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Mountain Coal Company, LLC
A subsidiary of Arch Resources, Inc.
West Elk Mine
5174 Highway 133
Somerset, CO 81434

December 17, 2021

Mr. Leigh Simmons
Colorado Division of Reclamation, Mining and Safety
Office of Mined Land Reclamation
1313 Sherman Street, Room 215
Denver, Colorado 80203

**Re: Mountain Coal Company, LLC, West Elk Mine; Permit No. C-1980-007; Technical Revision No. TR-150, E-Seam Panels LWE15, LWE16 and LWE17.**

Dear Mr. Simmons:

Mountain Coal Company, LLC (MCC) submits revised map 51, revised permit pages and a proposed public notice in application of Technical Revision No. TR-150 to add longwall panels LWE15, LWE16 and LWE17 to replace the previously planned LWE9 panel.

The plan for three new panels was needed to avoid faults in that area that rendered panel LWE9 unminable. Map 51 shows the configuration of the three (3) new panels.

MCC worked with Wright Water Engineers to update the Subsidence Evaluations, as well as Stream Channel studies to consider the three new panels. Both of those studies, i.e. revised Exhibits 55B and 60E, are attached to this application.

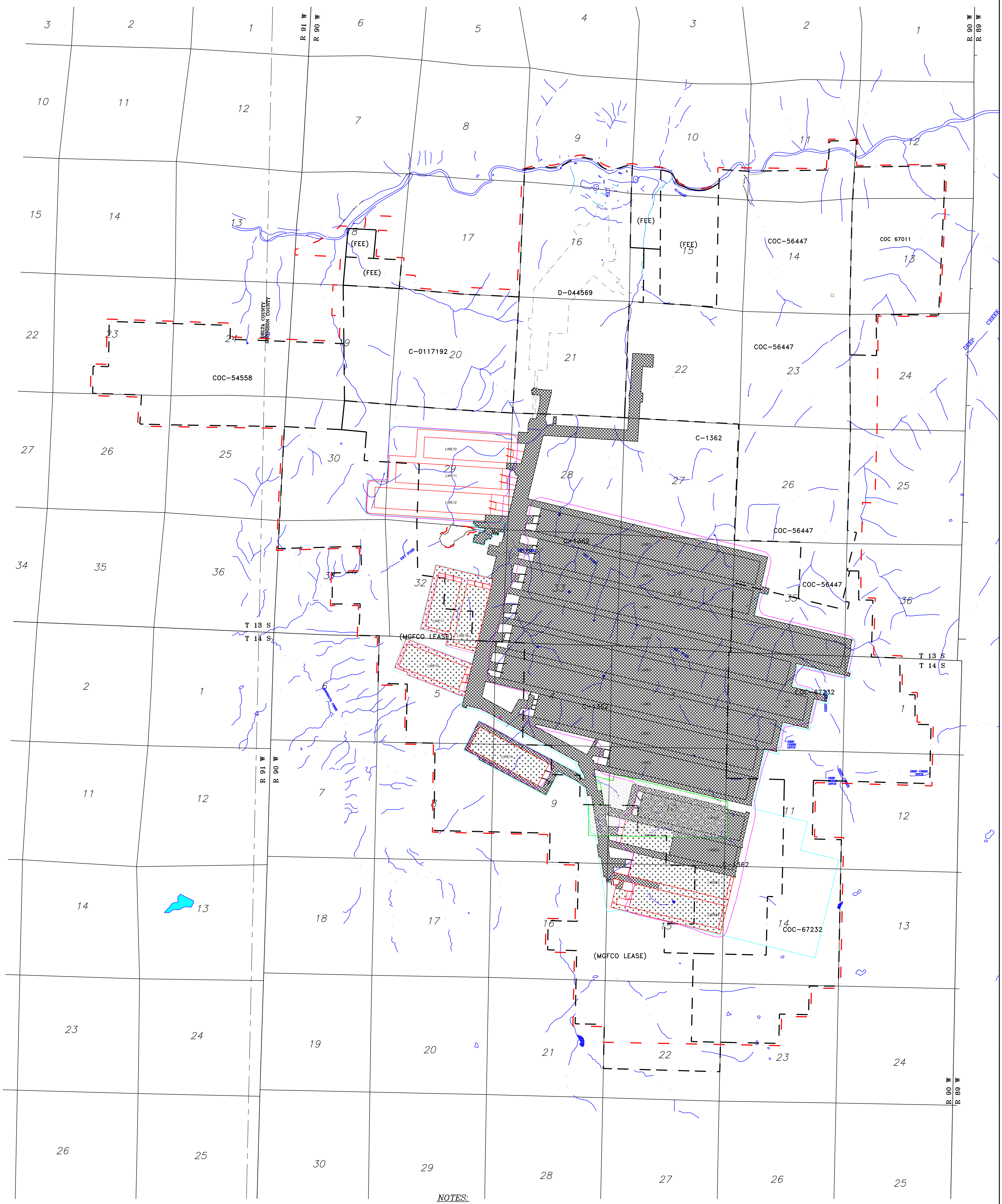
Please contact me at (970) 929-2238 or by e-mail should you have questions regarding this submittal.

Sincerely,

Nicole Poulos

Nicole Poulos
Environmental Engineer

cc: Desty Dyer – BLM
Dan Gray - USFS
Cathie Pagano - Gunnison Co.
Jessica Wilczek - MCC




## LEGEND

- Permit Area Boundary
- Coal Lease Boundary (Federal Lease C–1362 Excludes 24.8 Acres Under Minnesota Reservoir a.k.a. Independent Reservoir or Monument Dam)
- Approximate limit of the maximum predicted 19° E–seam angle of draw.[1]
- Maximum Projected Areal Extent of Potential Mineable E–seam.[2]
- Projected E Seam mining
- – MINED AREAS
- – PROJECTED POTENTIAL MINING AREA 2022–2025
- – AREA OF IN–MINE EXPLORATION

## NOTES:

- *Gateroad entries for longwall panels LWE1 through LWE8 were generally developed from west to east and then longwall mined from east to west. These longwall panels were mined in order from north to south within the coal lease areas shown.*
- *The proposed western longwall panels LWE9 through LWE12 will likely be the last E Seam panels mined due to the locations along the main entries.*
- *The projected panel layout and timing were based on the best available exploration data, professional judgement, and markets at the time this map was prepared. Pillar and panel dimensions may be adjusted within the Projected Potential Mining Area and permit boundary if warranted by actual mining conditions, including coal thickness, coal quality, and geotechnical conditions to fulfill federal coal lease maximum economic recovery requirements.*

1. *See Exhibit 60E. The actual E–seam angle–of–draw has been conservatively calculated as 16.3°. (See Appendix B of the Spring 2010 Subsidence Report.) The angle of draw is measured using the greatest vertical distance between the top of the E seam at the nearest edge of each longwall panel and the ground surface elevation equal to the point of no discernable subsidence.*
2. *Also referred to as the "Projected Potential Mining Area." Although not anticipated (based on available data, as above), should mining be extended in this area and beyond the projected E–seam mining shown, the associated projected impacts of subsidence have been evaluated in Exhibits 55B & 60E.*

THIS DRAWING WAS PREPARED UNDER MY SUPERVISION AND REPRESENTS INFORMATION THAT IS ACCURATE TO THE BEST OF MY KNOWLEDGE

COLORADO LICENSED PROFESSIONAL ENGINEER JESSICA A. WILCZEK 39802
Jessica Wilczek 12/31/2021

N

| DRAWN | |
|---|---|
| DATE | BY |
| 12/31/17 | TR–143 JAW |
| REVISED | |
| DATE | BY |
| 1–19–18 | TR–144 GBG |
| 3–19–18 | PR–15 GBG |
| 6–29–18 | PR–15 EDL |
| 2–1–21 | TR–149 GBG |
| 12–31–21 | TR–150 JAW |

ARCH WEST ELK
5174 Highway 133
Somerset, CO 81434
Operated by Mountain Coal Company, L.L.C.
A subsidiary of Arch Resources, Inc.

# MAP 51
# E-SEAM PROJECTED OPERATIONS

COORDINATE SYSTEM NAD 27

SCALE 0 2000 feet

FILE NO. CDRMS PERMIT MAP 51.DWG
Path: C:\USERS\JWILCZEK\DESKTOP

# Public Notice

Mountain Coal Company, LLC (MCC), 5174 Highway 133, Somerset, CO 81434, (970) 929-5015, has filed a complete application for Technical Revision No. TR-150 to MCC's Mining and Reclamation Permit No. C-1980-007 with the Colorado Mined Land Reclamation Board (Board), under the provisions of the Colorado Surface Coal Mining Reclamation Act of 1979. The permit was originally issued by the Board in July 1981, and subsequently renewed in August 1986, January 1993 (effective August 1991), July 1996, July 2001, April 2007 (effective July 2006), November 2011 (effective July 2011), and September 2020 (effective July 2016). The West Elk Mine five-year permit area contains lands in Sections 9-11, 13-36, T13S, R90W, 6th PM; Sections 23-26, T13S, R91W, 6th PM; and Sections 1-5, 8-12, 14-16, and 21-23, T14S, R90W, 6th PM in Delta and Gunnison Counties. The location of the lands can be found on the USGS 7.5 minute Somerset and Minnesota Pass Quadrangle Topographic Maps. The current permit area encompasses approximately 19,854.9 acres.

This Technical Revision is for longwall panels LWE15, LWE16 & LWE17 to replace longwall panel LWE9 on MCC property and on federal lease C-1362.

Copies of the technical revision application are available for review at the Colorado Division of Reclamation, Mining, and Safety (CDRMS) office, Centennial Building, 1313 Sherman Street, Room 215, Denver, Colorado, 80203, phone (303) 866-3567, and the Gunnison County Planning Office, 221 N. Wisconsin, Suite D, Gunnison, CO 81230. Comments or objections concerning the revision application should be directed to the CDRMS at the above address not later than 10 days after the date of publication of this notice in order to be considered.

# EXHIBIT 60E
# SUBSIDENCE EVALUATION FOR THE SOUTHERN PANELS, APACHE ROCKS WEST, & SUNSET TRAIL MINING AREAS

**PREPARED FOR:**

Mountain Coal Company, LLC.
West Elk Mine
5174 Highway 133
Somerset, CO  81434

**Wright Water Engineers, Inc.**

**Revised December 2021**
831-032.923

# EXHIBIT 60E
## SUBSIDENCE EVALUATION FOR THE SOUTHERN PANELS, APACHE ROCKS WEST, & SUNSET TRAIL MINING AREAS

## MOUNTAIN COAL COMPANY, LLC

## WEST ELK MINE


**Prepared By:**

**Wright Water Engineers, Inc.**
**818 Colorado Avenue, Suite 307**
**Glenwood Springs, CO  81601**


**Revised December 2021**

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## FIGURES



## TABLES



## APPENDICES

# DEFINITION OF SYMBOLS

| Symbol | Definition | Dimensions |
|---|---|---|
| $S$ | Vertical Displacement (Subsidence) | L |
| $S_m$ | Maximum Vertical Displacement ($S_m = a \cdot t$) | L |
| $S/S_m$ | Ratio of Vertical Displacement to Maximum Vertical Displacement | L/L |
| $S_h$ | Horizontal Displacement | L |
| $t$ | Coal Extraction Thickness | L |
| $a = (S_m/t)$ | Subsidence Factor | L/L |
| $a_{cp}$ | Subsidence Factor Above Chain Pillars | L/L |
| $S_{cp} = a_{cp} \cdot t$ | Maximum Subsidence Above Chain Pillars | L |
| $d$ | Overburden Depth | L |
| $S_m/d$ | Ratio of maximum vertical displacement to overburden depth | L/L |
| $W_{cr}$ | Critical Extraction Width | L/L |
| $W/d$ | Mining Width to Overburden Depth Ratio | L/L |
| $M$ | Tilt (Slope) | L/L |
| $M_m$ | Maximum Tilt | L/L |
| $C$ | Curvature, the reciprocal of Radius of Curvature | rad/L (1/L) |
| $C_m$ | Maximum Curvature | rad/L (1/L) |
| $E$ | Horizontal Strain (+) is Positive, (-) is Negative | L/L |
| $E_m$ | Maximum Horizontal Strain | L/L |
| $\phi$ | Angle of Draw | Degrees |
| $B$ | Break Angle | Degrees |
| $\beta$ | Angle of Major Influence | Degrees |
| $r$ | Radius of Major Influence | L |

# DEFINITION OF TERMS

**South of Divide Mining Area.** The mining area encompasses the E-seam longwall panels located primarily in Sections 32, 33, and 34 of Township 13 South, Range 90 West of the $6^{th}$ Principal Meridian, and Sections 3, 4, and 5 of Township 14 South, Range 90 West of the $6^{th}$ Principal Meridian. The panels are identified as E1 to E8 and E15 to E17.

**Dry Fork Mining Area.** The mining area encompasses the extension of the E-seam longwall panels from the South of Divide Mining Area into the Dry Fork Mining Area. The area is located primarily in Section 35 of Township 13 South, Range 90 West of the $6^{th}$ Principal Meridian and Sections 1 and 2 of Township 14 South, Range 90 West of the $6^{th}$ Principal meridian. The panels are identified as E2 to E6.

**Southern Panels Mining Area.** The mining area includes the E-seam longwall panels originally included in the South of Divide Mining Area and some of which were extended into the Dry Fork Mining Area (E1 to E8 and E15 to E17, as above). The Southern Panels mining area also includes the B-seam longwall panels (B26 to B29) that will underlie Southern Panels E1 to E5. Throughout this exhibit, this term will be used to identify what was formerly referred to as the South of Divide and Dry Fork mining areas.

**Apache Rocks West Mining Area.** The Apache Rocks West panels refer to the three western panels in the Apache Rocks Mining Area (as defined in the original Exhibit 60), which are located in Sections 28, 29, and 30, Township 13 South, Range 90 West, of the 6th P.M. Both B- and E-seam longwall mining will occur in this area.

**Sunset Trail Mining Area.** The mining area encompasses the E-seam longwall panels located primarily in Sections 10, 11, 14, and 15 of Township 14 South, Range 90 West of the $6^{th}$ Principal Meridian. The panels are identified as SS1 through SS4.

**Critical Mining Width.** The width of a mining panel necessary for maximum subsidence to occur; the length of the panel must also be greater than, or equal to, critical panel width for maximum subsidence to occur. Critical width ($W_{cr}$) commonly ranges from 1.0 to 1.4 times the mining depth (d).

**Subcritical Mining Width.** The width of a mining panel less than critical width (i.e., less than 1.0 to 1.4d).

**Supercritical Mining Width.** The width of a mining panel greater than critical width.

# EXHIBIT 60E
# SUBSIDENCE EVALUATION
# FOR THE SOUTHERN PANELS, APACHE ROCKS WEST, & SUNSET TRAIL MINING AREAS

## 1.0 INTRODUCTION

This exhibit describes longwall panel subsidence processes that have been observed from studies above longwall panels mined in Mountain Coal Company, LLC's (MCC) West Elk Mine and from other similar operations and studies. The subsidence information obtained from longwall mining to date in the West Elk Mine has been used to project subsidence processes, amounts, and effects to the Southern Panels, Apache Rocks West, and Sunset Trail mining areas within MCC's permit and affected area boundaries. This document is intended to comply with the Colorado Division of Reclamation, Mining and Safety (DRMS) Regulations for Coal Mining, as revised September 14, 2005, under Section 2.05.6, Mitigation of the Impacts of Mining Operations.

This report was updated by Tetra Tech September 2007 and was added to the approved permit document as Exhibit 60E to include the Dry Fork lease mining area with the longwall mining area of the South of Divide coal leases within the permit area. Since these areas are being mined together, it is logical to consider them together in one report. Most of the report is "as contained" in the Exhibit 60B prepared by C. Richard Dunrud of Wright Waters Engineers, Inc. (WWE) in March 2006 for the South of Divide mining area. Maximum projected mining was planned into the Dry Fork mining area in E-seam longwall panels E2 to E6 to the east permit area boundary and under the upper areas of Dry Fork, a tributary to Minnesota Creek, and the upper areas of Deep Creek. Panels E1, E7, E8, and E15 through E17 remain within the boundaries of the South of Divide mining area previously evaluated.

WWE further updated Exhibit 60E to reflect the maximum projected areal extent of potential longwall mining within the potentially mineable coal reserves of the Dry Fork mining area. MCC's projected E-seam mining has not changed and continues to reflect the best available information (including exploration and actual E-seam mining data) regarding the mineable E-seam coal. However, during ongoing longwall panel development, additional mineable coal has been and may be found to exist beyond the projected E-seam longwall panel shown on permit Map 51. If mineable coal is found beyond the projected longwall panel and is within the Maximum Projected Areal Extent area, MCC may continue mining within this area.

The 2015 update addressed a revised longwall panel layout in the two-seam mining area known as the Apache Rocks West panels that was addressed in the original Exhibit 60 (May 1995). In addition, the update evaluated the subsidence due to two-seam mining in the Southern Panels mining area as shown in Figure 1. The 2018 update evaluated the subsidence associated with longwall mining of the E-seam in the Sunset Trail mining area. WWE analyzed the proposed layout for longwall panels SS1 through SS4 as shown in Figure 1. The 2020 update was performed in order to reflect the most current information regarding the layout for the Sunset Trail longwall panels and panel E14 and the projected overburden thicknesses in these areas.

The geologic and mining conditions are consistent throughout the Southern Panels, Apache Rocks West, and Sunset Trail mining areas (Agapito, 2005). Therefore, no change was needed in the subsidence model prepared by Dunrud and predictions for subsidence over longwall panels in the South of Divide mining area are considered to also be applicable for the Dry Fork, Apache Rocks West, and Sunset Trail mining areas.

## 2.0 MINING METHOD

The longwall mining method has and will continue to be utilized in the Southern Panels, Apache Rocks West, and Sunset Trail mining areas. The projected longwall panels designs are similar to the B-seam and E-seam longwall panels mined to date in the West Elk Mine, where subsidence measurements were used to obtain the baseline data that were used in this report. A range of 8 to 14[1] feet of coal will be extracted from the E-seam in the Southern Panels mining area. The four longwall panels in the Sunset Trail mining area (SS1 through SS4) are proposed to have an extraction thickness ranging from 9 to 14 feet. The extraction thicknesses are projected based on exploration drillhole data; actual thicknesses may vary depending on mining conditions encountered, but will not be greater than 14 feet.

E-seam longwall panels E1 to E8 were approximately 1,080 feet wide[2] and extended up to approximately 15,000 feet in length. Panel E14 is projected to be 1,080 feet wide and approximately 3,300 feet long. The longwall panels will be mined by the retreat longwall mining method. Panels E1 to E8 were longwall mined from east to west as panel E14 will be. Panels E15 through E17 are projected to be 1,080 feet wide with lengths ranging from 2,300 to 2,890 feet. Panel E15 is planned to be mined from east to west and Panels E16 and E17 are planned to be longwall mined from south to north.

The trend of panels E1 to E8 is approximately N80ºW. Panel E15 trends N70°W. Projected Panel E16 and E17 trend roughly N13ºE and E14 trends approximately N60°W. The overburden depth above the longwall panels E1 to E4 ranged from roughly 375 to 1,800 feet, whereas, the overburden depth for longwall panels E5 to E8 ranged from approximately 500 to 1,800 feet. The overburden above the longwall panel blocks of E14 through E17 ranges in thickness from approximately 260 to 740 feet.

B-seam mining in the Southern Panels mining area will occur in panels B26 to B29, and will follow the same orientation as the overlying previously mined E-seam longwall panels. The longwall panels are projected to be approximately 1,080 feet wide with lengths varying from 11,500 feet up to 14,800 feet, and mining thicknesses from 9 feet up to 14 feet.

In the original Exhibit 60 (May 1995), MCC anticipated two-seam mining in the B- and E-seam in the Apache Rocks West mining area. MCC has already mined the B-seam in this area (B12, B13, and B13-A); however, the layout of the E-seam panels (E10 to E12) has shifted from being stacked over the B-seam panel to being offset. Panels E10 to E12 are projected to be approximately 850 to 1,080 feet wide and vary in length from approximately 3,800 feet to 5,300 feet. The mining thickness is anticipated to vary from 10 to 14 feet.

E-seam mining in the Sunset Trail mining area will occur in Panels SS1 to SS4 as shown in Figure 1. Panels SS1 to SS4 are projected to be approximately1,080 feet wide with maximum lengths ranging from approximately 7,200 feet up to 9,400 feet. The panels are and will be oriented

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[1] Practically speaking, the maximum mining height with the current longwall is 13.5 feet; however, WWE is using 14 feet in our analysis to be conservative, except with the computer modeling.
[2] All of the panels discussed in this exhibit are approximately 1,080 feet wide. When evaluating subsidence, a total extraction width of 1,120 feet was used to include the entries parallel and adjacent to the longwall panel block.

parallel to panels E1 to E8. The mining thickness is anticipated to vary from 10 to 14 feet. The overburden above panels SS1 to SS4 ranges in thickness from approximately 280 feet up to 1,300 feet.

All longwall panels are planned to be separated by two or three rows of chain pillars. The pillars on both the headgate and tailgate sides of the panels are typically on centers of about 125 feet wide by 200 feet long. The headgate for the adjacent panel becomes the tailgate panel on the subsequent panel. These mine plans and pillar designs may change as mining experience, geological-geotechnical conditions, and/or mine operational procedures dictate. This exhibit focuses on subsidence projections over the mined longwall panels.

# 3.0 FACTORS INFLUENCING SUBSIDENCE

Subsidence may be influenced by the local geology in the following ways:

1. Geologic structure. Attitude of the bedrock, faulting, and jointing may affect the mine layout and mining method employed. In steeply dipping, faulted coal beds, for example, a mine layout and method, such as room-and-pillar or limited panel-pillar, may be required. Joints often control the way in which the roof rocks break, cave, and fracture, both underground and at the surface during mining and subsidence. In relatively flat-lying, unfaulted coal seams like the Southern Panels, Apache Rocks West, and Sunset Trail mining areas, there is latitude to develop the most efficient layout and method to recover a maximum amount of the coal resource with a minimum of impact.

2. Strength and behavioral properties of the rocks. These properties control the amount and rate of subsidence. Strong, brittle sandstones and siltstones tend to break and cave in large blocks on the mine floor. The bulking factor is greater for strong rocks than it is for soft, weak rocks. The greater bulking factor of strong, caved material commonly reduces the height of caving and the subsidence factor compared to soft, weak rocks. Conversely, the height of fracturing often is greater for strong, brittle rocks than it is for soft, weak rocks.

3. Stratigraphic sequence. The stratigraphic distribution of rock units (stratigraphic sequence) influences the effects of mining and subsidence. For example, strong and brittle sandstones in the mine roof, as discussed above, can reduce the height of caving compared to shales, whereas sandstones in the fractured zone above the caved zone may increase the height of fracturing compared to shales. Conversely, the height of caving may be increased and the height of fracturing decreased where weaker shale and claystones occur in the fractured zone above the coal seam to be mined.

   In addition, the lithology of the overburden rock may control the subsidence factor. The subsidence factor may be less where the overburden contains a greater proportion of thick, strong sandstones, and greater where the overburden contains thin, weak shales. In the Southern Panels, Apache Rocks West, and Sunset Trail mining areas, the first 200 to 300 feet of rocks above the E-seam consist primarily of siltstones, shales, claystones, local lenticular sandstones, and coal seams.

4. Moisture content. Wet or saturated conditions in the mine roof and overburden tend to reduce the bulking factor of the caved roof rocks. Therefore, the subsidence factor commonly is greater under wet conditions than it is in dry conditions. In general, the greater the saturation of the mine roof and overburden rocks, the greater the subsidence factor.

# 4.0 FIELD RECOGNITION OF SUBSIDENCE AND NON-SUBSIDENCE FEATURES ABOVE THE WEST ELK MINE

Four different types of features are observed in the area above the West Elk Mine: 1) subsidence cracks and bulges, 2) construction cracks, 3) desiccation cracks, and 4) gravity-induced tension cracks. They can be distinguished easily in some areas—where, for example, no mining has occurred in that area. However, in other areas they may be difficult to distinguish, such as in areas that have been mined, but where conditions are also favorable for construction, desiccation, and/or gravity-induced tension cracks to occur.

## *4.1 Subsidence Cracks and Compression Features*

Subsidence cracks are open cracks that most likely occur in areas where the ground surface has undergone extension during subsidence processes. Cracks as much as 3.5 inches wide, for example, have been observed in sandstone outcrops at Apache Rocks where zones of maximum extension (or tension in rock mechanics terminology) occur. As discussed in Section 5.3.2, cracks close—and the underlying rocks become compressive—below the neutral surface (the boundary between tensile and compressive strain) of the rocks downwarping as a single unit. Therefore, any water located in cracks above the neutral surface is blocked from traveling downward into rocks in compression below the neutral surface.

Cracks in the zone of maximum tension occur approximately perpendicular to the orientation of the longwall mining faces (transverse cracks) and parallel to the orientation of the longwall mining panels (longitudinal cracks). The cracks commonly do not conform to such a precise pattern. As with other deformational processes in nature, crack orientation may be quite variable.

The transverse tension cracks that locally occur above the longwall mining face often have a dynamic history. They open when the longwall face moves beneath a particular area, and they close again when the longwall face moves out of the area of mining influence.

Longitudinal cracks occur above and roughly parallel to the edges of the longwall mining panel above the gateroad pillars and the haulageway (or beltway) pillars. Longitudinal tension cracks commonly remain open, particularly in areas above gate roads with a rigid-pillar configuration. The cracks may stay open or close in areas above gate roads with a combination rigid-pillar/yield-pillar configuration. However, as discussed in Section 5.3.2, it is unlikely that cracks will occur in colluvium and alluvium in the stream valleys of the Southern Panels and Sunset Trail mining area.

Compression features (bulges and warps) also occur above the longwall mining panels in areas where the ground surface undergoes compression in the subsidence process. The compression features, which occur toward the center of the mining panel in zones of maximum compression, are usually more difficult to recognize. They often are masked, or absorbed, by soil and colluvium, or are hidden in the brush and grass. They also may be indistinguishable from natural humps and mounds in the soil and colluvium.

### 4.2 Construction Cracks

Cracks caused by construction activities are common on the banks of newly constructed roads and drill pads. These cracks are caused by the bulldozer and related differential compaction during construction activities. The cracks are most noticeable where fractured and weathered bedrock is encountered. However, this type of cracking also occurs in soil and colluvium where roots of brush and trees are pulled out of the road cut by the bulldozer. In contrast to subsidence cracks, construction cracks occur in a continuous zone where weathered and/or fractured bedrock is encountered during road construction.

Construction cracks may be confused with subsidence cracks, particularly where mining has occurred in the area, and where local bedrock is weathered and fractured, or where brush and trees have been ripped out of soil and/or colluvium during the construction process. The most diagnostic features of construction cracks are that they 1) have a less regular pattern, 2) are related to the material they occur in, and 3) they lack of any spatial relationship to the underlying longwall mine geometry.

### 4.3 Desiccation Cracks

Desiccation cracks tend to occur in claystones and siltstones of the Mesaverde and Wasatch Formations in the area above the West Elk Mine, particularly where the rocks are weathered to clays and silts. The process of desiccation involves the shrinking of the clays and silts after a dry period that follows a wet period, when the material swells (the shrink/swell process).

Desiccation cracks can often be recognized by their irregular, branching and diverging pattern—less regular than typical subsidence cracks. Some of the largest desiccation cracks in the area above the West Elk Mine were observed in clays of the Barren Member of the Mesaverde Formation in the Horse Gulch-Minnesota Reservoir area and in the weathered claystones of the Wasatch Formation on West Flatiron, before there had been any mining. The larger, more regular desiccation cracks and construction cracks may be confused with subsidence cracks in areas where mining has occurred. However, transverse and longitudinal subsidence cracks have a definite spatial relationship to the longwall mining panel causing the cracks.

### 4.4 Pseudo Subsidence Features (Gravity-Induced Tension Cracks)

Cracks have been observed on high, steep ridges, near cliffs, and in landslides, in the Box Canyon and Apache Rocks mining areas. These cracks looked very much like subsidence cracks, but could not have been, because no mining had been done when they were observed. A good example of a gravity-induced crack is the extensive crack that Dunrud observed on the narrow ridge of West Flatiron in August 2002. This crack was as much as 3.5 in wide and 150 feet long. This was not a mining-related crack because no mining had occurred in the area. The possibility of gravity-induced cracking in the rugged country above planned mining activities in the West Elk Mine is a good reason to perform baseline studies of the area prior to any mining so that these features can be documented.

Cracks and bulges caused by landslides are other types of gravity-induced features that may appear to be related to subsidence, particularly in areas that have been, or are being, undermined.

However, landslide-induced features are related to the geometry of the landslide rather than the mine geometry. For example, cracks are most common in the upper area of a landslide, whereas, bulges are most common in the lower area of the slide. This spatial and geometric relationship to a landslide footprint on steep, unstable slopes, rather than the mine geometry can usually be used to differentiate between gravity-induced and mine-induced surface features.

# 5.0 SUBSIDENCE PREDICTION BASED ON LONGWALL MINING AT WEST ELK MINE

Subsidence, as it relates to longwall mining, is defined herein as the local downward displacement of the surface and overburden rock in response to mining under the influence of gravity. For purposes of describing subsidence effects on overburden material and the ground surface, subsidence can be divided into four zones (Figure 2): 1) caved zone, 2) fractured zone, 3) continuous deformation zone, and 4) near surface zone.

## *5.1 Caved Zone*

As coal is extracted and a void is produced, the roof rocks break along bedding planes, joints, and fractures and fall to the mine floor (Figure 2). Rotation of the caved debris occurs during the fall so that the caved fragments tend to pile up in a random fashion. This caved zone, according to Peng (1992, p. 1-2) occurs for the first 2 to 8 mining (or coal extraction) thicknesses (2t to 8t) in the roof rocks (for example, if t=12 feet, the caved zone would range from 24 to 96 feet [2t to 8t]). According to Wendell Koontz, former senior geologist at West Elk Mine, this caved zone averages about 2.5t for longwall mining of the B-seam in the West Elk Mine. This includes the Apache Rocks and Box Canyon mining areas (Koontz, oral communication March 2004).

Based on the stratigraphic and lithologic information obtained from drill holes in the Southern Panels and Sunset Trail mining areas, the rocks consist of a greater proportion of shales, siltstones, and claystones than are present in the Apache Rocks and Box Canyon mining areas. The height of the caved zone is therefore projected to range from 2t to 5t, depending on water conditions encountered and on specific roof lithology. In a dry environment, where lenticular sandstones comprise the E-seam roof, the caved zone will be closer to 2t. In a wet environment where soft shales and claystones occur in the roof, however, the caved zone will likely be closer to 5t. The average height of the caved zone is projected to average 3t in the Southern Panels and Sunset Trail mining areas.

## *5.2 Fractured Zone*

A zone of fracturing and local separation along rock bedding planes and joints occurs above the zone of caving (Figure 2, Enlargement 1). In this zone, which is transitional to the underlying caved zone, lateral and vertical constraints in the adjacent overburden strata and the caved rocks below prevent further large displacement or rotation of the fractured rock. Displacements in the fracture zone and severity of fracturing tend to decrease upward as lateral and vertical confining stresses increase.

Based on width and conductivity of fractures Peng (1992, p. 143) states that the upper one-third of the fractured zone (in terms of height) has only minor fractures with little potential for water conductivity. In the lower two-thirds of the fractured zone, water conductivity commonly increases progressively downward.

Compression arches (arcuate zones of compressive stress) commonly develop, or partially develop, above the mining panels. These arches temporarily transfer overburden stresses to the panel barrier or chain pillars and to the caved gob and the mining face (Dunrud 1976). Stresses temporarily increase in the zones of these compression arches. However, the arches in a given area commonly move upward and dissipate as longwall mining is completed in that area. Arches may not dissipate where the room-and-pillar mining method is used, because pillars and stumps left after mining can prevent dissipation of the compression arches. The overburden rocks affected by the arches are temporarily subjected to increased stress and strain as the arches move upward. In longwall mining areas, this increased stress and strain commonly are less than in room-and-pillar mining areas because stresses are relieved as the arches move upward and dissipate.

Peng (1992, p.4) reports that the combined height of the zone of caving and fracturing ranges from 20t to 30t, and that the height of the fractured zone is greater for hard, strong rocks than for soft, weak rocks.

The height of the zone of fracturing is a function of lithology and layer thickness, according to Peng (1992, p. 6-8). For example, the zone of fracturing commonly is higher for strong, thickly-bedded, brittle sandstones than it is for thinly layered, soft, shales and claystones. Liu (1981) reports ranges of heights of the zone of fracturing for various rock types as follows:

1. Heights of 20t to 30t are reported in strong brittle rocks, such as siliceous sandstones and limestones; a value of 28t was reported for overburden containing 70 percent sandstone. Also, because of hardness, fractures do not close as readily in brittle rocks as they do in soft rocks during recompression.

2. Heights of 9t to 11t are reported where all the rocks consist of soft shales and claystones. The fractures also commonly close again under stresses associated with static conditions, and become impermeable again.

Considering the lithology of the areas, Mr. Koontz estimated that 10t to 20t was a good projection for the height of fracturing in the Apache Rocks and Box Canyon mining areas. However, a projected fracture height of 30 times the coal extraction thickness (30t) may locally occur (Koontz, oral communication March 2004).

Within the Southern Panels and Sunset Trail mining areas, the fracture zone may become less continuous in the caved zone with increasing height because of the alternating sequence of harder and brittle rocks and softer and yielding rocks. The height of the fracture zone, therefore, will likely be less—by possibly 10 to 20 percent—than the height predicted for the Apache Rocks and Box Canyon mining areas because of the presence of more shale above the E-seam mining in the Southern Panels and Sunset Trail mining areas. Fractures near the top of the caved zone, therefore, will likely become less continuous with increasing height in the zone of fracturing.

The maximum height of fracturing above longwall panels in the Southern Panels and Sunset Trail mining area is estimated to range from about 10t to 20t. This is near the mid-range of 9t to 30t as reported by Peng (1992, p. 7). This estimate may be conservative for the particular rock strata or lithology above the E-seam. When considering a conservative 10 percent reduction for the softer rocks overlying the E-seam, the effective height of fracturing in the Southern Panels and Sunset Trail mining areas is estimated to range from 9t to 18t.

In areas of two-seam mining, it is possible for the heights of the fractured zones to become cumulative as the height of fracturing from the underlying B-seam could extend up to the E-seam. This potential exists in the Apache Rocks West and Southern Panels mining areas. However, this phenomenon would not increase the height of fracturing above the E-seam, which would govern the potential for near-surface impacts.

Also, with increasing height in this zone, and as lateral and vertical constraints increase, fracturing that could impact water bearing zones will tend to occur more in zones of convex upward curvature, along separated bedding planes toward the center of the panel, and along local cracks in zones of convex downward curvature (Figure 2). Fracturing within the expected zone of fracture may cease completely where soft shales and claystones occur as alternating sequences with sandstones.

Drainage into the fractured formations, however, may cease after mining is complete and any water bearing zones present may be restored. This is particularly likely in the upper part of the fractured zone in shale sequences between sandstone layers, once subsidence is completed and the separated beds re-compress and close in response to overburden load (Figure 2). Although very few water bearing zones have been encountered, evidence of restored water levels has been measured and reported in some wells in the West Elk Mine subsidence monitoring area after B-seam mining and subsidence were complete.

## 5.3 Continuous Deformation Zone and Near Surface Zone

These two zones are discussed together because the ground surface is where nearly all measurements are made that monitor subsidence processes active in the zone of continuous deformation.

The near surface zone, which typically consists of weathered bedrock, colluvium, alluvium, and soil a few feet to a few tens of feet thick, may deform differently than the underlying bedrock (Figure 2). Field studies by Dunrud indicate that near-surface colluvium and alluvium, which consist of predominantly clay and silt, can undergo significantly more extension without rupturing than can the underlying material. In both the Somerset, Colorado and Sheridan, Wyoming field study areas, colluvium and alluvium 5 to 10 feet thick were observed to cover cracks as much as 10 to 14 inches wide so that there was no indication of the underlying fractures.

The zone of continuous deformation, which is transitional to the overlying near-surface zone and also to the underlying zone of fracturing, undergoes differential vertical lowering and flexure as laterally-constrained plates (in three dimensions) or beams (in two dimensions). With flexure, shear occurs at the boundaries of rock units with different strength and stiffness, characteristics, such as sandstones and shales. Zones of tension above the neutral surfaces of a rock unit, for example, become compressive above the boundary with another rock unit and below its neutral surface (Figure 2, Enlargement 2). Any cracks, therefore, which occur in the tension zone of a rock unit, terminate at the neutral surface, because the unit is in compression below this point.

### 5.3.1 Vertical Displacement, Tilt, and Horizontal Strain

Differential vertical lowering of the continuous deformation and near surface zones causes vertical displacement (S), tilt (M), and horizontal strain (E). In flat or gently sloping terrain (slopes less than about 30 percent), surface profiles of subsidence depressions are similar to flexure of fixed-end, laterally constrained beams. Tensile stresses are present in areas of positive curvature, which become zero downward at the neutral surface, then reverse to compressive stresses below the neutral surface.

