Computer Applications for Hydrologic Analysis in Mining and Reclamation[1]

by

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Abstract: Since the mid-1980's, the Office of Surface Mining (OSM), in cooperation with State and Tribal coal regulatory and reclamation agencies, has employed a series of technical software tools, under the framework of a program known as the Technical Information Processing System (TIPS). The TIPS program also provides state-of-the-art technical workstations to our State and Tribal partners for use and administration of these software tools. Currently, UNIX-based workstations and software are being replaced by new workstations and servers operating Microsoft *Windows NT.* This has necessitated a re-evaluation of the technical software to bring legacy UNIX and DOS-based applications to an *NT*-platform standard. In 1999, a team of State and OSM scientists and engineers evaluated off-the-shelf hydrologic software. The functional areas covered by this review are: (1) aquifer test analyses: software used to evaluate aquifer parameters such as hydraulic conductivity, transmissivity, and storativity; (2) ground-water flow and contaminant transport modeling: application of aquifer parameter data and a U. S. Geological Survey-developed modeling code (*MODFLOW*) to a conceptual model of subsurface flow and transport conditions for evaluations of ground-water flow and contaminant transport; (3) watershed chemistry and storm runoff analysis: software for studying watershed surface-water quality and storm/runoff characteristics in both small and large watersheds; (4) erosion and sedimentation/channel and impoundment design: supplements to the existing core TIPS software *SEDCAD* and *SURVCADD*; and (5) water chemistry analysis: hydrochemical software used for statistical and graphical analysis of both baseline and post-mining data. Used together these hydrologic tools in conjunction with other geologic and engineering software form a powerful analytical software toolbox for scientists and engineers conducting permit review and reclamation design as mandated by the Surface Control and Reclamation Act (SMCRA) of 1977.

Additional Key Words: hydrology software, aquifer test analyses, ground-water modeling, watershed analysis, TIPS.

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Introduction

The Office of Surface Mining's (OSM's) Technical Information Processing System (TIPS) Team provides computer hardware and technical software to OSM and State scientists and engineers engaged in both coal mine permit review and reclamation activities mandated by the Surface Mining Control and Reclamation Act of 1977 (SMCRA). TIPS is in the process of a system-wide modernization of the hardware and software components by replacing existing UNIX, and, in some cases, DOS, operating system software with *Windows NT* applications. Most hydrology programs used by TIPS are older and are DOS-based. This DOS software included OSM-developed applications: *HC-Gram*, a hydrochemical plotting program; *STORM*, a surface-water runoff prediction program; and the *Theis Aquifer Analysis Program (TAAP)*, a pump test analysis program. Older TIPS "off-the-shelf" software included the DOS version of *SEDCAD*, used for surface-water hydrology design and sedimentation prediction. Because of the growing difficulty in operation of DOS-based software in the modern Microsoft *Windows 95/98/NT*-dominated software environment, these applications, while otherwise functional, have become obsolete. Due to the historic significance of mining impacts on the hydrologic environment, the upgrading of hydrology software is a high priority for TIPS.

To evaluate the next generation of hydrology software, TIPS developed teams of technical specialists from OSM and five states. The goals of the TIPS National Hydrology Software Review Team were: 1) to identify and procure hydrology software to be made available to State, Tribal and OSM hydrology specialists, and 2) to support the use of this software through training and technical support. This paper details the software needs of a hydrologist or engineer engaged in mine permit review and reclamation activities, the review process used to select the software, and presents hydrology applications reviewed in the 1999 TIPS effort. Based on the team's reviews, a recommended core group of hydrology software packages will be procured and distributed in 2000 as part of the TIPS 2000 upgrade program.

The TIPS Hydrology Software Review Team has also developed recommendations on a generalized curriculum of software courses to train users of the hydrology software and provide long-term technical support for each software package. OSM maintains three software training centers at our regional offices in Pittsburgh, Pennsylvania; Alton, Illinois; and Denver, Colorado to support TIPS training efforts.

Hydrology Software Needs

The TIPS Hydrologic Applications Review Project Team identified seven categories of hydrology software that was needed to support the mission of coal mine permit review and reclamation activities:

- Ground-water flow and contaminant transport analytical modeling,
- Aquifer parameter estimation and pump test analysis,
- Small watershed and storm runoff analysis,
- Large watershed analysis modeling,
- Erosion and sedimentation analysis,
- Channel or structure hydraulic design and analysis, and
- Water chemistry analysis.

The listing of a particular software package in this reports does not suggest either general rejection nor endorsement by the authors or the Office of Surface Mining, and is only presented to show the types of software that may be applicable to the TIPS program for permit review and reclamation activities.

