MODELING THE HYDROLOGIC EFFECTS RESULTING FROM UNDERGROUND MINING USING WCMS-HSPF AND GMS[1]

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Abstract. Spruce Laurel Fork is a major third order perennial stream in Boone County, West Virginia that has been significantly dewatered, which occurs over and/or adjacent to pre- and post-SMCRA (Surface Mining Control and Reclamation Act, 1977) underground mines. This project describes how the WVU-NRAC, WCMS-HSPF (West Virginia University, National Resource Analysis Center, Watershed Characterization and Modeling System-Hydrologic Simulation Program-Fortran), and the OSM TIPS GMS (EMS-i, Ground Water Modeling System) software applications has been used to model the effects from underground mining on the Spruce Laurel Fork watershed. The conceptual model indicates that some reaches of Spruce Laurel Fork and its tributaries have been dewatered. Flow is diverted from the stream downward into the underground mines that contribute to the development of the mine pools. A hydraulic connection exists between the pools formed in these mines and artesian effects to down-gradient residents' water wells and basements. The ground water flow model was constructed using a conceptual model of geographic, hydrogeologic, and mining features, which reflect the Spruce Laurel Fork study area sources/sinks and boundary conditions. This ground water model was based on prudent hydrologic assumptions that were necessary in order to develop the ground water flow model. The results of this project illustrate how the WCMS-HSPF and the GMS applications can compliment each other when modeling watershed hydrology that is associated with underground coal mining. The WCMS-HSPF application successfully modeled the watershed streamflow; however, the GMS ground water flow model still needs considerable refinement as this time. More accurate data for hydraulic parameters, rather than assumptions are needed in order to develop better predictive models that quantify the impacts from underground mining. Accordingly, this would result in models that would more accurately reflect field conditions such as the Spruce Laurel Fork dewatered stream reaches, mine pool development, and artesian conditions that occurred at residents' homes.

Additional key words: HSPF, hydraulic connection, mine pools, artesian, seepage face

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INTRODUCTION

This paper describes how ground water modeling was utilized to supplement an existing assessment of adverse hydrologic impacts from underground coal mining operations on Spruce Laurel Fork in Boone County, West Virginia (Figure 1). The conceptual model represents an aquifer system in which Spruce Laurel Fork is losing water to a series of underground mines that underlie the Spruce Laurel Fork watershed. As a result of the dewatering of Spruce Laurel Fork, streamflow descends down though the mined seam overburden, which infiltrates into the mines and develop mine pools. The mine pool water migrates downgradient to residents home and wells if not controlled by pumping.

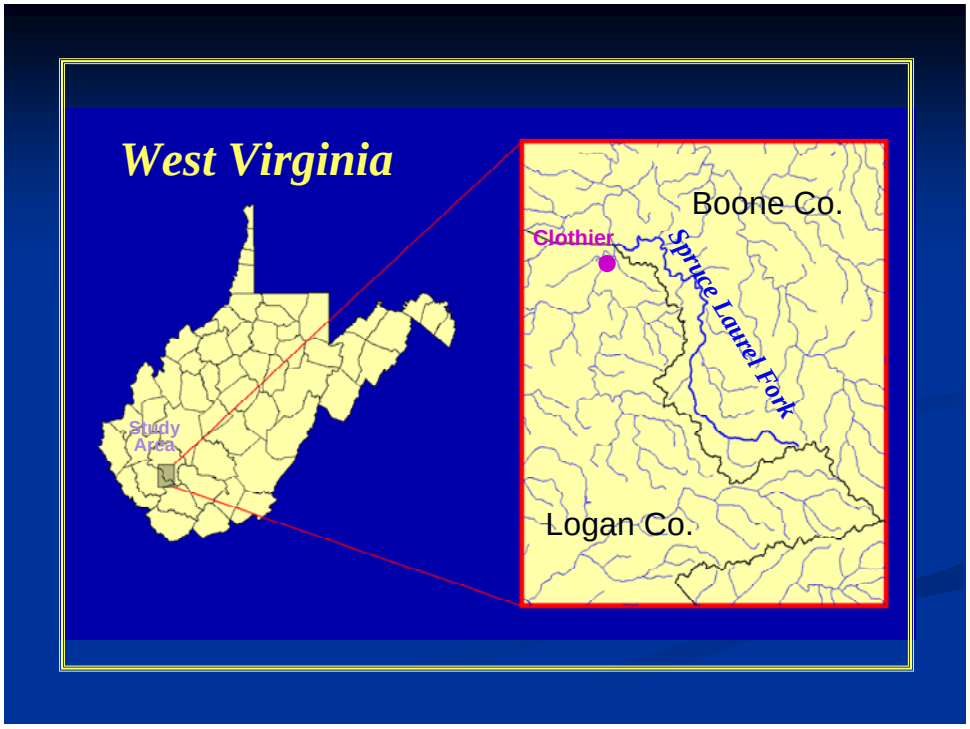


Figure 1. Location map of the study area

Effects from coal mining on hydrologic systems range from minimal to severe depending upon mining method, depth to mining, overburden depth, and mined seam overburden stratigraphy and structure. Modeling hydrologic systems, especially ground water associated with underground mines present numerous problems due to lack of site-specific data for such hydraulic parameters as recharge rate, hydraulic conductivity

within the overburden, in-mine voids. Determining hydraulic characteristics for the fractured mined seam roof rock overburden is also problematic. A simple ground water flow two layer approach is presented here that simulates the impacts from underground mining on the Spruce Laurel Fork watershed.

Deeper underground mines result in greater overburden thickness that result in confining conditions, albeit the mined seam roof rock overburden that will be cave, fracture or dilate in response to the mining method. Un-mined coal barriers between adjacent mines vary in thickness and allow mine water to migrate into adjacent mines. Barriers of excessive thickness allow large differences in hydraulic head that develop mine pools. Below drainage underground mines develop pools when mining is completed and can result in mine pool water that migrates to pressure breakout points at the surface, especially stream valleys, e.g., Spruce Laurel Fork watershed. Previous hydrologic studies concerning Spruce Laurel Fork operations mine pools has yielded only limited information on parameters such as horizontal and vertical hydraulic conductivities, mine storativity, and ground water flow patterns.

The Guyan mines are located below-drainage mines that occur in the Spruce Laurel Fork watershed and operated from the 1950's to 1977. Contiguous to the Guyan mine(s) are the Hampton No. 4 and No. 3 mines, which are downgradient and downstream with respect to the pre-SMCRA Guyan mines. A portion of the Hampton and Guyan mines occur under the main stem of Spruce Laurel Fork and its tributaries. Although portions of the Hampton and Guyan mining operations occurred in the Spruce Laurel Fork watershed, other mining also occurred in the adjacent Spruce River and Pond Fork watersheds. Hampton and Guyan mining in the Spruce Laurel Fork watershed encompassed 16,506 acres (Reed, 1998; Reed and Rauch, 2001).

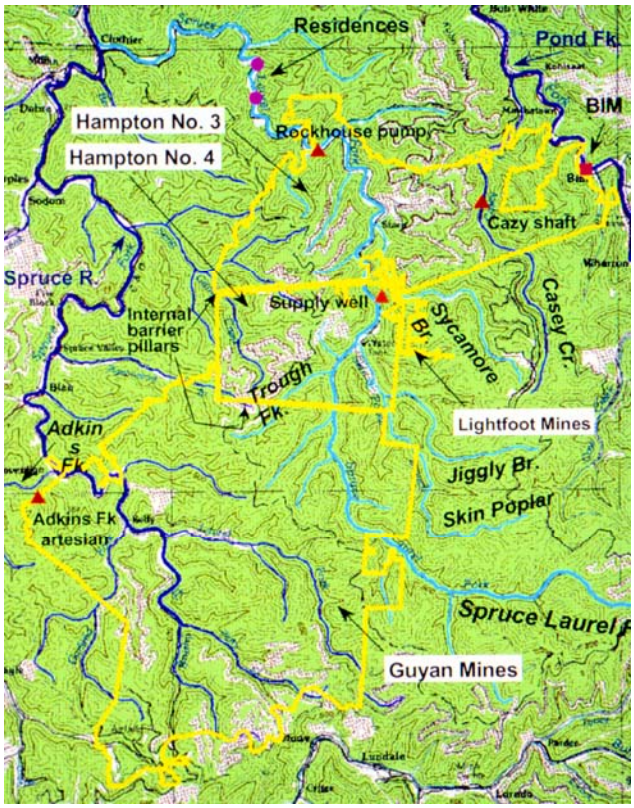


Figure 2. Site-specific location map of the study area

The available streamflow data show that certain reaches of Spruce Laurel Fork have been adversely impacted by Hampton and Guyan mining, resulting in the dewatering of reaches of Spruce Laurel Fork, which becomes a losing stream. Modeling the surface and ground water associated with underground mining helps illustrate hydrologic impacts to Spruce Laurel Fork. Ground water modeling was integrated with streamflow measurements, field observations, and surface water modeling Even though the ground water model needs much more refinement to correctly illustrate how streamflow was, and continues to be "pirated" from reaches of Spruce Laurel Fork. The "pirated" streamflow is diverted down into the Hampton and Guyan mines, which contribute to the development of mine pools.

Figure 3. Downstream view of dewatered Upper Reaches of Spruce Laurel Fork

Seepage from each adjacent upgradient mine coal barrier and recharge into the overburden also contributes to the development of each downgradient mine pool. Areas of the watershed that had been undermined by the Hampton and Guyan mining operations contribute less baseflow and runoff flow now to streamflow in Spruce Laurel Fork. The dewatering reflects a change to the hydrologic regime of the upper and middle Reaches of the stream. A hydraulic connection exists between the Hampton No. 3 mine pool and off-site impacts to residents by artesian AMD discharges. Artesian effects to residents have been controlled by continuous pumping of the Hampton No. 3 mine pool level in order to maintain the pool level down below surface discharge elevations.

During 1991-1992 the West Virginia Department of Environmental Protection (WVDEP) began to receive complaints from residents living along Spruce Laurel Fork and Pond Fork, Boone County that artesian conditions were occurring. The WVDEP investigated the complaints of artesian (water flowing above the land surface) AMD (Acid Mine Drainage, defined here as circum-neutral, with elevated iron and manganese levels) in the Spruce Laurel Fork area.

In 1992, the Company pumped the Hampton No. 3 mine in order to lower the mine pool, and alleviate the off-site artesian discharges in residents' water wells located along Spruce Laurel Fork, and in homes in the Bim area of Pond Fork. A cause-and-effect relationship was established when pumping from the Hampton No. 3 –Casey Shaft was successful in eliminating the offsite artesian effects. Pumping continues today from a pump site along Spruce Laurel Fork, in order to maintain a pool level that prevents artesian conditions from returning.

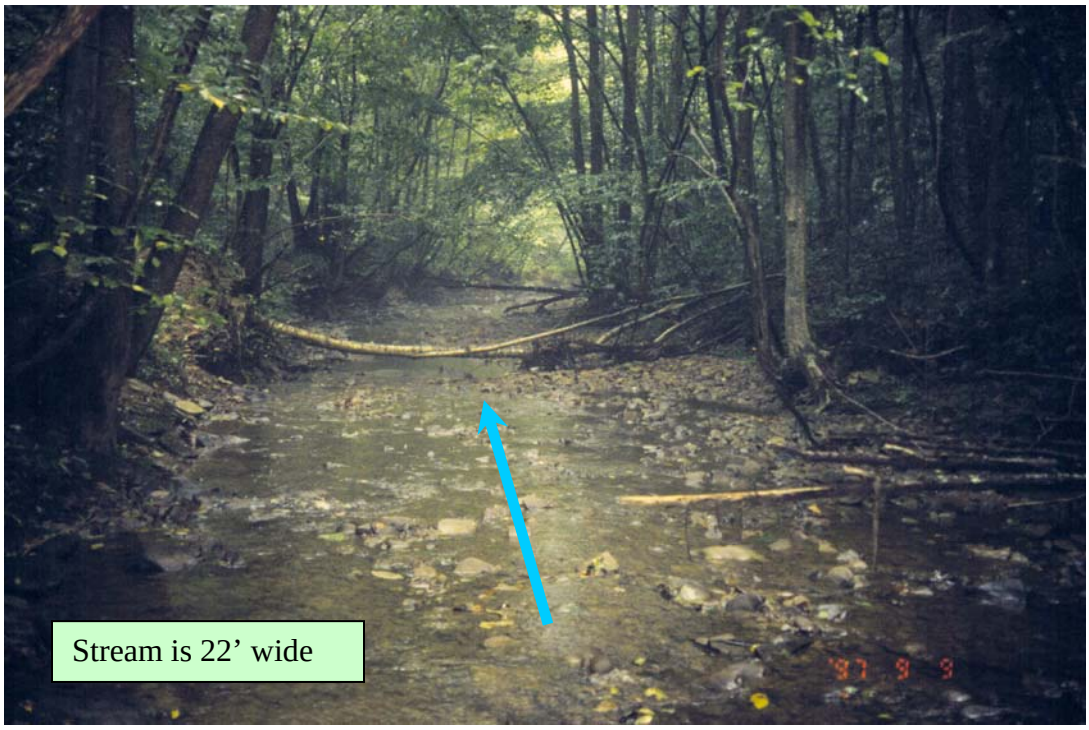


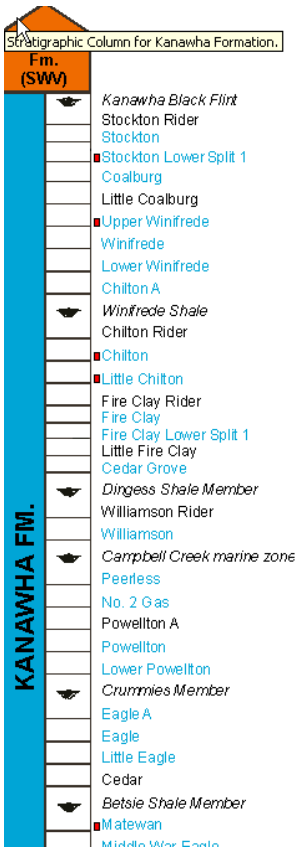
Figure 4. Headwaters of Spruce Laurel Fork, Site A1

Figure 5. Downstream view, dewatered Middle Reaches of Spruce Laurel Fork

HYDROGEOLOGIC SETTING

Precipitation in the study area averages about 42 inches annually and recharges the local and regional ground water systems. Ground water flow in the Appalachian Plateau is affected by site-specific topography, stratigraphy and lithology, and structural geology, which control the occurrence, movement, storage and flow of ground water, and also affect ground water quality. The strata in the study area dip towards the northwest and the Coalburg Syncline at approximately 2 percent Ground water flowpaths are short and confined to two principal aquifer systems: unconsolidated alluvial aquifers, comprised of sand, silt, clay, and gravel; and fractured bedrock aquifers, comprised of sedimentary rocks (Puente, 1984). Bedrock aquifers in the study area are part of the Kanawha Formation, which are cyclic sequences of coarsening-upwards or fining-upwards sequences of sandstone, siltstone, shales, and coal seams. Secondary permeability is due to joint and stress-relief fractures; primary or intergranular porosity does not convey any magnitude of ground water in the Appalachian Plateau.

