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**QUANTITATIVE EVALUATION OF MINING-INDUCED CHANGES TO
SPRING DISCHARGE ABOVE A MINE IN THE NORTHERN APPALACHIAN
COAL FIELD**

by

Joshua M. Silvis

**Thesis submitted to the Eberly College of Arts and Sciences
at West Virginia University
in partial fulfillment of the requirements
for the degree of**

**Master of Science
in
Geology**

Approved by

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**Morgantown, West Virginia
2009**

**Keywords: Longwall Mining, Environmental Effects, Spring Discharge Response,
Recharge Line, Natural Variation, Evapotranspiration Condition
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Abstract

QUANTITATIVE EVALUATION OF MINING-INDUCED CHANGES TO SPRING DISCHARGE ABOVE A MINE IN THE NORTHERN APPALACHIAN COAL FIELD

by Joshua M. Silvis

The objectives of this research were to develop methods to discern between naturally occurring reductions in spring discharge from mining-induced reductions to spring discharge, evaluate available hydrologic, geologic, topographic, and mine-specific variables to determine which variables are related to mining-induced spring discharge impairment, and evaluate the variables to determine the seasonality differences or similarities among the variable effects. The study area is at one mine site in the northern Appalachian coal basin.

Overburden thickness of the researched ground water sources above the mined coal bed level range from 135 feet to 550 feet. The overburden geology consists of cyclothemic deposits of sandstones, siltstones, shales, limestones, clays, and coal that comprise the Conemaugh and Monongahela Groups of Pennsylvanian age, and the lower part of the Dunkard Group, Washington and Greene Formations, undifferentiated, of Pennsylvanian and Permian age. The terrain of the research area is typical of the Appalachian Plateau physiographic province, having broad ridges, deeply incised valleys, and highly defined dendritic drainage. Land use is dominantly for farming. Average annual precipitation in the research area is 43 inches.

Mining-induced subsidence resulted in a partial environmental effect to springs. Spring discharge responses for 77 springs were evaluated across subsidence events. The methodological procedure developed through numerous, iterative investigations differentiated quantitative values separating natural changes in spring discharge from mining-induced changes to spring discharge. The influences of precipitation and evapotranspiration conditions were accounted for during the natural variation analysis used to determine if changes to spring discharge were mining-induced.

In addition, topographic, geologic, hydrologic, and mine-specific variables were statistically examined for significance of influence on spring discharge impairment during low and high evapotranspiration seasons.

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Most of all, the author wishes to thank Dr. Henry W. Rauch for the countless hours spent together, in a conference room, office, and over the phone. Although the research extended over five years due to employment, Dr. Rauch remained as dedicated as the author.

TABLE OF CONTENTS

Abstract	ii
ACKNOWLEDGEMENTS.....	iii
TABLE OF CONTENTS.....	iv
LIST OF FIGURES.....	xi
LIST OF TABLES.....	xiii
1.0 INTRODUCTION	1
1.1 Background.....	1
1.2 Purpose.....	2
2.0 LITERATURE REVIEW	5
2.1 Theory of Overburden Strata Movement.....	5
2.2 Stress-Relief Fractures.....	7
2.3 Environmental Effects on Ground Water and Surface Water.....	9
3.0 RESEARCH STUDY AREA	12
3.1 Geography.....	12
3.2 Precipitation.....	15
3.3 Geology.....	15
4.0 RESEARCH DATA	18
4.1 Existing Data.....	18
4.2 Measured Data.....	21
<u>4.2.1 Recharge Line</u>	21
<u>4.2.2 Spring Proximity to Nearest Surface Drainage Feature</u>	23

4.2.3 Spring Elevation.....	25
4.2.4 Overburden Thickness.....	25
4.2.5 Longwall Width-Depth Ratio.....	25
4.2.6 Spring Location Above a Longwall Panel.....	26
5.0 GENERAL METHODS OF INVESTIGATION.....	27
5.1 Statistical Examination.....	28
5.1.1 Median Contingency Test.....	29
5.1.2 Chi Square Contingency Test.....	31
5.1.3 Fisher Exact Probability Contingency Test.....	32
5.1.4 Guidelines Used for Apparent Data Trends.....	33
6.0 INVESTIGATION I.....	35
6.1 Methods of Investigation I.....	35
6.1.1 Spring Discharge Hydrograph Interpretation.....	35
6.2 Results from Investigation I.....	36
6.2.1 Spring Discharge Response.....	36
6.2.2 Spring Discharge Response Statistical Examination (Median Value).....	39
7.0 INVESTIGATION II.....	42
7.1 Methods of Investigation II.....	42
7.2 Results of Investigation II.....	43
7.2.1 Spring Discharge Response.....	43
7.2.2 Spring Discharge Response Statistical Examination	

(Median Value).....	45
7.2.2.1 All Springs (see Table 4).....	45
7.2.2.2 Springs Located Above Longwall Panels (see Table 5).....	47
7.2.2.3 Springs Located Above Main and Submain Development (see Table 6).....	49
7.2.2.4 Springs Located Within Off Panel Mining Environments (see Table 7).....	49
7.2.2.5 Springs Located Within the SCPA Boundary (see Table 8).....	52
8.0 INVESTIGATION III.....	55
8.1 Methods of Investigation III.....	55
8.1.1 Quantitative Evaluation of Spring Discharge Data.....	55
8.1.2 Natural Variation Analysis.....	55
8.1.2.1 Evapotranspiration Condition.....	56
8.1.2.2 Precipitation.....	56
8.1.3 Reduction Boundary Conditions.....	58
8.1.4 Quantitative Evaluation of Additional Dependent Variables.....	63
8.1.4.1 Recharge Line.....	63
8.1.4.2 Spring Proximity to Nearest Surface Drainage Feature.....	65

8.1.4.3 <i>Pre-Mining Average Low Flow Spring</i>	
<i>Discharge</i>	65
8.2 Results of Investigation III.....	65
8.2.1 <u>Quantitative Evaluation of Spring Discharge Data</u>	65
8.2.2 <u>Natural Variation Analysis</u>	69
8.2.3 <u>Reduction Boundary Conditions</u>	72
8.2.4 <u>Spring Discharge Response</u>	77
8.2.4.1 <i>Optimum Boundary Reduction</i>	77
8.2.4.2 <i>Absolute Boundary Reduction</i>	80
8.2.5 <u>Spring Discharge Response Statistical Examination</u>	
<u>Median Value</u>).....	80
8.2.5.1 <i>Low Evapotranspiration Condition – Optimum</i>	
<i>Reduction Boundary</i>	85
8.2.5.2 <i>Low Evapotranspiration Condition – Absolute</i>	
<i>Reduction Boundary</i>	86
8.2.5.3 <i>High Evapotranspiration Condition – Optimum</i>	
<i>Reduction Boundary</i>	87
8.2.5.4 <i>High Evapotranspiration Condition – Absolute</i>	
<i>Reduction Boundary</i>	88
8.2.6 <u>Degree of Spring Discharge Response Statistical</u>	
<u>Examination (Median Value)</u>	90
8.2.6.1 <i>Low Evapotranspiration Condition – Optimum</i>	

<i>Reduction Boundary</i>	93
8.2.6.2 <i>Low Evapotranspiration Condition – Absolute</i>	
<i>Reduction Boundary</i>	94
8.2.6.3 <i>High Evapotranspiration Condition – Optimum</i>	
<i>Reduction Boundary</i>	95
8.2.6.4 <i>High Evapotranspiration Condition – Absolute</i>	
<i>Reduction Boundary</i>	95
9.0 INVESTIGATION IV	97
9.1 Methods of Investigation IV.....	97
9.2 Results of Investigation IV.....	97
<u>9.2.1 Spring Discharge Response Statistical Examination</u>	
<u>(Interpreted Best Fit Value)</u>	97
9.2.1.1 <i>Low Evapotranspiration Condition – Optimum</i>	
<i>Reduction Boundary</i>	101
9.2.1.2 <i>Low Evapotranspiration Condition – Absolute</i>	
<i>Reduction Boundary</i>	102
9.2.1.3 <i>High Evapotranspiration Condition – Optimum</i>	
<i>Reduction Boundary</i>	103
9.2.1.4 <i>High Evapotranspiration Condition – Absolute</i>	
<i>Reduction Boundary</i>	104
<u>9.2.2 Degree of Spring Discharge Response Statistical</u>	
<u>Examination (Interpreted Best Fit Value)</u>	106

9.2.2.1 <i>Low Evapotranspiration Condition – Optimum</i>	
<i>Reduction Boundary</i>	109
9.2.2.2 <i>Low Evapotranspiration Condition – Absolute</i>	
<i>Reduction Boundary</i>	110
9.2.2.3 <i>High Evapotranspiration Condition – Optimum</i>	
<i>Reduction Boundary</i>	112
9.2.2.4 <i>High Evapotranspiration Condition – Absolute</i>	
<i>Reduction Boundary</i>	112
10.0 CONCLUSIONS	114
11.0 DISCUSSION AND THEORY	117
11.1 Independent Variable Analysis.....	118
<u>11.1.1 Bedrock Stratigraphy</u>	120
<u>11.1.2 Spring Recharge</u>	123
12.0 RECOMMENDATIONS	127
13.0 REFERENCES	129
14.0 APPENDIX	133
APPENDIX A: Spring Discharge Hydrographs Used to Assess Spring	
Discharge Response to Mining-Induced Subsidence as Discussed in	
Methods of Investigation I.....	133
APPENDIX B: Quantitative Data Related to the Hydrologic, Geologic,	
Topographic, and Mine-Specific Variables Discussed in Methods of	
Investigation I.....	211

APPENDIX C: Quantitative Data Related to the Additional Hydrologic, Geologic, Topographic, and Mine-Specific Variables Discussed in Methods of Investigation III.	217
APPENDIX D: Data Used to Calculate Changes to Spring Discharge Across Subsidence Events During Low and High Evapotranspiration Conditions as Discussed in Methods of Investigation III.	220
APPENDIX E: Figures Illustrating the Statistically Significant Variables Identified from the Spring Discharge Response to Mining-Induced Subsidence Analysis through the Use of the Calculated Median Values as Discussed in Results of Investigation III.	225
APPENDIX F: Figures Illustrating the Statistically Significant Variables Identified from the Degree of Spring Discharge Impairment to Mining- Induced Subsidence Analysis through the Use of the Calculated Median Values as Discussed in Results of Investigation III.	254
APPENDIX G: Figures Illustrating the Statistically Significant Variables Identified from the Spring Discharge Response to Mining-Induced Subsidence Analysis through the Use of the Interpreted Best Fit Values as Discussed in Results of Investigation IV.	261
APPENDIX H: Figures Illustrating the Statistically Significant Variables Identified from the Degree of Spring Discharge Impairment to Mining- Induced Subsidence Analysis through the Use of the Interpreted Best Fit Values as Discussed in Results of Investigation IV.	292

LIST OF FIGURES

Figure 1. Research Study Area.....	13
Figure 2. Simplified Longwall Mine Design at the Research Study Area.....	14
Figure 3. Simplified Stratigraphic Column for the Rock Units within the Research Study Area.....	16
Figure 4. Structural Contour Map for the Mined Coal Seam Within the Research Study Area.....	17
Figure 5. Schematic Depiction of a Contact Spring.....	19
Figure 6. Schematic Depiction of the Recharge Line for a Spring.....	22
Figure 7. Schematic Depiction of the Gradient Line from Spring Location to the Nearest Surface Drainage Feature.....	24
Figure 8. Conceptual Example of a 2x2 Contingency Table Test Using Overburden Thickness as the Independent Variable.....	30
Figure 9. Conceptual Example of the Three Possible Hypotheses Related to the 2x2 Contingency Table Tests Using Overburden Thickness as the Independent Variable.....	31
Figure 10. 2x2 Contingency Table Test Used for Investigation I.....	39
Figure 11. 2x2 Contingency Table Test Used for Investigation II.....	45
Figure 12. Schematic Depiction of the Recharge Line Length Component Perpendicular to Longwall Panel Face for Springs Overlying Longwall Panels.....	64
Figure 13. Pre-Mine to Post-Mine Spring Discharge Comparison for Averaged	

Spring Discharge and Precipitation Normalized Averaged Spring Discharge Data Collected During Low Evapotranspiration Seasonal Conditions.....	66
Figure 14. Pre-Mine to Post-Mine Spring Discharge Comparison for Averaged Spring Discharge and Precipitation Normalized Averaged Spring Discharge Data Collected During High Evapotranspiration Seasonal Conditions.....	67
Figure 15. 2x2 Contingency Table Test Used for the Natural Variation Analysis Associated with Investigation III.....	74
Figure 16. 2x2 Contingency Table Test Used for Spring Discharge Response, Investigation III.....	84
Figure 17. 2x2 Contingency Table Test Used for the Degree (Mild Versus Severe) of Spring Discharge Response for the Impaired Spring Group, Investigation III.....	93
Figure 18. 2x2 Contingency Table Test Used for Spring Discharge Response, Investigation IV.....	100
Figure 19. 2x2 Contingency Table Test Used for the Degree (Mild Versus Severe) of Spring Discharge Response for the Impaired Spring Group, Investigation IV.....	109
Figure 20. Scatter Plot Showing Direct Relationship Between Spring Vertical Relief and Lateral Distance to Nearest Surface Drainage Feature.....	122
Figure 21. Scatter Plot Showing Direct Relationship Between Recharge Line Length and Recharge Line Vertical Relief.....	124

LIST OF TABLES

Table 1. Results of Spring Discharge Hydrograph Interpretation as Discussed in Methods of Investigation I.....	37
Table 2. Results from Methods of Investigation I. Chi Square Contingency and Fisher Exact Probability Test Results Evaluated with the Calculated Median Values.....	40
Table 3. Results of Spring Discharge Hydrograph Interpretation as Discussed in Methods of Investigation II.....	44
Table 4. Results from Methods of Investigation II. Chi Square Contingency and Fisher Exact Probability Test Results for All Springs Evaluated with the Calculated Median Values.....	46
Table 5. Results from Methods of Investigation II. Chi Square Contingency and Fisher Exact Probability Test Results for Springs Located Above Longwall Panels Evaluated with the Calculated Median Values.....	48
Table 6. Results from Methods of Investigation II. Chi Square Contingency and Fisher Exact Probability Test Results for Springs Located Above Main and Submain Development Evaluated with the Calculated Median Values.....	50
Table 7. Results from Methods of Investigation II. Chi Square Contingency and Fisher Exact Probability Test Results for Springs Located Within Off Panel Mining Environments Evaluated with the Calculated Median Values.....	51
Table 8. Results from Methods of Investigation II. Chi Square Contingency and Fisher Exact Probability Test Results for Springs Located Within the SCPA	

Boundary Evaluated with the Calculated Median Values.....	53
Table 9. Monthly Precipitation Data.....	59
Table 10. Results from the Natural Variation Analysis During Low and High Evapotranspiration Conditions Using Averaged Spring Discharge Data as Discussed in Methods of Investigation III.....	70
Table 11. Results from the Natural Variation Analysis During Low and High Evapotranspiration Conditions Using Normalized Average Spring Discharge Data as Discussed in Methods of Investigation III.....	71
Table 12. Data Types and Use Associated with Four Spring Discharge Scenarios as Discussed in Methods of Investigation III.....	73
Table 13. Results from the Optimum Partition Tests Used to Determine the Optimum Reduction Boundaries as Discussed in Methods of Investigation III.....	75
Table 14. Results from the Optimum Partition Tests Used to Determine the Absolute Reduction Boundaries as Discussed in Methods of Investigation III.....	78
Table 15. Spring Discharge Response to Mining-Induced Subsidence Evaluated at the Optimum Spring Discharge Reduction Boundary During Low and High Evapotranspiration Conditions.....	79
Table 16. Spring Discharge Response to Mining-Induced Subsidence Evaluated at the Optimum Spring Discharge Reduction Boundary During Low and High Evapotranspiration Conditions.....	81

Table 17. Results from Methods of Investigation III. Chi Square Contingency Test Results Used to Determine Spring Discharge Response to Mining- Induced Subsidence through the Use of the Calculated Median Values.....	82
Table 18. Results from Methods of Investigation III. Fisher Exact Probability Results Used to Determine Spring Discharge Response to Mining-Induced Subsidence through the Use of the Calculated Median Values.....	83
Table 19. Results from Methods of Investigation IV. Chi Square Contingency Test Results Used to Determine the Degree of Spring Discharge Impairment to Mining-Induced Subsidence through the Use of the Calculated Median Values.....	91
Table 20. Results from Methods of Investigation III. Fisher Exact Probability Test Results Used to Determine the Degree of Spring Discharge Impairment to Mining-Induced Subsidence through the Use of the Calculated Median Values.....	92
Table 21. Results from Methods of Investigation III. Chi Square Contingency Test Results Used to Determine Spring Discharge Response to Mining- Induced Subsidence through the Use of the Interpreted Best Fit Values.....	98
Table 22. Results from Methods of Investigation III. Fisher Exact Probability Results Used to Determine Spring Discharge Response to Mining-Induced Subsidence through the Use of the Interpreted Best Fit Values.....	99
Table 23. Results from Methods of Investigation IV. Chi Square Contingency Test Results Used to Determine the Degree of Spring Discharge Impairment	

to Mining-Induced Subsidence through the Use of the Interpreted Best Fit Values.....	107
Table 24. Results from Methods of Investigation III. Fisher Exact Probability Test Results Used to Determine the Degree of Spring Discharge Impairment to Mining-Induced Subsidence through the Use of the Interpreted Best Fit Values.....	
	108
Table 25. Error Probability Calculated for Significant Data Trends Derived from Fisher Exact Probability Tests for Methods of Investigation I through IV at the 0.10 Alpha Level of Significance.....	
	119

INTRODUCTION

1.1 Background

Coal production in the United States in 2007 totaled 1,145.6 million short tons. Coal operations located in the Appalachian Region accounted for 33% (or 377.1 million short tons) of the 2007 production. Total U.S. coal consumption in 2007 was 1128.8 million short tons, an increase of 16.5 million short tons as compared to 2006 production.

Almost 93% of the coal consumed in the U.S. in 2007 was within the electric power sector; and the remaining 7% was consumed within other industrial and coking coal plants and residential and commercial users (Freme, 2008).

The coal extraction techniques applicable to this research are continuous and longwall underground mining; therefore open cast mining techniques, such as strip and mountaintop removal, will not be discussed. Longwall mining was first introduced to the Appalachian Region during the 1970s (Peng and Chiang, 1984). In 1981, 118 longwall panels were being operated at longwall mines. The number of active longwall panels decreased to 80 in 1995 and 52 in 2007 with 32 longwall panels within the Appalachian Region (Parizek and Ramani, 1995; Fiscor, 2008). The decrease in the number of operated longwall panels was due to increased longwall panel widths, lengths, and production rates, which made fewer, actively mined longwall panels more practical for operators.

Longwall mining is preferred over continuous mining for underground mines because the technique is safer for the coal miners, yields approximately 30% more coal (75% – 90% coal recovery), and the subsidence associated with longwall coal extraction is more predictable and controlled than the subsidence associated with continuous coal extraction (Coe and Stowe, 1984).

Longwall mining is an integral component of the Appalachian Region economy. However, adverse environmental effects resulting from mining-induced subsidence commonly occur, such as aquifer dewatering, spring discharge impairment, and surface water flow diminution or loss.

1.2 Purpose

Mining operators within the Appalachian Region examine case studies to assist in predicting probable hydrologic consequences (PHC) through the evaluation of mining-induced subsidence effects to ground water and surface water. These PHC reports characterize the prevailing hydrologic and geologic conditions inherent to unmined ground water and surface water supplies and predict their response to mining-induced subsidence.

The purpose of this research was to document and evaluate spring flow responses associated with underground longwall mining subsidence. Spring discharge impairment

data trends were evaluated to determine the statistically significant hydrologic, geologic, topographic, and mine-specific variables which associate with and could be used to predict mining-induced subsidence dewatering responses of springs that overlie underground coal mines.

Previous hydrologic, geologic, topographic, and mine-specific variables researched by others, such as overburden thickness and vertical proximity to baseflow elevation, have been proven to be related to surface and ground water diminution or loss. This research has been supplemented with additional hydrologic, topographic, and mine-specific variables that have not been evaluated in the above cited research. Essentially, variables that were perceived by the author to be associated with potentially creating adverse environmental effects to local hydrology were evaluated to determine which variables are related to mining-induced spring discharge impairment; i.e., spring discharge diminution or loss. The objectives of this research were as follows:

1. Evaluate available hydrologic, geologic, topographic, and mine-specific independent variables to determine which independent variables are related to mining-induced spring discharge impairment, in terms of occurrence and degree of impairment.
2. Evaluate the data trends and results at various degrees of sophistication to determine if increasing the discrimination of data through increasingly sophisticated approaches would yield better data trends and results than through the use of the simplest approach. Four investigative approaches of varying sophistication were used for this objective.

3. Offer recommendations for further mining related spring discharge impairment evaluation.

2.0 LITERATURE REVIEW

The following literature review was conducted to determine the variables that may result in flow disruption of streams and decreased production from ground water wells. These variables were used to assess their degree of association with spring discharge impairment to understand the environmental effects of underground mining imposed upon springs.

A literature review was conducted for the purposes of:

- summarizing the theory of overburden strata movement related to longwall coal extraction,
- gaining an understanding of the regional stress-relief fracturing model inherent to Appalachian stress relieved valleys, and
- reviewing the environmental effects imposed on ground water and surface water systems.

2.1 Theory of Overburden Strata Movement

During longwall coal extraction, the overburden is subjected to stress and strain (various degrees of movement). Primary factors that influence subsidence-induced ground movement include the thickness and physical properties of the overburden, the width and length of the longwall panel being extracted, the thickness and inclination of the coal bed being mined, and the surface topography (PA DEP, 1999). According to the movement characteristics, the damaged overburden can be divided into four subsidence zones starting at the mined coal bed and proceeding vertically upward (Peng, 1992).

1. caved zone

2. fractured zone
3. continuous bending deformation zone and
4. surface zone.

After the extraction of coal, the immediate mine roof caves irregularly and fills up the mined void with rock rubble (gob). The strata in this caved zone not only lose their continuity completely, the strata also lose their stratified bedding. The caved zone is normally 2 to 8 times the mine opening height (Peng, 1992).

The fractured zone is located immediately above the caved zone. The characteristics of the fractured zone are strata breakage and loss of continuity; however, the stratified beddings remain. The severity of strata breakage reduces from the bottom of the fractured zone to the top of the fractured zone. The permeability of the strata increases greatly. The fractured zone is generally 20 to 30 times the mine opening height (Peng, 1992).

Strata located above the fractured zone deform through ductile mechanics. The strata continuity and stratified beddings remain. Open fractures do occur within the continuous bending deformation zone; however, these fractures do not propagate vertically through the continuous bending deformation zone (Peng, 1992).

The surface zone has also been defined as the surface subsidence or surface fractured zone and consists of soil and weathered bedrock. Depending on the physical properties

of the soil and weathered bedrock, subsidence fractures may dilate when the active face is within close proximity and constrict when the subsidence event has been completed. However, some fractures, especially fractures located within tensional zones above the longwall panel, remain dilated when the subsidence event has been completed (Peng, 1992).

A fifth zone has recently been defined as the dilated zone, which is a zone of increased permeability and storativity adjacent to a longwall panel. The dilated zone is stratigraphically located above the fractured zone and below the continuous bending deformation zone (Kendorski, 2001).

It is important to understand that the overburden subsidence deformation model described above is a framework to understand how natural mining-induced fractures propagate to shallower zones. In addition, the apertures, or widths, of pre-existing fractures, such as stress relieved fractures, can increase due to overburden deformation.

2.2 Stress-Relief Fractures

In the Appalachian Plateau, there are two systems of fractures, or joints, cross-cutting the sedimentary rocks of Mississippian, Pennsylvanian, and Permian stratigraphic sections. The ‘macro’ system of fractures is a result of tectonic activity that caused the deformation in the Valley and Ridge Geologic Province to the east. The ‘micro’ system of fractures

developed due to local de-stressing of the nearly flatlying strata during downcutting of the deeply incised stream valleys (Borchers and Wyrick, 1981).

This 'micro' system of stress-relief fractures is a shallow near-surface phenomenon. They generally do not occur deeper than 200 feet below land surface. Stress-relief vertical fractures are categorized as either vertical tension fractures or vertical compressional shear fractures. Vertical tension fractures result from unequal horizontal stress applied to valley walls through erosion. Strata in the valley walls sag toward the valley center, fracture subvertically, and eventually slip downslope along subhorizontal bedding-plane fractures. Vertical compressional shear fractures form when vertical-compressional stress on rocks of the valley floor is relieved through erosion of the overlying strata. The weight of the rocks in the hills flanking the valley causes the midvalley strata to bow upward, separating along lateral bedding planes and cracking vertically and forming compressional shear fracturing (Borchers and Wyrick, 1981).

Similar to the formation of vertical compressional shear fractures, stress-relief lateral fractures form from the weathering and erosion of overlying strata in the valley centers. The valley strata bow upward in response to isostatic rebound to create lateral separations along bedding partings (Borchers and Wyrick, 1981).

2.3 Environmental Effects on Ground Water and Surface Water

Adverse environmental effects resulting from mining-induced subsidence on ground water supplies are minimal in valley bottoms, increase in magnitude from valley walls to hillsides, and are greatest at hilltops (Tieman and Rauch, 1986; Leavitt and Gibbens, 1992; Donohue and Parizek, 1994; Carver and Rauch, 1994; Elsworth and Liu, 1995). In general, greater effects occur for ground water supplies located at topographic highs and effects are least for valley bottoms.

Groundwater supplies located below local baseflow stream elevation are affected to a lesser degree than those supplies located above local baseflow stream elevation (Tieman and Rauch, 1986; Leavitt and Gibbens, 1992).

Location of the ground water supply above the longwall panel controls the degree to which ground water supplies are affected. The overburden exhibits tensional and compressional deformation within the quarter-panel and mid-panel mining environments, respectively. The degree to which ground water supplies are affected generally decreases from mid-panel to the off-panel mining environment, which is often stress neutral (Walker et al., 1986; Walker, 1988; Rauch, 1989; Matetic and Trevits, 1992; Trevits and Matetic, 1991; Matetic et al., 1991; and Leavitt and Gibbens, 1992).

The degree to which ground water supplies (water wells and springs) are affected is greatest during the period of maximum subsidence (or maximum tensional strain) as the

longwall panel face passes beneath the supply. The rate of water table decline decreases as ground strain transitions from tensional deformation to compressional deformation (Hill and Price, 1983; Walker, 1988; Roosendaal et al., 1990; and Trevits and Matetic, 1991).

Possible adverse environmental effects resulting from mining-induced subsidence on streams include flow diminution due to induced vertical leakage in response to the artificial lowering of the phreatic surface; pooling of streams due to superimposition of the subsidence trough on low-gradient systems; and local reversal of the hydraulic gradient. Conversely, streams that recover from mining-induced subsidence through natural attenuation processes, such as clay gouging, sedimentation, and chemical precipitate formation, display a more uniform discharge (Carver and Rauch, 1994). The greater uniformity in seasonal streamflow following post-subsidence stabilization is perceived to be a function of lower post-mine baseflow recession, which reflects increased sustainable aquifer discharge and storage capacity.

An inverse relationship exists between overburden thickness and the degree to which ground water and surface water supplies are affected. The greater thickness of overburden between the supply and the coal bed being mined, the lesser the degree to which the supply is affected (Owili-Eger and Johnson, 1987; Stoner, 1983; Rauch et al., 1984; Cifelli and Rauch, 1986; Carver and Rauch, 1994; Dixon and Rauch, 1988; Rauch, 1989; Dixon and Rauch, 1990; and Donohue and Parizek, 1994).

A higher percentage of soft rock there is within the overburden decreases the degree to which ground water and surface water supplies are affected due to distinctly different deformation mechanics between hard and soft rock units (Rauch, 1989). Hard rock units, sandstones and limestones, respond to subsidence-induced ground movement through tensional mechanics, creating and/or enlarging the apertures of existing fractures. Soft rock units, shales, claystones, and coals, respond to subsidence-induced ground movement through ductile mechanics; however, shales are susceptible to increasing vertical permeability. Claystone has the potential to effectively seal fractures created from subsidence-induced ground movement due to its ability to deform through ductile mechanics. In addition, claystone is intrinsically resistive to ground water flow and is effective at precluding vertical transmission of ground water and surface water.

3.0 RESEARCH STUDY AREA

Research was conducted for one mine site in the northern Appalachian Coal Basin (Figure 1). The particular research study area was made apparent to the author through contacts among other colleagues. The study area is typical of other mine sites in the Appalachian Plateau physiographic province, has well documented longwall mining history and well documented spring discharge data collected prior to, during, and after subsidence. In exchange for the spring discharge data, it was agreed that the coal mining company name and specific mine location of the research area remain anonymous.

The research study area is located above two developed blocks of coal. The eastern block of coal was extracted to the north with longwall panels being recovered to the west and the western block of coal was extracted to the south with longwall panels being recovered to the east (Figure 2). The width of the longwall panels ranged from 860 to 1020 feet. The longwall panels are oriented nearly east to west, along 91.5 – 271.5 degree orientation.

3.1 Geography

The terrain of the research area is typical of the Appalachian Plateau physiographic province, having broad ridges, deeply incised valleys, highly defined dendritic drainage. Land use is dominantly for farming. Surface elevation of the researched springs ranges from 930 feet to 1310 feet above mean sea level.

Figure 1. Research Study Area. Longwall panels were extracted counter-clockwise, beginning in the southeast. Springs locations are identified as solid red dots.

Figure 2. Simplified Longwall Mine Design at the Research Study Area.

3.2 Precipitation

Average annual precipitation in the research area is 43 inches. Based on the 30-year precipitation record, the average precipitation is approximately 3.6 inches per month; January (2.5 inches) typically receives the least precipitation and July (4.8 inches) typically receives the most precipitation (Schumacher, 2007).

3.3 Geology

Overburden geology consists primarily of cyclothemic deposits of sandstones, siltstones, shales, limestones, clays, and coal beds of Pennsylvanian and Permian Age. The strata comprise the Conemaugh and Monongahela Groups of Pennsylvanian age, and the lower part of the Dunkard Group, Washington and Greene Formations, undifferentiated, of Pennsylvanian and Permian age (Figure 3). The strata form a gentle monocline that dips to the southeast (Figure 4) at an average rate of 18 feet per mile (Berryhill, 1963).

Overburden thickness of the researched ground water sources above the mined coal bed level range from 135 feet to 550 feet. The majority of the soils overlying the strata are well-drained to moderately well-drained with a silt loam surface over clay loam subsoils (Schumacher, 2007).

Figure 3. Simplified Stratigraphic Column for the Rock Units Within the Research Study Area.

Figure 4. Structural Contour Map for the Mined Coal Seam Within the Research Study Area. Structural contour intervals are 5 ft for the depicted map. Strata are in general dipping to the southeast (lower right).

4.0 RESEARCH DATA

Two types of data were used for the research - existing and measured. The existing and measured data are located in Appendices A and B, respectively.

4.1 Existing Data

The existing data were provided by the coal company and consists of spring discharge measurements, spring emergence locations on ground surface (daylight locations), underground mine workings, mining progress timing maps for the mined longwall panels, unmined coal locations, and bottom of coal elevations.

The spring discharge data were collected previous to this research by coal company personnel and not the author. Spring discharge yields were collected monthly for a minimum of 12 months prior to the local subsidence event and 12 months following the subsidence event, in accordance with the state regulatory agency protocol established during issuance of the underground mining activity permit. The springs are assumed to be contact springs - springs that form at a lithologic contact (Figure 5). Locations of the springs were measured and collected using Global Positioning System (GPS) instrumentation. Spring discharge yields were measured using the timed-volumetric technique. Precision error associated with the measurement technique is assumed to be +/- 10 percent and consistent among measurements.

Spring discharge hydrographs were drafted by the author. These hydrographs graphically display the discharge data through the measurement period. In addition, information

Figure 5. Schematic Depiction of a Contact Spring.

related to underground longwall activity during the measurement period is shown. The spring discharge hydrographs are located in Appendix A.

The existing spring data were field verified to assess data quality. Information such as accuracy of mapped spring locations, spring use at time of visitation, degree of spring development and construction type, and spring yield at time of visitation were collected.

The author was able to visit 57 of the 77 springs to assess data quality and 100% were mapped properly within +/- 30 feet (accuracy associated with the GPS unit used). The degree of spring development and construction type did not provide adequate quality and assurance of data for the author to make a distinction between different degree of spring development (effectiveness to capture water), construction type, or if post-mine modifications were made to existing spring supplies following the subsidence event. Therefore, the springs are assumed to have the same degree of spring development and construction type.

In addition, anecdotal information, such as historical spring discharge patterns, post-mine spring discharge activity and location(s), and spring discharge disruption observations, were collected by the author from conversations with surface property owners.

Familiarity with local drainage features, surface bedrock types, and mining-induced subsidence effects to ground surface, structures, and infrastructure were also noted.

4.2 Measured Data

The measured data were computed by the author. The independent variable data were investigated due to known relationships between hydrologic, geologic, topographic, and mine-specific variables to mining-induced hydrologic changes, as previously discussed in

2.3 Environmental Effects on Ground Water and Surface Water. Quantitative information was obtained for the independent variables for later use in examining statistical data trends of these variables associated with underground longwall mine subsidence. The independent variable data are located in Appendix B and include the recharge line, spring proximity to nearest surface drainage feature, spring elevation, overburden thickness, width-depth ratio, and spring location above a longwall panel.

4.2.1 Recharge Line

The recharge line is a conceptual analog to the topographic subsurface drainage and recharge basin of a spring. The recharge line concept was modified from an earlier study (Cifelli and Rauch, 1986). The recharge line concept assumes that ground water flows down-dip along the steepest hydraulic gradient through homogenous and isotropic conditions (Fetter, 2001).

The recharge line is drawn in the linear up-slope direction perpendicular to topographic map elevation contour lines from the spring emergent location on ground surface (daylight location) to its first inflection point; or deviation from a straight line (Figure 6). The author decided to terminate the recharge line at its first inflection point due to the

Figure 6. Schematic Depiction of the Recharge Line for a Spring. Topographic contour intervals are 10ft for the depicted map.

assumptions that 1.) most springs in the Appalachian Plateau physiographic province occur along fractures and 2.) fractures, whether stress-relieved or tectonic, are linear.

The recharge line is a linear representation akin to the main stem of a tributary stream within a dendritic surface drainage system. The length, vertical relief, and gradient (percentage slope) of the recharge line were measured from USGS 7'30" quadrangle maps and the spring geographic location maps provided by the coal company. Due to the researcher's length measurements using an engineer rule and the 10ft topographic contour spacing inherent to USGS quadrangle maps, the errors associated with recharge line length, vertical relief, and gradient were assumed to be +/-10ft, +/-5ft, and +/-5.5 percent, respectively. The assumed gradient error of +/-5.5 percent was derived from the use of the averaged values of all the measured recharge line lengths and vertical reliefs in Appendix B.

4.2.2 Spring Proximity to Nearest Surface Drainage Feature

A spring's pre-mining proximity to the nearest surface drainage feature is equal to the shortest horizontal and vertical distance discharge water from a spring would travel on ground surface to the nearest surface drainage feature shown on the USGS 7'30" quadrangle maps (Figure 7). The stream order of each surface drainage feature was evaluated. Vertical relief and gradient to the nearest surface drainage features were measured from USGS 7'30" quadrangle maps and the spring geographic location maps

Figure 7. Schematic Depiction of the Gradient Line from Spring Location to the Nearest Surface Drainage Feature. Topographic contour intervals are 10ft for the depicted map.

provided by the coal company. Due to the researcher's length measurements using an engineer rule and the 10ft topographic contour spacing inherent to USGS quadrangle maps, the errors associated with a spring's horizontal and vertical distances to the nearest stream were assumed to be +/- 10ft and +/-5ft, respectively.

4.2.3 Spring Elevation

The pre-mining elevations of the springs at their daylight locations were identified through interpolation of USGS 7'30" quadrangle maps. The error associated with pre-mining elevations of the springs was assumed to be +/-5ft.

4.2.4 Overburden Thickness

Overburden thickness was determined from subtraction of the bottom of coal elevation directly beneath the spring, as determined by coal structural contour maps, from the daylight elevation of the spring. The error associated with overburden thickness was assumed to be +/-5ft.

4.2.5 Longwall Width-Depth Ratio

The width-depth ratio was calculated for springs located above mined longwall panels. The width of the mined longwall panel is the measured panel width perpendicular to the panel length between the closest ribs, or walls, of the support pillars between the headgate and tailgate submain developments paralleling the longwall panel. The ratio was determined from division of the measured longwall panel width by the panel

overburden thickness previously calculated for the springs. The error associated with width-depth ratio was assumed to be ± 0.16 (unitless). The assumed width-depth ratio of ± 0.16 was derived from the use of the ± 5 ft error associated with the overburden thickness and ± 10 ft error associated with the researcher's panel width measurements using an engineer rule. The errors were applied to the minimum and maximum calculated width-depth ratios in Appendix B to determine the maximum error that could be introduced.

4.2.6 Spring Location Above a Longwall Panel

The surface trace position of a spring above a longwall panel was determined from the width of the longwall panel and the lateral edge distance the spring is from the surface trace of the closest rib of the support pillars within the tailgate / headgate submain developments paralleling the longwall panel for the eastern / western blocks. The position above the longwall panel was determined from division of the measured lateral edge distance by the longwall panel width. The error associated with the surface trace position was assumed to be ± 0.02 (unitless). The assumed surface trace position error was derived from the use of the ± 10 ft error associated with the researchers panel width and length measurements using an engineer rule. The errors were applied to the minimum and maximum calculated surface trace positions in Appendix B to determine the maximum error that could be introduced.

5.0 GENERAL METHODS OF STATISTICAL ANALYSIS

The investigative sequence used to document and evaluate spring flow responses associated with underground longwall mine subsidence has been dissected into four separate investigations for the purpose of determining if an increase in the discrimination of data through more sophisticated approaches would yield better data trends and results than through the use of the simplest approach. These investigations, I through IV, are presented in chronological order of completion. The methodologies inherent to the more sophisticated investigations are reflections of the results from previous investigations. The dependent variable data, spring discharge, and the independent variable data, such as overburden thickness, were statistically examined to determine if basic, fundamental data trends exist.

The research itself focused entirely on spring discharge impairment trends. Apparent data trends were statistically examined to determine which independent variables were statistically significant at the appropriate alpha level of significance for the chi-square and Fisher exact probability contingency statistical tests used. The methodology was revised three times in an effort to discriminate the data more effectively. Boundary conditions to discern between naturally-occurring changes in spring discharge from mining-induced changes to spring discharge were eventually introduced to the research as a tool to evaluate more effectively the ‘gray area springs’ or springs with an indeterminate hydrologic response to subsidence as evident in the spring discharge hydrographs. In addition, seasonal evapotranspiration condition and precipitation were

evaluated to discern between spring discharge impairment trends during low and high periods of evapotranspiration between deficit and surplus departures from the 30-yr average normal precipitation.

5.1 Statistical Examination

Statistical tests are used to establish and determine basic data trends between two variables in a simple statistical manner. There are two types of statistical tests that could be used to identify data trends - parametric and nonparametric.

Parametric statistical testing was not considered for this study because it involves assumptions, such as normally distributed interval or ratio data, of the data that were not relevant to this study.

The existing data were randomly chosen by the coal company for this research and therefore, are a representative sample population of all the target population springs located within the research study area. In addition, the intent of the statistical examination involved the comparison of the statistical tests computed probability of error, associated with the trend relationship between spring discharge and the independent variables, to the alpha level of significance specific to the statistical test strength. This comparison would not have been reliable if parametric statistical testing had been done due to the nature of the tested data.

Nonparametric statistical tests were chosen for this study because they do not make assumptions for the type of data used, such as nominal, ordinal, interval, or ratio data. Nonparametric statistical tests apply the contingency test approach, which is applicable to all four types of data. Nonparametric statistical tests are more conservative than parametric statistical tests, and are more reliable for determining basic data trends. In addition, the dependent variable data (spring discharge) are noisy; that is, the spring discharge data are influenced by recent precipitation, seasonal evapotranspiration condition, degree and type of spring construction and development. Therefore, the use of a simpler statistical testing approach was warranted.

Nonparametric statistical testing was used to determine the hydrologic, geologic, topographic, and mine-specific independent variables that are statistically related to (show data trends with) mining-induced changes to spring discharge. The following testing procedures were applied to each independent variable:

- Median Contingency Test
- Chi Square Contingency Test
- Fisher Exact Probability Contingency Test

5.1.1 Median Contingency Test

The median contingency test procedure was used to determine if the two independent spring data groups differed in central tendencies; more specifically, if differences between the two independent groups could be drawn from a population with the same median value (Siegel, 1956). For example, springs that were concluded to be flow

impaired by mining-induced subsidence were compared to springs that were concluded to not be affected by mining-induced subsidence. These two groups were then compared to an independent variable, such as overburden thickness (Figure 8).

	Group 1	Group 2	Total
# of Springs $\geq$ Overburden Thickness Median	A	B	A+B
# of Springs $<$ Overburden Thickness Median	C	D	C+D
	A+C	B+D	

where, Group 1, springs whose discharge was impaired by mining-induced subsidence, and Group 2, springs whose discharge was not affected by mining-induced subsidence, are the independent spring data groups.

Figure 8: Conceptual Example of a 2x2 Contingency Table Test Using Overburden Thickness as the Independent Variable.

The median test procedure resulted in the formulation of one of three hypotheses – null (no space relationship), alternative (direct relationship), and alternative (inverse relationship), through the use of the contingency table approach (Figure 9). If the author judged that moderate to strong data trends, either alternative (direct) or alternative (inverse), were apparent within the frequency distribution, Chi square contingency and Fisher exact probability statistical tests were computed.