Ground-water Flow and Contaminant Transport Modeling

In coal mining the ground-water hydrologist must evaluate the impact of mining on both aquifer water quality and availability. Typical applications could include:

- Analysis of the impact of aquifer dewatering or depressurization due to surface mine pit pumping or dewatering wells,
- Analysis of the impact of aquifer dewatering due to underground mining and planned or un-planned subsidence,
- Prediction of the growth and impact of a contaminant plume from a coal mining facility (e.g., sulfate from a coarse refuse fill), and
- The effect of recharge on abandoned mine pool levels.

Ground-water flow and contaminant transport modeling are generally advanced applications using numeric processing. Considerable knowledge of the local hydrogeology (geologic framework and aquifer parameter data) and skill (knowledge of groundwater hydrology and mathematics) is needed for these types of analyses. Previous TIPS ground-water modeling software included *MODFLOW*, a modular, finite-difference, flow modeling code developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988). This program is programed with the aid of DOS-based pre- and post-processors, which can be tedious to operate and prone to input errors. No contaminant transport models have been distributed by TIPS to date.

Aquifer Parameter Estimation and Aquifer Test Analysis

Determination of an aquifer's characteristics (parameters) is imperative to the understanding of ground-water flow. Aquifer test analysis is an analytical approach most commonly used to obtain aquifer parameters such as hydraulic conductivity, transmissivity, storage coefficients, and leakance factors. To obtain this information, pump or slug tests are usually performed on wells and the resulting data analyzed. The baseline information in SMCRA permits may contain the aquifer test data and analysis for potentially impacted aquifer zones. Pre- and post-mine ground-water movement, drawdown, and other aspects of ground-water system can then be quantitatively discussed in the probable hydrologic consequences determination (PHC) section of a SMCRA permit application. Once determined, these parameters can then be applied in numeric modeling of ground-water flow in applications, such as *MODFLOW*. In some cases, aquifer test methods can also be used in place of numeric modeling in ground-water investigations. Typical applications include:

- Evaluation and prediction of aquifer drawdown by a well field,
- Evaluations and prediction of well performance (i.e., efficiency and yield),
- Analyses of boundary effects on aquifers.
- In addition to pump tests and slug tests, step-drawdown tests have application in estimating aquifer drawdown, due to mining-related pumping or gravity drainage.

The principal aquifer test program distributed by TIPS to date is the OSM-developed *Theis Aquifer Analysis Program (TAAP)*. This DOS program is limited in application to aquifer conditions that approximate the Theis aquifer assumptions. These assumptions can be inappropriate for many coal-mining applications. For example, fractured sandstone or limestone aquifers common in the

Interior and Appalachian Coal Basins require analytical solutions appropriate for dual porosity systems.

Watershed Analysis

A watershed-based analysis usually represents the "good science" approach to both prevention and remediation of surface-water impacts by mining. Examples of applications in which State, Tribal and Federal hydrologists and engineers would conduct watershed-based analysis are: (1) development of Cumulative Hydrologic Impact Assessments (CHIA's), calculation of a Total Maximum Daily Load (TMDL) of a pollutant, and (2) the development of an Environmental Impact Assessment (EIS) for a watershed petitioned as an Area Unsuitable for Surface Coal Mining Operations as defined in the SMCRA regulations (30 CFR Part 761). Examples of uses for watershed analysis software include capability for: modeling rainfall-runoff processes in large watersheds, estimating erosion rates and sedimentation, or calculating stream channel mass-balance calculations for chemical parameters.

Three surface water hydrology software programs have previously been distributed by TIPS. *STORM* is a DOS-based rainfall runoff prediction tool developed by OSM, that will not be updated to *Windows 95/98/NT*. Two others, Civil Software Design's (Ames, IA) *SEDCAD 4 for Windows* and Carlson Software's (Maysville, KY) *SURVCADD 2000*, are updated to the 95/98/NT standard and are expected to be distributed in the future. Prior TIPS software distributions relied on spreadsheet-based analysis for mass-balance calculations of chemical parameters.

Hydraulic Structure Design/Analysis Models

Additional hydrology software is used in conjunction with rainfall-runoff prediction tools for design of storm water, erosion and sedimentation control structures. In these roles State and Federal TIPS users have previously applied *SEDCAD 4 for Windows* and *SURVCADD 2000.*

The Review Process

OSM and the TIPS-participating State representatives formed seven sub-teams to conduct focused and comparative reviews of software in each of these categories; the reviews were coordinated by a core team. During initial meetings, the core team determined that the already distributed *Windows 95/88/NT* software *SEDCAD 4 for Windows* and *SURVCADD 2000* would serve most of TIPS user needs in both the Erosion and Sedimentation Analysis and the Small Watershed/Storm Runoff Analysis categories. However, additional software would be considered to supplement these programs. Whenever possible, full working versions of several applicable hydrology software programs were obtained. In a number of cases limited-function demonstration versions were evaluated due to funding limitations. Each subteam member used familiar, "real-life" data sets to conduct independent tests for ease-of-use and technical capabilities. Subteams worked independent of the core team to evaluate software options.