Ground water flow in West Virginia watersheds was described by Ferguson (1967) and Wyrick and Borchers (1981), and is adopted here to explain how horizontal bedding-plane fractures and vertical fracture systems develop into flowpaths for water movement in the Spruce Laurel Fork watershed. The Almes & Associates Engineering (1993) location map showed the occurrence of photolineaments in the Spruce Laurel Fork area. These features occur above the Guyan and Hampton mines, and in general are entrenched in all the drainage systems in the watershed. These photolineaments create large-scale secondary permeability flow paths for faster throughput of water movement downward into the Hampton and Guyan mines. Similarly, Hobba (1981) concluded that mine subsidence increases the total amount of water available for development of mine pools by permitting increased infiltration and reduced evapotranspiration.



Hampton and Guyan mine-induced overburden movements accentuated the existing stress-relief and tectonic fractures. Mining-induces movements contributed to a network of interconnected fractures that affects the hydrologic regime of the Spruce Laurel Fork watershed (WVDEP, 1997). Seepage flows through coal seam barrier pillars via flowpaths developed by secondary permeability features such as cleat systems, bedding planes, and fractures developed in the coal seam and associated roof rock overburden (Pearson, M.L., et al., 1981). Coal mine barrier pillars in mines are subjected to hydraulic pressure heads due to the build-up of mine water in the old workings and the pressure head results in seepage flow through the pillar and its surrounding strata (Luo et al., 2001).

Figure 6. Stratigraphic columnar section of the Kanawha Formation-No. 2 Gas coal seam

The Almes & Associates Engineering Figure 5 (1993) cross section shows that downstream of gaging Station A17, the mine pool rose above the level of the stream in 1991-1992 and caused artesian affects on residents' homes along Spruce Laurel Fork, and in the Bim area of the Pond Fork watershed; offsite impacts to the downstream residents are controlled by pumping the Hampton No. 3 mine pool. Figure 7 depicts the strata under the streambed as largely sandstone.

Both the WVDEP (1997) and Reed (1998) and Reed and Rauch noted alluvial material largely covered the stream. Stream dewatering can occur where the streambed is sandstone bedrock that contains fractures or dilated bedding-plane fractures (Reed, 1998). Natural filling of these fractures (subsidence cracks) with sediment in northern West Virginia stream channels allow the return of normal streamflow typically within three years of initial undermining and streamflow loss, if suitable alluvial particle sizes are present (Carver and Rauch, 1994; Gill, 2000).

The available data shows that there is abundant alluvial material covering the streambed. The thickness of the alluvial material that was determined by Reed (1998) and Reed and Rauch (2001) shows an alluvial thickness in Spruce Laurel Fork that ranged from 0.0 to 4.46 feet thick. Moreover, the WVDEP/AML restoration work in 2004 showed that the alluvium ranged from 2-19 feet thick in the Upper Reaches of Spruce Laurel Fork. Reed (1998) concluded that even though there is abundant alluvial material in the Spruce Laurel Fork streambed, the alluvial particle sizes are apparently not adequate (too large) to seal the mine-induced fractures to prevent loss of flow.

The Hampton No. 3 and Guyan mines have surface discharges from their mine pools; however, the Hampton No. 4 mine does not have a discharge point. The Adkins Fork artesian well that is located in the Guyan mine pool. Guyan mine pool development is somewhat restricted by the Adkins Fork flowing artesian (mine) discharge of approximately 200 gpm that relieves the head within the mine. Artesian is defined as ground water under sufficient hydrostatic head to rise above the aquifer containing it. The Amherst-Paragon Mine may provide some seepage water to the Guyan Mine, but no data is available. The Paragon mine is southwest of, and on strike with the Guyan Mine; there is no data available to determine any seepage contribution to the Guyan mine.

A mine power borehole is located in the east-central portion of the Guyan mine, but did not discharge. This borehole was used as a piezometer to determine pool levels in the 1997 and 1998 data gathering periods (Reed, 1998; Reed and Rauch, 2001). The power borehole in the Guyan mine is located in the east-central portion of the Guyan mine for location. MSHA personnel indicated that significant inflows of water occurred into the Hampton No. 4 mine during mining, which required pumps and an alarm system to monitor the level of water in the mine. Figure 6 shows the areas overlying the Hampton No. 4 mine in which streamflow was lost and “pirated” into the Hampton 4 mine through vertically downward fractured mine roof overburden (Price, 1998; 2004).

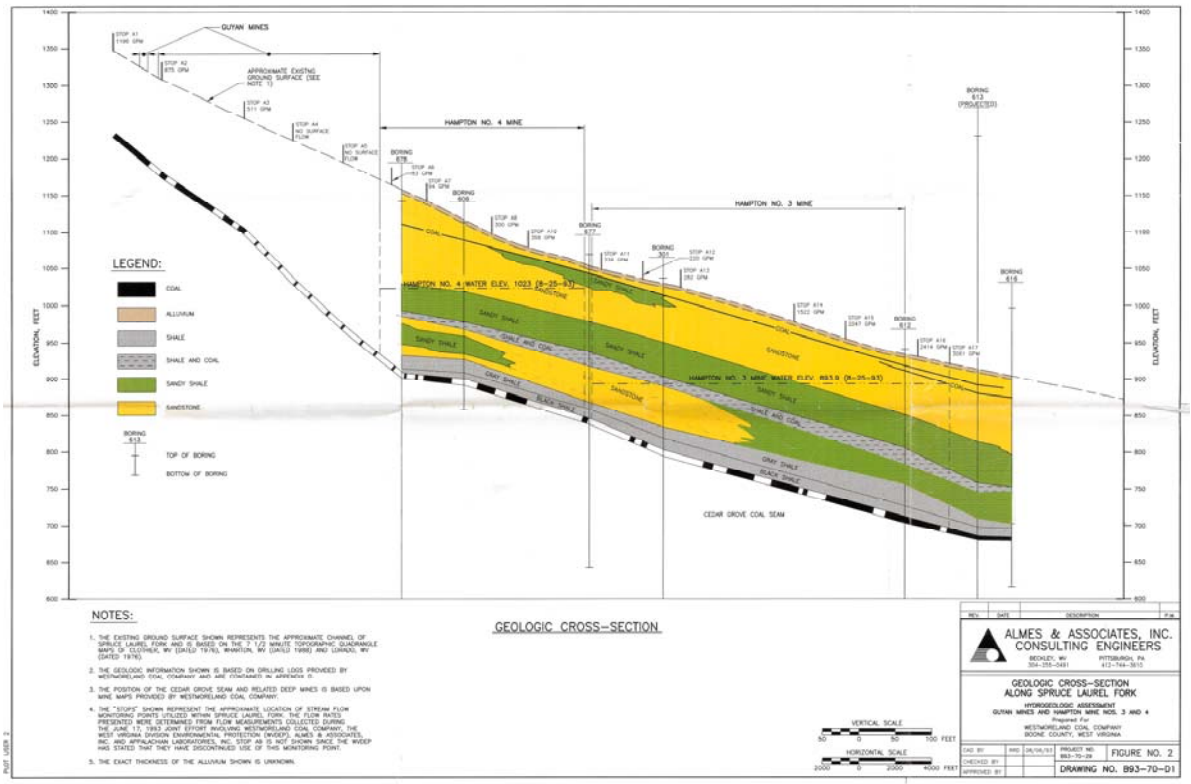


Figure 7. Longitudinal stratigraphic cross section of the Spruce Laurel Fork watershed

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Prior to the artesian conditions occurring along Spruce Laurel Fork and at Bim in 1991-1992, there were two discharge points for the Hampton No. 3 mine that controlled the two pools that developed in the eastern and western sections of the mine. The western pool is pumped at 500-800 gpm on an intermittent basis; this pump site was located at Rockhouse Branch. The second pump site was located at the eastern portion of the

Hampton No. 3 mine-Cazy Shaft, which pumped approximately 1000 gpm, but on an intermittent basis. Since 1993, the Hampton No. 3-Cazy shaft produces approximately 2500 gpm consistently in order to lower the pool level down, and alleviate the residential artesian conditions (Hager, 1993). The Hampton No.3 mine-Cazy Shaft was used as the pump site, and for mine pool level determinations.

MINING IN THE SPRUCE LAUREL FORK WATERSHED

Spruce Laurel Fork occurs approximately 180-265 feet above the Cedar Grove coal seam, which has been extensively deep and surface mined for about 45 years in the watershed. The pre-SMCRA Guyan underground operations are upstream and upgradient below of the Hampton No. 3 and No. 4 mines. The Guyan mines are located below-drainage mines that occur in the Spruce Laurel Fork watershed and operated from the 1950's to 1977. A portion of the Hampton and Guyan mines occur under the main stem of Spruce Laurel Fork and its tributaries. Contiguous to the Guyan mine(s) are the Hampton No. 4 and No. 3 mines, which are downgradient and downstream with respect to the pre-SMCRA Guyan mines.

Coal recovery of the Hampton No. 3, Hampton No. 4 mine, and the Guyan mine(s) were 65 percent, 70 percent, and 75 percent, respectively. The coal barrier and overburden widths ranged from 70-280 feet along the length of the mine coal barrier. The Guyan-No. 4 mine coal barrier is approximately 90-460 feet wide, and the Hampton No. 4 and 3 mine coal barrier ranges from 70-300 feet wide. The pre-SMCRA Island Creek Coal Company-Guyan underground operations are upstream and upgradient below of the Hampton No. 3 and No. 4 mines (Figures 1 and 2).

Additionally, the post-SMCRA Peabody-Eastern Associated Coal Company Lightfoot No. 1 and No. 2 mining operations are in part, located in the Spruce Laurel Fork watershed. The Lightfoot No. 1 mine operated in the Cedar Grove seam and is located adjacent (south) and upgradient with respect to the Hampton No. 3 mine. The Lightfoot No. 1 mine is also adjacent to the Hampton No. 4 and the Guyan mines. The

Lightfoot No. 2 mine is located in the underlying Powellton Seam. The two Lightfoot mines do not underlie the main stem of Spruce Laurel Fork, but underlie Sycamore Fork and other tributaries of Spruce Laurel Fork. The Lightfoot mines were actively pumping during the 1990's. Both the Lightfoot mines did not develop mine pools, and therefore did not provide any significant seepage water that would have contributed any significant water volume to the development of the Hampton mine pools. The Lightfoot mines pumped from several NPDES outlets and discharged to tributaries of Spruce Laurel Fork.

In addition to the Lightfoot mines, other mining operations in the watershed include Eastern Associated Winifrede mines, which produce discharges into tributaries of Spruce Laurel Fork. Two Winifrede mines in the headwaters of the watershed, the Meredith Branch and Camp Branch mines produced discharges of approximately 200 gpm each into Spruce Laurel Fork. The Paragon operations mined to the southwest of the Guyan mines, and to the west and northwest of the Guyan mines, is a large block of un-mined Cedar Grove coal seam reserves occurs that is currently being mined. Additional mining in the Spruce Laurel Fork watershed that overlie the Hampton No. 3 and No. 4 mine workings includes mines in the Upper Stockton, Lower Stockton, Chilton A seams, but have very limited mine extents in the watershed.

Effects from Mining

The Hampton No. 4 mine does not have a discharge point to the surface; however, the hydrostatic head is relieved through the coal barrier and the overburden. Seepage flows through the un-mined coal barrier pillar between the Guyan mine and the Hampton No. 4 mine that ranges from 70-265 feet wide. The Guyan-Hampton No. 4 coal barrier pillar conveys some mine pool water flows through the coal barrier pillar and up into the caved mine roof rock overburden to the Hampton No. 4 mine, which contributes to mine pool development. The Hampton No. 4 supply well is located in the downdip portion of Hampton No. 4 that was used to measure the pool level.

The network of fractures, including large-scale photolineaments in the Spruce Laurel Fork area provides the high-vertical permeability flowpaths. The lost streamflow is diverted and flows through the fractures to the abandoned Hampton and Guyan mine workings, which develops into the mine pools (WVDEP, 1997). One occurrence of subsidence surface effects occurs above the Hampton No. 4 mine. Figure 8 shows a subsidence induced impact resulting in “hooved” streambed. In this reach, dye placed in the stream shows streamflow that moves upstream.

