# Center for Water Resources Research
# Annual Technical Report
# FY 2001

## Introduction

A computerized source water assessment tool is being developed that uses digital elevation model (DEM) information and other geographical information system (GIS) databases to assist drinking water watershed managers in assessing the susceptibility of surface water supplies to pollution from current and future activities in the watershed. The major components of the tool and the approach to its development were described in detail in the annual report for FY2000. This report will provide a summary description of the tool, describe current efforts to incorporate groundwater source protection modeling, and describe the development of an on-site wastewater system inventory database.

The source water protection assessment tool described here is being designed to use scientific information and professional experience in the pollution susceptibility assessment process while minimizing the need for new data collection by the user.

## Research Program

# Source Water Protection Assessment Tools Development

## Basic Information

| | |
|---|---|
| **Title:** | Source Water Protection Assessment Tools Development |
| **Project Number:** | 2001UT3401B |
| **Start Date:** | 3/1/1999 |
| **End Date:** | 2/28/2004 |
| **Funding Source:** | 104B |
| **Congressional District:** | UT 1 |
| **Research Category:** | Water Quality |
| **Focus Category:** | Water Supply, Water Use, Solute Transport |
| **Descriptors:** | Contaminant transport; Decision models; Environmental sanitation; Pollutants; Risk analysis; Septic tanks |
| **Principal Investigators:** | Darwin L. Sorensen, R. Ryan Dupont, Mariush Kemblowski, Nancy Mesner, Ronald C. Sims, David K. Stevens, David G. Tarboton, Gilberto E. Urroz |

## Publication


1. Moncur, Kade D. 2002. Synthesis of a risk-based management tool for the prediction of source water protection concerns. M.S. Thesis. Department of Civil and Environmental Engineering, College of Engineering, Utah State University, Logan, UT.
2. Sorensen, D.L., K.D. Moncur, D.G. Tarboton, M. Kemblowski, S. Quiang, and S. Gogate. 2003. A surface water protection assessment tool that uses digital elevation models. In "Proceedings of the 2003 Source Water Protection Symposium," American Water Works Association, Denver, CO.

## Research Project Synopses

| | |
|---|---|
| **Title:** | **Source Water Protection Assessment Tools Development** |
| **Project Number:** | 2001UT3401B |
| **Start Date:** | 03/99 |
| **End Date:** | 02/04 (expected) |
| **Funding Source:** | 104B |
| **Congressional District:** | UT 1 |
| **Research Category:** | Water Quality |
| **Focus Category:** | Water Supply |
| **Descriptors:** | Drinking water, source water, pollution sources, watershed management |
| **Primary PI:** | Darwin L. Sorensen |
| **Other PIs** | David G. Tarboton, Mariush Kemblowski, Gilberto E. Urroz, David K. Stevens, Donald T. Jensen, R. Ryan Dupont, Nancy Mesner, and Ronald C. Sims |
| **Project Class:** | Research |

### Introduction

A computerized source water assessment tool is being developed that uses digital elevation model (DEM) information and other geographical information system (GIS) databases to assist drinking water watershed managers in assessing the susceptibility of surface water supplies to pollution from current and future activities in the watershed. The major components of the tool and the approach to its development were described in detail in the annual report for FY2000. This report will provide a summary description of the tool, describe current efforts to incorporate groundwater source protection modeling, and describe the development of an on-site wastewater system inventory database.

The source water protection assessment tool described here is being designed to use scientific information and professional experience in the pollution susceptibility assessment process while minimizing the need for new data collection by the user.

Source water assessments provide information about potential contamination risks to drinking water supplies in a watershed. This information may be used by watershed managers to rank risks and to prioritize activities that will protect the drinking water supplies. Protective measures may be expensive. Land use restrictions to protect water quality can extensively alter the potential for development of private property and diminish property values. These potential impacts of management make it very important that source water assessments correctly identify potential risks and present a scientifically credible evaluation of the magnitude of the risk so that the monetary and social costs of protective management can be minimized. Simultaneously, management activities must effectively protect public health. It is vital that sound scientific principles are used to direct the assessment approach and that arbitrariness is avoided. It is also important that the assessment be completed in a timely way and that the costs of the assessment be reasonable. To control costs, available information should be used and the need to collect new data should be minimized. Assessment tools are needed that will help watershed managers appropriately apply the scientific principles of pollutant transport while maximizing the use of available information. We are developing a source water assessment tool that will help fill this need.

The tool includes exploratory hydrologic and pollutant transport models that leave out some details of watershed processes and contaminant fate but retain indispensable mechanisms to provide managers with an assessment system with low data requirements (Grayson et al. 1992; Murray 2002). The model output is a first approximation of contaminant concentration at the drinking water withdrawal point. The model results may prompt questions about pollutant transport that can lead to an enhanced understanding of human activities and natural systems that influence unacceptable contamination risks. Major advantages of this modeling approach are that fundamental elements of watershed hydrology are included and arbitrary management boundaries are not used.

**Surface Water Assessment**

The development of geographic information systems (GIS) and digital elevation models (DEMs) has provided an unprecedented opportunity to describe the pathways of water movement in a watershed. DEM databases for the United States provide data that allows the extraction of drainage networks from the DEMs (Band 1986; O'Callaghan and Mark 1984). Topographic structure, watershed delineations, and overland flow paths derived from DEMs can be transferred to a vector-based GIS for further analysis. Garbrecht (1997) have developed a procedure for assigning flow direction over flat surfaces in raster DEMs. TOPMODEL (Beven et al. 1995; Beven and Kirkby 1979) used DEM topographical information in the simulation of runoff from natural watersheds and from agricultural watersheds with tile drain systems (Kim et al. 1999).

Tarboton (1997) developed a procedure for the representation of flow direction and calculation of upslope areas using rectangular grid DEMs. Rather than representing flow in one of the eight possible directions from a grid cell to an adjacent or diagonal neighbor (D8) this procedure represents flow direction as a vector along the direction of the steepest downward slope on eight triangular facets centered at each grid cell. An infinite number or flow directions, represented as an angle between 0 and $2\pi$ are possible, so this procedure is named D$\infty$. Flow from a grid cell is shared between the two, downslope grid cells closest to the vector flow angle based on angle proportioning. Drainage area is accumulated using this model that has multiple (two) flow paths from each grid cell based on the angle proportions. This procedure has been included in the Terrain Analysis using Digital Elevation Models (TauDEM) software (Tarboton 2000; Tarboton 2002) that is used as a basis for the Surface Water Protection Assessment Tool (SWPAT) developed here. Overland flow and the transport of contaminants simulated in the assessment tool are routed using the D∞ surface flow model.

Visualization of the locations of Potential Contaminant Sources (PCSs) relative to stream locations and topography within a watershed along with the possible route or routes of pollutant transport provides watershed managers with insight that can help in the risk ranking process and in selecting or designing pollution control mechanisms. GISs provide an elegant mechanism for displaying this kind of information as well as facilitating models for routing water and associated pollutants through the watershed to the drinking water treatment plant. Much of the information necessary to support water routing simulation including DEMs <http://mcmcweb.er.usgs.gov/status/dem_stat.html>, stream shapefiles, and precipitation data (SCAS and OCS 2002) are readily available through the internet for nearly all of the United States.

Our objective was to develop a risk-ranking assessment tool that models source water protection scenarios. The tool is being created using a GIS framework. Uses of this tool will expedite the pollution source inventory process. The assessment can be done without using arbitrary protection zones. The user has the option of incorporating fate processes such as volatilization of organic pollutants and dieoff of fecal indicator bacteria.

Moncur (2002) documented the assessment tool development through mid-2002. The system for conducting the surface water assessment process, including possible contamination from surface runoff and inflow from polluted ground water is essentially complete.

The tool provides assistance in finding the appropriate data for the PCS inventory and transport modeling. The D∞ flow model in TauDEM forms the basis for routing water and contaminants through the watershed. By adding algorithms for the transport and fate of pollutants to TauDEM, the simulation portion of the tool has become the Utah Pollutant Transport Model (UPTraM). The model formulation incorporates several simplifying assumptions about watershed processes and pollutant behavior. The principal assumptions are:

1. Both surface water and its associated contaminants move in directions following topography.
2. Ground water or subsurface flow is considered to be shallow subsurface flow that sustains base stream flow.
3. Surface flows are modeled as occurring a fraction of the time (in response to storms). During this fraction of time the surface flow is approximated as being steady state.
4. Discharge is separated into baseflow and stormflow, assumed to represent subsurface and surface flow paths, respectively.
5. During a storm the quantity of runoff contributed to stormflow from each grid cell within the watershed is spatially uniform and determined from precipitation times a surface runoff coefficient.

6. Water pollutants originating at identified source locations (grid cells) move downslope in the surface flow.
7. Surface flow velocity is estimated based on Mannings equation. Velocities are used to calculate travel times and depth is used in the first order parameterization of contaminant loss due to volatilization.