In flat or gently sloping terrain, vertical displacement typically increases inward from the limit of the subsidence depression, is half the maximum value at the point of inflection, and is maximum in the middle of the depression (also called subsidence basin or subsidence trough). Tilt increases inward from the margin of the depression to a maximum at the point of inflection and become zero again at the point of maximum vertical displacement (Figure 3). Maximum values of tilt, curvature, and strain, discussed herein, apply only to slopes less than about 30 percent; values may be greater on slopes steeper than 30 percent.

Positive curvature (convex upward) and horizontal tensile strain increase inward from the margin of the depression to a maximum about midway between the depression margin and the point of inflection and decrease to zero again at the point of inflection. Negative curvature (concave upward) and compressive horizontal strain increase inward from the point of inflection to a maximum about midway between the point of inflection and the point of maximum vertical displacement and decrease to zero again at the point of maximum vertical displacement.

#### 5.3.1.1 Maximum Vertical Displacement (Subsidence)

The following range of vertical displacements (subsidence values) are projected for the Southern Panels, Apache Rocks West, and Sunset Trail mining areas, based on the baseline data obtained from subsidence measurements above the B-seam longwall panels 1NW, 2NW, and 3NW (Figure 4, Table 1) and E-seam longwall panels E1 to E3 at West Elk Mine.

<u>Southern Panels Mining Area</u>: As noted above, the E-Seam longwall panels E1 to E8 were originally approved as part of the South of Divide mining area, and subsequently panels E2 to E7 were approved to extend into the Dry Fork mining area. To simplify the discussion of subsidence projections, the full-length panels are addressed as the Southern Panels E1 to E8. Similarly, the proposed B-seam panels in this area are referred to as the Southern Panels B26 to B29.

For purposes of the subsidence modeling evaluation, the overburden depth above the projected E-seam longwall centers ranges from approximately 370 to 1,800 feet. With a projected longwall panel width of approximately 1,080 feet, and assuming that the chain pillars (gate road pillars) are similar to those in longwall panel 17 of the Apache Rocks mining area, maximum subsidence (vertical displacement $S_m = a \cdot t$) is predicted as follows (Table 2) for the Southern Panels mining area of panels E1 to E8 and E14 to E17:

- *Panels E1 to E8 and E14 to E17:* These panels range in width from subcritical to supercritical (width-to depth ratio (W/d) ranges from 0.76 to 3.00).

1. Maximum vertical displacement above the chain pillars ($S_{cp}$) is expected to range from 0.9 to 2.7 feet (0.1 to 0.3t) where the extraction thickness is 9 feet, and from 1.4 to 4.2 feet (0.1 to 0.3t) where the extraction thickness is 14 feet.

2. Maximum vertical displacement above the mined longwall panels (subsidence, $S_m$= a • t) is projected to range from 5.4 to 7.2 feet (0.6 to 0.8t) where the extraction thickness is 9 feet, and from 8.4 to 11.2 feet (0.6 to 0.8t) where the extraction thickness is 14 feet.

Overburden depth above the projected B-seam longwall centers ranges from approximately 600 to 1,500 feet. With a projected longwall panel width of approximately 1,080 feet, maximum subsidence (vertical displacement $S_m$ = a • t) is predicted as follows (Table 2) for the Southern Panels mining area of panels B26 to B29:

- *Panels B26 to B29:* These longwall panels range in width from subcritical to supercritical (width-to depth ratio (W/d) ranges from 0.72 to 1.80).

  1. Maximum vertical displacement above the chain pillars ($S_{cp}$) is expected to range from 0.9 to 2.7 feet (0.1 to 0.3t) where the extraction thickness is 9 feet, and from 1.4 to 4.2 feet (0.1 to 0.3t) where the extraction thickness is 14 feet.

  2. Maximum vertical displacement above the mined longwall panels (subsidence, $S_m$= a • t) is projected to range from 5.4 to 7.2 feet (0.6 to 0.8t) where the extraction thickness is 9 feet, and from 8.4 to 11.2 feet (0.6 to 0.8t) where the extraction thickness is 14 feet.

The E-seam panels E1 to E5 and B-seam panels B26 to B29 occur on top of one another, but are not stacked based on the current panel layout (Figure 1). Therefore, while the subsidence (vertical displacement $S_m$ = a • t) of the two seams is additive, the maximum subsidence due to mining in each seam will not occur at the same location. The closer the alignment of the B-seam panel occurs in a stacked manner relative to the E-seam panels, the more additive the maximum subsidence will be.

The superposition of the subsidence curves for the longwall mining of the E-seam and B-seam indicates that the combined maximum subsidence will be roughly 80 percent of the sum of the maximums for each seam. To be conservative, the maximum for the two-seam mining will be estimated by summation of the maximums for each seam.

1. Maximum vertical displacement above the chain pillars ($S_{cp}$) due to both E-seam and B-seam mining is conservatively estimated to be the summation of the subsidence for each seam, as the chain pillars for the E-seam and B-seam are nearly located on top of one another. For the two-seam panel area, the maximum vertical displacement is estimated to range from 2.8 to 8.4 feet (0.1 to 0.3t) where the extraction thickness is 14 feet.

2. Maximum vertical displacement above the mined longwall panels (subsidence, $S_m$= a • t) for the B-seam and E-seam mining is projected to range from 10.8 to 14.4 feet (0.6 to 0.8t) where the extraction thickness is 9 feet, and from 16.8 to 22.4 feet (0.6

to 0.8t) where the extraction thickness is 14 feet. This estimate is only for the areas over panels E2 to E5 and B26 to B29.

Apache Rocks West Mining Area: Overburden depth above the projected E-seam longwall centers ranges from 400 to 1,100 feet. With a projected longwall panel width of approximately 1,080 feet, maximum subsidence (vertical displacement $s_m = a \bullet t$) is predicted as follows (Table 3) for the Apache Rocks West mining area of panels E10 to E12:

- *Panels E10 to E12*: These panels range in width from subcritical to supercritical (width-to depth ratio (W/d) ranges from 0.98 to 2.70).

    1. Maximum vertical displacement above the chain pillars ($s_{cp}$) is expected to range from 1.0 to 4.0 feet (0.1 to 0.3t) where the extraction thickness is 10 feet, and 1.4 to 5.6 feet (0.1 to 0.3t), where the extraction thickness is 14 feet.

    2. Maximum vertical displacement above the mined longwall panels (subsidence, $s_m = a \bullet t$) is projected to range from 6.0 to 8.0 feet (0.6 to 0.8t) where the extraction thickness is 10 feet, and from 8.4 to 11.2 feet where the extraction thickness is 14 feet.

Overburden depth above the B-seam longwall centers ranges from approximately 750 to 1,300 feet. With a longwall panel width of 950 feet, maximum subsidence (vertical displacement $S_m = a \bullet t$) is predicted as follows (Table 3) for the Apache Rocks West mining area of panels B12 to B13A:

- *Panels B12 to B13A:* These panels range in width from subcritical to supercritical (width-to depth ratio (W/d) ranges from 0.73 to 1.27).

    1. Maximum vertical displacement above the chain pillars ($S_{cp}$) is expected to range from 1.2 to 4.8 feet (0.1 to 0.3t) where the extraction thickness is 12 feet.

    2. Maximum vertical displacement above the mined longwall panels (subsidence, $S_m = a \bullet t$) is projected to range from 7.2 to 9.6 feet (0.6 to 0.8t) where the extraction thickness is 12 feet.

The E-seam panels E10 to E12 and B-seam panels B12 to B13-A occur on top of one another, but are not stacked based on the current panel layout (Figure 1). However, to be conservative, the maximum subsidence (vertical displacement $S_m = a \bullet t$) of the two seams is assumed to be additive.

3. Maximum vertical displacement above the chain pillars ($S_{cp}$) due to both E-seam and B-seam mining cannot be estimated, as the chain pillars for the E-seam and B-seam are not located on top of one another.

4. Maximum vertical displacement above the mined longwall panels (subsidence, $S_m = a \bullet t$) for the B-seam and E-seam mining is projected to range from 13.2 to 17.6 feet (0.6 to 0.8t) where the E-seam extraction thickness is 10 feet, and from 15.6 to 20.8 feet (0.6 to 0.8t) where the E-seam extraction thickness is 14 feet. This estimate is only for the areas over panels E10 to E-12 and B12 to B13-A. Due to the offset

alignment of the E-seam panels from the B-seam panels, the maximum subsidence over E-seam panel E12 will have very little influence from the B-seam mining in panel B13-A.

<u>*Sunset Trail Mining Area*</u>: Overburden depth above the centers of the projected E-seam longwall panels ranges from approximately 350 to 1,250 feet. With a projected longwall panel width of 1,080 feet, and assuming that the chain pillars (gate road pillars) are similar to those in longwall panel B17 of the Apache Rocks mining area, maximum subsidence (vertical displacement $s_m$ = a • t) is predicted as follows (Table 4) for panels SS1 through SS4:

- *Panels SS1 to SS4*: These panels range from subcritical to supercritical (width-to-depth ratio (W/d) ranges from 0.86 to 3.09).

    1. Maximum vertical displacement above the chain pillars ($s_{cp}$) is expected to range from 0.9 to 2.7 feet (0.1 to 0.3t) where the extraction thickness is 9 feet, and 1.4 to 4.2 feet where the extraction thickness is 14 feet.

    2. Maximum vertical displacement (subsidence, $s_m$ = a • t) is projected to range from 5.4 to 7.2 feet (0.6 to 0.8t) where the extraction thickness is 9 feet, and 8.4 to 11.2 feet, where the extraction thickness is 14 feet.

#### 5.3.1.2 Maximum Tilt

Maximum tilt ($M_m$) was calculated from differential vertical displacements at the West Elk Mine monitoring network in terms of the ratio of maximum vertical displacement to overburden depth ($S_m$/d in dimensionless units L/L) (Table 1 and Figure 5). Tilt values at West Elk Mine range from 1.4 to 2.1 percent. Maximum calculated tilt ranges from about two to three times $S_m$/d (2 to 3·($S_m$/d)) at West Elk Mine. Maximum tilt in the Southern Panels, Apache Rocks West, and Sunset Trail mining areas is projected to range from 2.2 to 2.3 $S_m$/d. Maximum tilt in four different mining areas studied by Dunrud in the Western United States ranges from 2.5 to 5·($S_m$/d).

<u>*Southern Panels Mining Area*</u>:

As stated earlier in this report, tilt above the nine E-seam longwall panels (panels E1 to E8 and E14 to E17) are projected to range between 2.2 and 2.3 $S_m$/d for coal extraction thickness ranging between 9 and 14 feet. These values are based on subsidence measurements at West Elk Mine (Table 1, Figure 5). The overburden depth above the longwall panel centers ranges from 360 to 1,425 feet (Table 2).

- *Panels E1 to E8 and E14 to E17:* Maximum tilt in these panels is projected to range from 0.008 to 0.046 (0.8 to 4.6 percent) where 9 feet of coal is extracted, and from 0.013 to 0.072 (1.3 to 7.2 percent) where 14 feet of coal is mined (Table 2).

Similarly, tilt above the longwall panels (panels B26 to B29) are projected to range between 2.2 and 2.3 $S_m$/d for coal extraction thickness ranging between 9 and 14 feet. These values are based on subsidence measurements at West Elk Mine (Table 1, Figure 5). The overburden depth above the longwall panel centers ranges from 600 to 1,500 feet (Table 2).

- *Panels B26 to B29:* Maximum tilt in this panel is predicted to range from 0.008 to 0.028 (0.8 and 2.8 percent) where 9 feet of coal is mined, and from 0.012 to 0.043 (1.2 to 4.3 percent) where 14 feet of coal is produced.

The E-seam panels E1 to E5 and B-seam panels B26 to B29 occur on top of one another, but are not stacked based on the current panel layout. However, to be conservative, the maximum tilt ($M_m$) of the two seams is assumed to be additive. The maximum tilt due to two-seam mining is only expected to increase by roughly 20 percent over the maximum for the individual seams.

- Maximum tilt ($M_m$) for the B-seam and E-seam mining is projected to range from 0.010 to 0.054 (1.0 and 5.4 percent) where 9 feet of coal is mined, and from 0.016 to 0.084 (1.6 to 8.4 percent) where 14 feet of coal is produced. This estimate is only for the areas over panels E1 to E5 and B26 to B29.

Apache Rocks West Mining Area:

Tilt above the longwall panels (panels E10 to E12) is projected to range between 2.2 and 2.3 $S_m/d$ for coal extraction thickness ranging between 10 and 14 feet. These values are based on subsidence measurements at West Elk Mine (Table 1, Figure 5). The overburden depth above the longwall panel centers ranges from generally 400 to 1,100 feet (Table 3).

- *Panels E10 to E12:* Maximum tilt in these panels is projected to range from 0.012 to 0.046 (1.2 to 4.6 percent) where 10 feet of coal is extracted, and from 0.017 to 0.064 (1.7 to 6.4 percent) where 14 feet of coal is mined.

Similarly, tilt above the longwall panels (panels B12 to B13-A) are projected to range between 2.2 and 2.3 $S_m/d$ for coal extraction thickness 12 feet. These values are based on subsidence measurements at West Elk Mine (Table 1, Figure 5). The overburden depth above the longwall panel centers ranges from 600 to 1,525 feet (Table 3).

- *Panels B12 to B13-A:* Maximum tilt in these panels is predicted to range from 0.012 to 0.029 (1.2 and 2.9 percent), where 12 feet of coal is mined.

The E-seam panels E10 to E12 and B-seam panels B12 to B13-A occur on top of one another, but are not stacked based on the current panel layout. The maximum tilt ($M_m$) of the two seams is projected to be 20 percent more than the maximum tilt associated with single-seam mining.

- Maximum tilt ($M_m$) for the B-seam and E-seam mining is projected to range from 0.014 to 0.055 (1.4 and 5.5 percent) where 10 feet of E-seam coal is mined, and from 0.020 to 0.077 (2.0 to 7.7 percent) where 14 feet of E-seam coal is produced. This estimate is only for the areas over panels E10 to E12 and B12to 13A.

Sunset Trail Mining Area: Maximum tilt above the four longwall panels (panels SS1 to SS4) is projected to range from 0.0094 to 0.0473 (0.9 to 4.7 percent) where approximately 9 feet of coal is extracted, and 0.0147 to 0.0736 (1.5 to 7.4 percent) where extraction thickness is approximately 14 feet.

#### 5.3.1.3 Maximum Horizontal Strain

Maximum positive horizontal strain ($E_m$) measured at the West Elk Mine monitoring network ranges between 1.1 and 1.4 times ($S_m$/d) (or 0.0058 and 0.0102—that is 0.58 and 1.0 percent); maximum negative strain between -0.20 and -4.0 times ($S_m$/d) (or 0.0009 and 0.0307—0.09 to 3.0 percent) (Table 1). The range of horizontal tensile strain in four different mine areas of the Western United States studied by Dunrud is 0.45 to 3 ($S_m$/d). The curves projected for tensile and compressive strain in the Southern Panels mining area, based on the West Elk Mine monitoring network and the National Coal Board of the United Kingdom, are shown in Figure 5.

Maximum tensile and compressive strain is significantly greater above large barrier pillars and rigid chain pillars and mine boundaries than it is above longwall mining faces. This is because tensile strains caused by mining the two adjacent panels are additive above the common rigid chain pillars or unyielding mine panel boundary pillars. Cracks tend to be wider and deeper above barrier pillars or the interface of mined and unmined coal at the limits of mining (e.g., mineable coal or lease boundary) than chain pillars because of their greater rigidity (for example, the large tension crack on the north side of Lone Pine Gulch).

The tensile strains obtained from the curves in Figure 5 are believed to be conservative for the Southern Panels mining area. Maximum horizontal tensile strains, measured Dunrud in bedrock during annual observations in the Apache Rocks West area (in hard brittle sandstone, where the only strain is revealed by cracks), were 0.0031 to 0.0062 (0.31 to 0.62 percent). These values are about 35 to 45 percent less than those shown in Table 1. The tensile strain is considered to be close to a maximum value for those observed by Dunrud in the Apache Rocks West mining area because 1) the features are located above the area if influence of a large solid coal pillar, and 2) no greater strain was observed in the Apache Rocks West mining area.

<u>*Southern Panels Mining Area*</u>:

Maximum tensile and compressive horizontal strains are calculated, using the values obtained from the area of the West Elk Mine, and as projected in Figure 5 (Table 2). These values are believed to be conservative, based on Dunrud's annual observations in the Apache Rocks West mining area.

- *Panels E1 to E8 and E14 to E17*: For these panels, projected horizontal tensile strain ranges from 0.005 to 0.028 (0.5 to 2.8 percent) where the planned coal extraction thickness is 9 feet, and from 0.007 to 0.044 (0.7 to 4.4 percent) where the extraction thickness equals 14 feet.

  Horizontal compressive strain ranges from -0.005 to -0.030 (-0.5 to -3.0 percent) where the extraction thickness equals 9 feet, and -0.007 to -0.047 (-0.7 to -4.7 percent) where it equals 14 feet (Table 2).

- *Panels B26 to B29*: For these panels, projected horizontal tensile strain ranges from 0.004 to 0.017 (0.4 to 1.7 percent) where the planned coal extraction thickness is 9 feet, and from 0.007 to 0.026 (0.7 to 2.6 percent) where the extraction thickness equals 14 feet.

Horizontal compressive strain ranges from -0.004 to -0.018 (-0.4 to -1.8 percent) where the extraction thickness equals 9 feet, and -0.007 to -0.028 (-0.7 to -2.8 percent) where it equals 14 feet (Table 2).

The E-seam panels E1 to E5 and B-seam panels B26 to B29 occur on top of one another, but are not stacked based on the current panel layout. However, to be conservative, the strain of the two seams is assumed to be additive.

- For E-seam and B-seam panels, projected horizontal tensile strain ranges from 0.009 to 0.044 (0.9 to 4.4 percent) where the planned coal extraction thickness is 9 feet, and from 0.014 to 0.069 (1.4 to 6.9 percent) where the extraction thickness equals 14 feet.

  Horizontal compressive strain ranges from -0.009 to -0.047 (-0.9 to -4.7 percent) where the extraction thickness equals 9 feet, and -0.014 to -0.073 (-1.4 to -7.3 percent) where it equals 14 feet (Table 2).

<u>*Apache Rocks West Mining Area*</u>:

Maximum tensile and compressive horizontal strains are calculated, using the values obtained from the area of the West Elk Mine, and as projected in Figure 5 (Table 3). These values are believed to be conservative, based on Dunrud's annual observations in the Apache Rocks West mining area.

- *Panels E10 to E12*: For these panels, projected horizontal tensile strain ranges from 0.007 to 0.028 (0.7 to 2.8 percent) where the planned coal extraction thickness is 10 feet, and from 0.009 to 0.039 (0.9 to 3.9 percent) where the extraction thickness equals 14 feet.

  Horizontal compressive strain ranges from -0.007 to -0.030 (-0.7 to -3.0 percent) where the extraction thickness equals 10 feet, and -0.009 to -0.042 (-0.9 to -4.2 percent) where it equals 14 feet (Table 3).

- *Panels B12 to B13-A*: For these panels, projected horizontal tensile strain ranges from 0.007 to 0.018 (0.7 to 1.8 percent) where the planned coal extraction thickness is 12 feet.

  Horizontal compressive strain ranges from -0.007 to -0.019 (-0.7 to -1.9 percent) where the extraction thickness equals 12 feet.

The E-seam panels E10 to E12 and B-seam panels B12 to 13A occur on top of one another, but are not stacked based on the current panel layout. However, to be conservative, the strain of the two seams is assumed to be additive.

- For E-seam and B-seam panels, projected horizontal tensile strain ranges from 0.013 to 0.046 (1.3 to 4.6 percent) where the planned coal extraction thickness is 10 feet, and from 0.016 to 0.057 (1.6 to 5.7 percent) where the extraction thickness equals 14 feet.

Horizontal compressive strain ranges from -0.013 to -0.049 (-1.3 to -4.9 percent) where the extraction thickness equals 10 feet, and -0.016 to -0.061 (-1.6 to -6.1 percent) where it equals 14 feet (Table 3).

Sunset Trail Mining Area: Maximum tensile and compressive horizontal strains are calculated in the conceptual model, using the values obtained from the West Elk Mine area, and as projected in Table 4. These values are believed to be conservative, based on Dunrud's annual observations in the Apache Rocks mining area.

- Panels SS1 to SS4: For the four panels that extend into the Sunset Trail mining area, the projected horizontal tensile strain ranges from 0.005 to 0.029 (0.5 to 2.9 percent) where the planned coal extraction thickness is 9 feet, and 0.008 to 0.045 (0.8 to 4.5 percent) where the extraction thickness is 14 feet.

  Horizontal compressive strain ranges from -0.005 to -0.031 (-0.5 to -3.1 percent) where the extraction thickness equals 9 feet (Table 4), and -0.008 to -0.048 (-0.8 to -4.8 percent) where the extraction thickness is 14 feet.

### 5.3.2 Maximum Projected Depths of Surface Cracks

Curvature, or differential tilt (curvature is the second derivative of vertical displacement with respect to horizontal distance) of subsided rock layers causes horizontal strain. Comparison of calculated curvature values and horizontal tensile strain derived from horizontal displacement measurements, therefore, provides a means of calculating the depth of the neutral surface, and hence the maximum depth of tension cracks from the surface. The neutral surface is the boundary between tensile and compressive strain

In terrains with slopes less than about 30 percent, the depth of the neutral surface can be estimated by dividing the maximum horizontal strain values by those of maximum curvature at a given location. The calculated depth of the tension zone to the neutral surface—the boundary between tension above and compression below—ranges from 50 to 100 feet in the subsidence monitoring network at West Elk Mine. Crack depth may be much less than this projected 50 to 100-foot range of maximum values because most of the monitoring network was located on slopes exceeding 30 percent. An unpublished study for the U. S. Bureau of Mines (Engineers International) indicated that surface crack depth rarely is greater than 50 feet. Cracks will also be less extensive or terminate where shale and claystone layers occur. Based on annual field subsidence observations, maximum crack depth in bedrock in the Southern Panels, Apache Rocks West, and Sunset Trail mining areas is estimated to be 1) 5 to 15 feet in terrain sloping less than, or equal to, 30 percent, 2) 10 to 35 feet in terrain sloping more than 30 percent, and 3) 40 to 50 feet in thick, brittle sandstones in ridges (Tables 2 and 3).

Crack depth will likely be at a maximum value above massive coal barriers. The crack depth is projected to be less (probably 10 to 20 percent less) above the panel chain pillars, where even the rigid pillars are predicted to yield 10 to 30 percent of the coal extraction thickness (Tables 2 and 3).

Cracks that occur above the mined longwall panel area also tend to close, once longwall mining faces move out of the surface area of influence (DeGraff and Romesburg 1981). Any local bed separations during active subsidence between rocks of different strengths (Figure 2) will likely close once equilibrium conditions occur. However, any cracks present above rigid chain pillars, barrier pillars, or the outer limit of mined/unmined coal may remain open where permanent tensile stresses remain after mining is completed due to the convex curvature of the subsidence profile.

During the past 25 years of annual, or semi-annual, observations in the area of the West Elk Mine area by WWE, no cracks were observed above mined-out longwall panels in colluvium more than an estimated ten feet thick. No cracks have been observed in alluvium above mined-out longwall panels. No cracks were observed in the alluvium and colluvium of Sylvester Gulch and Deep Creek (estimated thickness range is 25 to 150 feet) during periodic field observations in the Apache Rocks and Box Canyon mining areas. The near-surface alluvial material consisted of primarily sand, silt, clay, and soil in the two areas mentioned, and was located above rigid pillars and panel boundaries where the overburden depth ranges from 800 to 1,050 feet. Longwall mining has already occurred in the E-seam under Dry Fork, where overburden thickness reaches a minimum of less than 400 feet. No cracks were observed in the alluvium of Dry Fork following longwall mining; therefore, no significant cracking in alluvial and colluvial deposits is anticipated with proposed mining in the Southern Panels mining area. The Sunset Trail mining area will include South Prong, where conditions are expected to mirror mining under Dry Fork, where alluvial and colluvial deposits are present. Reaches of South Prong underlain by bedrock will be more prone to surface cracking, with projected depths of 5 to 15 feet.

The probable reason for the lack of cracking in alluvial and colluvial deposits is that the fine sand- to clay-sized material and overlying soil can yield without cracking or bulging as it deforms as a discrete unit or units during the subsidence process. The alluvium in the Southern Panels and Sunset Trail mining areas is estimated to vary in thickness from about 25 feet to 75 feet. This same reasoning also applies to the colluvium in the area. Although subsidence cracks were locally observed in colluvium less than a foot to a few feet thick, no cracks were observed in colluvium more than about 10 feet thick.

### 5.4 Angle of Draw

The draw, or limit, angle ($\phi$, from a vertical reference) in the Somerset area ranges from about 8 to 21 degrees. The angle of draw measured for F-seam room-and-pillar mining at West Elk Mine, which has overburden rock lithology similar to the-E-seam, ranged from 11.3 to 16.1 degrees and averaged 14.4 degrees. The angle of draw for B-seam longwall mining at West Elk ranges from about 15 to 17 degrees after accounting for F-seam mining influence (Table 1). MCC collected survey data from the subsidence monuments following mining of E-seam longwall panel E1. WWE's analysis of that data indicates that the mean angle of draw is approximately 16°, with a range of 14° to 19° predicted for the Southern Panels (Table 2) and Apache Rocks West (Table 3) mining areas. For the Sunset Trail mining area, the angle of draw is projected to range from 14º to 19º (Table 4).

### 5.5 Break Angle

The break angle, the angle (B, from a vertical reference) of a straight line projected from the zone of maximum horizontal tensile strain at the ground surface to the boundary of the mine workings, is more important than the draw angle for hydrologic analyses (Figure 3). The break angle provides a means of determining zones, in relation to underground mine workings, where near-surface water most likely may be impacted. The break angle generally averages 10 degrees less than the corresponding draw angle, according to Peng and Geng (1982).

The break angle ranges from -9 to 3 degrees in the West Elk Mine subsidence monitoring network area (Table 1). Topography appears to control the location of the zone of maximum tensile strain and consequently the break angle. For example, the break angle is 3 degrees where tilt direction (caused by subsidence) is opposite to the direction to the slope of the ground surface (42 percent slope), but is -9 degrees where the tilt direction is in the same direction as the slope of the ground surface (32 percent slope) (Table 1).

Tensile strain caused by subsidence commonly reaches a maximum value in linear zones above mining panels. The location of these zones can be determined by the break angle (the angle of the break line from panel boundaries to the zone of high tensile strain. At panel boundaries with solid coal, subsidence data from the West Elk Mine monitoring network shows that the break angle for subcritical mining panels ranges from -9 to 3 degrees with an average expected value of about 0 degrees.

Information from the West Elk Mine subsidence monitoring network also indicates that the zone of increased horizontal tensile strain ranges from 100 to 150 feet wide above mine boundaries and from 100 to 250 feet wide above the chain pillars. This zone, which is also predicted for the Southern Panels, Apache Rocks West, and Sunset Trail mining areas, is located approximately above the edges of the panels or slightly outside the panel boundaries and above the center of the chain pillars, unless a down-slope component of movement occurs on steep slopes in addition to the differential tilt component. Cracks tend to be more common and more permanent in zones above mine boundaries, barrier pillars, and unyielding chain pillars. Any surface or near-surface water that might be present in this zone has a higher probability of being impacted than that occurring in any other areas above the mining panels.

### 5.6 Angle of Major Influence

The angle of major influence, β, (also called angle of influence of the point of evaluation) is defined by Peng (1992, p. 11) ". . . as the angle between the horizontal and the line connecting the inflection point and the edge of the radius of major influence." The radius of major influence (r) is therefore the horizontal distance from the vertical projection of the inflection point to the point of maximum subsidence and the limit of subsidence (Figure 3). The angle of major influence is used for computer modeling by the influence function method. In the B-seam mining at West Elk Mine, the angle of major influence ranges (from a horizontal reference) from about 70 to 80 degrees.

The angle of major influence may also be referenced to the vertical, as has been done for the break angle and angle of draw. The angle of major influence (from a vertical reference) is roughly equal to the angle of draw (Figure 3), and is therefore also predicted to range from 10 to 20 degrees for both B-seam and E-seam panels.

## 5.7 Relation between Dynamic and Final Subsidence Deformations

Maximum dynamic tilt (change of slope) and horizontal tensile and compressive strain are reportedly less above longwall mining panels than are the final tilt and strain values at panel boundaries. Dynamic tilt and strain decrease, relative to final tilt and strain, as the rate of face advance increases.

Dynamic tilt and strain reportedly decrease with increasing speed of longwall coal extraction (Peng 1992, p. 20-21). Based on observations in a West Virginia coal mine:

1. Maximum dynamic tilt decreased by an average of 42 percent (from 0.0024 to 0.0014) as the mining face rate of movement increased from 10 to 40 feet per day; dynamic tilt therefore decreased by 14 percent as the face rate of movement increased by 30 feet per day.

2. Maximum dynamic tensile strain decreased by an average of 22.5 percent (from 0.0031 to 0.0024) as the mining face velocity increased from 10 to 40 feet per day; dynamic horizontal tensile strain decreased by 7.5 percent as the face increased by 30 feet per day.

3. Maximum dynamic compressive strain decreased by an average of 48 percent (0.0062 to 0.0032) as the face velocity increased from 10 to 40 feet per day; dynamic horizontal compressive strain decreased by 16 percent as the face increased by 30 feet per day.

## 5.8 Critical Extraction Width of Mining Panels

Critical extraction width ($W_{cr}$) is the width of mining panels necessary for maximum subsidence to occur at a given overburden depth (d). Values for $W_{cr}/d$ typically range from about 1.0 to 1.4, with an average of about 1.2. Based on the subsidence development data for the 5th NW longwall panel, the critical extraction width may be closer to the average value of 1.2 than 1.4 in the Southern Panels, Apache Rocks West, and Sunset Trail mining areas (Figure 4).

## 5.9 Results of Computer Modeling

A computer software package was used to model the results of subsidence measurements at West Elk Mine and to project subsidence in the Southern Panels, Apache Rocks West, and Sunset Trail mining areas. The package used is entitled: “Surface Deformation Prediction System (SDPS)”, Version 6.2G developed by Department of Mining Engineering, University of Kentucky; Department of Mining and Minerals Engineering, Virginia Polytechnic Institute and State University. This program performed an influence function analysis and best fit of West Elk Mine subsidence data. The fit between the data points and the influence function output from the model is shown in Figure 6. Considering that there was some F-seam influence on the B-seam subsidence data, the actual subsidence measurements and subsidence profiles predicted by the influence function model compare favorably.

WWE further calibrated the computer model using subsidence monitoring data collected over E-seam panels E1 to E3. While the model over predicted the subsidence over panel E1, the previous calibration accurately predicted the subsidence along the Dry Fork survey points. Therefore, WWE elected to use the more conservative parameters, recognizing the model results may over-predict subsidence.

Once the computer program was calibrated to the West Elk Mine subsidence data, subsidence was then projected into Southern Panels, Apache Rocks West, and Sunset Trail mining areas using representative coal extraction thicknesses and overburden depths for the respective panels in order to obtain an independent check on the subsidence projections based on the conceptual model.

Comparison of the Dunrud's conceptual model calculations and the influence function of the SDPS computer model (which were done by WWE in Figures 7, 7A, 8, and 9) show the following:

1. Maximum vertical displacement (subsidence) above the chain pillars in the transverse profile (Figures 7 and 7A) is close to the maximum values predicted in the conceptual model calculations. Maximum vertical displacement above the longwall panel centers, however, is about equal to the median values projected in the conceptual model calculations.

2. The ranges calculated for vertical displacement in the conceptual model are conservative. The ranges account for rapidly changing overburden thicknesses in the local rugged terrain of the Southern Panels, Apache Rocks West, and Sunset Trail mining areas and for changing lithology—such as lenticular sandstones, coal seams, and shales—in the overburden rocks.

# 6.0 RATE AND DURATION OF SUBSIDENCE

A point on the surface begins to be affected when the longwall mining face is within 0.1d to 0.6d (d = overburden depth) of the point and is near maximum downward velocity. Subsidence is 50 percent complete when the face is 0.2d to 0.5d beyond the point and is more than 90 percent complete when the face is 1.0d to 1.4d (average about 1.2d) beyond the point if longwall mining is done. Data obtained above the 5th NW longwall panel at the West Elk Mine plot between the National Coal Board (NCB) and Somerset curves (Figure 12). The data also show that subsidence is more than 95 percent complete when the longwall face has moved 1.0d beyond the points of measurement. Critical extraction width, therefore, is approximately 1.0d for the B-seam panels at West Elk Mine and is projected to range from 1.0d to 1.2d for the Southern Panels, Apache Rocks West, and Sunset Trail mining areas.

Subsidence monitoring data collected over E-seam longwall panel E1 provides additional information on the rate and duration of subsidence at West Elk Mine. Survey measurements taken 11 days after the longwall passed beneath the point showed that total subsidence was 93 percent complete. The location of the longwall face was 1.5d beyond the survey point at the time of measurement.

Rate and duration of subsidence above longwall mining panels, therefore, are a function of mining rate. The faster and more uniformly the longwall face moves, the less time any surface cracks present will be open to potentially impact surface or ground water. Therefore, rapid, uniform mining beneath streams and other sensitive features causes minimum mining impact.

The duration of subsidence above room-and-pillar mines is less predictable, however, because not all pillars are removed. In Figure 12, subsidence at a given point (p) was only about 60 percent complete after room-and-pillar mining was completed within the area of influence of the point.

# 7.0 EFFECTS OF TOPOGRAPHY AND STRUCTURE ON SUBSIDENCE PROCESSES

In contrast to subsidence of rock units as fixed-end, laterally constrained, multiple plates, subsidence in steep topography may occur as non-fixed end, laterally unconstrained multiple plates (rock units). This lack of lateral confinement may cause reversals of horizontal displacement and excessive tensile strain may occur on steep slopes. Peng and Hsuing (1986) found that horizontal displacement is affected by slopes greater than 20 percent. Displacements on steep slopes and cliffs can cause cracks to open more along faults, fractures, and joints than would occur in subdued topography where the rock units are laterally constrained. Therefore, steep slopes and cliffs, which commonly are susceptible to rockfalls and landslides anyway, may become less stable when undermined.

The topography is less rugged in the Southern Panels and Sunset Trail mining areas than in the Box Canyon mining area, while the Apache Rocks West mining area is comparable. However, there are steep slopes and local cliffs and ledges. Therefore, these steeper slopes and cliffs may become less stable when they are undermined.

## *7.1 Effects of Topography on Subsidence Cracks*

Cracks commonly are wider, deeper, and may remain open longer above rigid chain pillars or mine boundaries on steep slopes where there is little or no lateral constraint. In addition, the direction of mining relative to slope direction may control crack width, depth, and abundance. For example, tension cracks were observed to be wider, deeper, and more abundant on steep canyon slopes that faced in the direction of mining than they were on slopes facing in directions opposite the mining direction (Dunrud and Osterwald 1980, p. 26-29; Gentry and Abel 1978, p. 203-204).

Cracks are projected to be the widest and deepest on the steep slopes, cliffs, and ridges adjacent to and on either side of Minnesota Creek and its tributaries, as well as Lick Creek, South Prong, and Deep Creek. Maximum crack depth on these steep slopes and cliffs is estimated to locally be from 15 to as much as 35 feet deep. Due to the lack of lateral constraint, these cracks may remain open until they are filled by processes such as sheet wash and sedimentation.

## *7.2 Effects of Rugged Topography on Subsidence and Mine Stresses*

The subsidence factor (a) reportedly can vary significantly in draws and on ridges in rugged topography. Gentry and Abel (1978, p. 203-204) report that vertical displacement was 25 to 30 percent greater on a ridge than it was in an adjacent draw in the York Canyon (Raton, New Mexico) longwall mining area (Figure 4). Based on this information, the subsidence factor is projected to be closer to 0.6 in deep draws and closer to 0.8 on isolated points and ridges in the Southern Panels, Apache Rocks West, and Sunset Trail mining areas. No significant similar influence is expected in these mining areas because there are few, if any, isolated ridges.

Based on observations by Dunrud in the Somerset Mine in the mid-1970s, stresses tended to be significantly higher beneath isolated ridges than they were beneath more uniform overburden of similar thickness. For a similar mine geometry, roof falls, bumps (rock bursts), and floor heaving were noticeably greater beneath the ridges than they were beneath more uniform overburden of similar thickness, because there is little or no lateral constraint to distribute the weight of the isolated load of the ridge.

# 8.0 FRACTURE-CONTROLLED DRAINAGES

Based on mapping in the Southern Panels mining area, Dunrud believes that there is reasonably good, but certainly not conclusive, evidence that some drainages are controlled by fractures and/or joints. The Dry Fork of Minnesota Creek and some of its tributaries exhibit linear trends on satellite images and on high-altitude photographs that indicate, or at least suggest, fracture control (Dunrud 1976, p. 14-15). These fractures may have been caused in part by stresses generated by the West Elk Mountain intrusive bodies—particularly Mt. Gunnison.

