th colspan="11">Volatile Organic Contaminants Common Uses & Physical Properties</th></tr>
<tr><th>Vol-Organic Compound</th><th>MCL (µg/L)</th><th>MW (g/gmol)</th><th>VP (mmHg)</th><th>Solubility (mg/L)</th><th>H (atm m^3/mol)</th><th>K_{oc} (mL/g)</th><th>Air/Water = 'H</th><th>Air/Soil = H'/K_{oc}</th><th>Water/Soil = 1/K_{oc}</th><th>R (0.5% oc, r = 1.8, q = 0.3)</th></tr>
<tr><td></td><td colspan="10">Solvent for natural & synthetic resins, oils, waxes, tar & alkaloids dry cleaning agent in cold type metal cleaning, cleaning plastic molds formerly used with ethylene gas for degreening citrus fruits & postharvest fumigation of strawberries solvent for various insecticides former use spotting fluid in textile processing; chem int for org chems (eg, vinylidene chloride); solvent for adhesives & coatings; coolant & lubricant in metal cutting oils; extraction solvent; component of inks & drain cleaners; solvent for photoresist polymers; solvent in textile dyeing. In aerosols, in which it acts both as a vapor pressure depressant and as a solvent and carrier for many of the active ingredients used in aerosols. Vapor degreasing solvent for cleaning precision instruments; metal degreasing, pesticide, textile processing. It is largely used as a solvent removing grease from machined metal products, in textile processing and dyeing and in aerosols.
1. 1,1,1-TCE is likely to enter the environment by evaporation or in wastewater from its production or use in metal cleaning. It can also enter the environment in leachates and volatile emissions from landfills. Releases are primarily from metal fabrication industries.</td></tr>
<tr><td rowspan="2">Epichlorohydrin</td><td>Treatment Technique</td><td>92.52</td><td>16.44</td><td>65900</td><td>3.04E-05</td><td>10</td><td>1.24E-03</td><td>0.0001</td><td>0.1</td><td></td></tr>
<tr><td colspan="10">The greatest use of epichlorohydrin is used to make glycerin and as a building block in making plastics and other polymers, some of which are used in water supply systems. It is also used in the paper and drug industries and as an insect fumigant.
1. The main source of concern for epichlorohydrin in drinking water is from its use as a clarifier during water treatment. When added to water, it coagulates and traps suspended solids for easier removal. However, some epichlorohydrin may not coagulate and may remain in the water as a contaminant.</td></tr>
<tr><td rowspan="2">Ethylbenzene</td><td>700</td><td>106.16</td><td>7</td><td>152</td><td>7.90E-03</td><td>676.08</td><td>3.23E-01</td><td>0.00001</td><td>0.001</td><td>21.28</td></tr>
<tr><td colspan="10">Used in the production of synthetic rubber as a solvent or diluent, a component of automotive and aviation fuels; mfr of cellulose acetate ethylbenzene is mainly used as a precursor to styrene. Solvent-eg, for alkyd surface coatings, chem int for Diethylbenzene & acetophenone, for ethyl anthraquinone, for ethylbenzene sulfonic acids (o-, m- & p-), for propylene oxide & alpha-methylbenzyl alcohol, unrecovered component of gasoline. The greatest use - over 99 percent - of ethylbenzene is to make styrene, another organic liquid used as a building block for many plastics. It is also used as a solvent for coatings, and in making rubber and plastic wrap.
1. It is released to the air primarily from its use in gasoline. More localized may be due to waste water and spills from its production and industrial use. Releases are primarily from petroleum refining industries.</td></tr>
<tr><td rowspan="2">Styrene</td><td>1000</td><td>104.15</td><td>6.4</td><td>310</td><td>2.75E-03</td><td>910</td><td>1.12E-01</td><td>0.00012</td><td>0.0011</td><td></td></tr>
<tr><td colspan="10">Styrene was used primarily in the synthetic rubber industry, but it is currently used as a building block for polymers in making plastics, resins, coatings, and paints. It is used to make paints.
1. It is released into the environment by emissions and effluents from its production and its use in polymer manufacture. Consumers may be exposed to styrene through contact with resin products used in fiberglass boat construction and repair, and in auto body fillers. Styrene may also leach from polystyrene containers used for food products. Releases are primarily from adhesives and sealants industries.</td></tr>
<tr><td>p-Xylene</td><td>10000</td><td>106.16</td><td>9</td><td>198</td><td>7.01E-03</td><td>691.83</td><td>2.87E-01</td><td>0.00001</td><td>0.001</td><td>21.75</td></tr>
</table>