Figure 9(a): Example of Null Hypothesis Categorical Distribution

	Group 1	Group 2
# of Springs $\geq$ Overburden Thickness Median	4	5
# of Springs $<$ Overburden Thickness Median	5	4

Figure 9(b): Example of Alternative (Direct) Hypothesis Categorical Distribution

	Group 1	Group 2
# of Springs $\geq$ Overburden Thickness Median	4 10	3
# of Springs $<$ Overburden Thickness Median	2	4 9

Figure 9(c): Example of Alternative (Inverse) Hypothesis Categorical Distribution

	Group 1	Group 2
# of Springs $\geq$ Overburden Thickness Median	1	7 7
# of Springs $<$ Overburden Thickness Median	6 6	2

Figure 9: Conceptual Example of the Three Possible Hypotheses Related to the 2x2 Contingency Table Tests Using Overburden Thickness as the Independent Variable.

5.1.2 Chi Square Contingency Test

The hypothesis under test was conducted using the Chi square 2 x 2 contingency table, as previously discussed (Siegel, 1956). The testing hypothesis, or alternative hypothesis, was that the two dependent spring groups defined by spring discharge differed with respect to some independent variable, such as overburden thickness, and therefore with respect to the spring frequency associated with each contingency table category. For example, overburden thickness for springs whose discharge was impaired by mining-induced subsidence was less than the overburden thickness for springs whose discharge was not affected by mining-induced subsidence. The null hypothesis was that the two independent groups did not differ with respect to some variable, such as overburden thickness, and therefore with respect to the frequency associated with each table category. For example, overburden thickness for springs whose discharge was impaired by mining-

induced subsidence was equal to the overburden thickness for springs whose discharge was not affected by mining-induced subsidence.

The Chi square value, X^2 , was determined from a published Chi square distribution table under one degree of freedom. The Chi square value was calculated using Equation 1 (Siegel, 1956). The higher the X^2 value, the more likely a significant data trend exists. An alternative hypothesis was accepted if the probability of error (p) was less than the 0.20 alpha significance level. An alternative hypothesis was rejected if the calculated probability of error was greater than 0.20 alpha. Essentially, the computed probability of error relative to alpha 0.20 either caused acceptance or rejection of the null hypothesis (test of equal distribution). The 0.20 alpha was used because of the conservative nature of this statistical test.

$$X^2 \text{ (at df=1)} = \frac{N(\text{abs}[AD-BC] - N/2)^2}{(A+B)(C+D)(A+C)(B+D)} \quad \text{Equation 1}$$

5.1.3 Fisher Exact Probability Contingency Test

The Fisher exact probability test was used in conjunction with the Chi square contingency test. The Fisher exact probability test computes the probability of error for a data trend of the counted frequency distribution using the same Chi square 2 x 2 contingency table approach. The Fisher exact probability was calculated using Equation 2 (Siegel, 1956). Fisher exact probability tests involve Equation 2 computations for

probability of error values for each data trend scenario, as extreme or more extreme than that identified in the 2 x 2 table. The cumulative final probability of error is the sum of all the data trend scenario probabilities.

$$p = \frac{(A+B)!(C+D)!(A+C)!(B+D)!}{N!A!B!C!D!} \quad \text{Equation 2}$$

An alternative hypothesis using the Fisher exact probability test was accepted if the calculated cumulative probability of error was less than 0.10 alpha. An alternative hypothesis was rejected (and the null hypothesis was accepted) if the probability of error was greater than 0.10 alpha. The Fisher exact probability test is more powerful than the Chi square contingency test; therefore, its alpha level of significance is less. This is evident in Equation 1, for Chi Square, where the ‘N/2’ term makes this test more conservative and weaker, to remove the bias of small numbers from the contingency table. This conservative factor is not used or needed for calculation of the Fisher exact probability.

5.1.4 Guidelines Used for Apparent Data Trend Testing

Chi square contingency and Fisher exact probability tests yield different probability of error values for apparent 2 x 2 data table trends. The Chi square probability test results in a range of probability of error values, and is a more conservative test. The Fisher exact probability test is statistically more powerful than the Chi square test and results in an exact calculated probability of error that can be compared more directly to alpha. Due to

the ease of probability computation, Fisher exact probability tests were evaluated for all variable data trends that had a calculated X^2 of 0.50 or greater. Also, Chi square probability tests are not reliable for sample populations (A+B+C+D) less than 20 (Siegel, 1956), which was the case for most data trends examined within this study. Therefore, Fisher exact probability tests were conducted for all apparent data trends.

6.0 INVESTIGATION I

6.1 Methods of Investigation I

The methodology used to evaluate the relationship of the known and predicted hydrologic, geologic, topographic, and mine-specific independent variables to mining-induced spring discharge impairment involved the following steps:

1. Prepare spring discharge hydrographs to evaluate for possible changes to spring discharge across a mined panel subsidence event through the seasonal comparison of pre-mine and post-mine spring discharge data.
2. Statistically examine the categorical distribution of spring response relative to the timing of mining-induced subsidence through the calculated median values of the hydrologic, geologic, topographic, and mine-specific independent variables to determine statistical association of these variables.

6.1.1 Spring Discharge Hydrograph Interpretation

Spring discharge hydrographs (discharge versus time data plots) were drafted to help determine if spring discharge changed due to a local mining-induced subsidence event. The discharge hydrographs were qualitatively examined through seasonal comparison (same season per-mining versus post-mining) across the subsidence event to determine apparent spring discharge response to the subsidence event. See Appendix A for these data plots.

Three qualitative discharge response scenarios were used for this initial investigation; impaired, unaffected, and indeterminate (Table 1). Spring discharge responses were considered to be impaired due to mine subsidence if the spring did not flow after mining occurred. Spring discharge responses were considered unaffected if the discharge rates and frequency observed during post-mine monitoring mimicked the discharge rates and frequency observed during the pre-mine monitoring data collection period. Springs that had a partial reduction in discharge rate and/or frequency between pre-mine and post-mine monitoring were considered to have an indeterminate response to the subsidence event that may have been caused by the subsidence or related to a naturally-occurring variable.

6.2 Results from Investigation I

6.2.1 Spring Discharge Response

A total of 77 spring discharge hydrographs were drafted to assess spring discharge response to mining-induced subsidence. A total of 29 springs, or 38% of the sample population, yielded indeterminate (equivocal) evidence as to whether the observed changes in spring discharge were due to naturally occurring circumstances or mining-induced change resultant from the effects of recent subsidence. Of the remaining springs, spring discharge response for 15 (20%) was unaffected and for 25 (32%) discharge was impaired. Eight springs, or 10%, were omitted from the investigation due to lack of sufficient data needed for seasonal comparison across the subsidence event.

Table 1: Results of Spring Discharge Hydrograph Interpretation as Discussed in Methods of Investigation I.

Spring No.	Spring Discharge Response	Spring No.	Spring Discharge Response
32	Unaffected	41	Impaired
33	Unaffected	63	Impaired
52	Unaffected	64	Impaired
78	Unaffected	83	Impaired
79	Unaffected	84	Impaired
99	Unaffected	90	Impaired
102	Unaffected	94	Impaired
118	Unaffected	101	Impaired
183	Unaffected	155	Impaired
253	Unaffected	157	Impaired
266	Unaffected	162	Impaired
268	Unaffected	165	Impaired
269	Unaffected	166	Impaired
271	Unaffected	167	Impaired
297	Unaffected	173	Impaired
38	Indeterminate Impairment	174	Impaired
39	Indeterminate Impairment	199	Impaired
43	Indeterminate Impairment	248	Impaired
44	Indeterminate Impairment	249	Impaired
91	Indeterminate Impairment	254	Impaired
92	Indeterminate Impairment	259	Impaired
93	Indeterminate Impairment	263	Impaired
97	Indeterminate Impairment	272	Impaired
99a	Indeterminate Impairment	54	Omitted
102a	Indeterminate Impairment	79a	Omitted
106	Indeterminate Impairment	154	Omitted
107	Indeterminate Impairment	177	Omitted
152	Indeterminate Impairment	224	Omitted
169	Indeterminate Impairment	260	Omitted
170	Indeterminate Impairment	261	Omitted
171	Indeterminate Impairment	262	Omitted
175	Indeterminate Impairment		
176	Indeterminate Impairment		
179	Indeterminate Impairment		
198	Indeterminate Impairment		
216	Indeterminate Impairment		
226	Indeterminate Impairment		
256	Indeterminate Impairment		
258	Indeterminate Impairment		
265	Indeterminate Impairment		
267	Indeterminate Impairment		
270	Indeterminate Impairment		
273	Indeterminate Impairment		
274	Indeterminate Impairment		
35	Impaired		
36	Impaired		

The following procedure was used to examine the 29 springs that had an indeterminate response to subsidence. The implementation of this procedure permitted the statistical examination of the entire sample population minus the springs omitted due to lack of data.

The median values of the hydrologic, geologic, topographic, and mine-specific independent variables for each of the spring discharge response categories - discharge impaired, unaffected, and indeterminate, were calculated. These median values were compared to determine if the indeterminate response category would be added to the discharge impaired or unaffected response categories. The rationale for this procedure assumes the hydrologic, geologic, topographic, and mine-specific independent variables are associated with spring discharge response.

The 29 springs that had an indeterminate response to subsidence were included in the statistical investigation based on the median values associated with the variables. The discharge impaired response category was supplemented with the 29 indeterminate response category springs if the median value calculated for the indeterminate response category was arithmetically closer to the median value calculated for the discharge impaired response category than the median value calculated for the unaffected response category, and vice versa. Essentially, the 29 springs comprising the indeterminate response category were supplemented to either the discharge impaired or unaffected response categories according to the calculated median values.

6.2.2 Spring Discharge Response Statistical Examination (Median Value)

The results from the Chi square contingency and Fisher exact probability statistical examination of spring discharge response are provided in Table 2. The variables were examined for statistical significance of data trends through the use of the calculated median values and the contingency table approach (Figure 10).

	Impaired	Unaffected	Total
Counted Frequency $\geq$ Combined Median	A	B	A+B
Counted Frequency $<$ Combined Median	C	D	C+D
	A+C	B+D	

where, the indeterminate discharge response category springs were supplemented to the impaired or unaffected discharge response category based upon median value comparison and

A is the number of impaired springs $\geq$ to the calculated median value
B is the number of unaffected springs $\geq$ to the calculated median value
C is the number of impaired springs $<$ the calculated median value
D is the number of unaffected springs $<$ the calculated median value.

Figure 10: 2x2 Contingency Table Test Used for Investigation I.

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for recharge line length, recharge line vertical relief, and recharge line gradient. The significant alternative hypothesis statements are as follows.

- Spring discharge impairment is associated with recharge line length greater than or equal to the calculated median value of 219 feet (+/- 10ft).

Table 2: Results from Methods of Investigation I. Chi Square Contingency and Fisher Exact Probability Test Results Evaluated with the Calculated Median Values.

Parameter	N	H _{alternate}	Chi Square Contingency Test			Fisher Exact Probability Test				
			Error	Chi-Square Value	Indeterminate Springs	A	B	C	D	P _{error}
Overburden Thickness	69	<425	+/-5ft	0.58807	Σ w/ Unaffected Springs	10	26	13	20	0.22164
Width-Depth Ratio	69	>=1.89	+/-0.16	0.06534	Σ w/ Unaffected Springs	13	23	10	23	0.39977
Recharge Line Length	69	>=219	+/-10ft	5.37404	Σ w/ Unaffected Springs	18	21	5	25	0.00921
Recharge Line Vertical Relief	69	>=35	+/-5ft	16.01061	Σ w/ Unaffected Springs	20	15	3	31	1.72812 x10⁻³
Recharge Line Gradient	69	>=19	+/-5.5%	3.59434	Σ w/ Impaired Springs	13	24	4	28	0.02741
Vertical Relief to Nearest Surface Drainage Features	69	<55	+/-5ft	0.35515	Σ w/ Unaffected Springs	13	21	10	25	0.27579
Vertical Relief to Headwater Drainage Features	60	<57.5	+/-5ft	0.07500	Σ w/ Unaffected Springs	11	19	9	21	0.39232
Vertical Relief to First Order Drainage Features	49	<55	+/-5ft	0.01896	Σ w/ Impaired Springs	4	19	6	20	0.44733
Vertical Relief to Second Order Drainage Features	11	<80	+/-5ft	na	Orited	2	2	2	5	0.46970
Position Above Longwall Panel	64	<0.25, >=0.75	+/-0.02	0.05224	Σ w/ Impaired Springs	8	28	6	22	0.59276
Gradient to Nearest Surface Drainage Features	69	>=18.96%	+/-5.5%	0.18120	Σ w/ Unaffected Springs	10	24	13	22	0.33566
Pre-Mine Spring Daylight Elevation	69	<1185	+/-5ft	0.58807	Σ w/ Unaffected Springs	9	24	14	22	0.22196

Key

- A: number of impaired springs >= to the calculated median value
 B: number of unaffected springs >= to the calculated median value
 C: number of impaired springs < to the calculated median value
 D: number of unaffected springs < to the calculated median value
 na: statistical test not applicable

- Spring discharge impairment is associated with recharge line relief greater than or equal to the calculated median value of 35 feet (+/- 5ft).
- Spring discharge impairment is associated with recharge line gradient greater than or equal to the calculated median value of 19 percent (+/- 5.5 percent).

The use of Chi square contingency tests resulted in calculated error probabilities of 0.05-0.02, <0.001, and 0.10-0.05, respectively for the above alternative hypotheses. The use of Fisher exact probability tests resulted in calculated error probabilities of 0.00921, $1.728 \times 10^{(-5)}$, and 0.02741, respectively. The remaining alternative hypotheses examined for the variables were rejected by the Chi square contingency and Fisher exact probability tests.

Based upon the statistical results, the use of recharge line length, recharge line vertical relief, and recharge line gradient resulted in 99 percent, 99 percent, and 97 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for these respective independent variables.

7.0 INVESTIGATION II

7.1 Methods of Investigation II

The methodology used in Investigation I permitted an initial examination of spring discharge response to mining-induced subsidence through the evaluation of known and predicted variables; however, the methodology did not account for the degree of spring discharge impairment. The methodology used in Investigation II uses the same methodology as used in Investigation I to address this issue but redefines the spring response categories. Qualitative spring response categories were defined in order to discern among permanently impaired springs, temporarily impaired springs, background low flow discharge impaired springs, and unaffected springs through statistical examination of the variables.

Spring discharge responses were considered permanently impaired if the spring did not flow after mining occurred. Spring discharge responses were considered temporarily impaired if post-mine monitoring visitations initially consisted of no flow observations and spring discharge recovered, partially or totally, during the post-mine monitoring data collection period. Spring discharge responses were considered background low flow discharge impaired if observations indicated a partial reduction in low flow discharge across the subsidence event. Spring discharge responses were considered unaffected if the discharge rates and frequency observed during post-mine monitoring mimicked the discharge rates and frequency observed during the pre-mine monitoring data collection period.

In addition, springs were evaluated according to mining environment. The following groups were evaluated to determine statistical significance of the variables.

- All springs
- Springs located directly above longwall panels
- Springs located directly above main and submain mine development sections
- Springs located directly above the off panel mining environment (over unmined coal)
- Springs located within the Subsidence Control Plan Area (SCPA) which is within the permit boundaries

7.2 Results of Investigation II

7.2.1 Spring Discharge Response

Of the 77 springs, data from 63 springs were used to assess the degree of spring discharge response to mining-induced subsidence (Table 3). Fourteen springs were omitted from the statistical examination; of these, six springs continued to yield indeterminate response to mining-induced subsidence and eight springs were omitted due to lack of data needed for seasonal comparison across the subsidence event.

Spring discharge response showed that 46 (73%) of the 63 springs were impaired and 17 (27%) of the springs were unaffected. Of the 46 impaired springs, 25 springs (54%) were permanently impaired through the duration of the post-mine monitoring program which typically lasts 2 years, 17 springs (37%) were temporarily impaired (for an average of 5.6 months, Table 3), and four springs (9%) had reduction in background low flow discharge.

Table 3: Results of Spring Discharge Hydrograph Interpretation as Discussed in Methods of Investigation II.

Spring No.	Spring Discharge Response	Extent of Temporary Impairment (months)	Spring No.	Spring Discharge Response
35	Permanently Impaired		32	Unaffected
36	Permanently Impaired		33	Unaffected
41	Permanently Impaired		52	Unaffected
63	Permanently Impaired		78	Unaffected
64	Permanently Impaired		79	Unaffected
83	Permanently Impaired		99	Unaffected
84	Permanently Impaired		102	Unaffected
90	Permanently Impaired		118	Unaffected
94	Permanently Impaired		170	Unaffected
101	Permanently Impaired		171	Unaffected
155	Permanently Impaired		183	Unaffected
157	Permanently Impaired		253	Unaffected
162	Permanently Impaired		266	Unaffected
166	Permanently Impaired		269	Unaffected
167	Permanently Impaired		297	Unaffected
173	Permanently Impaired		268	Unaffected
174	Permanently Impaired		271	Unaffected
179	Permanently Impaired		93	Indeterminate Impairment
199	Permanently Impaired		99a	Indeterminate Impairment
248	Permanently Impaired		107	Indeterminate Impairment
249	Permanently Impaired		198	Indeterminate Impairment
254	Permanently Impaired		216	Indeterminate Impairment
259	Permanently Impaired		273	Indeterminate Impairment
263	Permanently Impaired		54	Omitted
272	Permanently Impaired		79a	Omitted
92	Reduction in Low Flow Discharge		154	Omitted
152	Reduction in Low Flow Discharge		177	Omitted
169	Reduction in Low Flow Discharge		224	Omitted
265	Reduction in Low Flow Discharge		260	Omitted
38	Temporary Impaired	10	261	Omitted
39	Temporary Impaired	8	262	Omitted
43	Temporary Impaired	4		
44	Temporary Impaired	9		
91	Temporary Impaired	3		
97	Temporary Impaired	5		
106	Temporary Impaired	1		
165	Temporary Impaired	2		
175	Temporary Impaired	4		
176	Temporary Impaired	3		
226	Temporary Impaired	9		
256	Temporary Impaired	11		
258	Temporary Impaired	6		
267	Temporary Impaired	6		
270	Temporary Impaired	4		
274	Temporary Impaired	9		
102a	Temporary Impaired	2		

7.2.2 Spring Discharge Response Statistical Examination (Median Value)

The results from the Chi square contingency and Fisher exact probability statistical examinations of spring discharge response data are provided in Tables 4 through 8, according to mining environment. The variables were examined for statistically significant data trends through the use of the calculated median values and the contingency table approach (Figure 11).

	Impaired	Unaffected	Total
Counted Frequency $\geq$ Combined Median	A	B	A+B
Counted Frequency $<$ Combined Median	C	D	C+D
	A+C	B+D	

where, A is the number of impaired springs $\geq$ to the calculated median value
B is the number of unaffected springs $\geq$ to the calculated median value
C is the number of impaired springs $<$ the calculated median value
D is the number of unaffected springs $<$ the calculated median value.

Figure 11: 2x2 Contingency Table Test Used for Investigation II.

7.2.2.1 All Springs (see Table 4)

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for recharge line length, recharge line vertical relief, and recharge line gradient for these springs. The significant alternative hypothesis statements are as follows:

- Spring discharge impairment is associated with recharge line length greater than or equal to the calculated median value of 219 feet (+/- 10ft).

Table 4: Results from Methods of Investigation II. Chi Square Contingency and Fisher Exact Probability Test Results for All Springs Evaluated with the Calculated Median Values.												
Parameter		N	H _{alternate}	Chi Square Contingency Test			Fisher Exact Probability Test					
				Error	Chi-Square Value	P _{uncor}	A	B	C	D	P _{uncor}	
Overburden Thickness	(ft)	63	<425	+/-5ft	0.00101	0.98-0.95	9	26	8	20		0.51061
Width-Depth Ratio	(unitless)	58	>1.88	+/-0.16	0.09416	0.80-0.70	7	22	7	22		0.62009
Recharge Line Length	(ft)	63	>219	+/-10ft	5.36648	0.05-0.02	14	21	3	25		0.00883
Recharge Line Vertical Relief	(ft)	63	>140	+/-5ft	11.96456	<0.001	16	19	1	27		0.00012
Recharge Line Gradient	(% slope)	63	>19	+/-5.5%	4.17479	0.05-0.02	13	20	4	26		0.01927
Vertical Relief to Nearest Surface Drainage Features	(ft)	63	<55	+/-5ft	0.05292	0.90-0.80	9	21	8	25		0.40851
Vertical Relief to Headwater Drainage Features	(ft)	54	<55	+/-5ft	0.02239	0.90-0.80	7	19	7	21		0.55849
Vertical Relief to First Order Drainage Features	(ft)	43	<40	+/-5ft	0.07679	0.90-0.80	5	17	5	16		0.60798
Vertical Relief to Second Order Drainage Features	(ft)	11	<80	+/-5ft	na	na	2	2	2	5		0.46970
Position Above Longwall Panel	(unitless)	58	<0.24, >19	+/-0.02	0.08320	0.80-0.70	8	25	6	19		0.61576
Gradient to Nearest Surface Drainage Features	(% slope)	63	>19	+/-5.5%	0.00587	0.95-0.90	8	23	9	23		0.53072
Pre-Mine Spring Daylight Elevation	(ft)	63	<1185	+/-5ft	0.24122	0.70-0.50	7	24	10	22		0.31228
Key												
A: number of impaired springs >19 to the calculated median value												
B: number of unaffected springs >19 to the calculated median value												
C: number of impaired springs < the calculated median value												
D: number of unaffected springs < the calculated median value												
na: statistical test not applicable												

- Spring discharge impairment is associated with recharge line relief greater than or equal to the calculated median value of 40 feet (+/- 5ft).
- Spring discharge impairment is associated with recharge line gradient greater than or equal to the calculated median value of 19 percent (+/- 5.5 percent).

The use of Chi square contingency tests resulted in calculated error probabilities of 0.05-0.02, <0.001, and 0.05-0.02, respectively, for the above data trends. The use of Fisher exact probability tests resulted in calculated error probabilities of 0.00883, 0.00011, and 0.01926, respectively. The remaining alternative hypotheses examined for the variables were rejected by the Chi square contingency and Fisher exact probability tests.

Based upon the statistical results, the use of recharge line length, relief, and gradient resulted in 99 percent, 99 percent, and 98 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for these respective independent variables.

7.2.2.2 Springs Located Above Longwall Panels (see Table 5)

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for recharge line vertical relief and recharge line gradient for these springs. The significant alternative hypothesis statements are as follows:

- Spring discharge impairment is associated with recharge line relief greater than or equal to the calculated median value of 40 feet (+/- 5ft).

Table 5: Results from Methods of Investigation II. Chi Square Contingency and Fisher Exact Probability Test Results for Springs Located Above Longwall Panels Evaluated with the Calculated Median Values.												
Parameter	Chi Square Contingency Test				Fisher Exact Probability Test							
	N	H _{alternate}	Error	Chi-Square Value	P _{error}	A	B	C	D	P _{error}		
Overburden Thickness	45	<425	+/-5ft	0.14063	0.80-0.70	6	19	3	17	0.35761		
Width-Depth Ratio	45	>1.87	+/-0.16	0.00556	0.95-0.90	4	19	5	17	0.46981		
Recharge Line Length	45	>1.250	+/-10ft	0.45022	0.70-0.50	6	17	3	19	0.25243		
Recharge Line Vertical Relief	45	>1.40	+/-5ft	4.06808	0.05-0.02	8	16	1	20	0.01890		
Recharge Line Gradient	45	>1.19	+/-5.5%	2.55208	0.20-0.10	8	19	1	17	0.05038		
Vertical Relief to Nearest Surface Drainage Features	45	<55	+/-5ft	0.05022	0.90-0.80	4	17	5	19	0.59000		
Vertical Relief to Headwater Drainage Features	39	<55	+/-5ft	0.09942	0.80-0.70	3	16	5	15	0.37791		
Vertical Relief to First Order Drainage Features	31	<45	+/-5ft	0.13455	0.80-0.70	2	13	4	12	0.35941		
Vertical Relief to Second Order Drainage Features	8	<80	+/-5ft	na	na	1	2	1	4	0.64286		
Position Above Longwall Panel	45	<0.24, >1.76	+/-0.02	0.45022	0.70-0.50	6	17	3	19	0.25243		
Gradient to Nearest Surface Drainage Features	45	>1.19	+/-5.5%	0.45022	0.70-0.50	3	19	6	17	0.25243		
Pre-Mine Spring Daylight Elevation	45	<1185	+/-5ft	0.00556	0.95-0.90	4	18	5	18	0.53019		
Key												
A: number of impaired springs >1.25 to the calculated median value												
B: number of unaffected springs >1.25 to the calculated median value												
C: number of impaired springs < the calculated median value												
D: number of unaffected springs < the calculated median value												
na: statistical test not applicable												

Spring discharge impairment is associated with recharge line gradient greater than or equal to the calculated median value of 19 percent (+/- 5.5 percent).

The use of Chi square contingency tests resulted in calculated error probabilities of 0.05-0.02 and 0.20-0.10, respectively, for the above data trends. The use of Fisher exact probability tests resulted in calculated error probabilities of 0.01890 and 0.05038, respectively. The remaining alternative hypotheses examined for the variables were rejected by the Chi square contingency and Fisher exact probability tests. Based upon the statistical results, the use of recharge line relief and gradient resulted in 98 percent and 95 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for these respective independent variables.

7.2.2.3 Springs Located Above Main and Submain Development (see Table 6)

Nonparametric statistical tests resulted in rejection of all the alternative hypotheses for these springs, therefore, there are no statistically significant relationships between spring impairment and the independent variables for springs located above main and submain development environments.

7.2.2.4 Springs Located Within Off Panel Mining Environments (see Table 7)

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for recharge line vertical relief for these springs. This significant alternative hypothesis statement is as follows:

Table 6: Results from Methods of Investigation II. Chi Square Contingency and Fisher Exact Probability Test Results for Springs Located Above Main and Submain Development Evaluated with the Calculated Median Values.											
Parameter	N	H _{alternate}	Chi Square Contingency Test			Fisher Exact Probability Test					
			Error	Chi-Square Value	P _{error}	A	B	C	D	P _{error}	
Overburden Thickness (ft)	10	<400	+/-5ft	na	na	1	5	1	3	0.66667	
Width-Depth Ratio (unitless)	7	>=2.23	+/-0.16	na	na	0	4	0	3	1.00000	
Recharge Line Length (ft)	10	>=188	+/-10ft	na	na	1	5	1	3	0.66667	
Recharge Line Vertical Relief (ft)	10	>=42.5	+/-5ft	na	na	2	3	0	5	0.22222	
Recharge Line Gradient (% slope)	10	>=23	+/-5.5%	na	na	1	3	1	5	0.66667	
Vertical Relief to Nearest Surface Drainage Features (ft)	10	<83	+/-5ft	na	na	1	1	1	7	0.37778	
Vertical Relief to Headwater Drainage Features (ft)	9	<25	+/-5ft	na	na	1	2	1	5	0.58333	
Vertical Relief to First Order Drainage Features (ft)	8	<25	+/-5ft	na	na	1	2	1	4	0.89286	
Vertical Relief to Second Order Drainage Features (ft)	1	na	+/-5ft	na	na	na	na	na	na	na	
Gradient to Nearest Surface Drainage Features (% slope)	10	>=18	+/-5.5%	na	na	1	4	1	4	0.77778	
Pre-Mne Spring Daylight Elevation (ft)	10	<185	+/-5ft	na	na	1	5	1	3	0.66667	
Key											
A: number of impaired springs >= to the calculated median value											
B: number of unaffected springs >= to the calculated median value											
C: number of impaired springs < the calculated median value											
D: number of unaffected springs < the calculated median value											
na: statistical test not applicable											

Table 7: Results from Methods of Investigation II. Chi Square Contingency and Fisher Exact Probability Test Results for Springs Located Within Off Panel Mining Environments Evaluated with the Calculated Median Values.												
Parameter	Chi Square Contingency Test				Fisher Exact Probability Test							
	N	H _{alternate}	Error	Chi-Square Value	P _{error}	A	B	C	D	P _{error}		
Overburden Thickness	8	<420	+/-5ft	na	na	2	1	4	1	0.64286		
Width-Depth Ratio	6	>=1.98	+/-0.16	na	na	3	0	2	1	0.50000		
Recharge Line Length	8	>=125.5	+/-10ft	na	na	4	0	2	2	0.21429		
Recharge Line Vertical Relief	8	>=30	+/-5ft	na	na	6	0	0	2	0.03571		
Recharge Line Gradient	8	>=20	+/-5.5%	na	na	4	0	2	2	0.21429		
Vertical Relief to Nearest Surface Drainage Features	8	<77.5	+/-5ft	na	na	3	1	3	1	0.78571		
Vertical Relief to Headwater Drainage Features	6	<87.5	+/-5ft	na	na	2	1	2	1	0.80000		
Vertical Relief to First Order Drainage Features	4	<87.5	+/-5ft	na	na	1	1	1	1	0.83333		
Vertical Relief to Second Order Drainage Features	2	<87.5	+/-5ft	na	na	1	0	1	0	1.00000		
Gradient to Nearest Surface Drainage Features	8	>=21	+/-5.5%	na	na	4	0	2	2	0.21429		
Pre-Mine Spring Daylight Elevation	8	<1207.5	+/-5ft	na	na	3	1	3	1	0.78571		
Key												
A: number of impaired springs >= to the calculated median value												
B: number of unaffected springs >= to the calculated median value												
C: number of impaired springs < the calculated median value												
D: number of unaffected springs < the calculated median value												
na: statistical test not applicable												

- Spring discharge impairment is associated with recharge line relief greater than or equal to the calculated median value of 30 feet (+/- 5ft).

The use of the Fisher exact probability test resulted in a calculated error probability of 0.03571. The remaining alternative hypotheses examined for other variables were rejected by the Fisher exact probability tests.

Based upon the statistical results, the use of recharge line relief resulted in a 96 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for this independent variable.

7.2.2.5 Springs Located Within the SCPA Boundary (see Table 8)

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for recharge line length, recharge line vertical relief, and recharge line gradient. The significant alternative hypothesis statements are as follows:

- Spring discharge impairment is associated with recharge line length greater than or equal to calculated median value of 219 feet (+/- 10ft).
- Spring discharge impairment is associated with recharge line relief greater than or equal to the calculated median value of 40 feet (+/- 5ft).
- Spring discharge impairment is associated with recharge line gradient greater than or equal to the calculated median value of 19 percent (+/- 5.5 percent).

The use of Chi square contingency tests resulted in calculated error probabilities of 0.20-0.10, 0.02-0.01, and 0.10-0.05, respectively, for the above data trends. The use of Fisher

Table 8: Results from Methods of Investigation II. Chi Square Contingency and Fisher Exact Probability Test Results for Springs Located Within the SCPA Boundary Evaluated with the Calculated Median Values.

Parameter	Chi Square Contingency Test					Fisher Exact Probability Test				
	N	H _{liberate}	Error	Chi-Square Value	P _{major}	A	B	C	D	P _{major}
Overburden Thickness	(ft)	55	<420	+/-5ft	0.00455	6	22	5	22	0.52723
Width-Depth Ratio	(unitless)	52	>=1.88	+/-0.16	0.00000	4	22	5	21	0.50000
Recharge Line Length	(ft)	55	>=219	+/-10ft	1.64145	8	20	3	24	0.09938
Recharge Line Vertical Relief	(ft)	55	>=40	+/-5ft	6.24130	10	19	1	25	0.00464
Recharge Line Gradient	(% slope)	55	>=19	+/-5.5%	3.32352	9	20	2	24	0.03184
Vertical Relief to Nearest Surface Drainage Features	(ft)	55	<45	+/-5ft	0.04103	5	21	6	23	0.58126
Vertical Relief to Headwater Drainage Features	(ft)	48	<45	+/-5ft	0.04306	4	19	6	19	0.41944
Vertical Relief to First Order Drainage Features	(ft)	39	<40	+/-5ft	0.99420	4	15	4	16	0.68314
Vertical Relief to Second Order Drainage Features	(ft)	9	<80	+/-5ft	na	1	2	1	5	0.58333
Position Above Longwall Panel	(unitless)	52	<0.23, >=0.77	+/-0.02	0.01612	4	21	5	22	0.55140
Gradient to Nearest Surface Drainage Features	(% slope)	55	>=19	+/-5.5%	0.36830	4	23	7	21	0.27305
Pre-Mine Spring Daylight Elevation	(ft)	55	<1185	+/-5ft	0.00455	5	23	6	21	0.47277

Key

A: number of impaired springs >/= to the calculated median value
B: number of unaffected springs >/= to the calculated median value
C: number of impaired springs < the calculated median value
D: number of unaffected springs < the calculated median value
na: statistical test not applicable

exact probability tests resulted in calculated error probabilities of 0.09938, 0.00464, and 0.03184, respectively. The remaining alternative hypotheses examined for all other variables were rejected by the Chi square contingency and Fisher exact probability tests.

Based upon the statistical results, the use of recharge line length, relief, and gradient resulted in 90 percent, 99 percent, and 97 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for these respective independent variables.

8.0 INVESTIGATION III

8.1 Methods of Investigation III

The methodology of Investigations I and II permitted the initial evaluation of spring discharge response to mining-induced subsidence events through the use of median values calculated for hydrologic, geologic, topographic, and mine-specific independent variables but did not account for natural variations in evapotranspiration seasonal conditions and precipitation. The methodology used for Investigation III examined these natural seasonal conditions and applied techniques to control for their respective influence on spring discharge. In addition, the methodology for Investigation III removed the subjectivity inherent to interpretation of spring discharge hydrographs. Spring discharge responses were derived from the existing spring discharge data.

8.1.1 Quantitative Evaluation of Spring Discharge Data

Previous investigations, I and II, used qualitative (categorical) analysis to determine spring discharge data trends. Discharge, Q , graphs were drafted for Investigation III to determine if spring discharge data trends were apparent between the pre-mining discharge data and post-mining discharge data. These Q plots were to be used to determine if quantitative evaluation of the spring discharge data was feasible.

8.1.2 Natural Variation Analysis

The purpose of the natural variation analysis was to allow for greater discrimination of the spring discharge data as these data were compared across (before versus after) a

subsidence event. The objective was to decipher between naturally occurring changes in spring discharge from mining-induced changes to spring discharge, which was predominantly manifested in the indeterminate spring discharge response category of Investigations I and II. The natural variation in evapotranspiration seasonal condition and precipitation were examined to determine the techniques that could be implemented to control for their respective influence on spring discharge.

8.1.2.1 Evapotranspiration Condition

Control of evapotranspiration condition was accomplished through the comparison of pre-mine spring discharge data collected during similar evapotranspiration seasonal conditions within two pre-mining consecutive years; for example, fall of 1998 and fall of 1999. In addition, the evaluation periods would be comprised of identical months for which the data were collected; for example, September through November of 1998 could be compared to September through November of 1999. Utilization of this technique assumed that the evapotranspiration conditions would be addressed, and thus satisfies the objective for the natural variation analysis.

8.1.2.2 Precipitation

Precipitation cannot be assumed to be consistent within two consecutive seasonal evaluation periods like evapotranspiration can. Precipitation can be controlled through a normalization technique; however, this technique is dependent upon determining the period of antecedent precipitation to be used; in other words, which precipitation data in

the precipitation record should be used for the normalization technique. Normalization of the spring discharge data means that the spring discharge data were to be divided by antecedent precipitation over some time period. Essentially, the question involved the need to determine the quantification of time between the precipitation (storm) recharge event and the time when that recharge arrived at the spring discharge location.

An attempt at determining the elapsed time between ground water recharge and spring discharge for storm events was conducted for several springs. The antecedent precipitation data prior to times of spring discharge measurements were investigated in numerous configurations – single day (singular) data, consecutive day (cumulative) data, singular data and cumulative data collected at one week, two, weeks, three weeks, one month, two months, et cetera antecedently. However, conclusions could not be drawn from the evaluation for the following reason.

The technique used for determining the elapsed time between storm event recharge and spring discharge was similar to a type curve fitting technique; however, the monitoring frequencies associated with spring discharge data collection and precipitation data collection were different; spring discharge data were collected once per month and precipitation data were collected daily. Alignment of the type curves could not be accomplished due to the unknown temporal positioning associated with the spring discharge data; i.e., is the spring discharge measurement representative of the upward-

rising limb of a hydrograph or the falling limb of a hydrograph, if a detailed hydrograph were available.

Due to the unsuccessful attempt at determining the length and antecedent extent of the evaluation period, monthly precipitation data (Table 9) recorded during the months when spring discharge was measured were used to account for the precipitation effects of the spring discharge data. This partially controlled for the impact of precipitation on spring discharge in an attempt to satisfy the objective associated with the natural variation analysis.

The use of the precipitation data would be more indicative of seasonal fluctuations in precipitation and related less to recharge for a spring. Knowledge of the departure from normal precipitation, or deviation from the 30 year average, would focus upon the degree of fluctuation within the precipitation record; i.e., surmise if the evaluation period is within a precipitation deficit or surplus. Spring discharge is assumed to be lower during times of precipitation deficit, or low precipitation event activity, and higher during times of precipitation surplus, or high precipitation event activity.

8.1.3 Reduction Boundary Conditions

As stated previously, the purpose of the natural variation analysis was to allow for greater discrimination of the spring discharge data as the data were compared across a

Table 9: Monthly Precipitation Data. Monthly precipitation data (Upper) were collected from a USGS rain gauge station approximately 18 miles west of the research study Aarea. Thirty year monthly precipitation averages (30 Yr Mo Ave) are provided to discern deviations of precipitation with respect to the 30 Yr month average (lower table).												
	January	February	March	April	May	June	July	August	September	October	November	December
30 Yr Mo Ave	2.50	2.70	3.70	4.00	4.50	4.40	4.80	3.70	3.30	2.90	3.50	3.20
1992									2.76	1.73	3.40	2.41
1993	3.83	3.22	4.93	3.57	1.94	4.76	3.67	3.23	4.67	3.08	4.86	2.99
1994	5.06	1.85	5.50	4.38	2.95	5.65	5.10	5.23	2.41	0.78	3.56	3.02
1995	3.61	2.03	2.02	2.90	5.43	6.39	2.79	2.85	1.85	4.07	3.32	2.35
1996	4.29	4.51	4.75	3.38	6.56	3.74	5.77	0.75	6.72	2.63	3.15	2.69
1997	2.85	1.69	5.61	1.79	5.58	4.22	5.37	6.84	4.03	1.43	4.16	2.13
1998	4.32	3.27	2.89	5.11	3.76	9.44	1.76	2.84	2.67	2.95	1.74	2.21
1999	6.92	2.77	2.21	4.95	2.79	1.87	7.22	2.74	2.36	2.41	3.95	2.78
2000	2.54	4.28	3.61	4.31	4.52	3.83	3.32	4.65	3.49	1.60	1.79	0.35
2001	2.63	1.76	3.61	4.53	5.38	4.88	4.11	3.06	2.28	3.15	3.35	3.12
2002	2.09	0.81	4.00	3.44	6.37	4.16	2.09	0.63	3.90	3.08	3.39	2.30
2003	2.11	3.06	1.42									
30 Yr Mo Ave	2.50	2.70	3.70	4.00	4.50	4.40	4.80	3.70	3.30	2.90	3.50	3.20
1992									-0.54	-1.17	-0.10	-0.79
1993	1.33	0.52	1.23	-0.43	-2.56	0.36	-1.13	-0.47	1.37	0.18	1.36	-0.21
1994	2.56	-0.85	1.80	0.38	-1.55	1.25	0.30	1.53	-0.89	-2.12	0.06	-0.18
1995	1.11	-0.67	-1.68	-1.10	0.93	1.99	-2.01	-0.85	-1.45	1.17	-0.18	-0.85
1996	1.79	1.81	1.05	-0.62	2.06	-0.66	0.97	-2.95	3.42	-0.27	-0.35	-0.51
1997	0.35	-1.01	1.91	-2.21	1.08	-0.18	0.57	3.14	0.73	-1.47	0.66	-1.07
1998	1.82	0.57	-0.81	1.11	-0.74	5.04	-3.04	-0.86	-0.63	0.05	-1.76	-0.99
1999	4.42	0.07	-1.49	0.95	-1.71	-2.53	2.42	-0.96	-0.94	-0.49	0.45	-0.42
2000	0.04	1.58	-0.09	0.31	0.02	-0.57	-1.48	0.95	0.19	-1.30	-1.71	-2.85
2001	0.13	-0.94	-0.09	0.53	0.88	0.48	-0.69	-0.64	-1.02	0.25	-0.15	-0.08
2002	-0.41	-1.89	0.30	-0.56	1.87	-0.24	-2.71	-3.07	0.60	0.18	-0.11	-0.90
2003	-0.39	0.36	-2.28									
Italics (for example, 0.35, during December 2001) denotes not completely measured precipitation data during the month; for these months, negative deviation values are overestimated.												

subsidence event (before vs. after mining). Appropriate boundary conditions, or acceptable tolerance values derived from naturally occurring changes in spring discharge, were used to separate naturally occurring changes in spring discharge from mining-induced changes to spring discharge. The boundary conditions were derived from the evaluation of several spring discharge scenarios.

The data used for the spring discharge scenarios were not distorted but rather applied in different ways. The scenarios differ in context for use of the spring discharge data (averaged spring discharge data or precipitation normalized averaged spring discharge data) with regard to seasonal evapotranspiration condition (low or high).

The spring discharge data were evaluated through two techniques - averaged and precipitation normalized averaged. The averaging technique was used to average the spring discharge data during the evaluation period; for example, spring discharge measured during the months of May, June, and July was averaged. The averaged spring discharge data were further discriminated through normalization of the pre-mine averaged spring discharge data and post-mine averaged spring discharge data with precipitation data collected during the same evaluation periods; for example, spring discharge measured during the months of May, June, and July was averaged and divided by the averaged precipitation recorded during the months of May, June, and July. The averaged spring discharge data and the normalized averaged spring discharge data would be evaluated during similar seasonal evapotranspiration conditions. Two separate

investigations were later examined - spring discharge impairment and degree of spring discharge impairment.

Two types of spring discharge reduction boundary conditions were evaluated - optimum and absolute. The spring discharge reduction boundary conditions were determined through the use of nonparametric statistical tests and optimum partition testing. The optimum partition (or optimum spring discharge reduction boundary) would be the spring discharge reduction boundary that had the lowest calculated probability of error and spring misclassification percentage during contingency table data testing. Essentially, the optimum spring discharge reduction boundary is assumed to be close to the true reduction boundary if more data existed. The absolute spring discharge reduction boundaries were identified at the partition where zero control springs were misclassified, or at the partition with the maximum spring discharge natural reduction. The optimum and absolute spring discharge reduction boundaries were statistically derived during both low and high evapotranspiration seasonal conditions to permit examination of the hydrologic, geologic, topographic, and mine-specific independent variables during low and high evapotranspiration seasonal conditions.