Figure 8. Upstream view of Middle Reaches showing “hooved” streambed.

Subsidence theory indicates that a subsidence profile develops when mining impacts can extend upwards 30 to 60 times the mining height (Kendorski, 1993). A mining height of approximately 6 feet was used in the calculation of estimating maximum fracture extension into overlying strata. Using 30 to 60 times the mining height, fracturing can extend 180 to 360 feet upwards from mining in the second mined sections of the mines; there is approximately 245 feet of overburden over mining. In addition to the subsidence fracturing, natural stress relief fracturing can extend downwards to depths of 80 feet (Kipp and Dinger, 1991). In overburden strata less than 60 times mined thickness, it is possible that stress relief and subsidence-induced

fracturing can intersect, resulting in a direct hydraulic connection between the surface and fractured strata overlying the mines.

There are 5 zones that have been identified by Kendorsky (1993) for high extraction mining impacts on the mined roof overburden (descending stratigraphically)

1. **Surface Fractured zone**-zone of potentially vertically transmissive surface cracks
2. **Constrained Zone**- Zone no significant effect on transmissivity or storativity.
3. **Dilated Zone**- Zone of increased storativity with little or no vertical transmissivity
4. **Fractured Zone**- Zone of vertically transmissive fractures
5. **Caved Zone**- Zone of complete disruption to the roof rock 6-10 X MH

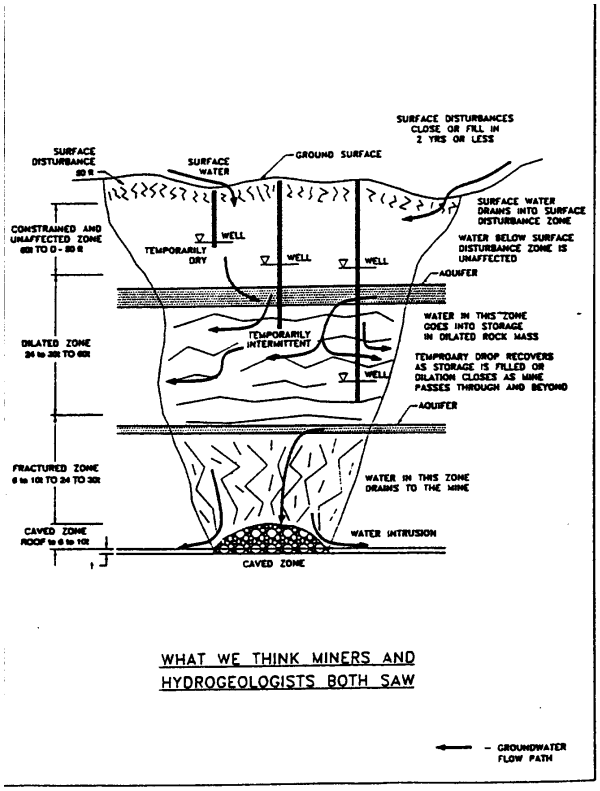


Figure 4. Present Concept of Strata Disturbance Zones.

Figure 9. Kendorski (1993) subsidence profiles showing hydrologic impacts

In addition to mine-induced altered stress-relief fractures, mining-induced fractures can intersect and provide high-vertical permeability flowpaths. These flowpaths allow the "pirated" streamflow to flow through fractures, and enter the abandoned Hampton and Guyan mine workings, which develop into the mine pools (WVDEP, 1997). Figure 9 shows the January 25, 1998 streamflow (from C1 to A17) overlying areas of the Hampton

No. 3 mine in which fracturing may also have contributed to the loss of strteamflow. Feddock (1997) studied concluded that pillar failure probably resulted in subsidence in two more areas of the Hampton No. 3 mine and that these areas may have experienced overburden movements immediately after mining, and would contribute to ground water inflows into the mine.

Figure 10 illustrates that the mine pool have developed at all three mines. The pool levels are normally below the level of Spruce Laurel Fork; however, when mine pool potentiometric levels rise at times to the surface, artesian conditions occur into Spruce Laurel Fork. The Hampton No. 4 pool levels reported were 1087 feet MSL (3/28/1998), 1066 feet MSL (5/15/1998), and 1034 feet MSL (1/25/1998). The Hampton No. 3 mine map (1988) shows the development of two mine pools, an eastern (near the Cazy Shaft) and western mine pool. The Hampton No. 3 mine western pool had an elevation of 760 feet MSL. The Hampton No. 3 eastern pool at the Cazy Shaft had an elevation of approximately 886 feet MSL, which is maintained in order to prevent artesianing from occurring downstream. Guyan mine pool levels were 1186 feet MSL on 3/28/1998, 1165 feet MSL on 5/15/1998, and 1133 feet MSL, 1/25/198.

The potentiometric levels of the Guyan, Hampton 4 mine, and the Hampton No. 3 mine pool levels used were: 1133 feet MSL, 1034 feet MSL, and 885.5 (east) feet MSL, respectively. For the January 25, 1998, data shows that the head difference between the Guyan mine and the Hampton No. 4 mine reflects the mine pool elevation minus the elevations of the mined seam along the barrier segments. The Hampton No.3 Final MSHA mine map (1987) showed two mine pools located in the eastern and western portions of the Hampton No. 3 mine but the eastern pool level was used for the water budget calculations.

The Hampton No. 3 mine pool (eastern) pool level was reported in 1993 to be at a level of approximately 894 feet MSL. After pumping began from the Cazy Shaft the pool level lowered the pool level to approximately 886 feet MSL (WVDEP, 1997, Reed, 1998). The 885.5 feet MSL level reflects the level of the eastern Hampton No. 3 mine pool that is to be maintained, in order to prevent downstream artesian occurrences.

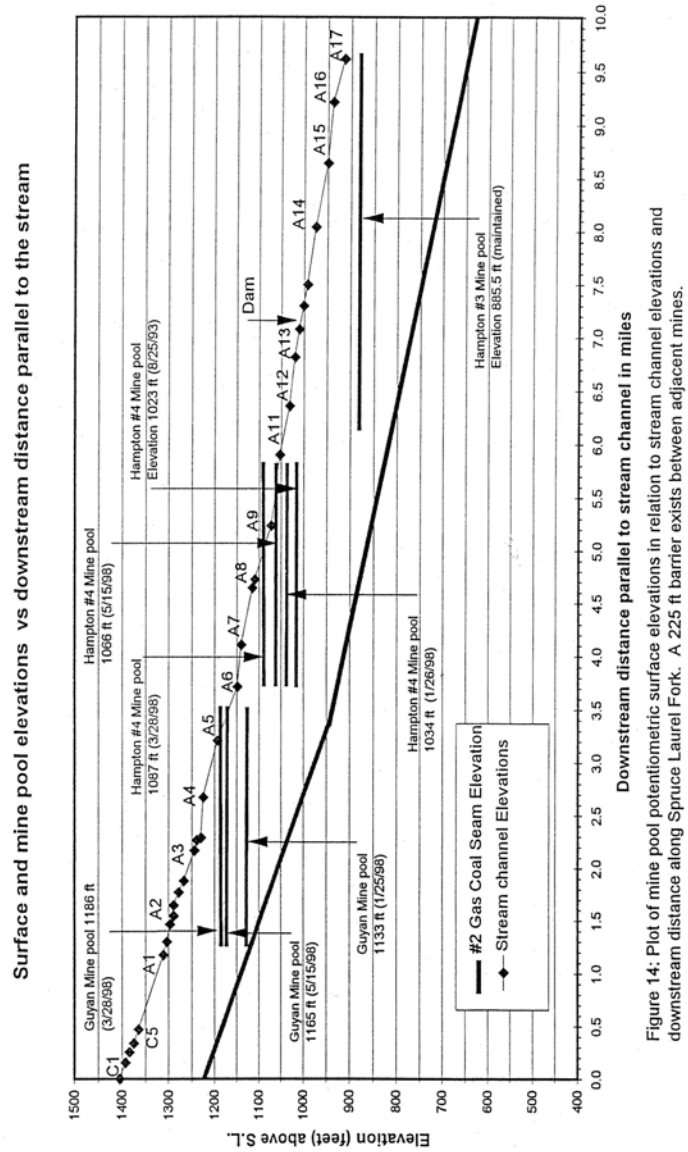


Figure 14: Plot of mine pool potentiometric surface elevations in relation to stream channel elevations and downstream distance along Spruce Laurel Fork. A 225 ft barrier exists between adjacent mines.

Figure 10- Mine pool elevations of Hampton and Guyan mines **(**Reed, 1998 and Reed and Rauch-Figure 14, 2001)

DISCUSSION OF THE HYDROLOGIC DATA

Precipitation data

Modeling of Spruce Laurel Fork streamflow was conducted utilizing the WVU NRAC –W.C.M.S. (Watershed Characterization and Modeling System) software

application to model the hydrology of West Virginia watersheds. The purpose was to compare stream flow measurements and weather data to determine if precipitation conditions varied from long term trends. WCMS is a set of GIS tools for watershed hydrologic analysis and water quality modeling developed by the Natural resource Analysis Center at West Virginia University for the WVDEP. Precipitation data for the Spruce Laurel Fork watershed comes from the ZEDEX Corporation, which created a statewide precipitation dataset for WVU/NRAC WCMS-HSPF software application. The WCMS program utilizes the modeled precipitation data for watershed surface water modeling (Eli, et al., 2004).

The precipitation data from 1992 to 2000 indicates that there were seasonal rainfall amounts for the period leading up to the date of the two sets of Almes/WVDEP streamflow measurements that were obtained during June, 1993. ZEDEX modeled precipitation data for January 25, 1998 streamflow data is comparable with the nearby Eastern Associated-Colony Bay Coal Company automated rain gauge data for 1997 (WVDEP, 1997). The rain gauge data show that precipitation did not vary substantially from long term trends when the January 25 flow measurements were taken.

Seepage run methodology and data measurements

Hydrologic studies were conducted in Spruce Laurel Fork from 1991-2002 to determine if streamflow was being lost as the stream flowed over the Guyan and Hampton mines. Measurement and computation of streamflow were followed utilizing the procedures in Corbett (1945), Rantz et al. (1982), and Fetter (1980) for the 1993, 1996-1998 streamflow data. The streamflow measurements were conducted in the Upper Reaches of Spruce Laurel Fork and tributaries that overlie the pre-SMCRA Guyan Mine, and the Middle Reaches that extend from the Hampton No. 4 mine to the Hampton No. 3 mine. Gaging station locations are shown are shown in Figure 11. Each set of seepage run streamflow measurements were gauged on a single day from upstream Station A1 located above Guyan mines to downstream Station A17 below Hampton No. 3. The study area is approximately 9.5 miles of Spruce laurel Fork. The stream flow gaging stations were

located approximately 0. 5 mile apart; the 1998 data sub-divided some reaches. The gaging sites were located by GPS, and data was differentially corrected.

Seepage run streamflow measurements were taken at in-stream sites in Spruce Laurel Fork that were located on approximate 0.5 mile centers and were denoted as gaging Stations A1-A17. Also, streamflow measurements were also taken at each tributary mouth in order to normalize the data with tributary flows subtracted out. WVDEP and Almes & Associates & Consulting Engineering data streamflow data includes January 20-21, 1993, February 17, 1993, April 22, 1993, June 3, 1993, June 17, 1993, and October 17, 1996; and WVU data December 17, 1997 (low flow); January 25, 1998 (moderate flow); and March 28, 1998 (Reed, 1998). From these sets of streamflow (seepage run) data, one dataset was chosen to illustrate moderate flow during low, moderate, and high baseflow conditions that existed in Spruce Laurel Fork.

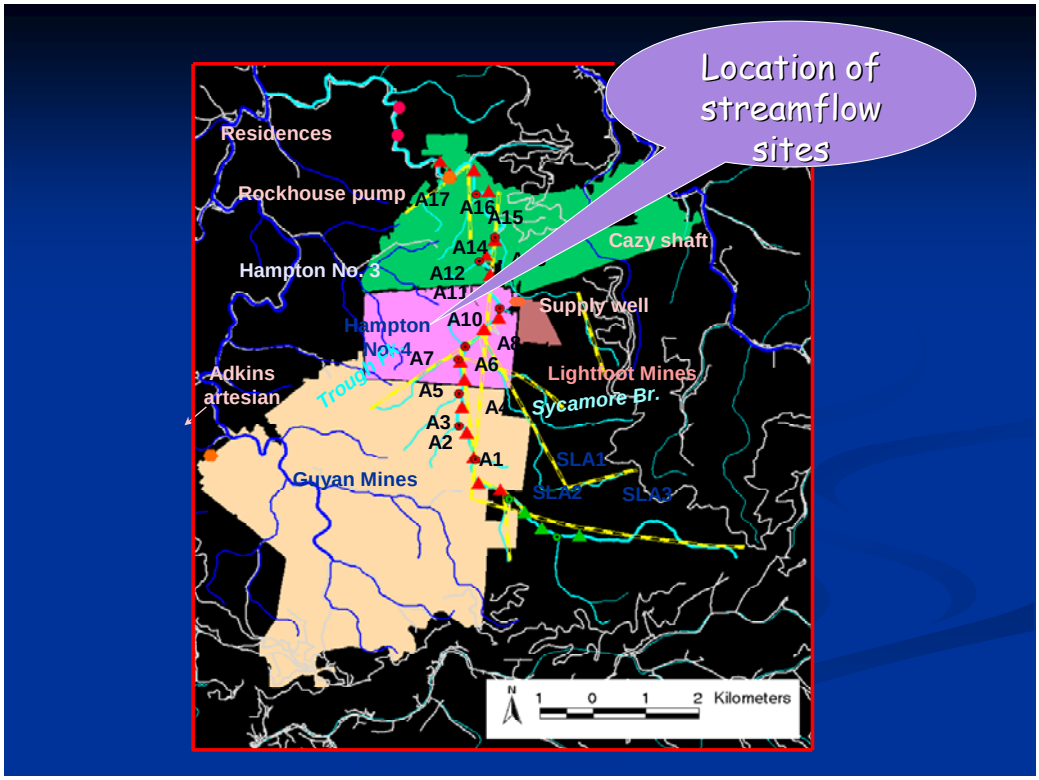


Figure 11. Location map of Spruce Laurel Fork stramflow sites

The streamflow data shown in Figure 12 is on a normalized gpm/acre basis. The data that are illustrated on these figures reflect streamflow in which all tributary flow

contributions have been subtracted out. These figures show streamflow gains and losses that occur from one streamflow gaging Station relative to the next downstream Station. Figure 12 shows streamflow impact assessments illustrated by the map legends that show five categories of streamflow impact by Guyan and Hampton mining in the Spruce laurel Fork watershed. The channel (negative) loss of flow values are calculated values since contributions from tributary flows are subtracted out from each of the streamflow data in the main stem. Even with alternating gains and losses occurring in the stream, Spruce Laurel Fork is still a losing stream overall.