Volatile Organic Contaminants Common Uses & Physical Properties

Vol-Organic Compound	MCL (µg/L)	MW (g/gmol)	VP (mmHg)	Solubility (mg/L)	H (atm m^3/mol)	K_{oc} (mL/g)	Air/Water = 'H	Air/Soil = H'/K_{oc}	Water/Soil = 1/K_{oc}	R (0.5% oc, r = 1.8, q = 0.3)
	p-Xylene frequently used for paints or in the printing trade. The greatest use of xylenes is as a solvent which is much safer than benzene. Other uses include: in gasoline as part of the BTX component (benzene-toluene-xylene); Xylene mixtures are used to make phthalate plasticizers, polyester fiber, film and fabricated items. 1. Major environmental releases of xylenes are due to evaporation from the refining and use of petroleum products. It may also be released by leaks or spills during the transport and storage of gasoline and other fuels. Xylenes are a natural products of many plants, and are a component of petroleum and coal tar. These releases were primarily from petroleum refining industries.									
m-Xylene	10000	106.16	9	200	6.91E-03	691.83	2.82E-01	0.00001	0.001	21.75
	Solvent; intermediate for dyes & org synth; insecticides; aviation fuel m-Xylene is used in the manufacturing of polyester and alkyl resins. The greatest use of xylenes is as a solvent which is much safer than benzene. Other uses include: in gasoline as part of the BTX component (benzene-toluene-xylene); Xylene mixtures are used to make phthalate plasticizers, polyester fiber, film and fabricated items. 1. Major environmental releases of xylenes are due to evaporation from the refining and use of petroleum products. It may also be released by leaks or spills during the transport and storage of gasoline and other fuels. Xylenes are a natural products of many plants, and are a component of petroleum and coal tar. These releases were primarily from petroleum refining industries.									
o-Xylene	10000	106.16	7	170	4.94E-03	691.83	2.02E-01	0.00001	0.001	21.75
	Raw material for production of plasticizers; alkyd resins, glass-enforced polyesters, manufacture of phthalic anhydride Vitamin and pharmaceutical syntheses; dyes; insecticides; motor fuels. The greatest use of xylenes is as a solvent, which is much safer than benzene. Other uses include: in gasoline as part of the BTX component (benzene-toluene-xylene); Xylene mixtures are used to make phthalate plasticizers, polyester fiber, film and fabricated items. 1. Major environmental releases of xylenes are due to evaporation from the refining and use of petroleum products. It may also be released by leaks or spills during the transport and storage of gasoline and other fuels. Xylenes are a natural products of many plants, and are a component of petroleum and coal tar. These releases were primarily from petroleum refining industries.									
o-Dichlorobenzene	600	147	0.96	100	1.88E-03	1148.2	7.68E-02	0	0.001	35.44
	The greatest use of o-dichlorobenzene is as a chemical intermediate for making agricultural chemicals, primarily herbicides. Other present and past uses include: solvent for waxes, gums, resins, wood preservatives, paints; insecticide for termites and borers; in making dyes; as a coolant, deodorizer, degreaser. Solvent for waxes, gums, resins, tars, rubbers, oils, asphalts, insecticide for termites & locust borers removing sulfur from illuminating gas; as intermed in mfr of dyes; as heat transfer medium as degreasing agent for metals, leather, wool; as ingredient of metal polishes indust odor control herbicide, insecticide, and soil fumigant as solvent mixt used to remove lead & carbonaceous deposits from engine parts; as component of rust-proofing mixt as a magnetic coil coolant; in wood-preserving cmpd chem intermed for making agric chem; emulsifiable form recommended for deodorizing garbage & sewage org synth esp of pesticides & solvent in chem processes used as a process solvent in the manufacture of toluene diisocyanate.									
	1. Its use in manufacturing and solvents may be significant sources of discharges into water. Dichlorobenzenes also enter water systems from the use of o-DCB as a deodorant in industrial wastewater treatment. Chemical waste dump leachates and industrial wastewater are the major source of pollution of dichlorobenzenes to Lake Ontario. Releases are primarily form organic chemical manufacturing industries.									