The conservative approach may be to assume that the drainage system is fracture controlled. However, even if fractures control the present drainage system, they may not extend downward as continuous joints of fractures to the E-seam located several hundreds of feet below. Even if the fractures were present in the more brittle sandstone units, it would be very unlikely that these fractures would occur in the softer siltstone and shale units. Even under the conservative approach that the drainages in the Southern Panels, Apache Rocks West, and Sunset Trail mining areas are fracture controlled, it is extremely unlikely that they extend downward to the E-seam through multiple shale, claystone, and siltstone units. Using this conservative evaluation, it is now important to evaluate the potential impact that subsidence may have on any pre-mining fractures.

Evaluation of subsidence due to downwarping of laterally constrained strata shows, as stated previously, that rock strata with different deformation and strength characteristics deform as discrete units. For example, strata of shale and siltstone behave as units discrete from sandstone. Above the fractured zone (Section 4.2) and within the continuous deformation zone (Section 4.3) these units undergo continuous flexure (Figure 2, enlargement 2). Above the neutral surfaces, in zones of convex-upward curvature, the material is in tension and below them, and the material is in compression.

Consequently, stresses change across neutral surfaces from tension to compression across each successive rock unit that deforms as a plate. Fractures already present would thus tend to open more in the zones of tension, but would close more in the zones of compression, which would close these fractures more than they were prior to mining and subsidence.

After longwall mining is completed in the area and static conditions are attained, the zones of tension and compression commonly cease, and any fractures present will likely resume the pre-mining condition. Therefore, the impacts on surface flow in the drainages of the Southern Panels, Apache Rocks West, and Sunset Trail mining areas are likely to be minimal or non-existent under even the most conservative assumptions.

# 9.0 WATER AND METHANE

Observations of the north and west flanks of Mt. Gunnison during aerial geologic mapping and an October 1996 field trip revealed numerous talus and rock glacier deposits that occur in the valleys and lower part of this intrusive body. Snowmelt and rain can easily infiltrate these deposits, which may eventually enter any permeable rocks, faults, fractures, and joints near the mountain. Coal beds and rocks in the deformed zone around Mt. Gunnison may also contain increased concentrations of methane where the coal is deformed and perhaps metamorphosed to a higher rank by the intrusive body. Greater quantities of water and methane may therefore be expected as coal is mined closer to Mt. Gunnison.

## *9.1 Potential Impact of Water on Subsidence in Wet Mining Areas*

As discussed in Section 3.0, the moisture content of the caved and downwarped rocks controls the amount of subsidence that can be expected. In the Southern Panels, Apache Rocks West, and Sunset Trail mining areas where water might be encountered in an area equal to, or greater than, the width of the proposed longwall panels, maximum vertical displacement may be expected to approach 0.8t.

# 10.0 POTENTIAL IMPACTS OF SUBSIDENCE AND MINE-INDUCED SEISMIC ACTIVITY ON LANDSLIDES AND ROCKFALLS

## *10.1 Landslides*

The landslides listed below are all naturally occurring features, which become less stable, or become unstable and slide, during periods of increased precipitation. A review of aerial photographs of the Apache Rocks and South of Divide mining areas, which were taken in 1963 and 2004, show that the slides listed below appeared to be more stable in 1963 than they are now. Mr. C. Richard Dunrud (retired U.S. Geological Survey coal mine subsidence expert and author of USGS Map C-115) observed that many of the existing landslides during periods of high precipitation were less stable, or became unstable and moved in the mid-1980s and mid-1990s. Landslides were identified in the Dry Fork mining area as part of the Final Environmental Impact Statement (2005). Map 1 is a composite showing the landslides in the Southern Panels mining area.

The landslides in the southeast side of West Flatiron and on the west side of Deep Creek in the Apache Rocks mining area showed no visual effects when longwall mining occurred beneath the areas. It therefore seems apparent that wet seasons affect landslides more than does longwall mining. During very wet periods, however, landslides that are already unstable may locally be triggered by mine subsidence.

A total of twelve landslides, landslide areas, or landslide and rockfall areas, have been mapped in the Apache Rocks West and Southern Panels mining areas during field mapping with the U.S. Geological Survey (USGS) in the 1980s and also during the annual subsidence observations in these areas.

1. Apache Rocks West mining area:

    a. Landslide located just north of Minnesota Reservoir in SW¼ of Section 29. Mining of the B-seam longwall panels B12, B13, and B13-A did not have any observable effect on the landslide.

    b. Landslide area located above mined longwall panels E14 and E15 in NW¼ of Section 26. These landslides appeared to be unaffected by longwall mining beneath them.

    c. Landslide area located on the west side of Deep Creek, located above the southeastern part of mined B-seam longwall panel 17 in the NW¼ of Section 35. This landslide also appeared to be unaffected by mining below when observed in July 2003.

2. Southern Panels mining area (Map 1):

    a. An extensive landslide is located south of Minnesota Reservoir north of the projected E-seam longwall Panels E16 and E17, in the N½ of Section 32, Township 13 South, Range 90 West (Dunrud 1989). Minimum overburden depth to the E-seam ranges from 360 to 600 feet. The average slope of the slide is roughly 20 percent. The landslide contains more cracks and scarps in the upper part and more depressions and bulges in the lower part than were present in the early 1960s (based on image data from July 1963 aerial photographs).

- Based on a stereographic review of July 2004 vertical aerial photographs, renewed activity occurred locally in western part of the landslide areas north and south of Dry Fork during wet periods in the 1980s (1984 to 1987) and the mid-1990s (1994-1996). The Dry Fork road was taken out one half-mile west of the Minnesota Reservoir dam by this renewed movement in 1987 (Map 1).

b. Landslides were identified on the Dry Fork mining area in the Final Environmental Impact Statement prepared for the U.S. Department of Agriculture – Forest Service in August 2005. The report identified three active landslide areas in the southeast corner of the area. These are located outside the area of influence from mining in longwall panels E4 and E5. The erosional escarpment at the headwaters of Deep Creek is also outside of the area of influence mining. Two small landslides (slope failures) were identified by a Tetra Tech geologist during a site inspection on September 20, 2007. These are located just above the Deep Creek Ditch.

3. Sunset Trail mining area:

   a. As shown on Map 1, there are several identified landslides within the Lick Creek drainage and others near the mouth of South Prong. Most of the mapped features will be outside the influence of mining, while the remaining few will be monitored throughout mining.

### *10.1.1 Effects of Subsidence and Mine-induced Seismic Activity on Landslides*

Some of the most important information regarding mine subsidence and mine-induced seismicity was obtained from observations of active landslides on Jumbo Mountain above B-seam longwall panels 8 and 9, which were mined during the mid-1990s. Landslide movement occurred during unusually wet periods before mining, during mining, and after mining and subsidence was complete. The landslides located north and south of Minnesota Reservoir are similar to those on Jumbo Mountain. Both occur in surficial material (rocks, gravel, sand, silt, clay, and soil) and local outcrops of bedrock that have slumped and flowed downhill during periods of increased saturation. Cracks, bulges, and depressions or troughs, and springs were locally observed in both landslide areas.

It is important to note that no earth tremors (seismic activity) were felt by Mr. Dunrud and other field observers in all the annual traverses and observations made above the longwall mining areas in the Jumbo Mountain, Apache Rocks, Box Canyon, Southern Panels, and Sunset Trail mining areas during the past 25 years (1996-2020 inclusive). For example, no tremors were felt during the annual traverse above B-seam longwall panel 13 in 1999, when the mining face was located directly beneath one of the subsidence observation points. This point was located approximately 1,200 feet vertically above the active mining face, and 2,800 feet north of Minnesota Reservoir.

In contrast to room-and-pillar mining, longwall mining is a uniform extraction procedure that basically involves 1) the uniform cutting of a coal face, 2) the caving of the roof behind the moving coal face, and 3) the recompression of the caved material behind the support system. This system therefore causes only a minimum amount of very low magnitude seismic activity (below the threshold of feeling at the ground surface), particularly where the overburden depth to the coal being mined is less than about 1,500 feet.

Based on field observations during the past 25 years, the major finding is that landslide movement occurs in response to moisture and ground saturation and is not noticeably affected by subsidence or any mine-related seismic activity caused by longwall mining beneath or near the landslides.

With regard to the landslide north of Minnesota Reservoir, longwall mining in the B-seam panel B13-A did not have any observable effect on the landslide. The proposed E-seam mining in panel E12 will occur further south and with shallower overburden. As shown in Map 1, the head of the landslide will be located over the southern edge of panel E12, where subsidence is projected to be between 4 and 4.5 feet. As a result, the upper portion will be subject to subsidence with the outcome being a flattening of the slope in the upper reaches of the slide. This flattening of the upper reaches of the slide will reduce the movement potential and likely focus any movement that might occur to just the upper reaches. In addition, the overall slope of the mapped slide is less than in adjacent areas, further suggesting greater stability and a reduced potential for reactivation.

Based on the above-mentioned historical evidence from the annual observations, the landslide areas located north and south of Minnesota Reservoir are not expected to be impacted by mine-induced subsidence and seismic activity when longwall Panels E16 and E17 is mined. Similar to the landslide north of Minnesota Reservoir, any subsidence effect on the topography should be a flattening of the slope, which would reduce movement potential.

Lastly, Mr. Dunrud has reviewed the conditions associated with the proposed mining activities and the mapped landslide. It is his opinion that while subsidence might cause minor reactivation of the landslide near the upper end, it is unlikely that there will be any movement that would reach or effect Minnesota Reservoir.

### *10.2 Rockfalls*

Rockfalls are the free-falling movement of rocks, which have become detached from cliffs or other steep slopes, and move under the influence of gravity and the underlying ground surface. The detached rocks roll and/or bounce downhill, depending on the slope (configuration of the ground surface). Their movement continues until they are stopped by an obstruction or lose potential energy and stop naturally.

A low to high potential exists for rockfalls in the Southern Panels and Sunset Trail mining areas. Analysis of the terrain in these mining areas reveal slopes that range from 30 to 80 percent along Minnesota Creek, the Dry Fork of Minnesota Creek and its tributaries, and in local areas along the main fork of Lick Creek. Vertical displacement, tilt, and strain produced by mining may locally trigger already unstable rocks to fall during, or shortly after mining.

The areas with steep slopes in the Southern Panels and Sunset Trail mining areas, which have the greater potential for rockfalls, are located either in areas with local access roads, which have only limited travel, or in areas remote from any access roads or other man-made features. Based on a review of aerial photographs and analysis of the USGS 7.5-minute quadrangles, there are areas with slopes ranging from 30 to 80 percent that contain local cliffs and ledges (small cliffs 5 to 10 feet high). The general areas listed below (listed in an east-to-west, north-to-south direction) have a low to high rockfall potential (Map 1):

1. Steep slopes (with an estimated rockfall potential ranging from moderate to high) located north of Dry Fork and west of Minnesota Reservoir. However, no mining is planned in this area, so this rockfall area would not be impacted.

2. Two steep ridges with cliffs and ledges, located above the northern part of longwall Panels E16 and E17 east of the landslide area described in Section 10.1 (mostly in the SE¼ of Section 32, Township 13 South, Range 90 West). There are no roads or man-made structures in the area.

3. The south end of a steep ridge containing cliffs and ledges located north of Minnesota Reservoir and Dry Fork and north of the confluence of Deer Creek and Dry Fork above the western edge (within the area of mining influence) of longwall panels E1 and E2 (S1/2, Section 29 and the NW¼ of Section 33, Township 13 South, Range 90 West). The Dry Fork road is located 400 to 500 feet south of the nearest area boundary. Following mining in these longwall panels, no additional rockfall was observed during semi-annual field studies.

4. A steep to moderately steep slope containing eight separate rockfall areas, located north and south of Dry Fork and its tributaries. The estimated rockfall potential is low to moderate. The rockfall areas are located above longwall panels E1 to E4 (Sections 33 and 34 and the NE½ of Section 35, Township 13 South, Range 90 West). Following mining in these longwall panels, no additional rockfall was observed during semi-annual field studies.

5. The area is located in the southwestern part of the South of Divide mining area east of the main fork of Minnesota Creek. While the majority of this area is located outside the influence of mining, the northeastern part of this area, which has an estimated moderate to high rockfall potential, is within the area of mining influence of the western part of longwall panels E14 and E15 (located mostly in the W½ and S½, Section 5, Township 14 South, Range 90 West).

6. This area contains six rockfall areas that have locally steep ridges. The area is located near the headwaters of Deer Creek, Poison Creek, Lick Creek, and a tributary of Dry Fork. The areas, which have an estimated low to moderate rockfall potential, are located above, or partly within, the area of mining influence of longwall panels E5 to E8, and SS1 (located in parts of Sections 3, 4, 9, and 10, Township 14 South, Range 90 West).

7. This area contains three rockfall areas that have an estimated low to high rockfall potential. It is located in the Lick Creek area and above, or partly within, the area of mining influence of longwall panels E14 and SS1 to SS4 (located in parts of Sections 8, 9, and 16, Township 14 South, Range 90 West).

8. This area is located on the east side of the main Deep Creek channel above longwall panel E3. This area is identified as having low to moderate rockfall potential. It is located in an area too remote for any access roads or manmade features. Following mining in these longwall panels, no additional rockfall was observed during semi-annual field studies.

9. This area is located on the eastern boundary of the Deep Creek watershed. This rockfall area would have been over the eastern ends of panels E3, E4, and E5 if mined to the maximum projected potential extent. However, based on where mining stopped in these panels, the rockfall areas were outside the influence of mining.

Of the areas listed above, most occur near local drill roads or agricultural access roads, which have only local, limited traffic on them. Any rocks that may fall in these areas could be readily removed before local traffic is impacted, should rockfalls occur on these remote roads. Evidence of naturally occurring rockfalls, such as remnant boulders located at the base of steep slopes, or in the run-out zones of these areas, and documentation of these areas prior to mining is recommended.

Based on semi-annual observations in the Apache Rocks, Box Canyon, Southern Panels, and Sunset Trail mining areas, subsidence and any seismic activity caused by longwall mining is not expected to significantly affect rockfall areas with an estimated high to low rockfall potential. Only rockfall areas with an estimated very high rockfall potential were noticeably affected. However, because there are no rockfall areas with an estimated very high rockfall potential in the Southern Panels and Sunset Trail mining areas, the planned longwall panels in these mining areas will most likely not affect rockfall areas.

### *10.3 Importance of Baseline Landslide and Rockfall Data*

The most significant landslide in the Southern Panels mining area, in terms of proximity to man-made structures, is located above the northern part of E-seam longwall Panels E16 and E17 (Map 1). Although there is a large landslide within the area of mining influence of the southeast corner of E-seam longwall panel E8 (mostly in the NE¼ of Section 8), the landslides located north and south of Minnesota Reservoir are the most important in the mining area. Existing, natural (baseline) conditions are monitored before mining begins in order to document their natural state. The cracks, bulges, and depressions observed in the landslide areas north and south of Minnesota Reservoir are much more extensive and dramatic than those caused by subsidence. The vertical aerial photographs obtained by the West Elk Mine (dated July 2, 2004) provide good baseline images of all the natural, pre-mine features in the Southern Panels mining area.

Observations made by WWE in the area of the West Elk Mine indicate that mining may accelerate the natural landslide process, where there are landslides that have already become unstable. However, annual observations of the surface cracks and depressions in the landslide area on Jumbo Mountain above mined B-seam longwall panels 8 and 9 determined that landslides are very likely only related to natural mass-gravity movements and not related to mining.

Baseline observations and photographs have been gathered in the areas with low to moderate rockfall potential that are listed in Section 10.2 prior to mining activities. Evidence of naturally occurring rockfalls, such as remnant boulders of the base of steep slopes, or in the run-out zones of these areas with a rockfall potential have been documented prior to mining.

# 11.0 EFFECTS OF SUBSIDENCE AND MINE-INDUCED SEISMIC ACTIVITY ON MAN-MADE STRUCTURES AND RENEWABLE RESOURCES

Man-made structures and renewable resources in the Southern Panels, Apache Rocks West, and Sunset Trail mining areas basically consist of 1) a reservoir (Minnesota Reservoir), 2) stock watering ponds, 3) streams (primarily Dry Fork and the upper part of Lick Creek) and Deep Creek Ditch, 4) roads, and 5) local cabins. Minnesota Reservoir, the ponds, and the Deep Creek Ditch diversion to Dry Fork serve the dual purpose of being both man-made structures and containment structures for the valuable water resources in the area. Based on annual subsidence observations in the Jumbo Mountain, Apache Rocks, Box Canyon, and South of Divide mining areas since 1996, the following information is considered appropriate for the Southern Panels, Apache Rocks West, and Sunset Trail mining areas.

## *11.1 Minnesota Reservoir*

Minnesota Reservoir, which provides storage water primarily for irrigation, is located between two landslides—one beginning at the north shore and the other beginning at the south shore. As explained in Section 10.1.1 (above), landslide movement on Jumbo Mountain occurred during unusually wet periods before mining began, during mining, and after mining and subsidence was complete. The conclusions were that landslide movement occurs in response to ground saturation and is not noticeably affected by subsidence and seismic activity produced by longwall mining beneath, or near, landslide areas.

Both the landslides on Jumbo Mountain and those north and south of Minnesota Reservoir occur in surficial material (loose rock, gravel, sand, silt, clay, and soil) and local bedrock outcrops. Dunrud therefore expects that the mining of longwall Panels E16 and E17 will not noticeably affect the large landslide south of Minnesota Reservoir.

Mining of the longwall mining panels in the Southern Panels, Apache Rocks West, and Sunset Trail mining areas, as currently planned (Map 1) will not affect Minnesota Reservoir. The reservoir is located outside the area of mining influence of both the B- and E-seam panels, using an extremely conservative 45-degree angle of draw. Monitoring data is presented in the annual Fall Subsidence Reports to verify and demonstrate the accuracy of the predictions.

## *11.2 Stock Watering Ponds and U.S. Forest Service Water Resources*

The stock watering ponds in the Southern Panels mining area are located in debris flows or colluvium derived from the debris flows (Dunrud 1989). Some of these ponds are also classified as U.S. Forest Service water resources. The debris flows consist of a heterogeneous mixture of clay derived from the Wasatch Formation and boulders and gravels derived primarily from the Mount Gunnison intrusive (granodiorites and quartz monzanites). Based on observations made during geologic mapping in the area, these debris flows are even less likely to be affected by longwall mining than the alluvium. The debris flows have a very low permeability and, because the clay matrix is armored by the interstitial gravel and boulders, are resistant to erosion (the Deep Creek Ditch locally flows in this material at steep gradients). Based on the above-mentioned observations, no effects are expected when ponds in the Southern Panels, Apache Rocks West, and

Sunset Trail mining areas are undermined. The clay-rich material that lines these ponds is expected to provide a seal against subsidence effects.

Numerous observations have been made of the stock watering ponds and U.S. Forest Service water resources over both B-seam and E-seam longwall mining. Based on years of field studies, none of these resources has been noticeably affected when longwall mining occurred beneath them. These observations are documented in the annual Subsidence and Geologic Field Observations reports.

## 11.3 Streams and Ditches

The primary streams in the Southern Panels mining area are Dry Fork of Minnesota Creek, Deep Creek, Poison Creek, and Lick Creek. A primary source of water to the Dry Fork and Minnesota Reservoir comes from the Deep Creek Ditch, wherein the trans-basin water is conveyed through the upper drainage of Deep Creek and transmitted to Dry Fork. The Deep Creek Ditch was constructed in debris flows or colluvium and alluvium derived from the debris flow, as described in Section 11.2, this debris flow material is not expected to be impacted by longwall mining. There is an area of the Deep Creek Ditch that has a hard rock bottom. This area is limited to the lower gradient areas above the first landslide in the Dry Fork mining area (Refer to Map 1). The Deep Creek Ditch is not anticipated to be affected by longwall mining based on the eastern extent of E-seam longwall panel E5 and the projected extent of longwall panel E6.

Longwall mining of the E-seam panels E1 to E5 has occurred under Dry Fork where the overburden depth above the longwall panels drops as low as about 375 feet. No adverse impacts were observed during or subsequent to the longwall panel mining. The proposed B-seam panels B26 to B29 will have 200 to 300 feet of additional overburden, and do not extend as far west as the E-seam panels where the overburden under the Dry Fork channel is at a minimum. In the Apache Rocks West mining area, Horse Gulch enters Minnesota Reservoir from the north and has already had longwall mining occur beneath it in B-seam longwall panels B12 to B13-A with no apparent cracking in the alluvial material. Although E-seam mining had less overburden (down to about 350 feet), the experience of mining beneath Dry Fork with similar overburden indicated that there will not be adverse impacts to the Horse Gulch channel even though the alluvial thickness is less than Dry Fork.

As discussed in Section 5.3.2, no cracks were observed in the alluvium and colluvium of Sylvester Gulch, Deep Creek, and Dry Fork during periodic field observations. The near-surface alluvial material consists of primarily sand, silt, clay, and soil that ranges in estimated thickness from 25 to 75 feet. The alluvium and colluvium in Dry Fork and Lick Creek, which also has an estimated thickness range of 25 to 75 feet, contains more clay than does the Deep Creek alluvium. Therefore, it is even less likely that cracks will occur in colluvium and alluvium in the stream valleys of the Southern Panels mining area despite the shallow overburden.

The Sunset Trail mining area includes South Prong and some of its tributaries. The channels all have steep gradients and are not anticipated to be adversely affected by longwall mining of Panels SS1 to SS4. Exhibit 55B addresses potential impacts to South Prong in more detail.

The probable reason for the lack of cracking in alluvium is that the fine sand-to clay-sized material and overlying soil yields without cracking or bulging as it deforms as a discrete unit, or as discrete units, in the subsidence process. This same reasoning also applies to the colluvium in the area. Although mined longwall panel subsidence cracks were locally observed in colluvium less than one foot to a few feet thick, no cracks were observed in colluvium more than about ten feet thick. No cracks were observed in alluvium above mined longwall panels in the Apache Rocks and Box Canyon mining areas.

### *11.3.1 Potential for Hydraulic Connection between Mine Workings and Surface*

Near the southwest corner of E-seam longwall panel E2, the Dry Fork channel encounters a short reach where the E-seam overburden above the longwall panel block is less than 400 feet, with a minimum of approximately 375 feet. A prudent concern is whether mining induced longwall panel subsidence could establish a hydraulic connection between the Dry Fork stream channel and the mine workings. To address this scenario, the maximum projected height of longwall panel fracturing and the maximum depth of surface cracks were considered. As discussed in Section 5.2, the effective height of longwall panel fracturing in the Southern Panels and Sunset Trail mining areas is estimated to range from 9t to 18t, or a maximum fracture height of 252 feet for a mining height of up to 14 feet. However, Peng (1992) states that the upper one-third of the longwall panel fractured zone has only minor fractures with little potential for water conductivity. Therefore, the height of the fractured zone capable of transmitting water would be two-thirds of the 18t, or 168 feet.

The maximum height of the mined longwall panel caved zone is projected to be 5t, or 70 feet, for the Southern Panels and Sunset Trail mining areas with a projected mining thickness of up to 14 feet. The maximum mined longwall panel fracture zone height is projected to be 18t, or 252 feet, of which the lower two-thirds, or 168 feet, are capable of transmitting water. Therefore, the combined height of the mined longwall panel caved and fracture zones capable of transmitting water is projected to be a maximum of 238 feet.

As discussed in Section 5.3.2, the maximum crack depth in the Southern Panels and Sunset Trail mining areas is estimated to be 15 feet in terrains with slopes less than 30 percent, with depths up to 35 feet occurring locally in steep topography. For the South Prong channel near the western edge of longwall panel SS4, the maximum projected crack depth is 15 feet. Consequently, the combined maximum height of the caved and fractured zones and the maximum crack depth is 253 feet.

Based on previous mine plans and overburden thickness projections, the previous modeling evaluation indicated that no longwall panel subsidence impacts were projected with a minimum overburden thickness of 375 feet, leaving an estimated 122-foot "buffer" of unfractured bedrock remaining intact. It was not the intent of the previous analysis to indicate or specify that the 122-foot buffer was necessary or that longwall mining could not occur in overburden less than 375 feet. WWE does believe that it is prudent to have a "buffer" to reduce the possibility of a hydraulic connection between the ground surface and the mined longwall panels. We recommend that a factor of safety of 20 percent be added to the combined fracture height and crack depth total to yield the minimum overburden necessary to avoid a hydraulic connection. For example, if mining at a thickness of up to 14 feet, then the minimum overburden cover should be 253 feet plus 20 percent, or about 304 feet.

This minimum overburden is directly a function of the mining height as shown above, and can be reduced if the longwall mining height is lowered. For example, if the mining height were to be reduced to 12 feet near the western end of longwall panel SS4, then the combined height of the caved and fracture zones capable of transmitting water is projected to be 204 feet (5t = 60'; 2/3(18t) = 144'). Adding in the maximum projected crack depth of 15 feet yields a combined height of 219 feet, or 263 feet with the 20 percent "buffer." Therefore, the mine can make operational decisions based on the actual overburden encountered in specific locations. We do not recommend that longwall mining occur where overburden thickness is not at least 250 feet, even with reduced mining height.

The current projection of minimum overburden over the Sunset Trail longwall panel is approximately 280 feet at the western end of longwall panel SS4. Should this projected overburden prove to be accurate, MCC can either shorten the longwall panel at a location where the overburden drops below approximately 300 feet or reduce the mining height in accordance with the actual overburden thickness.

Another factor that will help maintain a lack of hydraulic connection between the surface and the mined longwall panels is the presence of soft shales and claystones in the E-seam overburden that will increase the probability that the strata will warp rather than fracture during the subsidence process. The projected lack of hydraulic connection was confirmed as mining occurred in E-seam panel E2 without any adverse impacts to Dry Fork or any anomalous water inflows observed in the mine. With the proposed B-seam mining occurring below the E-seam, we do not foresee the potential for hydraulic connection between Dry Fork and the mine workings.

### *11.4 Springs and Water-Bearing Zones*

MCC has produced the Spring and Stock Pond Location Map that covers the Southern Panels, Apache Rocks West, and Sunset Trail mining areas. Only a few springs in the West Elk Mine area indicate a source from a local bedrock water-bearing zone. Most springs likely have sources from local water-bearing zones in surficial material (debris flows, colluvium, and possibly alluvium).

In contrast to surface water containment structures, such as reservoirs, ponds, streams and ditches, springs and water-bearing zones may have water sources that are either in bedrock beneath the blanket of clay-rich surficial material (debris flows, alluvium, and colluvium), or have a source from within the surficial material. Subsidence may affect a spring or water-bearing zone source located in bedrock, whereas effects may or may not be expected where the spring source is within the surficial material. Tension cracks produced in sandstone bedrock during the subsidence process, for example, may divert water to a lower rock layer and therefore change the flow location. However, local water-bearing zones in permeable zones, which are interlayered with clay-rich zones (Wasatch clays) in the surficial deposit, may yield to tensile stresses without cracking. Therefore, spring flows are monitored for a few years (to account for seasonal variations) prior to any mining in the area. Monitoring data and field observations are provided each year in MCC's Annual Hydrology Report.

### 11.5 Roads

As was observed in the Apache Rocks and Box Canyon mining areas, effects from mine subsidence are typically limited to cracks that do not prevent passage on most of the access roads and drill roads in the Southern Panels mining area. Also, as expected, no effects from landslide movements or rockfalls have occurred, because the mining rockfall potential is mapped in the moderate-high category or lower, and rockfalls were observed to occur only in the high to very high rockfall category areas in the Box Canyon mining area.

No cracks have been observed in the soft, pliable alluvium, but a few cracks have occurred on the harder and more highly compacted Dry Fork access road, particularly in the area near the confluence of Deer Creek and Dry Fork, although all have been of a small extent. Observations along these roads are documented in the semi-annual Subsidence and Geologic Field Observations reports.

### 11.6 Buildings

Baseline information on buildings, such as foundations, walls, chimneys, and roofs, has already been obtained on the Dry Fork Cow Camp in July 2004 (Dunrud 2004b) prior to any mining. A pre-mining survey of the Cow Camp structures was performed by West Elk Land Surveying in February 2006 and is included as Exhibit 73. The Minnesota Creek ditch rider's cabin is located near the headwaters of Dry Fork in the Dry Fork mining area. An exterior inspection of the cabin was performed in 2004 by the U.S. Forest Service and Agapito Associates, Inc. (Agapito, 2005). The structure was reported to be in average structural condition.

#### 11.6.1 Lower Dry Fork Cow Camp

The cabin exterior is approximately 13 feet wide, 20 feet long, and 8.5 feet high (the wall height). A lean-to 7 feet long and a porch 5.5 feet wide are located on the north and south ends of the cabin (see Figures 7 and 8, of Exhibit 60D for details). The outside walls are of a wood, board-and-bat construction.

The foundation, which is of rock and mortar construction (and an estimated 1½ feet thick), ranges from about 1 foot high in the back to 20 inches high in the front. The roof is covered with tin. The side windows, which measure 2 by 3 feet in outside dimension, are located in the approximate center of either wall.

Post-mining observations and measurements of the cabin following mining have been documented in the Subsidence and Geologic Field Observations Reports.

#### 11.6.2 Minnesota Creek Ditch Rider's Cabin

This cabin was built in the 1950's and is 24 feet 4 inches by 16 feet 4 inches single-story wood framed building. The cabin is located over the projected potential extended eastern end of E-seam longwall panel E6.

## 12.0 POSSIBLE SUBSIDENCE CONSEQUENCES

Predicted subsidence impacts for the Southern Panels and Sunset Trail mining areas has been described in detail above. The greatest surface impacts are expected to occur along the precipitous slopes and cliffs that flank Minnesota Creek, Lick Creek, Deep Creek, and other tributaries. Though unlikely, the worst possible consequences foreseen are that cracks could locally form and be as much as 25 to 50 feet deep above chain pillars and barrier pillars in bedrock on the precipitous slopes, ridges, and/or cliffs that flank Minnesota Creek, Lick Creek, and other tributaries, and may locally accelerate the naturally-occurring rockfall and landslide process.

E-seam mining in longwall panel E2 has already occurred underneath Dry Fork with mining thickness near 14 feet and with overburden as little as 375 to 400 feet. No adverse impacts to the Dry Fork stream channel or flow were observed during or subsequent to mining. Since this case represented the worst-case scenario, the stream channels in the Dry Fork watershed are not expected to be adversely impacted, even with two-seam mining.

In the Sunset Trail mining area, conditions under the South Prong channel are expected to be similar to the Dry Fork channel in the South of Divide mining area. As noted in Section 5.3.2, reaches of South Prong underlain by bedrock are more susceptible to surface cracking. If this occurs away from the edge of the panel, then the crack will likely be short term and closed once the longwall mining progresses as discussed in Section 4.1. Surface cracks that persist are projected to be 5 to 15 feet deep and will not be hydraulically connected to the mine workings as discussed in Section 11.3.1

Based on subsidence observations by WWE (as discussed in Section 5.3.2), no cracks are expected to occur in either the alluvium in the Dry Fork, Lick Creek, and other tributaries or stock watering ponds and drainage diversion ditches. In addition, no cracks are predicted to occur in colluvium more than about ten feet thick.

# 13.0 POTENTIAL IMPACTS FROM LOCAL SEISMIC ACTIVITY

Earth tremors have been recorded or felt by local residents in the Somerset area since the early 1960s. The tremors commonly are the result of coal mine bumps and rock bursts, which are spontaneous releases of strain energy in highly stressed mined/caved coal and rock. In the Somerset Mine area before closure, the bumps and rock bursts were common in room-and-pillar mining areas where stresses concentrated within isolated pillars and blocks of coal (called bump blocks). Earth tremors have continued sporadically in the Somerset Mine area since the mine was closed in the 1980s.

Tremors generated by bumps and rock bursts in the Somerset Mine area attain magnitudes that have shaken structures in the West Elk Mine area and have sometimes been felt by West Elk Mine personnel. These local tremors may affect, to a minor degree, underground workings, landslide or potential rockfall areas, particularly during prolonged periods of increased precipitation. It is noteworthy, however, that the Rulison nuclear shot in 1969, which produced a tremor with a Richter magnitude of 5.2 (the magnitude of energy released was many times greater than the magnitudes of any recorded bump or rock burst), did not affect the Somerset Mine. To our knowledge the Rulison nuclear shot did not trigger any landslides or rockfalls, nor did it impact reservoirs, ponds, or streams in the Southern Panels, Apache Rocks West, or Sunset Trail mining areas.

# 14.0 SUBSIDENCE CONTROL PLAN

Longwall mining has been and is being used for extraction of the B-seam and E-seam in the West Elk Mine. Although longwall mining may initially induce more caving and fracturing of the roof rocks as compared to the room-and-pillar method due to the complete removal of coal in the panel, it offers the advantages of maximizing resource recovery. The longwall method also causes more uniform subsidence (full extraction of panel) and causes equilibrium conditions to be reached in a shorter period of time (i.e., there is no additional, lingering pillar crushing in panels).

## *14.1 Anticipated Effects*

Long-term impacts on the surface are predicted to be minimal above the longwall panels. The few surface cracks over the mined longwall panels that may occur are expected to close once the longwall face moves past the surface area of influence. Surface cracks present above the rigid chain or barrier pillars or mine boundaries may remain open for many years where permanent tensile strains remain after longwall mining is completed. However, several hundred feet of rock will typically exist between any mine-induced surface fractures and the upper part of any longwall mine-induced fractures above the caved zone in the longwall mining panels. Therefore, from a practical standpoint, no interconnection between the surface fractures and the longwall mine workings is anticipated. Again, under a worst-case scenario, if a surface fracture were to occur concurrently within an area controlled by faults or bedrock lineaments, there could be interconnection between adjacent sandstones. However, even under these conditions, the fractures would not extend through the claystones and shales present in the overburden.

Minnesota Reservoir is located well outside of the area of longwall mining influence of the projected B-seam and E-seam panels for the Southern Panels, Apache Rocks West, and Sunset Trail mining areas and, therefore, will not be affected by longwall mining.

## *14.2 Reduction Measures (Underground)*

Underground measures that may be taken to reduce surface strains above the longwall panel chain pillars could include: (1) designing the pillars to yield and crush after mining (thus minimizing humps in the subsidence profile), and/or (2) planning a rapid and uniform longwall mining rate. Any plans to reduce chain pillar dimensions in order to reduce subsidence impacts must, of course, be balanced with health and safety conditions in the mine. Plans for a rapid and uniform mining rate are affected by market demands (or lack thereof) for a constant, high volume of coal.

## *14.3 Development Mining*

Although subsidence is primarily a result of the secondary recovery of coal from a longwall coal panel, subsidence-type features may occur when developing main entries/roadways under shallow, unconsolidated, and saturated cover. Such was the case in October 2020 when developing main entries under South Prong Creek. To avoid similar issues in the future, MCC has performed an analysis of the minimum depth of cover required for development mining in the West Elk Mine to avoid the potential for this type of surface subsidence impacts. WWE has included this Technical Memo as Appendix A to this exhibit.

# 15.0 SUMMARY AND CONCLUSIONS

The measured subsidence parameters over the B-seam and E-seam longwall panels at the West Elk Mine has fallen within the range of predicted subsidence parameters developed from the original subsidence data collected over the Northwest B-seam longwall panels. In addition, the annual subsidence field studies have observed subsidence effects at the expected locations and consistent with the projections resulting from the modeling completed in the Exhibit 60 series.

The subsidence parameters also fall within the range of those measured and calculated by Dunrud in four different coal mining areas in Colorado, Utah, and Wyoming (Dunrud 1987). The subsidence parameters also are consistent with the appropriate National Coal Board graphs (Figures 4 and 5).

Results of subsidence measurements and analyses in the West Elk subsidence monitoring area also are in general agreement with the computer modeling programs developed in the Eastern United States. These favorable comparative results calibrated by West Elk subsidence measurements, therefore, give added assurance that the subsidence parameters projected for the Southern Panels, Apache Rocks West, and Sunset Trail mining areas are realistic and correct.

Specific conclusions are as follows:

1. Maximum vertical displacement (subsidence), tilt, and horizontal strain predicted for longwall mining in the Southern Panels, Apache Rocks West, and Sunset Trail mining areas are likely to be conservative values. Subsidence monitoring data collected after mining of longwall panels E1 through E3 show that actual subsidence was at the lower end of the predicted range. Similarly, the computer model projections overestimated the subsidence over panel E1, while accurately predicting subsidence along Dry Fork over panels E2 and E3.

2. Mining of the longwall mining panels in the Southern Panels mining area will not impact Minnesota Reservoir. The reservoir is completely out of the area of mining influence. All mine workings, including E-seam and B-seam longwall panels are 500 to 600 feet farther away from the reservoir footprint, using even a 45-degree angle of draw. Mining in panels E2 and E3 occurred without any adverse impacts to the reservoir. In addition, Minnesota Reservoir is the outside area of influence for two-seam mining in the Apache Rocks West mining area.

3. No cracks have been observed in the alluvium in any of the drainages of the Dry Fork of Minnesota Creek, or Deep Creek. The composition and thickness of the alluvium in these drainages make it unlikely for cracks to form in the stream channels of drainages in the Southern Panels, Apache Rocks West, and Sunset Trail mining areas. Two-seam mining under Dry Fork will produce some of the largest projected subsidence parameters experienced at the West Elk Mine. However, based on the lack of adverse impacts due to the E-seam mining, the B-seam panels B26 to B29 are not anticipated to impact the channel due, in part, to the greater overburden thickness.