These simplifying assumptions allow the model to function without detailed soils data and infiltration capacity information. Managers can use this model, which has low data requirements, to systematically evaluate the possibility of unacceptable source water contamination from specific events or activities within the watershed. A first approximation estimate of pollutant concentration reaching the drinking water treatment plant point of diversion (POD) and the time-of-travel of the pollutant are calculated. The contaminant flow path is graphically displayed as an overlain GIS coverage with respect to the POD's location. The contaminant concentration at the POD is then compared to the Maximum Contaminant Level (MCL). The tool also outputs estimates of flow velocity, travel time, and flow per unit contour width in GIS grid format. This information can be used to help delineate source water protection zones around the POD as well as to rank possible contamination sources, helping determine how source water protection areas are delineated. This method of inventorying possible contamination source within a watershed first and then modeling to obtain a screening level prediction of the contaminant flow path and concentration at the POD has advantages over setting arbitrary source water protection zones. These advantages include being able to set source water protection zones based on realistic travel times and flow paths. Because of the simplified flow and transport model the results must be considered a first approximation but they can help identify areas of the watershed where specific pollution possibilities should be kept under strict control or eliminated. If the uncertainties associated with the simulation lead to an ambiguous indication of risk, more site-specific data should be collected and more detailed modeling should be performed to support management decisions.

## Surface Water Assessment Tool Structure and Features

Figure 1 is a conceptual diagram of the source water protection assessment tool's structure. There are four major components that make up the assessment tool: (1) a spatial GIS database of watershed physical characteristics, (2) a pollution source inventory and chemical properties database, (3) a graphical user interface, and (4) UPTraM. 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 in the watershed. After evaluating the risk associated with each source, the user can rank the source or a combination of sources so that management action can be appropriately planned and implemented.

### The Inventory and Quick Reference Database

The watershed inventory is a user input database of the current and/or future PCSs within the watershed. A quick-reference database of chemical properties, including toxicity information, is provided to help the user identify and prioritize potential pollution sources. The chemical

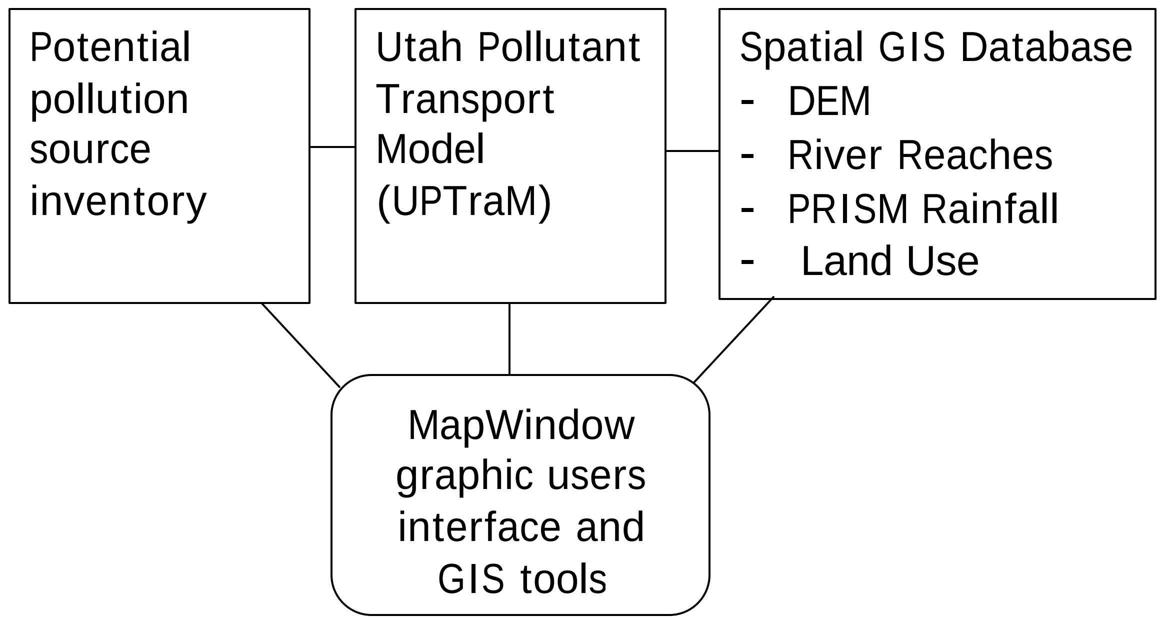


Figure 1. Source Water Protection Assessment Tool Schematic

properties within the quick-reference database are physical and chemical properties for EPA's National Primary Drinking Water Regulation listed compounds (USEPA 2002).

Ranges of loading rates for total and fecal coliforms and nitrogen and phosphorus are also available in the database. GIS land use coverages that delineate urban and agricultural land use practices may be used with loading rate data to evaluate pathogen risk, as indicated by coliforms, from urban runoff, animal feeding operations, and pastures. Potential nutrient inputs to reservoirs may be estimated using the nutrient loading data. Land use coverages may be available from state natural resource management or environmental protection agencies or the National Land Cover Dataset, NLCD (http://edcwww.cr.usgs.gov/programs/lccp/nationallandcover.html). In Utah, land use data for much of the state is maintained by the Department of Natural Resources, Division of Water Resources.

The GIS Spatial Database

A GIS spatial database stores the GIS datasets used by the tool. These datasets include DEMs, river reach files, land use grids, road shape files, precipitation grids, and shapefiles for watershed boundaries. Digital versions of USGS maps are also useful. The SWPAT uses grid DEMs to determine flow paths of water and contamination movement. The standard USGS 7.5 minute quadrangle DEMs with 30-meter grid size, or National Elevation Dataset DEMs interpolated to the coordinate system being used are acceptable for this purpose. The SWPAT requires mean annual precipitation input over the same grid domain as the DEM. The Parameter-elevation Regression on Independent Slopes Model (PRISM) (SCAS and OCS 2002) data is a useful source for mean annual precipitation. To use with SWPAT the PRISM data must be converted to grid format and interpolated to the same grid as the DEM. Commercial GIS software, ESRI's ArcView or ArcInfo (ESRI 2002), is used to do this.

The Pollutant Transport Model, UPTraM

UPTraM and other components of SWPAT have been developed using the MapWindow GIS Application Development Toolkit developed at Utah State University. This software package allows for visualization of the watershed geography and simulated surface flow paths of water and associated pollutants. The UPTraM programs within SWPAT access ESRI binary grid format data directly using the ESRI application programmers interface that is part of Spatial Analyst (version 1.0a or higher) with ArcView (version 3.0a or higher) (ESRI 2002). This allows for convenient simultaneous display and further analysis of the results in ArcView. For users who do not have ArcView, the programs use ASCII or simple binary grid format data files.

The UPTraM model is based on topographic accumulation as illustrated in Figure 2. The input, for illustrative purposes taken as precipitation, P(x,y) is allowed to be spatially variable. The volume of precipitation over the shaded area A is the area integral $\int_A P(x,y)dA$, so with the assumption of steady state flow along topographic flow directions and a runoff coefficient C the discharge from the shaded area is

$$Q = \int_A C\, P(x,y)dA \tag{1}$$

This is expressed as a per unit width, or specific discharge

$$q(x,y) = Q/b = \frac{1}{b}\int_A C\, P(x,y)dA \tag{2}$$

and has units of length$^2$/time (e.g., m$^2$/s). The spatial dependence of q(x, y) was shown above because q can be evaluated at each point in the terrain. Equation (2) defines the specific weighted flow accumulation function. Notationally we write this

$$q(x,y) = a[r(x,y)] \tag{3}$$

where r(x,y) = C P(x,y) is the spatially variable weighting and a[.] denotes the specific flow accumulation function.

Although input precipitation leading to overland flow was used to illustrate the accumulation function, the application is more general. The weight function r(x,y) may also represent a loading of contaminant that moves downslope in which case accumulation can be used to quantify downslope contaminant load.

The UPTraM model uses the D∞ flow model (Tarboton and Ames 2001) to numerically evaluate the specific weighted flow accumulation from a DEM grid. The grid DEM processing routines used build upon methods described by (Band 1986; Garbrecht and Martz 1997; Jenson and Domingue 1988; Marks et al. 1984; O'Callaghan and Mark 1984; Tarboton 1997; Tarboton and Ames 2001). The steps involved are: (1) pit filling corrections, (2) computation of slopes and flow directions; (3) computation of contributing area, specific catchment area and weighted accumulation. These DEM procedures can also be continued to map channel networks extraction and calculate other quantities (Tarboton and Ames 2001).

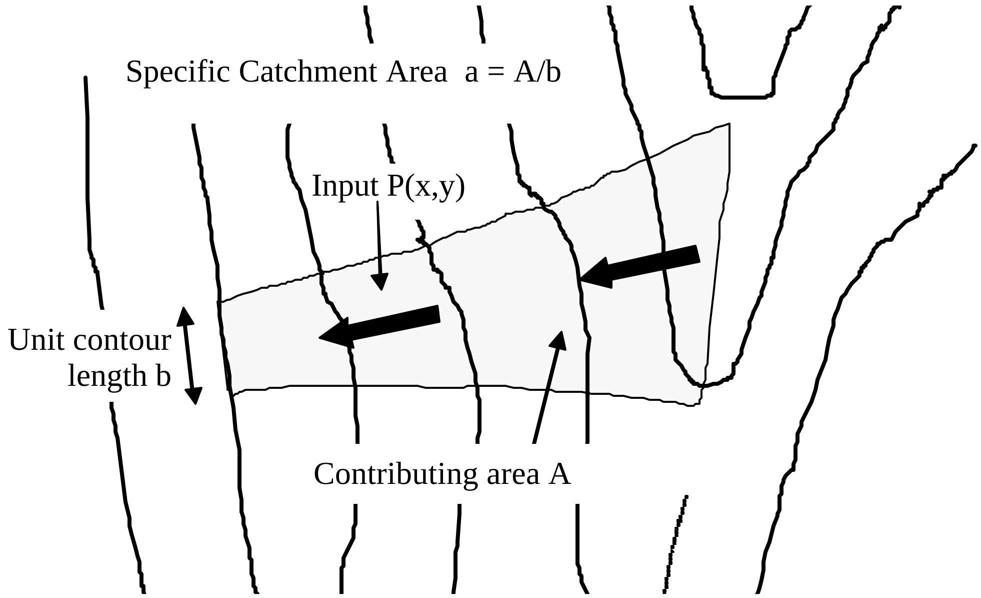


Figure 2. Topographic flow accumulation. Lines are topographic contours with flow away from a ridge at the right.

