Hydrologic Modeling Tools for Cumulative Hydrologic Impact Assessment of West Virginia Coal Mine Permits[1]

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Abstract. The West Virginia Department of Environmental Protection (WVDEP) with the cooperation of the Office of Surface Mining (OSM) in the U.S. Department of the Interior (USDOI) is supporting the development of GIS-based hydrologic modeling tools to conduct Cumulative Hydrologic Impact Assessments (CHIAs) of mining activities on watersheds within the coal regions of West Virginia. Approximately 235 watersheds have been established within the coal fields based on Trend Station water quality and flow monitoring points. Designed to develop baseline data to support the CHIA process, these Trend Station Watersheds (TSW) cover an area equal to approximately 40% of the state. The Natural Resource Analysis Center (NRAC), West Virginia University, is developing modeling tools to provide predictive capability for assessing the hydrologic and water quality impact of new mining permits on streams. This capability is being provided by a new set of GIS tools developed to supplement the basic functions of the Watershed Characterization and Modeling System (WCMS), an ArcGIS extension developed by NRAC. WCMS GIS tools have been used by WVDEP staff to analyze coal mine permit applications for a number of years. New WCMS tools create input files for the Hydrological Simulation Program – FORTRAN (HSPF) watershed model. These tools include mine site modeling capabilities that simulate NPDES outflows from both underground and surface coal mines. Each TSW is divided into subwatersheds consistent with the 1:24,000 NHD (National Hydrography Dataset) stream segments. The hydrology and landcover are modified to reflect the proposed impacts of mining based on information provided in permit applications. Surface mine discharges are modeled in a fashion consistent with the specific runoff curve numbers, limits, and discharges specified in the permit application. HSPF components are also used to model the watershed hydrology from underground mine discharges contribution consistent with NPDES permit effluent limitations and WV in-stream water quality standards. Water quality components of HSPF were modified to improve the simulation of acid mine drainage (AMD) discharges.

Additional Key Words: CHIA, AMD, WCMS, Mining, HSPF, Watershed Modeling

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Introduction

WVDEP CHIA Needs for Mine Permit Applications

The West Virginia Department of Environmental Protection (WVDEP) is required by existing regulations to review mine permit applications and conduct a cumulative hydrologic impact assessment (CHIA) on those watersheds which receive outflows from within the mine permit boundaries (through NPDES outflow points). Since no suitable modeling tools are currently available to support the CHIA evaluations within WVDEP, they have joined in a cooperative project with the Office of Surface Mining (OSM) to support the development of new GIS-based hydrologic modeling tools within WCMS (Watershed Characterization and Modeling System). WCMS, a GIS spatial data base and modeling system, was developed by the West Virginia University Natural Resource Analysis Center (NRAC), and has been used for a number of years by WVDEP staff to assist in the evaluation of coal mining environmental impacts. WCMS is an ArcGIS 8.x extension that has unique hydrologic tools to extract watershed subbasin boundaries and trace flow paths down slope using a DEM (Digital Elevation Model). Additionally, it can produce mean discharge and 7Q10 low flows at any point on any stream within WV.

Under current regulations, mine permit applications must be evaluated with respect to their outflows and potential water quality impacts to their receiving streams. This latter assessment requires modeling tools that can predict potential impacts to stream water quality under a variety of flow conditions. NRAC is developing new hydrologic tools that support the use of HSPF (Hydrological Simulation Program - FORTRAN) within WCMS. This new capability is being implemented with a particular emphasis on ease-of-use by WVDEP staff. A new section of the WCMS interface is being developed to support the application of HSPF to any watershed within the data base. Additional tools are nearing completion that extend the application of HSPF to subbasins within individual mine sites so that runoff into sediment control structures and the outflows through NPDES points can be modeled. Development of underground mine hydrologic modeling tools are still being conceptualized. A new version of HSPF is now under final review by the EPA and the USGS, which incorporates the USGS groundwater model, MODFLOW. This new version is to be adapted to the WCMS system, as soon as it is available, to provide underground mine modeling capability in support of CHIA.

To provide information to guide the CHIA process and to collect the data necessary for the model development and calibration discussed in this paper, the WVDEP developed a long term water quality monitoring program coordinated with flow measurement in the coal area of West Virginia. To provide appropriate representation of the coal region, the area was subdivided on a watershed basis. Approximately 235 watersheds were delineated and the pour points for each such watershed designated as a “Trend Station” location for long-term monitoring. These Trend Stations and the associated Trend Stations Watersheds provide the basic spatial scale for the CHIA assessment modeling process and the base data for the water quality modeling.

Hydrologic Model Selection: HSPF

HSPF was selected as the hydrologic model for CHIA of mine-impacted watersheds in the state of West Virginia because of its wide use and acceptance as a joint watershed and stream water quality model. It is a comprehensive, continuous watershed simulation model, designed to simulate all the water quantity and water quality processes that occur in a watershed (Bicknell, et al., 2001). This includes sediment transport and movement of contaminants overland and through the stream channel system. HSPF has its origins in the Stanford Watershed Model (SWM) developed by Crawford and Linsley (www. hydrocomp.com). This latter model was the first truly comprehensive land surface and subsurface hydrologic processes model that treated every component of the hydrologic cycle. It has been widely adopted in various forms and its hydrologic components have been included in related models, such as the Kentucky Watershed Model. Crawford and Linsley further developed the original SWM model and created HSP, the Hydrocomp Simulation Program, which included sediment transport and water quality simulation. Hydrocomp also developed the ARM (Agricultural Runoff Management Model) and the NPS (Nonpoint Source Pollutant Loading Model) for the EPA (U.S. Environmental Protection Agency) during the early 1970’s. In 1976, EPA commissioned Hydrocomp, Inc. to develop a set of simulation modules in standard Fortran that would handle all the functions handled by HSP, plus those within two additional models, ARM and NPS. The intention was to produce a modeling system that was easy to maintain and modify. The result was HSPF, which can be applied to most watersheds using commonly available meteorologic and hydrologic data, although data requirements are extensive and it takes a large investment in time to properly apply the model (Bicknell, et al., 2001).

HSPF has been applied to a variety of watershed studies, including the U.S.EPA Chesapeake Bay Program, Carson - Truckee River (California, Nevada), Minnesota River Assessment Project, Florida Water Management District, King Co. Washington Management Plan, and others (Donigian, 2003). Other work that relates specifically to various aspects of the calibration methodology used here includes Sams and Witt (1995), and Dinicola (2001). Sams and Witt (1995) utilized HSPF to model two surface-mined watersheds in Fayette County, Pa. The significance of this latter study is the location of these two watersheds, located within and just to the north of the Big Sandy calibration watershed used in this study. The Stony Fork Basin is a sub-basin of Big Sandy, and the Poplar Run Basin is located just 15 miles to the north of Big Sandy. The geology, soils, topography, and land cover of these two watersheds are very similar to the characteristics of many of the trend station, calibration, and verification watersheds used in this study. Therefore, the fitting parameters as determined by Sams and Witt (1995), where adopted as a starting point in the calibration processes for the CHIA project. Additional studies of note are those by Al-Abed, et al., (2002), Lohani, et al., (2002), Martin, et al., (1990), Riberio (1996), and Srinivasan, et al., (1998).

HSPF Basic Capabilities and Characteristics

The HSPF model has the following general characteristics:

- It is a continuous simulation model (It can simulate streamflow for many years at hourly time increments).
- It can be applied to natural or developed watersheds (including those with surface and underground mine sites).
- Model components simulate both the land surface and subsurface hydrology and water quality processes.
- HSPF utility programs provide time series data management, statistical analysis tools, and graphic display of results.
- Both stream and lake hydraulics and water quality processes can be simulated.
- HSPF is the core watershed model in EPA BASINS and the U.S. Army Corps of Engineers WMS modeling system.
- Development and maintenance of HSPF related software is sponsored by EPA and USGS.