4. The South Prong channel in the Sunset Trail mining area overlays panel SS4, where the overburden is projected to be roughly 300 feet at the western end of the panel. The potential for hydraulic connection between a surface crack and fractures from the mine are negligible when overburden is 300 feet or more. If actual conditions show the overburden to be less than 300 feet, then the mining height should be reduced to continue to minimize the risk of a hydraulic connection forming.

5. Mining impacts on rockfalls were not observed during annual subsidence observations in the Apache Rocks and Box Canyon mining areas over six years (1999 to 2004 inclusive), in areas where the estimated rockfall potential was moderate to high. The highest estimated rockfall potential is classified as moderate to high in the Southern Panels mining area, and many of these are located in areas where no mining is currently planned. Consequently, the natural rockfall process is not expected to be significantly accelerated by longwall mining.

6. The landslides that are located north and south of Minnesota Reservoir and above the northern part of E-seam longwall Panels E16 and E17, are not expected to be noticeably impacted by subsidence or seismic activity caused by longwall mining. Based on field observations, the major finding is that landslide movement occurs in response to moisture and ground saturation and is not noticeably affected by subsidence or any mine-related seismic activity caused by longwall mining beneath or near the landslides.

7. There is no historical record from annual observations in the West Elk Mine area regarding effects of mining on springs and local water-bearing zones, with sources in either surficial material or bedrock. These observations are documented in the Annual Hydrology Reports.

8. Small cracks have occurred on the hard, compacted access roads following longwall mining. However, these cracks have never affected use of the roads.

# 16.0 REFERENCES


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# TABLES

# TABLE 1

## MAXIMUM SUBSIDENCE PARAMETERS FROM WEST ELK MINE SUBSIDENCE MONITORING NETWORK

| Parameter | Longitudinal Profile So. End 1 NW LW | Longitudinal Profile No. End 1 NW LW | Transverse Profile Above 2,3 NW LW |
|---|---|---|---|
| W/d | 750/1240=0.6 | 750/1350=0.56 | 2 NW: 750/1000=0.75<br>3 NW: 750/900=0.83 |
| $a_{cp}=S_{cp}/t$ | N/A | N/A | 0.20 to 0.35 |
| $a=S_m/t$ | 6.94/12=0.58 | 6.06/11.5=0.53 | 2 NW: 0.62<br>3 NW: 0.58 |
| $S_m/d$ | 0.005597 | 0.004489 | 2 NW: 0.00729<br>3 NW: 0.00762 |
| $S_m/d^2$ | 0.000004514 | 0.000003325 | 2 NW: 0.00000729<br>3 NW: 0.00000847 |
| $M_m$ | 0.015<br>($2.7 \cdot S_m/d$) | 0.014<br>($3.1 \cdot S_m/d$) | 2 NW: 0.014<br>3 NW: 0.021 |
| $C_m$(1) | 0.000065<br>($14.4 \cdot S_m/d^2$)<br><br>-0.000111<br>($-24.6 \cdot S_m/d^2$) | 0.000060<br>($18.0 \cdot S_m/d^2$)<br><br>-0.000066<br>($-19.9 \cdot S_m/d^2$) | 2 NW: 0.00022<br>3 NW: 0.00014<br><br>2 NW: -0.00025<br>3 NW: -0.00012 |
| $E_m$ | 0.0070<br>($1.25 \cdot S_m/d$)<br><br>-0.0047<br>($-0.8 \cdot S_m/d$) | 0.0058<br>($1.3 \cdot S_m/d$)<br><br>-0.0009<br>($-0.2 \cdot S_m/d$) | 2 NW: 0.0102<br>3 NW: 0.0085<br><br>2 NW: -0.0236<br>3 NW: -0.0307 |
| Maximum Crack Depth(2) | 80 feet | 100 feet | 50 feet |
| Break Angle(3) | -9° 32percent Slope - Slope in same Direction as tilt | 3° 42percent Slope - Slope in opposite Direction to tilt | — |
| Angle of Draw(3) | 17°(4) | 15°(4) | — |

Notes:
(1) Numerical curvature values are in radians per foot (rad/ft).
(2) Maximum crack depth is projected for hard, brittle sandstones; depth is expected to be much less, or non-existent, in soft, ductile shales and claystones.
(3) Measurement from vertical reference.
(4) Measurement takes into account influence of development entries, chain pillars, and prior F-seam mining.

# TABLE 2
# MAXIMUM SUBSIDENCE PARAMETERS FOR SOUTHERN PANELS MINING AREA[1]

| Parameter | | | E-Seam Mining: Panels E1 - E8, E14 - E17 (t = 9 to 14 ft) | | B-Seam Mining: Panels B26 - B29 (t = 9 to 14 ft) | | Sum of E and B-Seam Mining: Sum of E & B Panels | |
|---|---|---|---|---|---|---|---|---|
| W/d:[2] | | Max | E1-E5: 1080 / 400 | 2.70 | B26-29: 1080 / 600 | 1.80 | | |
| | | Min | 1080 / 1425 | 0.76 | 1080 / 1500 | 0.72 | | |
| | | Max | E6-E8, E14-E17: 1080 / 360 | 3.00 | | | | |
| | | Min | 1080 / 1200 | 0.90 | | | | |
| | | | **t = 9 ft** | **t = 14 ft** | **t = 9 ft** | **t = 14 ft** | **t = 9 ft** | **t = 14 ft** |
| $S_{cp} = a_{cp} \cdot t$ [3] | | Max | 2.7 | 4.2 | 2.7 | 4.2 | -- | -- |
| | | Min | 0.9 | 1.4 | 0.9 | 1.4 | -- | -- |
| ($a_{cp}=S_{cp}/t$) | | Max | 0.3 | 0.3 | 0.3 | 0.3 | -- | -- |
| | | Min | 0.1 | 0.1 | 0.1 | 0.1 | -- | -- |
| $S_m = a \cdot t$ [4] | | Max | 7.2 | 11.2 | 7.2 | 11.2 | 14.4 | 22.4 |
| | | Min | 5.4 | 8.4 | 5.4 | 8.4 | 10.8 | 16.8 |
| ($a = S_m/t$) | | Max | 0.8 | 0.8 | 0.8 | 0.8 | -- | -- |
| | | Min | 0.6 | 0.6 | 0.6 | 0.6 | -- | -- |
| $S_m/d$ [5] | | Max | 0.020 | 0.031 | 0.012 | 0.019 | 0.032 | 0.050 |
| | | Min | 0.004 | 0.006 | 0.004 | 0.006 | 0.007 | 0.011 |
| $M_m$ (2.2 to 2.3 $S_m/d$) [6] | | Max | 0.046 | 0.072 | 0.028 | 0.043 | 0.055 | 0.086 |
| | | Min | 0.008 | 0.013 | 0.008 | 0.012 | 0.010 | 0.016 |
| $E_m$ (in terms of $S_m/d$) [7] | | Max | 0.028 | 0.044 | 0.017 | 0.026 | 0.045 | 0.070 |
| (1.2 to 1.4 $S_m/d$) | | Min | 0.005 | 0.007 | 0.004 | 0.007 | 0.009 | 0.014 |
| $-E_m$ (in terms of $S_m/d$) [7] | | Max | -0.030 | -0.047 | -0.018 | -0.028 | -0.048 | -0.075 |
| (-1.2 to -1.5 $S_m/d$) | | Min | -0.005 | -0.007 | -0.004 | -0.007 | -0.009 | -0.014 |
| Maximum Crack Depth [8] | 1 | Max | 10 | 15 | 10 | 15 | 10 | 15 |
| | | Min | 5 | 5 | 5 | 5 | 5 | 5 |
| | 2 | Max | 25 | 35 | 25 | 35 | 25 | 35 |
| | | Min | 10 | 15 | 10 | 15 | 10 | 15 |
| Break Angle [9] | | Max | 5° | 5° | 5° | 5° | 5° | 5° |
| | | Min | 0° | 0° | 0° | 0° | 0° | 0° |
| Angle of Draw [9] | | Max | 19° | 19° | 19° | 19° | 19° | 19° |
| | | Min | 14° | 14° | 14° | 14° | 14° | 14° |

(1) Maximum tilt and strain parameters apply only to ground surfaces with slopes less that 30 percent; values may be greater on slopes steeper than 30 percent.

(2) All panels are numbered according to planned panel identifications.

(3) Subsidence and subsidence factor above chain pillars.

(4) Subsidence (maximum vertical displacement) above longwall panel centers, based on planned coal extraction thickness listed.

(5) Ratio of the range of maximum vertical displacement to overburden depth range for the longwall panels.

(6) Maximum range of tilt in terms of Sm/d; values of 2.2 to 2.3 $S_m/d$ are obtained from the graph in Figure 5.

(7) Maximum range of horizontal strain in terms of $S_m/d$; values for tensile (positive) strain of 1.2 to 1.4 $S_m/d$ and compressive (negative) strain of -1.2 to -1.5 $S_m/d$ are obtained from the graph in Figure 5.

(8) Maximum crack depth (in feet) in bedrock predicted to locally occur on or near steep slopes and ledges in the Minnesota Creek and Lick Creek drainage areas and above barrier pillars and rigid chain (gate road) pillars. The first depth range (1) is for bedrock sloping less than, or equal to, 30 percent; the second depth range (2) is for slopes more than 30 percent. Add 5 to 15 feet where thick, brittle sandstones occur in ridges and near cliffs. No cracks are predicted to occur in alluvium. No cracks are predicted to occur at the surface of colluvium thicker than about 10 feet.

(9) Angle measured from a vertical reference.

# TABLE 3
# MAXIMUM SUBSIDENCE PARAMETERS FOR
# APACHE ROCKS WEST MINING AREA[1]

| Parameter | | | E-Seam Mining: Panels E10 - E12 (t = 10 to 14 ft) | | B-Seam Mining: Panels B12 - B13A (t = 12 ft) | Sum of E and B-Seam Mining: Sum of E & B Panels | |
|---|---|---|---|---|---|---|---|
| W/d:[2] | Max | | E10-E12: 1080 / 400 | 2.70 | B12-13A: 950 / 750 1.27 | | |
| | Min | | 1080 / 1100 | 0.98 | 950 / 1300 0.73 | | |
| | | | t = 10 ft | t = 14 ft | t = 12 ft | t = 10 ft | t = 14 ft |
| $S_{cp} = a_{cp} \bullet t$ [3] | | Max | 4.0 | 5.6 | 4.8 | -- | -- |
| | | Min | 1.0 | 1.4 | 1.2 | -- | -- |
| ($a_{cp}$=$S_{cp}$/t) | | Max | 0.4 | 0.4 | 0.4 | -- | -- |
| | | Min | 0.1 | 0.1 | 0.1 | -- | -- |
| $S_m = a \bullet t$ [4] | | Max | 8.0 | 11.2 | 9.6 | 17.6 | 20.8 |
| | | Min | 6.0 | 8.4 | 7.2 | 13.2 | 15.6 |
| (a = $S_m$/t) | | Max | 0.8 | 0.8 | 0.8 | -- | -- |
| | | Min | 0.6 | 0.6 | 0.6 | -- | -- |
| $S_m$/d [5] | | Max | 0.020 | 0.028 | 0.013 | 0.033 | 0.041 |
| | | Min | 0.005 | 0.008 | 0.006 | 0.011 | 0.013 |
| $M_m$ (2.2 to 2.3 $S_m$/d) [6] | | Max | 0.046 | 0.064 | 0.029 | 0.055 | 0.077 |
| | | Min | 0.012 | 0.017 | 0.012 | 0.014 | 0.020 |
| $E_m$ (in terms of $S_m$/d) [7] | | Max | 0.028 | 0.039 | 0.018 | 0.046 | 0.057 |
| (1.2 to 1.4 $S_m$/d) | | Min | 0.007 | 0.009 | 0.007 | 0.013 | 0.016 |
| $-E_m$ (in terms of $S_m$/d) [7] | | Max | -0.030 | -0.042 | -0.019 | -0.049 | -0.061 |
| (-1.2 to -1.5 $S_m$/d) | | Min | -0.007 | -0.009 | -0.007 | -0.013 | -0.016 |
| Maximum Crack Depth [8] | 1 | Max | 100 | 100 | 100 | 100 | 100 |
| | | Min | 50 | 50 | 50 | 50 | 50 |
| | 2 | Max | 150 | 150 | 150 | 150 | 150 |
| | | Min | 75 | 75 | 75 | 75 | 75 |
| Break Angle [9] | | Max | 5° | 5° | 5° | 5° | 5° |
| | | Min | 0° | 0° | 0° | 0° | 0° |
| Angle of Draw [9] | | Max | 19° | 19° | 19° | 19° | 19° |
| | | Min | 14° | 14° | 14° | 14° | 14° |

(1) Maximum tilt and strain parameters apply only to ground surfaces with slopes less that 30 percent; values may be greater on slopes steeper than 30 percent.

(2) All panels are numbered according to planned panel identifications.

(3) Subsidence and subsidence factor above chain pillars.

(4) Subsidence (maximum vertical displacement) above longwall panel centers, based on planned coal extraction thickness listed.

(5) Ratio of the range of maximum vertical displacement to overburden depth range for the longwall panels.

(6) Maximum range of tilt in terms of Sm/d; values of 2.2 to 2.3 $S_m$/d are obtained from the graph in Figure 5.

(7) Maximum range of horizontal strain in terms of $S_m$/d; values for tensile (positive) strain of 1.2 to 1.4 $S_m$/d and compressive (negative) strain of -1.2 to -1.5 $S_m$/d are obtained from the graph in Figure 5.

(8) Maximum crack depth (in feet) in bedrock predicted to locally occur on or near steep slopes and ledges in the Minnesota Creek and Lick Creek drainage areas and above barrier pillars and rigid chain (gate road) pillars. The first depth range (1) is for bedrock sloping less than, or equal to, 30 percent; the second depth range (2) is for slopes more than 30 percent. Add 5 to 15 feet where thick, brittle sandstones occur in ridges and near cliffs. No cracks are predicted to occur in alluvium. No cracks are predicted to occur at the surface of colluvium thicker than about 10 feet.

(9) Angle measured from a vertical reference.

# TABLE 4
# MAXIMUM SUBSIDENCE PARAMETERS FOR SUNSET TRAIL MINING AREA[1]

| Parameter | | Panels SS1 - SS4 (t = 9 to 14 ft) | | |
|---|---|---|---|---|
| W/d:[2] | Max | SS1 | 1080 / 770 | 1.40 |
| | Min | | 1080 / 1220 | 0.89 |
| | Max | SS2 | 1080 / 650 | 1.66 |
| | Min | | 1080 / 1260 | 0.86 |
| | Max | SS3 | 1080 / 390 | 2.77 |
| | Min | | 1080 / 1250 | 0.86 |
| | Max | SS4 | 1080 / 350 | 3.09 |
| | Min | | 1080 / 1100 | 0.98 |

| Parameter | | | t = 9 ft | t = 14 ft |
|---|---|---|---|---|
| $S_{cp} = a_{cp} \bullet t$ [3] | | Max | 2.7 | 4.2 |
| | | Min | 0.9 | 1.4 |
| ($a_{cp}=S_{cp}/t$) | | Max | 0.3 | 0.3 |
| | | Min | 0.1 | 0.1 |
| $S_m = a \bullet t$ [4] | | Max | 7.2 | 11.2 |
| | | Min | 5.4 | 8.4 |
| ($a = S_m/t$) | | Max | 0.8 | 0.8 |
| | | Min | 0.6 | 0.6 |
| $S_m/d$ [5] | | Max | 0.021 | 0.032 |
| | | Min | 0.004 | 0.007 |
| $M_m$ (2.2 to 2.3 $S_m/d$) [6] | | Max | 0.047 | 0.074 |
| | | Min | 0.009 | 0.015 |
| $E_m$ (in terms of $S_m/d$) [7] (1.2 to 1.4 $S_m/d$) | | Max | 0.029 | 0.045 |
| | | Min | 0.005 | 0.008 |
| $-E_m$ (in terms of $S_m/d$) [7] (-1.2 to -1.5 $S_m/d$) | | Max | -0.031 | -0.048 |
| | | Min | -0.005 | -0.008 |
| Maximum Crack Depth [8] | 1 | Max | 10 | 15 |
| | | Min | 5 | 5 |
| | 2 | Max | 35 | 35 |
| | | Min | 15 | 15 |
| Break Angle [9] | | Max | 5° | 5° |
| | | Min | 0° | 0° |
| Angle of Draw [9] | | Max | 19° | 19° |
| | | Min | 14° | 14° |

(1) Maximum tilt and strain parameters apply only to ground surfaces with slopes less that 30 percent; values may be greater on slopes steeper than 30 percent.

(2) All panels are numbered according to planned panel identifications. Because the tables provides for the full range of values, there is no need to distinguish between Layouts A and B.

(3) Subsidence and subsidence factor above chain pillars.

(4) Subsidence (maximum vertical displacement) above longwall panel centers, based on planned coal extraction thickness listed.

(5) Ratio of the range of maximum vertical displacement to overburden depth range for the longwall panels.

(6) Maximum range of tilt in terms of Sm/d; values of 2.2 to 2.3 $S_m/d$ are obtained from the graph in Figure 5.

(7) Maximum range of horizontal strain in terms of $S_m/d$; values for tensile (positive) strain of 1.2 to 1.4 $S_m/d$ and compressive (negative) strain of -1.2 to -1.5 $S_m/d$ are obtained from the graph in Figure 5.

(8) Maximum crack depth (in feet) in bedrock predicted to locally occur on or near steep slopes and ledges in the Minnesota Creek and Lick Creek drainage areas and above barrier pillars and rigid chain (gate road) pillars. The first depth range (1) is for bedrock sloping less than, or equal to, 30 percent; the second depth range (2) is for slopes more than 30 percent. Add 5 to 15 feet where thick, brittle sandstones occur in ridges and near cliffs. No cracks are predicted to occur in alluvium. No cracks are predicted to occur at the surface of colluvium thicker than about 10 feet.

(9) Angle measured from a vertical reference.

# FIGURES

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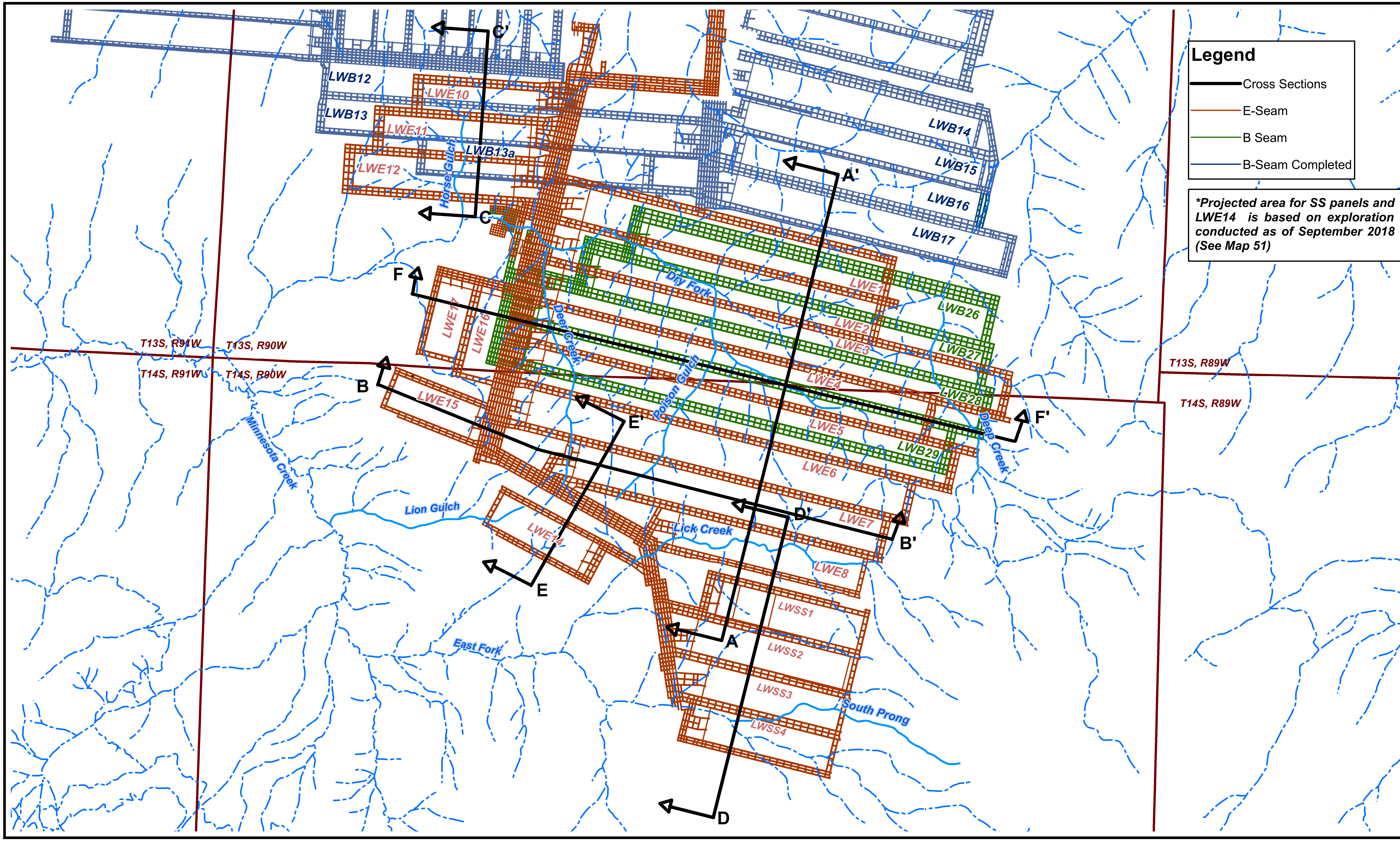



WRIGHT WATER ENGINEERS, INC.
818 COLORADO AVENUE, SUITE 307
GLENWOOD SPRINGS, CO 81601
(970) 945-7755

Mountain Coal Company - West Elk Mine

# Longwall Panel Layout

T13S-T14S, R89W-R91W of the 6th P.M.

Designed by: AWP/BBT
Checked by: JMK
Date: 12/14/2021
Project Number: 831-032.923

DRAFT

0 1,500 3,000
Feet

FIGURE 1

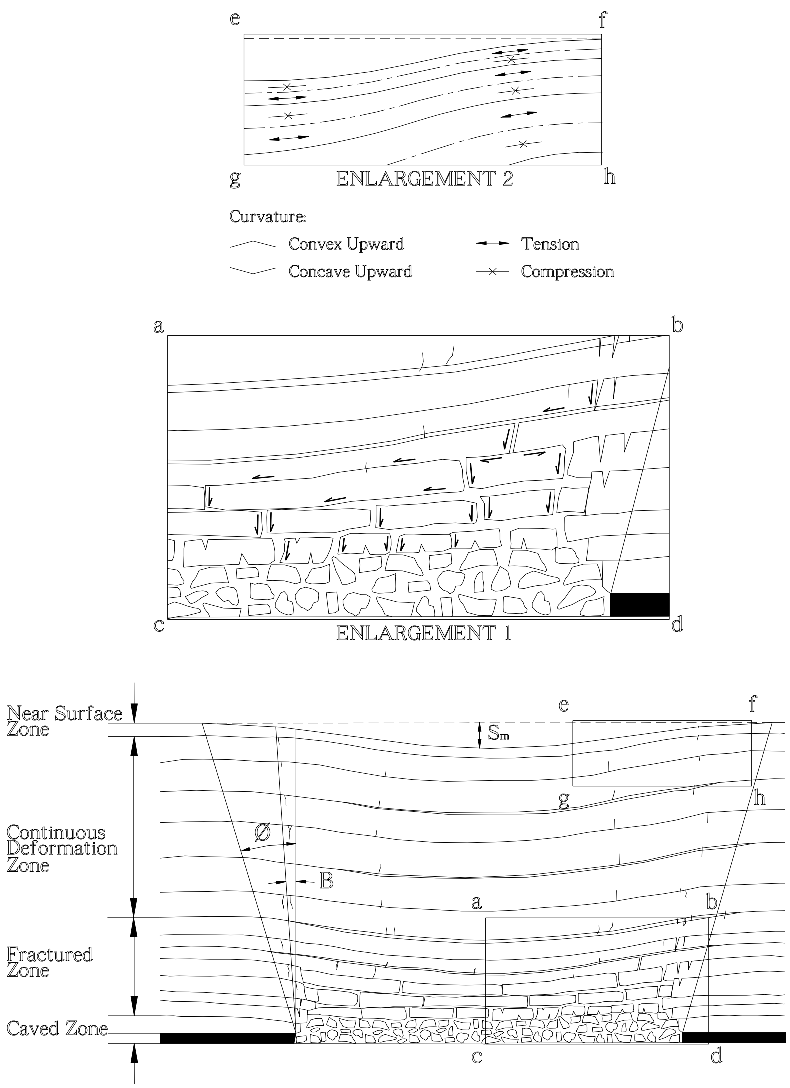



**Figure 2**. Conceptual diagram showing subsidence processes shortly after longwall mining (dynamic state). Enlargement shows some possible water flow directions in the fractured zone along fractures and separated bedding planes within the fractured zone. Enlargement 2 shows deflections of material in the near-surface and continuous-deformation zones and resulting tilt, curvature, and strain.

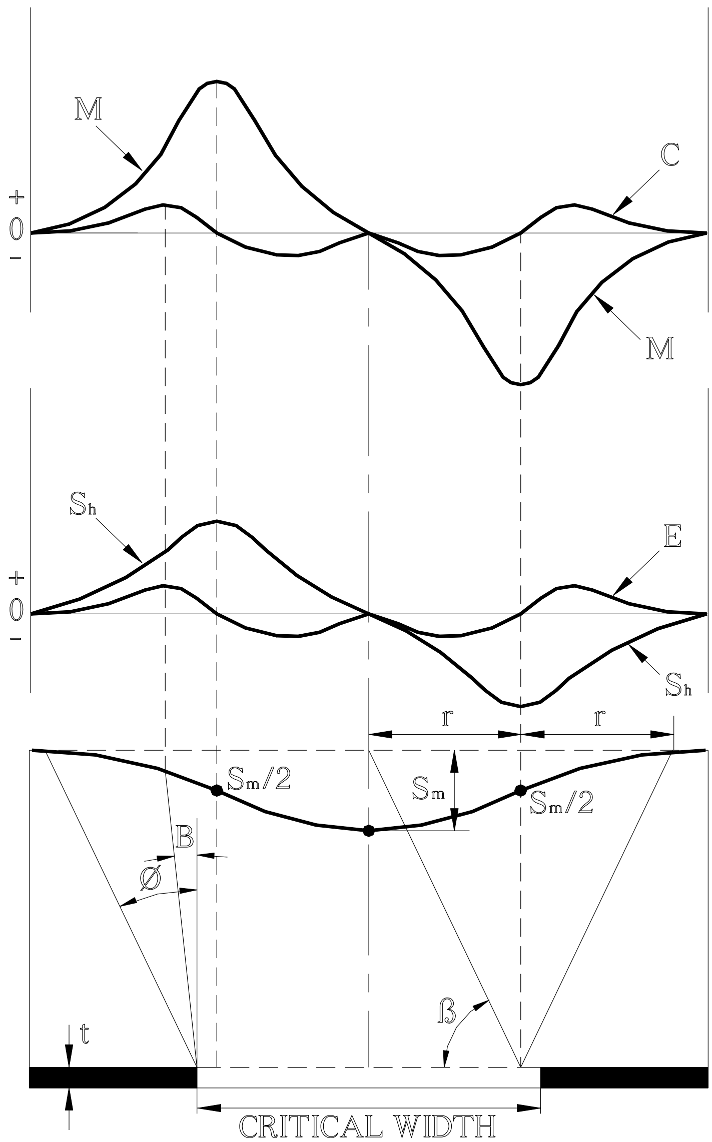



**Figure 3**. Diagram showing subsidence profile and parameters for a mining panel of critical width. The parameters are maximum vertical displacement ($S_m$), horizontal displacement ($S_h$), tilt (M), curvature (C), strain (E), angle of draw ($\phi$), break angle (B), radius (r), and angle of major influence ($\beta$).

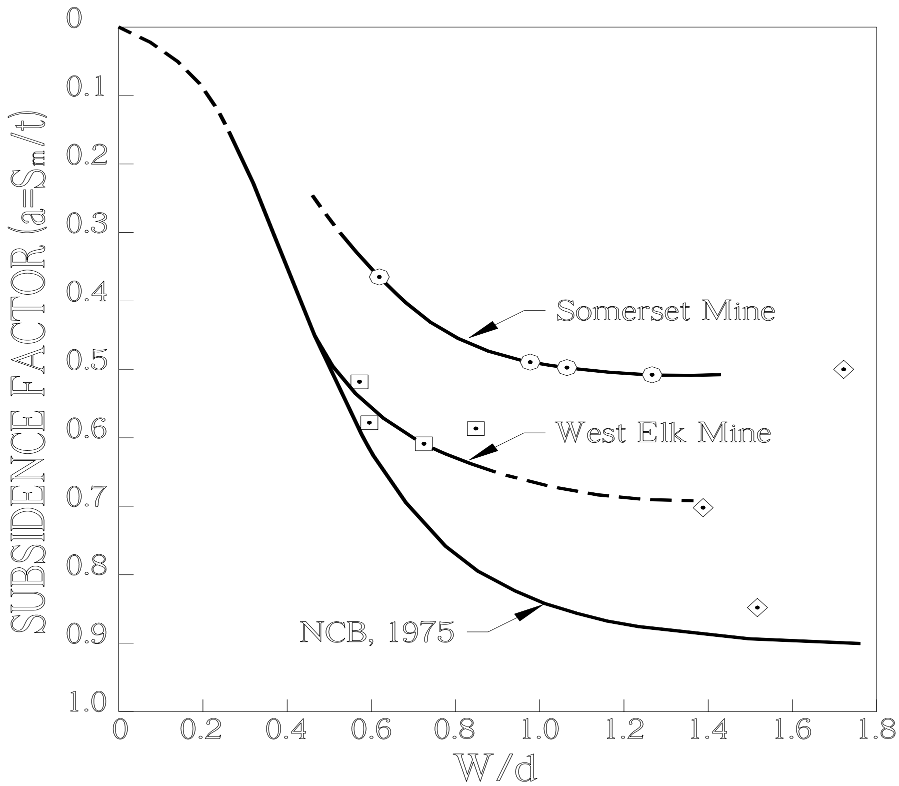



**Figure 4**. Graph showing subsidence factors (a = $S_m$/t) versus mining panel width to depth ratios (W/d) for the West Elk longwall mine (squares), 1972 to 1976 Somerset room-and-pillar mine (circles), and the York Canyon, New Mexico longwall mine (diamonds), along with the average National Coal Board (NCB) longwall curve. Topographic effects on subsidence factors for the York Canyon, New Mexico longwall mining area (upper point of measurement was in a deep draw; middle point was on an isolated ridge; lower point is maximum for area).

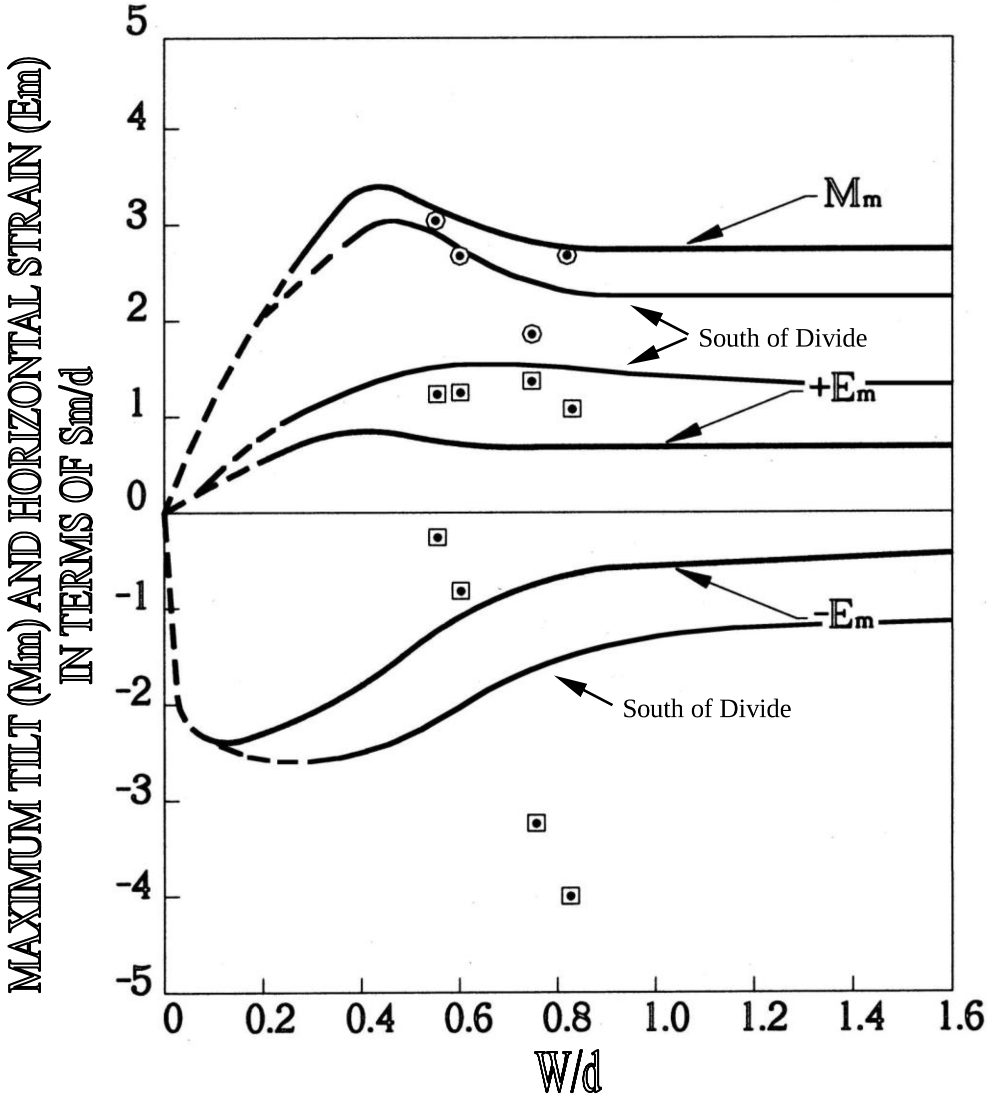



**Figure 5.** Graph showing maximum tilt ($M_m$) and horizontal strain ($E_m$) versus the mining panel width to depth ratio (W/d). Tilt (circles) and horizontal strain (squares) for the West Elk Mine subsidence monitoring network are shown with the average National Coal Board (1975) longwall curves. New curves were developed for the South of Divide and Dry Fork mining areas.