Volatile Organic Contaminants Common Uses & Physical Properties

Vol-Organic Compound	MCL (µg/L)	MW (g/gmol)	VP (mmHg)	Solubility (mg/L)	H (atm m^3/mol)	K_{oc} (mL/g)	Air/Water = 'H	Air/Soil = H'/K_{oc}	Water/Soil = 1/K_{oc}	R (0.5% oc, r = 1.8, q = 0.3)
p-Dichlorobenzene	750	147	0.6	80	1.58E-03	1174.9	6.46E-02	0	0.001	36.25
	It is used mainly as an insecticidal fumigant against clothes moths and as a deodorant for garbage and restrooms. It is also used as an insecticide and fungicide on crops, and in the manufacture of other organic chemicals and in plastics, dyes, pharmaceuticals. Insecticidal fumigant; popular for domestic use against clothes moths germicide; mfr of 2,5-dichloroaniline; dyes; used in pharmacy p-dichlorobenzene is sometimes used as a deodorant for garbage and restrooms, as well as an insecticide for control of fruit borers and ants. May be applied to tobacco seedbeds for blue mold control; for the control of peach tree borer; and mildew and mold on leather and fabrics. 1. Chemical waste dump leachates and direct manufacturing effluents are reported to be the major source of p-DCB pollution									

References:
http://esc.syrres.com (Physical Properties)
http://www.epa.gov/safewater/hfacts.html (MCL's & Common Uses)
http://www.speclab.com/ (Common Uses)

APPENDIX C

Inorganic Contaminants Common Uses & Physical Properties

Inorganic Contaminants Common Uses & Physical Properties

Compound (Inorganic)	MCL (mg/L)	MW (g/gmol)	Anion	Cation
Antimony	6	121.76		**X**
	Antimony is a metal found in natural deposits as ores containing other elements. The most widely used antimony compound is antimony trioxide, used as a flame retardant. It is also found in batteries, pigments, and ceramics/glass. 1. Releases are primarily from copper and lead smelting and refining industries.			
Arsenic	50	74.9	**X**[1]	
	Approximately 90 percent of industrial arsenic in the U.S. is currently used as a wood preservative, but arsenic is also used in paints, dyes, metals, drugs, soaps, and semi-conductors. 1. Agricultural applications, mining, and smelting also contribute to arsenic releases in the environment.			
Asbestos	7 (million fibers/ Liter)			
	Asbestos is a fibrous mineral occurring in natural deposits. Because asbestos fibers are resistant to heat and most chemicals, they have been mined for use in over 3,000 different products, including roofing materials, brake pads, and cement pipe often used in distributing water to communities. Asbestos fibers may be released from natural sources such as erosion of asbestos-containing ores, but the primary source is through the wear or breakdown of asbestos-containing materials, particularly from the wastewaters of mining and other industries, and by the use of asbestos cement pipes in water supply systems. 1. Releases are primarily from asbestos products industries, which use asbestos in roofing materials, friction materials, and cement.			
Barium	2000	137.33		**X**
	It is used in making a wide variety of electronic components, in metal alloys, bleaches, dyes, fireworks, ceramics and glass. In particular, it is used in well drilling operations where it is directly released into the ground. Barium is released to water and soil in the discharge and disposal of drilling wastes, from the smelting of copper, and the manufacture of motor vehicle parts and accessories. 1. Releases are primarily from copper smelting industries.			
Beryllium	4	9.01		**X**