There are three application modules that make up the core of the HSPF hydrologic model (each also includes several sub-modules of importance):

1) PERLND (Simulate a Pervious Land segment)
   a) ATEMP (Correct air temperature for elevation difference)
   b) SNOW (Simulate the accumulation and melting of snow and ice)
   c) PWATER (Simulate water budget for pervious land segments)
2) IMPLND (Perform computations on a segment of impervious land)
   a) ATEMP (Same as in PERLND above)
   b) SNOW (Same as in IMPLND above)
   c) IWATER (Simulate water budget for impervious land segment)
3) RCHRES (Perform computations for a stream reach or mixed reservoir)
   a) HYDR (Simulate hydraulic behavior)
   b) ACIDpH (Simulate mine acid drainage in-stream chemistry)

Of the three application modules above, PERLND and RCHRES were used in the calibration phase of the CHIA project. The PERLND module simulates the watershed areas, with each land cover/land use classification category being described by its own unique set of PERLND parameters. The RCHRES module is applied to each stream reach, which is equivalent to a stream segment in the stream drainage network within a given watershed. Each stream reach has its own unique descriptive parameters, which are applied in the RCHRES module. The IMPLND module is for the purpose of simulating impervious areas, such as urban areas. This module was not used since no urban areas larger than a few percent of the total watershed area are encountered in the CHIA project.

HSPF Calibration for CHIA

Selection of Calibration and Verification Watersheds

The hydrologic component of the project involves the fitting of a suitable hydrologic model to each of the 235 Cumulative Hydrologic Impact Assessment (CHIA) or Trend Station Watersheds identified by WVDEP. They have boundaries defined by stream water quality sampling points, or Trend Stations, located at the watershed outlets. These stream water sampling points generally do not coincide with USGS stream gaging locations that are required for the model calibration process. Therefore, model calibration must be conducted using watersheds that have a gaging station at their outlet, and are also representative of the hydrologic characteristics found in CHIA watersheds. An additional factor is the obvious impracticality of individual calibration of 235 watersheds, regardless of gaging data availability. The only practical approach to finding a set of model parameters for each of the 235 trend station watersheds is to calibrate the model to a selected few watersheds that contain representative characteristics of the whole population of watersheds. It is then assumed that watersheds with similar characteristics have similar model parameters representing those characteristics. It is therefore possible to calibrate a limited number of watersheds as long as their hydrologic characteristics are simulated as separable components in the hydrologic model. The suitability of the parameter sets determined during calibration is tested using a set of verification watersheds that are also representative of the CHIA watersheds. This calibration strategy follows that recommended by Donigian (2002), and successfully employed by Dinicola (1990, 2001). The Dinicola (2001) study involved 12 small watersheds in King and Snohomish Counties, in and near Seattle, Washington. The purpose of this latter study was to model the effects of urbanization on watershed response. Five of the watersheds were selected for use in calibration, characterized by various degrees of development. The calibration process proceeded with the intent to arrive at a consistent set of parameters across all 5 watersheds for each land use category. The study was successful in that it demonstrated that satisfactory model performance could be achieved by using common land use categories with single valued parameter sets. The approach used in the CHIA calibration study follows Dinicola's lead in maintaining a single valued set of model parameter values for each land use category.

The calibration and verification watersheds lie within the coal regions and either encompass or are adjacent to trend station watersheds. Figure 1 shows the locations of the trend station watersheds within the state of West Virginia, including the five watersheds selected for calibration purposes. It will be noted that the Twelve Pole Creek, Clear Fork, Buffalo Creek, and Big Sandy watersheds contain trend station watersheds in whole or in part. Big Sandy lies partially in the state of Pennsylvania, and therefore only the West Virginia portion contains trend station watersheds. Tygart Valley at Elkins does not contain trend station watersheds, but lies adjacent to trend station watersheds on its western boundary. Figure 2 shows the location of five verification watersheds which are used to test the modeling parameters determined in the calibration process. These include Big Sandy (same as the calibration watershed, except using a different meteorological record), Tygart Valley at Belington, Tygart Valley at Daily, Piney Creek, and Panther Creek. It will be noted that the two Tygart Valley verification watersheds are a superset and subset of Tygart Valley at Elkins, respectively. These latter two verification watersheds are defined by different gaging locations along the same stream, and hence share a portion of the same watershed. The Big Sandy watershed is present in both the calibration and verification watershed groups to provide for error checking.