Station	Streamflow gpm/acre	Streamflow 1/25/1998
C1	1.656	5970
C2	1.659	6065
C3	1.653	6205
C4	1.653	6242
C5	1.652	6283
A1	1.198	4880
A1a	1.377	5647
A1b	1.152	4794
A1c	1.321	5558
A2	1.335	5647
A2a	1.313	5645
A2b	1.300	5624
A3	1.300	5767
A3a	1.308	5979
A3b	1.086	4972
A4	0.812	3854
A5	0.655	3382
A6	0.684	3895
A7	0.656	3795
A7a	0.273	1697
A8	0.471	2968
A9	0.289	1964
A11	0.333	2314
A12	0.231	1697
A13	0.396	2957
A13a	0.499	3792
A13b	0.400	3215
A13c	0.326	2643
A14	0.324	2669
A15	0.442	3844
A16	0.287	2638
A17	0.419	3972

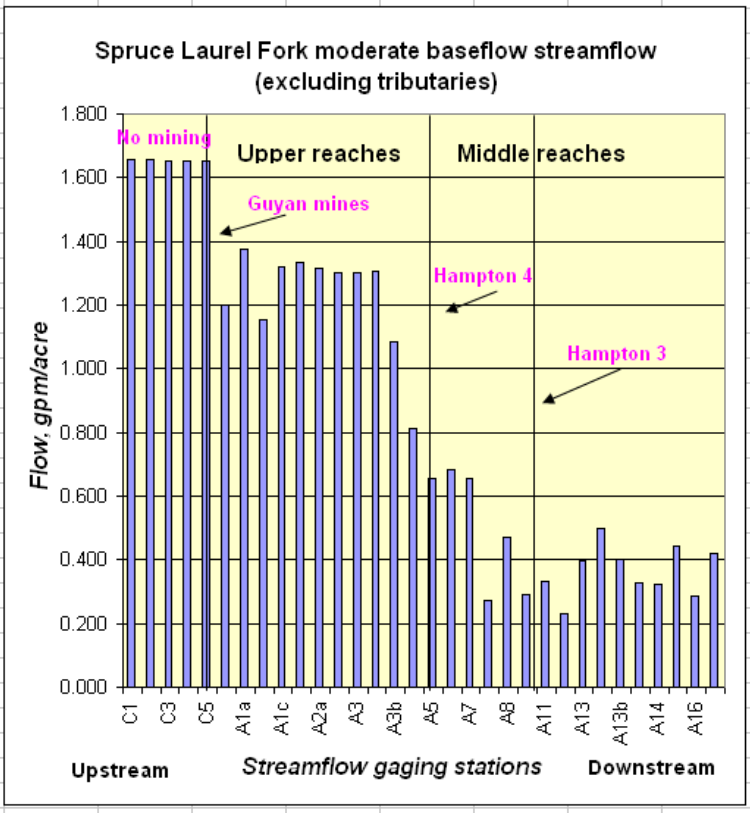


Figure 12. January 25, 1998 measured seepage run streamflow, excluding tribs.

The January 25, 1998, streamflow data of Reed (1998) and Reed and Rauch (2001) show that moderate baseflow conditions occurred in Spruce Laurel Fork. The data show that the upper reaches were dewatered from as the stream flows begins to flow over the Guyan mine, but there is an overall alternating gains and losses in the stream that occur over the Guyan, Hampton No. 4 , and No. 3 mines. There is a gain of flow that

occurs over the Guyan-Hampton No. 4 and the Hampton No. 4-No. 3 barrier pillar. Overall, the moderate baseflow shows an alternating pattern of gains and losses in the stream; however, the overall character of flow from Station C1 to Station A17 is a losing stream.

Figure 13 shows the January 1998 is an ArcGIS map that shows the relationship between streamflow and mines in plan view. This figure shows that shows the change in streamflow vs. distance downstream measured at each streamflow gaging station.

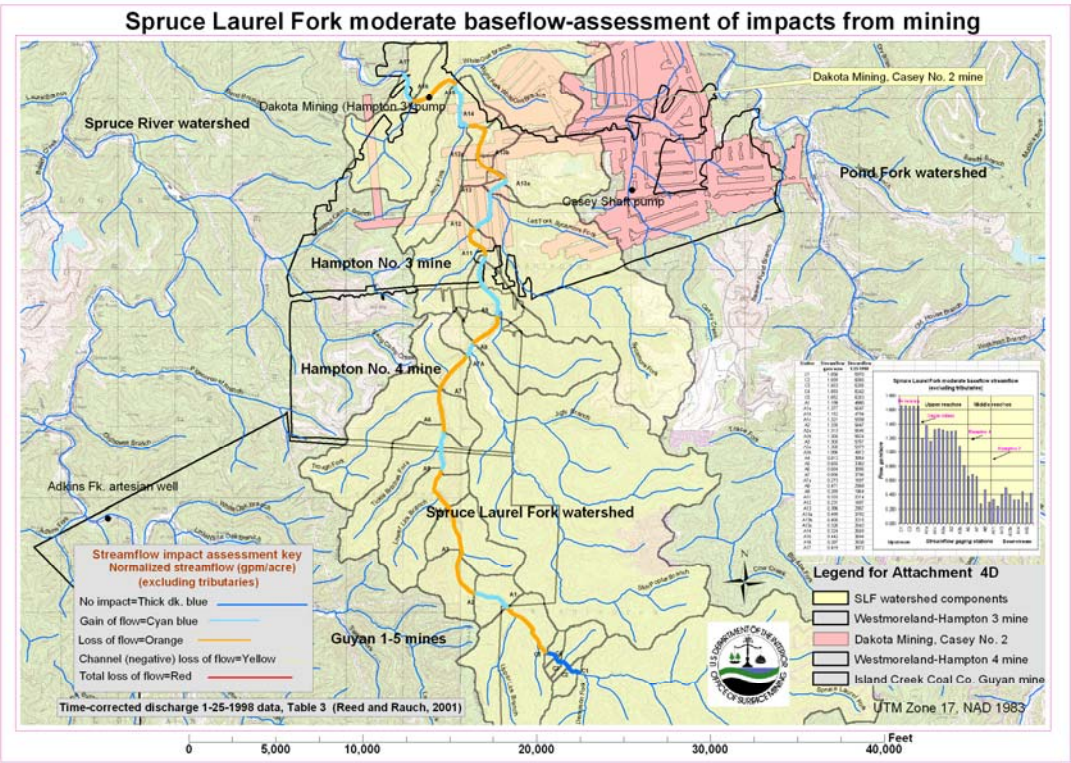


Figure 13. Shows the January 25, 1998 streamflow, C1-A17, excluding tributaries

Streamflow modeling

Modeling of Spruce Laurel Fork streamflow was conducted utilizing the WVU NRAC –W.C.M.S. (Watershed Characterization and Modeling System) software application to model the hydrology of West Virginia watersheds. Figure 14 shows a comparison of Spruce Laurel Fork measured streamflow (gpm/acre-mined, tributary flow included vs. modeled 30 year average gpm/acre streamflow.

This data illustrates that the measured streamflow is significantly lower than the modeled streamflow; increases in the flow at Station A13 are due to mine pumpage discharge from Sycamore Fork. The baseflow data of January 1998(with tributary contributions included) were used to compare to the WCMS modeled streamflow 30-year monthly average flow. The January 25, 1998, measured streamflow shown by Figure 14 that ranged from approximately 29-75 percent lower than the WCMS modeled streamflow for the 30-year monthly average.

Stations	Reed (1998) 25-Jan-98 gpm	WCMS model January-98 gpm
C5	6283	7316
A1	5939	8666
A2	6706	8904
A3	6826	9546
A4	4913	9883
A5	4441	10731
A6	4918	11655
A7	4950	13105
A7A	6510	13495
A8	7781	20483
A9	6777	21358
A11	7127	21695
A12	6510	22525
A13	7770	26156
A13A	10146	26906
A13B	9569	27157
A13C	8997	27283
A14	9023	27547
A15	10198	28440
A16	10258	31304
A17	11592	31587

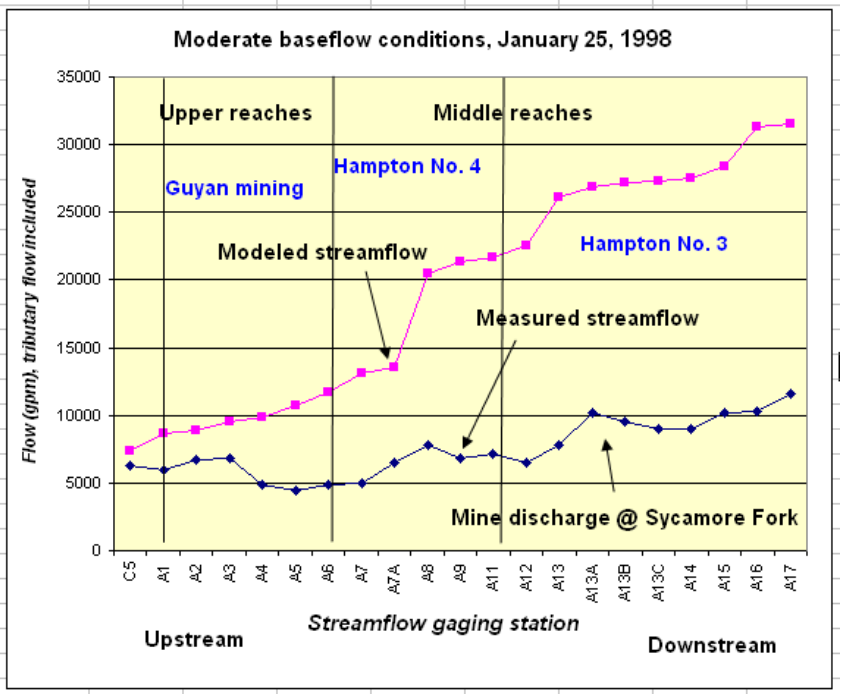


Figure 14. Comparison of measured streamflow v.WCMS modeled 30-year average flow

Stations	Reed (1998) 012/17/1997 Flow (gpm)	WCMS model 012/17/1997 Flow (gpm)
C5	849	1228
A1	868	1455
A2	776	1495
A3	324	1603
A4	0	1659
A5	0	1801
A6	0	1957
A7	0	2201
A7A	0	2266
A8	0	3397
A9	0	3588
A11	0	3642
A12	0	3782
A13	179	4393
A13A	510	4520
A13B	428	4558
A13C	319	4580
A14	16	4628
A15	43	4776
A16	266	5256
A17	466	5301

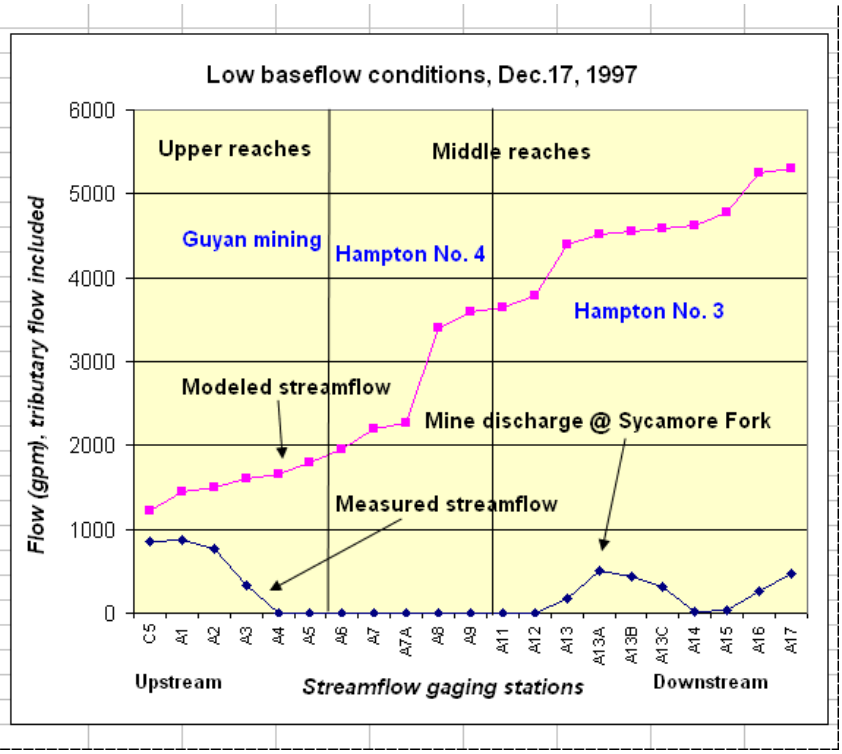


Figure 15. Comparison of measured streamflow v. WCMS modeled 7Q10 flow

Areas of the watershed that had been mined by Hampton and Guyan mining operations now produce less baseflow and runoff flow in Spruce Laurel Fork. The result is an adverse change to the hydrologic regime from a gaining stream to a losing stream. There are no data available to support the notion that streamflow recedes into the alluvium and moves as underflow. In fact, if this were the case, no visible surface flow would ever have been seen upstream of Station A1, or downstream of Station A17. Moreover, streams in the Appalachian Plateau do not flow exclusively as underflow; ground water discharges as baseflow to streams. Streams or reaches of streams in which the flow of which is increased by inflow of ground water, also known as an effluent stream (Fetter, 1988). Losing streams can be connected to the ground water system by a continuous saturated zone, or can be disconnected from the watershed-wide ground water system by an unsaturated zone due to the mining process

GROUND WATER MODELING METHODOLOGY

Ground Water Flow Movement in the Mined Watershed

The study area encompasses four U.S.G.S. 7.5 minute quadrangles: Clothier; Lorado; Amherstdale; and Wharton quadrangles . Ground water flow for the model area flows from topographically high areas in the south (or bottom) of the model to the north (or top of the model). Large quantities of surface water flows are funneled from the southern recharge area through streams that drain to the north, i.e., Spruce Laurel Fork and its tributaries. Ground water heads flows from the southern recharge area high of approximately 450 meters, downgradient towards the north (top of model) of approximately 260 meters, which covers an area of two U.S.G.S. 7.5 minute quadrangles.