Digital elevation data contains pits that are defined as grid cells or sets of grid cells that do not drain because they are surrounded by higher grid cells. Non-draining areas are uncommon in natural topography and are assumed to be artifacts that came about due to the discrete nature and data errors in the production of the DEM. We use a "flooding" approach to remove them. 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 (Jenson and Domingue 1988).

Once pits have been filled, slope and flow direction are evaluated using the D$\infty$ method (Tarboton 1997). In this method, the flow direction angle measured counter clockwise from east is represented as a continuous quantity between 0 and $2\pi$. 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 3. 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. 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 $45^o$ ($\pi/4$ 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. Further details are 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. Later, flow velocity in these flat areas is determined by assuming an arbitrary small minimum slope.

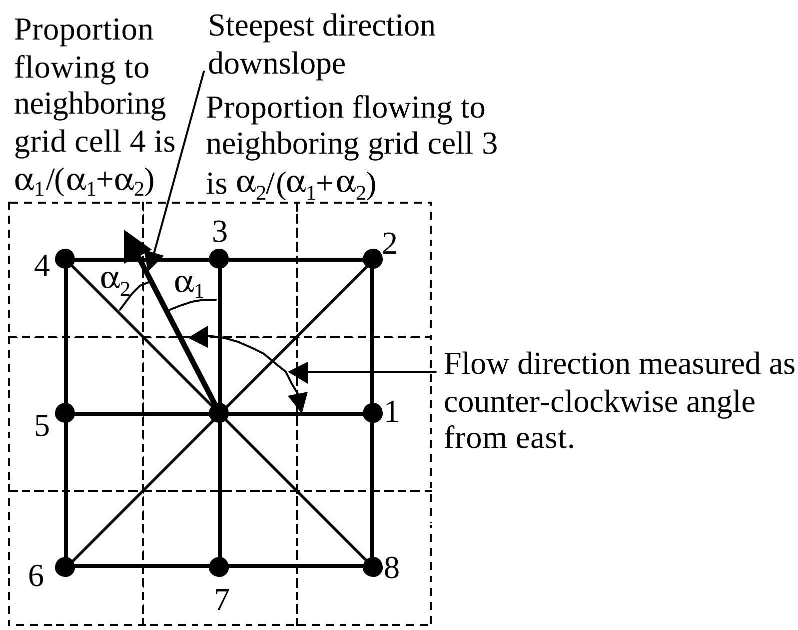


Figure 3. Flow direction defined as steepest downward slope on planar triangular facets on a block centered grid.

The flow direction angles calculated using the procedure described define a flow field that quantifies the proportion of flow that is transferred from each grid cell to downslope neighbors. The accumulation of weighted upslope input (equation 3) is then evaluated numerically using

$$a[r(x,y)] = r(x,y)\Delta + \sum_{k \text{ contributing neighbors}} p_k a(x_k, y_k) \qquad (4)$$

where $\Delta$ is the grid cell size, r(x, y) the weight being accumulated, $p_k$ the proportion of neighbor k that drains to the cell under consideration and $a(x_k, y_k)$ represents the accumulation function evaluated at a neighbor that contributes flow from upslope. A recursive procedure is used to calculate the accumulation of weighted upslope input. This procedure is an extension of the very efficient recursive algorithm for single directions (Mark 1988) to the multiple flow direction case used in D∞.

Inputs to the calculation for flow are mean annual precipitation rate $P_1(x,y)$, event precipitation rate $P_2$, and surface and base flow runoff coefficients, $C_s$ and $C_b$. At present, subsurface flow is only used to estimate base flow. Subsurface contaminant transport is not modeled. The graphic user interface (described below) provides the opportunity for the user to input per unit area surface flow, $C_sP_2$, and average baseflow, $C_bP_1(x,y)$. An annual precipitation grid provides for a representation of spatially variable precipitation inputs to baseflow. The model further assumes that surface flow occurs only over a fraction, w, of the year so where a yearly surface precipitation rate is given the surface input is taken as

$$r_s = C_sP_2/w \qquad (5)$$

In cases where an event of a specific duration is specified the surface input is

$$r_s = C_sP_2 \qquad (6)$$

The specific (per unit width) discharge at any point due to surface input is

$$q_s(x,y) = a[r_s] \qquad (7)$$

The specific (per unit width) baseflow at any point is

$$q_b(x,y)=a[C_b P_1(x,y)] \quad (8)$$

The flow at any point is taken as $q_s(x,y)$ for non stream locations and $q_s(x,y) + q_b(x,y)$ for stream locations. Where a stream is present, as indicated in the EPA river reach file, subsurface baseflow is assumed to have entered the stream.

Contaminants that move with surface water may be subject to reduction due to various processes, such as die off (in the case of fecal coliforms) or volatilization (in the case of chemical spills). We have incorporated the capability to model first order decay in UPTraM to represent these processes. Where reduction is present equation (4) is modified to

$$a_d[r(x,y)] = r(x,y)\Delta + \sum_{k\ \text{contributing neighbors}} p_k d(x_k, y_k) a_d(x_k, y_k) \quad (9)$$

where the subscript on $a_d[.]$ indicates the specific accumulation function with decay and d(x,y) is a reduction factor given by

$$d(x,y) = \exp(-\lambda(x,y)t(x,y)) \quad (10)$$

Here $\lambda(x,y)$ is a decay coefficient that quantifies dieoff rate or volatilization Coliform dieoff occurs both in overland flow and in streams. Volatilization occurs only in streams and the rate coefficient is estimated using the two-film method of Rathbun (1998). An estimated stream velocity, depth, and wind speed are needed for this calculation. t(x,y) is the residence time in each grid cell, taken as $\Delta/v(x,y)$ where v is velocity. Velocity is estimated using Manning's equation for steady flow, with the roughness parameter n a function of land cover.

To model the concentration of contaminants originating over a localized area, such as a transportation spill, or an animal feeding operation (AFO) the loading of contaminant into flow is set to a threshold level $C_{sol}$ over an indicator area i(x,y) designating the area of the spill or contaminant source. i(x,y) has the value 1 within the source and 0 out of it. For transportation or above ground tank spills the $C_{sol}$ is set at the compound solubility with the assumption that there is an unlimited amount of compound on the soil that enters water at a threshold solubility. For AFO operations $C_{sol}$ is set at a concentration representative of runoff leaving the source area.

A concentration limited accumulation function is then used to evaluate the contaminant concentration downslope from the source. Flow is written

$$q(x,y)=a[r_s] \quad (11)$$

Over the substance supply area, concentration is at the threshold $C_{sol}$.

If i(x, y) = 1

$$C(x,y) = C_{sol} \quad (12)$$
$$L(x,y) = C_{sol}\, q(x,y)$$

Where L(x,y) denotes the load being carried by the flow (per unit width). At remaining locations the load is determined by accumulation of this Load L with decay

$$L(x,y) = \sum_{k\ \text{contributing neighbors}} p_k d(x_k, y_k) L(x_k, y_k) \quad (13)$$

Concentration is determined by

$$C(x,y) = L(x,y)/q(x,y) \quad (14)$$

The denominator in (14) includes the baseflow for stream locations, but includes only surface flow for off stream locations.

The Graphical User Interface

The components of the graphical user interface for the source water protection assessment tool are: (1) the main GIS graphical interface, (2) the GIS coverage project builder, (3) the PCS inventory data management utility, (4) the transportation accident data form, and (5) the pollutant transport and degradation/volatilization analysis model, UPTraM. To get the program started, the user must obtain and input the necessary GIS coverages of the watershed of interest. These coverages include a watershed boundary shape file, a grid DEM, and an average annual precipitation grid. The user may also add a land use shape file and grid, a river reach shape file, and a major road shape file. All of these can be displayed graphically through the MapWindow part of the GIS interface. The input GIS coverages can be used as a platform for the input of PCS locations and for model analysis visualization. Once these GIS coverages are input via the user interface program lead project builder, the user can start to inventory a watershed for PCSs.

Figure 4 shows the SWPAT MapWindow graphical interface. The GIS coverages shown in Figure 4, are a grid DEM, an animal feeding operation inventory shape file, an above ground tank inventory shape file, and a watershed boundary shape file (green). Other GIS datasets that are included in the table of contents panel on the left but are not active in this display are the annual average precipitation grid, a major roads shape file, an EPA level 3 river reach shape file, and several accident scenario shape files.