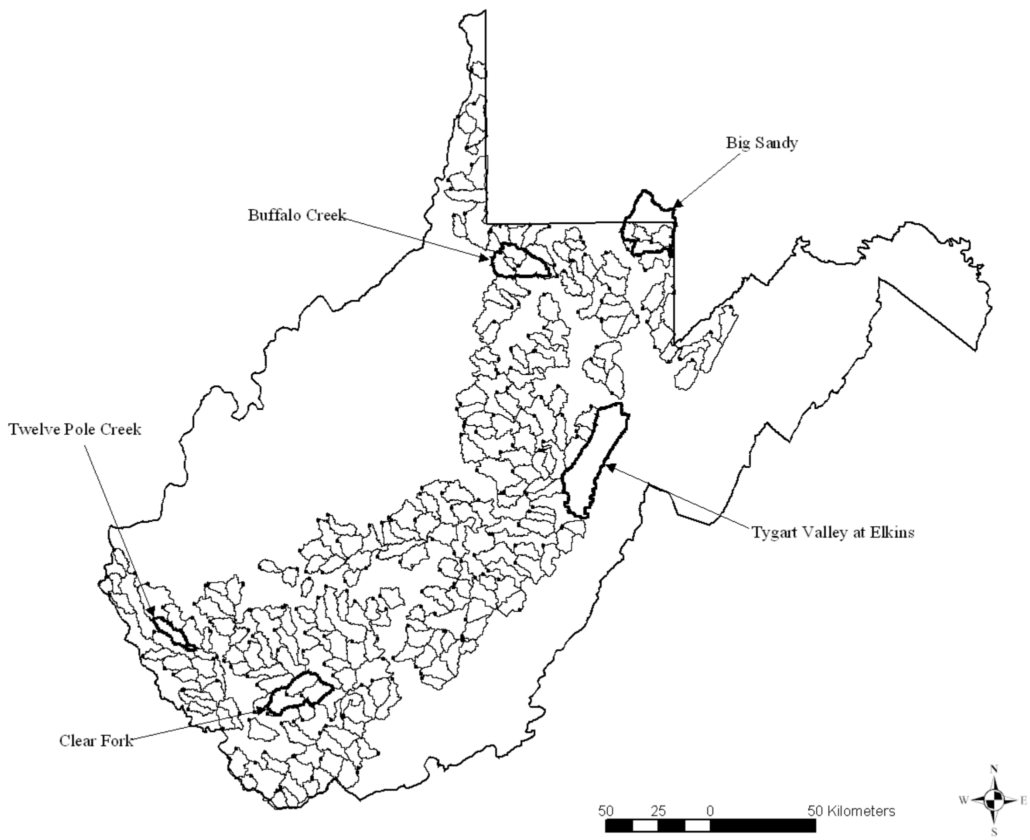


Figure 1 : West Virginia CHIA Trend Stations and Calibration Watersheds

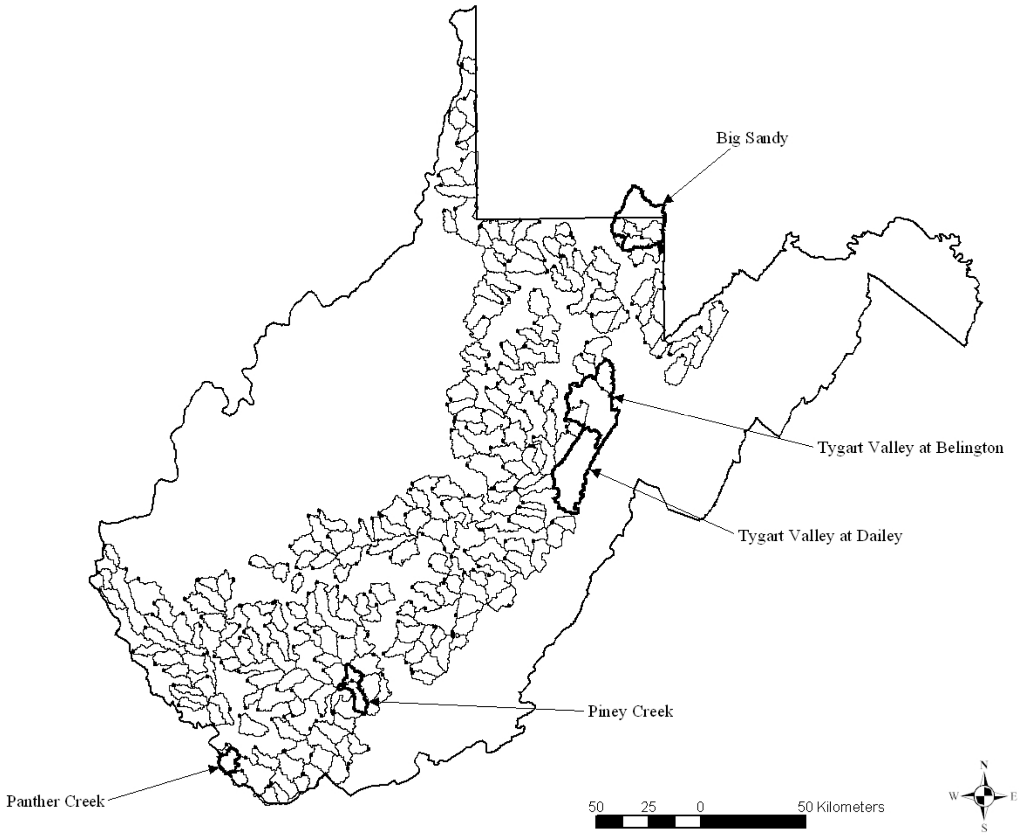


Figure 2 : West Virginia CHIA Trend Stations and Verification Watersheds

Data Requirements for Calibration

The calibration and verification watersheds, shown in Figures 1 and 2, required stream flow gaging data to support the HSPF model fitting process. Table 1 lists the watersheds along with the available USGS stream flow record and corresponding gage number.

Table 1 : List of Calibration and Verification Watershed Characteristics, and Available Gaging Records

	Watersheds	**Stream Flow Record**		
	Calibration	**From**	**To**	**Gage Number**
1	Twelve Pole Creek	10/01/1964	09/30/2000	03206600
2	Buffalo Creek	06/03/1907	09/30/2000	03061500
3	Tygart River at Elkins	10/01/1944	09/30/2000	03050500
4	Clear Fork	06/28/1974	9/30/200	03202750
5	Big Sandy	05/07/1909	09/30/2000	03070500
	Verification			
1	Panther Creek	08/01/1946	09/30/1986	03213500
3	Tygart River at Belington	06/05/1907	09/30/2000	03051000
	Tygart River at Dailey	04/20/1915	09/30/2000	03050000
4	Piney Creek	08/21/1951	09/30/1982	03185000
5	Big Sandy	See above		

The land use/cover classifications are based on 1993 GAP data. The classifications used are:

1. Forest
    a. Steep Slope
    b. Moderate Slope
    c. Mild Slope
2. Barren
3. Mined
4. Pasture/Grassland
5. Row Crop
6. Agriculture
7. Shrubland
8. Surface Water
9. Urban/Developed
10. Wetland

It should be noted that a total of 12 classifications result due to the forested slope sub-categories are considered as separate classifications. Table 2 lists the distribution of areas in the forest slope classifications for each of the calibration watersheds.

Table 2 : Slope Distribution for Calibration Watersheds

Watershed	Total Area (acres)	Total Forested Area (acres)	% Forested	% Mild Forest	% Moderate Forest	% Steep Forest
Twelve Pole Creek	23646	20402	86	10	16	74
Buffalo Creek	72257	57590	80	19	28	53
Tygart Valley at Elkins	172642	137950	80	16	22	62
Clear Fork	79862	71455	89	7	10	83
Big Sandy	123027	96713	79	61	29	10

Other input data required to run HSPF for the calibration process included PET, TEMP, and PREC (potential evapotranspiration, average air temperature, and precipitation). The values for PET and TEMP are estimated from daily maximum and minimum air temperatures (TMAX and TMIN). These data are supplied by NCDC (National Climatic Data Center) and downloaded from the internet (or obtained from a secondary supplier). PET is estimated using a HSPF data utility program called WDMUtil (using the Hamon formula). HSPF uses an hourly time increment for precipitation data input. The precipitation data was supplied under contract by Zedx Inc., which is formatted into average hourly values for each of 5 km grid squares covering the state of West Virginia, for the period from 1948 through 2000. The daily streamflow data was downloaded from a USGS internet web site. Snow cover was simulated using the Temperature-Index method option within HSPF.

The HSPF Modeling Environment: BASINS and WCMS

The HSPF model is typically applied to a watershed using BASINS (USEPA, 1999) because of its built-in spatial data base and analysis tools that greatly simplify the input data preprocessing. BASINS automates much of what was formally a very tedious text editing process of building the HSPF user control input (uci) file, by taking the user through a much simpler Windows-based data entry process. The BASINS version of HSPF works reasonably well for general purpose water quality applications but does not have an acceptable acid mine drainage (AMD) water quality (chemistry) modeling capability. The BASINS user interface still requires considerable investment in user time to overcome a steep learning curve. It requires familiarity with four separate pieces of software to prepare the input data, edit the user control input (uci) file, then execute the model, and finally, analyze the results. These latter shortcomings are being addressed by expanding the capability of WCMS to include all of the HSPF modeling and data analysis tools in a single simplified user interface.

It was necessary to conduct the trend station watershed calibration study using BASINS to process the spatial data, and to generate the uci (user control input) files, since the corresponding WCMS tools were still under development. In its default form, BASINS provides for automated watershed closure and subdivision using the 1:100,000 scale national DEM. Corrected 1:24,000 DEM (30 m resolution) coverage for West Virginia was substituted to provide the resolution needed for the WVDEP CHIA HSPF model. Additionally, the existing DLG of the stream networks within BASINS was upgraded to the 14 digit NHD (National Hydrologic Database standard). These modifications then matched the topographic and stream network data resolution to that of the standard 7.5 min. USGS quadrangle map, instead of the 1:100,000 scale map base.

Watershed Segmentation

Segmentation of each calibration watershed into sub-watersheds was based on selection of a sub-watershed size that yields a maximum of approximately 10 sub-watersheds. This was a requirement for calibration only, since the calibration method used limits the number of sub-watersheds and their associated stream segments. Figure 3 shows the Twelve Pole Creek watershed segmented based on a 100 hectare sub-watershed area threshold, yielding 59 sub-watersheds. This is equivalent to the resolution to be used in the final operational CHIA simulations. This is compared to the segmentation of Twelve Pole Creek using a 600 hectare threshold area, as shown in Figure 4, which is representative of the approximate number of sub-watersheds used for the 5 calibration watersheds. Experience of other investigators (personal communication, Kate Flynn, USGS, 2003), points out that the model calibration parameters are not significantly different for coarse segmentation as compared to a fine (high resolution) segmentation of the watershed, as long as the grouped option of assigning the PERLND properties is used (explained later). Independent testing of this thesis was confirmed by simulation comparisons. Figure 5 shows the output of a HSPF simulation for Twelve Pole Creek using 59 and 5 sub-watersheds, respectively, with all other parameters and inputs held constant. The only noticeable difference between the hydrographs is the slightly higher estimation of storm peaks by the 5 sub-watershed model, which is considered of minor significance for calibration purposes. The calibration and verification HSPF watershed model used the 600 hectare threshold criteria for segmentation in order to meet the requirements of the HSPEXP software used for the calibration process (Users Manual, HSPEXP, (1994)). Final segmentation of the all of the trend station watersheds will be done at the higher resolution (100 hectare). This level of detail corresponds to an order of magnitude increase in numbers of sub-watersheds and stream segments necessary to accurately represent the outflows from mine sites and to support the modeling of in-stream chemistry of mine acid drainage.