Recharge from infiltration through the overburden and own to the mined seam is believed to be the most important source of recharge to the Spruce Laurel Fork watershed. Coal recovery from high extraction operations can alter the recharge flowpaths and adversely affect the hydrologic regime. Second mining that occurred in the watershed causes the overburden to collapse and enhances recharge due to increases in vertical hydraulic conductivity in the overlying strata of the mine seam.

This analysis in this report assumes that the coal barrier horizontal conductivity K is spatially uniform. The seepage analysis of outflow (Q) through the coal barrier pillars was conducted with K permeability values of scenarios that ranged from 0.10 feet/day, 0.15, 0.20, 0.25, and 0.5 feet/day. The Dames and Moore (1981) report K values were not used in this report since the horizontal hydraulic conductivity (K) rates are applicable for outcrop coal seams and/or shallow coal seam mines, and therefore not applicable to Spruce Laurel Fork mining. Coal barrier K values used in the water budget in this report however, are similar to the K values from the eastern bituminous coal region. The data and assumptions for horizontal hydraulic conductivity Kh values used in the water budget and seepage calculations in this report reflect data from mined areas in West Virginia, Pennsylvania, and northeastern Ohio.

Among these studies were aquifer tests by Aljoe and Hawkins (1992), Hobba (1991), Schubert (1980), and Miller and Thompson (1974). Additional aquifer tests were conducted by Olyphant (1993) in Kentucky, Virginia, and Indiana, respectively. Other researchers such as Dabbaus et al., 1974; Dames and Moore, 1981; Luo et al., McCoy, 2003; and McCoy et al., 2004, evaluated the hydraulic characteristics of other eastern coal seams. Isotropic hydraulic conductivity values of the West Virginia- Jamison # 9 Mine, ranged from 0.17 ft/day to 0.46 ft/day, with a median of 0.31 ft/day. Data from the Odonnell mine study showed hydraulic conductivity values that ranged from 0.12 ft/day to 0.59 ft./day (1992, 1993), with a median of 0.30 ft./day (Leavitt, 1999).

Anisotropic model face and butt cleat hydraulic conductivity values for the Pittsburgh coal seam in northern West Virginia for the Pittsburgh coal seam were 0.24 to 1.1 ft/day, and 0.072 to 0.32 ft/day, respectively (McCoy et al. 2004; 2006). Schubert (1980) noted that Kh (mean) values of PA Allegheny Formation strata were 0.14 ft/day. Among these studies were aquifer tests by Aljoe and Hawkins (1992), Hobba (1991), Schubert (1980), and Miller and Thompson (1974). Additional aquifer tests were conducted by Olyphant (1993) in Kentucky, Virginia, and Indiana, respectively. Other researchers such as Dabbaus et al., 1974; Dames and Moore, 1981; Luo et al.,

GMS Ground Water Model Coverages

The GMS ground water flow model attempts to illustrate the hydrology of the Spruce Laurel Fork watershed and impacts from stream dewatering, mine pool development, ground water flow between mines, and artesian conditions occurring at residents' homes. This is a very rudimentary ground water flow model that encompasses only two layers. Layer 1 is the first layer and consists of the overburden that overlies the mined coal seam; and occurs 180-265 feet above the mines. Layer 2 is the No. 2 Gas (or Cedar Grove) coal seam that was mined at the Hampton and Guyan mines. The first layer (the overburden) is considered by GMS as non-confined or "convertible" layer, due to the presence of natural and mining-induced horizontal and vertical fractures. The second layer or mined coal seam, has a base that is considered to be confined in which water will

descend vertically through the seam top, but not pass (vertically) down through the base of this layer.

The USGS MODFLOW ground water model (Harbaugh, 2005) is the most widely used ground water model in the United States. It has been used to model the impacts of underground mining on ground water systems. It can simulate non-steady flow in irregular shaped flow systems in which aquifer layers can be confined, unconfined, or a combination of the two. Flow to wells, spatially distributed discharge, evapotranpiration, flow to drains, and flow exchange with rivers can all be included in the simulation. MODFLOW requires extensive data review, acquisition, and entry and is commonly used in conjunction with pre- and pos-processing commercial graphic interface software such as GMS (ground water Modeling System) or Visual MODFLOW. It cannot be overstated the importance of elevation and hydrologically corrected DEM's (Digital Elevation Models) in order for the simulation to accurately reflect the hydrogeology.

The DEM elevation data used in the ground water model has a Z (elevation) resolution of 10 meters; the DEM's have been hydrologically corrected for anomalies of elevation problems. The following GIS coverages (NAD83, Zone 17) were used in the GMS Spruce Laurel Fork model. The GSM (Ground Water Modeling System) utilizes the MODFLOW 2000 (MF2K) cell-centered, finite difference ground water flow model that was developed by McDonald & Harbaugh, USGS, 1983. The following boundary conditions were used in the Spruce Laurel Fork study model:

1. Boundary of study- Boundary arcs
2. Barriers- Barrier arcs ; no flow boundary to the east (pond Fork watershed) and west (Spruce River)
3. Recharge- Recharge arcs; rates assigned to all three mine polygons
4. Wells- Rockhouse well and Cazy shaft, Hampton No. 3 pump sites
5. River – River arcs; Spruce Laurel Fork arcs, with calculated conductance values
6. Specific heads-reflect head values from 450 meters in the south of the boundary and 260 meters to the north in the boundary
7. Seepage faces- these are the un-mined coal barriers that occur at downgradient sections of Guyan-Hampton 4; Hampton 4-Hampton 3 mines.

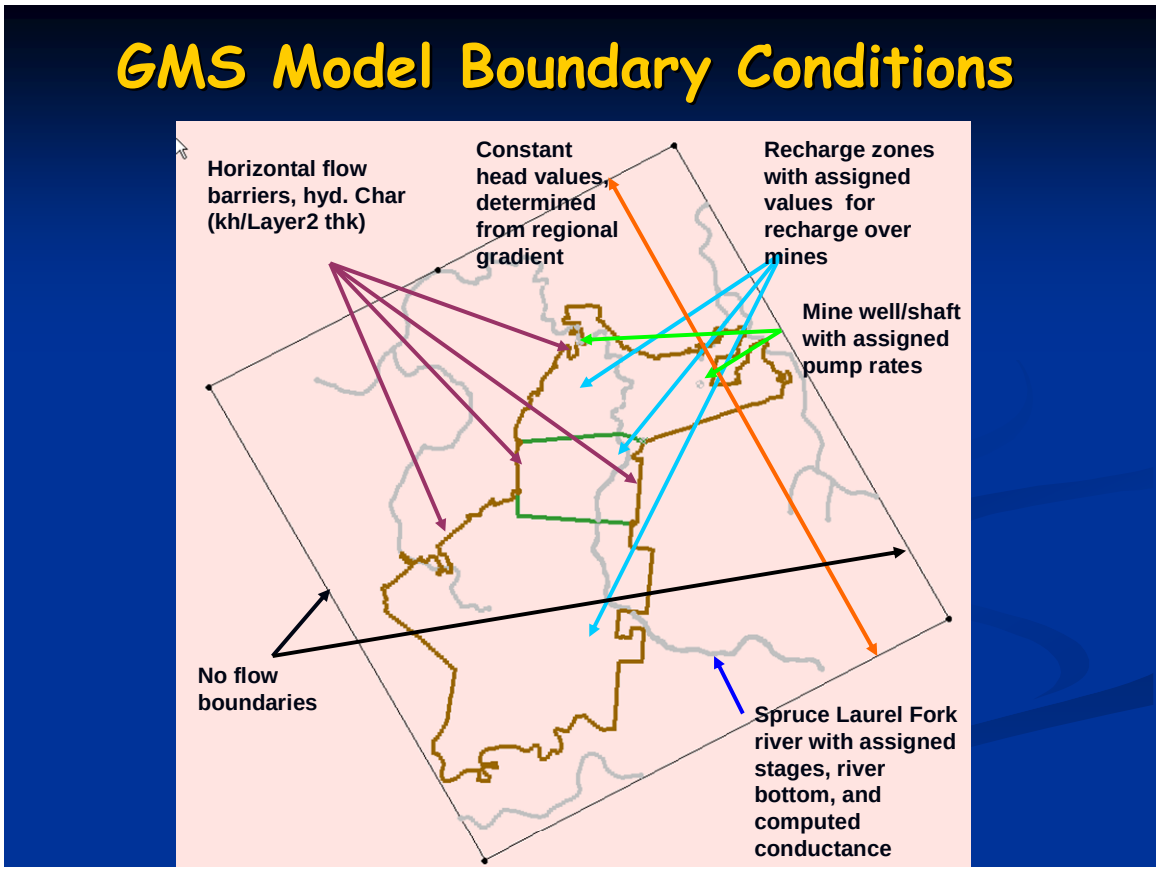


Figure 16. Boundary conditions assigned to the Spruce Laurel Fork area

GMS MODFLOW Ground Water Flow Packages

There were six packages that were used in the modeling of the ground water system in the study area: River (R1V1); Drain- Seepage face (DRN1);Well (WEL1); Horizontal Flow Barrier (HFB1); Specific head (CHD1); and Recharge (RCH1).

The flow packages that were used are the Layer Property Flow (LPF) where head flow occurs in each cell. The Kh and Kv (horizontal and vertical hydraulic conductivity) values are used for the overburden layer, and Kh for the mined seam. The layers were determined to be leaky aquitards and the GMS LPF convertible layer types (non-confined) aquifer type was selected. The solver package that was used in the model was the Pre-conditioned Conjugate Gradient (PCG2).

The Horizontal Flow Barrier package (HFB1) was used to simulate low permeability barriers that surround the mine polygons. Each mine polygon arc was assigned a hydraulic characteristic that was calculated using the relationship of K/thickness of the Layer 2 mined seam, or 0.001.

The Recharge Package (RCH1) utilized the recharge over the study area that was obtained from back-calculating specific information from each mine. This package is used to simulate recharge to an aquifer due to precipitation events and infiltration.

The River Package (R1V1) is used to simulate the flow of water between an aquifer and a river. The package allows water to flow from the aquifer to the river, thereby removing water from the model by seepage to gaining stream reaches. Water can also flow out of the stream into the aquifer, but the seepage out of the stream is independent of the stream discharge. Thus, a losing reach of stream could recharge the aquifer with more water than is being carried in the stream. If the head is above river stage, flow is from the aquifer to the river. If head is below river stage, flow is from river to aquifer. Required parameters are: conductance, bottom elevation, and stage (Anderson and Woessner, 1992)

Spruce Laurel Fork Model-River Package

Each Spruce Laurel Fork stream reach measured at 0.5 miles apart had streamflow computed. The January 1998 reflects streamflow in gpm/acre-mined with tributary contributions subtracted out at each streamflow site (node). Each reach segment (arcs) has the following attributes: river stage (elevations); stream bottom elevations (Table 1A); and conductance values (Table 1B), which were used in the modeling process. The field measurements include stream width and length reaches, and estimation of streambed permeability (k) values. Computed conductance values were computed for each Spruce Laurel Fork streamflow gaging station, C1 to A17. Head-stage and streambed elevations (Reed, 1998) were used at nodes in the stream coverage. These nodes correspond to the field streamflow sites.