**FIGURE 6**
**COMPARISON OF MODEL PREDICTED VS OBSERVED SUBSIDENCE[1]**

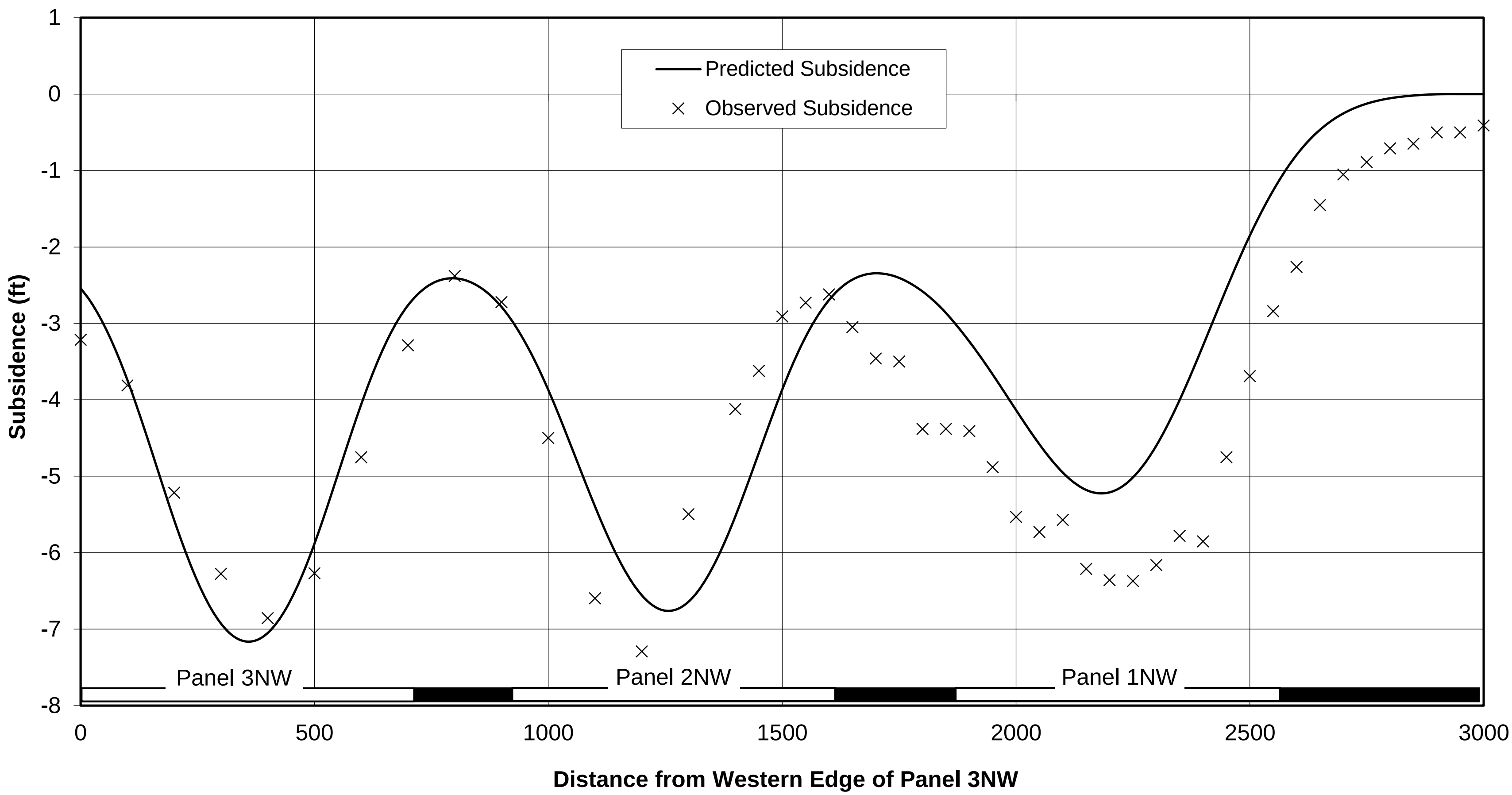
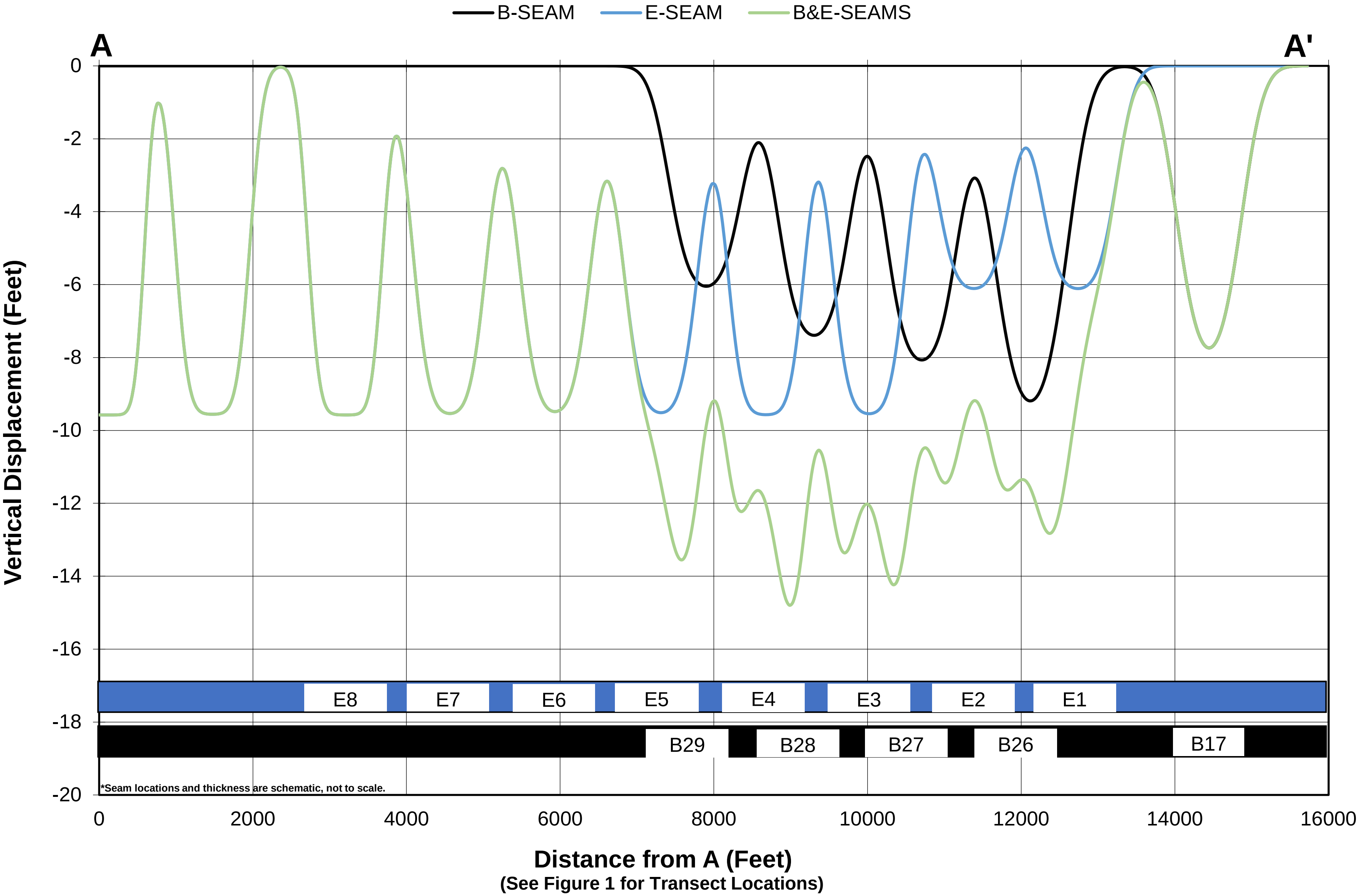


**Figure 7**
**Panels E8 through E1 & B29 through B17 - Vertical Displacement**



## Figure 7A
## Panels B13-A through B12 & E12 through E10 Vertical Displacement

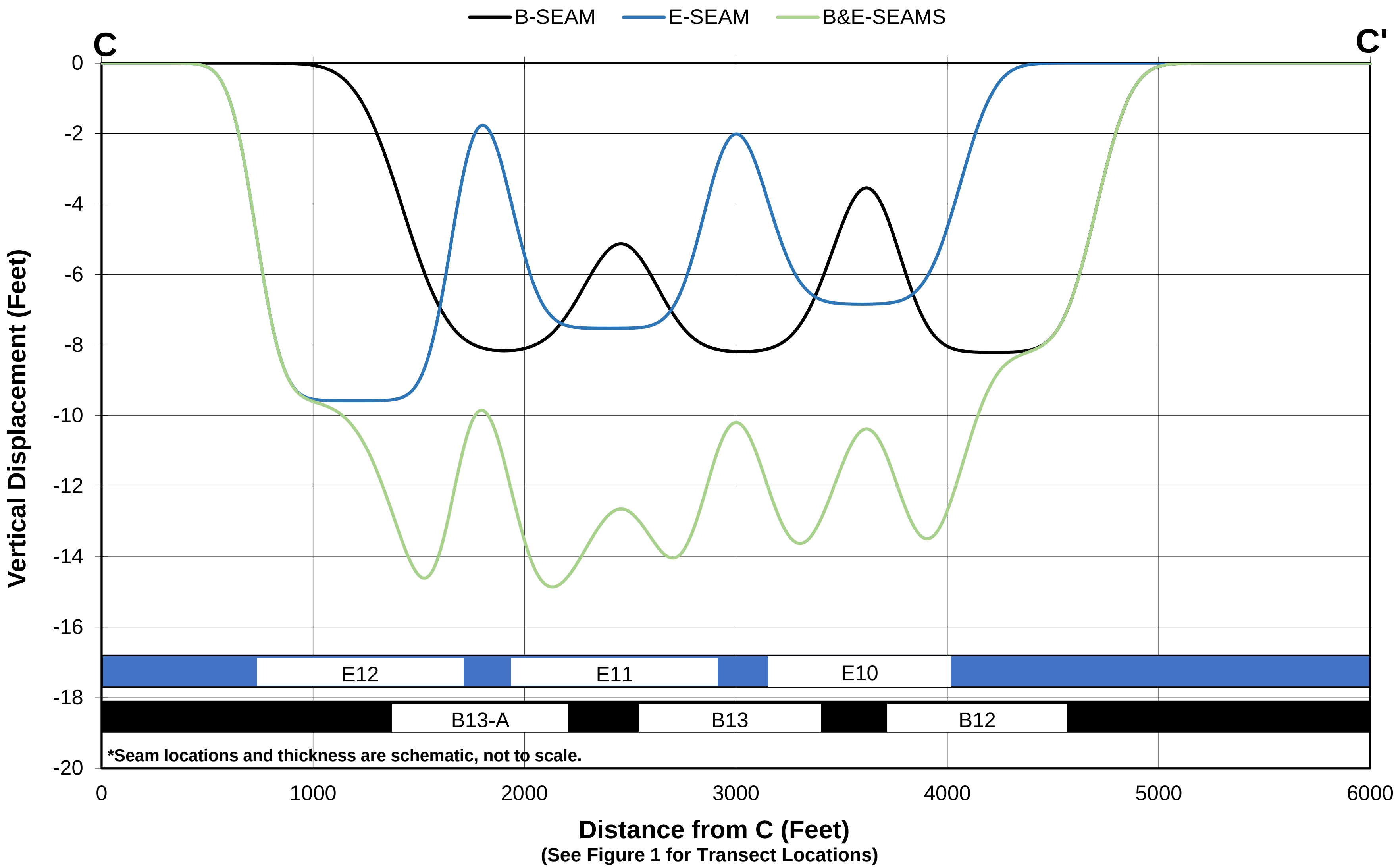
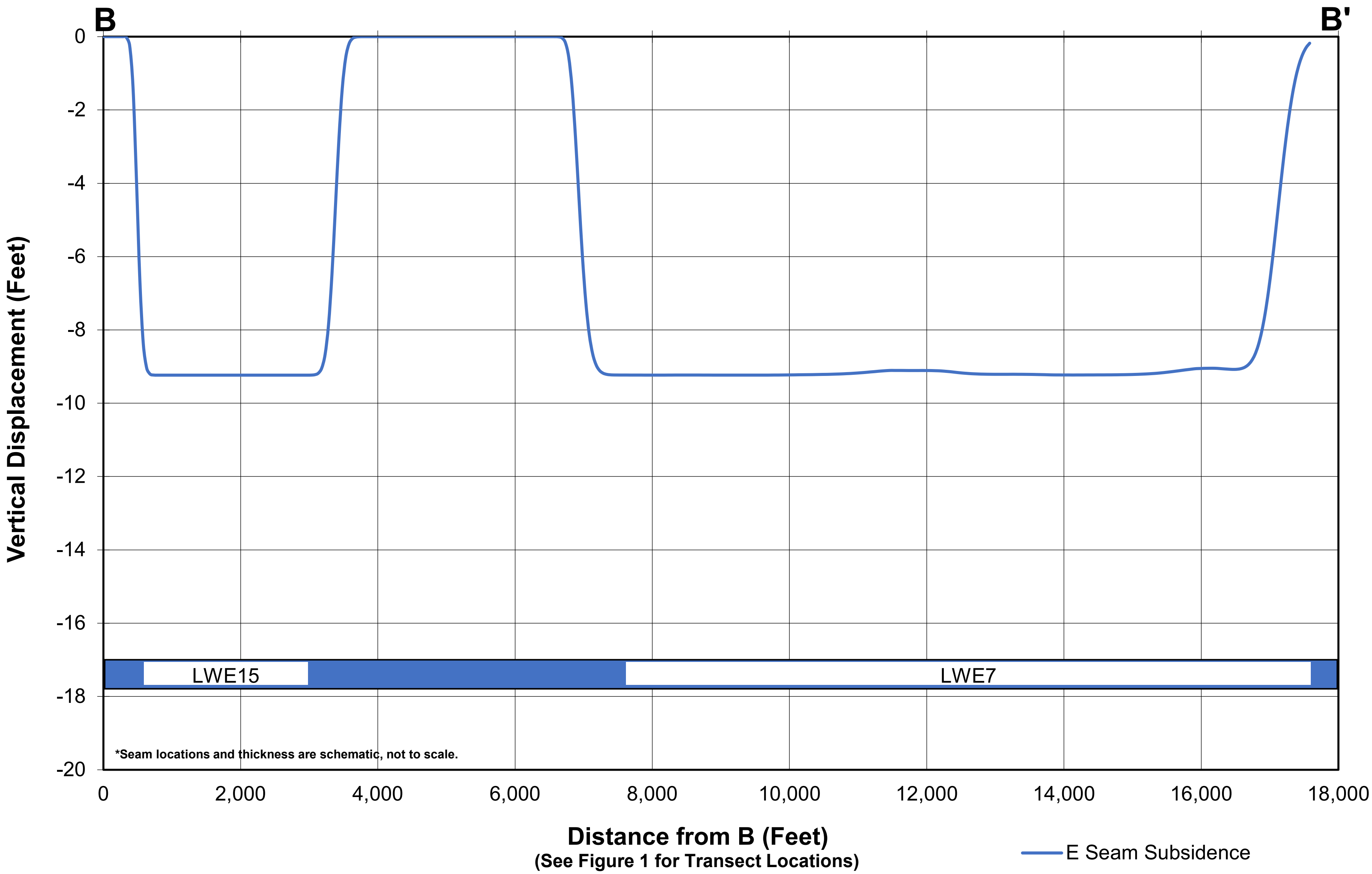


**Figure 8**
**Panels LWE15 and LWE7 - Vertical Displacement**

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*Wright Water Engineers, Inc.*
*December 15, 2021*

Prpd By: BBT
Chkd By: JMK

**Figure 9**
**Panels SS4 through E8 - Vertical Displacement**

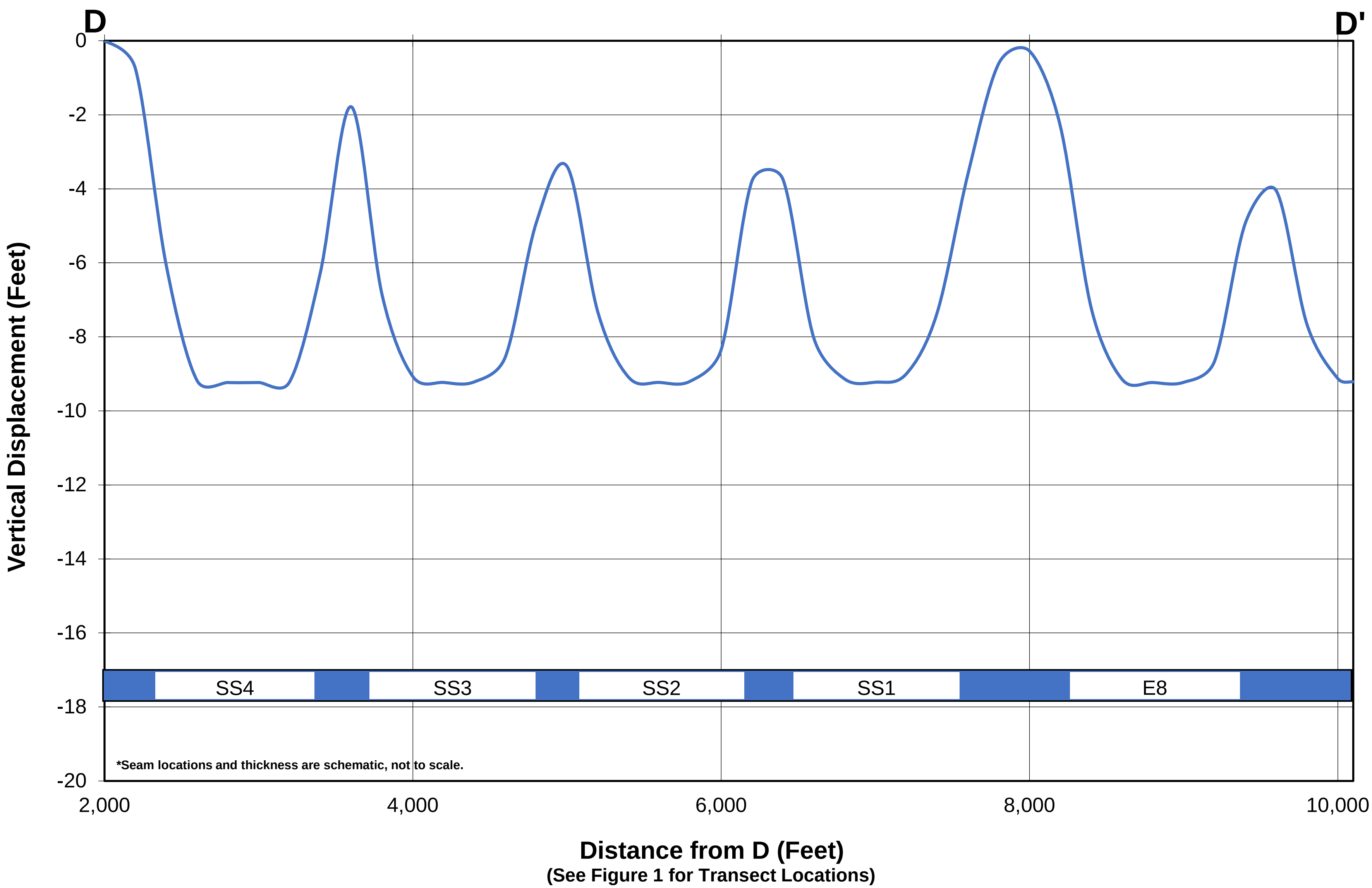
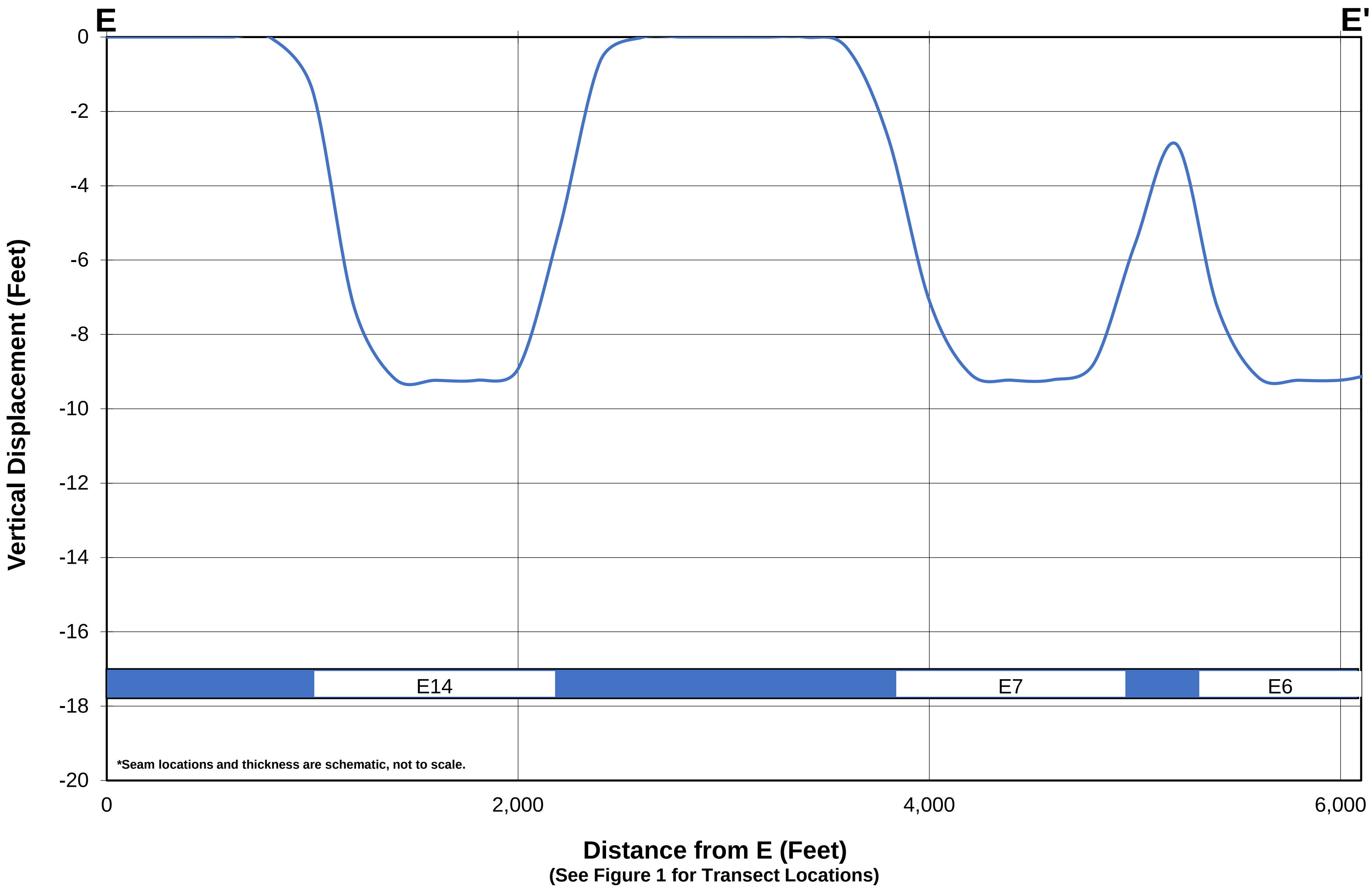


**Figure 10**
**Panels E14 through E6 - Vertical Displacement**

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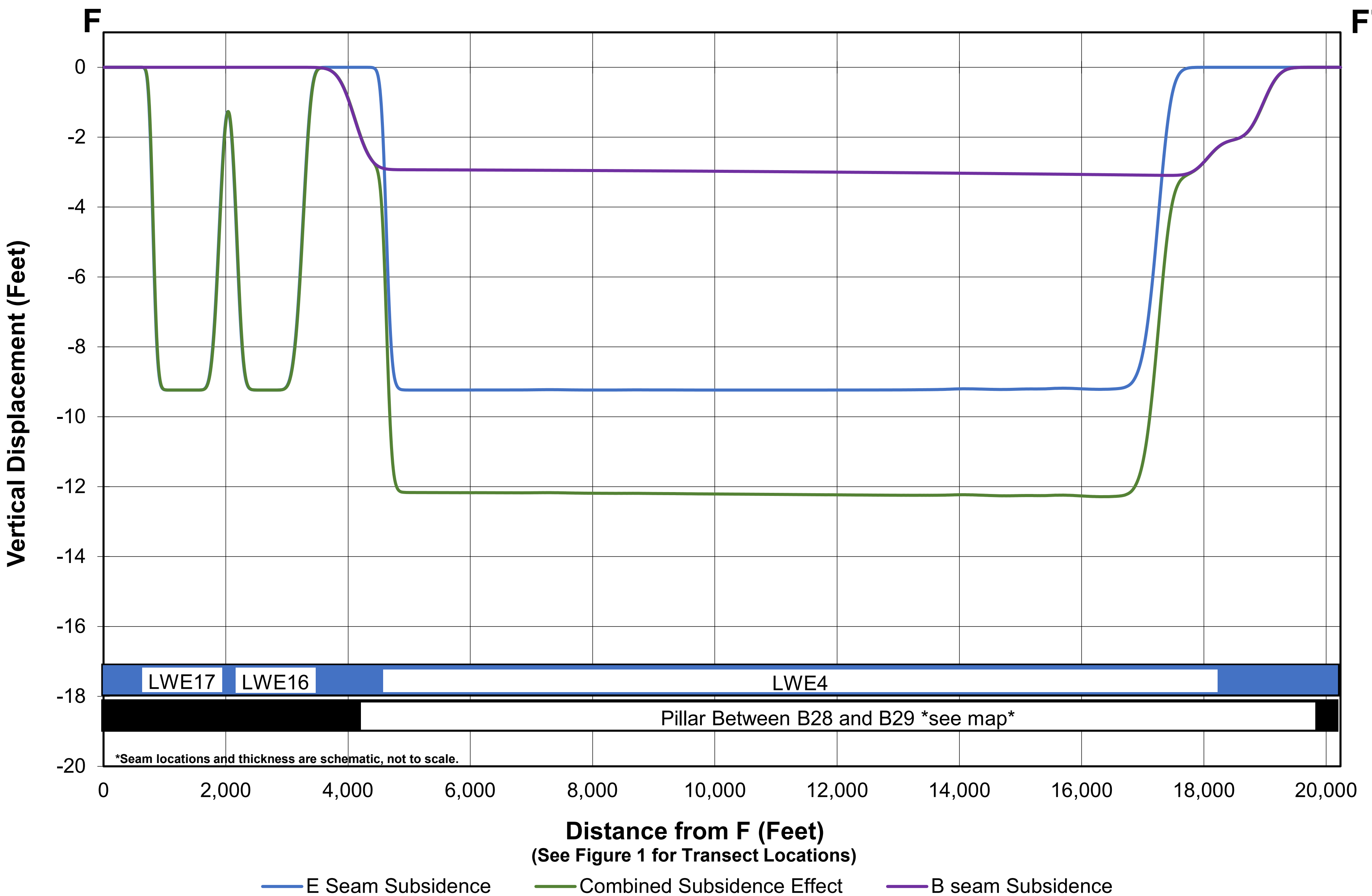
*Wright Water Engineers, Inc.*
*December 15, 2020*

Prpd By: AWP
Chkd By: JMK

## Figure 11
## Panels LWE17, LWE16, LWE4, B28, and B29 - Vertical Displacement

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*Wright Water Engineers, Inc.*
*December 15, 2021*

Prpd By: BBT
Chkd By: JMK

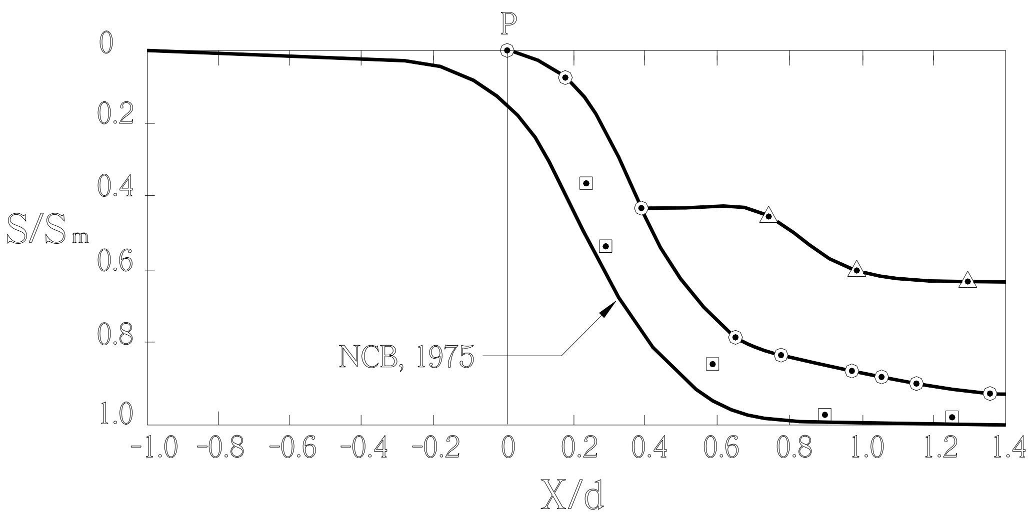
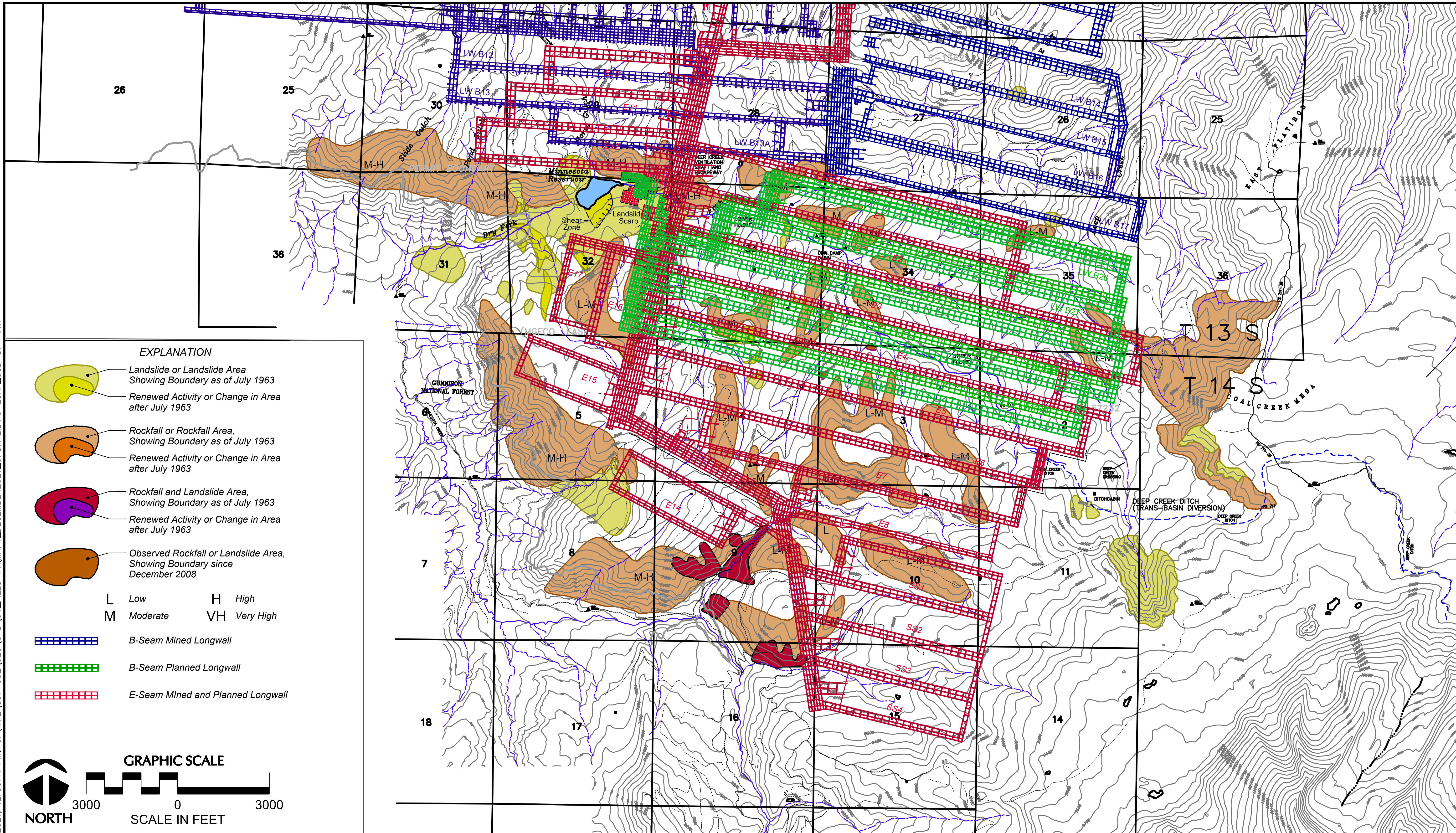



**Figure 12.** Subsidence development curves relative to a point (P) from the 5NW longwall panel at the West Elk Mine (squares), and Somerset room-and-pillar (circles, subsidence more than 90 percent complete and triangles, subsidence only 60 percent complete) as compared to the average National Coal Board curve (1975). This relationship is shown as the ratio of subsidence to maximum subsidence ($S/S_m$) versus the ratio of face position to overburden depth (X/d).

# MAPS




WRIGHT WATER ENGINEERS, INC.
2490 W. 26TH AVE. SUITE 100A
DENVER, CO 80211
(303)480-1700

| | |
|---|---|
| DESIGN | BBT |
| DETAIL | TMV |
| CHECK | JMK |
| DATE | 12/15/21 |
| SCALE | 1"=3000' |

*MOUNTAIN COAL COMPANY WEST ELK MINE*

## LANDSLIDES AND ROCKFALLS IN THE SOUTHERN PANELS, APACHE ROCKS WEST, AND SUNSET TRAIL MINING AREAS

PROJECT NO. 831-032.923

MAP 1

Plot Date/Time: 12/15/2021, 12:30:11 PM; G:\WWE\831-032\923\CAD\04_FILES-IN\MAP1_DECEMBER2021_UPDATE.DWG-LSRF_SOD-DF-ARW

# APPENDICES

APPENDIX A

ARCH WEST ELK

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Mine Engineer
rmunz@archrsc.com
Phone: 970.929.2265

**Mountain Coal Company, LLC**
A subsidiary of Arch Resources, Inc.
West Elk Mine
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# TECHNICAL MEMO

## WEST ELK MINE

### POTENTIAL FOR SURFACE SUBSIDENCE DUE TO DEVELOPMENT MINING AT WEST ELK MINE UNDER PERENNIAL STREAMS

By Bob Munz, Mine Engineer December 2020

### INTRODUCTION

The purpose of this Technical Memo was to research and summarize the published engineering and scientific literature regarding the potential for surface subsidence due to development mining under perennial streams. The minimum depth of cover required for development mining in the West Elk Mine was then assessed to avoid the potential for surface subsidence should a roof fall/collapse occur.

### GENERAL DATA

Development mining produces entries or roadways underground within the mine with a nominal roadway height of 11 feet. Roadway widths range between 18 and 20 feet and the maximum entry-crosscut intersection diagonal spans 34 feet.

Based on drill hole data, the overburden typically consists of 25 to 50 feet of alluvium/colluvium and/or weathered rock near the surface, although alluvium may not be present in some areas. Below this, a variable lithology of sandstones, siltstones, mudstones and shales exist.

### DISCUSSION

To ascertain the likelihood that surface subsidence will occur due to development mining, two mechanisms were addressed. One was that a roof fall occurs which would extend directly up to the surface. The second was the potential associated extension of the roof fall resulting in a subsidence basin on the surface.

With competent strata typically present in the immediate mine roof up to at least a height of between 30 and 40 feet, it was assessed that it is practically impossible for a roof fall in an underground roadway or intersection to extend up to the surface and cause subsidence. In a roof fall, the strata tends to form a natural arch (often termed a "failure arch") until it reaches a rock unit that is competent enough to span and in effect "cap" the arch.

Ignoring all other factors such as the presence of anomalously weak or strong strata, general experience suggests that roof falls typically extend up to a height of between 0.8 to 1 times the roadway width or diagonal span of an intersection, as such it was evident that a roof fall should not progress higher than 20 to 34 feet.

In those areas where shallow cover and weak strata or unconsolidated alluvium/colluvium are present, it was determined that in areas that are deeper than approximately 100 feet, the potential for a surface subsidence basin to develop due to development mining is practically impossible. The possibility of a subsidence basin developing as a result of a roof fall and a subsequent progressive “chimney-type” failure, where the roof has no spanning ability, was investigated by Whittaker and Reddish (1989).

The model, shown in Figure 1, indicates that the maximum height of a potential collapse is based on a volume balance between the in situ rock and the caved/bulked material in the “chimney”. Considering the variable roof lithology observed at the mine, it was assumed that the natural angle of repose of the caved roof rock materials will be around 35 degrees and the bulking factor will vary between 1.33 and 1.5. To be conservative, 1.33 was assumed for this assessment (see Wittaker and Reddish (1989) and Canbulet *et al*, 2002).

**CONCLUSIONS**

Using the conservatively assumed material properties and development roadway dimensions, the maximum height that a chimney-type failure can progress in a development mining section would range between 50 and 60 feet (see Appendix A for detailed calculations). Further to this point, it is worth noting that the Wardell Guidelines (1975) state that “…in general terms, collapse above a height of 5t (where t is the thickness of the extracted seam) is unusual, although possible. Collapse above a height of 10t would be quite exceptional”. In this case, that would equate to a roof fall height of between 55 and 110 feet respectively.

Given that drillhole information indicates that the upper 25 to 50 feet of overburden consists of alluvium and weathered rock, for the purpose of this assessment it was assumed that the upper 50 feet of overburden is weak and saturated in the area of perennial streams. As such, this 50 foot depth was added to the above-calculated maximum “chimney-type” failure height (i.e. of 50 to 60 feet) to ensure that the cave does not extend into this zone, potentially allowing the bulked material in the “chimney” to be washed away resulting in subsidence at depths greater than the calculated failure height.

Considering the above, this assessment concludes that the potential for a subsidence basin to develop above a development mining area, located under a perennial stream, is practically impossible at depths greater than 110 feet. Therefore, no future development mining will be conducted at overburden depths shallower than this beneath a perennial stream. It should be emphasized that this assessment used all worst-case conditions and if mining below a perennial stream would be required at depths less than this, a more in-depth review of the individual area should be completed on a site-specific basis to determine the appropriate minimum depth.

## REFERENCES


Whittaker, B.N. and Reddish, D.J (1989). **Subsidence: Occurrence, Prediction and Control.** Development in Geotechnical Engineering Series, 56, Elsevier Science Publishing.

Canbulat, I., van der Merwe, J.N., van Zyl, M., Wilkinson, A., Daehnke, A. and Ryder, J. (2002). **The Development of Techniques to Predict and Manage the Impact of Surface Subsidence.** CSIR Division of Mining Technology Report No. 2002-0318 for Coaltech 2020.

Wardell, K. and Partners (1975). **Mining Under Tidal Waters**. Report presented to the Ministry for Mines and Power, NSW.