Software Analysis

Many of the packages reviewed within a hydrology category were not directly comparable, because they possessed certain unique features that some users would apply more than others, depending on the type of software/computer environment they operated or specialized analysis that were needed due to the local geology and nature of the pollution. For example, engineers familiar with operating in a CAD environment may prefer applying *SURVCADD 2000* for a channel design instead of *SEDCAD 4 for*

Windows, which is a user-friendly program for non-CAD users.

Ground-water Flow and Contaminant Transport Modeling

One subteam evaluated several commonly-used Graphical User Interface (GUI) programs that pre-and post-process DOS-based *MODFLOW*-96, the updated, USGS, three-dimensional, ground-water flow model (Harbaugh and McDonald, 1996), *MODPATH*, a USGS-developed particle tracking program (Pollack, 1994), and *MT3D*, a solute transport model developed in part with U.S. Environmental Protection Agency (EPA) funding (Zheng, 1990). There are various third party sources of the individual modeling programs with value-added improvements. For example, updated MT3D code is available from both, a commercial source, S. S. Papadopulus and Associates, Bethesda, MD (*MT3D*[99]) or as U.S. Army COE-supported freeware from the University of Alabama (*MT3DMS*). These three DOS-based modeling programs are programed using the GUI interface instead of the tedious, DOS-based, pre-and post-processors previously used. The evaluation focused only on those software packages having GUI interfaces compatible with *Microsoft Windows 95/98/NT*. Based on this requirement, three packages were chosen for evaluation: the U.S. Department of Defense (DOD)-developed *Groundwater Modeling System (GMS)*, *Groundwater Vistas* from Environmental Simulations (Herndon, VA) and *Visual MODFLOW* from Waterloo Hydrologic (Waterloo, Ontario, Canada).

Although not a *95/98/NT*-based program, the USGS ground-water modeling code *SUTRA* (Voss, 1984) was also examined due to its specialized application and freeware status. Factors considered in the evaluation of ground-water flow models are: the ability of support the pre-and post-processing of the USGS code in a user-friendly manner, the support of model calibration, and the ability to post-processing visualization. All of the software packages evaluated are capable of processing ground-water flow, particle tracking and contaminant transport codes.

The TIPS evaluation concentrated on the software's documentation, technical support, multiple-model comparison capabilities, GUI user-friendliness, calibration tools, compatibility with standard input and output data formats, and its visualization and presentation capabilities. The *.dxf file format, a common CAD format, is supported by all of the reviewed ground-water modeling programs for use in base map drawing.

Groundwater Vistas. *Groundwater Vistas* version 1.15 is a model-independent graphical design system for *MODFLOW*, *MODPATH* and *MT3D*. *Groundwater Vistas* couples an model design interface with graphical analysis tools to construct a model of a system (Figure 1), calibrate the model and evaluate the output (validation). Both cross-section and plan views of model results can be displayed simultaneously. *Groundwater Vistas* also supports viewing the input information and output models from multiple model runs simultaneously, which speeds the calibration process and enables the ability to cut and paste information between models. To further aid the calibration process an automated sensitivity analysis capability is included that tests the model's response to varying parameters such as hydraulic conductivity or unit thickness. *PEST*, a model-independent parameter estimator (Watermark Computing, Corinda, Australia), is optionally supported by *Groundwater Vistas*.

GMS. Version 2.1 of the DOD-funded and Environmental Modeling Research Lab (EMRL)-developed program, the *Groundwater Modeling System* (*GMS*) was reviewed by the subteam. *GMS* is distributed by Environmental Modeling Systems, Inc. (EMS-I, Provo, UT). With *GMS*, a conceptual model can be constructed directly on top of a scanned map of the site. This conceptual model is automatically