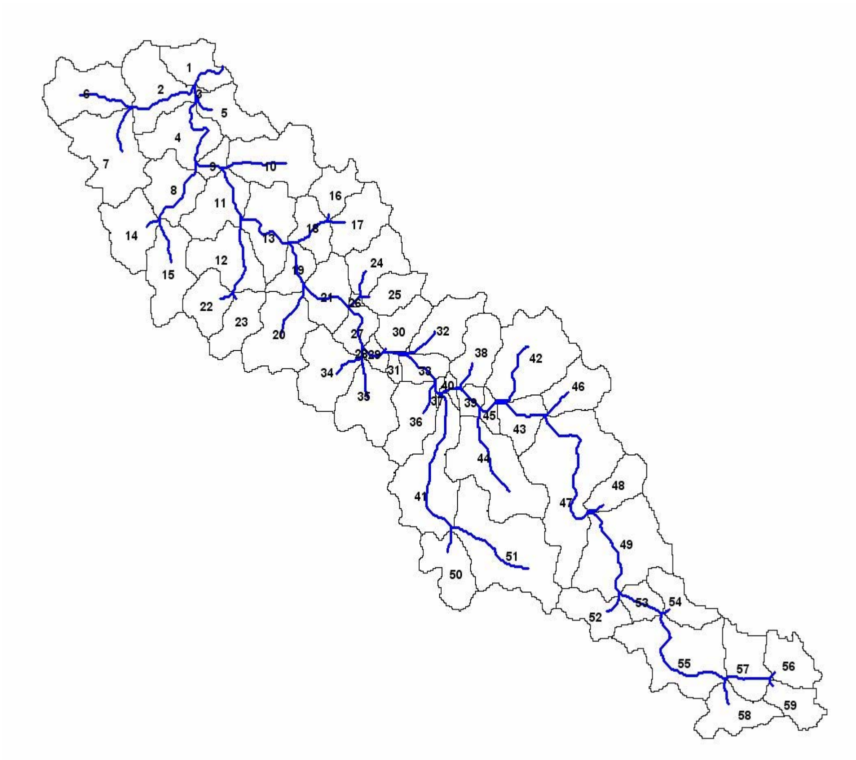


Figure 3 : Twelve Pole Creek Watershed with a 100 ha Threshold Area (59 Sub-Watersheds)

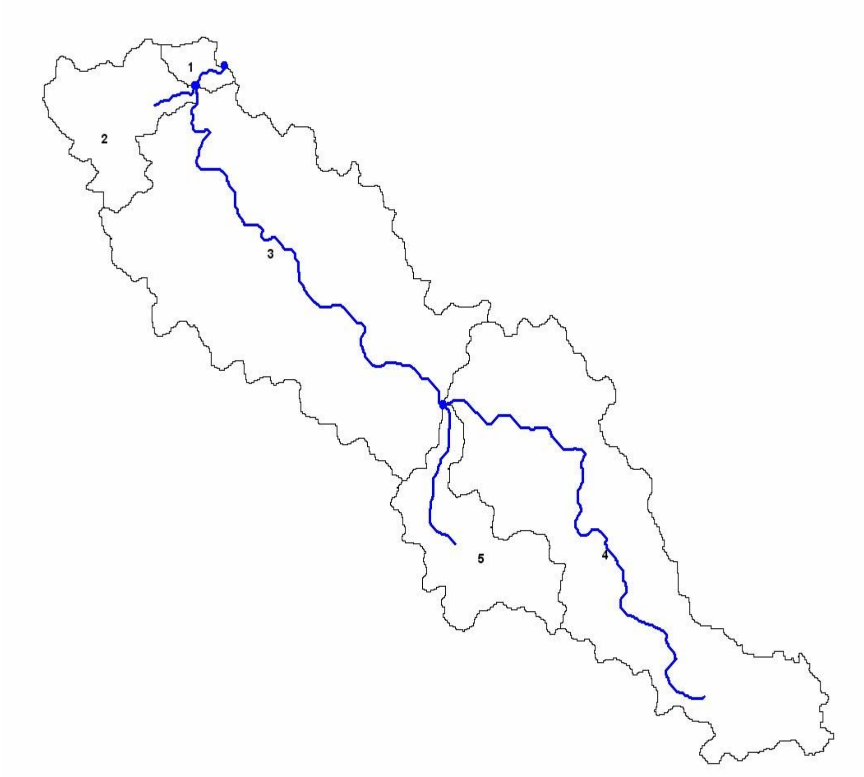


Figure 4 : Twelve Pole Creek watershed with a 600 ha threshold area (5 sub-watersheds)

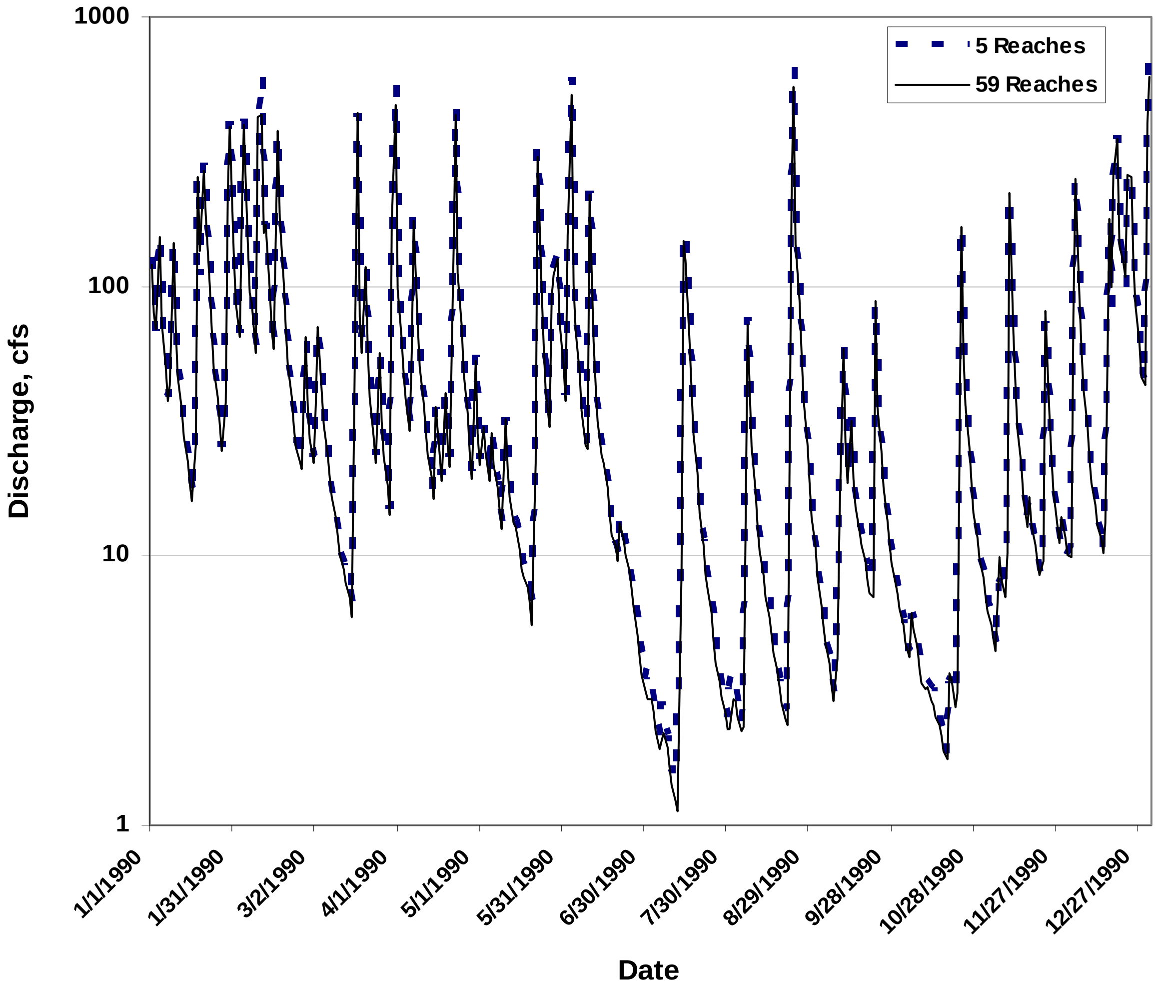
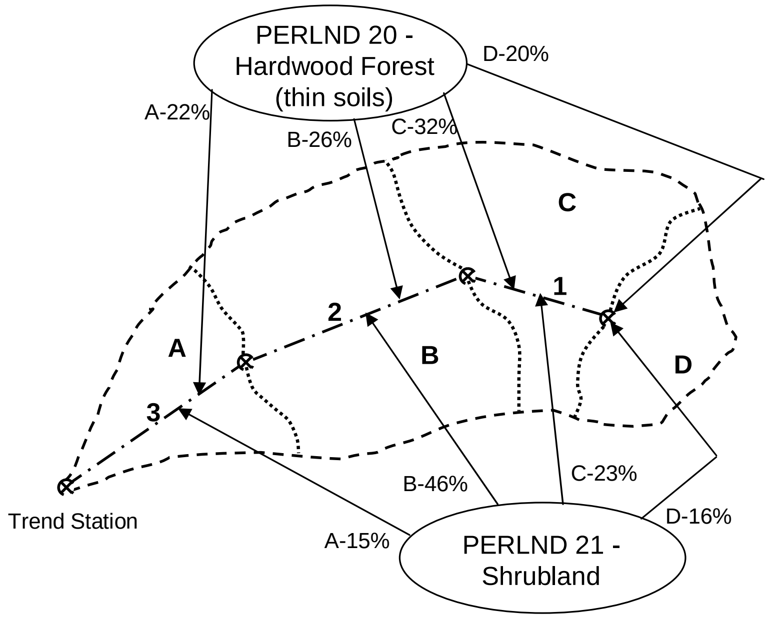