# APPENDIX A

**Height of collapse-chimney equation (Whittaker and Reddish,1989)**

$$z = \frac{4}{(\mathrm{k}-1)(\Pi)(d^2)}\left(2(w)(h^2)\cot(\emptyset) + h(w^2)\right)$$

k = bulking factor
z = height of collapse-chimney
d = diameter of collapse-chimney
w = width of mined roadway
h = height of mined roadway
Φ = angle of repose of caved rock

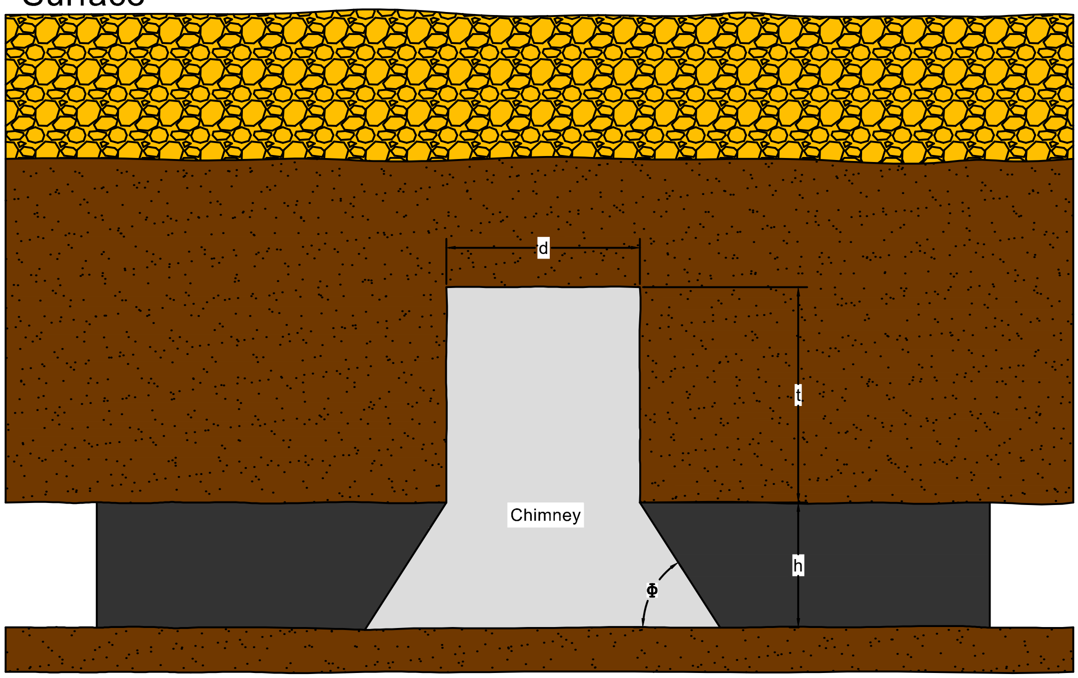
**Variables for an 18 feet wide roadway:**

k = 1.33
z = variable solved for
d = 7.8m
w = 5.5m
h = 3.35m
Φ = 35°

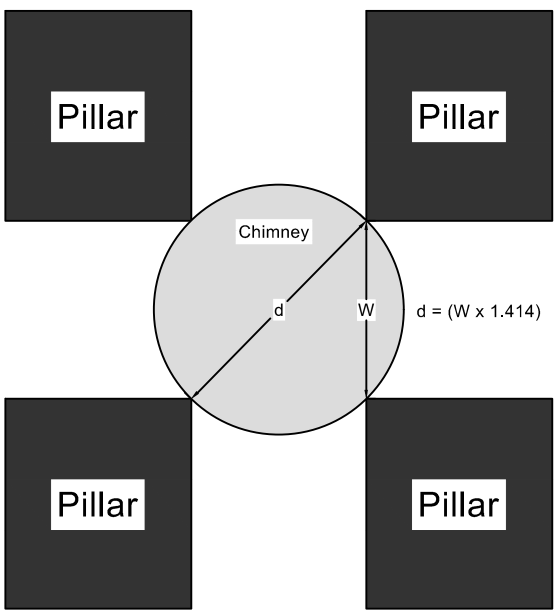
**Variables for a 34 feet diagonal intersection:**

k = 1.33
z = variable solved for
d = 10.3m
w = 7.3m
h = 3.35m
Φ = 35°

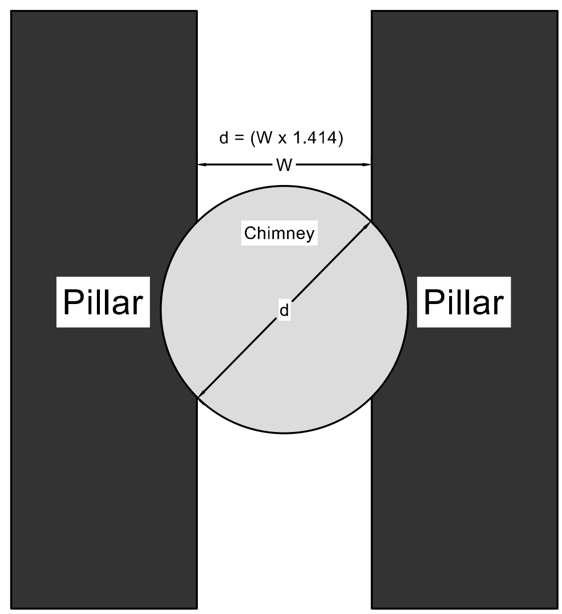
## Section View




## Plan View (Intersection)




## Plan View (Entry)




$$\text{Height of chimney } (z) = \frac{4}{(k - 1)\,(\Pi)(d^2)}\,[2(w)(h^2)\cot Ø + h(w^2)]$$

where:

| | | |
|---|---|---|
| h | = | mining height (m) |
| $\Phi$ | = | Angle of Repose of the caved rock |
| k | = | Bulking Factor |
| w | = | roadway width(m) |

| DRAWN | |
|---|---|
| DATE | BY |
| 12/7/20 | GBG |
| REVISED | |
| DATE | BY |

ARCH WEST ELK

5174 Highway 133
Somerset, CO 81434
Operated by Mountain Coal Company, L.L.C.
A subsidiary of Arch Resources, Inc.

Figure 1
Mechanism of Chimney Development above an Intersection and Roadway in a Development Mining Section
**(Whitaker and Reddish, 1989)**

SCALE 0 NTS feet

FILE NO.
20EURS600.DWG
Path: W:\MCC-ENGINEERING\ENG(E)\UNDERGROUND(U)\ROOF SUPPORT(RS)\ROOFSUPPORT(600)

# EXHIBIT 55B
# STREAM CHANNEL PARAMETERS AND CHANGES DUE TO MINING-INDUCED SUBSIDENCE

**PREPARED FOR:**

Mountain Coal Company, LLC.
West Elk Mine
5174 Highway 133
Somerset, CO 81434

**Wright Water Engineers, Inc.**

**Revised December 2021**
831-032.923

# EXHIBIT 55B
# STREAM CHANNEL PARAMETERS AND CHANGES DUE TO LONGWALL MINING-INDUCED SUBSIDENCE

## MOUNTAIN COAL COMPANY, LLC

## WEST ELK MINE


**Prepared By:**

**Wright Water Engineers, Inc.**
**818 Colorado Avenue, Suite 307**
**Glenwood Springs, CO 81601**


**Revised December 2021**

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# EXHIBIT 55B
# STREAM CHANNEL PARAMETERS AND CHANGES DUE TO LONGWALL MINING-INDUCED SUBSIDENCE

## INTRODUCTION TO STUDY

Wright Water Engineers, Inc. (WWE) and Ernest Pemberton, P.E.[1] determined the extent to which projected subsidence due to longwall mining would impact stream channel stability and sediment transport at Mountain Coal Company, LLC's (MCC) West Elk Mine. Exhibit 55 was originally prepared for the B-seam longwall panels in the Apache Rocks and Box Canyon mining areas in May 1995, with revisions in November 1997 and November 1999. Exhibit 55A was prepared to address the E-seam longwall panels in the South of Divide mining area in April 2004, with a revision in November 2004. Subsequent to Exhibit 55A, MCC obtained the coal lease to the adjacent Dry Fork mining area. Tetra Tech prepared Exhibit 55B in September 2007, using Exhibit 55A as a base and incorporating the Dry Fork mining area. The December 2020 update was performed in order to reflect the most current information regarding the layout for the Sunset Trail longwall panels and panel E14 and the projected overburden thickness in these areas. The December 2021 update addressed the replacement of longwall panel E9 with panels E15, E16, and E17.

Figure 1 shows the drainage basins and stream channels in the vicinity of the Southern Panels (South of Divide and Dry Fork), Apache Rocks West, and Sunset Trail longwall panels study areas. Although Figure 1 also shows the layout of the development mining, this exhibit only addresses potential impacts due to longwall mining of the panels. Each basin has an identification number that will be used throughout this discussion of stream channel parameters and subsequent changes. As shown on Figure 1, Basins 3 through 6 and 26 through 35 are located in the Dry Fork of Minnesota Creek (Dry Fork) drainage; Basin 36, Lick Creek, is a tributary to the East Fork of Minnesota Creek. Minnesota Creek is a tributary to the North Fork of the Gunnison River (North

[1] Prior to his passing, adjunct Scientist with WWE, Former Head of Sedimentation and River Hydraulics Section, Hydrology Department, Chief Engineer and Assistant Commissioner's Office, U.S. Bureau of Reclamation.

Fork). Basin 37 is Deep Creek, a tributary to Raven Creek, which is a tributary to the North Fork. Basins 38 and 39 are within the South Prong watershed, tributary to the East Fork of Minnesota Creek. Basin 41 is Lion Gulch, a tributary to Minnesota Creek.

This report evaluates the extent of potential subsidence due to mining of the B-seam in longwall panels LWB26 through LWB29 within the Southern Panels mining area and the E-seam longwall panels LWE10 through LWE12 in the Apache Rocks West mining area. Finally, this report assesses potential subsidence over panels LWE14, and LWSS1 through LWSS4 in the Sunset Trail mining area. All panel layouts evaluated in this exhibit are shown in Figure 1.

As of December 2020, MCC had completed mining in E-seam longwall panels in LWE1 through LWE8. LWSS1 has been mostly mined. LWE14, LWSS2, LWSS3, and LWSS4 have not yet been mined. This exhibit assesses potential subsidence over portions of these unmined and partially mined panels, depending on the location of the study reach. As of December 2021, mining of longwall panel LWSS1 has been completed and panel LWSS2 is approximately one-half completed.

Table 1 identifies streams that may be impacted by the proposed mining. The mining area encompasses portions of 20 separate minor tributaries of the Dry Fork, Lick Creek, South Prong and Deep Creek in the study area. Table 1 lists the basins and whether or not they are potentially impacted by proposed mining. This study focuses on a detailed evaluation of the potential subsidence impacts to 7 representative basins overlying the existing and/or proposed longwall mining. A detailed discussion of the mine plan and projected subsidence for these areas is given in Exhibit 60E.

The first portion of this hydraulic and hydrologic evaluation establishes pre-mining, or baseline, conditions. The second portion of this evaluation describes the potential and likely impacts of mining operations on the surface drainage system and channel characteristics.

## EXISTING STREAM CHANNEL CHARACTERISTICS

The existing stream channel characteristics have been defined for various parameters, including channel slopes, peak flow rates for a variety of frequencies of occurrence, flow velocities for each of the frequencies, sediment transport regime, stage-discharge relationships, channel profiles, and channel and over-bank stability.

The existing channel shapes were related to the dominant discharge (2-year frequency of occurrence). Sediment transport has been defined for each stream using the annual sediment load; however, sediment transport is a long-term value and represents the full range of flows including the 10-year and 100-year frequency peak discharges.

For each of the existing stream channels, many hydrologic and stream channel parameters were defined and evaluated, including:

1. Mean annual runoff
2. Peak discharges for the 2-year, 10-year, and 100-year frequency floods
3. Mean annual sediment yields
4. Average thalweg[2] slopes
5. Channel characteristics (consisting of width and depth relationships as well as other geomorphic properties)
6. The range of the channel slopes from near mouth to upper reach

Other factors that influence the long-term channel characteristics include the forested area and frequency of landslides.

[2] Line following lowest part of a valley, i.e., invert of channel.

## BASIN HYDROLOGIC CHARACTERISTICS

WWE evaluated and studied each of the 8 basins and corresponding stream channels to define basic hydrologic characteristics related to the streams. This information is summarized in Table 2. While there are differences in soils and vegetation within the study areas, for the purpose of this conceptual analysis, conservative estimates of water yield and sediment yield have been adopted.

### *Average Annual Runoff*

The mean annual runoff expressed in acre-feet (AF) per year per square mile is a fundamental parameter for determining annual average sediment yield. Total annual precipitation varies widely throughout the 526-square-mile basin of the North Fork Gunnison River (North Fork) at Somerset. In the higher elevations of the entire North Fork basin, precipitation can total up to 50 inches per year. Annual precipitation for the drainage basins near West Elk Mine typically ranges from 22 to 30 inches. Precipitation in excess of that portion lost to evapotranspiration and deep percolation (i.e., precipitation that ultimately becomes streamflow), also varies widely in the basin.

Woodward-Clyde conducted a water balance analysis for Horse Creek and Lick Creek for 1978 to 1980. The study, based on the Lick Creek stream gaging station, indicated an average annual runoff of 8.9 inches, representing 475 AF per square mile.

MCC's Exhibit 18 indicates an annual runoff approaching 1,000 AF for one square mile for a variety of North Fork watersheds. However, that finding is modified by their reference to much lowered water yields in South Prong and Horse Creek for the 1977 to 1978 period, which were lower than the driest-year yields of the regional basins.

The North Fork gage near Somerset provides the best long-term runoff data in the region, with 69 years of continuous gaging records. The 69-year period of record identifies a mean annual runoff of 630 AF per square mile; the runoff magnitude is significantly affected by the higher precipitation values at higher elevations in the drainage basin.

Analyses of water yield by WWE for the Division No. 4 Water Court approved water augmentation plan (Case No. 86CW38), indicated that typical annual water yields for tributaries of Dry Fork were approximately 200 AF per square mile. This value compares favorably with the yield estimate of 160 AF per square mile per year based on the U.S. Geological Survey (USGS) regional regression equations (USGS 1985).

The 1936 through 1947 and 1985 through 2002 periods of gaging flow on Minnesota Creek show an average annual yield for 41.3 square miles of 385 AF per square mile.

For the purpose of annual average sediment yields for the subject basins, WWE has concluded that an appropriate (i.e., conservative) mean annual runoff for the subject basins of 475 AF per square mile should be adopted, even though site-specific data for the basins would likely indicate a mean annual runoff of less than 475 AF per square mile. The adopted value represents a high mean annual runoff for use in conservative sediment and channel stability studies. For water rights purposes, the average year yield estimate of 200 AF per year is suitable, as approved by the Colorado Water Court in 1986.

The adopted mean annual runoff for the subject basins is used for sediment and channel stability purposes only. It is not proposed for use in water rights studies or for site-specific water budgets.

### *Peak Runoff Rates*

Peak rates of storm runoff from rainfall and snowmelt events were defined for three return frequencies: 2-, 10-, and 100-year events.

These discharges are based on statistical evaluation of peak daily flow data collected by MCC in the permit area since 1978, study of the long-term published records for the North Fork at Somerset, and statistical evaluation of published streamflow data for basins in the vicinity of West Elk Mine. Special evaluations were made of the Lick Creek, Sylvester Gulch, and Horse Creek basins using the USGS peak rate of runoff computational procedure applicable to small basins in the Colorado mountainous area (USGS 1985).

Figure 2 provides a semi-logarithmic plot of the peak discharge rates. The semi-logarithmic plotting technique was adopted to analyze the small tributary basins under consideration. The results are consistent with the regional analyses for the North Fork.

### *Sediment Yield*

The mean annual sediment yield for each of the streams is presented, for convenience, in terms of three units of measurement:

1. Tons per year
2. AF per year
3. Cubic yards per year

The mean annual sediment yields for each basin were estimated by utilizing a wide range of published and unpublished data combined with site-specific information and basin characteristics.

Sediment yield parameters for similar basins were evaluated using the USGS *Water Resources Investigation Report 87-4193* by John Elliott entitled *Regionalization of Mean Annual Suspended Sediment Loads in Streams, Central, Northwestern, and Southwestern Colorado* (1988). In addition, the rate of sediment production was evaluated using field observations of the basin characteristics, photographs, maps, aerial photos, and comparison with other mountainous regions with similar vegetative cover and similar characteristics for which sediment yield data were available. The typical suspended sediment concentrations of similar streams were taken into consideration for comparison and for “reasonableness” checks.

The adopted sediment yield rate of 0.03 AF per square mile per year for the subject basins, when coupled with annual water yield, results in an average annualized sediment concentration of approximately 70 mg/L. This is consistent with regional analyses for the North Fork.

## STREAM CHANNEL HYDRAULIC CHARACTERISTICS

The stream channel regime and characteristics were defined using still photographs, videotapes, USGS topographic maps, detailed topographic maps prepared for the mine area, soil surveys, geological evaluations prepared by the late John Rold (former State Geologist and consultant to WWE), aerial photographs, and related evaluations. Channel profiles portraying the pre-mining slope and the range of slopes for each stream segment are presented in Figures 3 through 20. In previous versions of Exhibit 55B, USGS quads (40-foot contour interval) were used to develop the pre-mining channel profile. Pre-mining channel profiles in the December 2020 update have been developed based on topography provided by MCC with 20-foot contour intervals.

A summary of the stream channel hydraulic characteristics (width, depth, and velocity) for each of the 8 drainage basins is provided in Table 3. The channel dimensions are intended to generally represent each stream and provide a baseline, against which to compare potential changes due to longwall mining. The slope in the lower reach of the channel potentially impacted by mining is shown in addition to the average channel slope since only the lower reach will receive the full basin runoff.

The dominant discharge is the flow for the stream that tends to shape the stream channel and help establish the width and depth of the defined channel. The dominant discharge can vary based upon a number of watershed conditions, but correlates best with 1- to 2-year peak flow rates. For this analysis, the dominant discharge was assumed to be the 2-year return interval peak flow.

Erosion and sediment yield of a stream basin are normally a product of rainfall, ground cover, land use, topography, upland erosion, runoff, soil types, geology, sediment, and channel hydraulic characteristics. All of these factors were considered in this analysis.

The channel characteristics shown in Table 3 for the dominant discharge are for the stream near the mouth or at a point just downstream of each segment of stream channel potentially impacted by longwall mining. The width and depth values at the dominant discharge in Table 3 are approximate values based upon computed physical basin regime characteristics and identification of characteristics from photographs taken on selected stream channels in the area.

In 2020, WWE performed work relating to the South Prong stream channel through which we gained site-specific knowledge of the hydraulic characteristics. As a result, we have updated our channel geometry and refined our analyses of potential effect of longwall mining to incorporate this experience.

The width to depth ratio, floodplain connectivity, substrate material, and channel slope provide an understanding of the geomorphic context of the study stream systems. The hydraulic characteristics provided in Table 3 result in existing width-to-depth ratios of 12 and 4 for South Prong and Lion Gulch, respectively. As typically observed in headwater systems, the steep terrain surrounding each study reach sets both streams within a confined valley. A confined-valley type results in channels that are relatively entrenched, with little to no access to a broad floodplain. Similarly, the existing terrain results in steeper channel slopes and stream substrate that can withstand the higher velocities associated with the steep terrain. Together, these hydraulic and geomorphic characteristics indicate that both study reaches consist of cascading stream channels within the steeper sections and step-pool channel morphology where channel slopes are less than 4%.

## IMPACTS OF SUBSIDENCE ON STREAM CHANNELS

The projected subsidence under each of the 8 studied stream channels in the study area was calculated using Surface Deformation Prediction System (SDPS), Version 6.2G (Department of Mining Engineering, University of Kentucky; Department of Mining and Minerals Engineering, Virginia Polytechnic Institute and State University), as calibrated using site-specific subsidence data. Exhibit 60E presents a detailed discussion of the subsidence evaluation.

All longwall panels were set at an elevation of zero, with the stream channel represented above based on overburden thickness. In utilizing SDPS, each stream channel reach was represented as a series of points (spaced 200 feet apart) with X, Y, and Z coordinates. The Z value for each point is the approximate overburden depth based on 10-foot overburden contours provided by MCC. Subsidence and changes to channel slope were determined along the profile.

Table 4 shows that the most significant changes will occur in the tributaries overlying a significant portion of both the B-seam and E-seam panels. The E-seam mining thickness is projected to be 14[3] feet at a maximum to the west, and 11 feet at a maximum to the east. The B-seam thickness is projected to be 9 feet in the most southerly panel, and 14 feet at a maximum to the north. The Sunset Trail panels mined in the E-seam are expected to have similar mining thickness values, with lower mining heights projected near the eastern end of the panels.

Basin Number 3 is the Horse Gulch basin, a tributary to Minnesota Reservoir. Because the B-seam has already been mined, this basin will only be affected by proposed E-seam mining. Basin 3 channel's slope will increase by a maximum 10.6% and will decrease by a maximum 2.9% due to E-seam mining. Because the pre-mining average slope of this channel is 11.1%, the slope changes due to subsidence do not create any reaches with negative or flat slopes. Maximum subsidence along the stream profile is approximately 8.3 feet. The pre- and post-mining profiles for Basin 3 are shown in Figure 21. This figure demonstrates that the overall channel slope is not

[3] Practically speaking, the maximum mining height with the current longwall is 13.5 feet; therefore, WWE used a height of 13.5 in the computer modeling.

projected to be significantly impacted by subsidence.

Basins 29 (Poison Gulch) and Basin 32 (Deer Creek) are tributary to Basin 35 (Dry Fork of Minnesota Creek). These three basins will be affected by both B-seam and E-seam mining. E-seam mining in the lower reaches of these drainage basins has already occurred without any noticeable adverse impacts. Within these three basins, the maximum changes in slope are an increase of 3.5% and a decrease of 5.1%. Because the pre-mining average slope of these channels ranged from 5.3% to 9.7%, the slope changes due to subsidence do not create any reaches with negative or flat slopes. Maximum subsidence along the stream profile of Basins 29, 32, and 35 is approximately 14.7 feet, 14.3 feet, and 15.2 feet, respectively. The pre- and post-mining profiles for Basins 29, 32, and 35, are shown in Figures 22, 23, and 24; these figures demonstrate that the overall channel slope is not projected to be significantly impacted by subsidence. There may be localized reaches within Deer Creek (Basin 32) where the post-mining slope flattens to roughly 1%.

Basin Number 36 is the Lick Creek basin, a tributary to East Fork Minnesota Creek. This basin will only be affected by E-seam mining. The Basin 36 channel's slope will increase by a maximum of 2.3% and will decrease by a maximum 4.4%. However, since the pre-mining average slope of this channel is 7.1%, the slope changes due to subsidence do not create any reaches with negative or flat slopes. Maximum subsidence along the stream profile is approximately 6.5 feet. The pre- and post-mining profiles for Basin 36 are shown in Figure 25. This figure demonstrates that the overall channel slope is not projected to be significantly impacted by subsidence.

Basin Number 37 is the Deep Creek basin, tributary to Raven Gulch. This basin will be affected by both B-seam and E-seam mining. The Basin 37 channel's slope will increase by a maximum 1.7% and will decrease by a maximum 3.0%. However, because the pre-mining average slope of this channel is 8.3%, the slope changes due to subsidence do not create any reaches with negative or flat slopes. Maximum subsidence along the stream profile is approximately 13.4 feet. The pre- and post-mining profiles for Basin 37 are shown in Figure 26. This figure demonstrates that the overall channel slope is not projected to be significantly impacted by subsidence.

Subsidence along the South Prong channel (Basin 39) ranges from zero to approximately nine feet. As shown in Table 3, the maximum decrease in slope is 3.7%, and the maximum increase is 1.5%. Given the average pre-mining slope of 18.1%, slope changes due to subsidence are not expected to create any reaches with negative or flat slopes. Figures 27A and 27B show subsidence along the full extent of South Prong and zoomed in to the western edge of LWSS4, respectively.

Subsidence along the Lion Gulch channel (Basin 41) ranges from zero to approximately nine feet. As shown in Table 3, the maximum decrease in slope is 3.0%, and the maximum increase is 1.8%. Given the average pre-mining slope of 24.2%, slope changes due to subsidence are not expected to create any reaches with negative or flat slopes. Figures 28A and 28B show subsidence along the full extent of Lion Gulch and zoomed in to the western edge of LWE14, respectively.

As shown in Figures 27B and 28B, the existing slope at the downstream limit of the subsidence was projected to decrease due to the projected subsidence. Reduction of the stream slope will likely result in an increased width to depth ratio, a reduction in channel velocity, increased floodplain connectivity, and increased potential for sediment deposition. South Prong will likely maintain a step-pool morphology where larger pools are developed, and riparian plants establish upon the gentler channel side slopes. Morphological changes to Lion Gulch are predicted to be less prominent due to the ephemeral nature of the drainage and relatively low flow rates.

The existing slope at the upstream limit of the subsidence is projected to increase. An increased stream slope generally results in a decreased width-to-depth ratio, an increased channel velocity, reduced floodplain connectivity, and increased potential for erosion. As the channel in the upper reaches currently maintains a cascade morphology, steepening of this reach will not fundamentally change the stream type. Furthermore, the observed outcroppings of bedrock in South Prong and larger material indicative of these steep streams will likely further mitigate against the potential for erosion where slopes have steepened beyond their existing condition. The Lion Gulch drainage will experience minimal change in its headwaters as the subsidence extends to the top of the watershed.

Although the changes in slope may impact the geomorphic characteristics of the channel, the potential for adverse impacts to stream function remain low. The dominant discharge will naturally shape a channel dimension that will be in dynamic equilibrium with the existing up- and downstream reaches that are not impacted by the subsidence.

## CHANGES IN STREAM CHANNEL HYDRAULIC CHARACTERISTICS

The channel characteristics for each of the basins (as shown in Table 3) were analyzed using geomorphic and sedimentation engineering relationships and formulas to determine the extent and type of change to each channel segment. These relationships were then used to estimate the amount of sediment yield change.

Hydrologic review has determined that the following basin characteristics will not change significantly as a result of subsidence:

1. Mean annual runoff
2. Peak discharge
3. Dominant discharge
4. Forest cover

Mean annual runoff, peak discharge, and the dominant discharge are greatest for the lower end of each stream segment studied, priming these areas of the channel for maximum geomorphic change. Therefore, this analysis focuses primarily on the lower portion of each stream segment. Computations were performed for the lowest channel reach within the influence of the mining.

A principle of fluvial morphology, as confirmed by Manning's equation, is that the channel width and channel depth will respond to changes in slope as shown in the following table.

| | **Channel Width** | **Channel Depth** |
|---|---|---|
| **Slope Increase Due to Subsidence** | Larger | Smaller |
| **Slope Decrease Due to Subsidence** | Smaller | Larger |

The deformation of the ground surface due to subsidence results in a change in the existing channel slope. The magnitudes of changes were first computed based on the subsidence model output, then the changes were applied to the existing channel slope to determine the resultant post-mining channel slope. For purposes of determining changes in channel hydraulic characteristics, the channel slope near the lowest reach with predicted subsidence was used for calculations.

Utilizing geomorphic channel regime relationships, it was determined that the changes to channel geometry shown in Table 5 would typically occur over a period of approximately three to five years. There is potential for more rapid channel change in localized areas depending on factors such as forest cover, soil saturation, and channel composition. The changes in depth and width are the maximum computed values considering both a slope increase and slope decrease. However, it should be recognized that the maximum changes in channel width and depth would not occur over the same channel reach.

## CHANGES IN SEDIMENT YIELD

The mean annual sediment yield for each basin is not expected to change except for minor channel cutting and filling over a period of three to five years or more. Overall, there will be a tendency for these changes in sediment production to balance out within the basins.

As shown in Table 2, the mean annual sediment yield for the subject basins ranges from approximately 30 to 90 cubic yards per year. These sediment yields are not expected to change (i.e., increase or decrease) by more than about 5 percent due to any change in hydraulic characteristics resulting from the increase in slope as identified in Table 4.

## SUMMARY

Stream channel characteristics will change as a result of longwall panel subsidence. This analysis of stream channels was undertaken to determine the magnitude of subsidence along channel profiles and changes to channel slope due to longwall mining. The changes to stream channel parameters were analyzed using standard procedures of the sedimentation and geomorphic engineering professions based on the effects of thalweg slope changes (either increase or decrease) due to mining-induced subsidence. The results are summarized in Table 4.

Of those streams and longwall panels analyzed, the maximum estimated change in channel width is 9 feet, and the maximum change in channel depth is 0.8 feet (Table 5). Changes in stream channel width and depths generally are expected to occur over a period of three to five years. However, there is potential for more rapid localized change due to factors such as soil saturation, forest cover, and channel stability. The likely change in sediment yield is not expected to deviate by more than 5 percent from the values given in Table 1.

Subsidence in the studied basins can reach magnitudes of up to nine feet and extend along hundreds of feet of channel. Although the changes in slope may impact the geomorphic characteristics of the channel, the potential for adverse impacts to stream function remain low. The dominant discharge will naturally shape a channel dimension that will be in dynamic equilibrium with the existing up- and downstream reaches that are not impacted by the subsidence.

In general, channel geometry changes and channel profile lowering are expected to occur over a period of three to five years. However, localized factors may lead to more rapid change in which certain channel segments lower more quickly than others.

## REFERENCES

U.S. Geological Survey. 1985. James Kircher. *Estimation of Natural Streamflow Characteristics in Western Colorado.* Water Resources Investigations Report 85-4086.

U.S. Geological Survey. 1988. John Elliot. *Regionalization of Mean Annual Suspended Sediment Loads in Streams, Central, Northwestern, and Southwestern Colorado*. Water Resources Investigations Report 87-4193.

# TABLES

**TABLE 1**
**BASINS POTENTIALLY IMPACTED BY MINING**

| BASIN NO. | POTENTIALLY IMPACTED BY MINING | SELECTED FOR DETAILED STUDY |
|---|---|---|
| 3 | X | X |
| 4 | X | |
| 5 | X | |
| 6 | X | |
| 26 | X | |
| 27 | X | |
| 28 | X | |
| 29 | X | X |
| 30 | X | |
| 31 | X | |
| 32 | X | X |
| 33 | X | |
| 34 | X | |
| 35 | X | X |
| 36 | X | X |
| 37 | X | X |
| 38 | X | |
| 39 | X | X |
| 41 | X | X |

# TABLE 2
# BASIN HYDROLOGIC CHARACTERISTICS

| Basin Number (1) | Area | | Mean Annual Runoff (2) | Peak Flood Flow (cfs) (3) | | | Mean Annual Sediment Yield (4) | | |
|---|---|---|---|---|---|---|---|---|---|
| | (acres) | (sq-mi) | (ac-ft) | 2-yr | 10-yr | 100-yr | (ac-ft) | (tons) | (cu-yd) |
| 3 | 430 | 0.68 | 320 | 9.5 | 19 | 31 | 0.02 | 30 | 32 |
| 29 | 220 | 0.35 | 170 | 4.9 | 10 | 16 | 0.01 | 17 | 18 |
| 32 | 610 | 0.95 | 450 | 13.3 | 27 | 43 | 0.03 | 44 | 47 |
| 35 | 2,900 | 4.60 | 2,200 | 64.0 | 130 | 207 | 0.14 | 210 | 220 |
| 36 | 1,200 | 1.85 | 880 | 25.8 | 53 | 84 | 0.06 | 85 | 90 |
| 37 | 2,300 | 3.56 | 1,700 | 49.6 | 102 | 160 | 0.11 | 160 | 170 |
| 39 | 1,320 | 2.06 | 980 | 29.0 | 59 | 94 | 0.06 | 93 | 100 |
| 41 | 170 | 0.27 | 130 | 3.5 | 7 | 11 | 0.01 | 12 | 13 |

(1) Refer to Figure 1 for basin numbers and locations.

(2) Based on "Water Balance Analysis of Horse and Lick Creek" Table 24 by Woodward-Clyde Consultants.

(3) Flood frequency based on Figure 2, Regional Flood Frequency Curves.

(4) Sediment yields derived by Ernest Pemberton based on regional sediment yields of 0.03 ac-ft/sq mi.

# TABLE 3
# PRE-MINING CHANNEL HYDRAULIC CHARACTERISTICS

| Basin Number | Channel Thalweg Slope (%) | | Dominant Discharge (Q) Near Mouth | | | |
|---|---|---|---|---|---|---|
| | Average | Lower Reach [1] | Flow (cfs) | Width (ft) | Depth (ft) | Velocity (ft/sec) |
| 3 | 11.1% | 15.5% | 9.5 | 8 | 0.3 | 3.1 |
| 29 | 9.7% | 4.8% | 4.9 | 6 | 0.3 | 2.9 |
| 32 | 8.5% | 4.0% | 13.3 | 10 | 0.4 | 3.2 |
| 35 | 5.3% | 5.6% | 64.0 | 22 | 0.7 | 3.8 |
| 36 | 7.1% | 5.9% | 25.8 | 14 | 0.5 | 3.5 |
| 37 | 8.3% | 5.4% | 49.6 | 19 | 0.7 | 3.7 |
| 39 | 15.9% | 8.6% | 29.0 | 10 | 0.8 | 3.5 |
| 41 | 30.0% | 25.3% | 3.5 | 2 | 0.5 | 3.5 |

(1) This refers to the lowest reach potentially impacted by mining.

# TABLE 4
# EFFECTS OF SUBSIDENCE ON STREAM CHANNELS

| Basin Number | Pre-Mining Slope (%) | | Maximum Subsidence (E-seam + B-seam)[2] (ft) | Change in Slope | | Post-Mining Slope [3] | |
|---|---|---|---|---|---|---|---|
| | Average | Lower Reach [1] | | Maximum Negative | Maximum Positive | Minimum | Maximum |
| 3 | 11.1% | 15.5% | 8.3 | -2.9% | 10.6% | 4.8% | 18.3% |
| 29 | 9.7% | 4.8% | 14.7 | -5.1% | 2.0% | 2.8% | 9.9% |
| 32 | 8.5% | 4.0% | 14.3 | -3.5% | 2.4% | 1.6% | 7.5% |
| 35 | 5.3% | 5.6% | 15.2 | -2.1% | 3.5% | 2.1% | 7.7% |
| 36 | 7.1% | 5.9% | 6.5 | -4.4% | 2.3% | 3.7% | 10.3% |
| 37 | 8.3% | 5.4% | 13.4 | -3.0% | 1.7% | 3.7% | 8.4% |
| 39 | 15.9% | 8.6% | 9.2 | -6.6% | 1.5% | 7.0% | 15.2% |
| 41 | 30.0% | 25.3% | 9.2 | -3.0% | 1.8% | 23.5% | 28.3% |

(1) This refers to the lowest reach potentially impacted by mining.

(2) Basins 3, 36, 39, and 41 are only affected by E-seam mining.

(3) Slope range given for lowest reach potentially impacted by mining.

## TABLE 5
## POST-MINING STREAM CHANNEL HYDRAULIC CHARACTERISTICS

| Basin Number | Flow (cfs) | Velocity (ft/sec) | Channel Size Near Mouth After Subsidence [1] | | Max. Projected Channel Size Changes [2] | |
|---|---|---|---|---|---|---|
| | | | Width (ft) | Depth (ft) | Width (ft) | Depth (ft) |
| 3 | 9.5 | 3.1 | 12 | 0.7 | 4 | 0.4 |
| 29 | 4.9 | 2.9 | 11 | 0.4 | 5 | 0.1 |
| 32 | 13.3 | 3.2 | 17 | 0.8 | 7 | 0.4 |
| 35 | 64.0 | 3.8 | 29 | 1.5 | 7 | 0.8 |
| 36 | 25.8 | 3.5 | 22 | 0.7 | 8 | 0.2 |
| 37 | 49.6 | 3.7 | 28 | 0.9 | 9 | 0.2 |
| 39 | 29.0 | 3.5 | 16 | 0.9 | 6 | 0.1 |
| 41 | 3.5 | 3.5 | 2 | 0.5 | 0 | 0.0 |

(1) Maximum values resulting from the maximum changes in slope due to subsidence.

(2) These values represent estimated maximum channel size changes for the subject basin.