Inorganic Contaminants Common Uses & Physical Properties

Compound (Inorganic)	MCL (mg/L)	MW (g/gmol)	Anion	Cation
	The greatest use of beryllium is in making metal alloys for nuclear reactors and the aerospace industry. released principally in the smoke stacks and ash wastes of power plants which burn coal. It is also found in discharges from other industrial and municipal operations. Rocket exhaust products also consist of various beryllium compounds. 1. Releases are primarily from copper rolling and drawing industries, which use it as a hardener in alloys.			
Cadmium	5	112.41		**X**
	The greatest use of cadmium is primarily for metal plating and coating operations, including transportation equipment, machinery and baking enamels, photography, television phosphors. It is also used in nickel-cadmium and solar batteries and in pigments. Major industrial releases of cadmium are due to waste streams and leaching of landfills, and from a variety of operations that involve cadmium or zinc. In particular, cadmium can be released to drinking water from the corrosion of some galvanized plumbing and water main pipe materials. 1. Releases are primarily from zinc, lead and copper smelting and refining industries, with the largest releases occurring in Arizona and Utah.			
Chromium	100	51.996	**X**[1]	
	The greatest use of chromium is in metal alloys such as stainless steel; protective coatings on metal; magnetic tapes; and pigments for paints, cement, paper, rubber, composition floor covering and other materials. Its soluble forms are used in wood preservatives. The two largest sources of chromium emission in the atmosphere are from the chemical manufacturing industry and combustion of natural gas, oil, and coal. 1. Releases are primarily from industrial organic chemical industries.			
Copper	1300	63.5		**X**
	It is widely used in household plumbing materials. Corrosion of plumbing is by far the greatest cause for concern. Copper is rarely found in source water, but copper mining and smelting operations and municipal incineration may be sources of contamination. 1. Releases are primarily from copper smelting industries.			
Cyanide	200	26.02	**X**	
	The most commonly used form, hydrogen cyanide, is mainly used to make the compounds needed to make nylon and other synthetic fibers and resins. Other cyanides are used as herbicides. The major cyanide releases to water are discharges from metal finishing industries, iron and steel mills, and organic chemical industries. Releases to soil appear to be primarily from disposal of cyanide wastes in landfills and the use of cyanide-containing road salts. Chlorination treatment of some wastewaters can produce cyanides as a by-product.			

Inorganic Contaminants Common Uses & Physical Properties				
Compound (Inorganic)	**MCL (mg/L)**	**MW (g/gmol)**	**Anion**	**Cation**
	1. Releases are primarily from steel mills and metal heat-treating industries.			
Fluoride	400	18.9984	**X**	
	Communities add fluoride to their drinking water to promote dental health. 1. Releases are primarily from drinking water treatment plants			
Lead	15	207.2		**X**
	It is sometimes used in household plumbing materials or in water service lines used to bring water from the main to the home. Corrosion of plumbing is by far the greatest cause for concern. All water is corrosive to metal plumbing materials to some degree. Grounding of household electrical systems to plumbing may also exacerbate corrosion. Over time, lead-containing plumbing materials will usually develop a scale that minimizes further corrosion of the pipe. 1. Releases are primarily from lead and copper smelting industries.			
Mercury	2	200.59		**X**
	Electrical products such as dry-cell batteries, fluorescent light bulbs, switches, and other control equipment account for 50% of mercury used. Large amounts of mercury are released naturally from the earths crust. Combustion of fossil fuels, metal smelters, cement manufacture, municipal landfills, sewage, metal refining operations, r most notably, from chloralkali plants are important sources of mercury release. 1. Releases are primarily from chemical and allied industries.			
Nickel[2]		58.7		**X**
	The greatest use of nickel is in making stainless steel and other alloys. Nickel compounds can be made as a by-product during various industrial processes that use nickel catalysts, such as coal gasification, petroleum refining, and hydrogenation of fats and oils. They have also been identified in residual fuel oil and in atmospheric emissions from nickel refineries.			
	1. Releases are primarily from nickel smelting/refining and steelworks industries			
Nitrate	10000	63	**X**	
	Nitrates and nitrites are nitrogen-oxygen chemical units, which combines with various organic and inorganic compounds. Once taken into the body, nitrates are converted into nitrites. The greatest use of nitrates is as a fertilizer. Most nitrogenous materials in natural waters tend to be converted to nitrate, so all sources of combined nitrogen, particularly organic nitrogen and ammonia, should be considered as potential nitrate sources.			