Figure 5: A Comparison of Hydrographs for the Simulation of Twelve Pole Creek

PERLND Grouping Within the CHIA Model

Within the HSPF CHIA model, the grouping approach to modeling each PERLND (one for each land use/cover classification) was selected since it accumulates all areas of like land use/cover classification within the watershed into a single PERLND. This effectively reduces model complexity and the number of parameters that must be calibrated. Figure 6 illustrates the principle behind the distribution of PERLND outflows based on the percent area of its land use/cover classification contained within each sub-watershed. Each sub-watershed has a single stream segment (RCHRES) to which its outflow is assigned. Each PERLND outflow to a particular stream segment is based on the fraction of its land use/cover classification area contained in the contributing sub-watershed.



Group option for PERLND definition

Figure 6: Grouping Land Use/Cover Classifications across Sub-Watershed Boundaries.

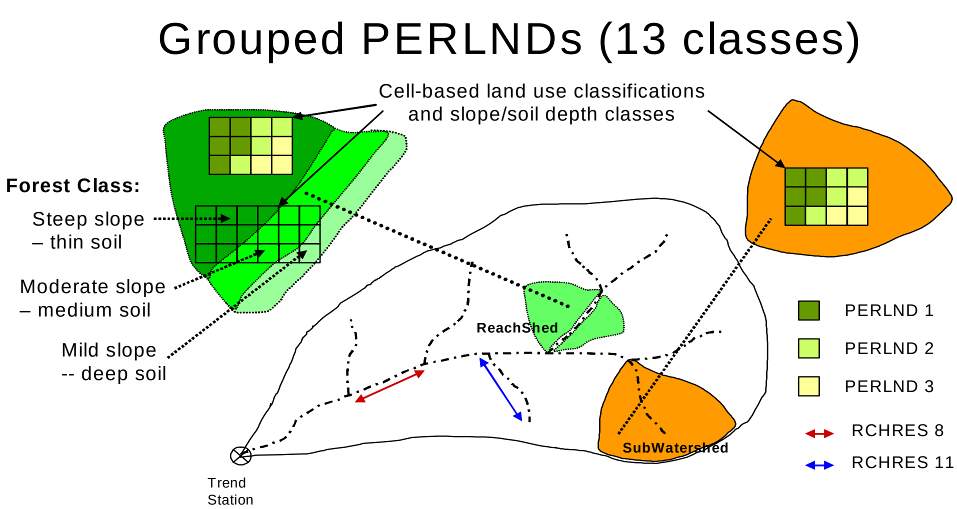


Figure 7 : Illustration of Assignment of Land Use/Cover Classification in PERLND Grouping.

Implementation of Land Use/Cover Classifications in PERLND Grouping

Figure 7 illustrates how the 13 different land use/cover classifications selected for the CHIA HSPF model are implemented. Since the Forest classification is by far the most prevalent on each trend station watershed, it is subdivided into three slope categories, steep, moderate, and mild. The remaining 10 categories are not subdivided by slope, since their portion of the watershed area is typically a small percentage. Preliminary calibration experience pointed out a need to provide slope differentiation in the most prevailing classification, since there are apparently significant hydrologic response differences between steep and milder slopes for the forest classification. The forest data slope categories were computed using the underlying DEM, and then incorporated into the land use/cover classification GIS layer, which is based on the 1993 GAP data (Strager and Yuill, 2002). Each grid cell is classified according to one of the 13 assigned land use/cover classifications. Within each sub-watershed the area associated with each classification is assigned to its corresponding PERLND, and a record is maintained of which stream segment receives the outflow from that area (Figure 6).

Calibration and Verification Results

In order to initiate the calibration study, initial values of selected calibration parameters needed to be assigned. These initial values were based on a review of parameters from other calibration studies within the Mid-Atlantic region, as determined from the HSPFParm, (1999) database (a database maintained by EPA as part of the BASINS software package), and values from similar studies (Sams, et al., (1995)), including EPA BASINS Technical Note 6, (2000). Personal communications with Kate Flynn of the USGS, Reston, in 2003 resulted in a calibration procedure that uses a single HSPF uci that is designed to combine all of the calibration watersheds into a single HSPF model run. Following a combined HSPF model run, the current calibration parameters could then be checked for suitability using a utility program called HSPEXP (USGS Report 94-4168, (1994)). This approach resulted in the creation of a single uci for Twelve Pole Creek, Buffalo Creek, Tygart Valley at Elkins, Clear Fork, and Big Sandy (Figure 1). Some simplifications were required since HSPEXP has a limit on the number of PERLND's and RCHRES's it can handle at one time, which is the reason for the 600 hectare threshold watershed subdivision used for calibration (Figure 4). Successful HSPF calibration runs were made using the combined uci within the HSPEXP software. A second combined uci was created for the 5 verification watersheds: Panther Creek, Piney Creek, Tygart Valley at Belington, Tygart Valley at Daily, and Big Sandy (Figure 2). Table 3 shows the preliminary calibration results for the calibration watersheds, while Table 4 shows the corresponding results for the verification watersheds. The statistics are based on average annual values, and show that, in most cases, the total runoff depths in each of the categories are in good agreement. The data available for calibration is considered the bare minimum for HSPF applications; therefore, it was impossible to meet the standard error criteria limits in all cases. However, since the application of HSPF for CHIA is a comparative analysis between the baseline hydrology and water quality, to that following additional mining, absolute accuracy is less important than comparative accuracy. The calibration errors are considered acceptable for the needs of CHIA, when used in the comparative analysis mode.