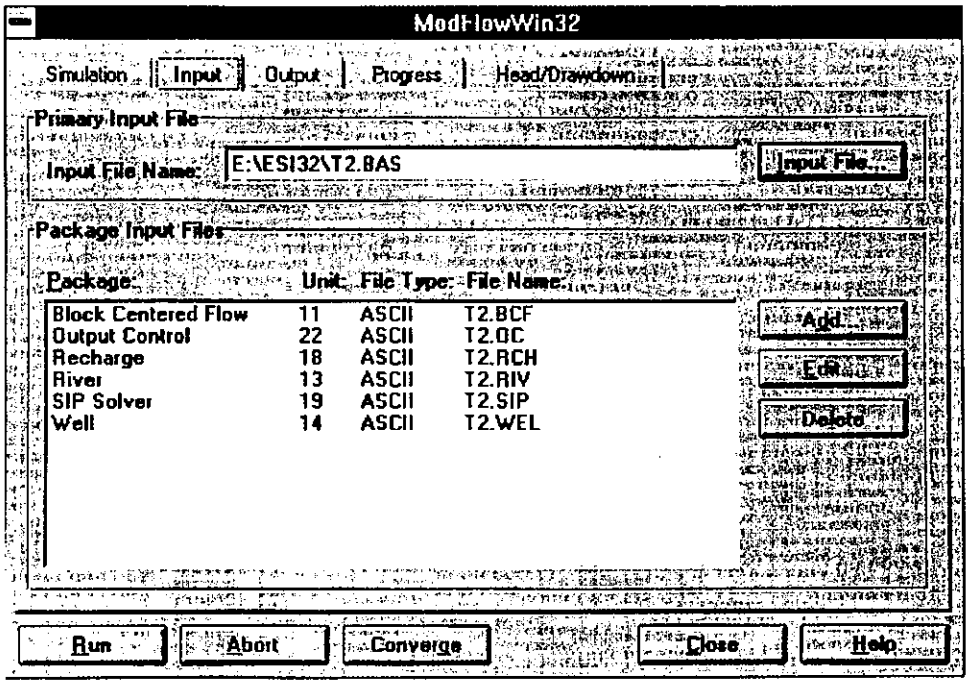

Figure 1.Typical GUI Pre-processor for *MODFLOW: Groundwater Vistas' ModflowWin32.*

converted into a *MODFLOW* (or *MODPATH/MT3D*) grid with stresses, sources/sinks, and material properties assigned to the appropriate cells. *GMS* also offers the ability to construct finite-element models for problems having irregular boundaries or properties, and provides additional modeling options through use of an editing interface for *MODFLOW* code. The *GMS* calibration tools include the ability to define one or more observed values at specified locations to residual statistics for individual observation points. Sensitivity analysis operations can be performed manually, but *PEST* is currently not supported directly by *GMS*. The graphical and textual output capabilities of *GMS* is extensive and includes the ability to generate an animation film loop in *.AVI format playable by *GMS* or Microsoft *PowerPoint* or can be published on the internet.

Visual MODFLOW *Visual MODFLOW* version 2.81 is a modeling pre- and post-processor for *MODFLOW, MODPATH* and *MT3D*, that provides many of the same features as *Groundwater Vistas*. *Visual MODFLOW* allows the import of scanned maps for use as a model base map. An automatic sensitivity analysis is not available in *Visual MODFLOW*.

SUTRA *SUTRA* is a USGS-developed, numerical, ground-water flow model that uses another USGS freeware package, *SUTRA GUI*, and the commercial software *ARGUS Open Numerical Environment* (*Argus ONE*; Argus Interware, Jericho , NY), as it's interface and database, respectively. *Argus ONE* is a Geographic Information System (GIS) that interfaces with *SUTRA* via the *SUTRA GUI*, a Programable Interface Extension (PIE; Voss et al., 1997). *SUTRA* was developed to model density dependant fluids (e.g., petroleum contaminants), as well as, thermal pollution. Such types of fluid flow are rarely, if ever, encountered in coal mine permitting situations. *The Argus ONE* GIS can also be used to provide data entry for *MODFLOW-96,* through another PIE, the USGS freeware interface *MODFLOW GUI* (Shapiro et al., 1997). However, TIPS has already invested heavily in terms of training and GIS development in the *ArcInfo* and *ArcView* programs by Environmental

System Research Institute, Inc. (ESRI, Redlands, CA) and the *StrataFact* database/correlation software from GRG Corp.(Wheat Ridge, CO). TIPS users would require additional training and data transfer activity to use another GIS program such as *Argus ONE.*

Aquifer Parameter Estimation and Pump Test Analysis Software

The automation provided by aquifer test software allows the hydrologist to use multiple methodologies easily and quickly to determine the best solution for the site condition. Two Microsoft *Windows 95/98/NT*-compatible programs reviewed were *AQTESOLV* for Windows from HydroSOLVE (Reston, VA) and Starpoint Software's (Cincinnati, OH) bundled package of *Infinite Extent* for pump test analysis, *Super Slug* for slug tests, and *StepMaster* for step-drawdown tests. Basic user features are similar. Both software packages have similar analysis capabilities, but there are some notable differences. Because each program supports different sets of test analyses, direct comparison is difficult. The software choice is, therefore, dependent on the support for analyses applicable to site conditions prevalent for the user and other software aspects such as cost and technical support. The *Windows*-based help menus for both programs are well developed.