The following three steps outline the statistical procedure to discern between naturally occurring changes in spring discharge and mining-induced changes to spring discharge.

1. Determine the boundary conditions associated with naturally occurring changes in spring discharge through the statistical examination of the

control (pre-mine) group against the spring discharge data collected after subsidence events, during low and high evapotranspiration seasonal conditions separately.

2. Determine if an apparent mining-induced change to spring discharge occurred across a subsidence event through the evaluation of the pre-mine and post-mine averaged spring discharge and precipitation normalized averaged spring discharge data and if so, quantify the magnitude of the change to spring discharge during low and high evapotranspiration seasonal conditions, separately.
3. Compare the magnitude of the apparent mining-induced change to spring discharge to the calculated boundary conditions during low and high evapotranspiration seasonal conditions, separately, to determine if the change in spring discharge was due to naturally occurring changes or mining-induced changes.

Due to the subjectivity inherent to the natural variation analysis, the following procedural data conditions were used.

- Averaged spring discharge data contained a minimum of 2 months of data and maximum of 4 months of data.
- Data within one month of a subsidence event were omitted from calculating the averaged spring discharge.
- Obvious anomalies, or abnormal, single-event peaks or troughs, in the data record were omitted by the author from calculating the averaged spring discharge.
- Thirty-year average monthly precipitation values were used for months without precipitation data or unrecorded precipitation data.

8.1.4 Quantitative Evaluation of Additional Dependent Variables

In addition to the hydrologic, geologic, topographic, and mine-specific independent variables listed in **4.2 Measured Data**, the following independent variables were added to Investigation III. The measured data for these additional variables are located in Appendix C.

8.1.4.1 Recharge Line

The length component of the recharge line perpendicular to the longwall panel face was arithmetically calculated (Figure 12). The error associated with this variable was assumed to be +/- 10ft.

The recharge line, as described in **4.2 Measured Data**, was further examined to determine if a subsidence event beginning at the origin (uphill end) of the recharge line and terminating at the spring daylight position was statistically different than if the subsidence event began at the spring daylight position and terminated at the origin of the recharge line. In addition, the percentage of the recharge line subsided was calculated.

Pre-mining origin (uphill) elevation data of the recharge lines were extracted from USGS 7'30" Quadrangle maps. The error associated with the pre-mining origin elevation of the recharge line was assumed to be +/- 5ft.

Figure 12. Schematic Depiction of the Recharge Line Length Component Perpendicular to Longwall Panel Face for Springs Overlying Longwall Panels. Recharge lines at acute angles to the longwall panel face have less length perpendicular to the longwall panel face.

8.1.4.2 Spring Proximity to Nearest Surface Drainage Feature

A spring's pre-mining lateral distance to the nearest surface drainage feature had been previously measured to calculate the gradient (percent slope) from a spring to the nearest surface drainage feature; however, the lateral distance a spring was from the nearest surface drainage feature was not statistically examined for Investigations I and II. The error associated with a spring's lateral distance to the nearest stream was assumed to be +/- 10ft.

8.1.4.3 Pre-Mining Average Low Flow Spring Discharge

The pre-mining average low flow spring discharge was calculated to determine if the mining-induced response from springs with higher low flow average discharges were statistically different than springs with lower low flow average discharges.

8.2 Results of Investigation III

8.2.1 Quantitative Evaluation of Spring Discharge Data

Discharge, Q, plots were graphed for Investigation III to determine if spring discharge data trends were apparent between the pre-mining discharge data and post-mining discharge data.

The Q plots created for pre-mining to post-mining spring discharge comparisons during low (Figure 13) and high (Figure 14) evapotranspiration seasonal conditions resulted in a distinction between three spring discharge response categories – unaffected spring

Figure 13. Pre-Mine to Post-Mine Spring Discharge Comparison for Averaged Spring Discharge and Precipitation Normalized Averaged Spring Discharge Data Collected During Low Evapotranspiration Seasonal Conditions.

Figure 14. Pre-Mine to Post-Mine Spring Discharge Comparison for Averaged Spring Discharge and Precipitation Normalized Averaged Spring Discharge Data Collected During High Evapotranspiration Seasonal Conditions.

discharge, spring discharge improvement and spring discharge impairment. The springs that plotted on the 45 degree line, which differentiates spring discharge improvement from spring discharge impairment, were considered unaffected from the effects of mining-induced subsidence. Springs with comparatively higher post-mine Q values than pre-mine Q values were considered to have an improvement to spring discharge from the effects of mining-induced subsidence. Springs with comparatively lower post-mine Q values than pre-mine Q values were considered to have an impairment to spring discharge from the effects of mining-induced subsidence.

The Q plots differentiated the degree of spring discharge impairment. This discrimination warranted evaluation of the spring discharge data to determine if the degree of spring discharge impairment was related to (show trends with) the independent variables.

The variability associated with the spring discharge data supports the differentiation of data according to evapotranspiration seasonal conditions. The averaged spring discharge data collected during low evapotranspiration seasonal conditions (Figure 13) were more variable than the averaged spring discharge data collected during high evapotranspiration seasonal conditions (Figure 14) – maximum Q collected during low and high evapotranspiration seasonal conditions were 8.97gpm and 1.56gpm, respectively.

Spring discharge data trends (spring discharge response categories, degree of spring discharge impairment, and evapotranspiration seasonal conditions) were apparent within the Q plots. Quantitative evaluation of the pre-mine and post-mine spring discharge data was acceptable.

8.2.2 Natural Variation Analysis

A total of 13 springs within the research study area were used to determine natural variation in spring discharge. These 13 springs were chosen for natural variation analysis because the data collection period for these springs exceeded 12 months, therefore, evaluation of naturally-occurring changes to spring discharge during two consecutive, pre-mine years was possible. Pre-mine data for the remaining 64 springs was not adequate enough to include in the natural variation analysis. The pre-mining spring discharge data used for these 13 springs resulted in 12 springs with discharge measured during low evapotranspiration conditions (November through May) and nine springs with discharge measured during high evapotranspiration conditions (May through November).

The use of the averaged spring discharge data resulted in naturally occurring (unmined) reduction in spring discharge as high as 88% during low evapotranspiration conditions, and as high as 72% during high evapotranspiration conditions (Table 10). Use of the precipitation normalized averaged spring discharge data resulted in naturally occurring reduction in spring discharge as high as 86% during low evapotranspiration conditions, and as high as 69% during high evapotranspiration conditions (Table 11).

Table 10: Results from the Natural Variation Analysis (Non-Subsidence) During Low (upper) and High (lower) Evapotranspiration Conditions Using Averaged Spring Discharge Data as Discussed in Methods of Investigation III.						
Spring No.	Evaluation Period During Low Evapotranspiration Condition	Year 1	Year 2	Averaged Spring Discharge	Year 1	Year 2
				(gpm)	(gpm)	(gpm)
183	Jan - March ('94)		Jan - March ('95)	0.37	0.32	14.43
32	Jan - March ('94)		Jan - March ('95)	2.54	0.64	74.83
297	Nov - Dec ('98)		Nov - Dec ('99)	0.74	1.87	(152.03)
266	Feb - April ('99)		Feb - April ('00)	0.88	0.73	16.67
253	Jan - March ('98)		Jan - March ('99)	3.24	6.07	(87.22)
273	Feb - April ('99)		Feb - April ('00)	1.28	0.90	29.47
270	April - May ('99)		April - May ('00)	0.13	0.56	(330.77)
267	Feb - April ('99)		Feb - April ('00)	1.97	1.73	11.85
258	Jan - March ('98)		Jan - March ('99)	3.17	3.48	(9.68)
256	Jan - March ('98)		Jan - March ('99)	10.21	6.11	40.17
157	Jan - March ('97)		Jan - March ('98)	0.64	1.65	(157.81)
272	Jan - March ('99)		Jan - March ('00)	3.53	0.43	87.81
Spring No.	Evaluation Period During High Evapotranspiration Conditions	Year 1	Year 2	Averaged Spring Discharge	Year 1	Year 2
				(gpm)	(gpm)	(gpm)
183	July - Sept ('94)		July - Sept ('95)	0.29	0.18	38.57
32	July - Sept ('94)		July - Sept ('95)	0.55	0.29	48.17
78	July - Sept ('95)		July - Sept ('96)	0.23	0.49	(113.91)
297	Sept - Nov ('98)		Sept - Nov ('99)	1.07	0.62	41.56
266	Aug - Oct ('99)		Aug - Oct ('00)	0.08	0.23	(187.50)
253	July - Oct ('98)		July - Oct ('99)	0.65	0.30	54.62
267	Aug - Oct ('00)		Aug - Oct ('00)	0.22	0.29	(31.39)
256	Aug - Oct ('98)		Aug - Oct ('99)	0.76	0.21	71.83
272	May - July ('99)		May - July ('00)	0.63	3.87	(513.65)
Footnote: Natural reduction in spring discharge values in parentheses indicate a discharge improvement from Year 1 to Year 2. Natural reduction in spring discharge values not in parentheses indicate a discharge impairment from Year 1 to Year 2.						

Table 11: Results from the Natural Variation Analysis (Non-Subsidence) During Low (upper) and High (lower) Evapotranspiration Conditions Using Normalized Average Spring Discharge Data as Discussed in Methods of Investigation III .						
Spring No.	Evaluation Period During Low	Evapotranspiration Condition	Precipitation Normalized Averaged Spring Discharge	Natural Reduction in Spring Discharge Ratio		
	Year 1	Year 2	Year 1	Year 2	(see footnote)	(%)
183	Jan - March ('94)	Jan - March ('95)	0.089	0.124	(39)	59
32	Jan - March ('94)	Jan - March ('95)	0.615	0.251	(123)	32
297	Nov - Dec ('98)	Nov - Dec ('99)	0.249	0.554	(65)	43
266	Feb - April ('99)	Feb - April ('00)	0.265	0.180	(278)	28
253	Jan - March ('98)	Jan - March ('99)	0.928	1.530	3	47
273	Feb - April ('99)	Feb - April ('00)	0.385	0.221	(150)	86
270	April - May ('99)	April - May ('00)	0.034	0.127		
267	Feb - April ('99)	Feb - April ('00)	0.594	0.426		
258	Jan - March ('98)	Jan - March ('99)	0.908	0.877		
256	Jan - March ('98)	Jan - March ('99)	2.924	1.541		
157	Jan - March ('97)	Jan - March ('98)	0.189	0.472		
272	Jan - March ('99)	Jan - March ('00)	0.889	0.124		
Spring No.	Evaluation Period During High	Evapotranspiration Conditions	Precipitation Normalized Averaged Spring Discharge	Natural Reduction in Spring Discharge Ratio		
	Year 1	Year 2	Year 1	Year 2	(see footnote)	(%)
183	July - Sept ('94)	July - Sept ('95)	0.069	0.072	(4)	12
32	July - Sept ('94)	July - Sept ('95)	0.130	0.115	(21)	51
78	July - Sept ('95)	July - Sept ('96)	0.092	0.111	(122)	69
297	Sept - Nov ('98)	Sept - Nov ('99)	0.435	0.214	(1)	68
266	Aug - Oct ('99)	Aug - Oct ('00)	0.032	0.071	(526)	
253	July - Oct ('98)	July - Oct ('99)	0.254	0.080		
267	Aug - Oct ('00)	Aug - Oct ('00)	0.089	0.090		
256	Aug - Oct ('98)	Aug - Oct ('99)	0.268	0.085		
272	May - July ('99)	May - July ('00)	0.159	0.994		
Footnote: Natural reduction in spring discharge values in parentheses indicate a discharge/precipitation ratio improvement from Year 1 to Year 2. Natural reduction in spring discharge values not in parentheses indicate a discharge/precipitation ratio impairment from Year 1 to Year 2.						

8.2.3 Reduction Boundary Conditions

Two general questions were investigated. First, which use of the spring discharge data was more statistically significant and should be used for the remaining statistical examination of hydrologic, geologic, topographic, and mine-specific independent variable data trends during low and high evapotranspiration conditions? Secondly, what are the optimum and absolute values of spring discharge reduction boundaries during low and high evapotranspiration seasonal conditions?

Four spring discharge scenarios were examined through the use of the optimum partition testing technique. The spring discharge scenarios (Table 12) were different combinations of the use of the spring discharge data and seasonal evapotranspiration conditions.

Different partitions (10% reduction increments) were used to determine the optimum and absolute values of the spring discharge reduction boundaries through the utilization of the contingency table approach (Figure 15).

The optimum spring discharge reduction boundary was determined through the evaluation of each partition that contained at least one spring within each contingency table box (A, B, C, and D). The optimum partition for each scenario was additionally determined as the partition that had the lowest calculated error probability.

Table 12: Data Types and Use Associated with Four Spring Discharge Scenarios as Discussed in Methods of Investigation III.				
Scenario	Type of Response Tested	Evapotranspiration Condition	Data Tested	
1	Discharge Impairment	Low Evapotranspiration Condition	Averaged Spring Discharge Data	
2	Discharge Impairment	Low Evapotranspiration Condition	Normalized Averaged Spring Discharge Data	
3	Discharge Impairment	High Evapotranspiration Condition	Averaged Spring Discharge Data	
4	Discharge Impairment	High Evapotranspiration Condition	Normalized Averaged Spring Discharge Data	

	$\geq x$	$< x$	Totals
Number of Control Springs	A	B	A+B
Number of Undermined Springs	C	D	C+D
Totals	A+C	B+D	

where,

'x' is the partition percentage (reduction in spring discharge)

A is the number of control springs that had natural changes to spring discharge $\geq x$

B is the number of control springs that had natural changes to spring discharge $< x$

C is the number of undermined springs that had changes to spring discharge $\geq x$

D is the number of undermined springs that had changes to spring discharge $< x$

Figure 15: 2x2 Contingency Table Test Used for the Natural Variation Analysis Associated with Investigation III.

The absolute spring discharge reduction boundary was determined as the partition with the maximum naturally occurring change in spring discharge.

The use of averaged spring discharge data and precipitation normalized averaged spring discharge data resulted in different partitions associated with the optimum and absolute values of the spring discharge reduction boundaries during low and high seasonal evapotranspiration conditions. The following rationale was used to determine which partitions would be used to decipher between naturally occurring changes in spring discharge and mining-induced changes to spring discharge during low and high evapotranspiration conditions.

The following results are from the optimum partition tests used to determine the optimum reduction boundary (Table 13).

Table 13: Results from the Optimum Partition Tests Used to Determine the Optimum Reduction Boundaries as Discussed in Methods of Investigation III.

Scenario 1	x'	A	B	C	D	n	$C/(C+D)*100$	$A/(A+B)*100$	$(A+D)/(A+B+C+D)*100$	$P_{(error)}$
	10%	7	5	54	9	75	86%	58%	21%	0.99277
	20%	4	8	48	15	75	76%	33%	25%	0.00583
	30%	3	9	48	15	75	76%	25%	24%	0.00114
	40%	3	9	44	19	75	70%	25%	29%	0.00487
	50%	2	10	44	19	75	70%	17%	28%	0.00086
	55%	2	10	43	20	75	68%	17%	29%	0.00123
	60%	2	10	40	23	75	63%	17%	33%	0.00338
	65%	2	10	39	24	75	62%	17%	35%	0.00458
	70%	2	10	36	27	75	57%	17%	39%	0.01069
Scenario 2	80%	1	11	35	28	75	56%	8%	39%	0.00246
	88%	0	12	33	30	75	52%	0%	40%	0.00042
	x'	A	B	C	D	n	$C/(C+D)$	$A/(A+B)$	$(A+D)/(A+B+C+D)*100$	$P_{(error)}$
	10%	6	6	53	10	75	84%	50%	21%	0.01624
	20%	6	6	52	11	75	83%	50%	23%	0.02301
	30%	5	7	49	14	75	78%	42%	25%	0.01684
	40%	4	8	47	16	75	75%	33%	27%	0.00818
	50%	2	10	43	20	75	68%	17%	29%	0.00124
	55%	2	10	41	22	75	65%	17%	32%	0.00245
	60%	1	11	40	23	75	63%	8%	32%	0.00047
Scenario 3	65%	1	11	37	26	75	59%	8%	36%	0.00131
	70%	1	11	37	26	75	59%	8%	36%	0.00131
	80%	1	11	35	28	75	56%	8%	39%	0.00246
	88%	0	12	33	30	75	52%	0%	40%	0.00042
	x'	A	B	C	D	n	$C/(C+D)$	$A/(A+B)$	$(A+D)/(A+B+C+D)*100$	$P_{(error)}$
	10%	5	4	49	9	67	84%	56%	21%	0.98943
	20%	5	4	49	9	67	84%	56%	21%	0.98943
	30%	5	4	49	9	67	84%	56%	21%	0.98943
	40%	4	5	49	9	67	84%	44%	19%	0.01547
	50%	2	7	48	10	67	83%	22%	18%	0.00059
Scenario 4	55%	1	8	48	10	67	83%	11%	16%	5.13×10^{-5}
	60%	1	8	48	10	67	83%	11%	16%	5.13×10^{-5}
	65%	1	8	48	10	67	83%	11%	16%	5.13×10^{-5}
	70%	1	8	47	11	67	81%	11%	18%	8.70×10^{-5}
	80%	0	9	46	12	67	79%	0%	18%	6.87×10^{-6}
	88%	0	9	44	14	67	76%	0%	21%	1.91×10^{-5}
	x'	A	B	C	D	n	$C/(C+D)$	$A/(A+B)$	$(A+D)/(A+B+C+D)*100$	$P_{(error)}$
	10%	4	5	49	9	67	84%	44%	19%	0.01547
	20%	3	6	49	9	67	84%	33%	18%	0.00279
	30%	3	6	48	10	67	83%	33%	19%	0.00426
Scenario 4	40%	3	6	48	10	67	83%	33%	19%	0.00426
	50%	3	6	48	10	67	83%	33%	19%	0.00426
	55%	2	7	48	10	67	83%	22%	18%	0.00059
	60%	2	7	48	10	67	83%	22%	18%	0.00059
	65%	2	7	48	10	67	83%	22%	18%	0.00059
	70%	0	9	48	10	67	83%	0%	15%	2.16×10^{-6}
	80%	0	9	46	12	67	79%	0%	18%	6.87×10^{-6}
	88%	0	9	44	14	67	76%	0%	21%	1.91×10^{-5}

Key										
x': partition percentage reduction in spring discharge										
$P_{(error)}$: Error probability										
A: number of control springs that had natural changes to spring discharge $\geq$ 'x'										
B: number of control springs that had natural changes to spring discharge $<$ 'x'										
C: number of undermined springs that had changes to spring discharge $\geq$ 'x'										
D: number of undermined springs that had changes to spring discharge $<$ 'x'										
$C/(C+D)*100$ Percentage of Undermined Springs Significantly Impaired										
$A/(A+B)*100$ Percentage of Misclassified Control Springs										
$(A+D)/(A+B+C+D)*100$ Percentage of Deviation from Optimum Distribution										

- The use of averaged spring discharge data (scenario 1) during low evapotranspiration conditions resulted in a probability of error less statistically significant (comparatively higher p) than the use of precipitation normalized averaged spring discharge data (scenario 2); p is 0.00086 and 0.00047, respectively.
- The use of averaged spring discharge data (scenario 3) during high evapotranspiration conditions resulted in a probability of error more statistically significant (comparatively lower p) than the use of precipitation normalized averaged spring discharge data (scenario 4); p is 0.0000513 and 0.00059, respectively.
- Percent deviation from the optimum distribution, $[(A+D)/(A+B+C+D)]*100$, was less for the averaged spring discharge data than from the precipitation normalized averaged spring discharge data during low and high evapotranspiration conditions; 28 percent to 32 percent and 16 percent to 18 percent, respectively.

Due to the low calculated error probability for both the averaged spring discharge and precipitation normalized averaged spring discharge data, the selected optimum spring discharge reduction boundaries during low and high evapotranspiration conditions were chosen based in part upon percent deviation from the optimum distribution of the data; that is, misclassified control springs (contingency table box A) and misclassified undermined springs (contingency table box D) were zero. Deviation from the optimum distribution was less for the averaged spring discharge data than for the precipitation normalized averaged spring discharge data during both evapotranspiration conditions; therefore, it is perceived that the averaged spring discharge data are slightly more

significant than the precipitation normalized averaged spring discharge data. This does not assume that precipitation data are not needed to assess spring discharge response to mining-induced subsidence. This is only suggestive that the technique employed for use of the precipitation data is slightly less valuable to this research methodology.

Therefore, the selected optimum spring discharge reduction boundaries (most probable naturally occurring reduction in spring discharge) range from 50 and 60 percent during low and high evapotranspiration conditions (Table 13). The selected absolute spring discharge reduction boundaries (maximum naturally occurring reduction in spring discharge) range from 80 to 88 percent during low and high evapotranspiration conditions (Table 14).

8.2.4 Spring Discharge Response

8.2.4.1 Optimum Boundary Reduction

Averaged spring discharge data were used to assess spring discharge response to mining-induced subsidence under the optimum boundary spring discharge reduction percentages statistically derived during low and high seasonal evapotranspiration conditions.

Subsidence-induced spring discharge response was 88 percent impaired and 12 percent unaffected (Table 15). Of the 53 impaired springs, 17 percent were partially impaired during low evapotranspiration conditions but not during high evapotranspiration conditions, 23 percent were partially impaired during high evapotranspiration conditions but not during low evapotranspiration conditions, 21 percent were partially impaired

Table 14: Results from the Optimum Partition Tests Used to Determine the Absolute Reduction Boundaries as Discussed in **Methods of Investigation III.**

Scenario 1	x'	A	B	C	D	n	C/(C+D)	A/(A+B)	(A+D)/(A+B+C+D)*100	P _(error)
	10%	7	5	54	9	75	86%	58%	21%	0.99277
	20%	4	8	48	15	75	76%	33%	25%	0.00583
	30%	3	9	48	15	75	76%	25%	24%	0.00114
	40%	3	9	44	19	75	70%	25%	29%	0.00487
	50%	2	10	44	19	75	70%	17%	28%	0.00086
	55%	2	10	43	20	75	68%	17%	29%	0.00123
	60%	2	10	40	23	75	63%	17%	33%	0.00338
	65%	2	10	39	24	75	62%	17%	35%	0.00458
	70%	2	10	36	27	75	57%	17%	39%	0.01069
Scenario 2	80%	1	11	35	28	75	56%	8%	39%	0.00246
	88%	0	12	33	30	75	52%	0%	40%	0.00042
	x'	A	B	C	D	n	C/(C+D)	A/(A+B)	(A+D)/(A+B+C+D)*100	P _(error)
	10%	6	6	53	10	75	84%	50%	21%	0.01624
	20%	6	6	52	11	75	83%	50%	23%	0.02301
	30%	5	7	49	14	75	78%	42%	25%	0.01684
	40%	4	8	47	16	75	75%	33%	27%	0.00818
	50%	2	10	43	20	75	68%	17%	29%	0.00124
	55%	2	10	41	22	75	65%	17%	32%	0.00245
	60%	1	11	40	23	75	63%	8%	32%	0.00047
Scenario 3	65%	1	11	37	26	75	59%	8%	36%	0.00131
	70%	1	11	37	26	75	59%	8%	36%	0.00131
	80%	1	11	35	28	75	56%	8%	39%	0.00246
	88%	0	12	33	30	75	52%	0%	40%	0.00042
	x'	A	B	C	D	n	C/(C+D)	A/(A+B)	(A+D)/(A+B+C+D)*100	P _(error)
	10%	5	4	49	9	67	84%	56%	21%	0.98943
	20%	5	4	49	9	67	84%	56%	21%	0.98943
	30%	5	4	49	9	67	84%	56%	21%	0.98943
	40%	4	5	49	9	67	84%	44%	19%	0.01547
	50%	2	7	48	10	67	83%	22%	18%	0.00059
Scenario 4	55%	1	8	48	10	67	83%	11%	16%	5.13 x 10 ⁻⁵
	60%	1	8	48	10	67	83%	11%	16%	5.13 x 10 ⁻⁵
	65%	1	8	48	10	67	83%	11%	16%	5.13 x 10 ⁻⁵
	70%	1	8	47	11	67	81%	11%	18%	8.70 x 10 ⁻⁵
	80%	0	9	46	12	67	79%	0%	18%	6.87 x 10 ⁻⁶
	88%	0	9	44	14	67	76%	0%	21%	1.91 x 10 ⁻⁵
	x'	A	B	C	D	n	C/(C+D)	A/(A+B)	(A+D)/(A+B+C+D)*100	P _(error)
	10%	4	5	49	9	67	84%	44%	19%	0.01547
	20%	3	6	49	9	67	84%	33%	18%	0.00279
	30%	3	6	48	10	67	83%	33%	19%	0.00426
Scenario 4	40%	3	6	48	10	67	83%	33%	19%	0.00426
	50%	3	6	48	10	67	83%	33%	19%	0.00426
	55%	2	7	48	10	67	83%	22%	18%	0.00059
	60%	2	7	48	10	67	83%	22%	18%	0.00059
	65%	2	7	48	10	67	83%	22%	18%	0.00059
	70%	0	9	48	10	67	83%	0%	15%	2.16 x 10 ⁻⁶
	80%	0	9	46	12	67	79%	0%	18%	6.87 x 10 ⁻⁶
	88%	0	9	44	14	67	76%	0%	21%	1.91 x 10 ⁻⁵

Key										
x': partition percentage reduction in spring discharge										
P _(error) : Error probability										
A: number of control springs that had natural changes to spring discharge >= 'x'										
B: number of control springs that had natural changes to spring discharge < 'x'										
C: number of undermined springs that had changes to spring discharge >= 'x'										
D: number of undermined springs that had changes to spring discharge < 'x'										
C/(C+D)*100 Percentage of Undermined Springs Significantly Impaired										
A/(A+B)*100 Percentage of Misclassified Control Springs										
(A+D)/(A+B+C+D)*100 Percentage of Deviation from Optimum Distribution										

Table 15. Spring Discharge Response to Mining-Induced Subsidence Evaluated at the Optimum Spring Discharge Reduction Boundary During Low and High Evapotranspiration Conditions.

Source	Optimum Value of Discharge Reduction		Spring Discharge Response
	Low ET (50%)	High ET (60%)	
33	87	(1)	Impaired During Low Evapotranspiration Conditions
198	92	(23)	Impaired During Low Evapotranspiration Conditions
155	100	100	Permanently Impaired
166	100	100	Permanently Impaired
167	100	100	Permanently Impaired
173	100	100	Permanently Impaired
174	100	100	Permanently Impaired
177	100	100	Permanently Impaired
199	100	100	Permanently Impaired
224	100	100	Permanently Impaired
249	100	100	Permanently Impaired
254	100	100	Permanently Impaired
259	100	100	Permanently Impaired
263	100	100	Permanently Impaired
272	100	100	Permanently Impaired
35	100	100	Permanently Impaired
36	100	100	Permanently Impaired
41	100	100	Permanently Impaired
63	100	100	Permanently Impaired
64	100	100	Permanently Impaired
84	100	100	Permanently Impaired
94	100	100	Permanently Impaired
269	(126)	(61)	Unaffected
271	(133)	(74)	Unaffected
297	(6)	10	Unaffected
268	(31)	(118)	Unaffected
99A	(600)	100	Impaired During High Evapotranspiration Conditions
258	(149)	100	Impaired During High Evapotranspiration Conditions
216	(338)	100	Impaired During High Evapotranspiration Conditions
43	2	80	Impaired During High Evapotranspiration Conditions
38	13	100	Impaired During High Evapotranspiration Conditions
176	17	100	Impaired During High Evapotranspiration Conditions
226	20	100	Impaired During High Evapotranspiration Conditions
154	18		Unaffected
265	32	100	Impaired During High Evapotranspiration Conditions
79	54	100	Impaired During Low and High Evapotranspiration Conditions
99	14	100	Impaired During High Evapotranspiration Conditions
107	58	85	Impaired During Low and High Evapotranspiration Conditions
270	57		Impaired During Low Evapotranspiration Conditions
102	39	100	Impaired During High Evapotranspiration Conditions
260	58		Impaired During Low Evapotranspiration Conditions
267	69	96	Impaired During Low and High Evapotranspiration Conditions
97	30	45	Unaffected
92	67		Impaired During Low Evapotranspiration Conditions
106	74	100	Impaired During Low and High Evapotranspiration Conditions
93	68	100	Impaired During Low and High Evapotranspiration Conditions
171	91		Impaired During Low Evapotranspiration Conditions
175	62	100	Impaired During Low and High Evapotranspiration Conditions
274	94	100	Impaired During Low and High Evapotranspiration Conditions
102A	88	99	Impaired During Low and High Evapotranspiration Conditions
273	95		Impaired During Low Evapotranspiration Conditions
256	98	88	Impaired During Low and High Evapotranspiration Conditions
169	98	65	Impaired During Low and High Evapotranspiration Conditions
91	97		Impaired During Low Evapotranspiration Conditions
90	99	100	Impaired During Low and High Evapotranspiration Conditions
152	100	100	Permanently Impaired
39	100		Impaired During Low Evapotranspiration Conditions
165		(64)	Unaffected
101		98	Impaired During High Evapotranspiration Conditions
83		100	Impaired During High Evapotranspiration Conditions

Footnote: spring discharge reduction values in parentheses indicate a discharge/precipitation ratio improvement from Year 1 to Year 2. Spring discharge reduction values not in parentheses indicate a discharge/precipitation ratio impairment from Year 1 to Year 2.

during both low and high evapotranspiration conditions, and 39 percent were permanently impaired through the duration of the post-mine monitoring program.

8.2.4.2 Absolute Boundary Reduction

Averaged spring discharge data were used to assess spring discharge response to mining-induced subsidence under the absolute boundary reduction percentages statistically derived during low and high seasonal evapotranspiration conditions. Subsidence-induced spring discharge response was 80 percent impaired and 20 percent unaffected (Table 16). Of the 48 impaired springs, 10 percent were partially impaired during low evapotranspiration conditions but not during high evapotranspiration conditions, 40 percent were partially impaired during high evapotranspiration conditions but not during low evapotranspiration conditions, 6 percent were partially impaired during both low and high evapotranspiration conditions, and 44 percent were permanently impaired through the duration of the post-mine monitoring program.

8.2.5 Spring Discharge Response Statistical Examination (Median Value)

The following results from the Chi square contingency and Fisher exact probability statistical examination of spring discharge response are provided in Tables 17 and 18, respectively. These results are listed according to evapotranspiration condition and spring discharge reduction boundary. The hydrologic, geologic, topographic, and mine-

Table 16. Spring Discharge Response to Mining-Induced Subsidence Evaluated at the Absolute Spring Discharge Reduction Boundary During Low and High Evapotranspiration Conditions.

Source	Absolute Value of Discharge Reduction		Spring Discharge Response
	Low ET (88%)	High ET (80%)	
33	87	(1)	Unaffected
198	92	(23)	Impaired During Low Evapotranspiration Conditions
155	100	100	Permanently Impaired
166	100	100	Permanently Impaired
167	100	100	Permanently Impaired
173	100	100	Permanently Impaired
174	100	100	Permanently Impaired
177	100	100	Permanently Impaired
199	100	100	Permanently Impaired
224	100	100	Permanently Impaired
249	100	100	Permanently Impaired
254	100	100	Permanently Impaired
259	100	100	Permanently Impaired
263	100	100	Permanently Impaired
272	100	100	Permanently Impaired
35	100	100	Permanently Impaired
36	100	100	Permanently Impaired
41	100	100	Permanently Impaired
63	100	100	Permanently Impaired
64	100	100	Permanently Impaired
84	100	100	Permanently Impaired
94	100	100	Permanently Impaired
269	(126)	(61)	Unaffected
271	(133)	(74)	Unaffected
297	(6)	10	Unaffected
268	(31)	(118)	Unaffected
99A	(600)	100	Impaired During High Evapotranspiration Conditions
258	(149)	100	Impaired During High Evapotranspiration Conditions
216	(338)	100	Impaired During High Evapotranspiration Conditions
43	2	80	Unaffected
38	13	100	Impaired During High Evapotranspiration Conditions
176	17	100	Impaired During High Evapotranspiration Conditions
226	20	100	Impaired During High Evapotranspiration Conditions
154	18		Unaffected
265	32	100	Impaired During High Evapotranspiration Conditions
79	54	100	Impaired During High Evapotranspiration Conditions
99	14	100	Impaired During High Evapotranspiration Conditions
107	58	85	Impaired During High Evapotranspiration Conditions
270	57		Unaffected
102	39	100	Impaired During High Evapotranspiration Conditions
260	58		Unaffected
267	69	96	Impaired During High Evapotranspiration Conditions
97	30	45	Unaffected
92	67		Unaffected
106	74	100	Impaired During High Evapotranspiration Conditions
93	68	100	Impaired During High Evapotranspiration Conditions
171	91		Impaired During Low Evapotranspiration Conditions
175	62	100	Impaired During High Evapotranspiration Conditions
274	94	100	Impaired During Low and High Evapotranspiration Conditions
102A	88	99	Impaired During High Evapotranspiration Conditions
273	95		Impaired During Low Evapotranspiration Conditions
256	98	88	Impaired During Low and High Evapotranspiration Conditions
169	98	65	Impaired During Low Evapotranspiration Conditions
91	97		Impaired During Low Evapotranspiration Conditions
90	99	100	Impaired During Low and High Evapotranspiration Conditions
152	100	100	Permanently Impaired
39	100		Impaired During High Evapotranspiration Conditions
165		(64)	Unaffected
101		98	Impaired During High Evapotranspiration Conditions
83		100	Impaired During High Evapotranspiration Conditions

Footnote: spring discharge reduction values in parentheses indicate a discharge/precipitation ratio improvement from Year 1 to Year 2. Spring discharge reduction values not in parentheses indicate a discharge/precipitation ratio impairment from Year 1 to Year 2.

Table 17: Results from Methods of Investigation III. Chi Square Contingency Test Results Used to Determine Spring Discharge Response to Mining-Induced Subsidence through the Use of the Calculated Median Value. Significant data trends are associated with error probability (P_{error}) at the 0.20 alpha level of significance.

Optimum Reduction Boundary									
Parameter	Low EvapoTranspiration Condition with 50% Discharge Reduction Tolerance				High EvapoTranspiration Condition with 60% Discharge Reduction Tolerance				
	N	H _{ultimate}	Chi-Square Value	H _{ultimate} Trend	P _{error}	N	H _{ultimate}	Chi-Square Value	H _{ultimate} Trend
Recharge Line Length Perpendicular to LW Face	54	>/=130	0.08882	Direct	H _{high}	49	>/=110	0.76563	Direct
Overburden Thickness	57	>/=430	0.14256	Direct	H _{high}	52	>/=425	0.07091	Direct
Width-Depth Ratio	54	>/=2.06	0.00000	Direct	H _{high}	49	<2.08	0.00340	Inverse
Recharge Line Length	57	>/=219	0.01426	Direct	H _{high}	52	>/=219	4.68594	Direct
Recharge Line Vertical Relief	57	>/=40	0.29567	Direct	H _{high}	52	>/=40	4.16788	Direct
Recharge Line Gradient	57	>/=19	0.01426	Direct	H _{high}	52	>/=19	0.07091	Direct
Recharge Line Mining Direction	54	n/d	0.08882	Inverse	H _{high}	49	n/d	0.00340	Inverse
Recharge Line Subsided	57	100	0.00003	Direct	H _{high}	52	100	0.04731	Direct
Vertical Relief to Nearest Surface Drainage Feature	57	>/=45	2.42375	Direct	0.20-0.10	52	<37.5	0.14731	Inverse
Vertical Relief to Headwater Drainage Features	52	>/=45	2.85091	Direct	0.10-0.05	47	<40	0.10377	Inverse
Vertical Relief to First Order Drainage Features	41	>/=40	2.10049	Direct	0.20-0.10	37	>/=35	0.21461	Direct
Vertical Relief to Second Order Drainage Features	11	>/=70	0.03438	Direct	H _{high}	10	<67.5	0.00000	Inverse
Lateral Distance to Nearest Surface Drainage Features	57	>/=250	0.00217	Direct	H _{high}	52	<240	1.07239	Inverse
Gradient to Nearest Surface Drainage Features	57	>/=19	1.13262	Direct	H _{high}	52	<19	0.00089	Inverse
Pre-Mine Spring Daylight Elevation	57	<1190	0.22318	Inverse	H _{high}	52	<1185	2.85694	Inverse
Pre-Mine Recharge Line Origin Elevation	57	>/=1235	0.03862	Direct	H _{high}	52	>/=1235	0.04448	Direct
Pre-Mine Averaged Low Flow Spring Discharge	55	>/=2.27	0.04433	Direct	H _{high}	34	<0.34	4.08654	Inverse
Absolute Reduction Boundary									
Parameter	Low EvapoTranspiration Condition with 88% Discharge Reduction Tolerance				High EvapoTranspiration Condition with 80% Discharge Reduction Tolerance				
	N	H _{ultimate}	Chi-Square Value	H _{ultimate} Trend	P _{error}	N	H _{ultimate}	Chi-Square Value	H _{ultimate} Trend
Recharge Line Length Perpendicular to LW Face	54	<130	0.29793	Inverse	H _{high}	49	>/=110	2.38336	Direct
Overburden Thickness	57	<430	0.01579	Inverse	H _{high}	52	<425	0.04696	Inverse
Width-Depth Ratio	54	>/=2.06	0.07500	Direct	H _{high}	49	<2.10	0.10464	Inverse
Recharge Line Length	57	<219	0.00963	Inverse	H _{high}	52	>/=219	4.14541	Direct
Recharge Line Vertical Relief	57	>/=40	0.14250	Direct	H _{high}	52	>/=40	3.59506	Direct
Recharge Line Gradient	57	>/=19	0.00963	Direct	H _{high}	52	<19	0.04696	Inverse
Recharge Line Mining Direction	54	n/d	0.29793	Inverse	H _{high}	49	n/d	0.00459	Direct
Recharge Line Subsided	57	100	0.00217	Direct	H _{high}	52	100	0.00081	Direct
Vertical Relief to Nearest Surface Drainage Feature	57	>/=45	0.43074	Direct	H _{high}	52	<37.5	0.12381	Inverse
Vertical Relief to Headwater Drainage Features	52	>/=45	1.23259	Direct	H _{high}	47	<40	0.07876	Inverse
Vertical Relief to First Order Drainage Features	41	>/=40	1.98870	Direct	0.20-0.10	37	>/=35	0.08342	Direct
Vertical Relief to Second Order Drainage Features	11	<70	0.07639	Inverse	H _{high}	10	<67.5	0.00000	Inverse
Lateral Distance to Nearest Surface Drainage Features	57	>/=250	0.02365	Direct	H _{high}	52	<245	1.11429	Inverse
Gradient to Nearest Surface Drainage Features	57	>/=19	0.93527	Direct	H _{high}	52	<19	0.58211	Inverse
Pre-Mine Spring Daylight Elevation	57	<1190	2.24908	Inverse	0.20-0.10	52	<1185	2.22931	Inverse
Pre-Mine Recharge Line Origin Elevation	57	>/=1235	0.00185	Direct	H _{high}	52	>/=1235	0.10955	Direct
Pre-Mine Averaged Low Flow Spring Discharge	55	>/=2.27	0.01754	Direct	H _{high}	34	<0.34	3.54167	Inverse

Table 18: Results from Methods of Investigation III. Fisher Exact Probability Test Results Used to Determine Spring Discharge Response to Mining-Induced Subsidence through the Use of the Calculated Median Value. Significant data trends are associated with error probability (P_{error}) at the 0.10 alpha level of significance.

Parameter	Optimum Reduction Boundary									
	Low EvapoTranspiration Condition with 50% Discharge Reduction					High EvapoTranspiration Condition with 60% Discharge Reduction				
	N	$H_{hydrate}$	A	B	C	D	P_{error}	N	$H_{hydrate}$	P_{error}
Recharge Line Length Perpendicular to LW Face	(ft)	54	≥ 130					49	≥ 110	
Overburden Thickness	(ft)	57	≥ 430					52	≥ 425	
Width-Depth Ratio	(unitless)	54	≥ 2.06					49	< 2.08	
Recharge Line Length	(ft)	57	≥ 219					52	≥ 219	7
Recharge Line Vertical Relief	(ft)	57	≥ 40					52	≥ 40	7
Recharge Line Gradient	(% slope)	57	≥ 19					52	≥ 19	0.01386
Recharge Line Mining Direction	(unitless)	54	n/d					49	n/d	0.01868
Recharge Line Subsided	(%)	57	100					52	100	
Vertical Relief to Nearest Surface Drainage Feature	(ft)	57	≥ 45	24	5	17	11	52	≥ 37.5	
Vertical Relief to Headwater Drainage Features	(ft)	52	≥ 45	22	5	14	11	47	< 40	
Vertical Relief to First Order Drainage Features	(ft)	41	≥ 40	17	4	11	9	37	≥ 35	
Vertical Relief to Second Order Drainage Features	(ft)	11	≥ 70					10	< 87.5	
Lateral Distance to Nearest Surface Drainage Features	(ft)	57	≥ 250					52	< 240	
Gradient to Nearest Surface Drainage Features	(% slope)	57	≥ 19					52	< 19	
Pre-Mine Spring Daylight Elevation	(ft)	57	< 190					52	< 185	1
Pre-Mine Recharge Line Origin Elevation	(ft)	57	≥ 1235					52	≥ 1235	
Pre-Mine Averaged Low Flow Spring Discharge	(gpm)	55	≥ 2.27					34	< 0.34	1
Parameter	Absolute Reduction Boundary									
	Low EvapoTranspiration Condition with 88% Discharge Reduction					High EvapoTranspiration Condition with 80% Discharge Reduction				
	N	$H_{hydrate}$	A	B	C	D	P_{error}	N	$H_{hydrate}$	P_{error}
Recharge Line Length Perpendicular to LW Face	(ft)	54	< 130					49	≥ 110	0.06013
Overburden Thickness	(ft)	57	< 430					52	< 425	
Width-Depth Ratio	(unitless)	54	≥ 2.06					49	< 2.10	
Recharge Line Length	(ft)	57	< 219					52	≥ 219	8
Recharge Line Vertical Relief	(ft)	57	≥ 40					52	≥ 40	8
Recharge Line Gradient	(% slope)	57	≥ 19					52	< 19	0.02769
Recharge Line Mining Direction	(unitless)	54	n/d					49	n/d	
Recharge Line Subsided	(%)	57	100					52	100	
Vertical Relief to Nearest Surface Drainage Feature	(ft)	57	≥ 45					52	< 37.5	
Vertical Relief to Headwater Drainage Features	(ft)	52	≥ 45					47	< 40	
Vertical Relief to First Order Drainage Features	(ft)	41	≥ 40	13	8	7	13	37	≥ 35	
Vertical Relief to Second Order Drainage Features	(ft)	11	< 70					10	< 67.5	
Lateral Distance to Nearest Surface Drainage Features	(ft)	57	≥ 250					52	< 245	
Gradient to Nearest Surface Drainage Features	(% slope)	57	≥ 19					52	< 19	
Pre-Mine Spring Daylight Elevation	(ft)	57	< 190	13	18	17	9	52	< 185	2
Pre-Mine Recharge Line Origin Elevation	(ft)	57	≥ 1235					52	≥ 1235	
Pre-Mine Averaged Low Flow Spring Discharge	(gpm)	55	≥ 2.27					34	< 0.34	2

specific independent variables were examined for statistically significant data trends through the use of the calculated independent variable median values and median contingency table tests (Figure 16). Refer to Appendix E for figures illustrating acceptance of the significant alternative hypotheses and data tables used for calculating Fisher exact error probabilities at the 0.10 alpha level of significance. Two or more springs plotted at the same position (spring discharge change and independent variable value) are not deciphered in the Appendix E independent variable-specific figures; consult the Appendix E independent variable-specific tables for information regarding this scenario.