Table 3 : HSPF Model Calibration Statistics, Simulation Period: 1/1/1985-1/1/1990.

	TWELVE POLE CREEK		BUFFALO CREEK		TYGART VALLEY AT ELKINS	
	Simulated	**Observed**	**Simulated**	**Observed**	**Simulated**	**Observed**
Total runoff, in inches	107.3	102.9	123.9	121.21	179.4.	167.544
Total of highest 10% flows, in inches	58.25	57.3	66.7	63.11	89.22	78.442
Total of lowest 50% flows, in inches	6.91	5.39	9.58	10.33	17.98	18.503
	Simulated	**Potential**	**Simulated**	**Potential**	**Simulated**	**Potential**
Evapotranspiration, in inches	123.7	131.8	148.5	153.7	140.1	142.2
	Simulated	**Observed**	**Simulated**	**Observed**	**Simulated**	**Observed**
Baseflow recession rate	0.92	0.91	0.91	0.92	0.9	0.91
Summer flow volume, in inches	8.39	6.68	10.4	13.13	23.97	22.74
Winter flow volume, in inches	50.67	49.33	46.14	46.6	54.1	53.89
	Current	**Criteria**	**Current**	**Criteria**	**Current**	**Criteria**
Error in total volume	4.3	10	2.2	10	7.1	10
Error in low flow recession	-0.01	0.01	0.01	0.01	0.01	0.01
Error in 50% lowest flows	28.3	10	-7.2	10	-2.8	10
Error in 10% highest flows	1.7	15	5.7	15	13.7	15
Seasonal volume error	19.7	10	19.8	15	5	10

	CLEAR FORK		BIG SANDY	
	Simulated	**Observed**	**Simulated**	**Observed**
Total runoff, in inches	113.9	109.298	179	173.25
Total of highest 10% flows, in inches	58.27	54.427	86.62	76.686
Total of lowest 50% flows, in inches	8.75	9.451	19.37	21.924
	Simulated	**Potential**	**Simulated**	**Potential**
Evapotranspiration, in inches	149.7	154.6	118.7	120
	Simulated	**Observed**	**Simulated**	**Observed**
Baseflow recession rate	0.91	0.93	0.92	0.92
Summer flow volume, in inches	6.76	6.904	20.55	19.729
Winter flow volume, in inches	43.56	44.658	51.44	63.8
	Current	**Criteria**	**Current**	**Criteria**
Error in total volume	4.2	10	3.7	10
Error in low flow recession	0.02	0.01	0	0.01
Error in 50% lowest flows	-7.4	10	-11.6	10
Error in 10% highest flows	7.1	15	13	15
Seasonal volume error	0.4	10	23.6	10

Table 4 : HSPF Model Verification Statistics, Simulation Period: 1/1/1976-12/31/1981.

	TYGART VALLEY BELINGTON		PINEY CREEK		PANTHER CREEK	
	Simulated	Observed	Simulated	Observed	Simulated	Observed
Total runoff, in inches	149.9	162.593	114.7	90.047	102.4	102.117
Total of highest 10% flows, in inches	66.42	66.21	56.48	35.638	56.51	54.585
Total of lowest 50% flows, in inches	14.48	20.134	10.53	12.745	7.05	8.586
	Simulated	Potential	Simulated	Potential	Simulated	Potential
Evapotranspiration, in inches	113.3	114.5	104.1	108.6	134.8	137.5
	Simulated	Observed	Simulated	Observed	Simulated	Observed
Baseflow recession rate	0.87	0.91	0.88	0.92	0.9	0.9
Summer flow volume, in inches	15.18	21.151	10.01	11.037	5.36	8.489
Winter flow volume, in inches	60.87	63.773	43.04	33.556	39.84	40.357
	Current	Criteria	Current	Criteria	Current	Criteria
Error in total volume	-7.8	10	27.4	10	0.3	10
Error in low flow recession	0.04	0.01	0.04	0.01	0	0.01
Error in 50% lowest flows	-28.1	10	-17.4	10	-17.9	10
Error in 10% highest flows	0.3	15	58.5	15	3.5	15
Seasonal volume error	23.6	10	37.6	10	35.6	10

	BIG SANDY		TYGART VALLEY DAILEY	
	Simulated	Observed	Simulated	Observed
Total runoff, in inches	147.6	163.32	158.9	157.525
Total of highest 10% flows, in inches	79.67	66.886	72.69	66.621
Total of lowest 50% flows, in inches	11.12	19.971	14.4	18.782
	Simulated	Potential	Simulated	Potential
Evapotranspiration, in inches	92.51	93.3	109.6	110.3
	Simulated	Observed	Simulated	Observed
Baseflow recession rate	0.9	0.91	0.88	0.9
Summer flow volume, in inches	15.31	21.403	15.85	20.686
Winter flow volume, in inches	55.42	62.554	63.75	63.183
	Current	Criteria	Current	Criteria
Error in total volume	-9.6	10	0.9	10
Error in low flow recession	0.01	0.01	0.02	0.01
Error in 50% lowest flows	-44.3	10	-23.3	10
Error in 10% highest flows	19.1	15	9.1	15
Seasonal volume error	17.1	10	24.3	10

CHIA/HSPF Surface Mine Site Model

Modifications to the HSPF Baseline UCI File

The principal purpose of the CHIA/HSPF model is to evaluate the potential hydrologic impacts of accumulated mining activities in the watershed in question over time. New or proposed mines (or existing mines) are added to the baseline HSPF model by editing the user control input file (uci) to first exclude the baseline land use/classification areas within the boundary of the mine site, and then to add mine site area land use/classifications to replace what was removed. To assure that mass (runoff water) is conserved, the mine area added must match the baseline area removed from the uci. This process is best described by presenting a graphic example. Figure 8 shows the Constitution Mine site in south central West Virginia. The green area is that portion of the mine site that is hydrologically controlled, with outflows through NPDES points shown as red dots in the figure. Each of these points control a portion of the drainage area (the green area), and direct their outflows to a particular NHD stream segment (4 are selected as examples in Figure 8). The mine site is aligned from northwest to southeast along a ridge top that is the hydrologic boundary between two trend station watersheds. The mine is therefore split into a West Drainage and an East Drainage that flows into each respective trend station watershed. This split requires that the two individual trend station watershed uci's be sequentially edited to include the mine site. The mine site land use/classification area is added back into each uci (west and east) in segments, as defined by the NPDES drainage areas. The modeler has the option of segmenting the mine site by using the individual NPDES points, or by combining points to produce larger segments, which effectively reduces the amount of data that must be entered. The latter choice obviously reduces accuracy of the model representation of the mine site so that the modeler must balance time spent entering the data with the desire to model the mine site as accurately as possible. The modeler also has the option of selecting the desired stream segment into which the outflow is directed. The WCMS tools are designed to permit complete flexibility so that the modeler is free to segment the mine site and direct the segmented outflows as desired.