AQTESOLV The *AQTESOLV for Windows* version 2.5 program includes methodologies to analyze fractured bedrock aquifers and pseudo-karst type situations, which is required in some hydrologic settings in coal mine permit review (i.e., spoil backfill) and water well impact complaint analysis. *AQTESOLV* options for pump tests in normal confined/unconfined aquifer situations are numerous with extensive control over automatic curve fitting parameters and iterations (Figure 2). Along with the aquifer parameter estimations, statistics are generated to evaluate the analysis. Another desirable feature of *AQTESOLV* is the capability to perform "forward" analysis. Hypothetical distance/drawdown curves can be generated from pumping rates and aquifer parameters the user inputs. This allows the user to not only use the program to analyze test data, but also to determine where observation or monitoring wells should be placed in a proposed aquifer testing situation or to evaluate the siting of test wells used in a permit application. *AQTESOLV* has guided tutorials to aid first-time users and data input allows time-saving spreadsheet input. Technical support and updates for are available on-line via the internet. An electronic *AQTESOLV* manual is also available.

Infinite Extent/Super Slug/StepMaster Starpoint's *Infinite Extent/Super Slug/StepMaster* software bundle has an extensive choice of units for input and output. While Starpoint's *Infinite Extent 4.0* does not include methodologies to analyze fractured bedrock aquifers and pseudo-karst type situations important in some coal mining areas, *Super Slug 3.1* and *StepMaster 2.0* have a large number of options for slug and step-drawdown tests, respectively. The Starpoint programs have high-quality graphics.

Watershed Analysis

Two subteams were formed to evaluate watershed analysis software. One evaluated software applicable to large watershed analysis, the second was charged with reviewing programs applicable to small watersheds. The software included in the large watershed review are EMRL/U. S. Army Corps of Engineer (COE)'s *Watershed Modeling System (WMS)* and *Surface Water Modeling System (SMS)*, the Environmental Protection Agency's (EPA)'s *BASINS* and *QUAL2E* programs, and *SEDCAD 4 for Windows*. The goal of this effort was to identify *Windows 95/98/NT* software packages capable of modeling both rainfall-runoff processes and mass-balance calculations for chemical parameters in large watersheds. The selected software packages have different capabilities. Some programs in these packages do not meet the requirement for native operation in the *Windows 95/98/NT* operating system. The subteam determined that, for chemical mass-balance calculations, spreadsheet-based accounting