		Spring Discharge Reduction Boundary Condition		Totals
		$\geq$	$<$	
Spring Frequency for $\geq$ Median Independent Variable Value	A	B	A+B	
Spring Frequency for $<$ Median Independent Variable Value	C	D	C+D	
Totals	A+C	B+D		

where,

A is the number of undermined springs $\geq$ the calculated independent variable median value and $\geq$ the spring discharge reduction boundary condition

B is the number of undermined springs $<$ the calculated independent variable median value and $<$ the spring discharge reduction boundary condition

C is the number of undermined springs $\geq$ the calculated independent variable median value and $\geq$ the spring discharge reduction boundary condition

D is the number of undermined springs $<$ the calculated independent variable median value and $<$ the spring discharge reduction boundary condition

Figure 16: 2x2 Contingency Table Test Used for Spring Discharge Response, Investigation III.

8.2.5.1 *Low Evapotranspiration Condition – Optimum Reduction Boundary*

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for vertical relief to nearest surface drainage features, vertical relief to headwater surface drainage (first and second order) features, and vertical relief to first order surface drainage features. The significant alternative hypothesis statements are as follows:

- Spring discharge impairment is associated with vertical relief to nearest surface drainage features greater than or equal to the calculated median value of 45 feet (Appendix E_fig_1 and E_tab_1); +/- 5ft.
- Spring discharge impairment is associated with vertical relief to headwater surface drainage (first and second order) features greater than or equal to the calculated median value of 45 feet (Appendix E_fig_2 and E_tab_2); +/- 5ft.
- Spring discharge impairment is associated with vertical relief to first order surface drainage features greater than or equal to the calculated median value of 40 feet (Appendix E_fig_3 and E_tab_3); +/- 5ft.

The use of Chi square contingency tests resulted in calculated error probabilities of 0.20-0.10, 0.10-0.05, and 0.20-0.10, respectively, for the above data trends (Table 17). The use of Fisher exact probability tests resulted in calculated error probabilities of 0.05918, 0.04516, and 0.07315, respectively (Table 18). The remaining alternative hypotheses examined for the topographic and mine independent variables were rejected by the Chi square contingency and Fisher exact probability tests at the 0.20 and 0.10 alpha probability levels, respectively.

Based upon the statistical results, the use of vertical relief to nearest surface drainage features, vertical relief to headwater surface drainage features, and vertical relief to first order surface drainage features, resulted in 94 percent, 95 percent, and 92 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for these respective independent variables.

8.2.5.2 Low Evapotranspiration Condition – Absolute Reduction Boundary

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for vertical relief to first order surface drainage features and spring daylight elevation. The significant alternative hypothesis statements are as follows:

- Spring discharge impairment is associated with vertical relief to first order surface drainage features greater than or equal to the calculated median value of 40 feet (Appendix E_fig_4 and E_tab_4); +/- 5ft.
- Spring discharge impairment is associated with pre-mining spring daylight elevation less than the calculated median value of 1190 feet msl (Appendix E_fig_5 and E_tab_5); +/- 5ft.

The use of Chi square contingency tests resulted in calculated error probabilities of 0.20-0.10 and 0.20-0.10, respectively, for the above data trends (Table 17). The use of Fisher exact probability tests resulted in calculated error probabilities of 0.07888 and 0.06644, respectively (Table 18). The remaining alternative hypotheses examined for the topographic and mine independent variables were rejected by the Chi square contingency

and Fisher exact probability tests at the 0.20 and 0.10 alpha probability levels, respectively.

Based upon the statistical results, the use of vertical relief to first order surface drainage features, gradient to nearest surface drainage features, and pre-mining spring daylight elevation resulted in 92 percent and 93 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for these respective independent variables.

8.2.5.3 High Evapotranspiration Condition – Optimum Reduction Boundary

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for recharge line length, recharge line vertical relief, spring daylight elevation, and pre-mine average low flow discharge. The significant alternative hypothesis statements are as follows:

- Spring discharge impairment is associated with recharge line length greater than or equal to the calculated median value of 219 feet (Appendix E_fig_6 and E_tab_6); +/- 10ft.
- Spring discharge impairment is associated with recharge line vertical relief greater than or equal to the calculated median value of 40 feet (Appendix E_fig_7 and E_tab_7); +/- 5ft.
- Spring discharge impairment is associated with pre-mining spring daylight elevation less than the calculated median value of 1185 feet msl (Appendix E_fig_8 and E_tab_8); +/- 5ft.

- Spring discharge impairment is associated with pre-mine average low flow discharge less than the calculated median value of 0.34 gpm (Appendix E_fig_9 and E_tab_9).

The use of Chi square contingency tests resulted in calculated error probabilities of 0.05-0.02, 0.05-0.02, 0.10-0.05, and 0.05-0.02, respectively, for the above data trends (Table 17). The use of Fisher exact probability tests resulted in calculated error probabilities of 0.01386, 0.01868, 0.04189, and 0.01955, respectively (Table 18). The remaining alternative hypotheses examined for the topographic and mine independent variables were rejected by the Chi square contingency and Fisher exact probability tests, at the 0.20 and 0.10 alpha probability levels, respectively.

Based upon the statistical results, the use of recharge line length, recharge line vertical relief, recharge line gradient, pre-mining spring daylight elevation, and pre-mine average low flow discharge resulted in 99 percent, 98 percent, 96 percent, and 98 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for these respective independent variables.

8.2.5.4 *High Evapotranspiration Condition – Absolute Reduction Boundary*

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for the recharge line length component perpendicular to longwall panel face, recharge line length, recharge line vertical relief, spring daylight elevations, and pre-mine average low flow discharges. The significant alternative hypothesis statements are as follows:

- Spring discharge impairment is associated with the recharge line length component perpendicular to longwall panel face greater than or equal to the calculated median value of 110 feet (Appendix E_fig_10 and E_tab_10); +/- 10ft.
- Spring discharge impairment is associated with recharge line length greater than or equal to the calculated median value of 219 feet (Appendix E_fig_11 and E_tab_11); +/- 10ft.
- Spring discharge impairment is associated with recharge line vertical relief greater than or equal to the calculated median value of 40 feet (Appendix E_fig_12 and E_tab_12); +/- 5ft.
- Spring discharge impairment is associated with pre-mining spring daylight elevation less than the calculated median value of 1185 feet msl (Appendix E_fig_13 and E_tab_13); +/- 5ft.
- Spring discharge impairment is associated with pre-mine average low flow discharge less than the calculated median value of 0.34 gpm (Appendix E_fig_14 and E_tab_14).

The use of Chi square contingency tests resulted in calculated error probabilities of 0.20-0.10, 0.05-0.02, 0.10-0.05, 0.20-0.10, and 0.10-0.05, respectively, for the above data trends (Table 17). The use of Fisher exact probability tests resulted in calculated error probabilities of 0.06013, 0.02001, 0.02769, 0.06553, and 0.02851, respectively (Table 18). The remaining alternative hypotheses examined for the topographic and mine independent variables were rejected by the Chi square contingency and Fisher exact probability tests, at the 0.20 and 0.10 alpha probability levels, respectively.

Based upon the statistical results, the use of recharge line length component perpendicular to longwall panel face, recharge line length, recharge line vertical relief, pre-mining spring daylight elevation, and pre-mine average low flow discharge resulted in 94 percent, 98 percent, 97 percent, 93 percent, and 97 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for these respective independent variables.

8.2.6 Degree of Spring Discharge Response Statistical Examination (Median Value)

The following results from the Chi square contingency and Fisher exact probability statistical examination for the degree of spring discharge response are provided in Tables 19 and 20, respectively. These results are listed according to evapotranspiration condition and spring discharge reduction boundary. The hydrologic, geologic, topographic, and mine-specific independent variables were examined for statistically significant data trends through the use of the calculated independent variable median values and median contingency table tests (Figure 17). Refer to Appendix F for figures illustrating acceptance of the significant alternative hypotheses and data tables used for calculating Fisher exact error probabilities at the 0.10 alpha level of significance. Two or more springs plotted at the same position (spring discharge change and independent variable value) are not deciphered in the Appendix F independent variable-specific figures; consult the Appendix F independent variable-specific tables for information regarding this scenario.

Table 19: Results from Methods of Investigation II. Chi Square Contingency Test Results Used to Determine the Degree of Spring Discharge Impairment Associated with Mining-Induced Subsidence through the Use of the Calculated Median Value. Significant data trends are associated with error probability (P_{error}) at the 0.20 alpha level of significance.

Parameter		Optimum Reduction Boundary											
		Low EvapoTranspiration Condition with 50% Discharge Reduction						High EvapoTranspiration Condition with 60% Discharge Reduction					
		N	H _{alternate}	Chi-Square Value	H _{alternate}	Trend	P _{error}	N	H _{alternate}	Chi-Square Value	H _{alternate}	Trend	P _{error}
Recharge Line Length Perpendicular to LW Face	(ft)	47	>=140	0.04554	Direct	H _{tail}		44	>=115	0.52381	Direct	H _{tail}	
Overburden Thickness	(ft)	50	<437.5	0.00000	Inverse	H _{tail}		46	>=425	0.43660	Direct	H _{tail}	
Width-Depth Ratio	(unitless)	47	>=2.05	0.10377	Direct	H _{tail}		44	>=2.07	0.43380	Direct	H _{tail}	
Recharge Line Length	(ft)	50	<234.5	0.54201	Inverse	H _{tail}		46	>=250	0.61876	Direct	H _{tail}	
Recharge Line Vertical Relief	(ft)	50	>=40	0.11636	Direct	H _{tail}		46	>=42.5	0.52273	Direct	H _{tail}	
Recharge Line Gradient	(% slope)	50	>=19	0.11636	Direct	H _{tail}		46	>=19	0.43660	Direct	H _{tail}	
Recharge Line Mining Direction	(unitless)	47	n/d	0.00504	Inverse	H _{tail}		44	n/d	0.52381	Inverse	H _{tail}	
Recharge Line Subsid	(%)	50	100	0.23937	Direct	H _{tail}		46	100	0.08821	Direct	H _{tail}	
Vertical Relief to Nearest Surface Drainage Feature	(ft)	50	>=45	2.57995	Direct	H _{tail}	0.20-0.10	46	<37.5	0.52273	Inverse	H _{tail}	
Vertical Relief to Headwater Drainage Features	(ft)	45	>=45	2.95201	Direct	H _{tail}	0.10-0.05	41	<40	0.47589	Inverse	H _{tail}	
Vertical Relief to First Order Drainage Features	(ft)	36	>=42.5	1.44643	Direct	H _{tail}		33	>=35	0.04859	Direct	H _{tail}	
Vertical Relief to Second Order Drainage Features	(ft)	9	>=70	0.01406	Direct	H _{tail}		8	<67.5	0.00000	Inverse	H _{tail}	
Lateral Distance to Nearest Surface Drainage Features	(ft)	50	>=245	0.54201	Direct	H _{tail}		46	<218.82	0.52273	Inverse	H _{tail}	
Gradient to Nearest Surface Drainage Features	(% slope)	50	>=19	0.00000	Direct	H _{tail}		46	<19	0.29052	Inverse	H _{tail}	
Pre-Mine Spring Daylight Elevation	(ft)	50	>=1187.5	0.00000	Direct	H _{tail}		46	<1182.5	0.52273	Inverse	H _{tail}	
Pre-Mine Recharge Line Origin Elevation	(ft)	50	>=1235	0.00388	Direct	H _{tail}		46	>=1235	0.22927	Direct	H _{tail}	
Pre-Mine Averaged Low Flow Spring Discharge	(gpm)	48	<2.40	0.54701	Inverse	H _{tail}		28	<0.31	0.53846	Inverse	H _{tail}	
Parameter		Absolute Reduction Boundary											
		Low EvapoTranspiration Condition with 88% Discharge Reduction						High EvapoTranspiration Condition with 80% Discharge Reduction					
		N	H _{alternate}	Chi-Square Value	H _{alternate}	Trend	P _{error}	N	H _{alternate}	Chi-Square Value	H _{alternate}	Trend	P _{error}
Recharge Line Length Perpendicular to LW Face	(ft)	47	<140	1.34079	Inverse	H _{tail}		44	>=115	2.47500	Direct	H _{tail}	0.20-0.10
Overburden Thickness	(ft)	50	<437.5	0.08333	Inverse	H _{tail}		46	<425	0.18721	Inverse	H _{tail}	
Width-Depth Ratio	(unitless)	47	>=2.05	0.24746	Direct	H _{tail}		44	>=2.08	0.00000	Direct	H _{tail}	
Recharge Line Length	(ft)	50	<234.5	0.75000	Inverse	H _{tail}		46	>=250	0.37804	Direct	H _{tail}	
Recharge Line Vertical Relief	(ft)	50	>=40	0.03044	Direct	H _{tail}		46	>=42.5	0.27381	Direct	H _{tail}	
Recharge Line Gradient	(% slope)	50	>=19	0.03044	Direct	H _{tail}		46	<19	0.18721	Inverse	H _{tail}	
Recharge Line Mining Direction	(unitless)	47	n/d	0.17229	Direct	H _{tail}		44	n/d	0.27500	None	H _{tail}	
Recharge Line Subsid	(%)	50	100	0.46339	Direct	H _{tail}		46	100	0.01426	Direct	H _{tail}	
Vertical Relief to Nearest Surface Drainage Feature	(ft)	50	>=45	0.27043	Direct	H _{tail}		46	<37.5	0.27381	Inverse	H _{tail}	
Vertical Relief to Headwater Drainage Features	(ft)	45	>=45	0.97640	Direct	H _{tail}		42	<37.5	0.00000	Inverse	H _{tail}	
Vertical Relief to First Order Drainage Features	(ft)	36	>=42.5	1.01250	Direct	H _{tail}		33	>=35	0.15548	Direct	H _{tail}	
Vertical Relief to Second Order Drainage Features	(ft)	9	<70	0.05625	Inverse	H _{tail}		8	<67.5	0.00000	Inverse	H _{tail}	
Lateral Distance to Nearest Surface Drainage Features	(ft)	50	>=245	0.08333	Direct	H _{tail}		46	<229.41	0.27381	Inverse	H _{tail}	
Gradient to Nearest Surface Drainage Features	(% slope)	50	>=19	0.08333	Direct	H _{tail}		46	<19	0.64503	Inverse	H _{tail}	
Pre-Mine Spring Daylight Elevation	(ft)	50	<1187.5	0.75000	Inverse	H _{tail}		46	<1182.5	0.27381	Inverse	H _{tail}	
Pre-Mine Recharge Line Origin Elevation	(ft)	50	>=1235	0.00364	Direct	H _{tail}		46	>=1235	0.02615	Direct	H _{tail}	
Pre-Mine Averaged Low Flow Spring Discharge	(gpm)	48	>=2.40	0.08571	None	H _{tail}		28	<0.31	0.29167	Inverse	H _{tail}	

Table 20: Results from Methods of Investigation III. Fisher Exact Probability Test Results Used to Determine the Degree of Spring Discharge Impairment Associated with Mining-Induced Subsidence through the Use of the Calculated Median Value. Significant data trends are associated with error probability (P_{error}) at the 0.10 alpha level of significance.

Parameter	Optimum Reduction Boundary									
	Low EvapoTranspiration Condition with 50% Discharge Reduction					High EvapoTranspiration Condition with 60% Discharge Reduction				
	N	$H_{hydrate}$	A	B	C	D	P_{error}	N	$H_{hydrate}$	P_{error}
Recharge Line Length Perpendicular to LW Face	(ft)	47	>=140					44	>=115	
Overburden Thickness	(ft)	50	<437.5					46	>=425	
Width-Depth Ratio	(unitless)	47	>=2.05					44	>=2.07	
Recharge Line Length	(ft)	50	<234.5					46	>=250	
Recharge Line Vertical Relief	(ft)	50	>=40					46	>=42.5	
Recharge Line Gradient	(% slope)	50	>=19					46	>=19	
Recharge Line Mining Direction	(unitless)	47	n/d					44	n/d	
Recharge Line Subsidied	(%)	50	100					46	100	
Vertical Relief to Nearest Surface Drainage Feature	(ft)	50	>=45	24	2	17	7	46	<37.5	
Vertical Relief to Headwater Drainage Features	(ft)	45	>=45	22	2	14	7	41	<40	
Vertical Relief to First Order Drainage Features	(ft)	36	>=42.5					33	>=35	
Vertical Relief to Second Order Drainage Features	(ft)	9	>=70					8	<67.5	
Lateral Distance to Nearest Surface Drainage Features	(ft)	50	>=245					46	<218.82	
Gradient to Nearest Surface Drainage Features	(% slope)	50	>=19					46	<19	
Pre-Mine Spring Daylight Elevation	(ft)	50	>=1187.5					46	<1182.5	
Pre-Mine Recharge Line Origin Elevation	(ft)	50	>=1235					46	>=1235	
Pre-Mine Averaged Low Flow Spring Discharge	(gpm)	48	<2.40					28	<0.31	

Parameter	Absolute Reduction Boundary									
	Low EvapoTranspiration Condition with 88% Discharge Reduction					High EvapoTranspiration Condition with 80% Discharge Reduction				
	N	$H_{hydrate}$	A	B	C	D	P_{error}	N	$H_{hydrate}$	P_{error}
Recharge Line Length Perpendicular to LW Face	(ft)	47	<140					44	>=115	
Overburden Thickness	(ft)	50	<437.5					46	<425	
Width-Depth Ratio	(unitless)	47	>=2.05					44	>=2.08	
Recharge Line Length	(ft)	50	<234.5					46	>=250	
Recharge Line Vertical Relief	(ft)	50	>=40					46	>=42.5	
Recharge Line Gradient	(% slope)	50	>=19					46	<19	
Recharge Line Mining Direction	(unitless)	47	n/d					44	n/d	
Recharge Line Subsidied	(%)	50	100					46	100	
Vertical Relief to Nearest Surface Drainage Feature	(ft)	50	>=45					46	<37.5	
Vertical Relief to Headwater Drainage Features	(ft)	45	>=45					42	<37.5	
Vertical Relief to First Order Drainage Features	(ft)	36	>=42.5					33	>=35	
Vertical Relief to Second Order Drainage Features	(ft)	9	<70					8	<67.5	
Lateral Distance to Nearest Surface Drainage Features	(ft)	50	>=245					46	<229.41	
Gradient to Nearest Surface Drainage Features	(% slope)	50	>=19					46	<19	
Pre-Mine Spring Daylight Elevation	(ft)	50	<1187.5					46	<1182.5	
Pre-Mine Recharge Line Origin Elevation	(ft)	50	>=1235					46	>=1235	
Pre-Mine Averaged Low Flow Spring Discharge	(gpm)	48	>=2.40					28	<0.31

8.2.6.1 Low Evapotranspiration Condition – Optimum Reduction Boundary

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for vertical relief to nearest surface drainage features and vertical relief to headwater surface drainage (first and second order) features. The significant alternative hypothesis statements are as follows:

- Spring discharge impairment is associated with vertical relief to nearest surface drainage features greater than or equal to the calculated median value of 45 feet (Appendix F_fig_1 and F_tab_1); +/- 5ft.

- Spring discharge impairment is associated with vertical relief to headwater surface drainage (first and second order) features greater than or equal to the calculated median value of 45 feet (Appendix F_fig_2 and F_tab_2); +/- 5ft.

The use of Chi square contingency tests resulted in calculated error probabilities of 0.20-0.10, and 0.10-0.05, respectively, for the above data trends (Table 19). The use of Fisher exact probability tests resulted in calculated error probabilities of 0.05305 and 0.04206, respectively (Table 20). The remaining alternative hypotheses examined for the topographic and mine independent variables were rejected by the Chi square contingency and Fisher exact probability tests, at the 0.20 and 0.10 alpha probability levels, respectively.

Based upon the statistical results, the use of vertical relief to nearest surface drainage features and vertical relief to headwater surface drainage features resulted in 95 percent and 96 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for these respective independent variables.

8.2.6.2 *Low Evapotranspiration Condition – Absolute Reduction Boundary*

Nonparametric statistical tests resulted in rejection of all the alternative hypotheses; therefore, there are no significant statistical relationships between the degree of spring impairment and the independent variables during low evapotranspiration conditions when evaluated at the absolute reduction boundary.

8.2.6.3 *High Evapotranspiration Condition – Optimum Reduction Boundary*

Nonparametric statistical tests resulted in rejection of all the alternative hypotheses, therefore, there are no significant statistical relationships between the degree of spring impairment and the independent variables during high evapotranspiration conditions when evaluated at the optimum reduction boundary.

8.2.6.4 *High Evapotranspiration Condition – Absolute Reduction Boundary*

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for the recharge line length component perpendicular to longwall panel face. The significant alternative hypothesis statement is as follows:

- Spring discharge impairment is associated with the recharge line length component perpendicular to longwall panel face greater than or equal to the calculated median value of 115 feet (Appendix F_fig_3 and F_tab_3); +/- 10ft.

The use of the Chi square contingency test resulted in a calculated error probability of 0.20-0.10, for this data trend (Table 19). The use of the Fisher exact probability test resulted in a calculated error probability of 0.05389 (Table 20). The remaining alternative hypotheses examined for the topographic and mine independent variables were rejected by the Chi square contingency and Fisher exact probability tests, at the 0.20 and 0.10 alpha probability levels, respectively.

Based upon the statistical results, the use of recharge line length component perpendicular to longwall panel face resulted in a 95 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for this independent variable.

9.0 INVESTIGATION IV

9.1 Methods of Investigation IV

The previous investigations have evaluated the hydrologic, geologic, topographic, and mine-specific independent variables for association with spring discharge impairment through the use of the calculated variable median values. The methodology of Investigation IV uses interpreted best-fit partitioning values in place of the calculated median values. These interpreted best-fit values were determined through shifting the boundary condition of the independent variable from the median value in order to minimize the probability of error through optimizing the distribution of the spring discharge responses among the group data classes of the 2x2 contingency statistical tests. The best-fit partition value tests are more representative of data trends for spring discharge associated with the variables than data trends determined from the median value tests.

9.2 Results of Investigation IV

9.2.1 Spring Discharge Response Statistical Examination (Interpreted Best Fit Value)

The following results from the Chi square contingency and Fisher exact probability statistical examinations of spring discharge response trends are provided in Tables 21 and 22, respectively. These results are listed according to evapotranspiration condition and spring discharge reduction boundary. The hydrologic, geologic, topographic, and mine-specific independent variables were examined for statistical significance through the use

Table 21: Results from Methods of Investigation IV Chi Square Contingency Test Results Used to Determine Spring Discharge Response to Mining-Induced Subsidence through the Use of the Interpreted Best Fit Value. Significant data trends are associated with error probability (P_{error}) at the 0.20 alpha level of significance.

Parameter	Optimum Reduction Boundary									
	Low EvapoTranspiration Condition with 50% Discharge Reduction					High EvapoTranspiration Condition with 60% Discharge Reduction				
	N	H _{alternate}	Chi-Square Value	H _{alternate} Trend	Perior	N	H _{alternate}	Chi-Square Value	H _{alternate} Trend	Perior
Recharge Line Length Perpendicular to LW Face	54				H _{real}	49				H _{real}
Overburden Thickness	57				H _{real}	52				H _{real}
Width-Depth Ratio	(unitless)					49				H _{real}
Recharge Line Length	57				H _{real}	52	>/=189	4.68594	Direct	0.05-0.02
Recharge Line Vertical Relief	57				H _{real}	52	>/=36	4.16788	Direct	0.05-0.02
Recharge Line Gradient	(% slope)				H _{real}	52				H _{real}
Recharge Line Mining Direction	(unitless)				H _{real}	52				H _{real}
Recharge Line Subsidied	(%)				H _{real}	49				H _{real}
Vertical Relief to Nearest Surface Drainage Feature	(ft)	57	>/=36		H _{real}	52				H _{real}
Vertical Relief to Headwater Drainage Features	(ft)	52	>/=36	Direct	0.10-0.05	52				H _{real}
Vertical Relief to First Order Drainage Features	(ft)	41	>/=36	Direct	0.10-0.05	47				H _{real}
Vertical Relief to Second Order Drainage Features	(ft)	11	>/=36	Direct	0.20-0.10	37				H _{real}
Lateral Distance to Nearest Surface Drainage Features	(ft)	57			H _{real}	10				H _{real}
Gradient to Nearest Surface Drainage Features	(% slope)	57			H _{real}	52				H _{real}
Pre-Mine Spring Daylight Elevation	(ft)	57			H _{real}	52	<1209	6.40254	hverse	0.02-0.01
Pre-Mine Recharge Line Origin Elevation	(ft)	57			H _{real}	52				H _{real}
Pre-Mine Averaged Low Flow Spring Discharge	(gpm)	55			H _{real}	34	<0.43	6.93602	hverse	0.01-0.001
Parameter	Absolute Reduction Boundary									
	Low EvapoTranspiration Condition with 88% Discharge Reduction					High EvapoTranspiration Condition with 80% Discharge Reduction				
	N	H _{alternate}	Chi-Square Value	H _{alternate} Trend	Perior	N	H _{alternate}	Chi-Square Value	H _{alternate} Trend	Perior
Recharge Line Length Perpendicular to LW Face	54				H _{real}	49	>/=101	2.38336	Direct	0.20-0.10
Overburden Thickness	57				H _{real}	52				H _{real}
Width-Depth Ratio	(unitless)				H _{real}	49				H _{real}
Recharge Line Length	57				H _{real}	52	>/=189	4.14541	Direct	0.05-0.02
Recharge Line Vertical Relief	(ft)	57			H _{real}	52	>/=31	4.75191	Direct	0.05-0.02
Recharge Line Gradient	(% slope)	57			H _{real}	52				H _{real}
Recharge Line Mining Direction	(unitless)	54			H _{real}	49				H _{real}
Recharge Line Subsidied	(%)	57			H _{real}	52				H _{real}
Vertical Relief to Nearest Surface Drainage Feature	(ft)	57			H _{real}	52				H _{real}
Vertical Relief to Headwater Drainage Features	(ft)	52	>/=36	Direct	0.20-0.10	47				H _{real}
Vertical Relief to First Order Drainage Features	(ft)	41	>/=36	Direct	0.20-0.10	37				H _{real}
Vertical Relief to Second Order Drainage Features	(ft)	11			H _{real}	10				H _{real}
Lateral Distance to Nearest Surface Drainage Features	(ft)	57			H _{real}	52				H _{real}
Gradient to Nearest Surface Drainage Features	(% slope)	57			H _{real}	52				H _{real}
Pre-Mine Spring Daylight Elevation	(ft)	57			H _{real}	52				H _{real}
Pre-Mine Recharge Line Origin Elevation	(ft)	57	<1190	Inverse	0.20-0.10	52	<1209	6.81038	hverse	0.01-0.001
Pre-Mine Averaged Low Flow Spring Discharge	(gpm)	55			H _{real}	34	<0.43	6.69122	hverse	0.01-0.001

Table 22: Results from Methods of Investigation IV – Fisher Exact Probability Test Results Used to Determine Spring Discharge Response to Mining-Induced Subsidence through the Use of the Interpreted Best Fit Value. Significant data trends are associated with error probability (P_{error}) at the 0.10 alpha level of significance.

Parameter	Optimum Reduction Boundary										
	Low EvapoTranspiration Condition with 50% Discharge Reduction					High EvapoTranspiration Condition with 60% Discharge Reduction					
	N	H _{transpa}	A	B	C	D	P _{error}	N	H _{transpa}	A	P _{error}
Recharge Line Length Perpendicular to LW Face	54						H _{adj}	49			H _{adj}
Overburden Thickness	57						H _{adj}	52			H _{adj}
Width-Depth Ratio	54						H _{adj}	49			H _{adj}
Recharge Line Length	57						H _{adj}	52	>=189	27	1
Recharge Line Vertical Relief	57						H _{adj}	52	>=36	26	1
Recharge Line Gradient	57						H _{adj}	52	>=36	26	1
Recharge Line Mining Direction	54						H _{adj}	49			H _{adj}
Recharge Line Subsided	57						H _{adj}	52			H _{adj}
Vertical Relief to Nearest Surface Drainage Feature	57	>=36	26	5	15	11	0.02881	52			H _{adj}
Vertical Relief to Headwater Drainage Features	52	>=36	23	5	13	11	0.02988	47			H _{adj}
Vertical Relief to First Order Drainage Features	41	>=36	17	4	11	9	0.07315	37			H _{adj}
Vertical Relief to Second Order Drainage Features	11						H _{adj}	10			H _{adj}
Lateral Distance to Nearest Surface Drainage Features	57						H _{adj}	52			H _{adj}
Gradient to Nearest Surface Drainage Features	57						H _{adj}	52			H _{adj}
Pre-Mine Spring Daylight Elevation	57						H _{adj}	52	<1209	10	6
Pre-Mine Recharge Line Origin Elevation	57						H _{adj}	52			H _{adj}
Pre-Mine Averaged Low Flow Spring Discharge	55						H _{adj}	34	<0.43	7	7
											1
											0.00395
Parameter	Absolute Reduction Boundary										
	Low EvapoTranspiration Condition with 88% Discharge Reduction					High EvapoTranspiration Condition with 80% Discharge Reduction					
	N	H _{transpa}	A	B	C	D	P _{error}	N	H _{transpa}	A	P _{error}
Recharge Line Length Perpendicular to LW Face	54						H _{adj}	49	>=101	23	2
Overburden Thickness	57						H _{adj}	52			H _{adj}
Width-Depth Ratio	54						H _{adj}	49			H _{adj}
Recharge Line Length	57						H _{adj}	52	>=189	26	2
Recharge Line Vertical Relief	57						H _{adj}	52	>=31	27	2
Recharge Line Gradient	57						H _{adj}	52			H _{adj}
Recharge Line Mining Direction	54						H _{adj}	49			H _{adj}
Recharge Line Subsided	57						H _{adj}	52			H _{adj}
Vertical Relief to Nearest Surface Drainage Feature	57						H _{adj}	52			H _{adj}
Vertical Relief to Headwater Drainage Features	52	>=36	17	11	9	15	0.08185	47			H _{adj}
Vertical Relief to First Order Drainage Features	41	>=36	13	8	7	13	0.07888	37			H _{adj}
Vertical Relief to Second Order Drainage Features	11						H _{adj}	10			H _{adj}
Lateral Distance to Nearest Surface Drainage Features	57						H _{adj}	52			H _{adj}
Gradient to Nearest Surface Drainage Features	57						H _{adj}	52			H _{adj}
Pre-Mine Spring Daylight Elevation	57						H _{adj}	52	<1209	9	7
Pre-Mine Recharge Line Origin Elevation	57						H _{adj}	52			H _{adj}
Pre-Mine Averaged Low Flow Spring Discharge	55						H _{adj}	34	<0.43	6	8
											18
											2
											0.00466

of the interpreted best-fit values and contingency table tests (Figure 18). Refer to Appendix G for figures illustrating acceptance of the significant alternative hypotheses and data tables used for calculating Fisher exact error probabilities at the 0.10 alpha level of significance. Two or more springs plotted at the same position (spring discharge change and independent variable value) are not deciphered in the Appendix G independent variable-specific figures; consult the Appendix G independent variable-specific tables for information regarding this scenario.

		Spring Discharge Reduction Boundary Condition		Totals
		$\geq$	$<$	
Spring Frequency for $\geq$ Interpreted Best Fit Value		A	B	A+B
Spring Frequency for $<$ Interpreted Best Fit Value		C	D	C+D
	Totals	A+C	B+D	

where,

- A is the number of undermined springs $\geq$ the interpreted best fit value and $\geq$ the spring discharge reduction boundary condition
- B is the number of undermined springs $\geq$ the interpreted best fit value and $<$ the spring discharge reduction boundary condition
- C is the number of undermined springs $<$ the interpreted best fit value and $\geq$ the spring discharge reduction boundary condition
- D is the number of undermined springs $<$ the interpreted best fit value and $<$ the spring discharge reduction boundary condition

Figure 18: 2x2 Contingency Table Test Used for Spring Discharge Response, Investigation IV.

9.2.1.1 *Low Evapotranspiration Condition – Optimum Reduction Boundary*

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for vertical relief to nearest surface drainage features, vertical relief to headwater surface drainage (first and second order) features, and vertical relief to first order surface drainage features. The significant alternative hypothesis statements are as follows:

- Spring discharge impairment is associated with vertical relief to nearest surface drainage features greater than or equal to the interpreted best fit value of 36 feet (Appendix G_fig_1 and G_tab_1); +/- 5ft.
- Spring discharge impairment is associated with vertical relief to headwater surface drainage (first and second order) features greater than or equal to the interpreted best fit value of 36 feet (Appendix G_fig_2 and G_tab_2); +/- 5ft.
- Spring discharge impairment is associated with vertical relief to first order surface drainage features greater than or equal to the interpreted best fit value of 36 feet (Appendix G_fig_3 and G_tab_3); +/- 5ft.

The use of Chi square contingency tests resulted in calculated error probabilities of 0.10-0.05, 0.10-0.05, and 0.20-0.10, respectively, for the above data trends (Table 21). The use of Fisher exact probability tests resulted in calculated error probabilities of 0.02881, 0.02988, and 0.07315, respectively (Table 22). The remaining alternative hypotheses examined for the topographic and mine independent variables were rejected by the Chi square contingency and Fisher exact probability tests, at the 0.20 and 0.10 alpha probability levels, respectively.

Based upon the statistical results, the use of vertical relief to nearest surface drainage features, vertical relief to headwater surface drainage features and vertical relief to first

order surface drainage features resulted in 97 percent, 97 percent, and 93 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for these respective independent variables.

9.2.1.2 Low Evapotranspiration Condition – Absolute Reduction Boundary

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for vertical relief to headwater surface drainage (first and second order) features, vertical relief to first order surface drainage features, and spring daylight elevation. The significant alternative hypothesis statements are as follows:

- Spring discharge impairment is associated with vertical relief to headwater surface drainage (first and second order) features greater than or equal to the interpreted best fit value of 36 feet (Appendix G_fig_4 and G_tab_4); +/- 5ft.
- Spring discharge impairment is associated with vertical relief to first order surface drainage features greater than or equal to the interpreted best fit value of 36 feet (Appendix G_fig_5 and G_tab_5); +/- 5ft.
- Spring discharge impairment is associated with pre-mining spring daylight elevation less than the interpreted best fit value of 1190 feet msl (Appendix G_fig_6 and G_tab_6); +/- 5ft.

The use of Chi square contingency tests resulted in calculated error probabilities of 0.20-0.10, 0.20-0.10, and 0.20-0.10, respectively, for the above data trends (Table 21). The use of Fisher exact probability tests resulted in calculated error probabilities of 0.08185, 0.07888, and 0.06644, respectively (Table 22). The remaining alternative hypotheses examined for the topographic and mine independent variables were rejected by the Chi

square contingency and Fisher exact probability tests, at the 0.20 and 0.10 alpha probability levels, respectively.

Based upon the statistical results, the use of vertical relief to headwater surface drainage features, vertical relief to first order surface drainage features, and pre-mining spring daylight elevation resulted in 92 percent, 92 percent, and 93 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for these respective independent variables.

9.2.1.3 High Evapotranspiration Condition – Optimum Reduction Boundary

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for recharge line length, recharge line vertical relief, spring daylight elevation, and pre-mine average low flow discharge. The significant alternative hypothesis statements are as follows:

- Spring discharge impairment is associated with recharge line length greater than or equal to the interpreted best fit value of 189 feet (Appendix G_fig_7 and G_tab_7); +/- 10ft.
- Spring discharge impairment is associated with recharge line vertical relief greater than or equal to the interpreted best fit value of 36 feet (Appendix G_fig_8 and G_tab_8); +/- 5ft.
- Spring discharge impairment is associated with pre-mining spring daylight elevation less than the interpreted best fit value of 1209 feet msl (Appendix G_fig_9 and G_tab_9); +/- 5ft.

- Spring discharge impairment is associated with pre-mine average low flow discharge less than the interpreted best fit value of 0.43 gpm (Appendix G_fig_10 and G_tab_10).

The use of Chi square contingency tests resulted in calculated error probabilities of 0.05-0.02, 0.05-0.02, 0.02-0.01, and 0.01-0.001, respectively, for the above data trends (Table 21). The use of Fisher exact probability tests resulted in calculated error probabilities of 0.01385, 0.01868, 0.00727, and 0.00395, respectively (Table 22). The remaining alternative hypotheses examined for the topographic and mine independent variables were rejected by the Chi square contingency and Fisher exact probability tests, at the 0.20 and 0.10 alpha probability levels, respectively.

Based upon the statistical results, the use of recharge line length, recharge line vertical relief, recharge line gradient, pre-mining spring daylight elevation, and pre-mine average low flow discharge resulted in 99 percent, 98 percent, 99 percent, and 99 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for these respective independent variables.

9.2.1.4 *High Evapotranspiration Condition – Absolute Reduction Boundary*

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for the recharge line length component perpendicular to longwall panel face, recharge line length, recharge line vertical relief, spring daylight elevation, and pre-mine average low flow discharge. The significant alternative hypothesis statements are as follows.

- Spring discharge impairment is associated with the recharge line length component perpendicular to longwall panel face greater than or equal to the interpreted best fit value of 101 feet (Appendix G_fig_11 and G_tab_11); +/- 10ft.
- Spring discharge impairment is associated with recharge line length greater than or equal to the interpreted best fit value of 189 feet (Appendix G_fig_12 and G_tab_12); +/- 10ft.
- Spring discharge impairment is associated with recharge line vertical relief greater than or equal to the interpreted best fit value of 31 feet (Appendix G_fig_13 and G_tab_13); +/- 5ft.
- Spring discharge impairment is associated with pre-mining spring daylight elevation less than the interpreted best fit value of 1209 feet msl (Appendix G_fig_14 and G_tab_14); +/- 5ft.
- Spring discharge impairment is associated with pre-mine average low flow discharge less than the interpreted best fit value of 0.43 gpm (Appendix G_fig_15 and G_tab_15).

The use of Chi square contingency tests resulted in calculated error probabilities of 0.20-0.10, 0.05-0.02, 0.05-0.02, 0.01-0.001, and 0.01-0.001, respectively, for the above data trends (Table 21). The use of Fisher exact probability tests resulted in calculated error probabilities of 0.06013, 0.02001, 0.01415, 0.00570, and 0.00466, respectively (Table 22). The remaining alternative hypotheses examined for the topographic and mine independent variables were rejected by the Chi square contingency and Fisher exact probability tests, at the 0.20 and 0.10 alpha probability levels, respectively.

Based upon the statistical results, the use of recharge line length component perpendicular to longwall panel face, recharge line length, recharge line vertical relief, pre-mining spring daylight elevation, and pre-mine average low flow discharge resulted in 94 percent, 98 percent, 99 percent, 99 percent, and 99 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for these respective independent variables.

9.2.2 Degree of Spring Discharge Response Statistical Examination (Interpreted Best Fit Value)

The following results from the Chi square contingency and Fisher exact probability statistical examinations for the degree of spring discharge response trends are provided in Tables 23 and 24, respectively. These results are listed according to evapotranspiration condition and spring discharge reduction boundary type. The hydrologic, geologic, topographic, and mine-specific independent variables were examined for statistical significance through the use of the interpreted best-fit values and contingency table tests (Figure 19). Refer to Appendix H for figures illustrating acceptance of the significant alternative hypotheses and data tables used for calculating Fisher exact error probabilities at the 0.10 alpha level of significance. Two or more springs plotted at the same position (spring discharge change and independent variable value) are not deciphered in the Appendix H independent variable-specific figures; consult the Appendix H independent variable-specific tables for information regarding this scenario.

Table 23: Results from Methods of Investigation IV. Chi Square Contingency Test Results Used to Determine the Degree of Spring Discharge Impairment Associated with Mining-Induced Subsidence through the Use of the Interpreted Best Fit Value. Significant data trends are associated with error probability (P_{error}) at the 0.20 alpha level of significance.