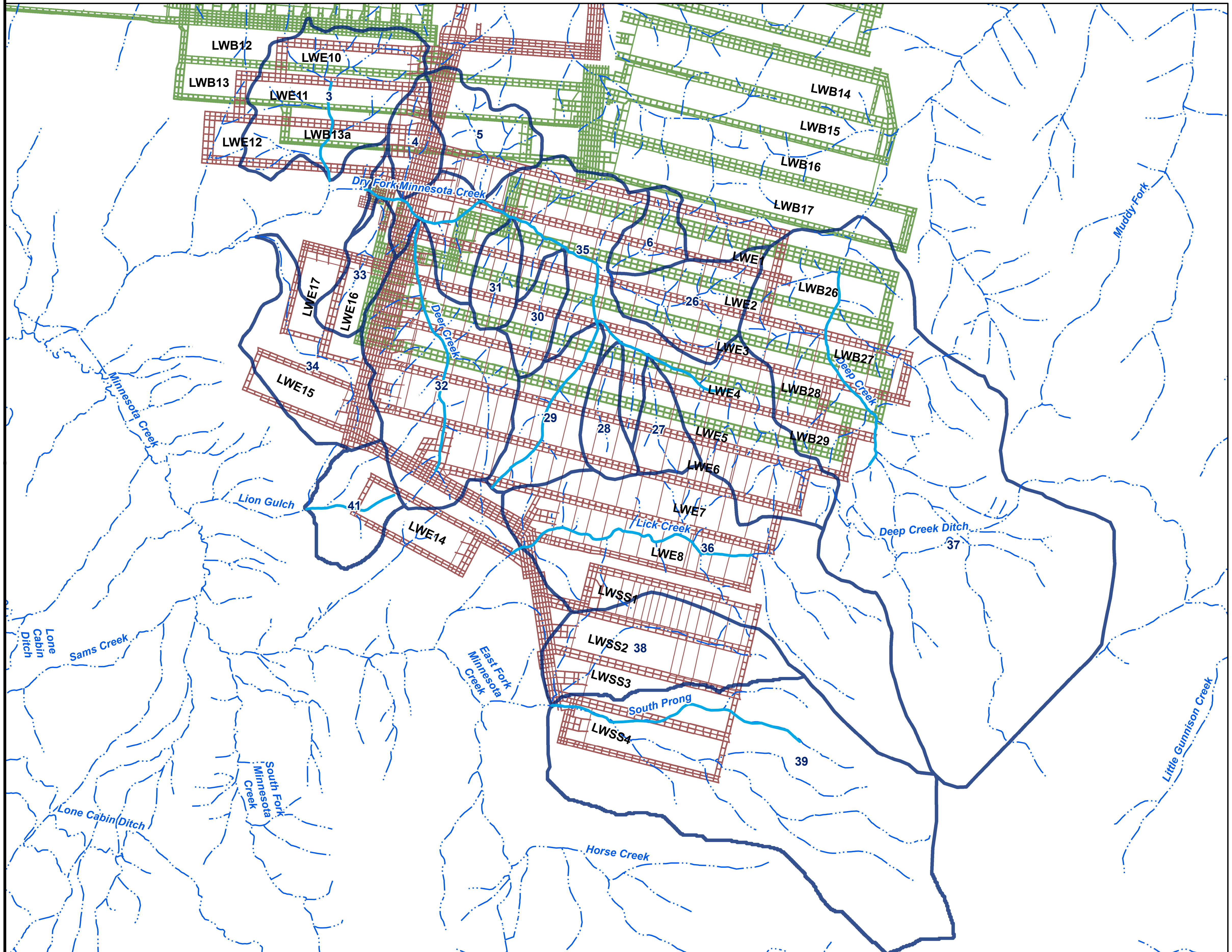
# FIGURES

# FIGURE 1

# EXHIBIT 55B STUDY BASINS

MOUNTAIN COAL COMPANY
WEST ELK MINE

DECEMBER 2021




Study Reach
Channel
Study Basin
E-Seam Minebase
B-Seam Minebase

SOURCES/NOTES:
1. E-Seam Minebase:
CAD drawing from MCC provided on 10/28/21.
2. Channel: NHD.
3. Study Reach, Study Basin: Drainages assessed for this iteration of Exhibit 55B.

N
W
E
S

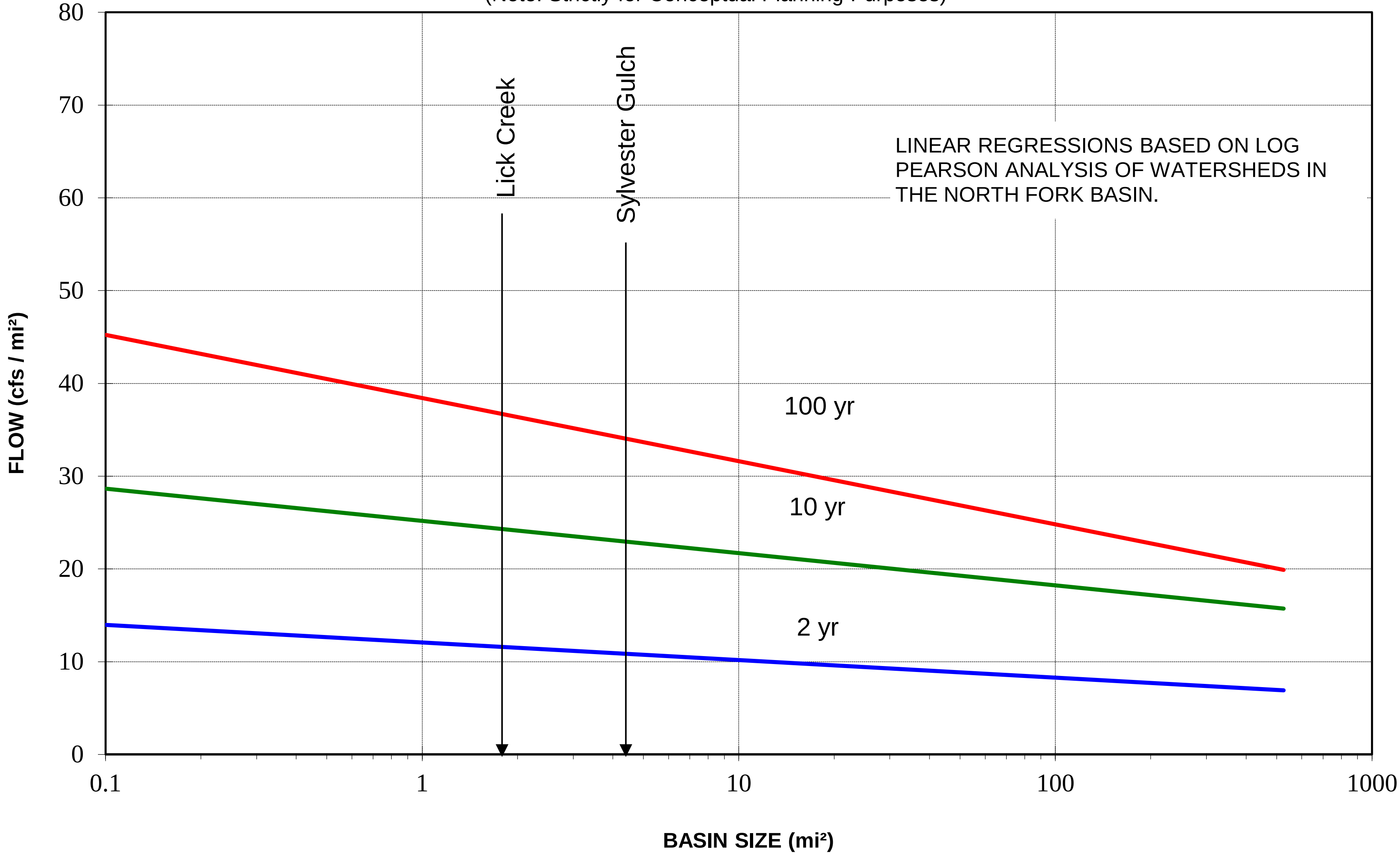
0 2,950 5,900
FEET

WWE
WRIGHT WATER ENGINEERS, INC.

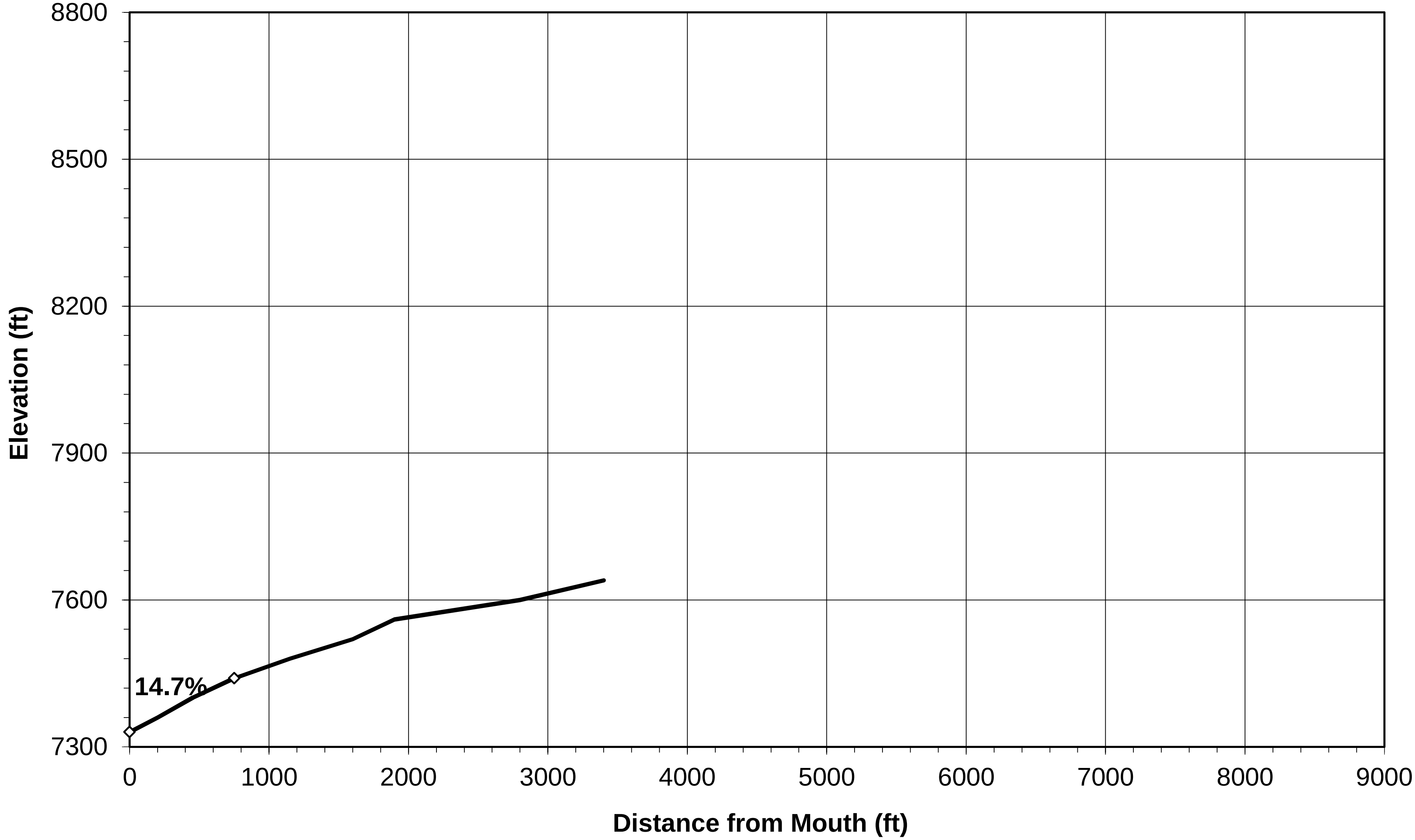
PROJECT NO. 831-032.923

**FIGURE 2**
**REGIONAL FLOOD FREQUENCY CURVES**

NORTH FORK OF THE GUNNISON RIVER BASIN
(Note: Strictly for Conceptual Planning Purposes)