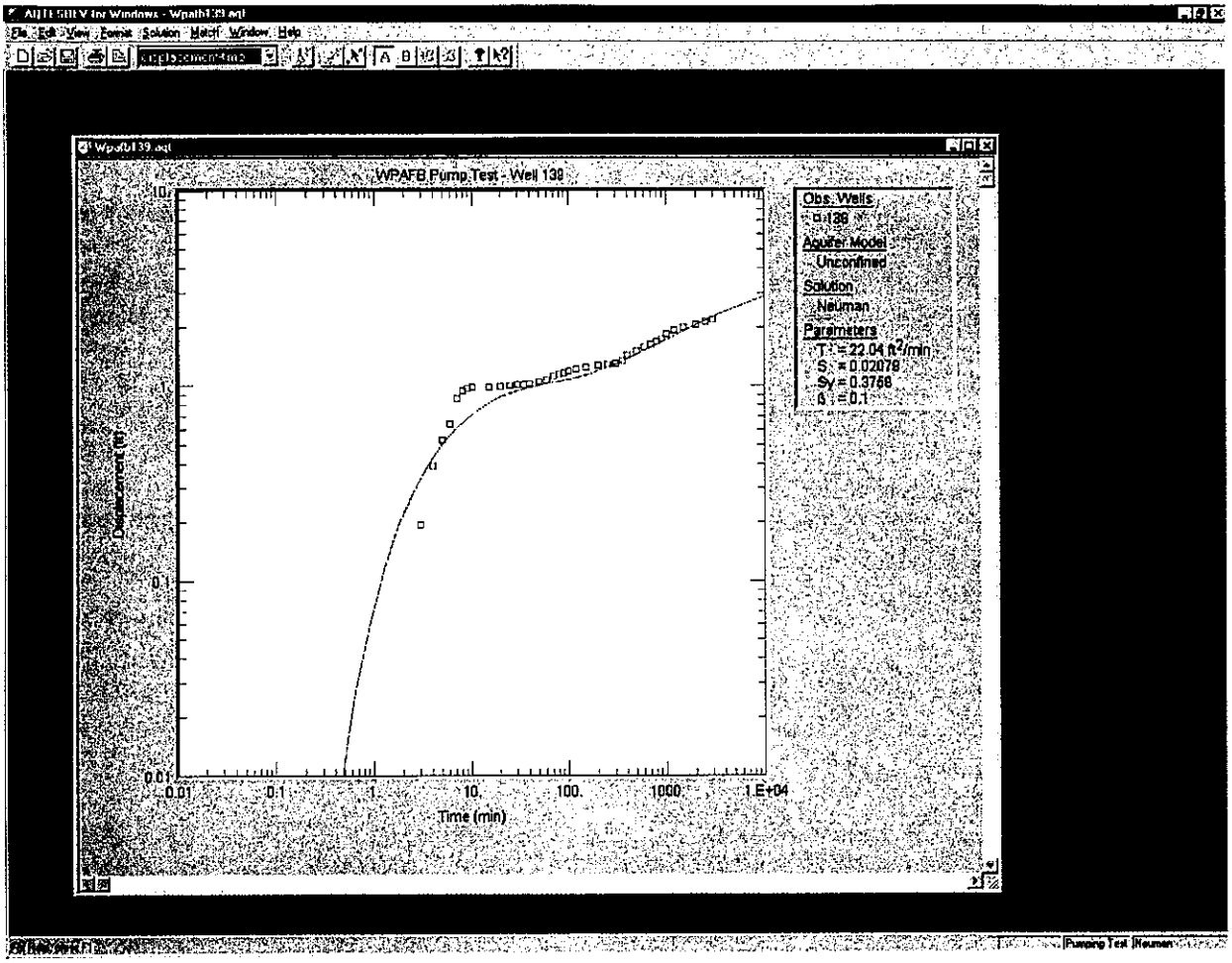

Figure 2. Example of Aquifer Parameters Estimation by Aquifer Test Analysis Curve Matching using AQTESOLV.

methods are sufficient. Large watershed rainfall-runoff analyses rely on U.S. Army COE's *HEC*-based programs.

The capabilities desired for watershed analysis include: (1) calculation of rain-fall runoff from large watersheds; (2) input of pollution discharge nodes using GIS files; and (3) calculation of flow quantity and parameter concentrations at any point within the stream system. Because the subteam has not identified software that fully supports this goal the large watershed software review is continuing.

SMS The current version 6.0 of *SMS* is distributed by EMS-I(Provo, UT). *SMS* is a surface water, stream flow model that interfaces directly with TIPS's GIS software *ARC/INFO* and *Arc/View*. Add-on modules include a sediment transport model and a mass balance mixing model for conservative and non-conservative pollutants. This model would be ideal for the hydrologist to evaluate surface-water quality impacts in a CHIA. Results from the TIPS software *SEDCAD 4 for Windows* plus mine discharge chemistry predictions could be routed (projected) downstream using this program. The *SMS* program does not fully meet the TIPS upgrade program goal, because the water chemistry module currently only runs in the DOS mode. Stream nodes can be set up using a GIS file, but the flow and concentration values must be entered into a file in a separate DOS program. This approach is not practical given the number of discharges evaluated in many coal mine CHIA's. *SMS*, however, does have advanced channel calculation hydraulics capabilities.

WMS Version 5.1 of the EMSL/U.S. Army COE-developed program *WMS*, distributed by EMS-I (Provo, UT), was reviewed in this study. The *WMS* program uses standard surface-water hydrology modules such as *HEC-1*, the *Rational Method*, and *TR-55* for modeling parameters in large watersheds. Data can be imported from *ARC/INFO* or other Triangular Interlaced Network (TIN) files. *WMS* is capable of mapping, interpolating, and contouring scalar data in multiple layers. Watershed sensitivity analysis can be performed by editing upstream data, which automatically changes downstream results. However, *WMS* is not capable of performing chemical mass-balance modeling. Although *WMS* duplicates many of the functions of the existing core TIPS software *SEDCAD 4 for Windows*, *WMS* is very powerful. *WMS* interfaces well with GIS programs, it can perform flood plain delineation, and can serve as an interface for *the National Flood Frequency Program* (*NFF*). Flood plain delineation and frequency analysis are especially needed in the Midwest States, where more mining is located in flood plain areas.

BASINS/QUAL2E EPA's *Basins* program is a comprehensive surface flow and constituent transport model. The primary water quality module in *BASINS* is *QUAL2E*. *QUAL2E* is a surface-water chemistry/mass balance package developed by the EPA and used widely for the analysis of water quality in relatively large stream systems. However, at the time of this evaluation, *QUAL2E* is a DOS-based program. The current version 3.2 of the *QUAL2E* model uses the program *QUAL2E Windows Interface* (*QUAL2EU*). This GUI is compatible with Windows 3.x, 95 and 98, but not with NT. Because *BASINS/QUAL2EU* is capable of simplifying surface-water quality impact evaluations, TIPS will reconsider EPA's package if *Windows NT* operation is developed.

Hydraulic Structure Design/Analysis Models

There are two types of hydraulic design/analysis software reviewed . One type is suited for designing the many simple structures found at mine sites using simplified methods. The other excels at evaluating the hydraulic effects of constructing larger, more complex structures such as large stream diversions or replacement channels, bridge piers, and river stabilization structures. The software reviewed included *SEDCAD 4 for Windows*, EMRL/ U.S. Army COE's *SMS*, *SURVCADD*, and the U.S. Army COE Hydrologic Engineering Center's (HEC)'s *River Analysis Software* (*HEC-RAS*).