Parameter	Optimum Reduction Boundary									
	Low EvapoTranspiration Condition with 50% Discharge Reduction					High EvapoTranspiration Condition with 60% Discharge Reduction				
	N	H _{ultimate}	Chi-Square Value	H _{ultimate} Trend	P _{error}	N	H _{ultimate}	Chi-Square Value	H _{ultimate} Trend	P _{error}
Recharge Line Length Perpendicular to LW Face	47				H _{ult}	44				H _{ult}
Overburden Thickness	50				H _{ult}	46				H _{ult}
Width-Depth Ratio	47				H _{ult}	44				H _{ult}
Recharge Line Length	50				H _{ult}	46				H _{ult}
Recharge Line Vertical Relief	50				H _{ult}	46				H _{ult}
Recharge Line Gradient	50				H _{ult}	46				H _{ult}
Recharge Line Mining Direction	47				H _{ult}	44				H _{ult}
Recharge Line Subside	50				H _{ult}	46				H _{ult}
Vertical Relief to Nearest Surface Drainage Feature	50	>=36	3.54789	Direct	0.10-0.05	46				H _{ult}
Vertical Relief to Headwater Drainage Features	45	>=36	3.51563	Direct	0.10-0.05	41				H _{ult}
Vertical Relief to First Order Drainage Features	36	>=36	1.91265	Direct	0.20-0.10	33				H _{ult}
Vertical Relief to Second Order Drainage Features	9				H _{ult}	8				H _{ult}
Lateral Distance to Nearest Surface Drainage Features	50				H _{ult}	46				H _{ult}
Gradient to Nearest Surface Drainage Features	50				H _{ult}	46				H _{ult}
Pre-Mine Spring Daylight Elevation	50				H _{ult}	46				H _{ult}
Pre-Mine Recharge Line Origin Elevation	50				H _{ult}	46				H _{ult}
Pre-Mine Averaged Low Flow Spring Discharge	48				H _{ult}	28				H _{ult}
Parameter	Absolute Reduction Boundary									
	Low EvapoTranspiration Condition with 88% Discharge Reduction					High EvapoTranspiration Condition with 80% Discharge Reduction				
	N	H _{ultimate}	Chi-Square Value	H _{ultimate} Trend	P _{error}	N	H _{ultimate}	Chi-Square Value	H _{ultimate} Trend	P _{error}
Recharge Line Length Perpendicular to LW Face	47	<169	2.19988	Inverse	0.20-0.10	44	>=101	2.78986	Direct	0.10-0.05
Overburden Thickness	50				H _{ult}	46				H _{ult}
Width-Depth Ratio	47				H _{ult}	44				H _{ult}
Recharge Line Length	50				H _{ult}	46				H _{ult}
Recharge Line Vertical Relief	50				H _{ult}	46				H _{ult}
Recharge Line Gradient	50				H _{ult}	46				H _{ult}
Recharge Line Mining Direction	47				H _{ult}	44				H _{ult}
Recharge Line Subside	50				H _{ult}	46				H _{ult}
Vertical Relief to Nearest Surface Drainage Feature	50				H _{ult}	46				H _{ult}
Vertical Relief to Headwater Drainage Features	45				H _{ult}	42				H _{ult}
Vertical Relief to First Order Drainage Features	36	>=36	1.70666	Direct	0.20-0.10	33				H _{ult}
Vertical Relief to Second Order Drainage Features	9				H _{ult}	8				H _{ult}
Lateral Distance to Nearest Surface Drainage Features	50				H _{ult}	46				H _{ult}
Gradient to Nearest Surface Drainage Features	50				H _{ult}	46				H _{ult}
Pre-Mine Spring Daylight Elevation	50				H _{ult}	46				H _{ult}
Pre-Mine Recharge Line Origin Elevation	50				H _{ult}	46				H _{ult}
Pre-Mine Averaged Low Flow Spring Discharge	48				H _{ult}	28				H _{ult}

Table 24: Results from Methods of Investigation IV. Fisher Exact Probability Test Results Used to Determine the Degree of Spring Discharge Impairment Associated with Mining-Induced Subsidence through the Use of the Interpreted Best Fit Value. Significant data trends are associated with error probability (P_{error}) at the 0.10 alpha level of significance.

Parameter		Optimum Reduction Boundary													
		Low EvapoTranspiration Condition with 50% Discharge Reduction Tolerance					High EvapoTranspiration Condition with 60% Discharge Reduction Tolerance								
		N	H _{transp}	A	B	C	D	P _{error}	N	H _{transp}	A	B	C	D	P _{error}
Recharge Line Length Perpendicular to LW Face	(ft)	47						H _{adj}	44						H _{adj}
Overburden Thickness	(ft)	50						H _{adj}	46						H _{adj}
Width-Depth Ratio	(unitless)	47						H _{adj}	44						H _{adj}
Recharge Line Length	(ft)	50						H _{adj}	46						H _{adj}
Recharge Line Vertical Relief	(ft)	50						H _{adj}	46						H _{adj}
Recharge Line Gradient	(% slope)	50						H _{adj}	46						H _{adj}
Recharge Line Mining Direction	(unitless)	47						H _{adj}	44						H _{adj}
Recharge Line Subsided	(%)	50						H _{adj}	46						H _{adj}
Vertical Relief to Nearest Surface Drainage Feature	(ft)	50	>=36	26	2	15	7	0.02951	46						H _{adj}
Vertical Relief to Headwater Drainage Features	(ft)	45	>=36	23	2	13	7	0.02999	41						H _{adj}
Vertical Relief to First Order Drainage Features	(ft)	36	>=36	17	2	11	6	0.08295	33						H _{adj}
Vertical Relief to Second Order Drainage Features	(ft)	9						H _{adj}	8						H _{adj}
Lateral Distance to Nearest Surface Drainage Features	(ft)	50						H _{adj}	46						H _{adj}
Gradient to Nearest Surface Drainage Features	(% slope)	50						H _{adj}	46						H _{adj}
Pre-Mine Spring Daylight Elevation	(ft)	50						H _{adj}	46						H _{adj}
Pre-Mine Recharge Line Origin Elevation	(ft)	50						H _{adj}	46						H _{adj}
Pre-Mine Averaged Low Flow Spring Discharge	(gpm)	48						H _{adj}	28						H _{adj}
Parameter		Absolute Reduction Boundary													
		Low EvapoTranspiration Condition with 88% Discharge Reduction Tolerance					High EvapoTranspiration Condition with 80% Discharge Reduction Tolerance								
		N	H _{transp}	A	B	C	D	P _{error}	N	H _{transp}	A	B	C	D	P _{error}
Recharge Line Length Perpendicular to LW Face	(ft)	47	<169	10	11	19	7	0.06894	44	>=101	23	0	17	4	0.04409
Overburden Thickness	(ft)	50						H _{adj}	46						H _{adj}
Width-Depth Ratio	(unitless)	47						H _{adj}	44						H _{adj}
Recharge Line Length	(ft)	50						H _{adj}	46						H _{adj}
Recharge Line Vertical Relief	(ft)	50						H _{adj}	46						H _{adj}
Recharge Line Gradient	(% slope)	50						H _{adj}	46						H _{adj}
Recharge Line Mining Direction	(unitless)	47						H _{adj}	44						H _{adj}
Recharge Line Subsided	(%)	50						H _{adj}	46						H _{adj}
Vertical Relief to Nearest Surface Drainage Feature	(ft)	50						H _{adj}	46						H _{adj}
Vertical Relief to Headwater Drainage Features	(ft)	45						H _{adj}	42						H _{adj}
Vertical Relief to First Order Drainage Features	(ft)	36	>=36	13	6	7	10	0.09551	33						H _{adj}
Vertical Relief to Second Order Drainage Features	(ft)	9						H _{adj}	8						H _{adj}
Lateral Distance to Nearest Surface Drainage Features	(ft)	50						H _{adj}	46						H _{adj}
Gradient to Nearest Surface Drainage Features	(% slope)	50						H _{adj}	46						H _{adj}
Pre-Mine Spring Daylight Elevation	(ft)	50						H _{adj}	46						H _{adj}
Pre-Mine Recharge Line Origin Elevation	(ft)	50						H _{adj}	46						H _{adj}
Pre-Mine Averaged Low Flow Spring Discharge	(gpm)	48						H _{adj}	28						H _{adj}

9.2.2.1 Low Evapotranspiration Condition – Optimum Reduction Boundary

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for vertical relief to nearest surface drainage features, vertical relief to headwater surface drainage (first and second order) features, and vertical relief to first order surface drainage features. The significant alternative hypothesis statements are as follows:

- Spring discharge impairment is associated with vertical relief to nearest surface drainage features greater than or equal to the interpreted best fit value of 36 feet (Appendix H_fig_1 and H_tab_1); ± 5 ft.

- Spring discharge impairment is associated with vertical relief to headwater surface drainage (first and second order) features greater than or equal to the interpreted best fit value of 36 feet (Appendix H_fig_2 and H_tab_2); +/- 5ft.
- Spring discharge impairment is associated with vertical relief to first order surface drainage features greater than or equal to the interpreted best fit value of 36 feet (Appendix H_fig_3 and H_tab_3); +/- 5ft.

The use of Chi square contingency tests resulted in calculated error probabilities of 0.10-0.05, 0.10-0.05, and 0.20-0.10, respectively, for the above data trends (Table 23). The use of Fisher exact probability tests resulted in calculated error probabilities of 0.02951, 0.02999, and 0.08295, respectively (Table 24). The remaining alternative hypotheses examined for the topographic and mine independent variables were rejected by the Chi square contingency and Fisher exact probability tests, at the 0.20 and 0.10 alpha probability levels, respectively.

Based upon the statistical results, the use of vertical relief to nearest surface drainage features, vertical relief to headwater surface drainage features, and vertical relief to first order surface drainage features resulted in 97 percent, 97 percent and 92 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for these respective independent variables.

9.2.2.2 Low Evapotranspiration Condition – Absolute Reduction Boundary

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for the recharge line length component perpendicular to longwall panel face and vertical relief to

first order surface drainage features. The significant alternative hypothesis statements are as follows:

- Spring discharge impairment is associated with the recharge line length component perpendicular to longwall panel face less than the interpreted best fit value of 169 feet (Appendix H_fig_4 and H_tab_4); +/- 10ft.
- Spring discharge impairment is associated with vertical relief to first order surface drainage features greater than or equal to the interpreted best fit value of 36 feet (Appendix H_fig_5 and H_tab_5); +/- 5ft.

The use of Chi square contingency tests resulted in calculated error probabilities of 0.20-0.10 and 0.20-0.10, respectively, for the above data trends (Table 23). The use of Fisher exact probability tests resulted in calculated error probabilities of 0.06894 and 0.09551, respectively (Table 24). The remaining alternative hypotheses examined for the topographic and mine independent variables were rejected by the Chi square contingency and Fisher exact probability tests, at the 0.20 and 0.10 alpha probability levels, respectively.

Based upon the statistical results, the use of recharge line length component perpendicular to longwall panel face and vertical relief to first order surface drainage features resulted in 93 percent and 90 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for these respective independent variables.

9.2.2.3 High Evapotranspiration Condition – Optimum Reduction Boundary

Nonparametric statistical tests resulted in rejection of all the alternative hypotheses, therefore, there are no significant statistical relationships between the degree of spring impairment and the independent variables during high evapotranspiration conditions when evaluated at the optimum reduction boundary.

9.2.2.4 High Evapotranspiration Condition – Absolute Reduction Boundary

Nonparametric statistical tests resulted in acceptance of the alternative hypothesis for the recharge line length component perpendicular to longwall panel face. The significant alternative hypothesis statement is as follows:

- Spring discharge impairment is associated with the recharge line length component perpendicular to longwall panel face greater than or equal to the interpreted best fit value of 101 feet (Appendix H_fig_6 and H_tab_6); +/- 10ft.

The use of the Chi square contingency test resulted in a calculated error probability of 0.10-0.05, for this data trend (Table 23). The use of the Fisher exact probability test resulted in a calculated error probability of 0.04409 (Table 24). The remaining alternative hypotheses examined for the topographic and mine independent variables were rejected by the Chi square contingency and Fisher exact probability tests, at the 0.20 and 0.10 alpha probability levels, respectively.

Based upon the statistical results, the use of recharge line length component perpendicular to longwall panel face resulted in 96 percent degree of confidence that a significant data trend exists, as determined from the complement of alpha, for this independent variable.

10.0 CONCLUSIONS

The methodology used for Investigation IV is the most discriminating of the four investigations of the study, in terms of mine-subsidence impacts on spring discharge. This research is a case study for one mine site, and therefore is limited in terms of its applicability to other mine sites, until additional research projects with similar objectives are conducted at other mine locations within the northern Appalachian Coal Basin.

The following conclusions are drawn from the results of Investigation IV and are offered for use to assist in the prediction of mining-induced changes to spring discharge within the research study area. Precision errors, related to the statistical noise and measurement techniques inherent to the research data, are assumed to have negligible impacts on observed statistical data trends.

1. Approximately 40 percent of springs were permanently (for at least 12 months) impaired within the research study area through the post-mine monitoring program. The remaining 60 percent of springs were either unaffected or only seasonally impaired.
2. The following conclusions are related to spring discharge impairment data trends identified for the data set studied during low evapotranspiration seasonal conditions (December through May). These data trends are associated with bedrock stratigraphy and the different mechanical deformation responses to mining-induced subsidence inherent to the formations. Specifically:

- a. Springs that were greater than 36 vertical feet (+/- 5ft) from the nearest surface drainage feature (stream channel) had a higher probability to experience some degree of flow impairment during low evapotranspiration conditions. This is the strongest low evapotranspiration statistical data trend.
 - b. Springs that daylighted at an elevation of 1190 ft (+/- 5ft) amsl or less had a higher probability to experience some degree of flow impairment during low evapotranspiration conditions.
3. The following conclusions are related to spring discharge impairment data trends identified for the data set studied during high evapotranspiration seasonal conditions (June through November). These data trends are associated with an inverse relationship between hydraulic gradient and hydraulic conductivity; higher hydraulic gradients were directly related to longer recharge line lengths and greater vertical reliefs but inversely related to pre-mining, averaged, low-flow spring discharge. In addition, spring recharge was more susceptible to mining-induced subsidence during high evapotranspiration seasonal conditions than for low evapotranspiration seasonal conditions. Specifically:
- a. Springs with recharge line length greater than 189 linear feet (+/- 10ft) had a higher probability to experience some degree of flow impairment during high evapotranspiration conditions.

- b. Springs with recharge line vertical relief greater than 36 vertical feet (+/- 5ft) had a higher probability to experience some degree of flow impairment during high evapotranspiration conditions.
- c. Springs that daylighted at an elevation of 1209 ft (+/- 5ft) amsl or less had a higher probability to experience some degree of flow impairment during high evapotranspiration conditions.
- d. Springs with pre-mine average low flow discharge of less than 0.43 gpm (+/- 10%) had a higher probability to experience some degree of flow impairment during high evapotranspiration conditions. This is the strongest high evapotranspiration statistical data trend.

11.0 DISCUSSION AND THEORY

The objectives of this research were, essentially, to determine what magnitude of spring discharge reduction constitutes mining-induced spring discharge impairment and what are the underlying factors, independent variables, associated with springs that induce such impairments.

The statistical examination of hydrologic, geologic, topographic, and mine-specific independent variables was conducted to determine what critical intrinsic values most strongly associate with spring discharge impairment. The independent variables were examined during low (December through May) and high (June through November) evapotranspiration conditions for both their calculated median values and interpreted best fit boundary values. These best fit boundary values were interpreted in an effort to identify the boundary value associated with the lowest probability of error for the trend with spring discharge.

The spring types encountered within the research study area are assumed to be contact springs and fracture-controlled springs. The spring discharge responses to mining-induced subsidence are associated with the natural setting conditions of these springs; springs form at the intersection of fractures and/or at the boundary of aquifers (like sandstone) with underlying confining layers (like shale) and ground surface. Confining layers deform through ductile mechanics and have a greater probability for healing of subsidence fractures through natural attenuation processes.

If vertical hydraulic conductivity of the confining layer increases through mine-subsidence fracturing, the perched ground water could drain vertically downward until it encounters another underlying confining layer. Springs located at lower elevations sometimes increase in discharge after the subsidence event. New post-mining springs typically change positions to lower elevations that are often laterally different than the pre-mining springs. It is theorized that the ground water within perched aquifers affected by mine subsidence is reporting to lower perched aquifers and/or the regional water table.

This theory is supported through the results of this research and collection of anecdotal information from surface property owners. Eleven of the 77 springs researched had higher average discharge during the post-mining monitoring period than during the pre-mining monitoring period. During the field work component of this research, 15 new post-mining spring discharge locations were reported by surface property owners.

11.1 Independent Variable Analysis

The methodologies used for Investigations I through IV yielded results related to which independent variables were and were not associated with mining-induced spring discharge impairment (Table 25). The following independent variables are associated with mining-induced spring discharge impairment.

- Spring recharge line length component perpendicular to longwall panel face
- Spring recharge line length

Table 25: Error Probabilities Calculated for Significant Data Trends Derived from Fisher Exact Probability Tests for Methods of Investigation I through IV at the 0.10 Alpha Level of Significance.

Parameter	Data Trend	Methods of Investigation I			Methods of Investigation II			Methods of Investigation III			Methods of Investigation IV		
					all springs			L ET / Opt	L ET / Abs	H ET / Opt	H ET / Abs	L ET / Opt	H ET / Abs
Recharge Line Length Perpendicular to LW Face	(ft)												
Overburden Thickness	(ft)												
Width:Depth Ratio	(unitless)												
Recharge Line Length	(ft)	0.00921			0.001983								
Recharge Line Vertical Relief	(ft)	0.00001			0.00012					0.01396		0.01395	0.02001
Recharge Line Gradient	(% slope)	0.02741			0.01927					0.01868		0.01868	0.01415
Recharge Line Mining Direction	(unitless)												
Recharge Line Subsidied	(%)												
Vertical Relief to Nearest Surface Drainage Feature	(ft)							0.05918				0.02881	
Vertical Relief to Headwater Drainage Features	(ft)							0.04516				0.02988	0.06185
Vertical Relief to First Order Drainage Features	(ft)							0.07315	0.07888			0.07315	0.07888
Vertical Relief to Second Order Drainage Features	(ft)												
Lateral Distance to Nearest Surface Drainage Features	(ft)												
Gradient to Nearest Surface Drainage Features	(% slope)												
Pre-Mine Spring Daylight Elevation	(ft)								0.06644	0.04189			0.06644
Pre-Mine Recharge Line Origin Elevation	(ft)												
Pre-Mine Averaged Low Flow Spring Discharge	(gpm)									0.01955			0.00395
Key													
L ET / Opt: Low Evapotranspiration Season Evaluated at the Optimum Discharge Reduction Boundary Condition (50%)													
L ET / Abs: Low Evapotranspiration Season Evaluated at the Absolute Discharge Reduction Boundary Condition (88%)													
H ET / Opt: High Evapotranspiration Season Evaluated at the Optimum Discharge Reduction Boundary Condition (60%)													
H ET / Abs: High Evapotranspiration Season Evaluated at the Absolute Discharge Reduction Boundary Condition (80%)													
Direct: Directly Proportional Data Trend (Greater Spring Discharge Reduction with Increased Independent Variable Value													
Inverse: Inversely Proportional Data Trend (Lesser Spring Discharge Reduction with Increased Independent Variable Value													

- Spring recharge line vertical relief
- Spring recharge line gradient
- Spring vertical relief to nearest surface drainage feature
- Spring vertical relief to first and second order surface drainage features
- Spring vertical relief to first order surface drainage features
- Pre-mine spring daylight elevation
- Pre-mine averaged low flow spring discharge

It is conjectured by the author that spring discharge impairment is controlled by two factors – bedrock stratigraphy and spring recharge. Bedrock stratigraphy is associated with spring discharge impairment during both low and high evapotranspiration seasonal conditions, and spring recharge is associated with spring discharge impairment during high evapotranspiration seasonal conditions.

11.1.1 Bedrock Stratigraphy

It is surmised by the author that pre-mining spring daylight elevations are associated with spring discharge impairment due to stratigraphic control; however, data needs to be collected to further support this speculation. This research did not evaluate stratigraphy, stratigraphic dip, or lineaments. Spring locations, and spring discharge mining responses, are widely distributed throughout the research study area. It is presumed that localized features, such as specific rock units and structures (such as lineaments) may be associated with specific spring discharge mining responses.

Springs that daylight lower in elevation are more susceptible to mining-induced subsidence. The assumptions associated with this variable are related to either the overburden strata movement zones or changes in stratigraphy. Overburden thickness is not a statistically significant independent variable. The uppermost surface fracture zone according to mine-subsidence theory is assumed to be involved with spring discharge response.

In addition to the spring discharge impairment association with daylight elevation, spring proximity to the nearest surface drainage feature (stream channel) is statistically significant. A spring's pre-mining proximity to the nearest surface drainage feature, as described within section 4.2.2 and 8.1.4.2, is equal to the shortest horizontal and vertical distance discharge water from a spring would travel on ground surface to the nearest surface drainage feature.

The vertical relief and lateral distance to the nearest surface drainage feature are directly proportional (Figure 20), that is, the greater the horizontal distance a spring is from a stream channel, the greater the vertical relief. Springs further from surface drainage features have greater vertical reliefs, such as springs that daylight within the mid- to upper hillside locations. Springs closer to surface drainage features have lower vertical reliefs, such as springs that daylight within the lower valley walls.

Figure 20: Scatter Plot Showing Direct Relationship Between Spring Relief and Lateral Distance to Nearest Surface Drainage Feature.

Spring discharge impairment is associated with greater vertical relief; therefore springs located further laterally from and up slope from surface drainage features (stream channel) are more susceptible to mining-induced spring discharge impairment. Near-surface fracturing from mining-induced subsidence probably influences spring response to mining.

Spring discharge impairment is not associated with overburden thickness. Therefore, it is postulated that spring discharge impairment is associated with different mechanical deformation responses to stress-relief fracturing and surface zone fracturing inherent to the formations of the bedrock stratigraphy within the research study area. More specifically, it is speculated that spring discharge impairment is associated with formations that respond to mining-induced subsidence through tensile deformation means, as opposed to formations that deform through ductile means.

11.1.2 Spring Recharge

The spring recharge line, as described within sections 4.2.1 and 8.1.4.1, is a conceptual analog to the topographic subsurface drainage and recharge basin of a spring. The recharge line concept assumes that ground water flows down-slope along the steepest hydraulic gradient (Fetter, 2001), essentially perpendicular to ground surface topographic elevation contours. The length and vertical relief of the spring recharge line are directly proportional (Figure 21); longer recharge lines typically have greater vertical reliefs. It is

Figure 21: Scatter Plot Showing Direct Relationship Between Spring Recharge Line Length and Spring Recharge Line Vertical Relief.

assumed that greater spring recharge line length and vertical relief are associated with higher hydraulic gradients, that is, higher gradients contain longer lengths and greater vertical reliefs. Therefore, direct relationships exist among the length, vertical relief, and gradient of the recharge line.

It is also hypothesized that aquifers with high ground water gradients are associated with low hydraulic conductivity (Fetter, 2001), therefore, higher recharge line gradients are inversely related to hydraulic conductivity. Hydraulic conductivity should be directly related to pre-mine averaged low flow spring discharge; that is, an aquifer with low hydraulic conductivity will transmit low spring discharge. Therefore, springs with low pre-mine averaged spring discharge should be associated with aquifers with low hydraulic conductivity, which are associated with higher recharge line hydraulic gradients, longer recharge line lengths, and greater recharge line vertical reliefs.

Therefore, lower hydraulic conductivity of shallow rock strata, supplying water to springs, could cause springs to be more susceptible to the greater subsidence-induced dewatering observed for springs with longer, steeper, and greater relief recharge lines. These recharge lines could provide greater opportunity for mining-induced fractures to negatively impact the spring recharge basins through increased vertical hydraulic conductivity.

This speculation is supported by the length component of the recharge line perpendicular to longwall panel face. This recharge line length component is an analog measure of the

relative amount of time that would have elapsed across a mined longwall panel subsidence event. Greater amounts of time, or longer recharge line length components, increase the opportunity for the formation of mining-induced fractures, or enlargement of the apertures of existing fractures, to intercept ground water from spring recharge basins through the influence of increased vertical hydraulic conductivity.

In addition, springs have lower discharges during high evapotranspiration conditions than during low evapotranspiration conditions; averaged spring discharge during high and low evapotranspiration conditions were 1.56gpm and 8.97gpm, respectively. Spring discharge response to mining-induced subsidence is therefore more noticeable during high evapotranspiration conditions than during low evapotranspiration conditions and a greater susceptibility exists for spring discharge impairment during high evapotranspiration conditions.

12.0 RECOMMENDATIONS

The natural variation analysis resulted in the determination of two spring discharge reduction boundaries; absolute and optimum. These spring discharge reduction boundaries were evaluated during both the low and high evapotranspiration conditions; however, the spring discharge reduction boundaries were not evaluated specifically during periods of precipitation deficit or surplus due to a lack of enough pre-mine spring discharge data.

It is recommended that further investigation into the natural variation analysis be conducted in a manner to account for meteorological influence. It is suggested that pre-mine spring discharge data be evaluated at different departures from normal precipitation to determine if pre-mine spring discharge variation exists. It is assumed that greater departures from normal precipitation would yield greater variation in pre-mine spring discharge. Spring discharge reduction boundaries could then be used to determine spring discharge responses more specific to the precipitation deficit or surplus across the subsidence events.

Knowledge of natural variation in spring discharge across subsidence events (before versus after mining) is significant in determining if a spring discharge impairment occurred, as well as if seasonal evapotranspiration conditions and precipitation are influential in concluding if a spring supply was affected by mining-induced subsidence. It is recommended that naturally-occurring changes in spring discharge be identified for

prior to declaring if a mining-induced environmental effect has occurred. Therefore, it is recommended by the author that a more sophisticated approach, with a greater degree of data discrimination, be used for hydrologic impairment analysis.

In addition, 11 of the 77 springs had higher average discharge during the post-mine monitoring period than during the pre-mine monitoring period. During the field work component of this research, 15 new post-mine spring discharge locations were reported by surface property owners. It is recommended that further investigation into post-mine “new” spring discharge locations and improved (increased) spring discharge locations be evaluated to determine if independent variables specific to those springs could be used for probable hydrologic consequence reports or for assistance to locate post-mine water replacement supplies.

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Footnote: * denotes location of research study area and would jeopardize the terms of anonymity.

14.0 APPENDIX

APPENDIX A: Spring Discharge Hydrographs Used to Assess Spring Discharge Response to Mining-Induced Subsidence as Discussed in Methods of Investigation I

Discharge Hydrograph for Spring 32

Discharge Hydrograph for Spring 33

Discharge Hydrograph for Spring 35

Discharge Hydrograph for Spring 36

Discharge Hydrograph for Spring 38

Discharge Hydrograph for Spring 41

Discharge Hydrograph for Spring 44

Discharge Hydrograph for Spring 52

Discharge Hydrograph for Spring 54

Discharge Hydrograph for Spring 63

Discharge Hydrograph for Spring 64

Discharge Hydrograph for Spring 78

Discharge Hydrograph for Spring 79

Discharge Hydrograph for Spring 79a

Discharge Hydrograph for Spring 83

Discharge Hydrograph for Spring 84

Discharge Hydrograph for Spring 91

Discharge Hydrograph for Spring 92

Discharge Hydrograph for Spring 93

Discharge Hydrograph for Spring 94

Discharge Hydrograph for Spring 97

Discharge Hydrograph for Spring 99

Discharge Hydrograph for Spring 99a

Discharge Hydrograph for Spring 101

Discharge Hydrograph for Spring 102

Discharge Hydrograph for Spring 106

Discharge Hydrograph for Spring 107

Discharge Hydrograph for Spring 118

Discharge Hydrograph for Spring 152

Discharge Hydrograph for Spring 154

Discharge Hydrograph for Spring 155

Discharge Hydrograph for Spring 157

Discharge Hydrograph for Spring 162

Discharge Hydrograph for Spring 165

Discharge Hydrograph for Spring 166

Discharge Hydrograph for Spring 167

Figure 1 consists of two vertically stacked line graphs sharing a common x-axis representing dates from April 1, 1992, to March 17, 1995. The y-axis for both graphs is Discharge in gallons per minute (gpm), ranging from 0.0 to 15.0.

The top graph, labeled "Adjacent Longwall Panel", shows a discharge that starts at approximately 7.5 gpm in April 1992, rises to about 11.0 gpm by June 1992, and then remains relatively stable, fluctuating between 10.5 and 11.0 gpm until March 1993. After this point, the discharge drops sharply to around 1.0 gpm by June 1993 and remains low, with minor fluctuations, until March 1995.

The bottom graph, labeled "Undermining Longwall Panel", shows a discharge that starts at approximately 1.0 gpm in April 1992, rises to about 2.0 gpm by June 1992, and then remains relatively stable, fluctuating between 1.5 and 2.5 gpm until March 1993. After this point, the discharge drops sharply to around 0.5 gpm by June 1993 and remains low, with minor fluctuations, until March 1995.

Discharge Hydrograph for Spring 170

Discharge Hydrograph for Spring 171

Discharge Hydrograph for Spring 173

Discharge Hydrograph for Spring 174

Discharge Hydrograph for Spring 175

Discharge Hydrograph for Spring 176

Discharge Hydrograph for Spring 177

Discharge Hydrograph for Spring 179

Discharge Hydrograph for Spring 183

Discharge Hydrograph for Spring 198

Discharge Hydrograph for Spring 199

Discharge Hydrograph for Spring 216

Discharge Hydrograph for Spring 224

Discharge Hydrograph for Spring 226

Discharge Hydrograph for Spring 248

Discharge Hydrograph for Spring 249

Discharge Hydrograph for Spring 253

Discharge Hydrograph for Spring 254

Discharge Hydrograph for Spring 256

Discharge Hydrograph for Spring 258

Discharge Hydrograph for Spring 259

Discharge Hydrograph for Spring 260

Discharge Hydrograph for Spring 261

Discharge Hydrograph for Spring 262

Discharge Hydrograph for Spring 263

Discharge Hydrograph for Spring 265

Discharge Hydrograph for Spring 266

Discharge Hydrograph for Spring 267

Discharge Hydrograph for Spring 268

Discharge Hydrograph for Spring 269

Discharge Hydrograph for Spring 270

Discharge Hydrograph for Spring 271

Discharge Hydrograph for Spring 272

Discharge Hydrograph for Spring 273

Discharge Hydrograph for Spring 274

Discharge Hydrograph for Spring 297

APPENDIX B: Quantitative Data Related to the Hydrologic, Geologic, Topographic, and
Mine-Specific Variables Discussed in Methods of Investigation I

Appendix B: Quantitative Data Related to Recharge Line of Springs as Discussed in Methods of Investigation I.							
Spring No.	Recharge Line			Spring No.	Recharge Line		
	Length (ft)	Vertical Relief (ft)	Gradient (% slope)		Length (ft)	Vertical Relief (ft)	Gradient (% slope)
33	157	30	19	43	63	15	24
198	170	20	12	38	282	55	20
155	188	40	21	176	375	70	19
157	219	50	23	226	313	60	19
162	250	80	32	154	430	105	24
166	94	20	21	265	594	75	13
167	219	40	18	79	188	30	16
173	219	35	16	99	32	5	16
174	94	25	27	107	90	10	11
177	310	60	19	270	407	85	21
199	188	50	27	102	313	25	8
224	120	20	17	260	440	95	22
248	344	75	22	267	750	160	21
249	407	0	0	97	157	30	19
254	375	105	28	118	219	15	7
259	657	80	12	92	157	35	22
263	63	15	24	106	250	45	18
272	219	50	23	93	330	80	24
35	157	50	32	171	282	60	21
36	125	30	24	175	94	10	11
41	63	5	8	274	469	100	21
63	532	100	19	102A	532	60	11
64	438	80	18	273	140	35	25
84	750	195	26	256	250	35	14
94	125	20	16	169	344	70	20
269	157	30	19	91	188	40	21
271	125	15	12	90	313	10	3
297	94	15	16	152	188	40	21
268	282	25	9	39	438	75	17
253	63	10	16	165	188	45	24
52	63	10	16	101	625	145	23
99A	75	15	20	83	813	195	24
258	532	45	8	183	94	25	27
216	360	75	21	32	94	30	32
266	157	30	19	78	125	30	24

Appendix B: Quantitative Data Related to Vertical Relief to Nearest Surface Drainage Features for Springs as Discussed in **Methods of Investigation I.**

Spring No.	Vertical Relief to Nearest Surface Drainage Feature				Spring No.	Vertical Relief to Nearest Surface Drainage Feature			
	All Drainage Features (ft)	1 st and 2 nd Order (ft)	1 st Order (ft)	2 nd Order (ft)		All Drainage Features (ft)	1 st and 2 nd Order (ft)	1 st Order (ft)	2 nd Order (ft)
33	80	80	n/a	80	43	10	10	10	n/a
198	80	80	80	n/a	38	35	35	35	n/a
155	35	35	35	n/a	176	5	5	5	n/a
157	75	75	75	n/a	226	45	45	45	n/a
162	120	n/a	n/a	n/a	154	15	15	15	n/a
166	80	80	n/a	80	265	25	25	n/a	25
167	60	60	60	n/a	79	95	n/a	n/a	n/a
173	60	60	60	n/a	99	10	10	10	n/a
174	60	60	60	n/a	107	50	50	50	n/a
177	25	25	n/a	25	270	10	10	10	n/a
199	10	n/a	n/a	n/a	102	5	5	5	n/a
224	10	10	10	n/a	260	70	70	n/a	70
248	100	100	100	n/a	267	25	25	25	n/a
249	25	25	25	n/a	97	145	145	145	n/a
254	60	60	60	n/a	118	20	20	20	n/a
259	55	55	n/a	55	92	60	60	60	n/a
263	30	30	30	n/a	106	35	35	35	n/a
272	55	55	55	n/a	93	50	50	50	n/a
35	25	25	25	n/a	171	45	45	45	n/a
36	25	25	25	n/a	175	10	10	10	n/a
41	10	10	n/a	10	274	40	40	40	n/a
63	140	140	n/a	140	102A	70	70	70	n/a
64	160	160	n/a	160	273	140	140	140	n/a
84	20	n/a	n/a	n/a	256	70	70	70	n/a
94	175	n/a	n/a	n/a	169	115	115	115	n/a
269	25	25	25	n/a	91	195	195	195	n/a
271	160	160	160	n/a	90	35	35	35	n/a
297	90	90	n/a	90	152	75	75	75	n/a
268	35	35	n/a	35	39	40	n/a	n/a	n/a
253	10	n/a	n/a	n/a	165	20	20	20	n/a
52	25	25	25	n/a	101	60	60	60	n/a
99A	15	15	15	n/a	83	30	n/a	n/a	n/a
258	30	30	30	n/a	183	145	145	145	n/a
216	50	50	50	n/a	32	95	95	95	95
266	75	n/a	n/a	n/a	78	90	90	90	n/a

Appendix B: Quantitative Data Related to Lateral Distance and Gradient to Nearest Surface Drainage Features for Springs as Discussed in **Methods of Investigation I.**

Spring No.	Lateral Distance (ft)	Gradient (% slope)	Spring No.	Lateral Distance (ft)	Gradient (% slope)
33	344	23	43	31	32
198	450	18	38	156	22
155	156	22	176	31	16
157	375	20	226	219	21
162	469	26	154	270	6
166	281	28	265	313	8
167	219	27	79	469	20
173	344	17	99	94	11
174	469	13	107	240	21
177	110	23	270	125	8
199	219	5	102	63	8
224	50	20	260	475	15
248	469	21	267	156	16
249	94	27	97	688	21
254	250	24	118	375	5
259	250	22	92	313	19
263	125	24	106	438	8
272	469	12	93	200	25
35	188	13	171	188	24
36	94	27	175	63	16
41	63	16	274	313	13
63	750	19	102A	531	13
64	844	19	273	610	23
84	125	16	256	469	15
94	563	31	169	469	25
269	156	16	91	562	35
271	781	20	90	187	19
297	563	16	152	406	18
268	250	14	39	125	32
253	63	16	165	63	32
52	63	40	101	470	13
99A	150	10	83	63	48
258	500	6	183	500	29
216	350	14	32	438	22
266	531	14	78	438	21

Appendix B: Quantitative Data Related to Spring Daylight Elevation, Overburden Thickness, and Width-Depth Ratio as Discussed in Methods of Investigation I.							
Spring No.	Spring Daylight Elevation (ft)	Overburden Thickness (ft)	Width-Depth Ratio (unitless)	Spring No.	Spring Daylight Elevation (ft)	Overburden Thickness (ft)	Width-Depth Ratio (unitless)
33	1240	510	n/a	43	1180	445	n/a
198	1250	515	1.69	38	1220	495	1.76
155	1115	345	2.96	176	1175	440	1.98
157	1165	390	n/a	226	1195	465	1.87
162	1060	320	n/a	154	1150	365	2.79
166	1130	385	2.23	265	1200	400	2.55
167	1170	420	2.07	79	1095	350	2.49
173	1260	525	1.66	99	1180	425	2.05
174	1230	495	1.76	107	1200	430	n/a
177	1175	440	1.98	270	1230	425	2.35
199	1010	270	3.22	102	1160	400	2.55
224	1215	475	1.83	260	1190	440	1.95
248	1210	425	n/a	267	1210	400	2.55
249	1120	340	3.00	97	1265	510	1.71
254	1130	335	3.04	118	1185	320	n/a
259	1155	370	2.76	92	1190	460	1.89
263	1160	375	2.72	106	1155	385	2.65
272	1265	440	2.32	93	1175	445	1.96
35	1185	455	1.91	171	1195	460	1.89
36	1225	495	1.76	175	1190	455	1.91
41	1180	445	1.96	274	1240	415	2.46
63	1165	415	2.10	102A	1200	445	1.96
64	1185	435	2.00	273	1280	455	2.24
84	1040	295	2.92	256	1190	400	2.55
94	1155	425	2.04	169	1225	485	1.79
269	1225	420	2.38	91	1195	460	1.88
271	1310	490	2.04	90	1125	395	2.20
297	1210	415	2.46	152	1195	465	1.87
268	1185	390	2.62	39	1150	420	2.07
253	930	135	n/a	165	1010	270	3.22
52	1205	455	n/a	101	1130	370	2.76
99A	1190	425	2.05	83	1040	295	2.92
258	1190	400	2.55	183	1280	550	n/a
216	1210	490	1.78	32	1265	535	n/a
266	1085	240	n/a	78	1210	455	n/a

Appendix B: Quantitative Data Related to the Position of a Spring Above a Longwall Panel as Discussed in Methods of Investigation I.									
Spring No.	Daylight Longwall (LW) Position			Spring No.	Daylight Longwall (LW) Position				
	Distance (ft)	LW Panel Width (ft)	Position Above LW		Distance (ft)	LW Panel Width (ft)	Position Above LW		
33		180 - 220 (daylight) N		43		-30 (daylight) - 40 S			
198	240	870	0.28	38	130	870	0.15		
155	-60	1020	-0.06	176	660	870	0.76		
157		150 - 370 (daylight) S		226	300	870	0.34		
162		40 - 250 (daylight) E		154	150	1020	0.15		
166	740	860	0.86	265	-90	1020	-0.09		
167	380	870	0.44	79	220	870	0.25		
173	220	870	0.25	99	690	870	0.79		
174	960	870	1.10	107		130 - 140 (daylight) W			
177	140	870	0.16	270	400	1000	0.40		
199	480	870	0.55	102	210	1020	0.21		
224	500	870	0.57	260	80	860	0.09		
248		210 (daylight) - 390 E		267	1070	1020	1.05		
249	900	1020	0.88	97	660	870	0.76		
254	270	1020	0.26	118		510 - 330 (daylight) W			
259	460	1020	0.45	92	340	870	0.39		
263	550	1020	0.54	106	740	1020	0.73		
272	710	1020	0.70	93	500	870	0.57		
35	-10	870	-0.01	171	220	870	0.25		
36	50	870	0.06	175	790	870	0.91		
41	100	870	0.11	274	480	1020	0.47		
63	680	870	0.78	102A	660	870	0.76		
64	710	870	0.82	273	900	1020	0.88		
84	680	860	0.79	256	950	1020	0.93		
94	330	865	0.38	169	730	870	0.84		
269	30	1000	0.03	91	230	865	0.27		
271	220	1000	0.22	90	560	870	0.64		
297	690	1020	0.68	152	200	870	0.23		
268	70	1020	0.07	39	770	870	0.89		
253		640 - 690 (daylight) N		165	-40	870	-0.05		
52		610 - 640 (daylight) E		101	470	1020	0.46		
99A	430	870	0.49	83	740	860	0.86		
258	120	1020	0.12	183		480 - 540 (daylight) N			
216	830	870	0.95	32		810 (daylight) - 880 N			
266		780 - 920 (daylight) N		78		530 (daylight) - 620 W			

APPENDIX C: Quantitative Data Related to the Additional Hydrologic, Geologic,
Topographic, and Mine-Specific Variables Discussed in Methods of Investigation III

Appendix C: Quantitative Data Related to Length of Subsidence Event, Order of Subsidence, and Percent of Recharge Line Subsidized as Discussed in **Methods of Investigation III.**

Spring No.	Recharge Line			Spring No.	Recharge Line		
	Length of Subsidence Event (ft)	Order of Subsidence	Percent Subsidized		Length of Subsidence Event (ft)	Order of Subsidence	Percent Subsidized (%)
33							
198	n/a		0	43	20	origin to daylight	57
155	100	daylight to origin	100	38	20	origin to daylight	46
157	15	origin to daylight	70	176	340	origin to daylight	100
162	n/a		0	226	260	origin to daylight	100
166	n/a		0	154	260	daylight to origin	79
167	30	daylight to origin	100	265	140	daylight to origin	84
173	160	daylight to origin	100	79	110	daylight to origin	100
174	140	daylight to origin	100	99	15	daylight to origin	100
177			0	107		n/a	0
199	280	origin to daylight	100	270	380	origin to daylight	100
224	220	origin to daylight	100	102	280	daylight to origin	100
248	120	origin to daylight	100	267	310	origin to daylight	100
249	n/a		0	97	250	daylight to origin	93
254	350	origin to daylight	100	118	100	daylight to origin	100
259	360	origin to daylight	100			n/a	0
263	100	origin to daylight	88	92	170	daylight to origin	100
272	15	daylight to origin	100	106	220	origin to daylight	100
35	30	origin to daylight	100	93	220	daylight to origin	100
36	70	origin to daylight	93	171	160	daylight to origin	100
41	50	origin to daylight	100	175	30	daylight to origin	100
63	40	daylight to origin	100	274	440	origin to daylight	100
64	370	origin to daylight	86	102A	180	origin to daylight	56
84	300	origin to daylight	84	273	100	origin to daylight	100
94	220	origin to daylight	92	256	200	daylight to origin	88
269	50	daylight to origin	100	169	90	origin to daylight	100
271	140	origin to daylight	100	91	70	daylight to origin	100
297	110	origin to daylight	100	90	50	daylight to origin	100
268	65	daylight to origin	100	152	80	daylight to origin	100
253	70	daylight to origin	100	39	200	daylight to origin	100
52	n/a		0	165	90	origin to daylight	67
99A	n/a		0	101	370	daylight to origin	94
258	75	daylight to origin	100	83	50	daylight to origin	93
216	225	origin to daylight	100	183		n/a	0
266	40	daylight to origin	100	32		n/a	0
	n/a		0	78		n/a	0