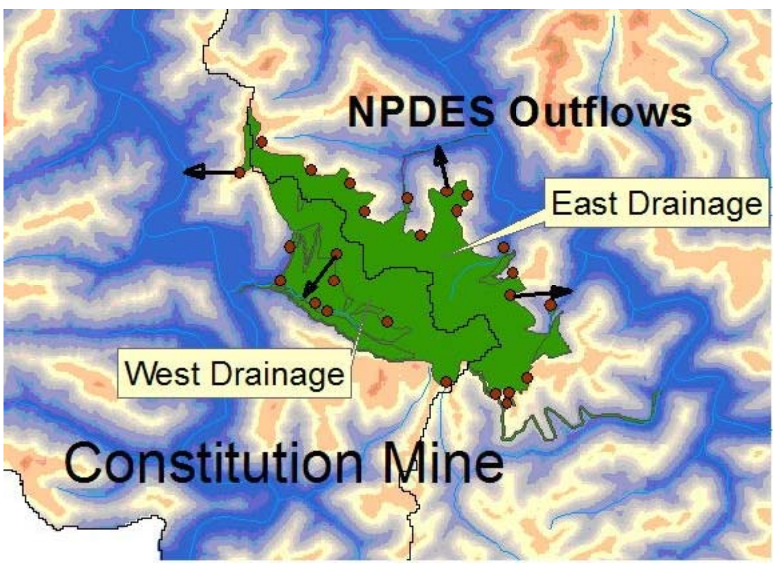


Figure 8 : Mine Segment Model Example: Constitution Mine, WV. [Note: red dots represent NPDES discharge points.]

The CHIA/HSPF Mine Segment Model

Each mine segment, as defined by the drainage area to each NPDES outflow point (or the combined drainage areas to combined NPDES outflow points) is modeled by a single PERLND that drains into a single RCHRES within the HSPF. As discussed in the previous section, the baseline uci is copied prior to removing the pre-existing land use/classification areas that are within the mine boundary. Following this removal, the uci is further edited (using WCMS tools) to add the mine segments, each consisting of the single PERLND and RCHRES as illustrated schematically in Figure 9. The mine segment areas added back into the uci must accumulate to the same area as was originally removed from that uci.

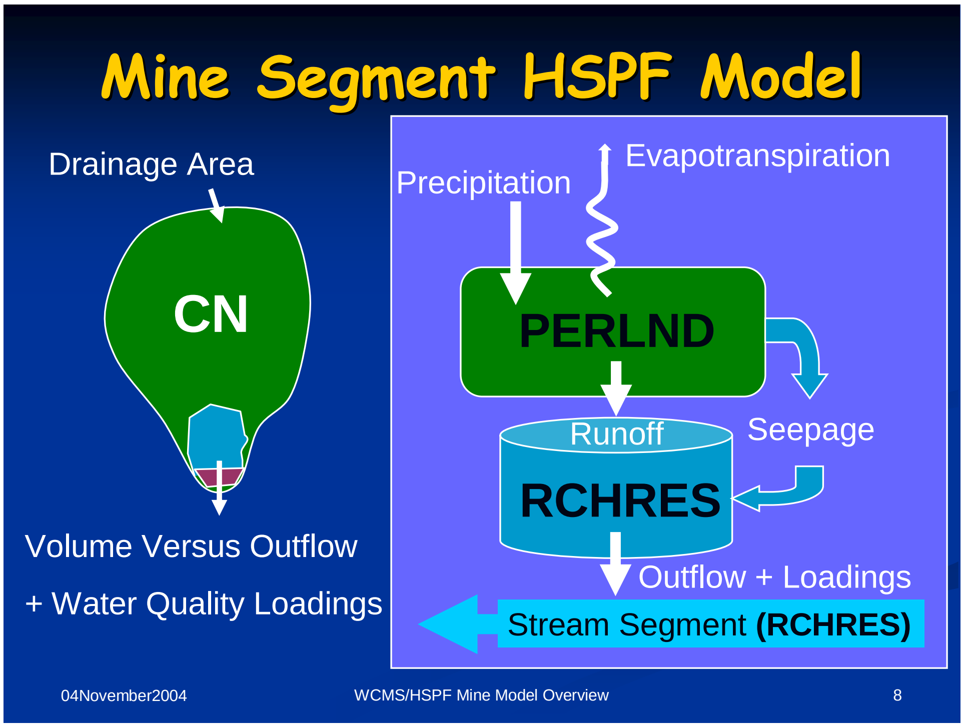


Figure 9 : HSPF Mine Segment Hydrologic Model.

As illustrated in Figure 9, each mine segment area is assumed to be represented by a single area weighted SCS (Soil Conservation Service) curve number (CN value), as specified in the mine permit application. In fact, the mine segment components of the trend station uci are modeled in such a way as to duplicate the hydrologic response of the mine segments provided by standard WVDEP mine permit application hydrology calculations. This adaptation of the WVDEP mine permit application hydrology calculations was the only option open to consideration since calibration data for mine sites is not available using HSPF. WCMS internally converts the standard SCS procedures into equivalent HSPF parameters so that the mine segments are modeled as an integral part of the trend station watershed.

Sediment ponds are typically modeled using SEDCAD (Civil Software Design, LLC) software, which uses the SCS TR-55 (1986) procedure to determine the sediment structure inflow. The storage versus outflow relationship is determined using standard hydraulic calculations (McCuen, 2005). Sediment ditches and other low volume structures are sized using the standard 0.125 ac-ft/ac design criterion, in conjunction with the SCS TR-55 peak discharge method. The mine segment model within HSPF accepts input data that matches data found in the standard mine permit application. Both sediment ditch design features and sediment pond design features are emulated in the software so that the outflow responses during continuous simulations are consistent with single event design calculations. The NPDES discharge is taken to be the peak discharge resulting from the design storm event at the specified frequency. The water quality loadings at each outflow point can be adjusted as desired by the modeler. The modeler has two data input options, as shown in Figure 10. The first option only requires a minimal amount of data input. If this option is selected, the peak discharge (the NPDES discharge) is assumed to be the sediment pond outflow peak discharge for the specified design storm frequency. The pond volume is then estimated based on this latter outflow discharge peak and the peak inflow discharge computed using the TR-55 peak discharge method. Therefore, the minimal data input option listed in Figure 10 is sufficient to indirectly specify the volume versus outflow characteristics of the pond (and sediment ditches), if the modeler is willing to use a built-in relationship between drainage area and time of concentration. The second option includes additional input data consisting of the actual sediment pond volume versus outflow table (from the permit application) and those additional hydraulic variables needed to compute the complete inflow unit hydrograph. This latter option fully specifies the hydrologic response of the mine segment according to the standard TR-55 procedures.

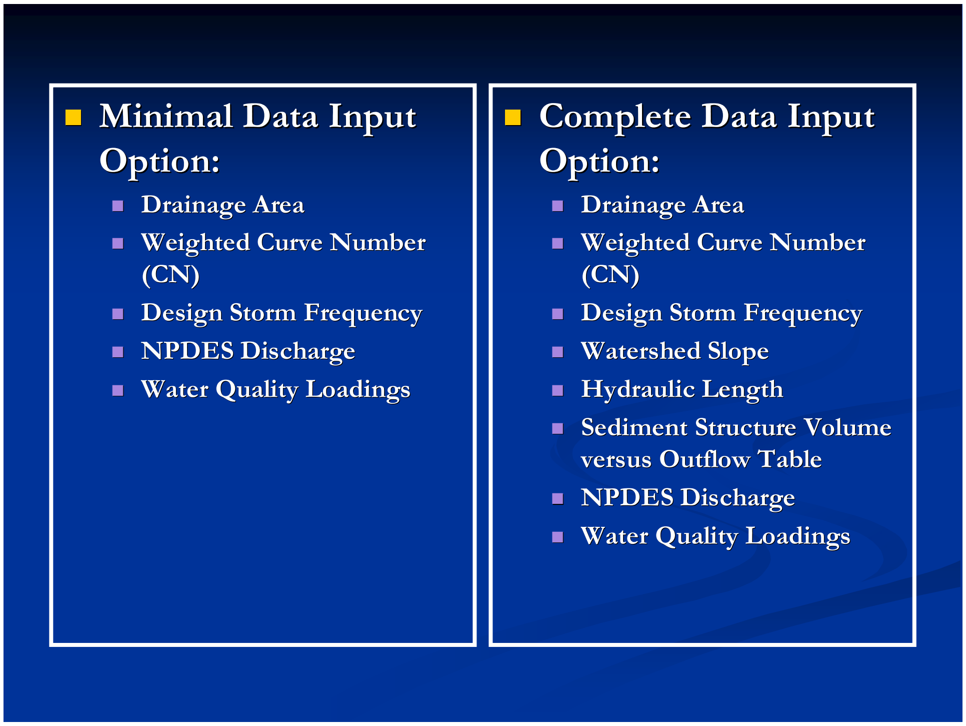


Figure 10 : WCMS/HSPF Mine Segment Model Input Data Options.