When starting a new project within the assessment tool, the program will guide the user to input the required GIS data sets for use in UPTraM. The data sets that must be input are: a grid DEM, a precipitation grid, a river reach shape file, a watershed boundary shape file, and a land use grid. The land use grid needs to be condensed into the five general land use groups to be used by the tool, namely (1) water, (2) urban, (3) pasture, (4) non-pasture agriculture, and (5) rangeland/forest areas. The GIS coverage project builder form is shown in Figure 5. The user selects the GIS coverage that is going to be input and the program prompts the user with another form that allows the user to browse the computer hard drive for the desired information. The inventory requires the user to input PCSs for geographical placement within the watershed and associated chemical property information from the quick-reference database. There are eight different PCS types that can be inventoried. Eventually a modeling scenario for each of these kinds of sources will be available. These different PCS types are:

1. Above ground tanks (AGTs)
2. Underground tanks (UGTs)
3. Animal feeding operations (AFOs)
4. Transportation accidents
5. Landfills
6. Superfund sites
7. Chemical Companies
8. Hazardous waste sites.

At this writing, only modeling scenarios for direct surface water contamination routes are available, i.e., above ground tanks, animal feeding operations, and transportation accidents.

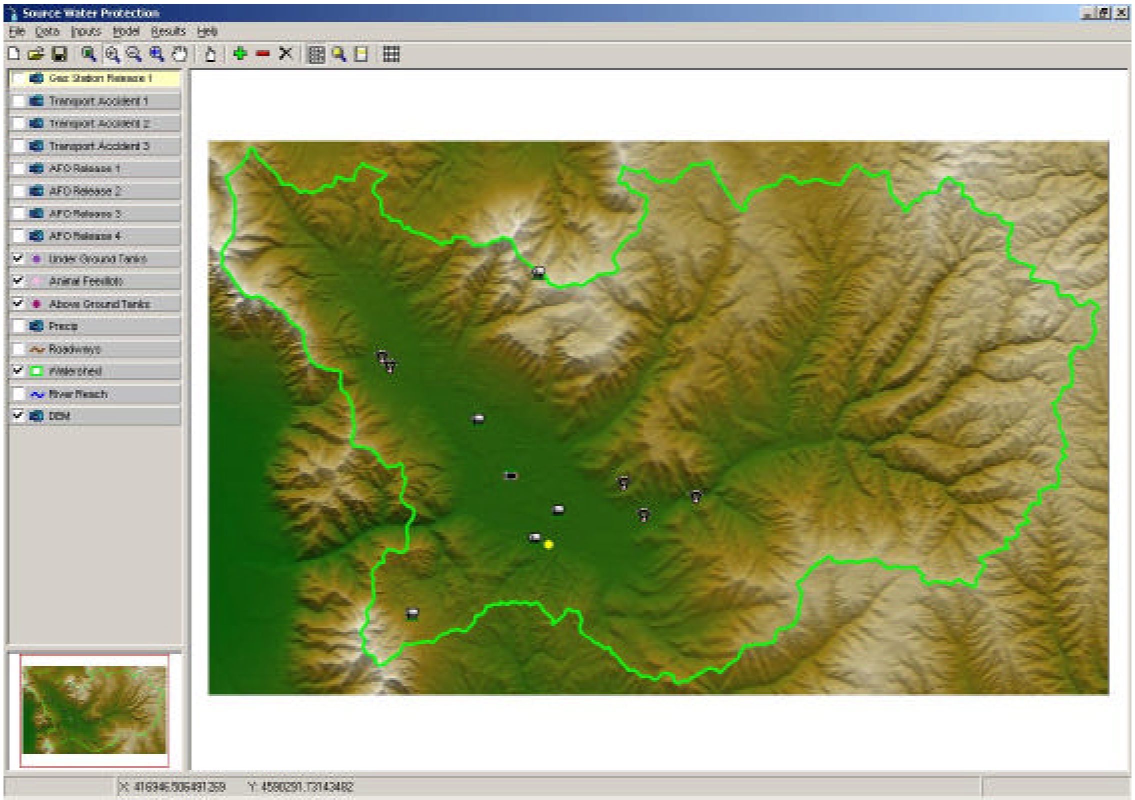


Figure 4.  Assessment tool main interface (MapWindow).

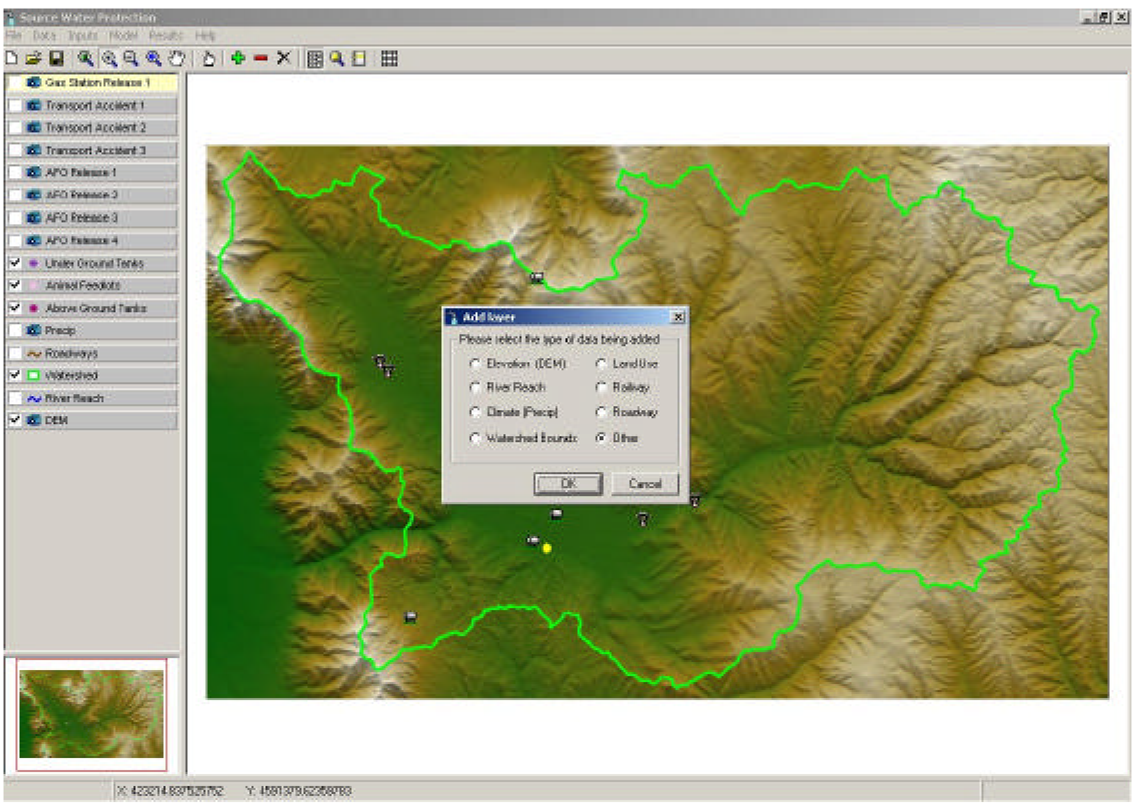


Figure 5.  SWPAT GIS coverage project builder form.

Figure 6 shows the PCS inventory collection form for aboveground tanks. Once a PCS is identified within the watershed it can be inventoried inside this database and have information concerning the contamination type input. The information input includes source location, source type or chemical, contaminant properties, loading rate, percentage of grid cell contaminated and release volume. The interface allows the user to select contaminant properties from the quick-reference chemical database and edit them as appropriate and the location of a PCS can be input by pointing and clicking the location on the input GIS coverages. If the user wants to model a chemical that is not within the supplied quick-reference chemical database, the user types in the chemical information manually, instead of getting the information from the database's pull down menus. The information that needs to be input includes the chemical name, water solubility, PCS owner/operator information, chemical amount stored, and amount of chemical spilled. If the user wants to have the chemical volatilize between the spill location and the drinking water plant's POD, the user will need to provide a first order volatilization rate (in units of per hour) within the UPTraM input form. Figure 7 shows the SWPAT aboveground tank inventory input form.

The AFO input form in Figure 8 requires facility location, owner/operator information, coliform load (high, medium, and low), approximate radius of the feedlot in meters, and a user choice selection concerning whether storm water discharge from the AFO is controlled or not. Modeled storm events can range from a 2-year, 5-minute to 500-year, 24-hour rainstorm. The amount of precipitation is measured in inches. EPA requires a CAFO to control runoff from a 25-year, 24-hour storm. This is considered to provide the most reliable and fail-safe means of protecting the environment from hazardous waste spills, leaks, or accumulated liquids (USEPA 1998).

If the AFO is uncontrolled then any storm event yields contaminated runoff. The user selected coliform load (high, medium, and low) information comes from the land use-coliform loading rate quick-reference database. Any surface runoff that comes in contact with the AFO will result in runoff with a coliform concentration set by the user at high, medium, or low concentration. Animal grazing on fenced pasture lands or open rangelands can be modeled as an uncontrolled AFO.

The transportation accident form in Figure 9 requires input of location, road where accident occurred; chemical spilled and percentage of one grid cell area (30 meters by 30 meters) the spill covers (values >100% are allowed to indicate that more than one cell is affected), and selected quick-reference chemical database information. If the user would like to model a contaminant release that spills directly into a stream, the user specifies the contaminant spill location in the stream using the point-and-click operation.