SEDCAD. *SEDCAD 4 for Windows* is very easy to use, allowing the user to create designs for a variety of structures and channels as well as water and sediment control systems very quickly. *SEDCAD* is an industry standard tool for designing small, mine-related hydraulic structures and is presently TIPS core software. *SEDCAD* can be more difficult to apply to the design of large, complex hydraulic structures, but version 4 significantly enhanced this capability. SEDCAD excels in design of sedimentation control structures such as ponds, check dams and even silt fences. Channel designs include mining-specific applications such as the Simons/OSM and the Pennsylvania Department of Environmental Resources (PADER) rip-rap channel design methods. A *TR55* emulator is included in *SEDCAD 4 for Windows*. A *SEDCAD* interface to Autodesk, Inc's (San Rafael, CA) *AutoCAD Map 2000* is under development.

Mining applications of *SEDCAD 4 for Windows* often benefit from the use a DOS program called the *Revised Universal Soil Loss Equation* (*RUSLE*: Renard et al, 1997; Toy et al, 1998). *RUSLE* considers mine site conditions and alternative slope profiles for a more realistic estimation of soil loss than is provided by the Universal Soil Loss Equation. TIPS will consider adding *RUSLE* when the *Windows* version becomes available.

SURVCADD *SURVCADD 2000* relies on *AutoCAD Map 2000* as the program's graphic engine. For a user unfamiliar with *AutoCAD* this is complicates

software use. However, many State and Federal engineers designing reclamation projects extensively use *AutoCAD* and many use *SURVCADD*. These users are able to take advantage of the efficiency of working within one design program. *SURVCADD 2000* is presently TIPS core software.

SMS The modeling methodology of *SMS* version 6.0 is very sophisticated. The user of *SMS* needs to have advanced proficiency at understanding complex hydraulic principles to develop and interpret an *SMS* model. Data requirements are extensive for many of the modules of this model. The *WSPRO* module, which models water surface profile, has particular application to coal mine permit review and reclamation activities.

HEC-RAS *HEC-RAS* is a widely accepted surface-water flow analysis model developed by the US Army COE. Users interact with *HEC-RAS* through an easy-to-use GUI. *HEC-RAS* version 2.2 uses include evaluating the hydraulic effects of large stream channels and structures such as bridges. *HEC-RAS* is easy to use for a complex model and has good graphics and is currently being used by OSM and at least four States: Wyoming, Texas, Tennessee and Pennsylvania.

Water Chemistry Analysis Software

AquaChem by Waterloo Hydrogeologic and *HydroChem* by Rockware are the two water chemistry analysis packages reviewed, that operate as native *Windows 95/98/NT* programs. These programs can both plot analytical data in the commonly used Piper (trilinear) and Stiff diagrams (Hem, 1989).

AquaChem *AquaChem* version 3.7 is a comprehensive program for geochemical analysis, plotting and modeling. Because of a complex interface, *AquaChem* can be difficult to apply by a new user. The program is capable of importing generic ASCII data files. Graphic output is high quality, but can be difficult to customize (Figure 3). *AquaChem* performs simple mixing calculations and can format data files for interfacing with *PHREEQC*, a USGS-developed, DOS-based geochemical model (Parkhurst, 1995). The program can also produce reports on simple data statistics, and hydrochemical analysis such as ion ratios, charge balance, and correlation matrixes. The program is capable of developing a wide variety of plots commonly used in geochemical analysis including time series, Schroeller semilogrithmic, Ludwig-Langelier, and trilinear Durov graphs. Graphs can be exported in a variety of graphics formats. Data can be exported in ASCII format.

HydroChem *HydroChem* version 97 is an easy-to-use geochemical analysis program. Graphs supported by *HydroChem 97* are limited to Stiff and Piper diagrams. The graphics quality, however, is high and graph customization is simple. Graphs can be exported in several common graphics formats. Reports can be generated on ion charge balance and the calculated total dissolved solids content. Data can be imported and exported in ASCII format. *HydroChem 97* lacks features such as time series, Schroeller semilogrithmic, Ludwig-Langelier, and trilinear Durov graphs. There is no *PHREEQC* interface supported by HydroChem 97.

A limited review was conducted of an advanced geochemical analysis package, the *GeoChemist Workbench* (Rockware, Golden, CO). This package is a series of programs that perform advanced geochemistry analysis such as stability diagrams, temperature-activity plots, and chemical analysis and equilibrium calculations. Reaction paths can also be plotted by a *GeoChemist Workbench* program.

A suite of USGS programs were not evaluated in this review. This includes the program *PHREEQC Interface* (*PHREEQCI*), a *Windows 95/98/NT*-compatible interface for the *PHREEQC* (Carlton et al., 1997). *PHREEQCI* is a freeware program is similar to the *PHREEQC* interface included in *AquaChem*. Geochemical transport simulations can be graphed using another companion, USGS program *PHRQGRF* (Vrabel and Glynn, 1998). *PHRQGRF* is a *Windows 95* program.