Appendix C: Quantitative Data Related to the Origin Elevation of the Recharge Line and Pre-Mine Average Background Low Flow Discharge as Discussed in Methods of Investigation III.									
Spring No.	Origin Elevation (ft)	Pre-Mine Average Background Low Flow Discharge		Spring No.	Origin Elevation (ft)	Pre-Mine Average Background Low Flow Discharge			
		Low Evapotranspiration (gpm)	High Evapotranspiration (gpm)			Low Evapotranspiration (gpm)	High Evapotranspiration (gpm)		
33	1270	4.22	0.27	43	1195	2.93	0.13		
198	1270	0.46	0.50	38	1275	0.51	0.24		
155	1155	n/a	0.26	176	1245	3.64	0.58		
157	n/a	1.65	n/a	226	1255	1.67	0.14		
162	n/a	2.09	n/a	154	1255	4.82	n/a		
166	1150	n/a	0.32	265	1275	1.70	0.37		
167	1210	4.33	n/a	79	1125	0.65	0.05		
173	1295	4.49	n/a	99	1185	4.34	0.05		
174	1255	8.97	n/a	107	1210	3.66	0.73		
177	1235	2.43	n/a	270	1315	0.33	n/a		
199	1060	0.98	n/a	102	1185	6.67	1.56		
224	1235	0.68	n/a	260	1285	2.59	n/a		
248	n/a	1.04	n/a	267	1370	2.15	0.29		
249	1120	8.22	n/a	97	1295	3.76	0.44		
254	1235	0.70	n/a	118	n/a	2.14	n/a		
259	1235	4.63	n/a	92	1225	1.23	n/a		
263	1175	1.96	n/a	106	1200	4.95	0.28		
272	1315	0.43	n/a	93	1255	1.64	0.30		
35	1235	2.70	n/a	171	1255	1.98	n/a		
36	1255	4.99	n/a	175	1200	0.19	0.13		
41	1185	0.84	n/a	274	1340	0.83	0.09		
63	1265	4.11	n/a	102A	1260	2.27	0.94		
64	1265	2.37	n/a	273	1315	0.90	n/a		
84	1235	2.73	n/a	256	1225	6.11	0.32		
94	1175	1.25	n/a	169	1295	7.61	0.64		
269	1255	2.42	0.44	91	1235	3.73	n/a		
271	1325	2.26	0.69	90	1135	2.81	1.36		
297	1225	1.75	0.62	152	1235	0.90	0.09		
268	1210	1.40	0.61	39	1225	0.10	n/a		
253	n/a	4.65	0.30	165	1055	n/a	0.45		
52	n/a	n/a	0.30	101	1275	n/a	0.46		
99A	1205	0.26	0.35	83	1235	n/a	0.15		
258	1235	2.57	0.38	183	n/a	n/a	n/a		
216	1285	0.32	0.10	32	n/a	n/a	n/a		
266	n/a	0.68	0.13	78	n/a	n/a	n/a		

APPENDIX D: Data Used to Calculate Changes to Spring Discharge Across Subsidence
Events During Low and High Evapotranspiration Conditions as Discussed in Methods of
Investigation III

Results for Changes to Spring Discharge Across a Subsidence Event Using Averaged Spring Discharge Data During Low Evapotranspiration Conditions as Discussed in Methods of Investigation III.					
Spring No.	Evaluation Period During Low Evapotranspiration Condition		Averaged Spring Discharge		Natural Reduction in Spring Discharge
	Year 1	Year 2	Year 1	Year 2	(see footnote)
			(gpm)	(gpm)	(%)
33	Feb - April ('94)	Feb - April ('95)	4.22	0.57	87
198	April - June ('93)	April - June ('95)	0.46	0.04	92
157	Jan - March ('98)	Jan - March ('99)	1.65	0.00	100
162	Jan - March ('96)	Jan - March ('97)	2.09	0.00	100
167	Jan - March ('95)	Jan - March ('96)	4.33	0.00	100
173	Jan - March ('93)	Jan - March ('95)	4.49	0.00	100
174	Jan - March ('93)	Jan - March ('95)	8.97	0.00	100
177	Jan - March ('93)	Jan - March ('94)	2.43	0.00	100
199	Jan - March ('96)	Jan - March ('97)	0.98	0.00	100
224	Jan - March ('92)	Jan - March ('93)	0.68	0.00	100
248	Jan - March ('98)	Jan - March ('00)	1.04	0.00	100
249	Jan - March ('98)	Jan - March ('99)	8.22	0.00	100
254	Jan - March ('99)	Jan - March ('00)	0.70	0.00	100
259	Jan - March ('99)	Jan - March ('00)	4.63	0.00	100
263	Jan - March ('99)	Jan - March ('00)	1.96	0.00	100
272	Jan - March ('00)	Jan - March ('02)	0.43	0.00	100
35	Jan - March ('94)	Jan - March ('95)	2.70	0.00	100
36	Jan - March ('94)	Jan - March ('95)	4.99	0.00	100
41	Jan - March ('94)	Jan - March ('95)	0.84	0.00	100
63	Jan - March ('94)	Jan - March ('95)	4.11	0.00	100
64	Jan - March ('94)	Jan - March ('95)	2.37	0.00	100
84	Jan - March ('96)	Jan - March ('97)	2.73	0.00	100
94	Jan - March ('95)	Jan - March ('96)	1.25	0.00	100
269	March - May ('00)	March - May ('01)	2.42	5.46	(126)
271	March - May ('99)	March - May ('01)	2.26	5.26	(133)
297	Jan - Feb ('00)	Jan - Feb ('01)	1.75	1.85	(6)
268	March - May ('00)	March - May ('01)	1.40	1.83	(31)
253	Jan - March ('98, '99)	Jan - March ('01)	4.65	3.92	16
99A	April - June ('97)	April - June ('98)	0.26	1.82	(600)
258	April - June ('98)	April - June ('00)	2.57	6.40	(149)
216	April - June ('93)	April - June ('95)	0.32	1.42	(338)
266	Jan - March ('01)	Jan - March ('03)	0.68	0.89	(32)
43	Jan - March ('93)	Jan - March ('94)	2.93	2.88	2
38	March - May ('93)	March - May ('95)	0.51	0.45	13
176	Jan - March ('93)	Jan - March ('94)	3.64	3.01	17
226	Jan - April ('93)	Jan - April ('94)	1.67	1.35	20
154	Jan - March ('98)	Jan - March ('99)	4.82	3.96	18
265	March - May ('00)	March - May ('02)	1.70	1.16	32
79	Jan - March ('96)	Jan - March ('97)	0.65	0.30	54
99	April - June ('97)	April - June ('98)	4.34	3.75	14
107	March - May ('97)	March - May ('99)	3.66	1.53	58
270	Feb - April ('00)	Feb - April ('01)	0.33	0.14	57
102	Jan - March ('97)	Jan - March ('99)	6.67	4.05	39
260	March - May ('97)	March - May ('98)	2.59	1.10	58
267	Feb - April ('00)	Feb - April ('02)	2.15	0.67	69
97	Jan - Feb ('97)	Jan - Feb ('98)	3.76	2.63	30
118	April - June ('97)	April - June ('98)	2.14	1.32	38
92	April - June ('95)	April - June ('96)	1.23	0.41	67
106	Jan - March ('98)	Jan - March ('99)	4.95	1.28	74
93	Feb - April ('95)	Feb - April ('96)	1.64	0.52	68
171	Jan - March ('93)	Jan - March ('95)	1.98	0.18	91
175	Jan - Feb ('93)	July - Sept ('92)	0.19	0.07	62
274	Feb - April ('00)	Feb - April ('02)	0.83	0.05	94
102A	April - June ('97)	April - June ('98)	2.27	0.28	88
273	Feb - April ('00)	Feb - April ('02)	0.90	0.05	95
256	Jan - March ('99)	Jan - March ('01)	6.11	0.14	98
169	Feb - April ('93)	Feb - April ('95)	7.61	0.14	98
91	Feb - April ('95)	Feb - April ('96)	3.73	0.12	97
90	Jan - March ('95)	Jan - March ('96)	2.81	0.03	99
152	Jan - March ('94)	Jan - March ('96)	0.90	0.00	100
39	April - June ('93)	April - June ('95)	0.10	0.00	100

Footnote: Natural reduction in spring discharge values in parentheses indicate a discharge improvement from Year 1 to Year 2. Natural reduction in spring discharge values not in parentheses indicate a discharge impairment from Year 1 to Year 2.

Results for Changes to Spring Discharge Across a Subsidence Event Using Averaged Spring Discharge Data During High Evapotranspiration Conditions as Discussed in Methods of Investigation III.					
Spring No.	Evaluation Period During High Evapotranspiration Condition		Averaged Spring Discharge		Natural Reduction in Spring Discharge
	Year 1	Year 2	Year 1	Year 2	(see footnote)
			(gpm)	(gpm)	(%)
33	July - Sept ('94)	July - Sept ('95)	0.27	0.28	(1)
198	July - Sept ('92)	July - Sept ('95)	0.50	0.61	(23)
155	Aug - Oct ('97)	Aug - Oct ('98)	0.26	0.00	100
166	Aug - Oct ('94)	Aug - Oct ('96)	0.32	0.00	100
269	Aug - Oct ('99)	Aug - Oct ('01)	0.44	0.71	(61)
271	Aug - Sept ('99)	Aug - Sept ('01)	0.69	1.20	(74)
297	Sept - Nov ('99)	Sept - Nov ('00)	0.62	0.56	10
268	Sept - Nov ('99)	Sept - Nov ('01)	0.61	1.33	(118)
253	July - Oct ('99)	July - Oct ('00)	0.30	0.32	(7)
52	Sept - Oct ('91)	Sept - Oct ('92)	0.30	0.28	8
99A	Oct - Dec ('96)	Oct - Dec ('98)	0.35	0.00	100
258	Aug - Nov ('98)	Aug - Nov ('00)	0.38	0.00	100
216	Aug - Oct ('93)	Aug - Oct ('94)	0.10	0.00	100
266	Aug - Oct ('01)	Aug - Oct ('02)	0.13	0.01	92
43	June - Aug ('92)	June - Aug ('94)	0.13	0.03	80
38	Aug - Sept ('93)	Aug - Sept ('94)	0.24	0.00	100
176	July - Aug ('92)	July - Aug ('94)	0.58	0.00	100
226	June - Aug ('92)	June - Aug ('93)	0.14	0.00	100
265	Sept - Nov ('99)	Sept - Nov ('01)	0.37	0.00	100
79	July - Aug ('95)	July - Aug ('97)	0.05	0.00	100
99	Sept - Oct ('97)	Sept - Oct ('98)	0.05	0.00	100
107	Aug - Oct ('97)	Aug - Oct ('99)	0.73	0.11	85
102	Aug - Sept ('97)	Aug - Sept ('98)	1.56	0.00	100
267	Aug - Oct ('00)	Aug - Oct ('01)	0.29	0.01	96
97	July - Aug ('96)	July - Aug ('98)	0.44	0.24	45
106	Aug - Oct ('97)	Aug - Oct ('99)	0.28	0.00	100
93	Aug - Sept ('94)	Aug - Sept ('96)	0.30	0.00	100
175	Jan - Feb ('94)	July - Sept ('94)	0.13	0.00	100
274	July - Sept ('99)	July - Sept ('02)	0.09	0.00	100
102A	July - Oct ('97)	July - Oct ('98)	0.94	0.01	99
256	July - Sept ('99)	July - Sept ('00)	0.32	0.04	88
169	June - Aug ('93)	June - Aug ('94)	0.64	0.22	65
90	July - Sept ('94)	July - Sept ('96)	1.36	0.00	100
152	Aug - Oct ('94)	Aug - Oct ('95)	0.09	0.00	100
165	July - Sept ('95)	July - Sept ('96)	0.45	0.74	(64)
101	Oct - Dec ('97)	Oct - Dec ('99)	0.46	0.01	98
83	Nov - Dec ('95)	Nov - Dec ('96)	0.15	0.00	100
Footnote: Natural reduction in spring discharge values in parentheses indicate a discharge improvement from Year 1 to Year 2. Natural reduction in spring discharge values not in parentheses indicate a discharge impairment from Year 1 to Year 2.					

Results for Changes to Spring Discharge Across a Subsidence Event Using Normalized Averaged Spring Discharge Data During Low Evapotranspiration Conditions as Discussed in **Methods of Investigation III**.

Spring No.	Evaluation Period During Low Evapotranspiration Condition	Averaged Spring Discharge		Averaged Precipitation		Spring Discharge Ratio		Natural Reduction in Spring Discharge Ratio	
		Year 1		Year 2		Year 1		Year 2	
		(gpm)	(gpm)	(in)	(in)	(gpm/in)	(gpm/in)	(see footnote)	(%)
33	Feb - April (94)								
198	April - June (93)	4.22	0.57	3.91	1.08	0.24	0.24		77
157	April - June (95)	0.46	0.04	3.42	4.81	0.01	0.01		94
	Jan - March (96)	2.09	0.00	3.49	3.97	0.60	0.00		100
162	Jan - March (95)	4.33	0.00	4.52	3.38	0.96	0.00		100
167	Jan - March (96)	8.97	0.00	2.55	4.32	3.52	0.00		100
173	Jan - March (93)	2.43	0.00	3.99	2.55	0.61	0.00		100
174	Jan - March (96)	0.98	0.00	3.99	2.55	0.24	0.00		100
177	Jan - March (92)	1.68	0.00	3.99	4.14	0.17	0.00		100
199	Jan - March (96)	1.04	0.00	4.52	3.38	0.23	0.00		100
224	Jan - March (98)	8.22	0.00	2.97	3.99	2.77	0.00		100
248	Jan - March (99)	0.70	0.00	3.49	3.48	0.20	0.00		100
249	Jan - March (99)	4.63	0.00	3.49	3.97	1.33	0.00		100
254	Jan - March (99)	1.96	0.00	3.97	3.48	0.49	0.00		100
259	Jan - March (00)	0.43	0.00	3.97	3.48	0.11	0.00		100
263	Jan - March (94)	2.70	0.00	3.97	3.48	0.68	0.00		100
272	Jan - March (94)	4.99	0.00	3.48	2.30	1.43	0.00		100
35	Jan - March (94)	0.84	0.00	4.14	2.55	0.20	0.00		100
36	Jan - March (94)	4.11	0.00	4.14	2.55	0.99	0.00		100
41	Jan - March (94)	2.37	0.00	4.14	2.55	0.57	0.00		100
63	Jan - March (96)	2.73	0.00	4.14	2.55	0.66	0.00		100
64	Jan - March (95)	1.25	0.00	4.14	2.55	0.30	0.00		100
84	March - May (00)	2.42	5.46	4.52	3.38	0.53	1.62		(202)
94	March - May (99)	2.26	5.26	2.55	4.52	0.89	1.16		(31)
269	Jan - Feb (00)	1.75	1.85	4.15	4.51	0.42	0.41		3
271	March - May (01)	1.40	1.83	3.32	4.51	0.42	0.41		4
297	Jan - March (98, 99)	4.65	3.92	3.41	2.20	1.36	1.78		(31)
268	April - June (97)	0.26	1.82	4.15	4.51	0.06	0.40		(544)
253	April - June (98)	2.57	6.40	3.73	2.67	0.69	2.40		(248)
99A	Jan - March (01)	0.68	0.89	3.86	6.10	0.18	0.15		17
258	Jan - March (93)	2.93	2.88	6.10	4.22	0.48	0.68		(42)
216	March - May (95)	0.51	0.45	3.42	4.91	0.15	0.09		38
266	Jan - March (93)	3.64	3.01	2.67	2.20	1.36	1.37		(0)
43	Jan - April (93)	1.67	1.35	3.99	4.14	0.42	0.33		22
38	Jan - March (98)	4.82	3.96	3.48	3.45	1.39	1.15		17
176	March - May (02)	1.70	1.16	3.99	4.14	0.43	0.28		34
226	Jan - March (96)	0.65	0.30	3.89	4.20	0.17	0.07		58
154	April - June (97)	4.34	3.75	3.49	3.97	1.24	0.94		24
265	March - May (99)	3.66	1.53	4.15	4.60	0.88	0.33		62
79	Feb - April (00)	0.33	0.14	4.52	3.38	0.07	0.04		43
99	Jan - March (97)	6.67	4.05	3.86	6.10	1.73	0.66		62
107	March - May (97)	2.59	1.10	4.33	3.32	0.60	0.33		46
270	Feb - April (00)	2.15	0.67	4.07	3.30	0.53	0.20		62
102	Jan - Feb (97)	3.76	2.63	3.38	3.97	1.11	0.66		40
260	April - June (98)	2.14	1.32	4.33	3.92	0.49	0.34		32
267	April - June (95)	1.23	0.41	4.07	2.75	0.30	0.15		51
97	Jan - March (96)	4.95	1.28	2.27	3.80	2.18	0.34		85
118	Feb - April (96)	1.64	0.52	3.86	6.10	0.42	0.09		80
92	Jan - March (93)	1.98	0.18	4.91	4.86	0.40	0.04		90
106	Jan - Feb (93)	0.19	0.07	3.49	3.97	0.05	0.02		67
93	Feb - April (00)	0.83	0.05	2.32	4.21	0.36	0.01		97
171	April - June (97)	2.27	0.28	3.99	2.55	0.57	0.11		81
175	Feb - April (02)	0.90	0.05	3.53	3.46	0.26	0.01		95
274	Jan - March (99)	6.11	0.14	4.07	2.75	1.50	0.05		97
102A	Feb - April (95)	7.61	0.14	3.86	6.10	1.97	0.02		99
273	Feb - April (96)	3.73	0.12	4.07	2.75	0.92	0.04		95
266	Jan - March (96)	2.81	0.03	3.97	2.67	0.71	0.01		99
169	Jan - March (94)	0.90	0.00	3.91	2.32	0.23	0.00		100
91	April - June (95)	0.10	0.00	2.32	4.21	0.04	0.00		100

Footnote: Natural reduction in spring discharge values in parentheses indicate a discharge/precipitation ratio improvement from Year 1 to Year 2. Natural reduction in spring discharge values not in parentheses indicate a discharge/precipitation ratio impairment from Year 1 to Year 2.

Results for Changes to Spring Discharge Across a Subsidence Event Using Normalized Averaged Spring Discharge Data During High Evapotranspiration Conditions as Discussed in Methods of Investigation III.												
Spring No.	Evaluation Period During High Evapotranspiration Condition		Averaged Spring Discharge		Averaged Precipitation		Spring Discharge Ratio		Natural Reduction in Spring Discharge Ratio			
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	(see footnote)	(%)
33	July - Sept (94)	July - Sept (95)	0.27	0.28	4.25	2.50	0.06	0.11	0.06	0.11	(72)	(72)
198	July - Sept (92)	July - Sept (95)	0.50	0.61	3.93	2.50	0.13	0.25	0.13	0.25	(93)	(93)
155	Aug - Oct (97)	Aug - Oct (98)	0.26	0.00	4.10	2.82	0.06	0.00	0.11	0.00	100	100
166	Aug - Oct (94)	Aug - Oct (96)	0.32	0.00	2.81	3.36	0.11	0.00	0.11	0.00	100	100
269	Aug - Oct (99)	Aug - Oct (01)	0.44	0.71	2.50	2.83	0.18	0.25	0.18	0.25	(43)	(43)
271	Aug - Sept (99)	Aug - Sept (01)	0.69	1.20	2.55	2.67	0.27	0.45	0.27	0.45	(66)	(66)
297	Sept - Nov (99)	Sept - Nov (00)	0.62	0.56	2.29	2.91	0.21	0.24	0.21	0.24	(15)	(15)
268	Sept - Nov (99)	Sept - Nov (01)	0.61	1.33	2.91	2.93	0.21	0.45	0.21	0.45	(117)	(117)
253	July - Oct (99)	July - Oct (00)	0.30	0.32	3.68	3.27	0.08	0.10	0.08	0.10	(20)	(20)
52	Sept - Oct (91)	Sept - Oct (92)	0.30	0.28	3.10	2.25	0.10	0.12	0.10	0.12	(27)	(27)
99A	Oct - Dec (96)	Oct - Dec (98)	0.35	0.00	2.82	2.30	0.12	0.00	0.12	0.00	100	100
258	Aug - Nov (98)	Aug - Nov (00)	0.38	0.00	2.55	2.88	0.15	0.00	0.15	0.00	100	100
216	Aug - Oct (93)	Aug - Oct (94)	0.10	0.00	3.66	2.81	0.03	0.00	0.03	0.00	100	100
266	Aug - Oct (01)	Aug - Oct (02)	0.13	0.01	2.83	2.54	0.04	0.00	0.04	0.00	91	91
43	June - Aug (92)	June - Aug (94)	0.13	0.03	4.30	5.33	0.03	0.01	0.03	0.01	84	84
38	Aug - Sept (93)	Aug - Sept (94)	0.24	0.00	3.95	3.82	0.06	0.00	0.06	0.00	100	100
176	July - Aug (92)	July - Aug (94)	0.58	0.00	4.30	5.33	0.13	0.00	0.13	0.00	100	100
226	June - Aug (92)	June - Aug (93)	0.14	0.00	4.30	3.89	0.03	0.00	0.03	0.00	100	100
265	Sept - Nov (99)	Sept - Nov (01)	0.37	0.00	2.91	2.93	0.13	0.00	0.13	0.00	100	100
79	July - Aug (95)	July - Aug (97)	0.05	0.00	2.82	6.11	0.02	0.00	0.02	0.00	100	100
99	Sept - Oct (97)	Sept - Oct (98)	0.05	0.00	2.73	2.81	0.02	0.00	0.02	0.00	100	100
107	Aug - Oct (97)	Aug - Oct (99)	0.73	0.11	4.10	2.50	0.18	0.04	0.18	0.04	75	75
102	Aug - Sept (97)	Aug - Sept (98)	1.56	0.00	5.44	2.26	0.29	0.00	0.29	0.00	100	100
267	Aug - Oct (00)	Aug - Oct (01)	0.29	0.01	3.25	2.83	0.09	0.00	0.09	0.00	95	95
97	July - Aug (96)	July - Aug (98)	0.44	0.24	3.26	2.30	0.13	0.10	0.13	0.10	23	23
106	Aug - Oct (97)	Aug - Oct (99)	0.28	0.00	4.10	2.50	0.07	0.00	0.07	0.00	100	100
93	Aug - Sept (94)	Aug - Sept (96)	0.30	0.00	3.82	3.74	0.08	0.00	0.08	0.00	100	100
175	Jan - Feb (94)	July - Sept (94)	0.13	0.00	3.75	4.25	0.03	0.00	0.03	0.00	100	100
274	July - Sept (99)	July - Sept (02)	0.09	0.00	4.11	2.21	0.02	0.00	0.02	0.00	100	100
102A	July - Oct (97)	July - Oct (98)	0.94	0.01	4.42	2.56	0.21	0.00	0.21	0.00	98	98
256	July - Sept (99)	July - Sept (00)	0.32	0.04	4.11	3.82	0.08	0.01	0.08	0.01	87	87
169	June - Aug (93)	June - Aug (94)	0.64	0.22	3.89	5.33	0.17	0.04	0.17	0.04	75	75
90	July - Sept (94)	July - Sept (96)	1.36	0.00	4.25	4.41	0.32	0.00	0.32	0.00	100	100
152	Aug - Oct (94)	Aug - Oct (95)	0.09	0.00	2.81	2.92	0.03	0.00	0.03	0.00	100	100
165	July - Sept (95)	July - Sept (96)	0.45	0.74	2.50	4.41	0.18	0.17	0.18	0.17	7	7
101	Oct - Dec (97)	Oct - Dec (99)	0.46	0.01	2.57	3.05	0.18	0.00	0.18	0.00	98	98
83	Nov - Dec (95)	Nov - Dec (96)	0.15	0.00	2.84	2.92	0.05	0.00	0.05	0.00	100	100

Footnote: Natural reduction in spring discharge values in parentheses indicate a discharge/precipitation ratio improvement from Year 1 to Year 2. Natural reduction in spring discharge values not in parentheses indicate a discharge/precipitation ratio impairment from Year 1 to Year 2.

APPENDIX E: Figures Illustrating the Statistically Significant Variables Identified from the Spring Discharge Response to Mining-Induced Subsidence Analysis through the Use of the Calculated Median Values as Discussed in Results of Investigation III

Appendix E. tab. 1: Data Used to Determine the Statistical Significance of the Spring Vertical Relief to Nearest Surface Drainage Feature Data Trend at the Optimum Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Vertical Relief to Nearest Surface Drainage Feature (ft)		
	Low ET (50%)	All	$\geq 50\%$	$< 50\%$
33	87	80	80	n/a
198	92	80	80	n/a
155	100	35	35	n/a
166	100	80	80	n/a
167	100	60	60	n/a
173	100	60	60	n/a
174	100	60	60	n/a
177	100	25	25	n/a
199	100	10	10	n/a
224	100	10	10	n/a
249	100	25	25	n/a
254	100	60	60	n/a
259	100	55	55	n/a
263	100	30	30	n/a
272	100	55	55	n/a
35	100	25	25	n/a
36	100	25	25	n/a
41	100	10	10	n/a
63	100	140	140	n/a
64	100	160	160	n/a
84	100	20	20	n/a
94	100	175	175	n/a
269	(126)	25	n/a	25
271	(133)	160	n/a	160
297	(6)	90	n/a	90
268	(31)	35	n/a	35
99A	(600)	15	n/a	15
258	(149)	30	n/a	30
216	(338)	50	n/a	50
43	2	10	n/a	10
38	13	35	n/a	35
176	17	5	n/a	5
226	20	45	n/a	45
154	18	15	n/a	15
265	32	25	n/a	25
79	54	95	95	n/a
99	14	10	n/a	10
107	58	50	50	n/a
270	57	10	10	n/a
102	39	5	n/a	5
260	58	70	70	n/a
267	69	25	25	n/a
97	30	145	n/a	145
92	67	60	60	n/a
106	74	35	35	n/a
93	68	50	50	n/a
171	91	45	45	n/a
175	62	10	10	n/a
274	94	40	40	n/a
102A	88	70	70	n/a
273	95	140	140	n/a
256	98	70	70	n/a
169	98	115	115	n/a
91	97	195	195	n/a
90	99	35	35	n/a
152	100	75	75	n/a
39	100	40	40	n/a
165				
101				
83				
n				
Median Value		57		
		45		
(A) # of Undermined Springs $\geq$ Median Value w / $\geq 50\%$ Discharge Reduction			24	
(B) # of Undermined Springs $\geq$ Median Value w / $< 50\%$ Discharge Reduction				5
(C) # of Undermined Springs $<$ Median Value w / $\geq 50\%$ Discharge Reduction			17	
(D) # of Undermined Springs $<$ Median Value w / $< 50\%$ Discharge Reduction				11
Absolute Value (AD-BC)		179		
Chi Square Value at 1 Degree of Freedom		2.42375		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.05918		

Appendix E_fig_1: Spring Vertical Relief to Nearest Surface Drainage Features Evaluated at the Optimum Reduction Boundary (50%) During Low Evapotranspiration Conditions

Appendix E. tab. 2: Data Used to Determine the Statistical Significance of the Spring Vertical Relief to Headwater, First and Second Order, Surface Drainage Feature Data Trend at the Optimum Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Vertical Relief to Headwater Surface Drainage Feature (ft)		
	Low ET (50%)	All	$\geq 50\%$	$< 50\%$
33	87	80	80	n/a
198	92	80	80	n/a
155	100	35	35	n/a
166	100	80	80	n/a
167	100	60	60	n/a
173	100	60	60	n/a
174	100	60	60	n/a
177	100	25	25	n/a
199				
224	100	10	10	n/a
249	100	25	25	n/a
254	100	60	60	n/a
259	100	55	55	n/a
263	100	30	30	n/a
272	100	55	55	n/a
35	100	25	25	n/a
36	100	25	25	n/a
41	100	10	10	n/a
63	100	140	140	n/a
64	100	160	160	n/a
84				
94				
269	(126)	25	n/a	25
271	(133)	160	n/a	160
297	(6)	90	n/a	90
268	(31)	35	n/a	35
99A	(600)	15	n/a	15
258	(149)	30	n/a	30
216	(338)	50	n/a	50
43	2	10	n/a	10
38	13	35	n/a	35
176	17	5	n/a	5
226	20	45	n/a	45
154	18	15	n/a	15
265	32	25	n/a	25
79				
99	14	10	n/a	10
107	58	50	50	n/a
270	57	10	10	n/a
102	39	5	n/a	5
260	58	70	70	n/a
267	69	25	25	n/a
97	30	145	n/a	145
92	67	60	60	n/a
106	74	35	35	n/a
93	68	50	50	n/a
171	91	45	45	n/a
175	62	10	10	n/a
274	94	40	40	n/a
102A	88	70	70	n/a
273	95	140	140	n/a
256	98	70	70	n/a
169	98	115	115	n/a
91	97	195	195	n/a
90	99	35	35	n/a
152	100	75	75	n/a
39				
165				
101				
83				
n				
Median Value		52		
		45		
(A) # of Undermined Springs $\geq$ Median Value w / $\geq 50\%$ Discharge Reduction			22	
(B) # of Undermined Springs $\geq$ Median Value w / $< 50\%$ Discharge Reduction				5
(C) # of Undermined Springs $<$ Median Value w / $\geq 50\%$ Discharge Reduction			14	
(D) # of Undermined Springs $<$ Median Value w / $< 50\%$ Discharge Reduction				11
Absolute Value (AD-BC)		172		
Chi Square Value at 1 Degree of Freedom		2.85091		
Error Probability as Derived from Chi Square Contingency Test		0.10-0.05		
Error Probability as Derived from Fisher Exact Probability Test		0.04516		

Appendix E_fig_2: Spring Vertical Relief to Headwater, First and Second Order, Surface Drainage Features Evaluated at the Optimum Reduction Boundary (50%) During Low Evapotranspiration Conditions

Appendix E. tab. 3: Data Used to Determine the Statistical Significance of the Spring Vertical Relief to First Order Surface Drainage Feature Data Trend at the Optimum Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Vertical Relief to First Order Surface Drainage Feature (ft)		
	Low ET (50%)	All	$\geq 50\%$	$< 50\%$
33				
198	92	80	80	n/a
155	100	35	35	n/a
166				
167	100	60	60	n/a
173	100	60	60	n/a
174	100	60	60	n/a
177				
199				
224	100	10	10	n/a
249	100	25	25	n/a
254	100	60	60	n/a
259				
263	100	30	30	n/a
272	100	55	55	n/a
35	100	25	25	n/a
36	100	25	25	n/a
41				
63				
64				
84				
94				
269	(126)	25	n/a	25
271	(133)	160	n/a	160
297				
268				
99A	(600)	15	n/a	15
258	(149)	30	n/a	30
216	(338)	50	n/a	50
43	2	10	n/a	10
38	13	35	n/a	35
176	17	5	n/a	5
226	20	45	n/a	45
154	18	15	n/a	15
265				
79				
99	14	10	n/a	10
107	58	50	50	n/a
270	57	10	10	n/a
102	39	5	n/a	5
260				
267	69	25	25	n/a
97	30	145	n/a	145
92	67	60	60	n/a
106	74	35	35	n/a
93	68	50	50	n/a
171	91	45	45	n/a
175	62	10	10	n/a
274	94	40	40	n/a
102A	88	70	70	n/a
273	95	140	140	n/a
256	98	70	70	n/a
169	98	115	115	n/a
91	97	195	195	n/a
90	99	35	35	n/a
152	100	75	75	n/a
39				
165				
101				
83				
n				
Median Value		41		
		40		
(A) # of Undermined Springs $\geq$ Median Value w / $\geq 50\%$ Discharge Reduction			17	
(B) # of Undermined Springs $\geq$ Median Value w / $< 50\%$ Discharge Reduction				4
(C) # of Undermined Springs $<$ Median Value w / $\geq 50\%$ Discharge Reduction			11	
(D) # of Undermined Springs $<$ Median Value w / $< 50\%$ Discharge Reduction				9
Absolute Value (AD-BC)		109		
Chi Square Value at 1 Degree of Freedom		2.10049		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.07315		

Appendix E_fig_3: Spring Vertical Relief to First Order Surface Drainage Features Evaluated at the Optimum Reduction Boundary (50%) During Low Evapotranspiration Conditions

Appendix E. tab. 4: Data Used to Determine the Statistical Significance of the Spring Vertical Relief to First Order Surface Drainage Feature Data Trend at the Absolute Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Spring Vertical Relief to First Order Surface Drainage Feature (ft)		
	Low ET (88%)	All	$\geq 88\%$	$< 88\%$
33				
198	92	80	80	n/a
155	100	35	35	n/a
166				
167	100	60	60	n/a
173	100	60	60	n/a
174	100	60	60	n/a
177				
199				
224	100	10	10	n/a
249	100	25	25	n/a
254	100	60	60	n/a
259				
263	100	30	30	n/a
272	100	55	55	n/a
35	100	25	25	n/a
36	100	25	25	n/a
41				
63				
64				
84				
94				
269	(126)	25	n/a	25
271	(133)	160	n/a	160
297				
268				
99A	(600)	15	n/a	15
258	(149)	30	n/a	30
216	(338)	50	n/a	50
43	2	10	n/a	10
38	13	35	n/a	35
176	17	5	n/a	5
226	20	45	n/a	45
154	18	15	n/a	15
265				
79				
99	14	10	n/a	10
107	58	50	n/a	50
270	57	10	n/a	10
102	39	5	n/a	5
260				
267	69	25	n/a	25
97	30	145	n/a	145
92	67	60	n/a	60
106	74	35	n/a	35
93	68	50	n/a	50
171	91	45	45	n/a
175	62	10	n/a	10
274	94	40	40	n/a
102A	88	70	n/a	70
273	95	140	140	n/a
256	98	70	70	n/a
169	98	115	115	n/a
91	97	195	195	n/a
90	99	35	35	n/a
152	100	75	75	n/a
39				
165				
101				
83				
n		41		
Median Value		40		
(A) # of Undermined Springs $\geq$ Median Value w / $\geq 50\%$ Discharge Reduction			13	
(B) # of Undermined Springs $\geq$ Median Value w / $< 50\%$ Discharge Reduction				8
(C) # of Undermined Springs $<$ Median Value w / $\geq 50\%$ Discharge Reduction			7	
(D) # of Undermined Springs $<$ Median Value w / $< 50\%$ Discharge Reduction				13
Absolute Value (AD-BC)		113		
Chi Square Value at 1 Degree of Freedom		1.98870		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.07888		

Appendix E_fig_4: Spring Vertical Relief to First Order Surface Drainage Features Evaluated at the Absolute Reduction Boundary (88%) During Low Evapotranspiration Conditions

Appendix E, tab 5: Data Used to Determine the Statistical Significance of the Spring Daylight Elevation Data Trend at the Absolute Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Spring Daylight Elevation (ft amsl)		
	Low ET (88%)	All	$\geq 88\%$	$< 88\%$
33	87	1240	n/a	1240
198	92	1250	1250	n/a
155	100	1115	1115	n/a
166	100	1130	1130	n/a
167	100	1170	1170	n/a
173	100	1260	1260	n/a
174	100	1230	1230	n/a
177	100	1175	1175	n/a
199	100	1010	1010	n/a
224	100	1215	1215	n/a
249	100	1120	1120	n/a
254	100	1130	1130	n/a
259	100	1155	1155	n/a
263	100	1160	1160	n/a
272	100	1265	1265	n/a
35	100	1185	1185	n/a
36	100	1225	1225	n/a
41	100	1180	1180	n/a
63	100	1165	1165	n/a
64	100	1185	1185	n/a
84	100	1040	1040	n/a
94	100	1155	1155	n/a
269	(126)	1225	n/a	1225
271	(133)	1310	n/a	1310
297	(6)	1210	n/a	1210
268	(31)	1185	n/a	1185
99A	(600)	1190	n/a	1190
258	(149)	1190	n/a	1190
216	(338)	1210	n/a	1210
43	2	1180	n/a	1180
38	13	1220	n/a	1220
176	17	1175	n/a	1175
226	20	1195	n/a	1195
154	18	1150	n/a	1150
265	32	1200	n/a	1200
79	54	1095	n/a	1095
99	14	1180	n/a	1180
107	58	1200	n/a	1200
270	57	1230	n/a	1230
102	39	1160	n/a	1160
260	58	1190	n/a	1190
267	69	1210	n/a	1210
97	30	1265	n/a	1265
92	67	1190	n/a	1190
106	74	1155	n/a	1155
93	68	1175	n/a	1175
171	91	1195	1195	n/a
175	62	1190	n/a	1190
274	94	1240	1240	n/a
102A	88	1200	n/a	1200
273	95	1280	1280	n/a
256	98	1190	1190	n/a
169	98	1225	1225	n/a
91	97	1195	1195	n/a
90	99	1125	1125	n/a
152	100	1195	1195	n/a
39	100	1150	1150	n/a
165				
101				
83				
n				
Median Value		57		
		1190		
(A) # of Undermined Springs $\geq$ Median Value w / $\geq 50\%$ Discharge Reduction			13	
(B) # of Undermined Springs $\geq$ Median Value w / $< 50\%$ Discharge Reduction				18
(C) # of Undermined Springs $<$ Median Value w / $\geq 50\%$ Discharge Reduction			17	
(D) # of Undermined Springs $<$ Median Value w / $< 50\%$ Discharge Reduction				9
Absolute Value (AD-BC)		189		
Chi Square Value at 1 Degree of Freedom		2.24908		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.06644		

Appendix E_fig_5: Spring Daylight Elevation Evaluated at the Absolute Reduction Boundary (88%) During Low Evapotranspiration Conditions

Appendix E. tab. 6: Data Used to Determine the Statistical Significance of the Spring Recharge Line Length Data Trend at the Optimum Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Recharge Line Length (ft)		
	High ET (60%)	All	$\geq 60\%$	$< 60\%$
33	(1)	157	n/a	157
198	(23)	170	n/a	170
155	100	188	188	n/a
166	100	94	94	n/a
167	100	219	219	n/a
173	100	219	219	n/a
174	100	94	94	n/a
177	100	310	310	n/a
199	100	188	188	n/a
224	100	120	120	n/a
249	100	407	407	n/a
254	100	375	375	n/a
259	100	657	657	n/a
263	100	63	63	n/a
272	100	219	219	n/a
35	100	157	157	n/a
36	100	125	125	n/a
41	100	63	63	n/a
63	100	532	532	n/a
64	100	438	438	n/a
84	100	750	750	n/a
94	100	125	125	n/a
269	(61)	157	n/a	157
271	(74)	125	n/a	125
297	10	94	n/a	94
268	(118)	282	n/a	282
99A	100	75	75	n/a
258	100	532	532	n/a
216	100	360	360	n/a
43	80	63	63	n/a
38	100	282	282	n/a
176	100	375	375	n/a
226	100	313	313	n/a
154				
265	100	594	594	n/a
79	100	188	188	n/a
99	100	32	32	n/a
107	85	90	90	n/a
270				
102	100	313	313	n/a
260				
267	96	750	750	n/a
97	45	157	n/a	157
92				
106	100	250	250	n/a
93	100	330	330	n/a
171				
175	100	94	94	n/a
274	100	469	469	n/a
102A	99	532	532	n/a
273				
256	88	250	250	n/a
169	65	344	344	n/a
91				
90	100	313	313	n/a
152	100	188	188	n/a
39				
165	(64)	188	n/a	188
101	98	625	625	n/a
83	100	813	813	n/a
n		52		
Median Value		219		
(A) # of Undermined Springs $\geq$ Median Value w / $\geq 50\%$ Discharge Reduction			27	
(B) # of Undermined Springs $\geq$ Median Value w / $< 50\%$ Discharge Reduction				1
(C) # of Undermined Springs $<$ Median Value w / $\geq 50\%$ Discharge Reduction			17	
(D) # of Undermined Springs $<$ Median Value w / $< 50\%$ Discharge Reduction				7
Absolute Value (AD-BC)		172		
Chi Square Value at 1 Degree of Freedom		4.68594		
Error Probability as Derived from Chi Square Contingency Test		0.05-0.02		
Error Probability as Derived from Fisher Exact Probability Test		0.01386		

Appendix E_fig_6: Spring Recharge Line Length Evaluated at the Optimum Reduction Boundary (60%) During High Evapotranspiration Conditions