Once all the required GIS coverages and inventory information are input, the pollutant transport and degradation analysis part of the SWPAT interface can be accessed and executed. The UPTraM input form requires the user to input information about the annual average surface runoff and baseflow in the watershed in units of inches per year, for runoff coefficient calculations. A storm event return period and duration needs to be selected from the provided pull down menus as shown in Figure 10.

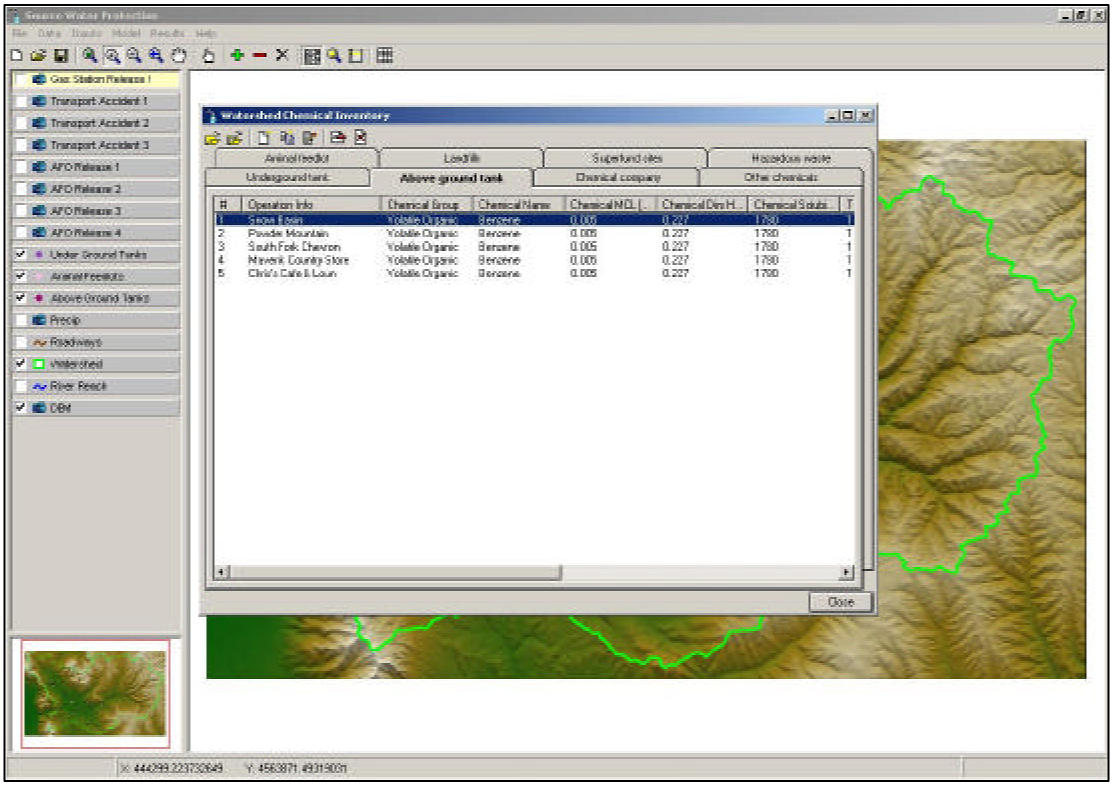


Figure 6. SWPAT watershed PCS inventory form.

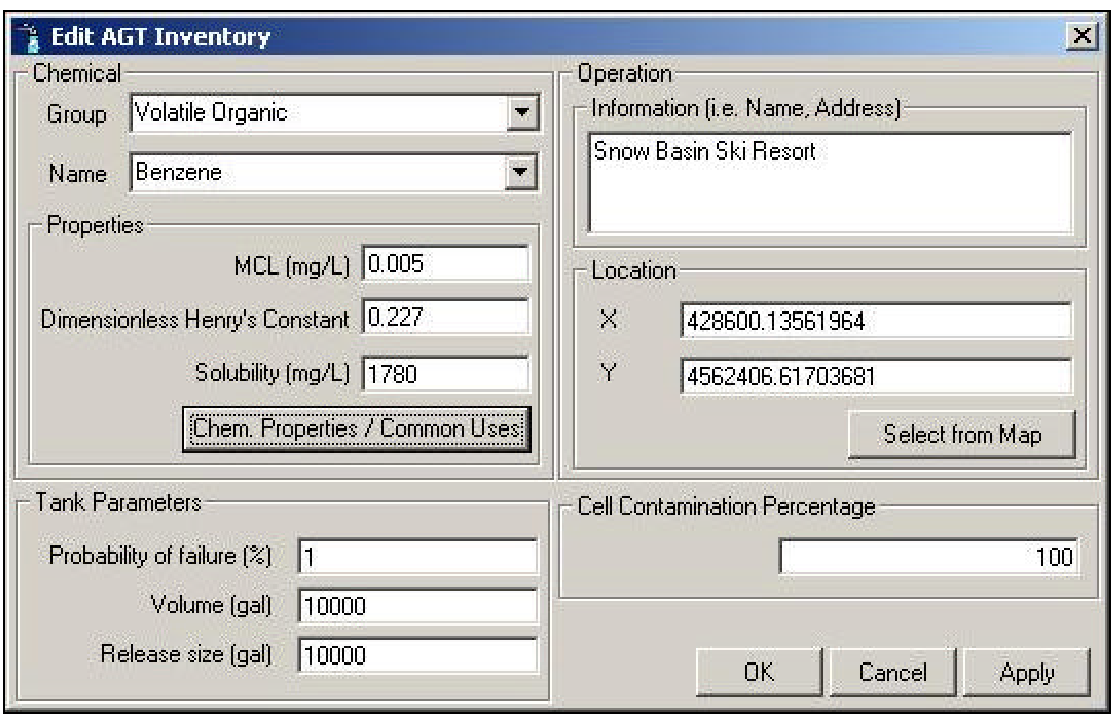


Figure 7. SWPAT above ground tank inventory input form.

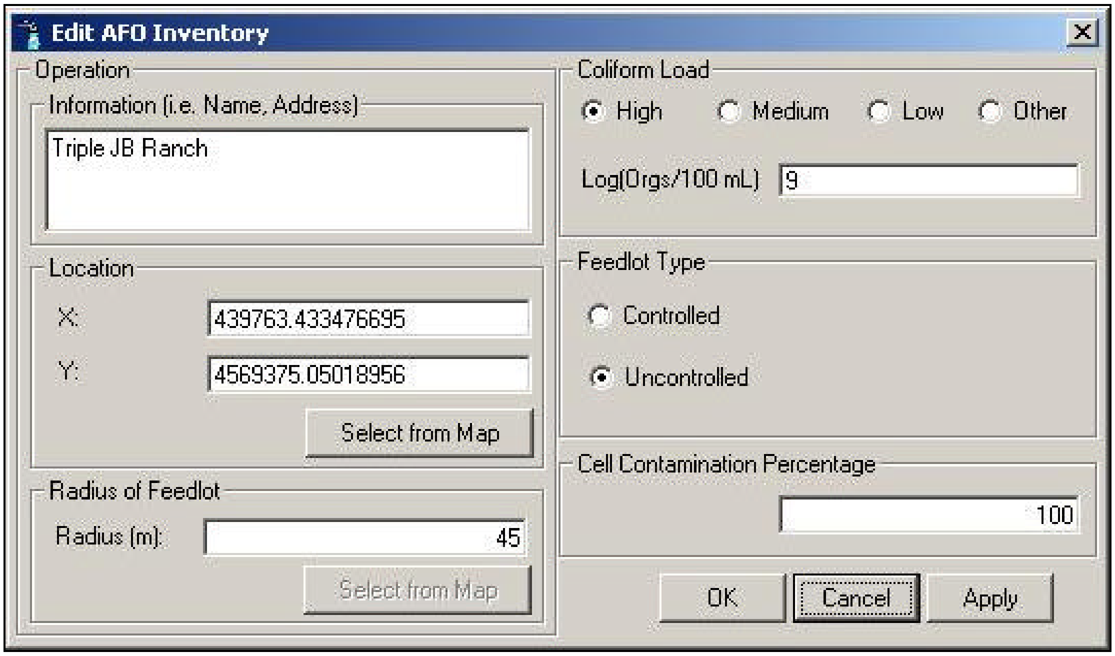


Figure 8. SWPAT animal feeding operation (AFO) inventory input form.