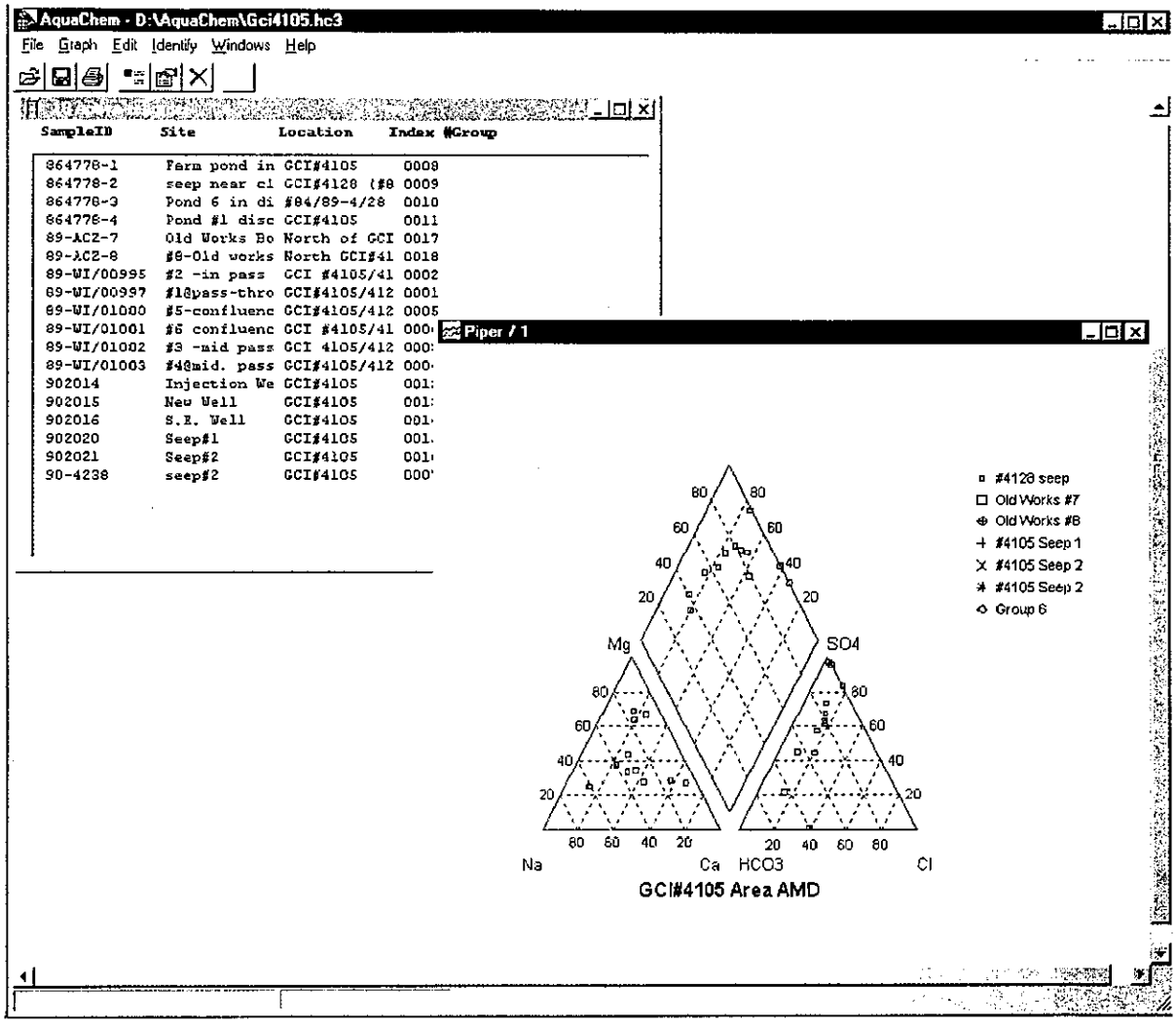

Figure 3. Example of a Piper Trilinear Diagram in *AquaChem*.

Conclusion

This paper and the TIPS National Hydrology Software Review is not intended to be completely comprehensive in terms of examining all of the software programs available internationally that are suitable for mining-related hydrologic investigations. Nor is it intended to endorse or criticize any particular hydrology software. However, the review discussed in this paper included many commonly used software programs and it is hoped this paper will illustrate the types of software applicable to coal mining and reclamation tasks and to illustrate an approach taken to develop evaluation criteria and consider the merits of a large assortment of software for selection to serve the needs of hydrologists and engineers nationally. The widespread availability of the software programs selected should ultimately lead to improved coal mine reclamation and surface and ground-water quality.

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