Appendix E. tab. 7: Data Used to Determine the Statistical Significance of the Spring Recharge Line Vertical Relief Data Trend at the Optimum Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Recharge Line Vertical Relief (ft)		
	High ET (60%)	All	$\geq 60\%$	$< 60\%$
33	(1)	30	n/a	30
198	(23)	20	n/a	20
155	100	40	40	n/a
166	100	20	20	n/a
167	100	40	40	n/a
173	100	35	35	n/a
174	100	25	25	n/a
177	100	60	60	n/a
199	100	50	50	n/a
224	100	20	20	n/a
249	100	0	0	n/a
254	100	105	105	n/a
259	100	80	80	n/a
263	100	15	15	n/a
272	100	50	50	n/a
35	100	50	50	n/a
36	100	30	30	n/a
41	100	5	5	n/a
63	100	100	100	n/a
64	100	80	80	n/a
84	100	195	195	n/a
94	100	20	20	n/a
269	(61)	30	n/a	30
271	(74)	15	n/a	15
297	10	15	n/a	15
268	(118)	25	n/a	25
99A	100	15	15	n/a
258	100	45	45	n/a
216	100	75	75	n/a
43	80	15	15	n/a
38	100	55	55	n/a
176	100	70	70	n/a
226	100	60	60	n/a
154				
265	100	75	75	n/a
79	100	30	30	n/a
99	100	5	5	n/a
107	85	10	10	n/a
270				
102	100	25	25	n/a
260				
267	96	160	160	n/a
97	45	30	n/a	30
92				
106	100	45	45	n/a
93	100	80	80	n/a
171				
175	100	10	10	n/a
274	100	100	100	n/a
102A	99	60	60	n/a
273				
256	88	35	35	n/a
169	65	70	70	n/a
91				
90	100	10	10	n/a
152	100	40	40	n/a
39				
165	(64)	45	n/a	45
101	98	145	145	n/a
83	100	195	195	n/a
n		52		
Median Value		40		
(A) # of Undermined Springs $\geq$ Median Value w / $\geq 50\%$ Discharge Reduction			26	
(B) # of Undermined Springs $\geq$ Median Value w / $< 50\%$ Discharge Reduction				1
(C) # of Undermined Springs $<$ Median Value w / $\geq 50\%$ Discharge Reduction			18	
(D) # of Undermined Springs $<$ Median Value w / $< 50\%$ Discharge Reduction				7
Absolute Value (AD-BC)		164		
Chi Square Value at 1 Degree of Freedom		4.16788		
Error Probability as Derived from Chi Square Contingency Test		0.05-0.02		
Error Probability as Derived from Fisher Exact Probability Test		0.01868		

Appendix E_fig_7: Spring Recharge Line Vertical Relief Evaluated at the Optimum Reduction Boundary (60%) During High Evapotranspiration Conditions

Appendix E. tab. 8: Data Used to Determine the Statistical Significance of the Spring Daylight Elevation Data Trend at the Optimum Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Daylight Elevation (ft amsl)		
	High ET (60%)	All	$\geq 60\%$	$< 60\%$
33	(1)	1240	n/a	1240
198	(23)	1250	n/a	1250
155	100	1115	1115	n/a
166	100	1130	1130	n/a
167	100	1170	1170	n/a
173	100	1260	1260	n/a
174	100	1230	1230	n/a
177	100	1175	1175	n/a
199	100	1010	1010	n/a
224	100	1215	1215	n/a
249	100	1120	1120	n/a
254	100	1130	1130	n/a
259	100	1155	1155	n/a
263	100	1160	1160	n/a
272	100	1265	1265	n/a
35	100	1185	1185	n/a
36	100	1225	1225	n/a
41	100	1180	1180	n/a
63	100	1165	1165	n/a
64	100	1185	1185	n/a
84	100	1040	1040	n/a
94	100	1155	1155	n/a
269	(61)	1225	n/a	1225
271	(74)	1310	n/a	1310
297	10	1210	n/a	1210
268	(118)	1185	n/a	1185
99A	100	1190	1190	n/a
258	100	1190	1190	n/a
216	100	1210	1210	n/a
43	80	1180	1180	n/a
38	100	1220	1220	n/a
176	100	1175	1175	n/a
226	100	1195	1195	n/a
154				
265	100	1200	1200	n/a
79	100	1095	1095	n/a
99	100	1180	1180	n/a
107	85	1200	1200	n/a
270				
102	100	1160	1160	n/a
260				
267	96	1210	1210	n/a
97	45	1265	n/a	1265
92				
106	100	1155	1155	n/a
93	100	1175	1175	n/a
171				
175	100	1190	1190	n/a
274	100	1240	1240	n/a
102A	99	1200	1200	n/a
273				
256	88	1190	1190	n/a
169	65	1225	1225	n/a
91				
90	100	1125	1125	n/a
152	100	1195	1195	n/a
39				
165	(64)	1010	n/a	1010
101	98	1130	1130	n/a
83	100	1040	1040	n/a
n		52		
Median Value		1185		
(A) # of Undermined Springs $\geq$ Median Value w/ $\geq 50\%$ Discharge Reduction			21	
(B) # of Undermined Springs $\geq$ Median Value w/ $< 50\%$ Discharge Reduction				7
(C) # of Undermined Springs $<$ Median Value w/ $\geq 50\%$ Discharge Reduction			23	
(D) # of Undermined Springs $<$ Median Value w/ $< 50\%$ Discharge Reduction				1
Absolute Value (AD-BC)		140		
Chi Square Value at 1 Degree of Freedom		2.85694		
Error Probability as Derived from Chi Square Contingency Test		0.10-0.05		
Error Probability as Derived from Fisher Exact Probability Test		0.04189		

Appendix E_fig_8: Spring Daylight Elevation Evaluated at the Optimum Reduction Boundary (60%) During High Evapotranspiration Conditions

Appendix E. tab. 9: Data Used to Determine the Statistical Significance of the Pre-Mine Averaged Low Flow Spring Discharge Data Trend at the Optimum Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Pre-Mine Averaged Low Flow Spring Discharge (gpm)		
	High ET (60%)	All	$\geq 60\%$	$< 60\%$
33	(1)	0.27	n/a	0.27
198	(23)	0.50	n/a	0.50
155	100	0.26	0.26	n/a
166	100	0.32	0.32	n/a
167				
173				
174				
177				
199				
224				
249				
254				
259				
263				
272				
35				
36				
41				
63				
64				
84				
94				
269	(61)	0.44	n/a	0.44
271	(74)	0.69	n/a	0.69
297	10	0.62	n/a	0.62
268	(118)	0.61	n/a	0.61
99A	100	0.35	0.35	n/a
258	100	0.38	0.38	n/a
216	100	0.10	0.10	n/a
43	80	0.13	0.13	n/a
38	100	0.24	0.24	n/a
176	100	0.58	0.58	n/a
226	100	0.14	0.14	n/a
154				
265	100	0.37	0.37	n/a
79	100	0.05	0.05	n/a
99	100	0.05	0.05	n/a
107	85	0.73	0.73	n/a
270				
102	100	1.56	1.56	n/a
260				
267	96	0.29	0.29	n/a
97	45	0.44	n/a	0.44
92				
106	100	0.28	0.28	n/a
93	100	0.30	0.30	n/a
171				
175	100	0.13	0.13	n/a
274	100	0.09	0.09	n/a
102A	99	0.94	0.94	n/a
273				
256	88	0.32	0.32	n/a
169	65	0.64	0.64	n/a
91				
90	100	1.36	1.36	n/a
152	100	0.09	0.09	n/a
39				
165	(64)	0.45	n/a	0.45
101	98	0.46	0.46	n/a
83	100	0.15	0.15	n/a
n		34		
Median Value		0.34		
(A) # of Undermined Springs $\geq$ Median Value w / $\geq 50\%$ Discharge Reduction			10	
(B) # of Undermined Springs $\geq$ Median Value w / $< 50\%$ Discharge Reduction				7
(C) # of Undermined Springs $<$ Median Value w / $\geq 50\%$ Discharge Reduction			16	
(D) # of Undermined Springs $<$ Median Value w / $< 50\%$ Discharge Reduction				1
Absolute Value (AD-BC)		102		
Chi Square Value at 1 Degree of Freedom		4.08654		
Error Probability as Derived from Chi Square Contingency Test		0.05-0.02		
Error Probability as Derived from Fisher Exact Probability Test		0.01955		

Appendix E_fig_9: Pre-Mine Averaged Low Flow Spring Discharge Evaluated at the Optimum Reduction Boundary (60%) During High Evapotranspiration Conditions

Appendix E. tab. 10: Data Used to Determine the Statistical Significance of the Spring Recharge Line Length Component Perpendicular to Longwall Face Data Trend at the Absolute Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Spring Recharge Line Length Component Perpendicular to Longwall Face (ft)		
	High ET (80%)	All	$\geq 80\%$	$< 80\%$
33				
198	(23)	100	n/a	100
155	100	15	15	n/a
166	100	30	30	n/a
167	100	160	160	n/a
173	100	140	140	n/a
174				
177	100	280	280	n/a
199	100	220	220	n/a
224	100	120	120	n/a
249	100	350	350	n/a
254	100	360	360	n/a
259	100	100	100	n/a
263	100	15	15	n/a
272	100	30	30	n/a
35	100	70	70	n/a
36	100	50	50	n/a
41	100	40	40	n/a
63	100	370	370	n/a
64	100	300	300	n/a
84	100	220	220	n/a
94	100	50	50	n/a
269	(61)	140	n/a	140
271	(74)	110	n/a	110
297	10	65	n/a	65
268	(118)	70	n/a	70
99A	100	75	75	n/a
258	100	225	225	n/a
216	100	40	40	n/a
43	80	20	n/a	20
38	100	20	20	n/a
176	100	340	340	n/a
226	100	260	260	n/a
154				
265	100	140	140	n/a
79	100	110	110	n/a
99	100	15	15	n/a
107				
270				
102	100	280	280	n/a
260				
267	96	250	250	n/a
97	45	100	n/a	100
92				
106	100	220	220	n/a
93	100	220	220	n/a
171				
175	100	30	30	n/a
274	100	440	440	n/a
102A	99	180	180	n/a
273				
256	88	200	200	n/a
169	65	90	n/a	90
91				
90	100	50	50	n/a
152	100	80	80	n/a
39				
165	(64)	90	n/a	90
101	98	370	370	n/a
83	100	50	50	n/a
n		49		
Median Value		110		
(A) # of Undermined Springs $\geq$ Median Value w / $\geq 50\%$ Discharge Reduction			23	
(B) # of Undermined Springs $\geq$ Median Value w / $< 50\%$ Discharge Reduction				2
(C) # of Undermined Springs $<$ Median Value w / $\geq 50\%$ Discharge Reduction			17	
(D) # of Undermined Springs $<$ Median Value w / $< 50\%$ Discharge Reduction				7
Absolute Value (AD-BC)		127		
Chi Square Value at 1 Degree of Freedom		2.38336		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.06013		

Appendix E_fig_10: Recharge Line Length Component Perpendicular to Longwall Face Evaluated at the Absolute Reduction Boundary (80%) During High Evapotranspiration Conditions

Appendix E. tab. 11: Data Used to Determine the Statistical Significance of the Spring Recharge Line Length Data Trend at the Absolute Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Spring Recharge Line Length (ft)		
	High ET (80%)	All	$\geq 80\%$	$< 80\%$
33	(1)	157	n/a	157
198	(23)	170	n/a	170
155	100	188	188	n/a
166	100	94	94	n/a
167	100	219	219	n/a
173	100	219	219	n/a
174	100	94	94	n/a
177	100	310	310	n/a
199	100	188	188	n/a
224	100	120	120	n/a
249	100	407	407	n/a
254	100	375	375	n/a
259	100	657	657	n/a
263	100	63	63	n/a
272	100	219	219	n/a
35	100	157	157	n/a
36	100	125	125	n/a
41	100	63	63	n/a
63	100	532	532	n/a
64	100	438	438	n/a
84	100	750	750	n/a
94	100	125	125	n/a
269	(61)	157	n/a	157
271	(74)	125	n/a	125
297	10	94	n/a	94
268	(118)	282	n/a	282
99A	100	75	75	n/a
258	100	532	532	n/a
216	100	360	360	n/a
43	80	63	n/a	63
38	100	282	282	n/a
176	100	375	375	n/a
226	100	313	313	n/a
154				
265	100	594	594	n/a
79	100	188	188	n/a
99	100	32	32	n/a
107	85	90	90	n/a
270				
102	100	313	313	n/a
260				
267	96	750	750	n/a
97	45	157	n/a	157
92				
106	100	250	250	n/a
93	100	330	330	n/a
171				
175	100	94	94	n/a
274	100	469	469	n/a
102A	99	532	532	n/a
273				
256	88	250	250	n/a
169	65	344	n/a	344
91				
90	100	313	313	n/a
152	100	188	188	n/a
39				
165	(64)	188	n/a	188
101	98	625	625	n/a
83	100	813	813	n/a
n		52		
Median Value		219		
(A) # of Undermined Springs $\geq$ Median Value w / $\geq 50\%$ Discharge Reduction			26	
(B) # of Undermined Springs $\geq$ Median Value w / $< 50\%$ Discharge Reduction				2
(C) # of Undermined Springs $<$ Median Value w / $\geq 50\%$ Discharge Reduction			16	
(D) # of Undermined Springs $<$ Median Value w / $< 50\%$ Discharge Reduction				8
Absolute Value (AD-BC)		176		
Chi Square Value at 1 Degree of Freedom		4.14541		
Error Probability as Derived from Chi Square Contingency Test		0.05-0.02		
Error Probability as Derived from Fisher Exact Probability Test		0.02001		

Appendix E_fig_11: Spring Recharge Line Length Evaluated at the Absolute Reduction Boundary (80%) During High Evapotranspiration Conditions

Appendix E. tab. 12: Data Used to Determine the Statistical Significance of the Spring Recharge Line Vertical Relief Data Trend at the Absolute Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Spring Recharge Line Vertical Relief (ft)		
	High ET (80%)	All	$\geq 80\%$	$< 80\%$
33	(1)	30	n/a	30
198	(23)	20	n/a	20
155	100	40	40	n/a
166	100	20	20	n/a
167	100	40	40	n/a
173	100	35	35	n/a
174	100	25	25	n/a
177	100	60	60	n/a
199	100	50	50	n/a
224	100	20	20	n/a
249	100	0	0	n/a
254	100	105	105	n/a
259	100	80	80	n/a
263	100	15	15	n/a
272	100	50	50	n/a
35	100	50	50	n/a
36	100	30	30	n/a
41	100	5	5	n/a
63	100	100	100	n/a
64	100	80	80	n/a
84	100	195	195	n/a
94	100	20	20	n/a
269	(61)	30	n/a	30
271	(74)	15	n/a	15
297	10	15	n/a	15
268	(118)	25	n/a	25
99A	100	15	15	n/a
258	100	45	45	n/a
216	100	75	75	n/a
43	80	15	n/a	15
38	100	55	55	n/a
176	100	70	70	n/a
226	100	60	60	n/a
154				
265	100	75	75	n/a
79	100	30	30	n/a
99	100	5	5	n/a
107	85	10	10	n/a
270				
102	100	25	25	n/a
260				
267	96	160	160	n/a
97	45	30	n/a	30
92				
106	100	45	45	n/a
93	100	80	80	n/a
171				
175	100	10	10	n/a
274	100	100	100	n/a
102A	99	60	60	n/a
273				
256	88	35	35	n/a
169	65	70	n/a	70
91				
90	100	10	10	n/a
152	100	40	40	n/a
39				
165	(64)	45	n/a	45
101	98	145	145	n/a
83	100	195	195	n/a
n		52		
Median Value		40		
(A) # of Undermined Springs $\geq$ Median Value w / $\geq 50\%$ Discharge Reduction			25	
(B) # of Undermined Springs $\geq$ Median Value w / $< 50\%$ Discharge Reduction				2
(C) # of Undermined Springs $<$ Median Value w / $\geq 50\%$ Discharge Reduction			17	
(D) # of Undermined Springs $<$ Median Value w / $< 50\%$ Discharge Reduction				8
Absolute Value (AD-BC)		166		
Chi Square Value at 1 Degree of Freedom		3.59506		
Error Probability as Derived from Chi Square Contingency Test		0.10-0.05		
Error Probability as Derived from Fisher Exact Probability Test		0.02769		

Appendix E_fig_12: Spring Recharge Line Vertical Relief Evaluated at the Absolute Reduction Boundary (80%) During High Evapotranspiration Conditions

Appendix E. tab. 13: Data Used to Determine the Statistical Significance of the Spring Daylight Elevation Data Trend at the Absolute Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Spring Daylight Elevation (ft amsl)		
	High ET (80%)	All	$\geq 80\%$	$< 80\%$
33	(1)	1240	n/a	1240
198	(23)	1250	n/a	1250
155	100	1115	1115	n/a
166	100	1130	1130	n/a
167	100	1170	1170	n/a
173	100	1260	1260	n/a
174	100	1230	1230	n/a
177	100	1175	1175	n/a
199	100	1010	1010	n/a
224	100	1215	1215	n/a
249	100	1120	1120	n/a
254	100	1130	1130	n/a
259	100	1155	1155	n/a
263	100	1160	1160	n/a
272	100	1265	1265	n/a
35	100	1185	1185	n/a
36	100	1225	1225	n/a
41	100	1180	1180	n/a
63	100	1165	1165	n/a
64	100	1185	1185	n/a
84	100	1040	1040	n/a
94	100	1155	1155	n/a
269	(61)	1225	n/a	1225
271	(74)	1310	n/a	1310
297	10	1210	n/a	1210
268	(118)	1185	n/a	1185
99A	100	1190	1190	n/a
258	100	1190	1190	n/a
216	100	1210	1210	n/a
43	80	1180	n/a	1180
38	100	1220	1220	n/a
176	100	1175	1175	n/a
226	100	1195	1195	n/a
154				
265	100	1200	1200	n/a
79	100	1095	1095	n/a
99	100	1180	1180	n/a
107	85	1200	1200	n/a
270				
102	100	1160	1160	n/a
260				
267	96	1210	1210	n/a
97	45	1265	n/a	1265
92				
106	100	1155	1155	n/a
93	100	1175	1175	n/a
171				
175	100	1190	1190	n/a
274	100	1240	1240	n/a
102A	99	1200	1200	n/a
273				
256	88	1190	1190	n/a
169	65	1225	n/a	1225
91				
90	100	1125	1125	n/a
152	100	1195	1195	n/a
39				
165	(64)	1010	n/a	1010
101	98	1130	1130	n/a
83	100	1040	1040	n/a
n		52		
Median Value		1185		
(A) # of Undermined Springs $\geq$ Median Value w/ $\geq 50\%$ Discharge Reduction			20	
(B) # of Undermined Springs $\geq$ Median Value w/ $< 50\%$ Discharge Reduction				8
(C) # of Undermined Springs $<$ Median Value w/ $\geq 50\%$ Discharge Reduction			22	
(D) # of Undermined Springs $<$ Median Value w/ $< 50\%$ Discharge Reduction				2
Absolute Value (AD-BC)		136		
Chi Square Value at 1 Degree of Freedom		2.22931		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.06553		

Appendix E_fig_13: Spring Daylight Elevation Evaluated at the Absolute Reduction Boundary (80%) During High Evapotranspiration Conditions

Appendix E. tab. 14: Data Used to Determine the Statistical Significance of the Pre-Mine Averaged Low Flow Spring Discharge Data Trend at the Absolute Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Pre-Mine Averaged Low Flow Spring Discharge (gpm)		
	High ET (80%)	All	$\geq 80\%$	$< 80\%$
33	(1)	0.27	n/a	0.27
198	(23)	0.50	n/a	0.50
155	100	0.26	0.26	n/a
166	100	0.32	0.32	n/a
167				
173				
174				
177				
199				
224				
249				
254				
259				
263				
272				
35				
36				
41				
63				
64				
84				
94				
269	(61)	0.44	n/a	0.44
271	(74)	0.69	n/a	0.69
297	10	0.62	n/a	0.62
268	(118)	0.61	n/a	0.61
99A	100	0.35	0.35	n/a
258	100	0.38	0.38	n/a
216	100	0.10	0.10	n/a
43	80	0.13	n/a	0.13
38	100	0.24	0.24	n/a
176	100	0.58	0.58	n/a
226	100	0.14	0.14	n/a
154				
265	100	0.37	0.37	n/a
79	100	0.05	0.05	n/a
99	100	0.05	0.05	n/a
107	85	0.73	0.73	n/a
270				
102	100	1.56	1.56	n/a
260				
267	96	0.29	0.29	n/a
97	45	0.44	n/a	0.44
92				
106	100	0.28	0.28	n/a
93	100	0.30	0.30	n/a
171				
175	100	0.13	0.13	n/a
274	100	0.09	0.09	n/a
102A	99	0.94	0.94	n/a
273				
256	88	0.32	0.32	n/a
169	65	0.64	n/a	0.64
91				
90	100	1.36	1.36	n/a
152	100	0.09	0.09	n/a
39				
165	(64)	0.45	n/a	0.45
101	98	0.46	0.46	n/a
83	100	0.15	0.15	n/a
n		34		
Median Value		0.34		
(A) # of Undermined Springs $\geq$ Median Value w / $\geq 50\%$ Discharge Reduction			9	
(B) # of Undermined Springs $\geq$ Median Value w / $< 50\%$ Discharge Reduction				8
(C) # of Undermined Springs $<$ Median Value w / $\geq 50\%$ Discharge Reduction			15	
(D) # of Undermined Springs $<$ Median Value w / $< 50\%$ Discharge Reduction				2
Absolute Value (AD-BC)		102		
Chi Square Value at 1 Degree of Freedom		3.54167		
Error Probability as Derived from Chi Square Contingency Test		0.10-0.05		
Error Probability as Derived from Fisher Exact Probability Test		0.02851		

Conditions

APPENDIX F: Figures Illustrating the Statistically Significant Variables Identified from
the Degree of Spring Discharge Impairment to Mining-Induced Subsidence Analysis
through the Use of the Calculated Median Values as Discussed in Results of Investigation

III

Appendix F, tab. 1: Data Used to Determine the Statistical Significance of the Spring Vertical Relief to Nearest Surface Drainage Feature Data Trend at the Optimum Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Vertical Relief to Nearest Surface Drainage Feature (ft)		
	Low ET (50%)	All	$\geq 50\%$	$< 50\%$
33	87	80	80	n/a
198	92	80	80	n/a
155	100	35	35	n/a
166	100	80	80	n/a
167	100	60	60	n/a
173	100	60	60	n/a
174	100	60	60	n/a
177	100	25	25	n/a
199	100	10	10	n/a
224	100	10	10	n/a
249	100	25	25	n/a
254	100	60	60	n/a
259	100	55	55	n/a
263	100	30	30	n/a
272	100	55	55	n/a
35	100	25	25	n/a
36	100	25	25	n/a
41	100	10	10	n/a
63	100	140	140	n/a
64	100	160	160	n/a
84	100	20	20	n/a
94	100	175	175	n/a
269				
271				
297				
268				
99A				
258				
216				
43	2	10	n/a	10
38	13	35	n/a	35
176	17	5	n/a	5
226	20	45	n/a	45
154	18	15	n/a	15
265	32	25	n/a	25
79	54	95	95	n/a
99	14	10	n/a	10
107	58	50	50	n/a
270	57	10	10	n/a
102	39	5	n/a	5
260	58	70	70	n/a
267	69	25	25	n/a
97	30	145	n/a	145
92	67	60	60	n/a
106	74	35	35	n/a
93	68	50	50	n/a
171	91	45	45	n/a
175	62	10	10	n/a
274	94	40	40	n/a
102A	88	70	70	n/a
273	95	140	140	n/a
256	98	70	70	n/a
169	98	115	115	n/a
91	97	195	195	n/a
90	99	35	35	n/a
152	100	75	75	n/a
39	100	40	40	n/a
165				
101				
83				
n				
Median Value		50		
		45		
(A) # of Undermined Springs $\geq$ Median Value w / $\geq 50\%$ Discharge Reduction			24	
(B) # of Undermined Springs $\geq$ Median Value w / $< 50\%$ Discharge Reduction				2
(C) # of Undermined Springs $<$ Median Value w / $\geq 50\%$ Discharge Reduction			17	
(D) # of Undermined Springs $<$ Median Value w / $< 50\%$ Discharge Reduction				7
Absolute Value (AD-BC)		134		
Chi Square Value at 1 Degree of Freedom		2.57995		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.05305		

Appendix F_fig_1: Spring Vertical Relief to Nearest Surface Drainage Features Evaluated at the Optimum Reduction Boundary (50%) During Low Evapotranspiration Conditions

Appendix F_tab_2: Data Used to Determine the Statistical Significance of the Spring Vertical Relief to Headwater, First and Second Order, Surface Drainage Feature Data Trend at the Optimum Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Vertical Relief to Headwater Surface Drainage Feature (ft)		
	Low ET (50%)	All	>= 50%	< 50%
33	87	80	80	n/a
198	92	80	80	n/a
155	100	35	35	n/a
166	100	80	80	n/a
167	100	60	60	n/a
173	100	60	60	n/a
174	100	60	60	n/a
177	100	25	25	n/a
199				
224	100	10	10	n/a
249	100	25	25	n/a
254	100	60	60	n/a
259	100	55	55	n/a
263	100	30	30	n/a
272	100	55	55	n/a
35	100	25	25	n/a
36	100	25	25	n/a
41	100	10	10	n/a
63	100	140	140	n/a
64	100	160	160	n/a
84				
94				
269				
271				
297				
268				
99A				
258				
216				
43	2	10	n/a	10
38	13	35	n/a	35
176	17	5	n/a	5
226	20	45	n/a	45
154	18	15	n/a	15
265	32	25	n/a	25
79				
99	14	10	n/a	10
107	58	50	50	n/a
270	57	10	10	n/a
102	39	5	n/a	5
260	58	70	70	n/a
267	69	25	25	n/a
97	30	145	n/a	145
92	67	60	60	n/a
106	74	35	35	n/a
93	68	50	50	n/a
171	91	45	45	n/a
175	62	10	10	n/a
274	94	40	40	n/a
102A	88	70	70	n/a
273	95	140	140	n/a
256	98	70	70	n/a
169	98	115	115	n/a
91	97	195	195	n/a
90	99	35	35	n/a
152	100	75	75	n/a
39				
165				
101				
83				
n				
Median Value		45		
(A) # of Undermined Springs >= Median Value w / >=50% Discharge Reduction			22	
(B) # of Undermined Springs >= Median Value w / < 50% Discharge Reduction				2
(C) # of Undermined Springs < Median Value w / >= 50% Discharge Reduction			14	
(D) # of Undermined Springs < Median Value w / < 50% Discharge Reduction				7
Absolute Value (AD-BC)		126		
Chi Square Value at 1 Degree of Freedom		2.95201		
Error Probability as Derived from Chi Square Contingency Test		0.10-0.05		
Error Probability as Derived from Fisher Exact Probability Test		0.04206		

Appendix F_fig_2: Spring Vertical Relief to Headwater, First and Second Order, Surface Drainage Features Evaluated at the Optimum Reduction Boundary (50%) During Low Evapotranspiration Conditions

Appendix F_tab_3: Data Used to Determine the Statistical Significance of the Spring Recharge Line Length Component Perpendicular to Longwall Face Data Trend at the Absolute Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Recharge Line Length Component Perpendicular to Longwall Face (ft)		
	High ET (80%)	All	$\geq 80\%$	$< 80\%$
33				
198				
155	100	15	15	n/a
166	100	30	30	n/a
167	100	160	160	n/a
173	100	140	140	n/a
174				
177	100	280	280	n/a
199	100	220	220	n/a
224	100	120	120	n/a
249	100	350	350	n/a
254	100	360	360	n/a
259	100	100	100	n/a
263	100	15	15	n/a
272	100	30	30	n/a
35	100	70	70	n/a
36	100	50	50	n/a
41	100	40	40	n/a
63	100	370	370	n/a
64	100	300	300	n/a
84	100	220	220	n/a
94	100	50	50	n/a
269				
271				
297	10	65	n/a	65
268				
99A	100	75	75	n/a
258	100	225	225	n/a
216	100	40	40	n/a
43	80	20	n/a	20
38	100	20	20	n/a
176	100	340	340	n/a
226	100	260	260	n/a
154				
265	100	140	140	n/a
79	100	110	110	n/a
99	100	15	15	n/a
107				
270				
102	100	280	280	n/a
260				
267	96	250	250	n/a
97	45	100	n/a	100
92				
106	100	220	220	n/a
93	100	220	220	n/a
171				
175	100	30	30	n/a
274	100	440	440	n/a
102A	99	180	180	n/a
273				
256	88	200	200	n/a
169	65	90	n/a	90
91				
90	100	50	50	n/a
152	100	80	80	n/a
39				
165				
101	98	370	370	n/a
83	100	50	50	n/a
n		44		
Median Value		115		
(A) # of Undermined Springs $\geq$ Median Value w/ $\geq 50\%$ Discharge Reduction			22	
(B) # of Undermined Springs $\geq$ Median Value w/ $< 50\%$ Discharge Reduction				0
(C) # of Undermined Springs $<$ Median Value w/ $\geq 50\%$ Discharge Reduction			18	
(D) # of Undermined Springs $<$ Median Value w/ $< 50\%$ Discharge Reduction				4
Absolute Value (AD-BC)		88		
Chi Square Value at 1 Degree of Freedom		2.47500		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.05389		

Appendix F_fig_3: Spring Recharge Line Length Component Perpendicular to Longwall Face Evaluated at the Absolute Reduction Boundary (80%) During High Evapotranspiration Conditions

APPENDIX G: Figures Illustrating the Statistically Significant Variables Identified from
the Spring Discharge Response to Mining-Induced Subsidence Analysis through the Use
of the Interpreted Best Fit Values as Discussed in Results of Investigation IV

Appendix G_tab_1: Data Used to Determine the Statistical Significance of the Spring Vertical Relief to Nearest Surface Drainage Feature Data Trend at the Optimum Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Vertical Relief to Nearest Surface Drainage Feature (ft)		
	Low ET (50%)	All	>= 50%	< 50%
33	87	80	80	n/a
198	92	80	80	n/a
155	100	35	35	n/a
166	100	80	80	n/a
167	100	60	60	n/a
173	100	60	60	n/a
174	100	60	60	n/a
177	100	25	25	n/a
199	100	10	10	n/a
224	100	10	10	n/a
249	100	25	25	n/a
254	100	60	60	n/a
259	100	55	55	n/a
263	100	30	30	n/a
272	100	55	55	n/a
35	100	25	25	n/a
36	100	25	25	n/a
41	100	10	10	n/a
63	100	140	140	n/a
64	100	160	160	n/a
84	100	20	20	n/a
94	100	175	175	n/a
269	(126)	25	n/a	25
271	(133)	160	n/a	160
297	(6)	90	n/a	90
268	(31)	35	n/a	35
99A	(600)	15	n/a	15
258	(149)	30	n/a	30
216	(338)	50	n/a	50
43	2	10	n/a	10
38	13	35	n/a	35
176	17	5	n/a	5
226	20	45	n/a	45
154	18	15	n/a	15
265	32	25	n/a	25
79	54	95	95	n/a
99	14	10	n/a	10
107	58	50	50	n/a
270	57	10	10	n/a
102	39	5	n/a	5
260	58	70	70	n/a
267	69	25	25	n/a
97	30	145	n/a	145
92	67	60	60	n/a
106	74	35	35	n/a
93	68	50	50	n/a
171	91	45	45	n/a
175	62	10	10	n/a
274	94	40	40	n/a
102A	88	70	70	n/a
273	95	140	140	n/a
256	98	70	70	n/a
169	98	115	115	n/a
91	97	195	195	n/a
90	99	35	35	n/a
152	100	75	75	n/a
39	100	40	40	n/a
165				
101				
83				
n				
Median Value		57		
Interpreted Best Fit Value		45		
		36		
(A) # of Undermined Springs >= Best Fit Value w / >=50% Discharge Reduction			26	
(B) # of Undermined Springs >= Best Fit Value w / < 50% Discharge Reduction				5
(C) # of Undermined Springs < Best Fit Value w / >= 50% Discharge Reduction			15	
(D) # of Undermined Springs < Best Fit Value w / < 50% Discharge Reduction				11
Absolute Value (AD-BC)		211		
Chi Square Value at 1 Degree of Freedom		3.59056		
Error Probability as Derived from Chi Square Contingency Test		0.10-0.05		
Error Probability as Derived from Fisher Exact Probability Test		0.02881		

Appendix G_fig_1: Spring Vertical Relief to Nearest Surface Drainage Features Evaluated at the Optimum Reduction Boundary (50%) During Low Evapotranspiration Conditions

Appendix G_tab_2: Data Used to Determine the Statistical Significance of the Spring Vertical Relief to Headwater, First and Second Order, Surface Drainage Feature Data Trend at the Optimum Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Vertical Relief to Headwater Surface Drainage Features (ft)		
	Low ET (50%)	All	>= 50%	< 50%
33	87	80	80	n/a
198	92	80	80	n/a
155	100	35	35	n/a
166	100	80	80	n/a
167	100	60	60	n/a
173	100	60	60	n/a
174	100	60	60	n/a
177	100	25	25	n/a
199				
224	100	10	10	n/a
249	100	25	25	n/a
254	100	60	60	n/a
259	100	55	55	n/a
263	100	30	30	n/a
272	100	55	55	n/a
35	100	25	25	n/a
36	100	25	25	n/a
41	100	10	10	n/a
63	100	140	140	n/a
64	100	160	160	n/a
84				
94				
269	(126)	25	n/a	25
271	(133)	160	n/a	160
297	(6)	90	n/a	90
268	(31)	35	n/a	35
99A	(600)	15	n/a	15
258	(149)	30	n/a	30
216	(338)	50	n/a	50
43	2	10	n/a	10
38	13	35	n/a	35
176	17	5	n/a	5
226	20	45	n/a	45
154	18	15	n/a	15
265	32	25	n/a	25
79				
99	14	10	n/a	10
107	58	50	50	n/a
270	57	10	10	n/a
102	39	5	n/a	5
260	58	70	70	n/a
267	69	25	25	n/a
97	30	145	n/a	145
92	67	60	60	n/a
106	74	35	35	n/a
93	68	50	50	n/a
171	91	45	45	n/a
175	62	10	10	n/a
274	94	40	40	n/a
102A	88	70	70	n/a
273	95	140	140	n/a
256	98	70	70	n/a
169	98	115	115	n/a
91	97	195	195	n/a
90	99	35	35	n/a
152	100	75	75	n/a
39				
165				
101				
83				
n				
Median Value		52		
Interpreted Best Fit Value		45		
		36		
(A) # of Undermined Springs >= Best Fit Value w / >=50% Discharge Reduction			23	
(B) # of Undermined Springs >= Best Fit Value w / < 50% Discharge Reduction				5
(C) # of Undermined Springs < Best Fit Value w / >= 50% Discharge Reduction			13	
(D) # of Undermined Springs < Best Fit Value w / < 50% Discharge Reduction				11
Absolute Value (AD-BC)		188		
Chi Square Value at 1 Degree of Freedom		3.52567		
Error Probability as Derived from Chi Square Contingency Test		0.10-0.05		
Error Probability as Derived from Fisher Exact Probability Test		0.02988		

Appendix G_fig_2: Spring Vertical Relief to Headwater Surface Drainage Features Evaluated at the Optimum Reduction Boundary (50%) During Low Evapotranspiration Conditions

Appendix G_tab_3: Data Used to Determine the Statistical Significance of the Spring Vertical Relief to First Order Surface Drainage Feature Data Trend at the Optimum Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Vertical Relief to First Order Surface Drainage Features (ft)		
	Low ET (50%)	All	$\geq 50\%$	$< 50\%$
33				
198	92	80	80	n/a
155	100	35	35	n/a
166				
167	100	60	60	n/a
173	100	60	60	n/a
174	100	60	60	n/a
177				
199				
224	100	10	10	n/a
249	100	25	25	n/a
254	100	60	60	n/a
259				
263	100	30	30	n/a
272	100	55	55	n/a
35	100	25	25	n/a
36	100	25	25	n/a
41				
63				
64				
84				
94				
269	(126)	25	n/a	25
271	(133)	160	n/a	160
297				
268				
99A	(600)	15	n/a	15
258	(149)	30	n/a	30
216	(338)	50	n/a	50
43	2	10	n/a	10
38	13	35	n/a	35
176	17	5	n/a	5
226	20	45	n/a	45
154	18	15	n/a	15
265				
79				
99	14	10	n/a	10
107	58	50	50	n/a
270	57	10	10	n/a
102	39	5	n/a	5
260				
267	69	25	25	n/a
97	30	145	n/a	145
92	67	60	60	n/a
106	74	35	35	n/a
93	68	50	50	n/a
171	91	45	45	n/a
175	62	10	10	n/a
274	94	40	40	n/a
102A	88	70	70	n/a
273	95	140	140	n/a
256	98	70	70	n/a
169	98	115	115	n/a
91	97	195	195	n/a
90	99	35	35	n/a
152	100	75	75	n/a
39				
165				
101				
83				
n				
Median Value		41		
Interpreted Best Fit Value		40		
		36		
(A) # of Undermined Springs $\geq$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			17	
(B) # of Undermined Springs $\geq$ Best Fit Value w / $< 50\%$ Discharge Reduction				4
(C) # of Undermined Springs $<$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			11	
(D) # of Undermined Springs $<$ Best Fit Value w / $< 50\%$ Discharge Reduction				9
Absolute Value (AD-BC)		109		
Chi Square Value at 1 Degree of Freedom		2.10049		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.07315		

Appendix G_fig_3: Spring Vertical Relief to First Order Surface Drainage Features Evaluated at the Optimum Reduction Boundary (50%) During Low Evapotranspiration Conditions

Appendix G_tab_4: Data Used to Determine the Statistical Significance of the Spring Vertical Relief to Headwater, First and Second Order, Surface Drainage Feature Data Trend at the Absolute Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Spring Vertical Relief to Headwater Surface Drainage Features (ft)		
	Low ET (88%)	All	$\geq 88\%$	$< 88\%$
33	87	80	n/a	80
198	92	80	80	n/a
155	100	35	35	n/a
166	100	80	80	n/a
167	100	60	60	n/a
173	100	60	60	n/a
174	100	60	60	n/a
177	100	25	25	n/a
199				
224	100	10	10	n/a
249	100	25	25	n/a
254	100	60	60	n/a
259	100	55	55	n/a
263	100	30	30	n/a
272	100	55	55	n/a
35	100	25	25	n/a
36	100	25	25	n/a
41	100	10	10	n/a
63	100	140	140	n/a
64	100	160	160	n/a
84				
94				
269	(126)	25	n/a	25
271	(133)	160	n/a	160
297	(6)	90	n/a	90
268	(31)	35	n/a	35
99A	(600)	15	n/a	15
258	(149)	30	n/a	30
216	(338)	50	n/a	50
43	2	10	n/a	10
38	13	35	n/a	35
176	17	5	n/a	5
226	20	45	n/a	45
154	18	15	n/a	15
265	32	25	n/a	25
79				
99	14	10	n/a	10
107	58	50	n/a	50
270	57	10	n/a	10
102	39	5	n/a	5
260	58	70	n/a	70
267	69	25	n/a	25
97	30	145	n/a	145
92	67	60	n/a	60
106	74	35	n/a	35
93	68	50	n/a	50
171	91	45	45	n/a
175	62	10	n/a	10
274	94	40	40	n/a
102A	88	70	n/a	70
273	95	140	140	n/a
256	98	70	70	n/a
169	98	115	115	n/a
91	97	195	195	n/a
90	99	35	35	n/a
152	100	75	75	n/a
39				
165				
101				
83				
n				
Median Value		52		
Interpreted Best Fit Value		45		
		36		
(A) # of Undermined Springs $\geq$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			17	
(B) # of Undermined Springs $\geq$ Best Fit Value w / $< 50\%$ Discharge Reduction				11
(C) # of Undermined Springs $<$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			9	
(D) # of Undermined Springs $<$ Best Fit Value w / $< 50\%$ Discharge Reduction				15
Absolute Value (AD-BC)		156		
Chi Square Value at 1 Degree of Freedom		1.93452		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.08185		

Appendix G_fig_4: Spring Vertical Relief to Headwater Surface Drainage Features Evaluated at the Absolute Reduction Boundary (88%) During Low Evapotranspiration Conditions

Appendix G_tab_5: Data Used to Determine the Statistical Significance of the Spring Vertical Relief to First Order Surface Drainage Feature Data Trend at the Absolute Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Spring Vertical Relief to First Order Surface Drainage Features (ft)		
	Low ET (88%)	All	>= 88%	< 88%
33				
198	92	80	80	n/a
155	100	35	35	n/a
166				
167	100	60	60	n/a
173	100	60	60	n/a
174	100	60	60	n/a
177				
199				
224	100	10	10	n/a
249	100	25	25	n/a
254	100	60	60	n/a
259				
263	100	30	30	n/a
272	100	55	55	n/a
35	100	25	25	n/a
36	100	25	25	n/a
41				
63				
64				
84				
94				
269	(126)	25	n/a	25
271	(133)	160	n/a	160
297				
268				
99A	(600)	15	n/a	15
258	(149)	30	n/a	30
216	(338)	50	n/a	50
43	2	10	n/a	10
38	13	35	n/a	35
176	17	5	n/a	5
226	20	45	n/a	45
154	18	15	n/a	15
265				
79				
99	14	10	n/a	10
107	58	50	n/a	50
270	57	10	n/a	10
102	39	5	n/a	5
260				
267	69	25	n/a	25
97	30	145	n/a	145
92	67	60	n/a	60
106	74	35	n/a	35
93	68	50	n/a	50
171	91	45	45	n/a
175	62	10	n/a	10
274	94	40	40	n/a
102A	88	70	n/a	70
273	95	140	140	n/a
256	98	70	70	n/a
169	98	115	115	n/a
91	97	195	195	n/a
90	99	35	35	n/a
152	100	75	75	n/a
39				
165				
101				
83				
n		41		
Median Value		40		
Interpreted Best Fit Value		36		
(A) # of Undermined Springs >= Best Fit Value w / >=50% Discharge Reduction			13	
(B) # of Undermined Springs >= Best Fit Value w / < 50% Discharge Reduction				8
(C) # of Undermined Springs < Best Fit Value w / >= 50% Discharge Reduction			7	
(D) # of Undermined Springs < Best Fit Value w / < 50% Discharge Reduction				13
Absolute Value (AD-BC)		113		
Chi Square Value at 1 Degree of Freedom		1.98870		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.07888		

Appendix G_fig_5: Spring Vertical Relief to First Order Surface Drainage Features Evaluated at the Absolute Reduction Boundary (88%) During Low Evapotranspiration Conditions