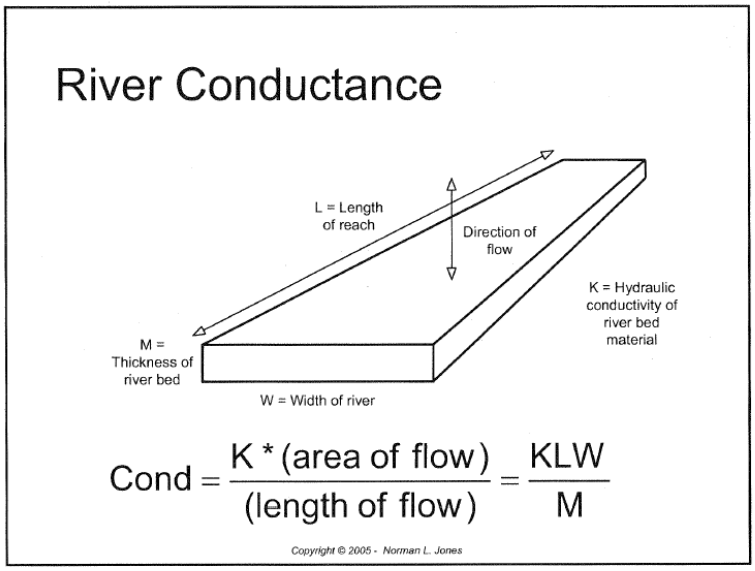


Figure 17. Formula used to compute steam reach conductance values

Station	Stream Elev.	Stream Bottom
	(m)	(m)
Bottom	442.0	441.7
C1	428.2	427.9
C2	424.0	423.7
C3	422.1	421.8
C4	419.1	418.8
C5	416.1	415.7
A1	399.9	399.6
A2	393.2	392.9
A3	379.5	379.2
A4	373.4	373.1
A5	363.9	363.6
A6	350.2	349.9
A7	347.8	347.5
A7a	340.2	339.9
A8	338.3	338.0
A9	322.2	321.9
A11	321.3	321.0
A12	314.6	314.2
A13	310.9	310.6
A13a	308.2	307.8
A13b	305.4	305.1
A13c	302.7	302.4
A14	297.2	296.9
A15	289.6	289.3
A16	285.9	285.6
A17	278.9	278.6
Top	244.8	244.4

Station	Conductance
	(m^2/d)/(m)
Bottom	1987.2
C1	1589.8
C2	1189.9
C3	1135.5
C4	1399.4
C5	518.9
A1	50000.0
A2	2394.2
A3	482.3
A4	596.8
A5	445.6
A6	2394.2
A7	1987.2
A7a	596.8
A8	1122.7
A9	794.9
A11	807.8
A12	1494.1
A13	3312.0
A13a	4968.0
A13b	3312.0
A13c	3974.4
A14	5677.7
A15	5229.5
A16	4968.0
A17	6021.8
Top	6624.0

Tables 1A and 1B. Calculated Spruce Laurel Fork reaches conductance values

Ground Water Model Methodology

Model Assumptions

1. The boundary of the Spruce Laurel Fork model spans from the Spruce River watershed (west) to the Pond Fork watershed (east) as no flow boundaries. Water enters in from the within the model from Pond Fork and Spruce River systems, but does not enter from outside the model boundary.

2. The Hampton No. 3 and 4 and Guyan mines are fully flooded with developed mine pools that are at equilibrium

3. Each of the overburden hydrostratigraphic units (aquifers) are homogenous, isotropic, and of semi-infinite in extent.

4 The boundary at which depletions are calculated is a linear stream that fully penetrates the aquifer, where the streambed is in hydraulic connection with the aquifer.

5. Ground water flow within the mined coal seam aquifer is primarily horizontal, laminar flow and follows the seam cleat system,

6. Vertical permeability values indicate vertical flow that descends from the stream downward through the overburden into the mines.

7. Mine pool water migrates through coal across barriers and saturated overburden

8. Large hydraulic conductivity in the mines is in contrast to small hydraulic conductivity in the overlying overburden, except for the Caved Zone. Vertical and horizontal flow occurs upward above the coal barrier into the overburden.

9. Darcy's Law is valid; where Darcian laminar flow conditions occur in the three mines, assuming Reynolds numbers remain less than 10. A hydraulic conductivity of 20 meters per day by Aljoe and Hawkins (1991) and was utilized for the ground water flow (Kh) in the Guyan and Hampton mines.

10. The mines are confined in which flow within the mines occurs through the coal barrier and rises with time to form each mine pool.

11. Mine pools provide seepage (along wetted un-mined seepage faces) from each adjacent upgradient mines that flows through the coal barriers and associated overburden.

12. Using the length from the upgradient Guyan mine to downgradient Hampton 3 mine which results in a hydraulic gradient of 0.0119.

Back-Calculation to Determine Hydraulic Conductivity and Recharge Values

In all cases, the water budget and seepage calculations assume that the mine pools were at or near steady-state (equilibrium) conditions. The Darcy equation was used for calculating the seepage flow between mines across the Guyan-Hampton No. 4 and Hampton No. 4 –Hampton No. 3 coal barriers. The ground water flow above the mined coal seam in the overburden was also computed. When site-specific data was not available, reasonable hydrogeologic assumptions were made. Also, some data for hydraulic parameters was based upon literature values, which were utilized in the Darcy Equation to determine barrier and overburden ground water flow (Q).

Flow across the un-mined coal barriers and overburden was calculated by utilizing the thickness (height) of the saturated overburden (aquifer) for use in the Darcy equation. This was determined by measuring the Width (W) and Length (L) overburden segments that correspond to the same coal barrier segments obtained from the detailed Hampton and Guyan mine maps. The saturated overburden (aquifer) thickness values were computed from the difference along the length of the downgradient areas between the pool level(s) elevations minus the coal barrier height structure contours (top of coal).

Flow through coal barriers and overburden was estimated using the Darcy flow equation, in the form:

$$Q = KA*(dh/dl)$$

<u>Where:</u>

Q is the discharge rate (gpm used in this report)

K is the hydraulic conductivity of the coal barrier (feet/day)

dh is the change in head along the flowpath (feet)

dl is the length of flowpath, in this case, thickness of the coal barrier (feet)

A is the x-sectional area of flow though the barrier seepage face (sq. feet)

The data and assumptions in the water budget analysis include several reasonable scenarios for the overburden Kv_ovb permeability rate values, which in part, reflect the dates of mine post-closure, timing of residential complaints, degree of mining, depth, structural inferences such as stress-relief and photo-lineament occurrences in the Spruce Laurel Fork study area. Coal recovery of the Hampton No. 3, Hampton No. 4 mine, and the Guyan mine(s) were 65 percent, 70 percent, and 75 percent, respectively. The coal barrier and overburden widths (Darcy L) ranged from 70-280 feet along the length of the mine coal barrier. The thickness of the mined Cedar Grove coal seam at the Hampton and Guyan mines was approximately six feet thick.

The W (Width) and L (Length) equation variables represent the width and length segments along the coal barrier that were determined from the 1”=400 feet Hampton and Guyan mine maps. The mine map measurements of the coal barrier segments were determined by selecting points along the coal barrier where mine map data existed. Seventeen segments were determined for along the Guyan-No. 4 mine coal barrier (90-460 feet), and the Hampton No. 4 and 3 mine coal barriers (70-300 feet). For large expanses of un-mined coal barriers that surround the Hampton and Guyan mines, a (constant) width of 10,000 feet was used. The water budget calculations for the Hampton and Guyan mines are based upon data and observations from the WVDEP (1993), Reed (1998), and Reed and Rauch (2001).

In addition to the mine pool level measurements, streamflow data, and visual observations, several assumptions were made for the water budget-seepage calculations. The January 25 and 26, 1998, streamflow and mine pool level data was used in order to calculate the Darcian seepage flow across coal barriers and overburden. in order to model the time required to develop the Hampton and Guyan mine pools that had developed by 1993, prior to the increased pump rate at Hampton No. 3 to lower the mine pool.

In a similar manner to the coal barriers, overburden calculations utilized the thickness (height) of the saturated overburden (aquifer) for use in the Darcy equation.

This was determined by measuring the Width (W) and Length (L) overburden segments that correspond to the same coal barrier segments obtained from the detailed Hampton and Guyan mine maps. The saturated overburden (aquifer) thickness values were computed from the difference along the length of the downgradient areas between the pool level(s) elevations minus the coal barrier height structure contours (top of coal).

The thickness of the overburden (aquifer) for the Guyan and Hampton No. 3 mine was reduced by 50 percent since the available data showed that these mines were not fully inundated at all upgraients sections. The available mine maps showed that the Hampton No. 4 was flooded, and the full extent (thickness) of the overburden aquifer was used. All these values were used in the Darcy formula for the determination of Q. The same general methodology that was used in the determination of the flow (Q) seepage through the coal barriers was used in ground water flow through the overburden.

Vertical permeability (Kovb) rates for Pennsylvania underground mined coal mines ranged from 1.74 feet/day to 2.92 feet/day Booth, 1986). The 0.74 feet/day value is an average permeability of shale with sandstone roof rock over solid Lower Kittanning coal seam in Pennsylvania (Miller and Thompson, 1974). The Kovb values that were used in this report were: 0.1, 0.25, 0.30, 0.5, and 0.65, 0.74, 1.0, 2.0, and 3.0 feet/day. Overburden K values used in the water budget in this report are similar to data from the Eastern Bituminous Region (Dames and Moore, 1981). Input values in these models reflect Kh of 0.3 m/day and Kv of 0.23 m/day; recharge values ranged from 0.0008, 0.0009 m/day, and 0.0039 m/day for the three mine polygons. A Kh of 20 m/day was used for Layer 2, the mine. A barrier coverage was used for the perimeter of the three mine polygons, which was 0.0001 (Kh/Thk-Layer 2). Seepage faces were used for the barriers: Guyan-Hampton 4 of 946 m^2/d/m, and Hampton 4-Hampton 3 of 1061 m^2/d/m.

Discussion of Model Results

<u>Low pumping rates at the Cazy shaft and Rockhouse dewatering borehole</u>

Figure 18 shows the model for the low pumping occurrence prior to controlled pumping by the Company. The available data shows a pumping rate of 5451 m3/day from the Cazy Shaft and 4361 m3/day from the Rockhouse dewatering borehole. The GMS model as shown in Figure 18 shows a trend in which Spruce Laurel Fork flows downgradient (north) with decreasing hydraulic head. The specific heads for this model range from 260-450 meters (south to north). The hydraulic head contours that cross Spruce Laurel Fork show that the head lines “V” upstream. In gaining reaches, the equipotential lines form a “V” pointing upstream; in losing reaches, they form a “V” pointing downstream. In Hampton No. 3, two areas of higher hydraulic head occur adjacent to Spruce Laurel Fork. These areas reflect the eastern and western mine pools that are depicted on Company mine maps. Figure 19 shows the Layer 2 mined seam model that shows essentially the same trend as shown in Figure 18. This figure demonstrates the influence that Layer 1-the roof rock overburden thickness has over the much thinner Layer 2 mined coal seam.