Incorporation of HSPF into WCMS

NRAC's WCMS mapping and modeling package is being modified to include the CHIA/HSPF modeling capability described above. The GIS and analysis tools needed to implement HSPF within the WCMS environment are being incorporated so that all steps, from mine site location to display of the final analysis results, are fully contained within WCMS. This greatly reduces the amount of effort required to effectively complete the complex CHIA analyses required to evaluate the impacts of mining on watershed hydrology and stream water quality. In the calibration phase described above, EPA BASINS (USEPA, (1998)) was used to generate the HSPF uci (user control input) files, and to conduct the model runs, and to analyze the results. When using BASINS, the GIS tools are used to generate four intermediate files, as shown in Figure 11, which provide the input required by a Windows uci generator and editing interface called WinHSPF (Duda, et al., (2001)). The four input files are read by WinHSPF which in turn creates the uci file and links it to HSPF for execution. The output of the model can then be viewed graphically, statistically, or in tabular form, using the post-processing software called GenScn (USEPA, (1998)). WCMS is being configured so that all of these steps are accomplished in one environment, the WCMS Windows interface. Tool bars and data entry windows will guide the entire process using customized GIS tools to insert and specify the mine segments, through to the final analyses of the output from HSPF simulations. Additional post analysis tools are to include graphic display of stream flows, water quality loadings, and data statistics; all accomplished with the same WCMS interface environment.

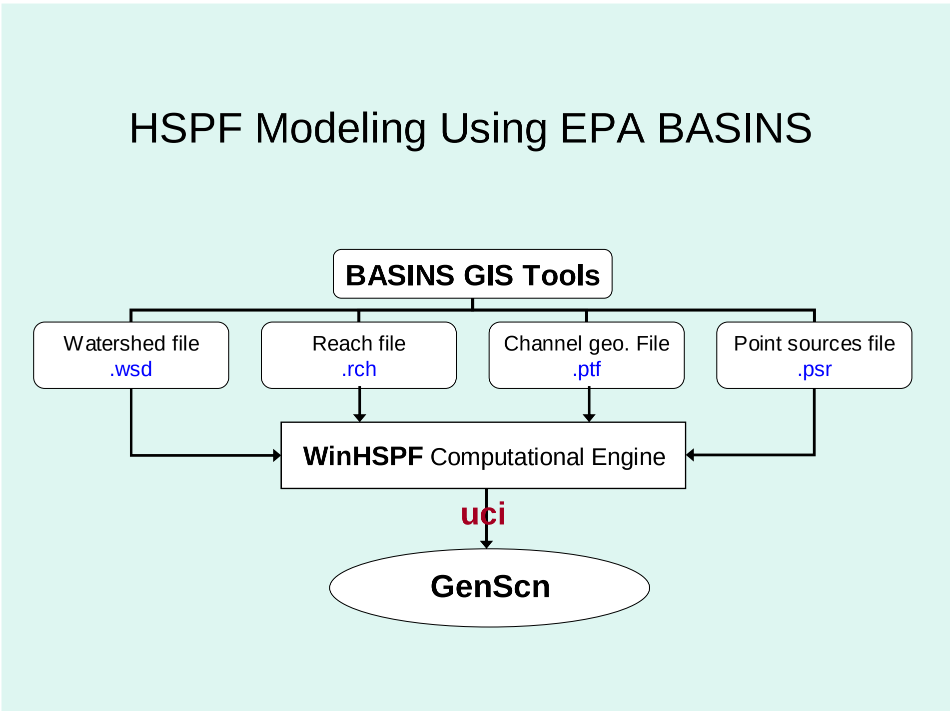


Figure 11 : HSPF Modeling Steps Using the EPA BASINS Software.

The CHIA/HSPF Mine Drainage Model

The WCMS implementation of the HSPF model includes a new water quality modeling component developed as the ACCAL4 option within the ACIDPH routine of HSPF. It is an integral part of the HSPF Fortran code, requiring its insertion into the source code and a recompilation of the code. The ACIDPH module operates within the stream segment components of HSPF (the RCHRES component). Each RCHRES is modeled as a reservoir into which the inflows are temporarily stored, and the outflows are governed by a volume versus discharge relationship determined by the geometry of the stream channel. The stream segments (RCHRES's) are joined in a standard dendretic pattern, with two stream segments joining at a point of confluence with a single downstream stream segment. When two streams segments (A and B) meet, the outflows are assumed to mix fully and inflow into the downstream segment (C) where acidity, metal concentrations, and other water quality parameters may change based on a series of geochemical reactions. The model simulates the major components of mine drainage or runoff. Changes in Fe, Al, Mn, pH, acidity, and alkalinity are assumed to interact according to appropriate geochemical balance equations while sulfate and electrical conductivity are included through a mass balance equation approach. The following is a brief summary of some of the primary concepts that support the ACALL4 option.

Electrical conductivity, EC, provides an estimate of the amount of total dissolved salts, TDS, or the total amount of dissolved ions in the water. The most common used unit of EC is microSiemens per centimeter (µS/cm).

Since metal ions can form various types of complex compounds in water, it is difficult to quantitatively model the precipitates that occur in each stream. Geochemistry balances use activity instead of concentrations for calculating metal precipitation calculated by concentrations and ion strength derived from conductivity. According to the research and field investigation of Evangelou and Garyotis (1985), ion strength is linearly related to conductivity.

The activity coefficient, which determines the activity of the parameters, can be derived from the revised Debye-Huckel equation (Nordstrom and Munoz, (1994)) and EPA's MINTEQA2 model. Models commonly use total iron which includes both ferric and ferrous forms instead of modeling them separately. In a coal mining context, most ferrous iron (Fe^{2+}) comes from soil leaching and acid mine drainage and has thus already been exposed to air over time (Fe^{2+} is easily oxidized into ferric form (Fe^{3+}) – under natural aerobic conditions 90% can be converted within 10-20 minutes at a pH 7 at a temperature of 25^{o}C under standard atmospheric pressure). Thus, it is assumed that ferric iron is the predominant form of iron and it is appropriate to model ferric iron instead of total iron (Sun, 2000).

Total acidity is affected by pH and heavy metal concentrations in water and thus is greatly affected by the precipitation of metals. Usually total acidity is presented as mg/L of $CaCO_3$ equivalent. To modify changes in total acidity, the effects of both metal ion concentrations and pH are used to calculate the total acidity measured in mg/L of $CaCO_3$.

This approach to in-stream modeling of coal mining related pollutants is now being included in the current HSPF code and calibration of the primary coefficient is expected to be concluded in early 2005. The ability to query water quality data stored in the WVDEP Oracle databases will provide the functionality necessary to use this approach in the modeling process.

Future Directions

The WCMS tools required to include the CHIA/HSPF hydrologic and ACIDPH modeling capability are currently in the process of being completed. The surface mine site hydrologic model conceptual design is complete and is in the process of being implemented in computer code that will be included in WCMS. The underground mine model is in conceptual development, but will not be the focus of development efforts until after the surface mine model is fully implemented and tested. The underground mine model will use a new version of HSPF that combines USGS MODFLOW (http://water.usgs.gov/nrp/gwsoftware/modflow.html) groundwater modeling capabilities with the current version of HSPF. This latter capability will be included within WCMS via new tools to be developed for subsurface mining to complement those for surface mining.

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