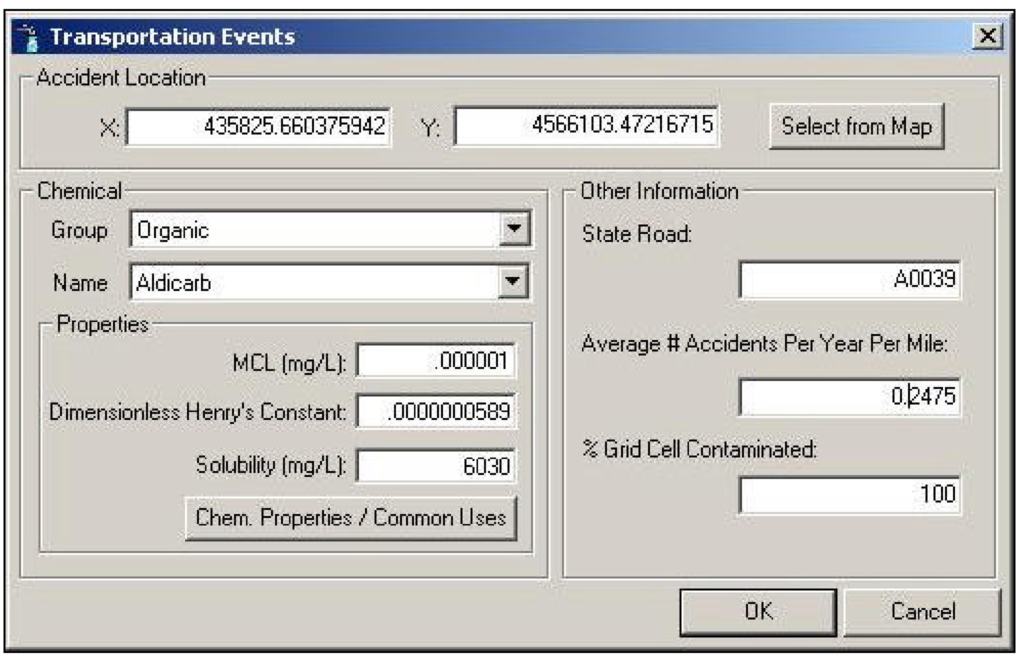


Figure 9. SWPAT transportation accident input form.

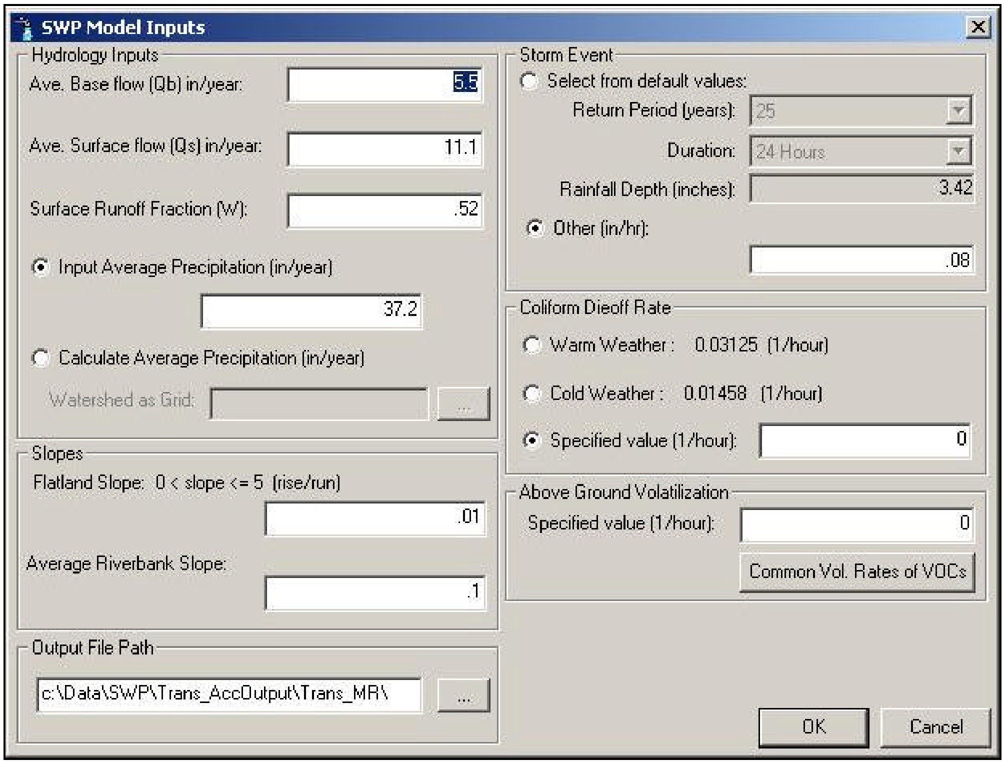


Figure 10.SWPAT UPTraM information input form.

The baseflow can be determined as the average of the low flows within 1 year. The average baseflow for a representative number of years can be averaged to obtain a single value for baseflow. Figure 11 shows an example for the Ogden River watershed in northern Utah.

UPTraM also needs an estimate of the surface runoff time fraction (*w*). This is the fraction of time in 1 year that runoff is present. One way of estimating this is to assume that the surface runoff is present each day within a year that total flow ($Q_t$) is greater that the baseflow (Qb) plus 10%. Another method for determining *w* is to assume *w* is the fraction of time when $Q_s$ (cfs) is greater than 10% of $Q_s$max. UPTraM uses these estimated valves to estimate surface runoff and subsurface infiltration coefficients, $C_s$ and $C_b$, respectively. This user selected and input information allows the SWPAT to create the storm event precipitation grid r(x) and separate it into surface runoff and baseflow input grids.

If the user wants a chemical to volatilize or the coliform load to dieoff, then a first order decay rate must be selected by the user from the menu or input manually in units of per hour. If no volatilization/dieoff is desired, then the user must enter a rate of zero.

The slopes box requires information on the minimum slope of flatland areas within a watershed. This information is required by UPTraM to assign a land slope when the difference in elevation between two grid cells is equal to zero or very small. The user also inputs a riverbank slope value for river reaches; a value of 0.1 is the default. The output file path requires the user to specify where the UPTraM output grid will be saved when the model is run. A grid of

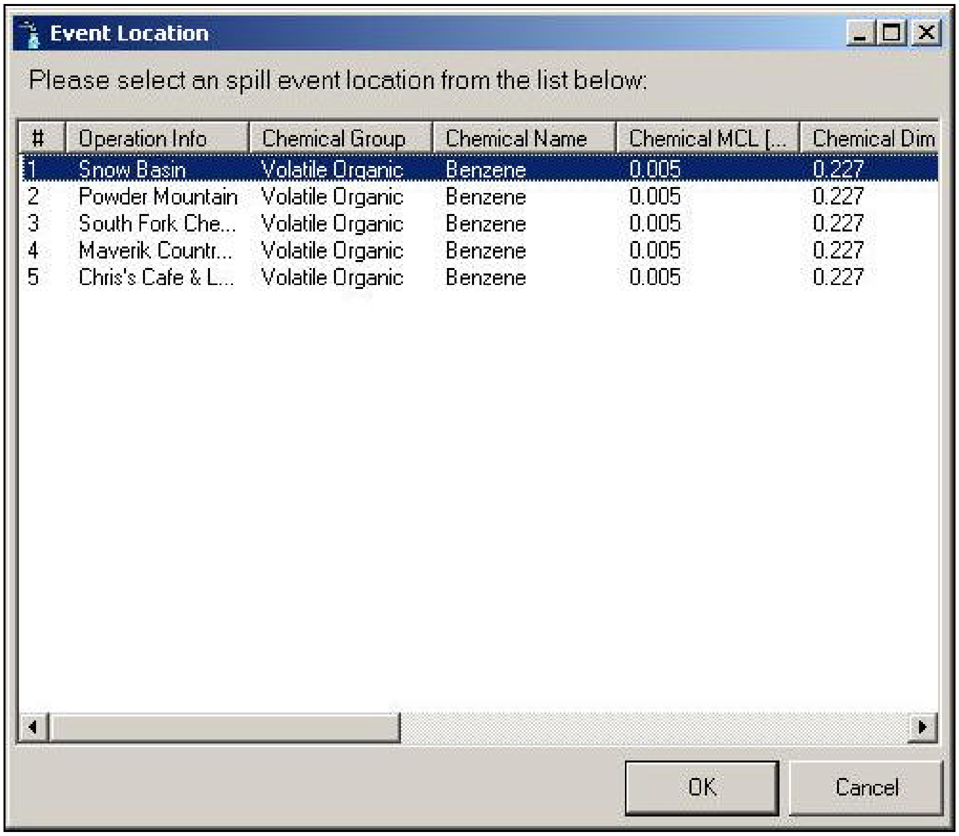


Figure 11. Event location selection form.

Manning's n values for the watershed is also generated and used in the simulation. To run, UPTraM accesses the event location selection form, Figure 10. By selecting the desired PCS the model will run with the model inputs provided for that PCS entry.