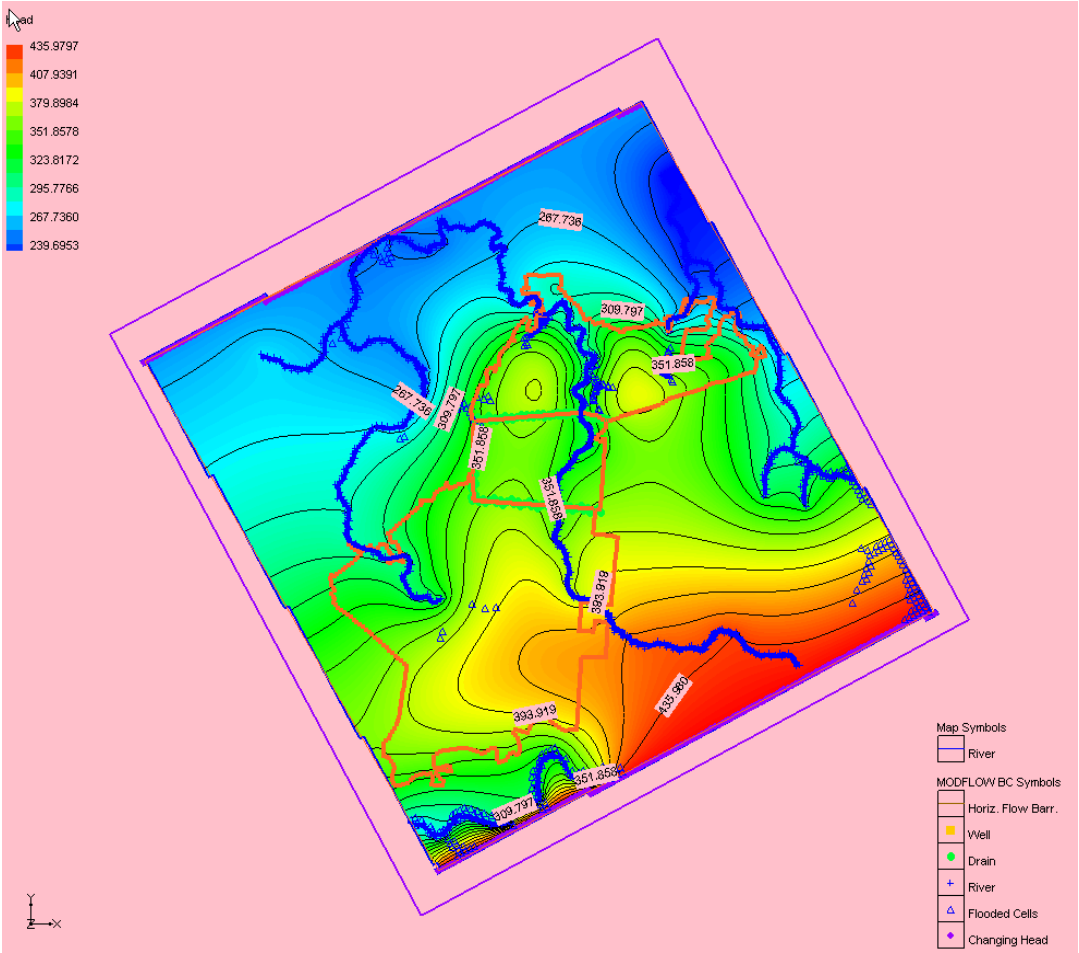


Figure 18. Layer 1 (OVB): Low pumping rates from borehole and shaft

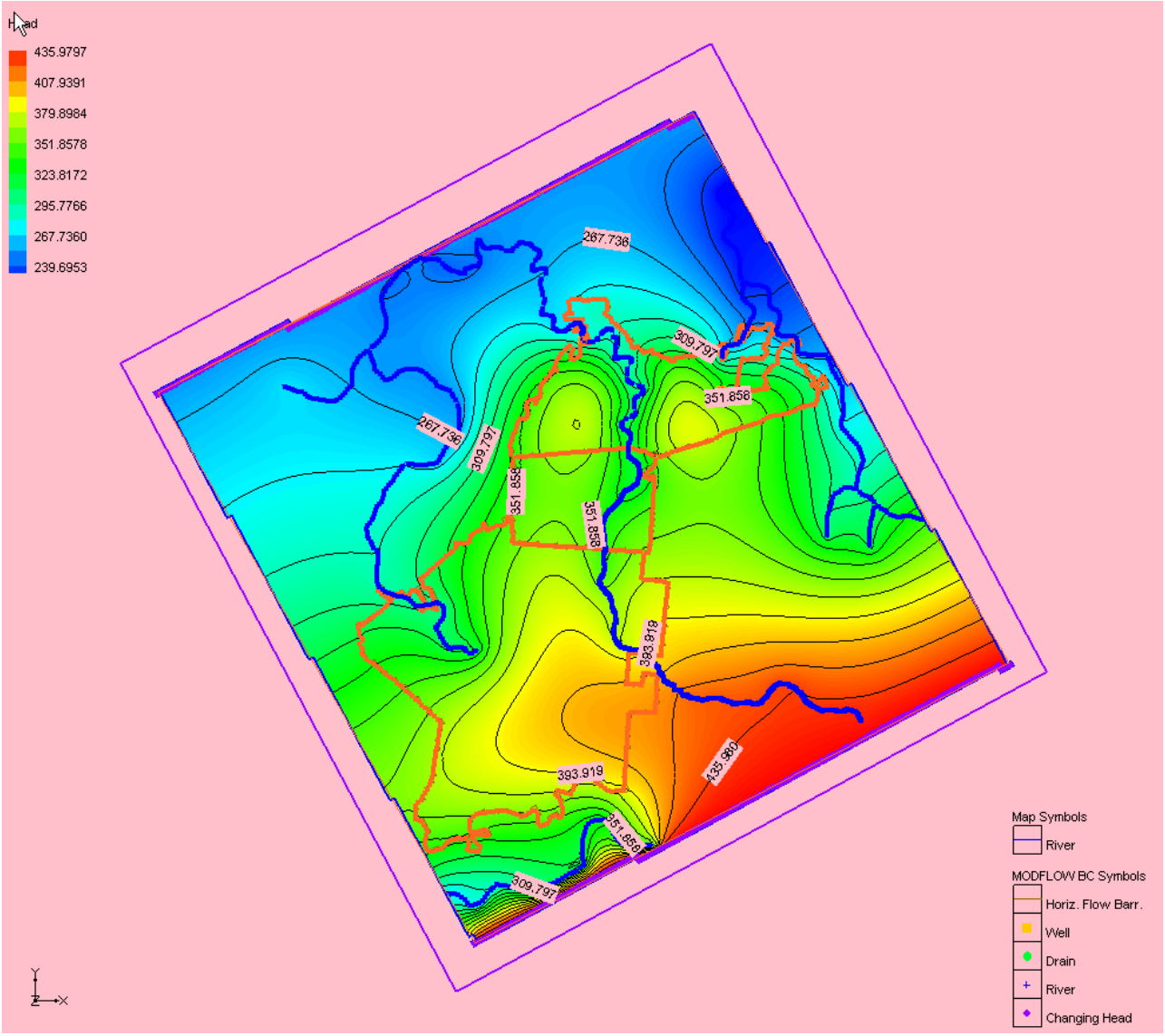
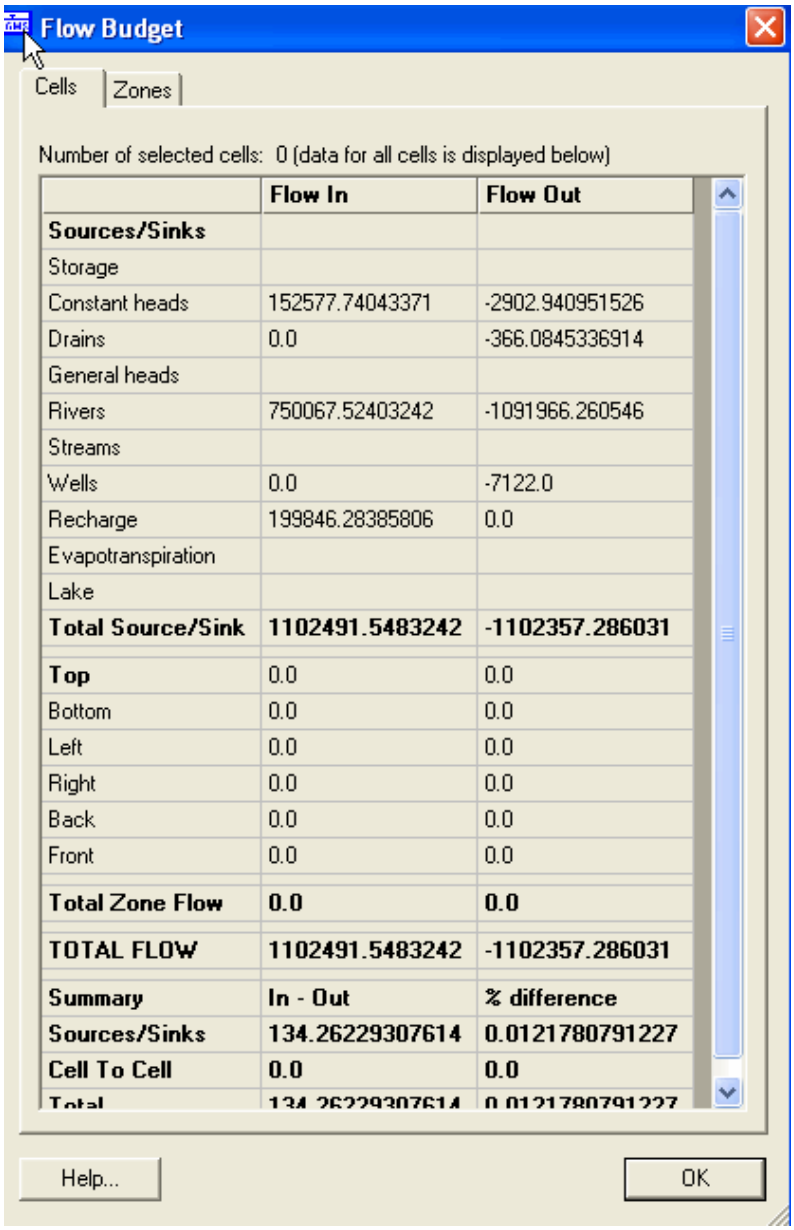


Figure 19. Layer 2 (Seam): Low pumping rates from borehole and shaft



Flow Budget

Cells | Zones

Number of selected cells: 0 (data for all cells is displayed below)

	Flow In	Flow Out
Sources/Sinks		
Storage		
Constant heads	152577.74043371	-2902.940951526
Drains	0.0	-366.0845336914
General heads		
Rivers	750067.52403242	-1091966.260546
Streams		
Wells	0.0	-7122.0
Recharge	199846.28385806	0.0
Evapotranspiration		
Lake		
Total Source/Sink	**1102491.5483242**	**-1102357.286031**
Top	0.0	0.0
Bottom	0.0	0.0
Left	0.0	0.0
Right	0.0	0.0
Back	0.0	0.0
Front	0.0	0.0
Total Zone Flow	**0.0**	**0.0**
TOTAL FLOW	**1102491.5483242**	**-1102357.286031**
Summary	**In - Out**	**% difference**
Sources/Sinks	**134.26229307614**	**0.0121780791227**
Cell To Cell	**0.0**	**0.0**
Total	**134.26229307614**	**0.0121780791227**

Help... OK

Figure 20. Flow budget from low pumping rates

Figure 20 shows the flow budget for the low pump discharge occurrence. The total inflow into the model system was 1,102,491 m3/day. The river flow is the biggest contributor provides approximately 68 percent of the total Flow In. The constant heads source/sink occurs at the north and south model boundaries and contributes approximately 14 percent of the total flow in. The recharge contribution to the model was approximately 18 percent. The largest contributor to the Flow Out was the River

source/sinks in which the Rivers Flow In was 750,067 m3/day and a Flow Out of -1,091966 m3/day.or approximately 99 percent, showing that it is a losing stream.

High pumping rates at the Cazy shaft and Rockhouse dewatering borehole

Figure 21 shows the model for the high pumping occurrence prior to controlled pumping by the Company. The available data shows a pumping rate of 13627 m3/day from the Cazy Shaft and 4361 m3/day from the Rockhouse dewatering borehole. The GMS model as shown in Figure 22 shows a trend in which Spruce Laurel Fork flows downgradient (north) with decreasing hydraulic head. The specific heads for this model range from 260-450 meters (south to north). Overall, the hydraulic head contours are descending towards the north or downgradient.

In gaining reaches, the equipotential lines form a “V” pointing upstream; in losing reaches, they form a “V” pointing downstream. Apparently, the head at some reaches are below river stage, and flow is diverted from Spruce Laurel Fork down to a lower aquifer. In the higher pumping rates, the two pools in Hampton No. 3 adjacent to Spruce Laurel Fork are pumped down and are eliminated. The high pumping rates have a significant effect on relieving the hydraulic mine in the mines, and thereby eliminating downgradient impacts to residents.