Appendix G_tab_6: Data Used to Determine the Statistical Significance of the Spring Daylight Elevation Data Trend at the Absolute Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Spring Daylight Elevation (ft amsl)		
	Low ET (88%)	All	>= 88%	< 88%
33	87	1240	n/a	1240
198	92	1250	1250	n/a
155	100	1115	1115	n/a
166	100	1130	1130	n/a
167	100	1170	1170	n/a
173	100	1260	1260	n/a
174	100	1230	1230	n/a
177	100	1175	1175	n/a
199	100	1010	1010	n/a
224	100	1215	1215	n/a
249	100	1120	1120	n/a
254	100	1130	1130	n/a
259	100	1155	1155	n/a
263	100	1160	1160	n/a
272	100	1265	1265	n/a
35	100	1185	1185	n/a
36	100	1225	1225	n/a
41	100	1180	1180	n/a
63	100	1165	1165	n/a
64	100	1185	1185	n/a
84	100	1040	1040	n/a
94	100	1155	1155	n/a
269	(126)	1225	n/a	1225
271	(133)	1310	n/a	1310
297	(6)	1210	n/a	1210
268	(31)	1185	n/a	1185
99A	(600)	1190	n/a	1190
258	(149)	1190	n/a	1190
216	(338)	1210	n/a	1210
43	2	1180	n/a	1180
38	13	1220	n/a	1220
176	17	1175	n/a	1175
226	20	1195	n/a	1195
154	18	1150	n/a	1150
265	32	1200	n/a	1200
79	54	1095	n/a	1095
99	14	1180	n/a	1180
107	58	1200	n/a	1200
270	57	1230	n/a	1230
102	39	1160	n/a	1160
260	58	1190	n/a	1190
267	69	1210	n/a	1210
97	30	1265	n/a	1265
92	67	1190	n/a	1190
106	74	1155	n/a	1155
93	68	1175	n/a	1175
171	91	1195	1195	n/a
175	62	1190	n/a	1190
274	94	1240	1240	n/a
102A	88	1200	n/a	1200
273	95	1280	1280	n/a
256	98	1190	1190	n/a
169	98	1225	1225	n/a
91	97	1195	1195	n/a
90	99	1125	1125	n/a
152	100	1195	1195	n/a
39	100	1150	1150	n/a
165				
101				
83				
n				
Median Value		57		
Interpreted Best Fit Value		1190		
(A) # of Undermined Springs >= Best Fit Value w / >=50% Discharge Reduction			13	
(B) # of Undermined Springs >= Best Fit Value w / < 50% Discharge Reduction				18
(C) # of Undermined Springs < Best Fit Value w / >= 50% Discharge Reduction			17	
(D) # of Undermined Springs < Best Fit Value w / < 50% Discharge Reduction				9
Absolute Value (AD-BC)		189		
Chi Square Value at 1 Degree of Freedom		2.24908		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.06644		

Appendix G_fig_6: Spring Daylight Elevation Location Evaluated at the Absolute Reduction Boundary (88%) During Low Evapotranspiration Conditions

Appendix G. tab. 7: Data Used to Determine the Statistical Significance of the Spring Recharge Line Length Data Trend at the Optimum Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Recharge Line Length (ft)		
	High ET (60%)	All	≥ 60%	< 60%
33	(1)	157	n/a	157
198	(23)	170	n/a	170
155	100	188	188	n/a
166	100	94	94	n/a
167	100	219	219	n/a
173	100	219	219	n/a
174	100	94	94	n/a
177	100	310	310	n/a
199	100	188	188	n/a
224	100	120	120	n/a
249	100	407	407	n/a
254	100	375	375	n/a
259	100	657	657	n/a
263	100	63	63	n/a
272	100	219	219	n/a
35	100	157	157	n/a
36	100	125	125	n/a
41	100	63	63	n/a
63	100	532	532	n/a
64	100	438	438	n/a
84	100	750	750	n/a
94	100	125	125	n/a
269	(61)	157	n/a	157
271	(74)	125	n/a	125
297	10	94	n/a	94
268	(118)	282	n/a	282
99A	100	75	75	n/a
258	100	532	532	n/a
216	100	360	360	n/a
43	80	63	63	n/a
38	100	282	282	n/a
176	100	375	375	n/a
226	100	313	313	n/a
154				
265	100	594	594	n/a
79	100	188	188	n/a
99	100	32	32	n/a
107	85	90	90	n/a
270				
102	100	313	313	n/a
260				
267	96	750	750	n/a
97	45	157	n/a	157
92				
106	100	250	250	n/a
93	100	330	330	n/a
171				
175	100	94	94	n/a
274	100	469	469	n/a
102A	99	532	532	n/a
273				
256	88	250	250	n/a
169	65	344	344	n/a
91				
90	100	313	313	n/a
152	100	188	188	n/a
39				
165	(64)	188	n/a	188
101	98	625	625	n/a
83	100	813	813	n/a
n				
Median Value		52		
Interpreted Best Fit Value		219		
		189		
(A) # of Undermined Springs ≥ Best Fit Value w / ≥ 50% Discharge Reduction			27	
(B) # of Undermined Springs ≥ Best Fit Value w / < 50% Discharge Reduction				1
(C) # of Undermined Springs < Best Fit Value w / ≥ 50% Discharge Reduction			17	
(D) # of Undermined Springs < Best Fit Value w / < 50% Discharge Reduction				7
Absolute Value (AD-BC)		172		
Chi Square Value at 1 Degree of Freedom		4.68594		
Error Probability as Derived from Chi Square Contingency Test		0.05-0.02		
Error Probability as Derived from Fisher Exact Probability Test		0.01385		

Appendix G_fig_7: Spring Recharge Line Length Evaluated at the Optimum Reduction Boundary (60%) During High Evapotranspiration Conditions

Appendix G_tab_8: Data Used to Determine the Statistical Significance of the Spring Recharge Line Vertical Relief Data Trend at the Optimum Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Recharge Line Vertical Relief (ft)		
	High ET (60%)	All	>= 60%	< 60%
33	(1)	30	n/a	30
198	(23)	20	n/a	20
155	100	40	40	n/a
166	100	20	20	n/a
167	100	40	40	n/a
173	100	35	35	n/a
174	100	25	25	n/a
177	100	60	60	n/a
199	100	50	50	n/a
224	100	20	20	n/a
249	100	0	0	n/a
254	100	105	105	n/a
259	100	80	80	n/a
263	100	15	15	n/a
272	100	50	50	n/a
35	100	50	50	n/a
36	100	30	30	n/a
41	100	5	5	n/a
63	100	100	100	n/a
64	100	80	80	n/a
84	100	195	195	n/a
94	100	20	20	n/a
269	(61)	30	n/a	30
271	(74)	15	n/a	15
297	10	15	n/a	15
268	(118)	25	n/a	25
99A	100	15	15	n/a
258	100	45	45	n/a
216	100	75	75	n/a
43	80	15	15	n/a
38	100	55	55	n/a
176	100	70	70	n/a
226	100	60	60	n/a
154				
265	100	75	75	n/a
79	100	30	30	n/a
99	100	5	5	n/a
107	85	10	10	n/a
270				
102	100	25	25	n/a
260				
267	96	160	160	n/a
97	45	30	n/a	30
92				
106	100	45	45	n/a
93	100	80	80	n/a
171				
175	100	10	10	n/a
274	100	100	100	n/a
102A	99	60	60	n/a
273				
256	88	35	35	n/a
169	65	70	70	n/a
91				
90	100	10	10	n/a
152	100	40	40	n/a
39				
165	(64)	45	n/a	45
101	98	145	145	n/a
83	100	195	195	n/a
n				
Median Value		52		
Interpreted Best Fit Value		40		
		36		
(A) # of Undermined Springs >= Best Fit Value w / >=50% Discharge Reduction			26	
(B) # of Undermined Springs >= Best Fit Value w / < 50% Discharge Reduction				1
(C) # of Undermined Springs < Best Fit Value w / >= 50% Discharge Reduction			18	
(D) # of Undermined Springs < Best Fit Value w / < 50% Discharge Reduction				7
Absolute Value (AD-BC)		164		
Chi Square Value at 1 Degree of Freedom		4.16788		
Error Probability as Derived from Chi Square Contingency Test		0.05-0.02		
Error Probability as Derived from Fisher Exact Probability Test		0.01868		

Appendix G_fig_8: Spring Recharge Line Vertical Relief Evaluated at the Optimum Reduction Boundary (60%) During High Evapotranspiration Conditions

Appendix G_tab_9: Data Used to Determine the Statistical Significance of the Spring Daylight Elevation Data Trend at the Optimum Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Daylight Elevation (ft amsl)		
	High ET (60%)	All	>= 60%	< 60%
33	(1)	1240	n/a	1240
198	(23)	1250	n/a	1250
155	100	1115	1115	n/a
166	100	1130	1130	n/a
167	100	1170	1170	n/a
173	100	1260	1260	n/a
174	100	1230	1230	n/a
177	100	1175	1175	n/a
199	100	1010	1010	n/a
224	100	1215	1215	n/a
249	100	1120	1120	n/a
254	100	1130	1130	n/a
259	100	1155	1155	n/a
263	100	1160	1160	n/a
272	100	1265	1265	n/a
35	100	1185	1185	n/a
36	100	1225	1225	n/a
41	100	1180	1180	n/a
63	100	1165	1165	n/a
64	100	1185	1185	n/a
84	100	1040	1040	n/a
94	100	1155	1155	n/a
269	(61)	1225	n/a	1225
271	(74)	1310	n/a	1310
297	10	1210	n/a	1210
268	(118)	1185	n/a	1185
99A	100	1190	1190	n/a
258	100	1190	1190	n/a
216	100	1210	1210	n/a
43	80	1180	1180	n/a
38	100	1220	1220	n/a
176	100	1175	1175	n/a
226	100	1195	1195	n/a
154				
265	100	1200	1200	n/a
79	100	1095	1095	n/a
99	100	1180	1180	n/a
107	85	1200	1200	n/a
270				
102	100	1160	1160	n/a
260				
267	96	1210	1210	n/a
97	45	1265	n/a	1265
92				
106	100	1155	1155	n/a
93	100	1175	1175	n/a
171				
175	100	1190	1190	n/a
274	100	1240	1240	n/a
102A	99	1200	1200	n/a
273				
256	88	1190	1190	n/a
169	65	1225	1225	n/a
91				
90	100	1125	1125	n/a
152	100	1195	1195	n/a
39				
165	(64)	1010	n/a	1010
101	98	1130	1130	n/a
83	100	1040	1040	n/a
n				
Median Value		52		
Interpreted Best Fit Value		1185		
		1209		
(A) # of Undermined Springs >= Best Fit Value w / >=50% Discharge Reduction			10	
(B) # of Undermined Springs >= Best Fit Value w / < 50% Discharge Reduction				6
(C) # of Undermined Springs < Best Fit Value w / >= 50% Discharge Reduction			34	
(D) # of Undermined Springs < Best Fit Value w / < 50% Discharge Reduction				2
Absolute Value (AD-BC)		184		
Chi Square Value at 1 Degree of Freedom		6.40254		
Error Probability as Derived from Chi Square Contingency Test		0.02-0.01		
Error Probability as Derived from Fisher Exact Probability Test		0.00727		

Appendix G_fig_9: Spring Daylight Elevation Location Evaluated at the Optimum Reduction Boundary (60%) During High Evapotranspiration Conditions

Appendix G_tab_10: Data Used to Determine the Statistical Significance of the Pre-Mine Averaged Low Flow Spring Discharge Data Trend at the Optimum Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Pre-Mine Averaged Low Flow Spring Discharge (gpm)		
		All	>= 60%	< 60%
33	High ET (60%) (1)	0.27	n/a	0.27
198	(23)	0.50	n/a	0.50
155	100	0.26	0.26	n/a
166	100	0.32	0.32	n/a
167				
173				
174				
177				
199				
224				
249				
254				
259				
263				
272				
35				
36				
41				
63				
64				
84				
94				
269	(61)	0.44	n/a	0.44
271	(74)	0.69	n/a	0.69
297	10	0.62	n/a	0.62
268	(118)	0.61	n/a	0.61
99A	100	0.35	0.35	n/a
258	100	0.38	0.38	n/a
216	100	0.10	0.10	n/a
43	80	0.13	0.13	n/a
38	100	0.24	0.24	n/a
176	100	0.58	0.58	n/a
226	100	0.14	0.14	n/a
154				
265	100	0.37	0.37	n/a
79	100	0.05	0.05	n/a
99	100	0.05	0.05	n/a
107	85	0.73	0.73	n/a
270				
102	100	1.56	1.56	n/a
260				
267	96	0.29	0.29	n/a
97	45	0.44	n/a	0.44
92				
106	100	0.28	0.28	n/a
93	100	0.30	0.30	n/a
171				
175	100	0.13	0.13	n/a
274	100	0.09	0.09	n/a
102A	99	0.94	0.94	n/a
273				
256	88	0.32	0.32	n/a
169	65	0.64	0.64	n/a
91				
90	100	1.36	1.36	n/a
152	100	0.09	0.09	n/a
39				
165	(64)	0.45	n/a	0.45
101	98	0.46	0.46	n/a
83	100	0.15	0.15	n/a
n		34		
Median Value		0.34		
Interpreted Best Fit Value		0.43		
(A) # of Undermined Springs >= Best Fit Value w / >=50% Discharge Reduction			7	
(B) # of Undermined Springs >= Best Fit Value w / < 50% Discharge Reduction				7
(C) # of Undermined Springs < Best Fit Value w / >= 50% Discharge Reduction			19	
(D) # of Undermined Springs < Best Fit Value w / < 50% Discharge Reduction				1
Absolute Value (AD-BC)		126		
Chi Square Value at 1 Degree of Freedom		6.93602		
Error Probability as Derived from Chi Square Contingency Test		0.01-0.001		
Error Probability as Derived from Fisher Exact Probability Test		0.00395		

Conditions

Appendix G_tab_11: Data Used to Determine the Statistical Significance of the Spring Recharge Line Length Component Perpendicular to Longwall Face Data Trend at the Absolute Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Spring Recharge Line Length Component Perpendicular to Longwall Face (ft)		
	High ET (80%)	All	$\geq 80\%$	$< 80\%$
33				
198	(23)	100	n/a	100
155	100	15	15	n/a
166	100	30	30	n/a
167	100	160	160	n/a
173	100	140	140	n/a
174				
177	100	280	280	n/a
199	100	220	220	n/a
224	100	120	120	n/a
249	100	350	350	n/a
254	100	360	360	n/a
259	100	100	100	n/a
263	100	15	15	n/a
272	100	30	30	n/a
35	100	70	70	n/a
36	100	50	50	n/a
41	100	40	40	n/a
63	100	370	370	n/a
64	100	300	300	n/a
84	100	220	220	n/a
94	100	50	50	n/a
269	(61)	140	n/a	140
271	(74)	110	n/a	110
297	10	65	n/a	65
268	(118)	70	n/a	70
99A	100	75	75	n/a
258	100	225	225	n/a
216	100	40	40	n/a
43	80	20	n/a	20
38	100	20	20	n/a
176	100	340	340	n/a
226	100	260	260	n/a
154				
265	100	140	140	n/a
79	100	110	110	n/a
99	100	15	15	n/a
107				
270				
102	100	280	280	n/a
260				
267	96	250	250	n/a
97	45	100	n/a	100
92				
106	100	220	220	n/a
93	100	220	220	n/a
171				
175	100	30	30	n/a
274	100	440	440	n/a
102A	99	180	180	n/a
273				
256	88	200	200	n/a
169	65	90	n/a	90
91				
90	100	50	50	n/a
152	100	80	80	n/a
39				
165	(64)	90	n/a	90
101	98	370	370	n/a
83	100	50	50	n/a
n				
Median Value		49		
Interpreted Best Fit Value		110		
Interpreted Best Fit Value		101		
(A) # of Undermined Springs $\geq$ Best Fit Value w/ $\geq 50\%$ Discharge Reduction			23	
(B) # of Undermined Springs $\geq$ Best Fit Value w/ $< 50\%$ Discharge Reduction				2
(C) # of Undermined Springs $<$ Best Fit Value w/ $\geq 50\%$ Discharge Reduction			17	
(D) # of Undermined Springs $<$ Best Fit Value w/ $< 50\%$ Discharge Reduction				7
Absolute Value (AD-BC)		127		
Chi Square Value at 1 Degree of Freedom		2.38336		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.06013		

Appendix G_fig_11: Spring Recharge Line Length Component Perpendicular to Longwall Face Evaluated at the Absolute Reduction Boundary (80%)
During High Evapotranspiration Conditions

Appendix G_tab_12: Data Used to Determine the Statistical Significance of the Spring Recharge Line Length Data Trend at the Absolute Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Spring Recharge Line Length (ft)		
	High ET (80%)	All	$\geq 80\%$	$< 80\%$
33	(1)	157	n/a	157
198	(23)	170	n/a	170
155	100	188	188	n/a
166	100	94	94	n/a
167	100	219	219	n/a
173	100	219	219	n/a
174	100	94	94	n/a
177	100	310	310	n/a
199	100	188	188	n/a
224	100	120	120	n/a
249	100	407	407	n/a
254	100	375	375	n/a
259	100	657	657	n/a
263	100	63	63	n/a
272	100	219	219	n/a
35	100	157	157	n/a
36	100	125	125	n/a
41	100	63	63	n/a
63	100	532	532	n/a
64	100	438	438	n/a
84	100	750	750	n/a
94	100	125	125	n/a
269	(61)	157	n/a	157
271	(74)	125	n/a	125
297	10	94	n/a	94
268	(118)	282	n/a	282
99A	100	75	75	n/a
258	100	532	532	n/a
216	100	360	360	n/a
43	80	63	n/a	63
38	100	282	282	n/a
176	100	375	375	n/a
226	100	313	313	n/a
154				
265	100	594	594	n/a
79	100	188	188	n/a
99	100	32	32	n/a
107	85	90	90	n/a
270				
102	100	313	313	n/a
260				
267	96	750	750	n/a
97	45	157	n/a	157
92				
106	100	250	250	n/a
93	100	330	330	n/a
171				
175	100	94	94	n/a
274	100	469	469	n/a
102A	99	532	532	n/a
273				
256	88	250	250	n/a
169	65	344	n/a	344
91				
90	100	313	313	n/a
152	100	188	188	n/a
39				
165	(64)	188	n/a	188
101	98	625	625	n/a
83	100	813	813	n/a
n				
Median Value		52		
Interpreted Best Fit Value		219		
		189		
(A) # of Undermined Springs $\geq$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			26	
(B) # of Undermined Springs $\geq$ Best Fit Value w / $< 50\%$ Discharge Reduction				2
(C) # of Undermined Springs $<$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			16	
(D) # of Undermined Springs $<$ Best Fit Value w / $< 50\%$ Discharge Reduction				8
Absolute Value (AD-BC)		176		
Chi Square Value at 1 Degree of Freedom		4.14541		
Error Probability as Derived from Chi Square Contingency Test		0.05-0.02		
Error Probability as Derived from Fisher Exact Probability Test		0.02001		

Appendix G_fig_12: Spring Recharge Line Length Evaluated at the Absolute Reduction Boundary (80%) During High Evapotranspiration Conditions

Appendix G_tab_13: Data Used to Determine the Statistical Significance of the Spring Recharge Line Vertical Relief Data Trend at the Absolute Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Spring Recharge Line Vertical Relief (ft)		
	High ET (80%)	All	$\geq 80\%$	$< 80\%$
33	(1)	30	n/a	30
198	(23)	20	n/a	20
155	100	40	40	n/a
166	100	20	20	n/a
167	100	40	40	n/a
173	100	35	35	n/a
174	100	25	25	n/a
177	100	60	60	n/a
199	100	50	50	n/a
224	100	20	20	n/a
249	100	0	0	n/a
254	100	105	105	n/a
259	100	80	80	n/a
263	100	15	15	n/a
272	100	50	50	n/a
35	100	50	50	n/a
36	100	30	30	n/a
41	100	5	5	n/a
63	100	100	100	n/a
64	100	80	80	n/a
84	100	195	195	n/a
94	100	20	20	n/a
269	(61)	30	n/a	30
271	(74)	15	n/a	15
297	10	15	n/a	15
268	(118)	25	n/a	25
99A	100	15	15	n/a
258	100	45	45	n/a
216	100	75	75	n/a
43	80	15	n/a	15
38	100	55	55	n/a
176	100	70	70	n/a
226	100	60	60	n/a
154				
265	100	75	75	n/a
79	100	30	30	n/a
99	100	5	5	n/a
107	85	10	10	n/a
270				
102	100	25	25	n/a
260				
267	96	160	160	n/a
97	45	30	n/a	30
92				
106	100	45	45	n/a
93	100	80	80	n/a
171				
175	100	10	10	n/a
274	100	100	100	n/a
102A	99	60	60	n/a
273				
256	88	35	35	n/a
169	65	70	n/a	70
91				
90	100	10	10	n/a
152	100	40	40	n/a
39				
165	(64)	45	n/a	45
101	98	145	145	n/a
83	100	195	195	n/a
n				
Median Value		52		
Interpreted Best Fit Value		40		
		31		
(A) # of Undermined Springs $\geq$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			27	
(B) # of Undermined Springs $\geq$ Best Fit Value w / $< 50\%$ Discharge Reduction				2
(C) # of Undermined Springs $<$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			15	
(D) # of Undermined Springs $<$ Best Fit Value w / $< 50\%$ Discharge Reduction				8
Absolute Value (AD-BC)		186		
Chi Square Value at 1 Degree of Freedom		4.75191		
Error Probability as Derived from Chi Square Contingency Test		0.05-0.02		
Error Probability as Derived from Fisher Exact Probability Test		0.01415		

Appendix G_fig_13: Spring Recharge Line Vertical Relief Evaluated at the Absolute Reduction Boundary (80%) During High Evapotranspiration Conditions

Appendix G_tab_14: Data Used to Determine the Statistical Significance of the Spring Daylight Elevation Data Trend at the Absolute Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Spring Daylight Elevation (ft amsl)		
	High ET (80%)	All	>= 80%	< 80%
33	(1)	1240	n/a	1240
198	(23)	1250	n/a	1250
155	100	1115	1115	n/a
166	100	1130	1130	n/a
167	100	1170	1170	n/a
173	100	1260	1260	n/a
174	100	1230	1230	n/a
177	100	1175	1175	n/a
199	100	1010	1010	n/a
224	100	1215	1215	n/a
249	100	1120	1120	n/a
254	100	1130	1130	n/a
259	100	1155	1155	n/a
263	100	1160	1160	n/a
272	100	1265	1265	n/a
35	100	1185	1185	n/a
36	100	1225	1225	n/a
41	100	1180	1180	n/a
63	100	1165	1165	n/a
64	100	1185	1185	n/a
84	100	1040	1040	n/a
94	100	1155	1155	n/a
269	(61)	1225	n/a	1225
271	(74)	1310	n/a	1310
297	10	1210	n/a	1210
268	(118)	1185	n/a	1185
99A	100	1190	1190	n/a
258	100	1190	1190	n/a
216	100	1210	1210	n/a
43	80	1180	n/a	1180
38	100	1220	1220	n/a
176	100	1175	1175	n/a
226	100	1195	1195	n/a
154				
265	100	1200	1200	n/a
79	100	1095	1095	n/a
99	100	1180	1180	n/a
107	85	1200	1200	n/a
270				
102	100	1160	1160	n/a
260				
267	96	1210	1210	n/a
97	45	1265	n/a	1265
92				
106	100	1155	1155	n/a
93	100	1175	1175	n/a
171				
175	100	1190	1190	n/a
274	100	1240	1240	n/a
102A	99	1200	1200	n/a
273				
256	88	1190	1190	n/a
169	65	1225	n/a	1225
91				
90	100	1125	1125	n/a
152	100	1195	1195	n/a
39				
165	(64)	1010	n/a	1010
101	98	1130	1130	n/a
83	100	1040	1040	n/a
n				
Median Value		52		
Interpreted Best Fit Value		1185		
		1209		
(A) # of Undermined Springs >= Best Fit Value w / >=50% Discharge Reduction			9	
(B) # of Undermined Springs >= Best Fit Value w / < 50% Discharge Reduction				7
(C) # of Undermined Springs < Best Fit Value w / >= 50% Discharge Reduction			33	
(D) # of Undermined Springs < Best Fit Value w / < 50% Discharge Reduction				3
Absolute Value (AD-BC)		204		
Chi Square Value at 1 Degree of Freedom		6.81038		
Error Probability as Derived from Chi Square Contingency Test		0.01-0.001		
Error Probability as Derived from Fisher Exact Probability Test		0.0057		

Appendix G_fig_14: Spring Daylight Elevation Location Evaluated at the Absolute Reduction Boundary (80%) During High Evapotranspiration Conditions

Appendix G_tab_15: Data Used to Determine the Statistical Significance of the Pre-Mine Averaged Low Flow Spring Discharge Data Trend at the Absolute Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Pre-Mine Averaged Low Flow Spring Discharge (gpm)		
	High ET (80%)	All	$\geq 80\%$	$< 80\%$
33	(1)	0.27	n/a	0.27
198	(23)	0.50	n/a	0.50
155	100	0.26	0.26	n/a
166	100	0.32	0.32	n/a
167				
173				
174				
177				
199				
224				
249				
254				
259				
263				
272				
35				
36				
41				
63				
64				
84				
94				
269	(61)	0.44	n/a	0.44
271	(74)	0.69	n/a	0.69
297	10	0.62	n/a	0.62
268	(118)	0.61	n/a	0.61
99A	100	0.35	0.35	n/a
258	100	0.38	0.38	n/a
216	100	0.10	0.10	n/a
43	80	0.13	n/a	0.13
38	100	0.24	0.24	n/a
176	100	0.58	0.58	n/a
226	100	0.14	0.14	n/a
154				
265	100	0.37	0.37	n/a
79	100	0.05	0.05	n/a
99	100	0.05	0.05	n/a
107	85	0.73	0.73	n/a
270				
102	100	1.56	1.56	n/a
260				
267	96	0.29	0.29	n/a
97	45	0.44	n/a	0.44
92				
106	100	0.28	0.28	n/a
93	100	0.30	0.30	n/a
171				
175	100	0.13	0.13	n/a
274	100	0.09	0.09	n/a
102A	99	0.94	0.94	n/a
273				
256	88	0.32	0.32	n/a
169	65	0.64	n/a	0.64
91				
90	100	1.36	1.36	n/a
152	100	0.09	0.09	n/a
39				
165	(64)	0.45	n/a	0.45
101	98	0.46	0.46	n/a
83	100	0.15	0.15	n/a
n				
Median Value		34		
Interpreted Best Fit Value		0.34		
		0.43		
(A) # of Undermined Springs $\geq$ Best Fit Value w/ $\geq 50\%$ Discharge Reduction			6	
(B) # of Undermined Springs $\geq$ Best Fit Value w/ $< 50\%$ Discharge Reduction				8
(C) # of Undermined Springs $<$ Best Fit Value w/ $\geq 50\%$ Discharge Reduction			18	
(D) # of Undermined Springs $<$ Best Fit Value w/ $< 50\%$ Discharge Reduction				2
Absolute Value (AD-BC)		132		
Chi Square Value at 1 Degree of Freedom		6.69122		
Error Probability as Derived from Chi Square Contingency Test		0.01-0.001		
Error Probability as Derived from Fisher Exact Probability Test		0.00466		

Appendix G_fig_15: Pre-Mine Averaged Low Flow Spring Discharge Evaluated at the Absolute Reduction Boundary (80%) During High Evapotranspiration Conditions

APPENDIX H: Figures Illustrating the Statistically Significant Variables Identified from
the Degree of Spring Discharge Impairment to Mining-Induced Subsidence Analysis
through the Use of the Interpreted Best Fit Values as Discussed in Results of
Investigation IV

Appendix H, tab 1: Data Used to Determine the Statistical Significance of the Spring Vertical Relief to Nearest Surface Drainage Feature Data Trend at the Optimum Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Vertical Relief to Nearest Surface Drainage Feature (ft)		
	Low ET (50%)	All	$\geq 50\%$	$< 50\%$
33	87	80	80	n/a
198	92	80	80	n/a
155	100	35	35	n/a
166	100	80	80	n/a
167	100	60	60	n/a
173	100	60	60	n/a
174	100	60	60	n/a
177	100	25	25	n/a
199	100	10	10	n/a
224	100	10	10	n/a
249	100	25	25	n/a
254	100	60	60	n/a
259	100	55	55	n/a
263	100	30	30	n/a
272	100	55	55	n/a
35	100	25	25	n/a
36	100	25	25	n/a
41	100	10	10	n/a
63	100	140	140	n/a
64	100	160	160	n/a
84	100	20	20	n/a
94	100	175	175	n/a
269				
271				
297				
268				
99A				
258				
216				
43	2	10	n/a	10
38	13	35	n/a	35
176	17	5	n/a	5
226	20	45	n/a	45
154	18	15	n/a	15
265	32	25	n/a	25
79	54	95	95	n/a
99	14	10	n/a	10
107	58	50	50	n/a
270	57	10	10	n/a
102	39	5	n/a	5
260	58	70	70	n/a
267	69	25	25	n/a
97	30	145	n/a	145
92	67	60	60	n/a
106	74	35	35	n/a
93	68	50	50	n/a
171	91	45	45	n/a
175	62	10	10	n/a
274	94	40	40	n/a
102A	88	70	70	n/a
273	95	140	140	n/a
256	98	70	70	n/a
169	98	115	115	n/a
91	97	195	195	n/a
90	99	35	35	n/a
152	100	75	75	n/a
39	100	40	40	n/a
165				
101				
83				
n				
Median Value		50		
Interpreted Best Fit Value		45		
		36		
(A) # of Undermined Springs $\geq$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			26	
(B) # of Undermined Springs $\geq$ Best Fit Value w / $< 50\%$ Discharge Reduction				2
(C) # of Undermined Springs $<$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			15	
(D) # of Undermined Springs $<$ Best Fit Value w / $< 50\%$ Discharge Reduction				7
Absolute Value (AD-BC)		152		
Chi Square Value at 1 Degree of Freedom		3.54789		
Error Probability as Derived from Chi Square Contingency Test		0.10-0.05		
Error Probability as Derived from Fisher Exact Probability Test		0.02951		

Appendix H_fig_1: Spring Vertical Relief to Nearest Surface Drainage Features Evaluated at the Optimum Reduction Boundary (50%) During Low Evapotranspiration Conditions

Appendix H_tab_2: Data Used to Determine the Statistical Significance of the Spring Vertical Relief to Headwater, First and Second Order, Surface Drainage Feature Data Trend at the Optimum Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Vertical Relief to Headwater Surface Drainage Features (ft)		
	Low ET (50%)	All	>= 50%	< 50%
33	87	80	80	n/a
198	92	80	80	n/a
155	100	35	35	n/a
166	100	80	80	n/a
167	100	60	60	n/a
173	100	60	60	n/a
174	100	60	60	n/a
177	100	25	25	n/a
199				
224	100	10	10	n/a
249	100	25	25	n/a
254	100	60	60	n/a
259	100	55	55	n/a
263	100	30	30	n/a
272	100	55	55	n/a
35	100	25	25	n/a
36	100	25	25	n/a
41	100	10	10	n/a
63	100	140	140	n/a
64	100	160	160	n/a
84				
94				
269				
271				
297				
268				
99A				
258				
216				
43	2	10	n/a	10
38	13	35	n/a	35
176	17	5	n/a	5
226	20	45	n/a	45
154	18	15	n/a	15
265	32	25	n/a	25
79				
99	14	10	n/a	10
107	58	50	50	n/a
270	57	10	10	n/a
102	39	5	n/a	5
260	58	70	70	n/a
267	69	25	25	n/a
97	30	145	n/a	145
92	67	60	60	n/a
106	74	35	35	n/a
93	68	50	50	n/a
171	91	45	45	n/a
175	62	10	10	n/a
274	94	40	40	n/a
102A	88	70	70	n/a
273	95	140	140	n/a
256	98	70	70	n/a
169	98	115	115	n/a
91	97	195	195	n/a
90	99	35	35	n/a
152	100	75	75	n/a
39				
165				
101				
83				
n		45		
Median Value		45		
Interpreted Best Fit Value		36		
(A) # of Undermined Springs >= Best Fit Value w / >=50% Discharge Reduction			23	
(B) # of Undermined Springs >= Best Fit Value w / < 50% Discharge Reduction				2
(C) # of Undermined Springs < Best Fit Value w / >= 50% Discharge Reduction			13	
(D) # of Undermined Springs < Best Fit Value w / < 50% Discharge Reduction				7
Absolute Value (AD-BC)		135		
Chi Square Value at 1 Degree of Freedom		3.51563		
Error Probability as Derived from Chi Square Contingency Test		0.10-0.05		
Error Probability as Derived from Fisher Exact Probability Test		0.02999		

Appendix H_fig_2: Spring Vertical Relief to Headwater, First and Second Order, Surface Drainage Features Evaluated at the Optimum Reduction Boundary (50%) During Low Evapotranspiration Conditions

Appendix H_tab_3: Data Used to Determine the Statistical Significance of the Spring Vertical Relief to First Order Surface Drainage Feature Data Trend at the Optimum Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Optimum Discharge Reduction Boundary	Spring Vertical Relief to First Order Surface Drainage Features (ft)		
	Low ET (50%)	All	$\geq 50\%$	$< 50\%$
33				
198	92	80	80	n/a
155	100	35	35	n/a
166				
167	100	60	60	n/a
173	100	60	60	n/a
174	100	60	60	n/a
177				
199				
224	100	10	10	n/a
249	100	25	25	n/a
254	100	60	60	n/a
259				
263	100	30	30	n/a
272	100	55	55	n/a
35	100	25	25	n/a
36	100	25	25	n/a
41				
63				
64				
84				
94				
269				
271				
297				
268				
99A				
258				
216				
43	2	10	n/a	10
38	13	35	n/a	35
176	17	5	n/a	5
226	20	45	n/a	45
154	18	15	n/a	15
265				
79				
99	14	10	n/a	10
107	58	50	50	n/a
270	57	10	10	n/a
102	39	5	n/a	5
260				
267	69	25	25	n/a
97	30	145	n/a	145
92	67	60	60	n/a
106	74	35	35	n/a
93	68	50	50	n/a
171	91	45	45	n/a
175	62	10	10	n/a
274	94	40	40	n/a
102A	88	70	70	n/a
273	95	140	140	n/a
256	98	70	70	n/a
169	98	115	115	n/a
91	97	195	195	n/a
90	99	35	35	n/a
152	100	75	75	n/a
39				
165				
101				
83				
n				
Median Value		36		
Interpreted Best Fit Value		42.5		
		36		
(A) # of Undermined Springs $\geq$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			17	
(B) # of Undermined Springs $\geq$ Best Fit Value w / $< 50\%$ Discharge Reduction				2
(C) # of Undermined Springs $<$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			11	
(D) # of Undermined Springs $<$ Best Fit Value w / $< 50\%$ Discharge Reduction				6
Absolute Value (AD-BC)		80		
Chi Square Value at 1 Degree of Freedom		1.91265		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.08295		

Appendix H_fig_3: Spring Vertical Relief to First Order Surface Drainage Features Evaluated at the Optimum Reduction Boundary (50%) During Low Evapotranspiration Conditions

Appendix H, tab 4: Data Used to Determine the Statistical Significance of the Recharge Line Length Component Perpendicular to Longwall Face Data Trend at the Absolute Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Recharge Line Length Component Perpendicular to Longwall Face (ft)		
	Low ET (88%)	All	$\geq 88\%$	$< 88\%$
33				
198	92	100	100	n/a
155	100	15	15	n/a
166	100	30	30	n/a
167	100	160	160	n/a
173	100	140	140	n/a
174				
177	100	280	280	n/a
199	100	220	220	n/a
224	100	120	120	n/a
249	100	350	350	n/a
254	100	360	360	n/a
259	100	100	100	n/a
263	100	15	15	n/a
272	100	30	30	n/a
35	100	70	70	n/a
36	100	50	50	n/a
41	100	40	40	n/a
63	100	370	370	n/a
64	100	300	300	n/a
84	100	220	220	n/a
94	100	50	50	n/a
269				
271				
297				
268				
99A				
258				
216				
43	2	20	n/a	20
38	13	20	n/a	20
176	17	340	n/a	340
226	20	260	n/a	260
154	18	260	n/a	260
265	32	140	n/a	140
79	54	110	n/a	110
99	14	15	n/a	15
107				
270	57	380	n/a	380
102	39	280	n/a	280
260	58	310	n/a	310
267	69	250	n/a	250
97	30	100	n/a	100
92	67	170	n/a	170
106	74	220	n/a	220
93	68	220	n/a	220
171	91	160	160	n/a
175	62	30	n/a	30
274	94	440	440	n/a
102A	88	180	n/a	180
273	95	100	100	n/a
256	98	200	200	n/a
169	98	90	90	n/a
91	97	70	70	n/a
90	99	50	50	n/a
152	100	80	80	n/a
39	100	200	200	n/a
165				
101				
83				
n		47		
Median Value		140		
Interpreted Best Fit Value		169		
(A) # of Undermined Springs $\geq$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			10	
(B) # of Undermined Springs $\geq$ Best Fit Value w / $< 50\%$ Discharge Reduction				11
(C) # of Undermined Springs $<$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			19	
(D) # of Undermined Springs $<$ Best Fit Value w / $< 50\%$ Discharge Reduction				7
Absolute Value (AD-BC)		139		
Chi Square Value at 1 Degree of Freedom		2.19988		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.06894		

Appendix H_fig_4: Recharge Line Length Component Perpendicular to Longwall Face Evaluated at the Absolute Reduction Boundary (88%) During Low Evapotranspiration Conditions

Appendix H_tab_5: Data Used to Determine the Statistical Significance of the Spring Vertical Relief to First Order Surface Drainage Feature Data Trend at the Absolute Discharge Reduction Boundary During Low Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Spring Vertical Relief to First Order Surface Drainage Features (ft)		
	Low ET (88%)	All	$\geq 88\%$	$< 88\%$
33				
198	92	80	80	n/a
155	100	35	35	n/a
166				
167	100	60	60	n/a
173	100	60	60	n/a
174	100	60	60	n/a
177				
199				
224	100	10	10	n/a
249	100	25	25	n/a
254	100	60	60	n/a
259				
263	100	30	30	n/a
272	100	55	55	n/a
35	100	25	25	n/a
36	100	25	25	n/a
41				
63				
64				
84				
94				
269				
271				
297				
268				
99A				
258				
216				
43	2	10	n/a	10
38	13	35	n/a	35
176	17	5	n/a	5
226	20	45	n/a	45
154	18	15	n/a	15
265				
79				
99	14	10	n/a	10
107	58	50	n/a	50
270	57	10	n/a	10
102	39	5	n/a	5
260				
267	69	25	n/a	25
97	30	145	n/a	145
92	67	60	n/a	60
106	74	35	n/a	35
93	68	50	n/a	50
171	91	45	45	n/a
175	62	10	n/a	10
274	94	40	40	n/a
102A	88	70	n/a	70
273	95	140	140	n/a
256	98	70	70	n/a
169	98	115	115	n/a
91	97	195	195	n/a
90	99	35	35	n/a
152	100	75	75	n/a
39				
165				
101				
83				
n				
Median Value		36		
Interpreted Best Fit Value		36		
(A) # of Undermined Springs $\geq$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			13	
(B) # of Undermined Springs $\geq$ Best Fit Value w / $< 50\%$ Discharge Reduction				6
(C) # of Undermined Springs $<$ Best Fit Value w / $\geq 50\%$ Discharge Reduction			7	
(D) # of Undermined Springs $<$ Best Fit Value w / $< 50\%$ Discharge Reduction				10
Absolute Value (AD-BC)		88		
Chi Square Value at 1 Degree of Freedom		1.70666		
Error Probability as Derived from Chi Square Contingency Test		0.20-0.10		
Error Probability as Derived from Fisher Exact Probability Test		0.09551		

Appendix H_fig_5: Spring Vertical Relief to First Order Surface Drainage Features Evaluated at the Absolute Reduction Boundary (88%) During Low Evapotranspiration Conditions

Appendix H, tab. 6: Data Used to Determine the Statistical Significance of the Recharge Line Length Component Perpendicular to Longwall Face Data Trend at the Absolute Discharge Reduction Boundary During High Evapotranspiration Conditions.

Spring No.	Absolute Discharge Reduction Boundary	Recharge Line Length Component Perpendicular to Longwall Face (ft)		
	High ET (80%)	All	$\geq 80\%$	$< 80\%$
33				
198				
155	100	15	15	n/a
166	100	30	30	n/a
167	100	160	160	n/a
173	100	140	140	n/a
174				
177	100	280	280	n/a
199	100	220	220	n/a
224	100	120	120	n/a
249	100	350	350	n/a
254	100	360	360	n/a
259	100	100	100	n/a
263	100	15	15	n/a
272	100	30	30	n/a
35	100	70	70	n/a
36	100	50	50	n/a
41	100	40	40	n/a
63	100	370	370	n/a
64	100	300	300	n/a
84	100	220	220	n/a
94	100	50	50	n/a
269				
271				
297	10	65	n/a	65
268				
99A	100	75	75	n/a
258	100	225	225	n/a
216	100	40	40	n/a
43	80	20	n/a	20
38	100	20	20	n/a
176	100	340	340	n/a
226	100	260	260	n/a
154				
265	100	140	140	n/a
79	100	110	110	n/a
99	100	15	15	n/a
107				
270				
102	100	280	280	n/a
260				
267	96	250	250	n/a
97	45	100	n/a	100
92				
106	100	220	220	n/a
93	100	220	220	n/a
171				
175	100	30	30	n/a
274	100	440	440	n/a
102A	99	180	180	n/a
273				
256	88	200	200	n/a
169	65	90	n/a	90
91				
90	100	50	50	n/a
152	100	80	80	n/a
39				
165				
101	98	370	370	n/a
83	100	50	50	n/a
n				
Median Value		44		
Interpreted Best Fit Value		115		
		101		
(A) # of Undermined Springs $\geq$ Best Fit Value w/ $\geq 50\%$ Discharge Reduction			23	
(B) # of Undermined Springs $\geq$ Best Fit Value w/ $< 50\%$ Discharge Reduction				0
(C) # of Undermined Springs $<$ Best Fit Value w/ $\geq 50\%$ Discharge Reduction			17	
(D) # of Undermined Springs $<$ Best Fit Value w/ $< 50\%$ Discharge Reduction				4
Absolute Value (AD-BC)		92		
Chi Square Value at 1 Degree of Freedom		2.78986		
Error Probability as Derived from Chi Square Contingency Test		0.10-0.05		
Error Probability as Derived from Fisher Exact Probability Test		0.04409		

Appendix H_fig_6: Recharge Line Length Component Perpendicular to Longwall Face Evaluated at the Absolute Reduction Boundary (80%) During High Evapotranspiration Conditions