An Example: Coliforms from an Animal Feeding Operation

A coliform releasing scenario was modeled for the Ogden River Basin in northern Utah. Two storm sizes were used in the assessment: a 25 yr-24 h storm (0.143 in/h) and a 1 yr-24 h storm (0.08 in/h). The location of the Triple JB Ranch was used as the source. High runoff concentrations of $10^9$ total coliforms/100 mL were used. The results with and without a decay rate of 0.03 $h^{-1}$ were examined. Without decay, the concentrations of coliforms in the runoff are reduced only by dilution as they are transported toward the POD. The annual average base flow was 5.5 in/yr and the runoff fraction was approximately 70%. Manning's n values of 0.03, 0.05 (Flammer and Jeppson 1996) and 0.1 (Kouwen and Fathi-Moghadam 2000) for typical rivers, residential areas, and rangeland/forestlands, respectively, were used to calculate overland flow velocity and residence times within each grid cell. Pineview Reservoir was assumed to be empty so that the reservoir bed served as a broad river channel with little slope. Table 1 and Figure 12 show the results of the simulations. Travel times for the contaminated water was approximately

Table 1.  Predicted concentration at the POD form the AFO scenarios

| Operation | AFO Radius (m) | Contaminant | Coliform Load at Source (Orgs/100 mL) | Storm Size | Decay ($hr^{-1}$) | % Grid Contaminated | Predicted Concentration at POD (Orgs/100 mL) | Travel Time (hr) |
|---|---|---|---|---|---|---|---|---|
| Triple JB Ranch, AFO | 45 | Coliforms | 1E+09 | 25 yr-24 hr | 0.03 | 100 | 3.1E+04 | 5.6 |
| Triple JB Ranch, AFO | 45 | Coliforms | 1E+09 | 25 yr-24 hr | None | 100 | 3.4E+04 | 5.6 |
| Triple JB Ranch, AFO | 45 | Coliforms | 1E+09 | 1 yr-24 hr | 0.03 | 100 | 3.0E+04 | 7 |
| Triple JB Ranch, AFO | 45 | Coliforms | 1E+09 | 1 yr-24 hr | None | 100 | 3.4E+04 | 7 |
| ***25 yr-24 hr storm = 0.1425 in/hr**<br>****1 yr-24 hr storm = 0.08 in/hr**<br>***** Total Coliform MCL  = 5000 orgs/100 mL** | | | | | | | | |

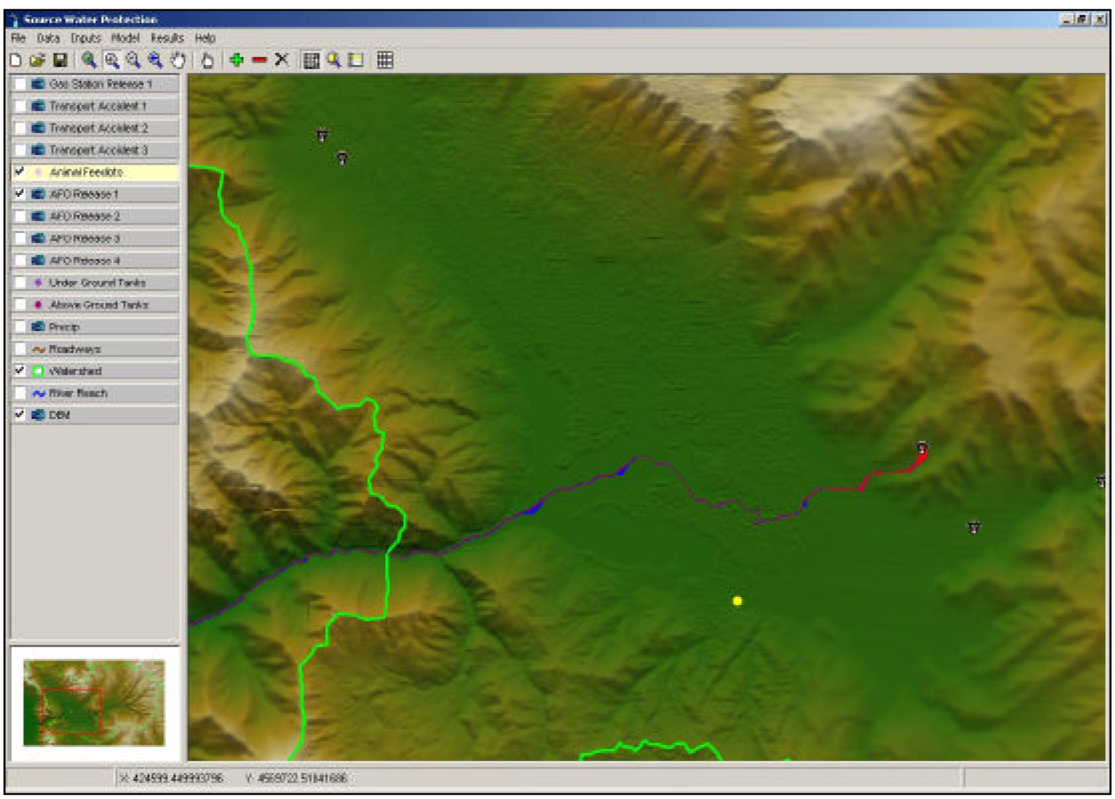


Figure 12.Coliform flow path from Triple JB Ranch.

6 to 7 h, depending on the storm intensity. Decay reduced the concentrations at the POD just below Pineview Dam only slightly. This "reasonable worst case" scenario simulation suggests that there may be a pathogen hazard associated with runoff from an animal feeding operation at this location.

**Developing a Ground Water Source Protection Modeling**

Research and development efforts are underway to incorporate groundwater pollutant transport modeling into the Assessment Tool. The initial focus is on modeling conjunctive sources, i.e., sources of pollutants to surface water from contaminated ground water that enters streams. MODFLOW (Harbaugh et al. 2000) is being used to estimate ground water flow parameters and MT3D (Zeng 1990) is being used to calculate concentrations of pollutants at the ground water/surface water interface. UPTraM will calculate the change in concentration as the pollutant moves down stream. Pollutant transport to drinking water wells will also be included in the model.

**An On-Site Wastewater System Database for Utah**

A major challenge in source water protection programs is collecting information about the density of on-site wastewater systems in the watershed. It is often assumed that on-site systems contribute nitrate, other nutrients, and pathogens to drinking water supplies. A quantitative assessment of the amount of on-site wastewater-associated contamination actually reaching source waters is rarely available. Watershed managers are often left to guess about whether more on-site wastewater systems should be allowed in drinking water watersheds. The Utah Department of Environmental Quality, Division of Water Quality has requested that a state-wide database system be implemented so that management information can be more readily available to local health department personnel and to state water quality managers. Because of the compatibility of this goal with the source water protection assessment mission of the present project, database development has been included in the project. Development of the database is nearly complete.

Selected commercially available on-site system databases were evaluated early in the project. We concluded from our evaluation that none of the databases that were evaluated were likely to be accepted by local health department personnel in Utah. It was our judgment that each of these databases required conformation of the data collection and data entry processes that would not be acceptable. Telephone interviews with personnel of health departments outside of Utah that had purchased these programs revealed that none of these potential users were, in fact, using the programs that they had purchased.

A database that was being actively used, and that was perceived as being very valuable, was a Microsoft Access database created by the Whatcom County, Washington, health department. Apparently, the database was well accepted because it was consistent with the practices of those using it and the users were actively involved in designing it. Following this model, we have worked closely with two of the 12 local health departments in Utah to construct a database program using Access software. Personnel from the Wasatch City-County Health Department and Tricounty Health Department have worked closely with student programmers to build the database. Data entry formats are consistent with Utah on-site wastewater rules and are similar to paper formats currently used by these two health departments. Informal inquiries with other health departments indicate that at least 7 of the 12 departments are interested in evaluating the database program. Workshops are planned to involve other health departments in creating the final version or versions of the database.

## Conclusions

The ease of obtaining GIS data combined with the development of a computational procedure for representing flow direction and calculating upslope areas using DEMs (Tarboton 1997) has opened the opportunity for simulating pollutant transport in watersheds in a new way. This approach is realistic, scientifically credible, and requires relatively little data. Simplifying assumptions about chemical pollutant loading into storm water and pollutant fate processes allows the use of chemical property data from the literature to estimate contaminant concentrations at a point of extraction for drinking water for drinking water use. Similarly, estimated coliform loading and die-away rates allows the estimation of coliform concentrations from possible sources in a watershed. This approach facilitates delineation and ranking of zones of potential contamination based on the risk that possible contamination sources within those zones present to a drinking water treatment and distribution system. The SWAPT helps managers to determine if other methods of analysis or additional system monitoring are needed to increase confidence in determining a possible contaminant source's threat to source water quality.

## Publications

Mocur, K.D. (2002). Synthesis of a risk-based management tool for the prediction of source water protection concerns. Department of Civil and Environmental Engineering, College of Engineering, Utah State University, Logan, UT.

Sorensen, D.L., K.D. Moncur, D.G. Tarboton, M. Kemblowski, S. Quiang, and S. Gogate (2003). A surface water protection assessment tool that uses digital elevation models. In "Proceedings of the 2003 Source Water Protection Symposium," American Water Works Association, Denver, CO.

## Literature Cited

Band, L. E. (1986). "Topographic partition of watersheds with digital elevation models." *Water Resour. Res.*, 22(1), 15-24.

Beven, K., Lamb, R., Quinn, P., Romanowicz, R., and Freer, J. (1995). "TOPMODEL." Models of Watershed Hydrology, V. P. Singh, ed., Highlands Ranch, CO., 627-668.

Beven, K. J., and Kirkby, M. J. (1979). "A physically based variable contributing area model of basin hydrology." *Hydrol. Sci. Bull.*, 24(1), 43-69.

ESRI. (2002). "ESRI GIS and mapping software. <http://www.esri.com/>." ESRI, Redlands, CA.

Flammer, G. H., and Jeppson, R. W. (1996). *Fundamental principles and application of fluid mechanics*, Utah State University, Logan, UT.

Garbrecht, J., and Martz, L. W. (1997). "The assignment of drainage direction over flat surfaces in raster digital elevation models." *J. Hydrol.*, 193, 204-213.