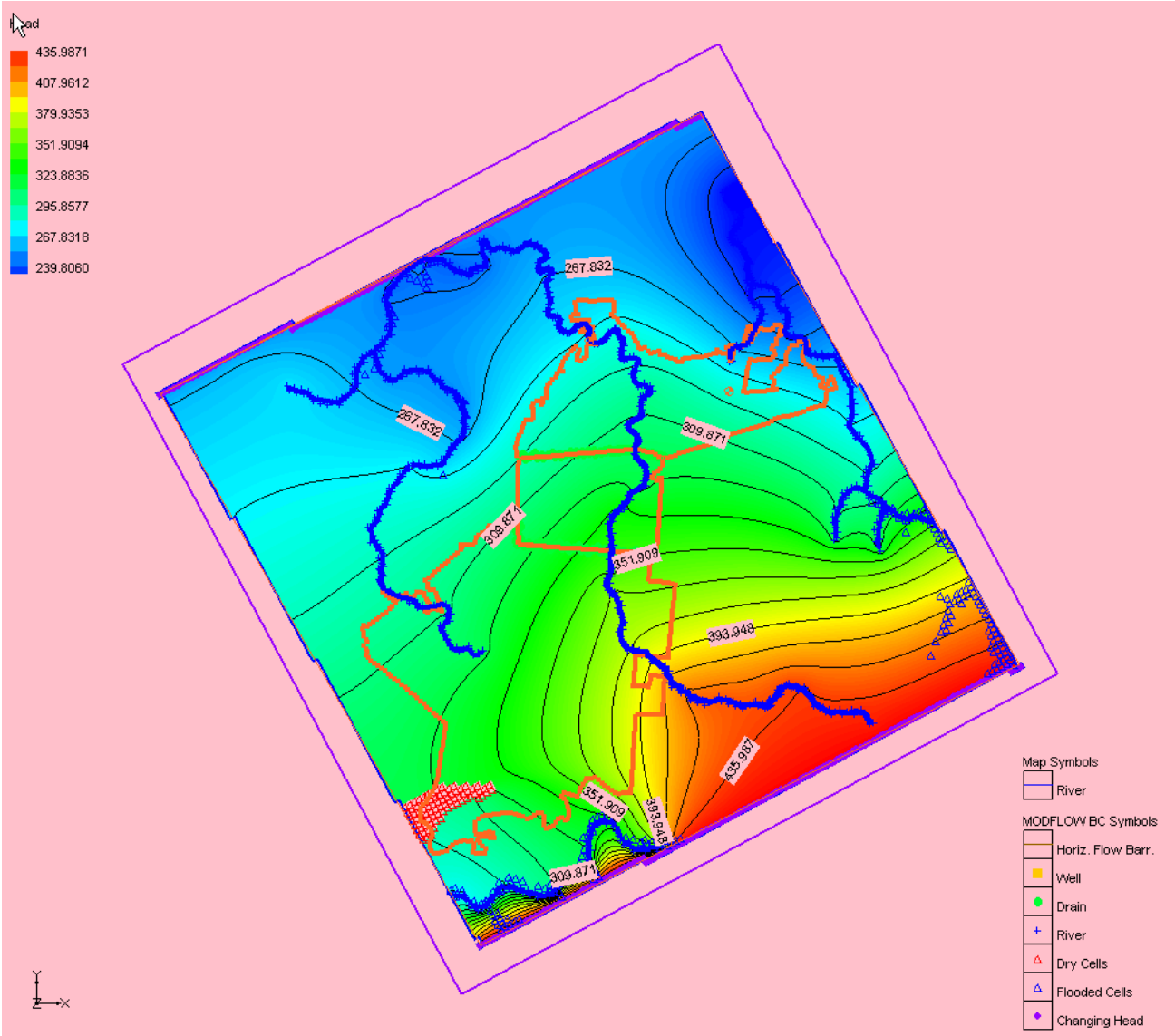


Figure 21. Layer 1 (OVB): High pumping rates from borehole and shaft

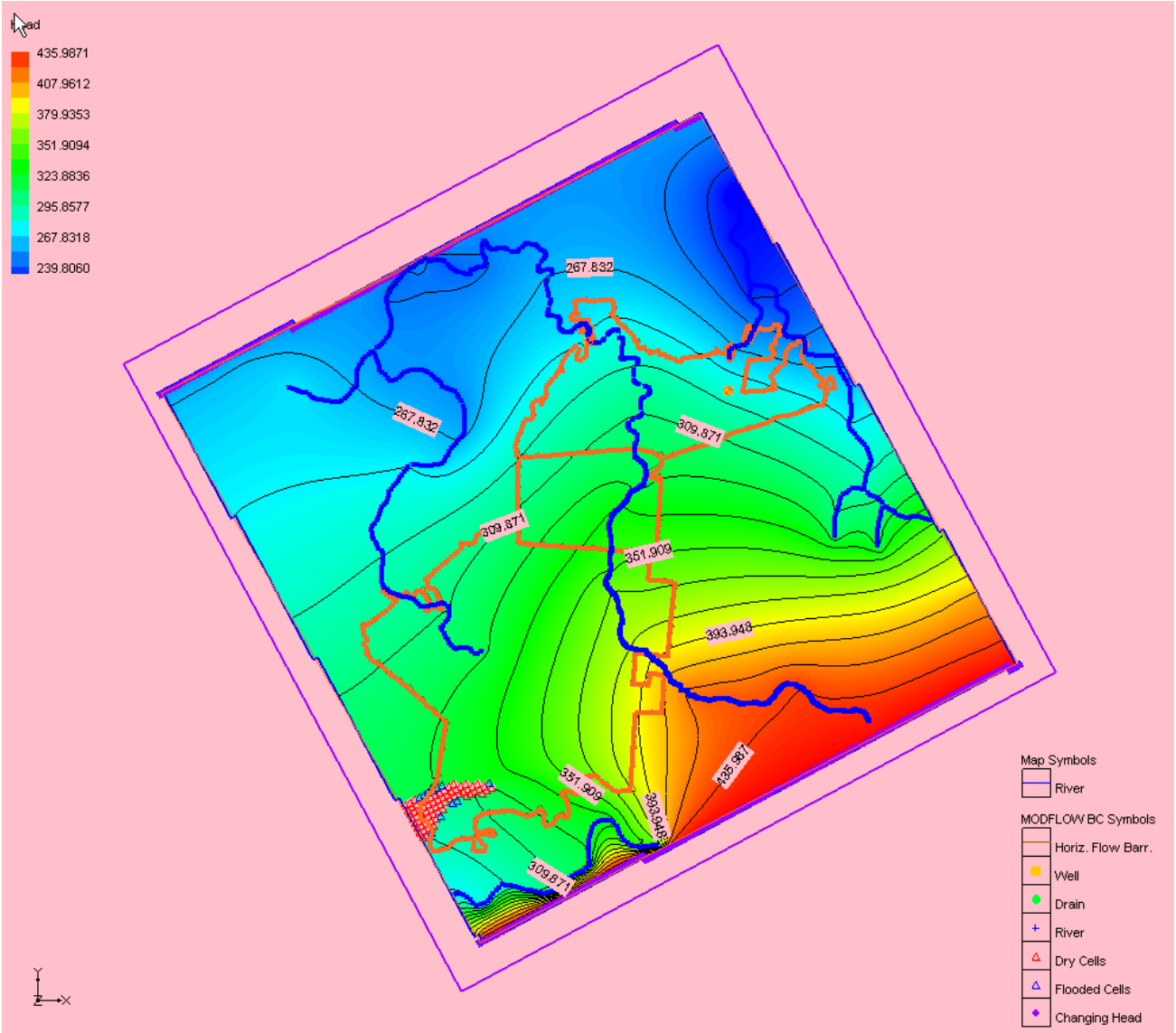


Figure 22. Layer 2 (Seam): High pumping rates from borehole and shaft

Figure 22 shows the Layer 2 mined seam model that shows essentially the same trend as shown in Figure 21. This figure demonstrates the influence that Layer 1-the roof rock overburden thickness has over the much thinner Layer 2 mined coal seam in the model. Overall, the hydraulic head contours are descending towards the north or downgradient, indicating losing reaches. Only two hydraulic head contours cross Spruce Laurel Fork in which the head lines “V” upstream, or gaining stream reaches.

In some gaining reaches, the equipotential lines form a “V” pointing upstream; in losing reaches, they form a “V” pointing downstream (refer to Figure 23). Apparently, the head at these reaches are below river stage, and flow is diverted from Spruce Laurel Fork down to a lower aquifer. In the higher pumping rates, the two pools in Hampton No. 3 adjacent to Spruce Laurel Fork are pumped down and are eliminated. The high pumping rates have significant effect on relieving the hydraulic mine in the mines, and thereby eliminating downgradient impacts to residents. Figure 24 shows the flow budget for the low pump discharge occurrence.

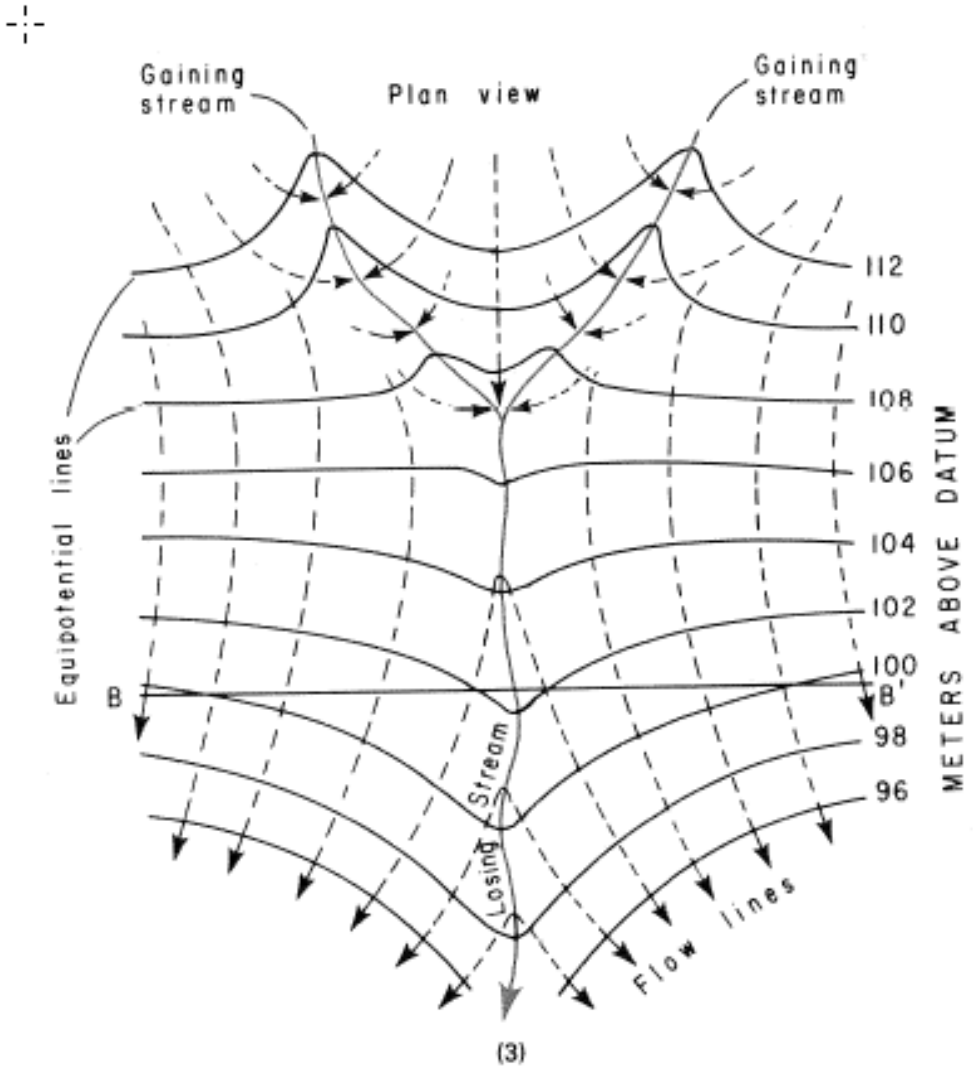
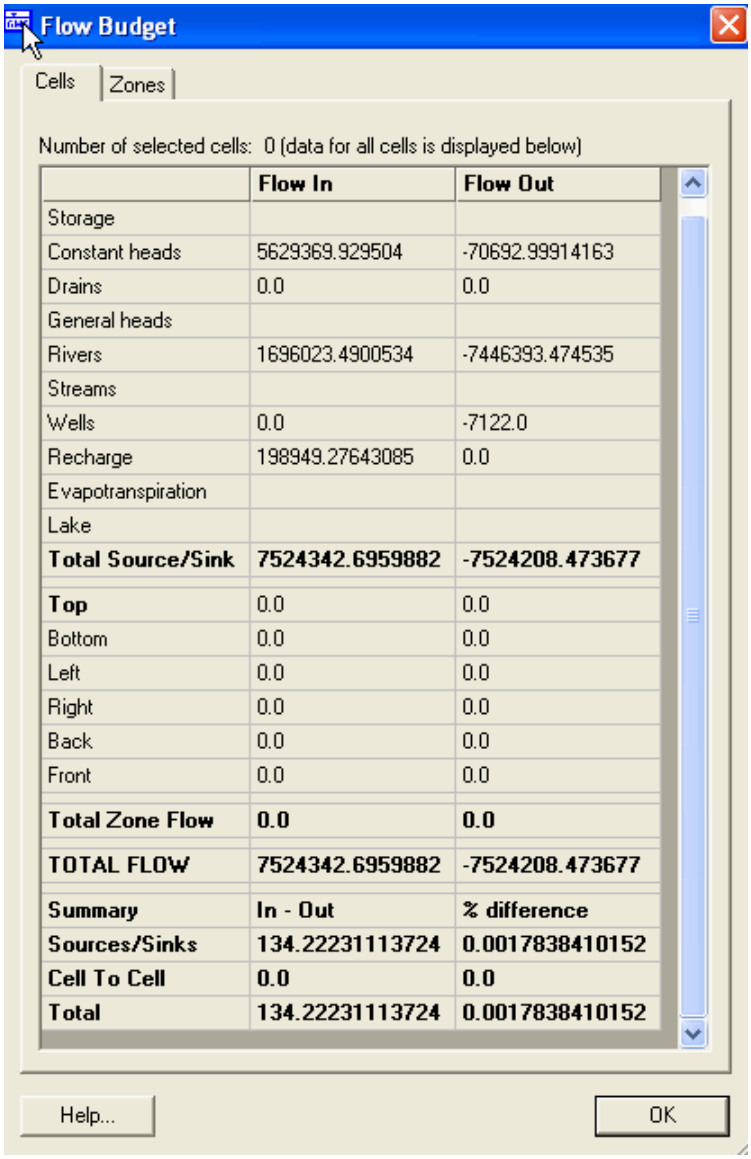


Figure 23. Ground water flow nets: gaining vs.losing streams (Heath, 1989)



Flow Budget

Cells | Zones

Number of selected cells: 0 (data for all cells is displayed below)

	Flow In	Flow Out
Storage		
Constant heads	5629369.929504	-70692.99914163
Drains	0.0	0.0
General heads		
Rivers	1696023.4900534	-7446393.474535
Streams		
Wells	0.0	-7122.0
Recharge	198949.27643085	0.0
Evapotranspiration		
Lake		
Total Source/Sink	**7524342.6959882**	**-7524208.473677**
Top	0.0	0.0
Bottom	0.0	0.0
Left	0.0	0.0
Right	0.0	0.0
Back	0.0	0.0
Front	0.0	0.0
Total Zone Flow	**0.0**	**0.0**
TOTAL FLOW	**7524342.6959882**	**-7524208.473677**
Summary	**In - Out**	**% difference**
Sources/Sinks	**134.22231113724**	**0.0017838410152**
Cell To Cell	**0.0**	**0.0**
Total	**134.22231113724**	**0.0017838410152**

Help... OK

Figure 23. Flow budget from low pumping rates

The total inflow shown in Figure 23 shows that the In Flow into the model system was 7,524,342 m3/day. The river flow is the biggest contributor provides approximately 23 percent of the total Flow In. The constant heads source/sink occurs at the north and south model boundaries and contribute approximately 74 percent of the total flow in. The recharge contribution to the model was approximately 3 percent. The largest contributor to the Flow Out was the River source/sinks in which the Rivers Flow In which was 1,696,023 m3/day and a Flow Out of -7,446,393 m3/day, showing that it is a losing stream.

CONCLUSIONS AND RECOMMENDATIONS

The case example that was used to model the hydrology of an impacted stream by underground mining is perennial Spruce Laurel Fork, which is losing streamflow to a series of subjacent, below-drainage underground coal mines in the watershed. The conceptual model indicates that some reaches of Spruce Laurel Fork and its tributaries are “pirated”, and flow diverted from the stream downward into the underground mines. The diverted flows contribute to the development of the mine pools where a hydraulic connection exists between the pools formed in these mines and artesian effects to down-gradient residents’ water wells and basements.

This ground water model was based on prudent hydrologic assumptions that were necessary in order to develop the ground water flow model. The results of this project illustrate how the WCMS-HSPF and the GMS applications can compliment each other when modeling watershed hydrology that is associated with underground coal mining.

The WCMS-HSPF application successfully modeled the watershed streamflow; however, the GMS ground water flow model still needs considerable refinement as this time. Gathering more data relating to the boundary conditions that apply in the study area, especially the regional flow system and verify upgradient and downgradient head elevations. More accurate information, rather than assumptions are needed relating to hydraulic parameters such as hydraulic conductivity and recharge values, which would improve model results.

The GMS model requires much more site-specific data for the model hydraulic parameters than is currently available. This would result in predictive models that more accurately reflects field conditions that impacted the watershed of Spruce Laurel Fork, which resulted in dewatered stream reaches, mine pool development, and artesian conditions that occurred at residents’ homes.

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