Inorganic Contaminants Common Uses & Physical Properties				
Compound (Inorganic)	**MCL (mg/L)**	**MW (g/gmol)**	**Anion**	**Cation**
	1. Primary sources of organic nitrates include human sewage and livestock manure, especially from feedlots. The primary inorganic nitrates, which may contaminate drinking water, are potassium nitrate and ammonium nitrate both of which are widely used as fertilizers.			
Nitrite	1000	46.0055	**X**	
	Nitrates and nitrites are nitrogen-oxygen chemical units, which combines with various organic and inorganic compounds. Once taken into the body, nitrates are converted into nitrites. The greatest use of nitrates is as a fertilizer. Most nitrogenous materials in natural waters tend to be converted to nitrate, so all sources of combined nitrogen, particularly organic nitrogen and ammonia, should be considered as potential nitrate sources. 1. Primary sources of organic nitrates include human sewage and livestock manure, especially from feedlots. The primary inorganic nitrates, which may contaminate drinking water, are potassium nitrate and ammonium nitrate both of which are widely used as fertilizers.			
Selenium	50	78.96	**X**[1]	
	The greatest use of selenium compounds is in electronic and photocopier components, but they are also widely used in glass, pigments, rubber, metal alloys, textiles, petroleum, medical therapeutic agents, and photographic emulsions. Selenium compounds are released to the air during the combustion of coal and petroleum fuels, and during the smelting and refining of other metals. 1. Releases are primarily from copper smelting industries			
Sodium[2]		22.989		**X**
	Nature salt deposits 1. Releases are primarily natural			
Sulfate	500000	96.0576	**X**	
Thallium	2	204.383		**X**
	The greatest use of thallium is in specialized electronic research equipment. Man-made sources of thallium pollution are gaseous emission of cement factories, coal burning power plants, and metal sewers. The leaching of thallium from ore processing operations is the major source of elevated thallium concentrations in water. Thallium is a trace metal associated with copper, gold, zinc, and cadmium.			
Total Dissolved Solids (TDS)	1000000			
	Total dissolved solids means the total dissolved (filterable) solids as determined by use of the method specified in Title 40 of the Code of Federal Regulations (40 CFR) Part 136.			

<table>
<tr><th colspan="5">Inorganic Contaminants Common Uses & Physical Properties</th></tr>
<tr><th>Compound (Inorganic)</th><th>MCL (mg/L)</th><th>MW (g/gmol)</th><th>Anion</th><th>Cation</th></tr>
<tr><td colspan="5">[1]Oxyanion
[2]Monitor and Report only. No MCL.
References:
http://esc.syrres.com (Physical Properties),
http://www.epa.gov/safewater/hfacts.html (MCL's & Common Uses)
http://www.speclab.com/ (Common Uses)</td></tr>
</table>

Information Transfer Program

USGS Summer Intern Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	0	2
Masters	4	0	0	3	7
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	6	0	0	3	6

Notable Awards and Achievements

The State of Utah Legislature (2000 - 2001 session) established a mechanism for ongoing support of the UCWRR’s On-Site Wastewater Treatment Training Center through the establishment of a fund for training and technology transfer related to on-site systems in Utah.

The UCWRR achieved the highest annual total resource income of $7.3 million of it’s history through contract and grant awards and through federal, state, and private funding support.

New UCWRR faculty member, Dr. Laurie McNeill was awarded first place in the American Water Works Association (AWWA) Dissertation contest for her research addressing arsenic contamination of water systems.

Dr. Ronald Sims, UCWRR Director, represented the UCWRR as an invited speaker at the NATO Advanced Research Workshop on "The Utilization of Bioremediation to Reduce Soil Contamination." Liblice Castle, Czech Republic, June, 2000.

UCWRR’s Institute for Natural Systems Engineering was awarded approximately $900,000 for the first phase of research in in-stream flow and water management for Whatcom County and four other local governments in the state of Washington. The funding is provided by state and local sources, and is being used to support the scientific and technical investigations necessary for preparing a watershed management plan for Whatcom County. The plan will address in-stream flow and fish habitat needs and water requirements for agricultural, municipal, and industrial uses.

Publications from Prior Projects