Grayson, R. B., Moore, I. D., and McMahon, T. A. (1992). "Physically based hydrologic modeling 2. Is the concept realistic?" *Water Resour. Res.*, 26(10), 2659-2666.

Harbaugh, A. W., Banta, E. R., Hill, M. C., and McDonald, M. G. (2000). "MODFLOW-2000, the U.S. Geological Survey modular ground-water model: user guide to modularization concepts and ground-water flow process." *Open-File Report 00-92*, U.S. Geological Survey, Branch of Information Services, Denver, CO.

Jenson, S. K., and Domingue, J. O. (1988). "Extracting topographic structure from digital elevation data for geographic information system analysis." *Photogrammet. Eng. Remote Sens.*, 54(11), 1593-1600.

Kim, S., Delleur, J. W., Mitchell, J. K., Engel, B. E., and Walker, S. E. (1999). "Simulation of runoff in agricultural watersheds with tile drains using an extended TOPMODEL." *Trans. ASAE*, 42(3), 639-650.

Kouwen, N., and Fathi-Moghadam. (2000). "Friction factors for coniferous trees along rivers." *J. Hydraulic Eng.*, 126(10), 732-740.

Mark, D. M. (1988). "Network models in geomorphology." Modelling Geomorphological Systems, M. G. Anderson, ed., Wiley, New York, NY, 73-97.

Marks, D., Dozier, J., and Frew, J. (1984). "Automated basin delineation from digital elevation data." *Geo-Processing*, 2, 299-311.

Murray, A. B. (2002). "Seeking explanation affects numerical modeling strategies." *EOS*, 83(38), 418-419.

O'Callaghan, J. F., and Mark, D. M. (1984). "The extraction of drainage networks from digital elevation data." *CVGIP Graphical Models Image Process*, 28, 328-344.

Rathbun, R. E. (1998). "Transport, behavior, and fate of volatile organic compounds in streams." *I19.16:1589*, US Geological Survey, Washington, DC.

SCAS, and OCS. (2002). "Climate mapping with PRISM. <http://www.ocs.orst.edu/prism/prism_new.html>." Spatial Climate Analysis Service and the Oregon Climate Service, Oregon State University, Corvalis, OR.

Tarboton, D. G. (1997). "A new method for the determination of flow directions and upslope areas in grid digital elevation models." *Water Resour. Res.*, 33(2), 309-319.

Tarboton, D. G. (2000). "Terrain analysis using digital elevation models (TauDEM).", Utah Water Research Laboratory, Utah State University, Logan, UT.

Tarboton, D. G. (2002). "TauDEM, a suite of programs for the analysis of digital elevation data. <http://www.engineering.usu.edu/cee/faculty/dtarb/>." Utah Water Research Laboratory, Utah State University, Logan, UT.

Tarboton, D. G., and Ames, D. P. (2001). "Advances in the mapping of flow networks from digital elevation data." *World Water and Environment Resources Congress*, Orlando, FL.

USEPA. (1998). "Strategy for addressing environmental and public health impacts from animal feeding operations (Draft).", US Environmental Protection Agency, Washington, DC.

USEPA. (2002). "Current drinking water standards. <http://www.epa.gov/safewater/mcl.html>.",, US Environmental Protection Agency, Washington, DC.

Zeng, C. (1990). "MT3D a modular three-dimensional transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems." US Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, OK.

# Information Transfer Program

# Information Transfer Plan

## Basic Information

| | |
|---|---|
| **Title:** | Information Transfer Plan |
| **Project Number:** | 2001UT3721B |
| **Start Date:** | 3/1/2001 |
| **End Date:** | 2/28/2002 |
| **Funding Source:** | 104B |
| **Congressional District:** | UT 1 |
| **Research Category:** | Not Applicable |
| **Focus Category:** | Education, None, None |
| **Descriptors:** | Public Education; Information Transfer |
| **Principal Investigators:** | Ronald C. Sims, R. Ivonne Harris, Tamara Peterson, Jan Urroz |

## Publication

# Center for Water Resources Research

## Annual Technical Report

The Source Water Protection project described under the Research Project section of this report is an integrated research and information transfer project that was planned, developed, and implemented with the collaboration of UCWRR and the relevant State of Utah water agencies. Please refer to the Research Project section of this Annual Report for specific information transfer activities related to the Source Water Protection project supported by the USGS Section 104 funds.

In FY 02, the Utah Water Research Laboratory (UWRL) expended approximately $9.9 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 research addressing source water protection (SWP), and outreach, information dissemination,, and strategic planning and water resources and environmental quality issues in the State of Utah.

USGS Section 104 funds were used specifically to address the Utah Source Water Protection Plans (SWPP) during FY 2002-2002 at the request for assistance from the Utah Department of Environmental Quality (UDEQ), Divisions of Water Quality and Drinking Water. Risks to Utah's source water include both point and non-point sources. Several UCWRR faculty members are involved from the Colleges of Engineering, Agriculture, and Natural Resources. The UCWRR has partnered with the UDEQ, Divisions of Water Quality and Drinking Water, to assess NPS pollution as part of the SWPP. As part of this partnership, UCWRR is developing specific information and a database concerning the location and status of on-site wastewater treatment systems in important watersheds in Utah. SWPPs are especially important during periods of lower than normal precipitation that is characteristic of this fiscal year.

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. 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 provides a mechanism to generate funds for training and technology transfer regarding siting, design, installation, maintenance, and monitoring of on-site wastewater treatment 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.

## Information Transfer

Information Transfer and Outreach within the UCWRR continues to be a form of scholarship that is stimulated, supported, and rewarded in FY 02. 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 continue to be involved in regular meetings with State of Utah agencies, including the Department of Environmental Quality (DEQ) the Department of Natural Resources (DNR), and the State Engineer Office to provide source water protection, on-site training, non-point source (NPS) pollution assistance, and technology transfer, and development of source water protection plans (SWPPs) within the context of Utah issues.

## 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 prepared two water education manuals for 4$^{th}$ grade elementary school teachers and students.

Technical publications in FY 01-02 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.

Longhurst, M. and Smith, G.G. (2002). The Search for the Water Cycle Teachers Edition and Student Findings Booklet. Utah Water Research Laboratory, Utah State University, Logan, UT.

Sims, J.L. and M. Cashell (2002). Basic Site Evaluation Techniques for On-Site Wastewater Treatment. Utah Water Research Laboratory, Utah State University, Logan, UT.

Sims, J.L. and M. Cashell (2002). Fundamentals of On-Site Wastewater Treatment and Disposal Systems. Utah Water Research Laboratory, Utah State University, Logan. UT.

Smith, G.G. (2001-2003). Powell States and Columbia Water Education Calendar. International Office for Water Education, Utah Water Research Laboratory, Utah State University, Logan, UT.

Smith, G.G. (2002). Substitute Teacher Handbook (Elementary V Edition). International Office for Water Education, Utah Water Research Laboratory, Utah State University, Logan, UT.

Smith, G.G. (2002). Substitute Teacher Handbook (Secondary V Edition). International Office for Water Education, Utah Water Research Laboratory, Utah State University, Logan, UT.

Smith, G.G. (2002). SubJournal, Best Practices in the Management of Substitute Teaching. Substitute Teaching Institute, Utah State University, Logan UT.

Utah Water Research Laboratory (2002). Stewardship Through Collaboration: Research and Testing, Education Support, and Outreach for July 1999-June 2001. Utah State University, Logan, UT.

# Student Support

| Student Support | | | | | |
|---|---|---|---|---|---|
| **Category** | **Section 104 Base Grant** | **Section 104 RCGP Award** | **NIWR-USGS Internship** | **Supplemental Awards** | **Total** |
| **Undergraduate** | 1 | 0 | 0 | 0 | 1 |
| **Masters** | 3 | 2 | 0 | 0 | 5 |
| **Ph.D.** | 1 | 2 | 0 | 0 | 3 |
| **Post-Doc.** | 0 | 0 | 0 | 0 | 0 |
| **Total** | 5 | 4 | 0 | 0 | 9 |

# Notable Awards and Achievements

The State of Utah Legislature established a mechanism during the 2000-2001 Session 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 its history, $8.4 million, through contract and grant awards and through federal, state, and private funding support.

UCWRRs Institute for Natural Systems Engineering was awarded approximately $2,060,000 for the third 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.

Dr. Laurie McNeill has been appointed to the Utah Drinking Water Board.

Ryan Anderson, Environmental Engineering graduate student, was selected as the best student presentation at the Spring Symposium sponsored by the Intermountain section of the American Water Works Association. As a result, Ryan got a two-day all-expense paid trip to St. George, Utah to present his paper titled Field Measurement Methods for Arsenic in Drinking Water, at the AWWA Intermountain Section Conference on September 26, 2002.

Kevin Hall and Mike Bundy, two Environmental Engineering graduate students were recently awarded $500.00 scholarships from the Intermountain Section of the American Water Works Association.

Kade Moncur and Said Ghabayen tied for third place at the AWRA Student Paper Competition held at Brigham Young University, Provo, Utah (Spring). Each was awarded $150.00.

Mike Bundy, Brandon Chard, Karl Nieman, and Yanna Liang, Environmental Engineering students, were facilitators for the Third International Conference on Remediation of Chlorinated and Recalcitrant Compounds in Monterrey, CA on May 20-23, 2002.

# Publications from Prior Projects