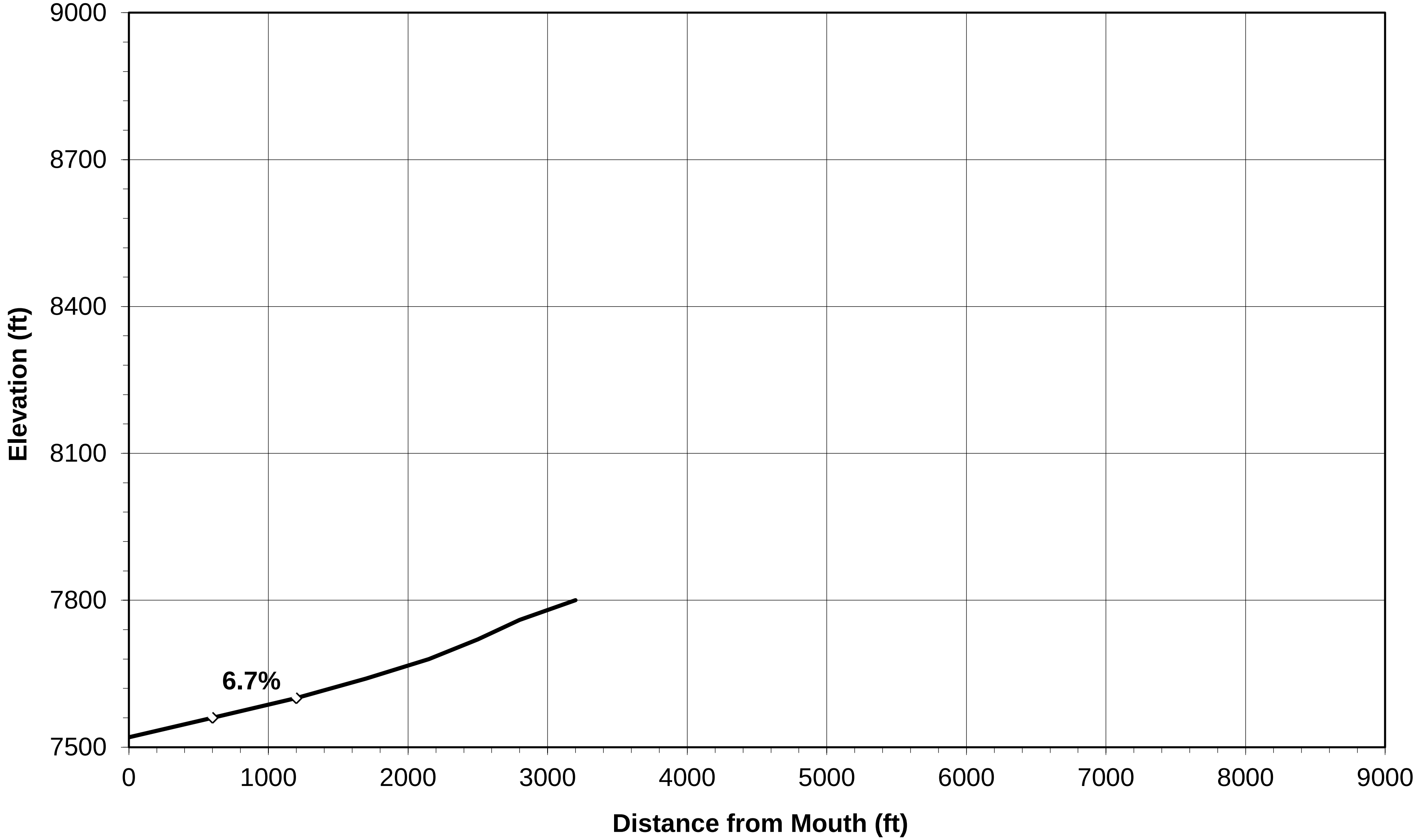


# FIGURE 3
# BASIN 3 CHANNEL PROFILE



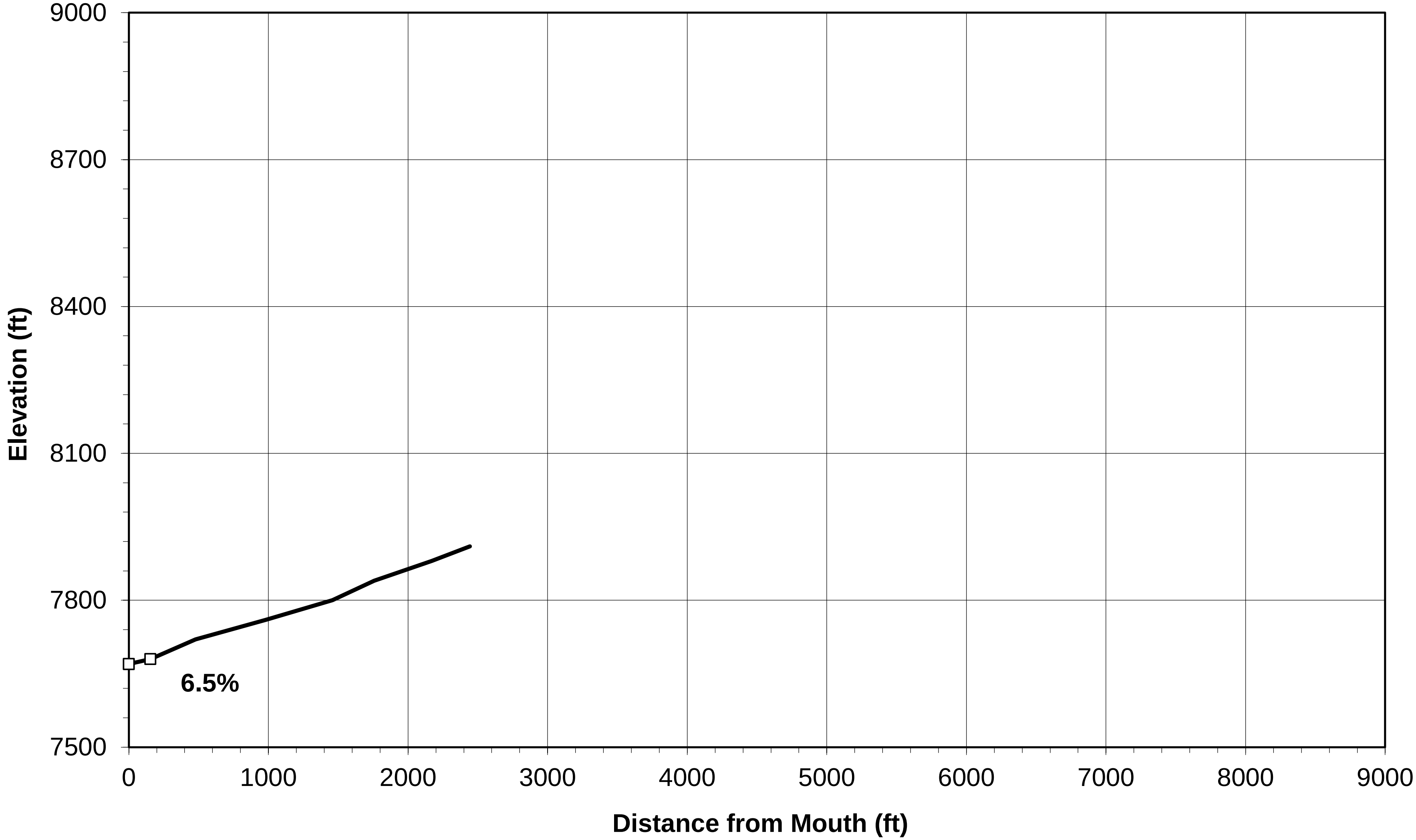

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

## FIGURE 4
## BASIN 5 CHANNEL PROFILE



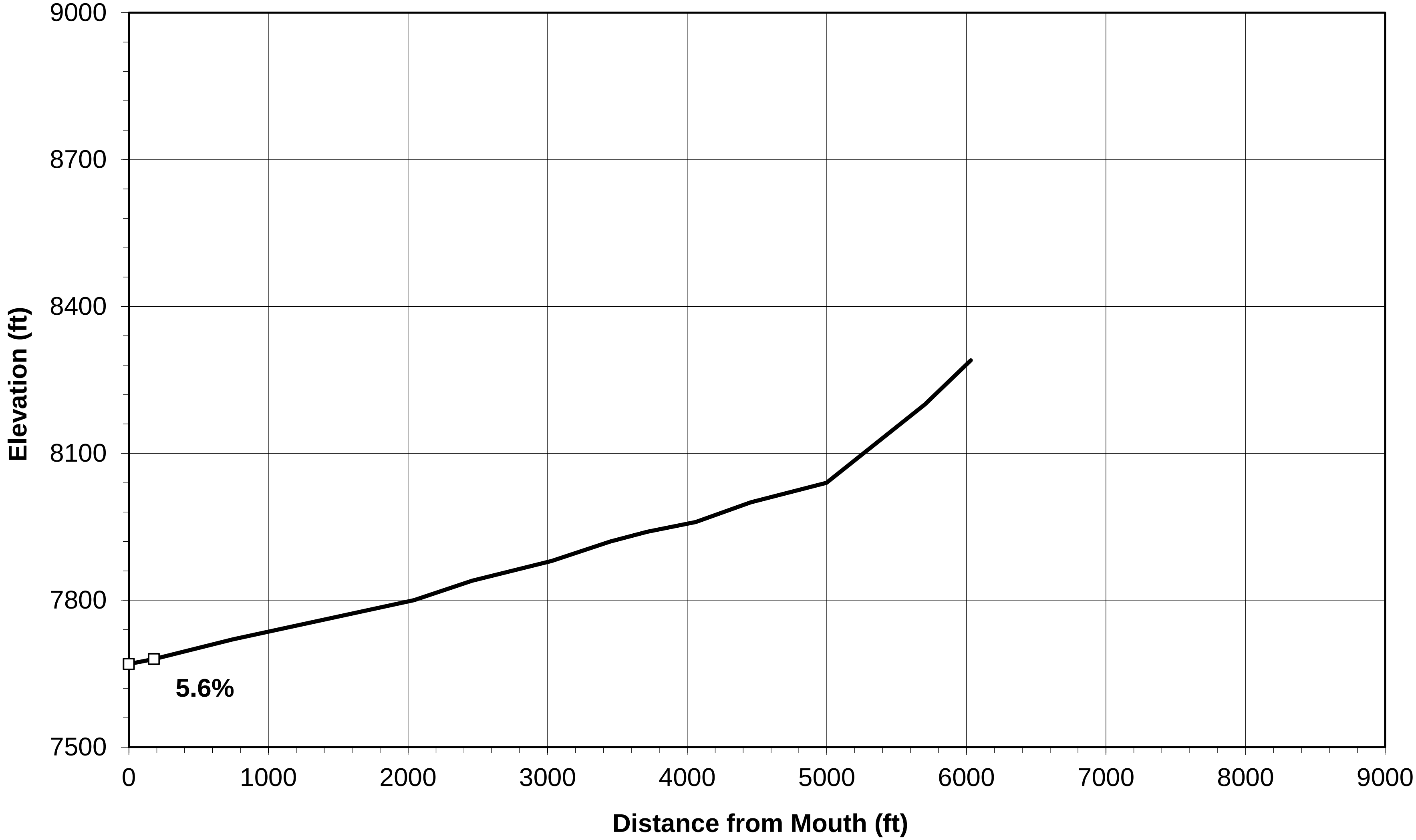

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

## FIGURE 5
## BASIN 6 CHANNEL PROFILE



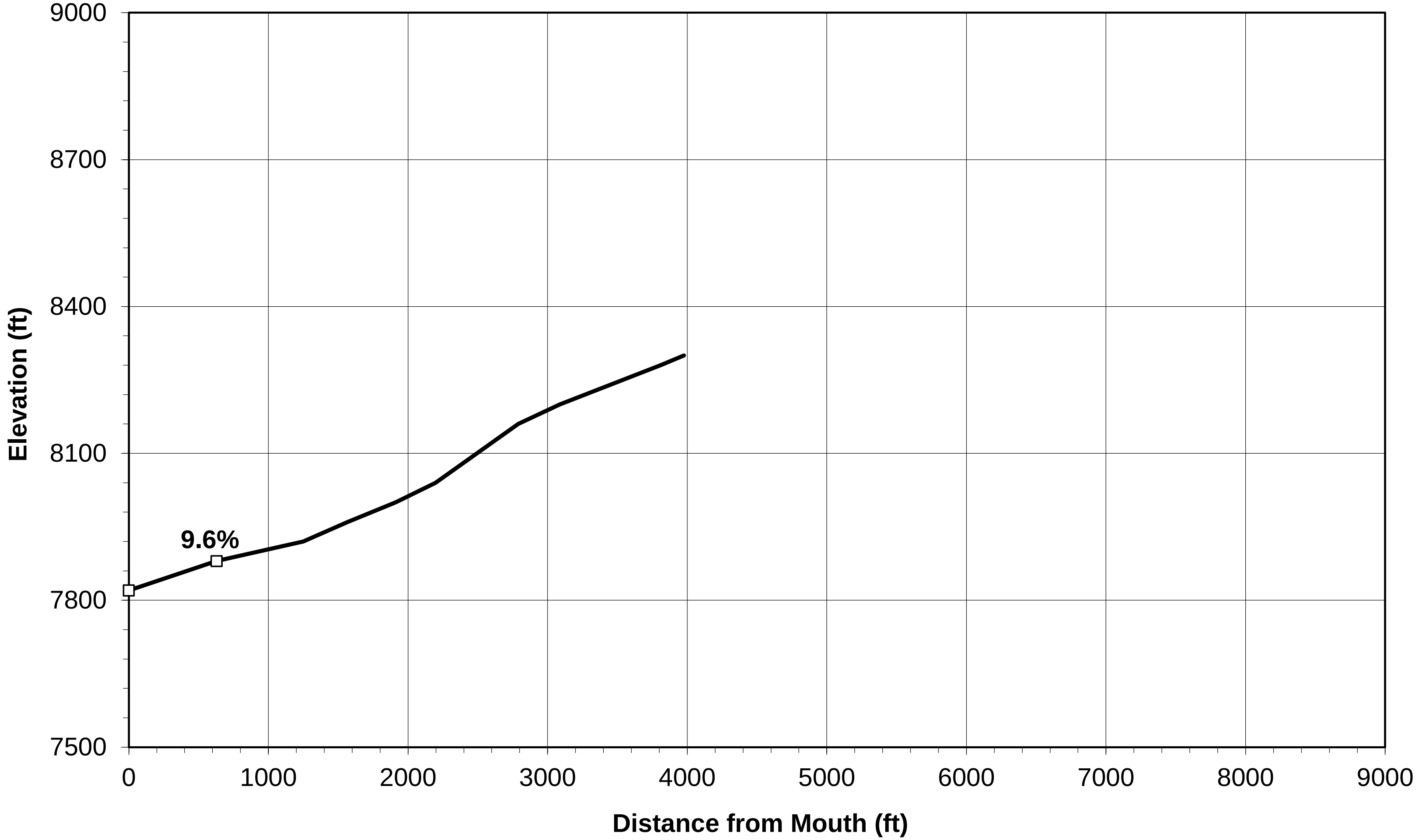

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

## FIGURE 6
## BASIN 26 CHANNEL PROFILE



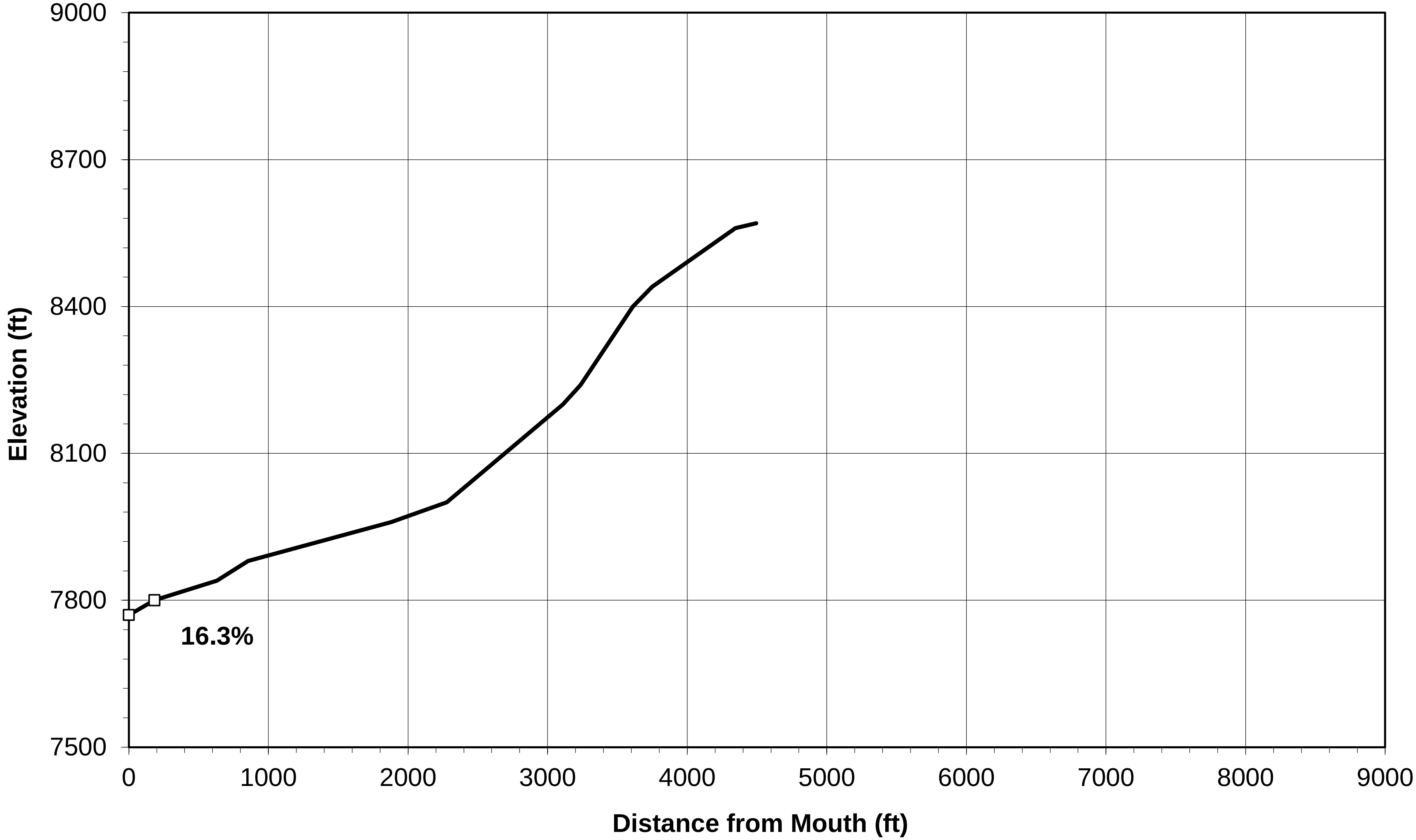

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

# FIGURE 7
# BASIN 27 CHANNEL PROFILE



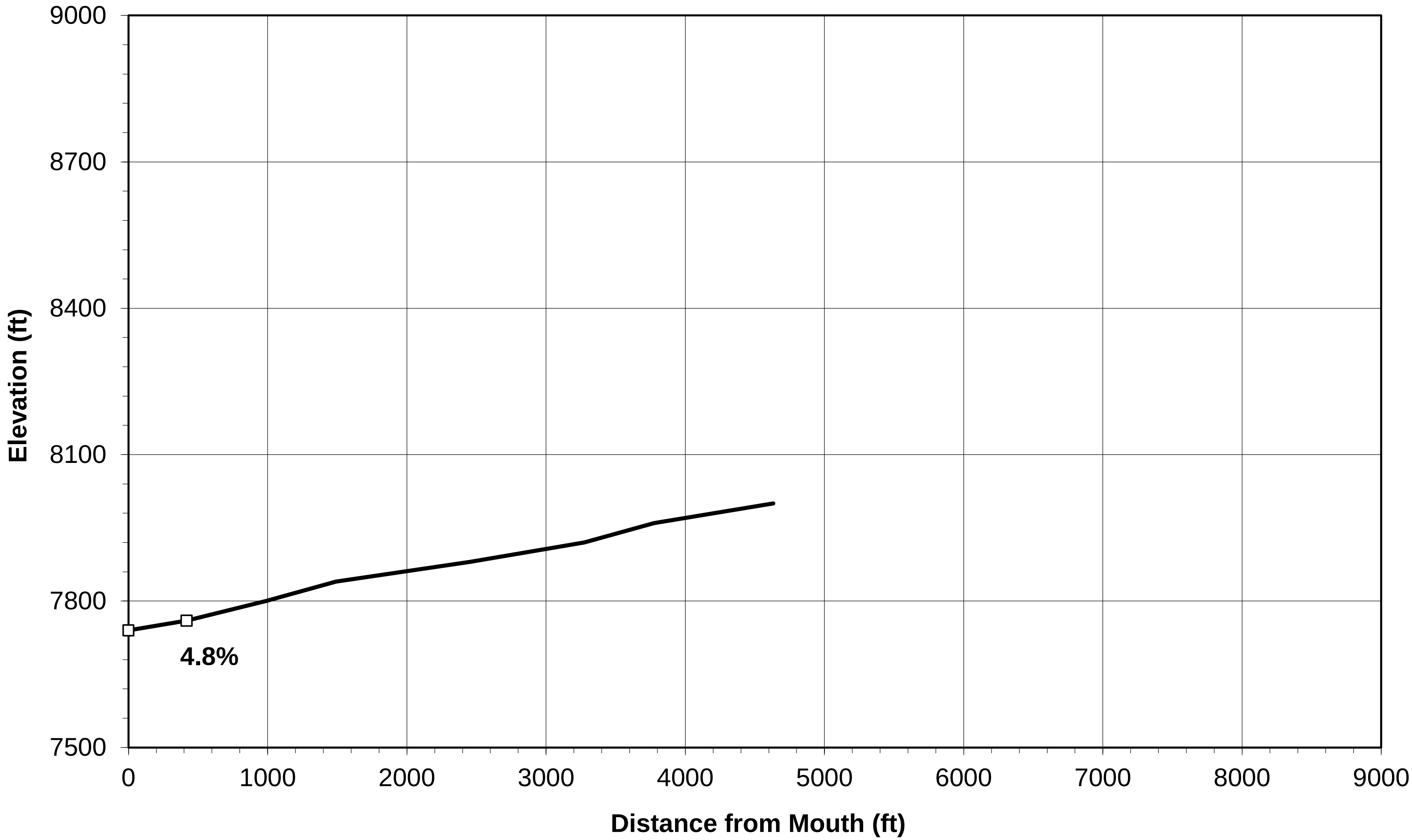

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

# FIGURE 8
# BASIN 28 CHANNEL PROFILE



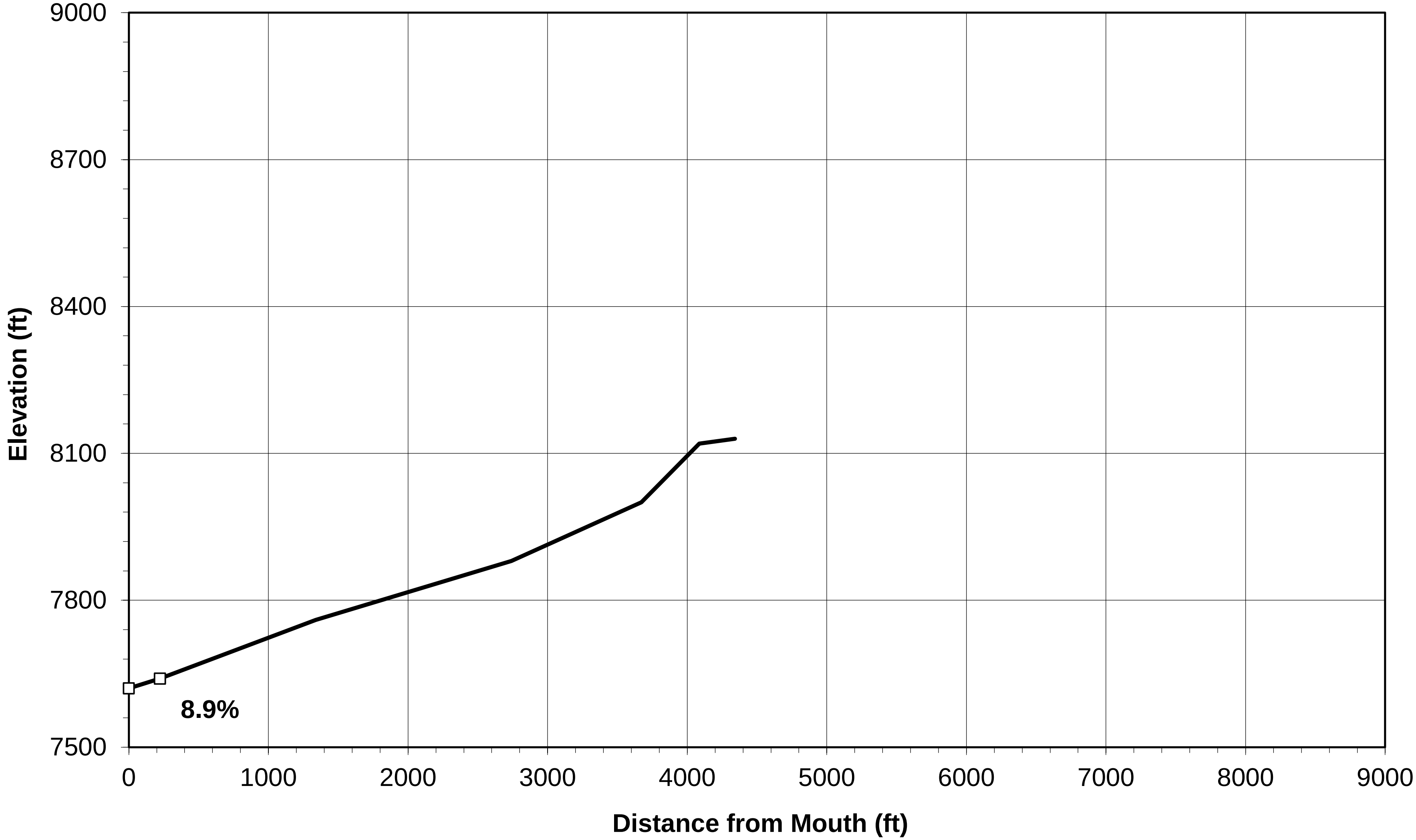

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

# FIGURE 9
# BASIN 29 CHANNEL PROFILE



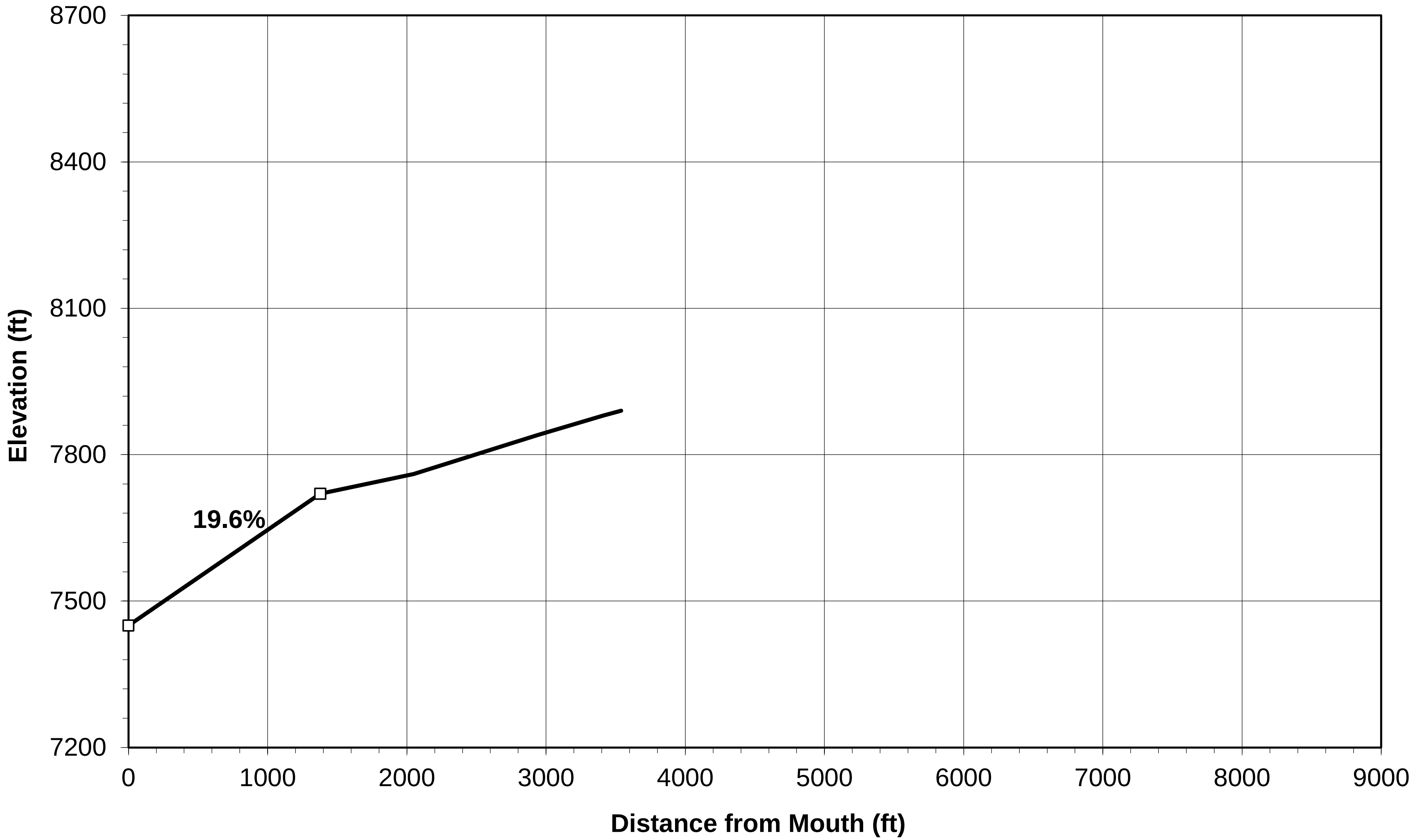

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

## FIGURE 10
## BASIN 30 CHANNEL PROFILE



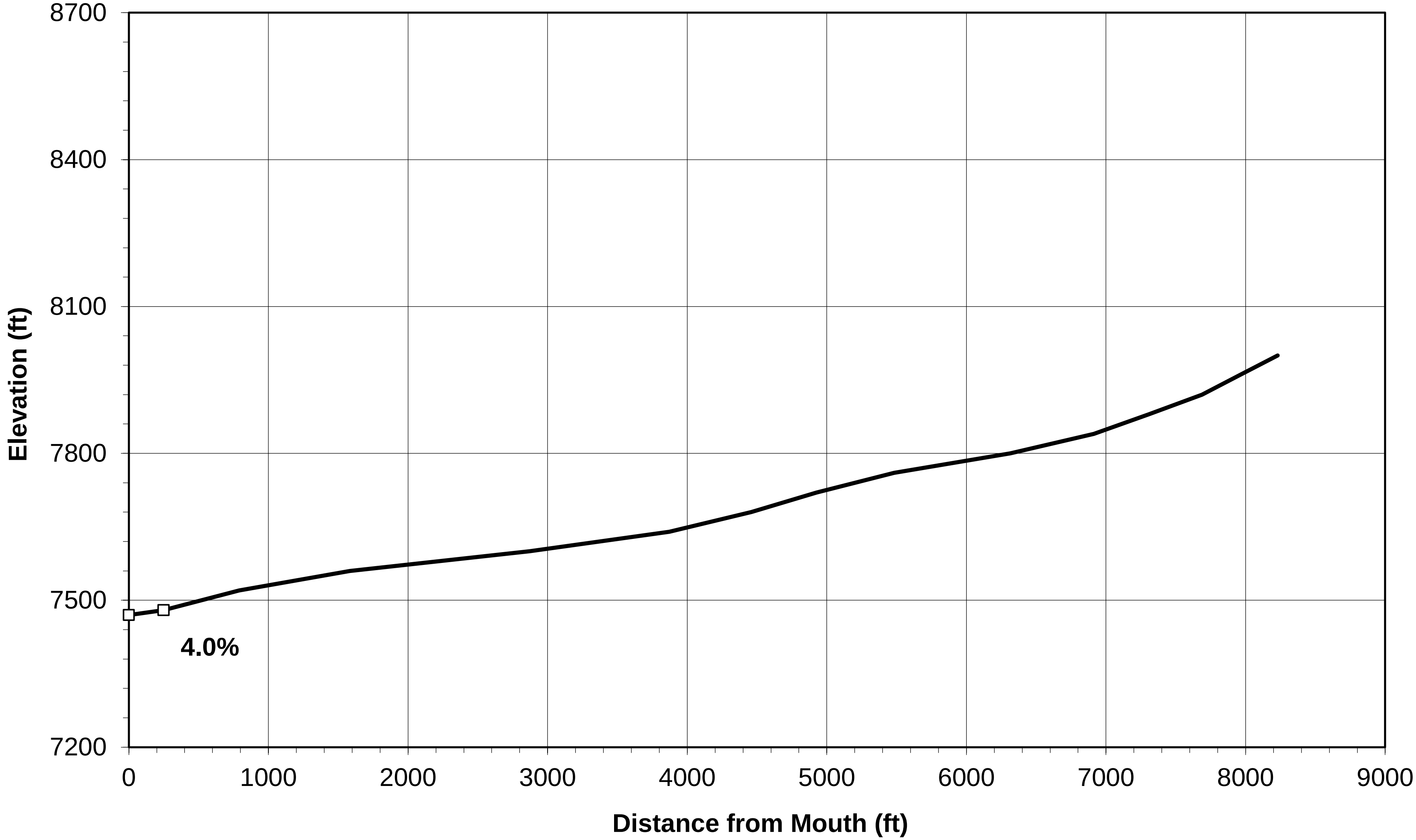

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

# FIGURE 11
# BASIN 31 CHANNEL PROFILE



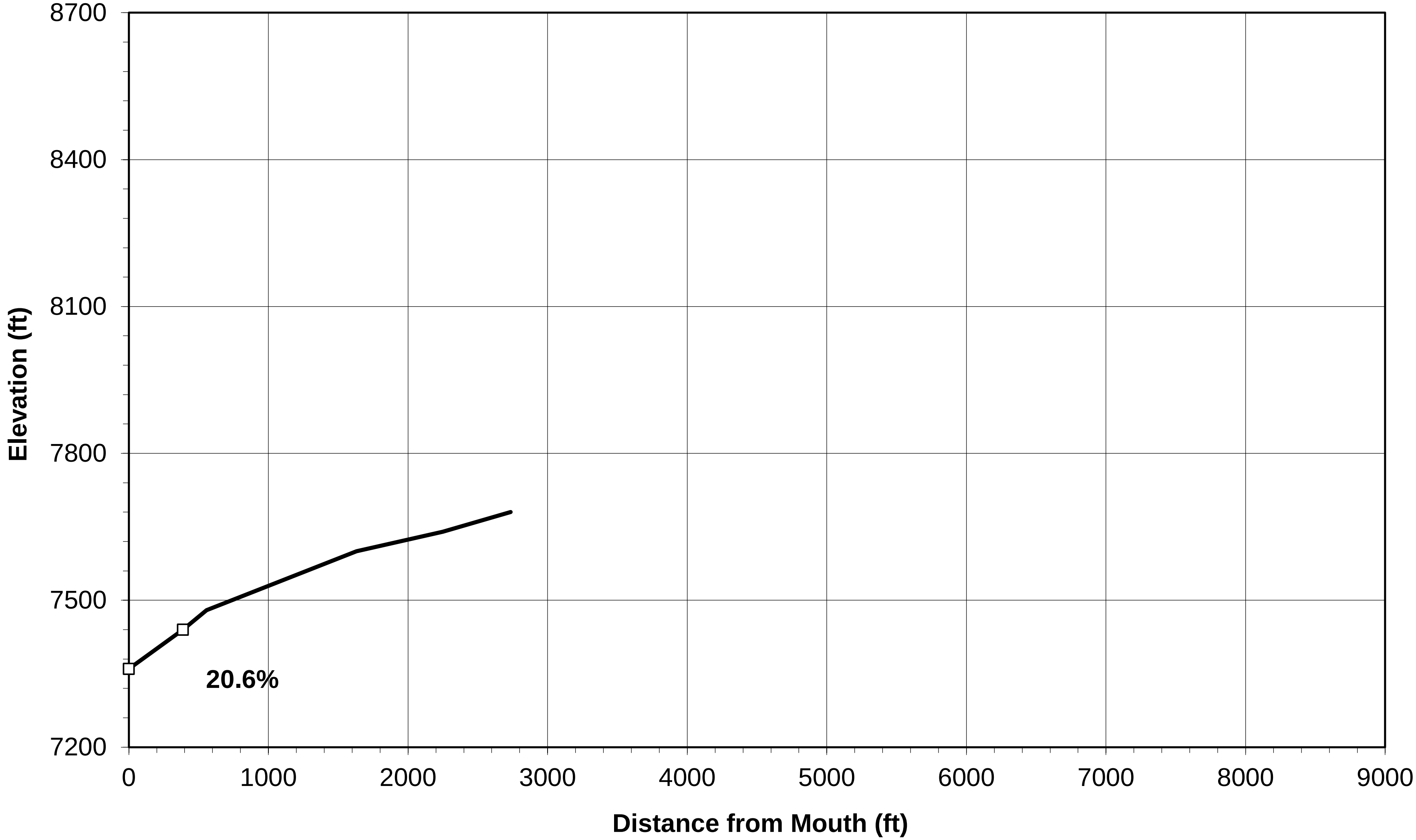

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

# FIGURE 12
# BASIN 32 CHANNEL PROFILE



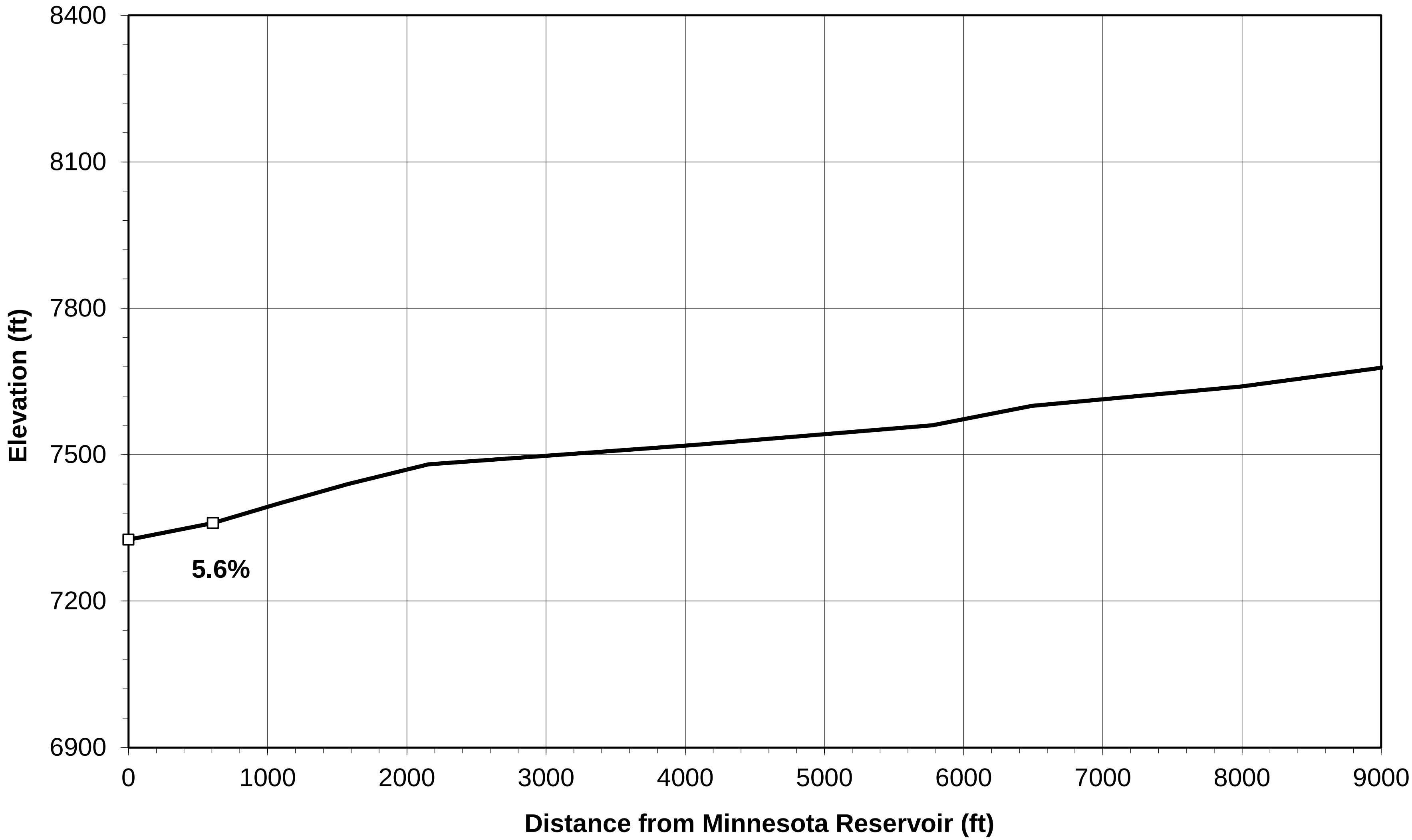

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

**FIGURE 13**
**BASIN 33 CHANNEL PROFILE**



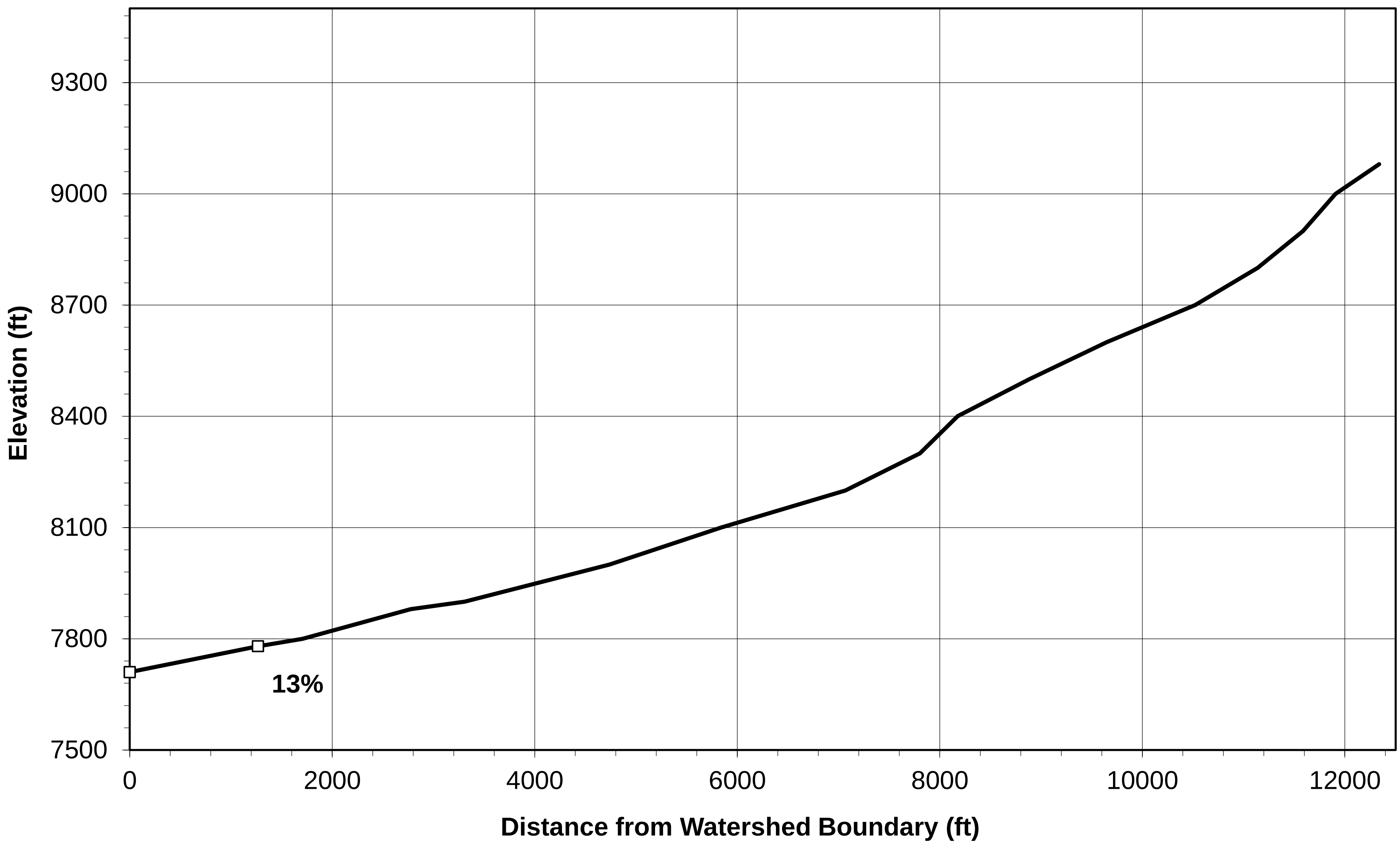

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

## FIGURE 14
## BASIN 35 CHANNEL PROFILE (Lower Reach)



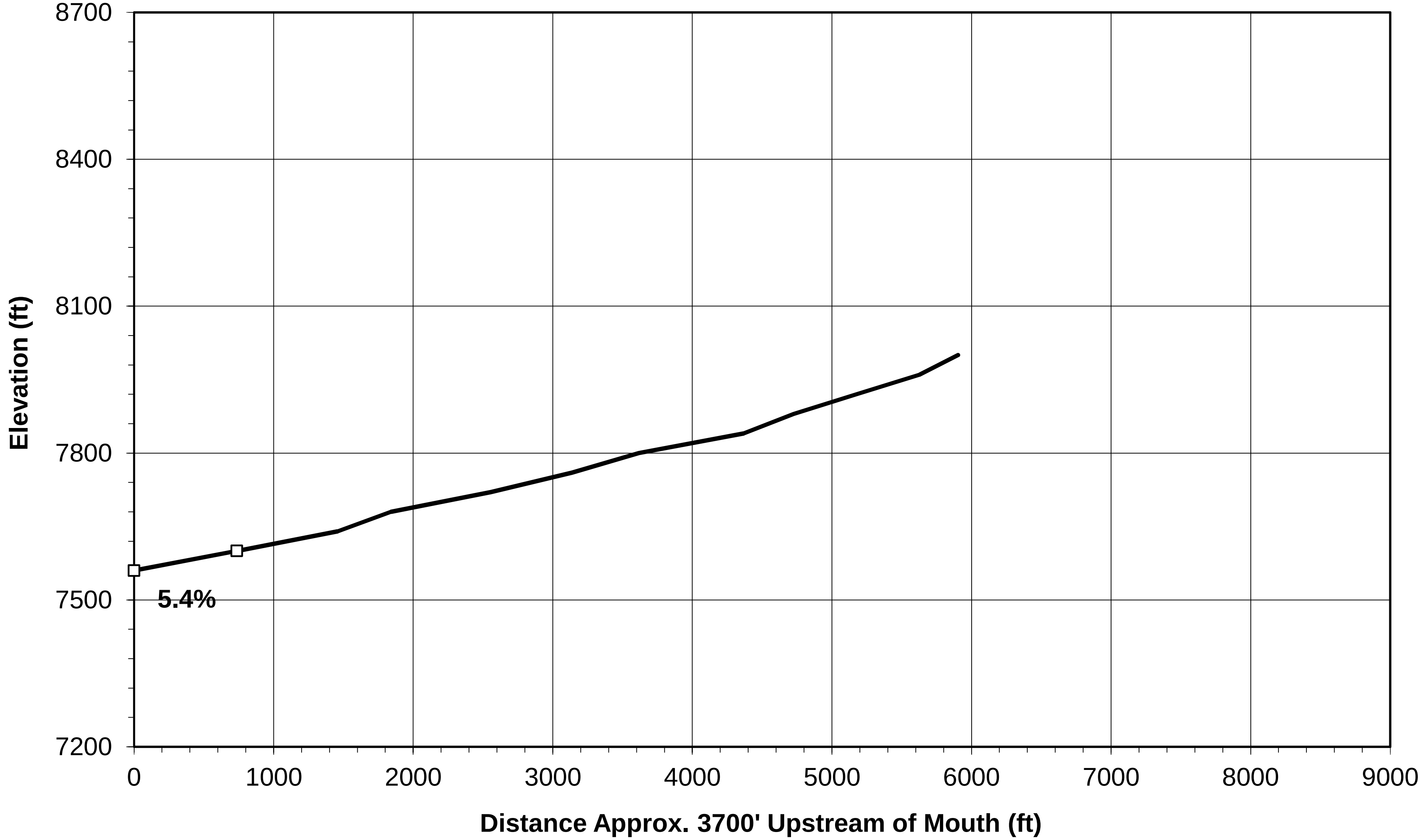

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

# FIGURE 15
# BASIN 36 PROFILE



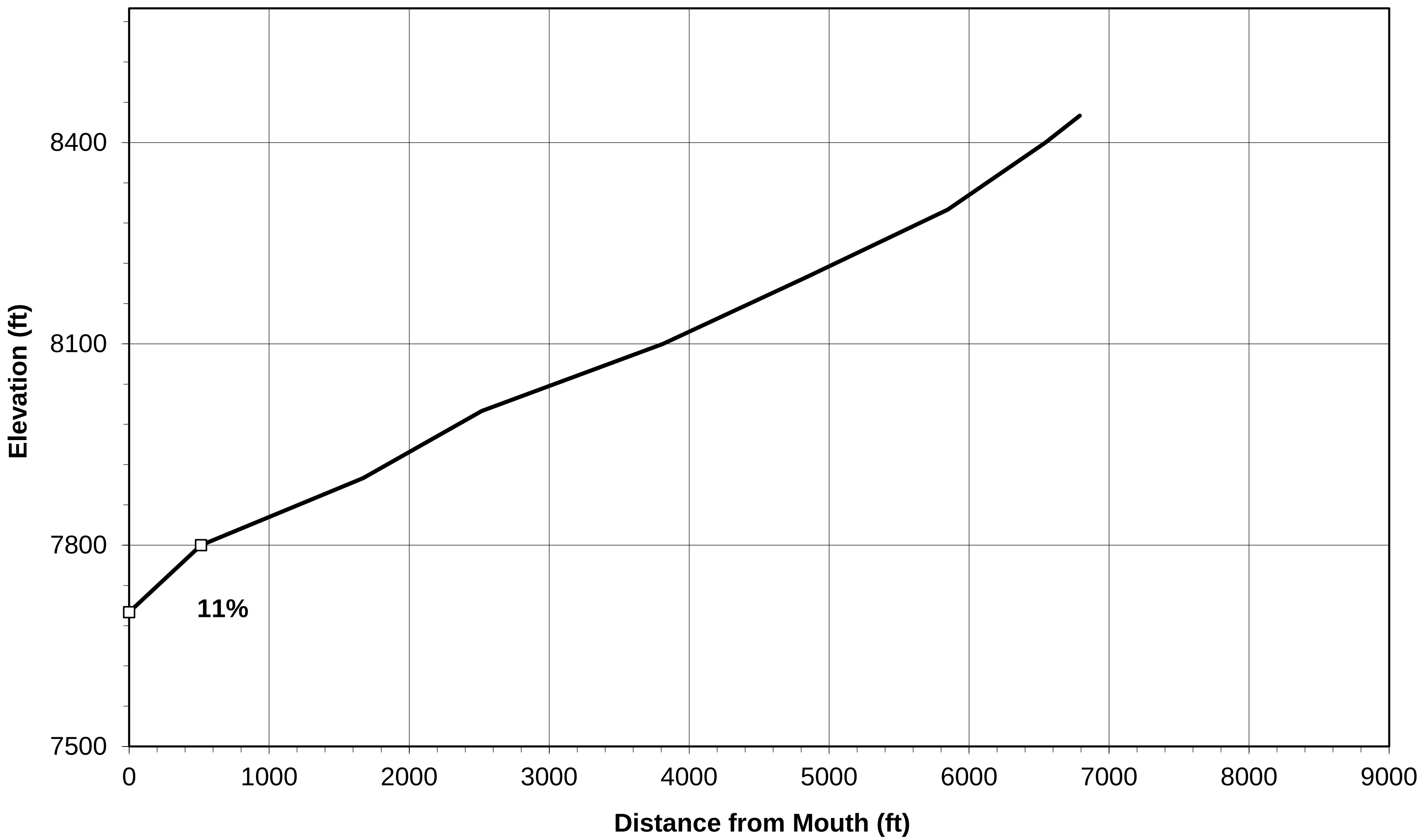

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

## FIGURE 16
## BASIN 37 DEEP CREEK CHANNEL PROFILE



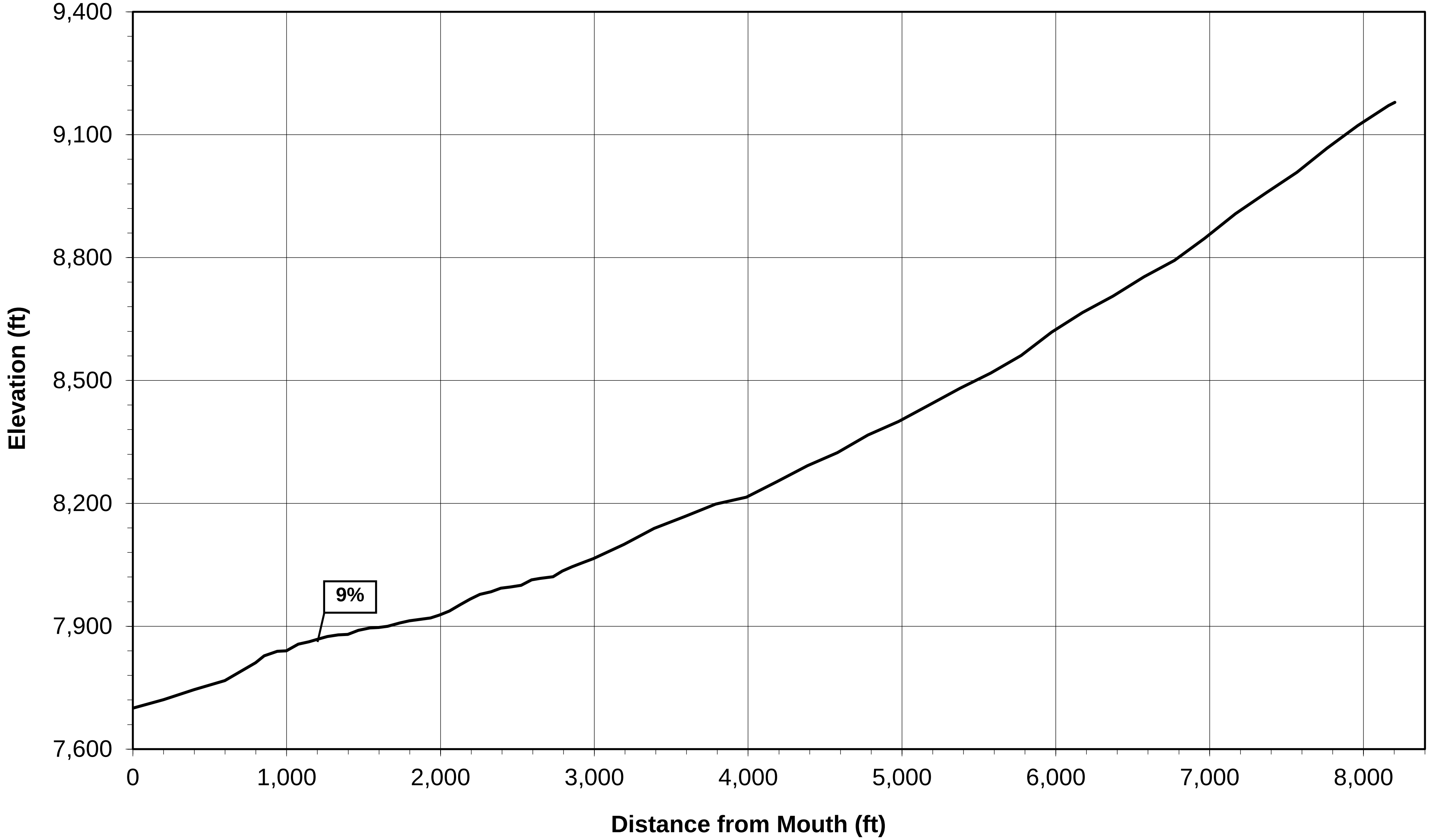

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

## FIGURE 17
## BASIN 38 CHANNEL PROFILE



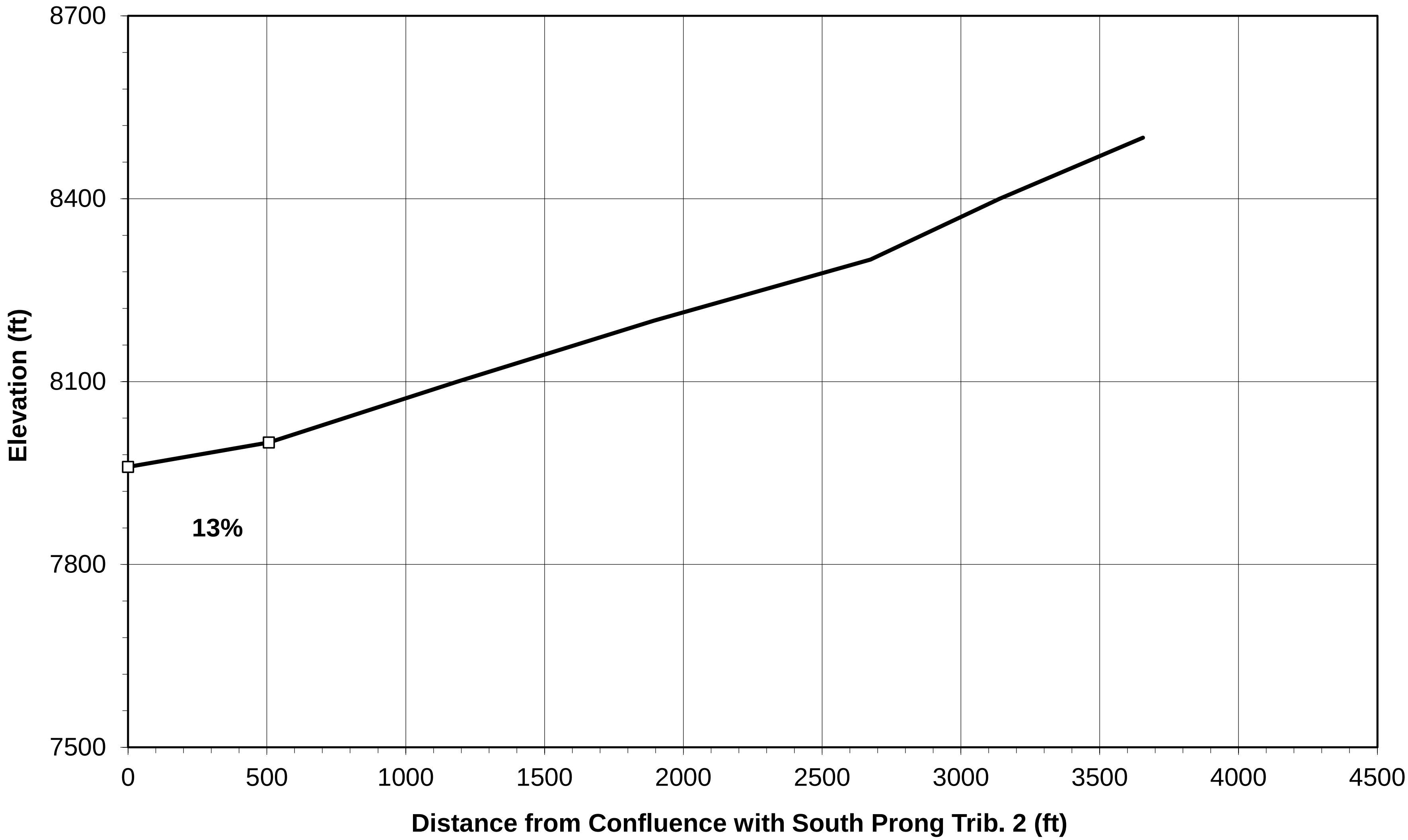

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

# FIGURE 18
# BASIN 39 SOUTH PRONG CHANNEL PROFILE



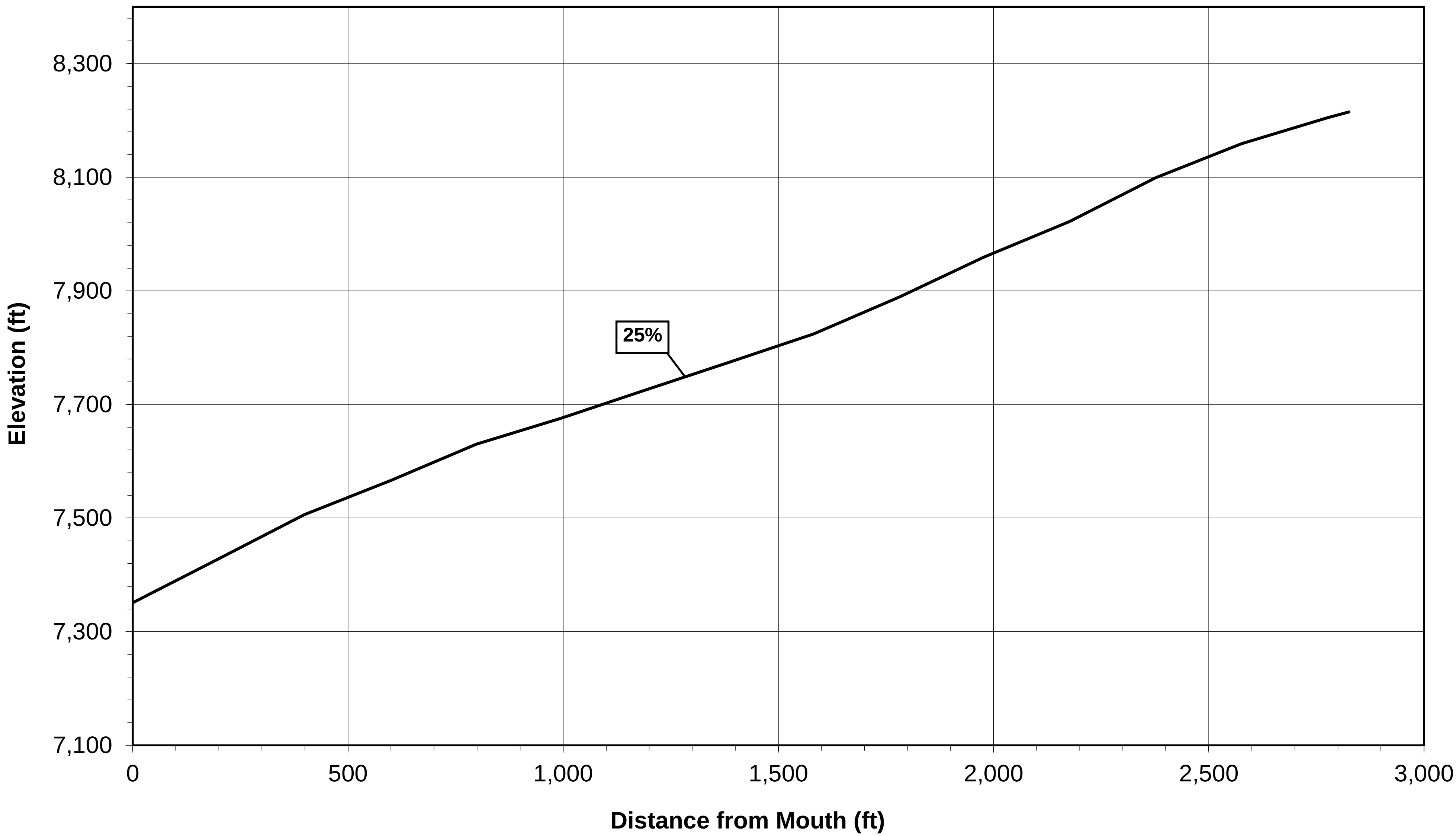

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.

## FIGURE 19
## BASIN 40 CHANNEL PROFILE



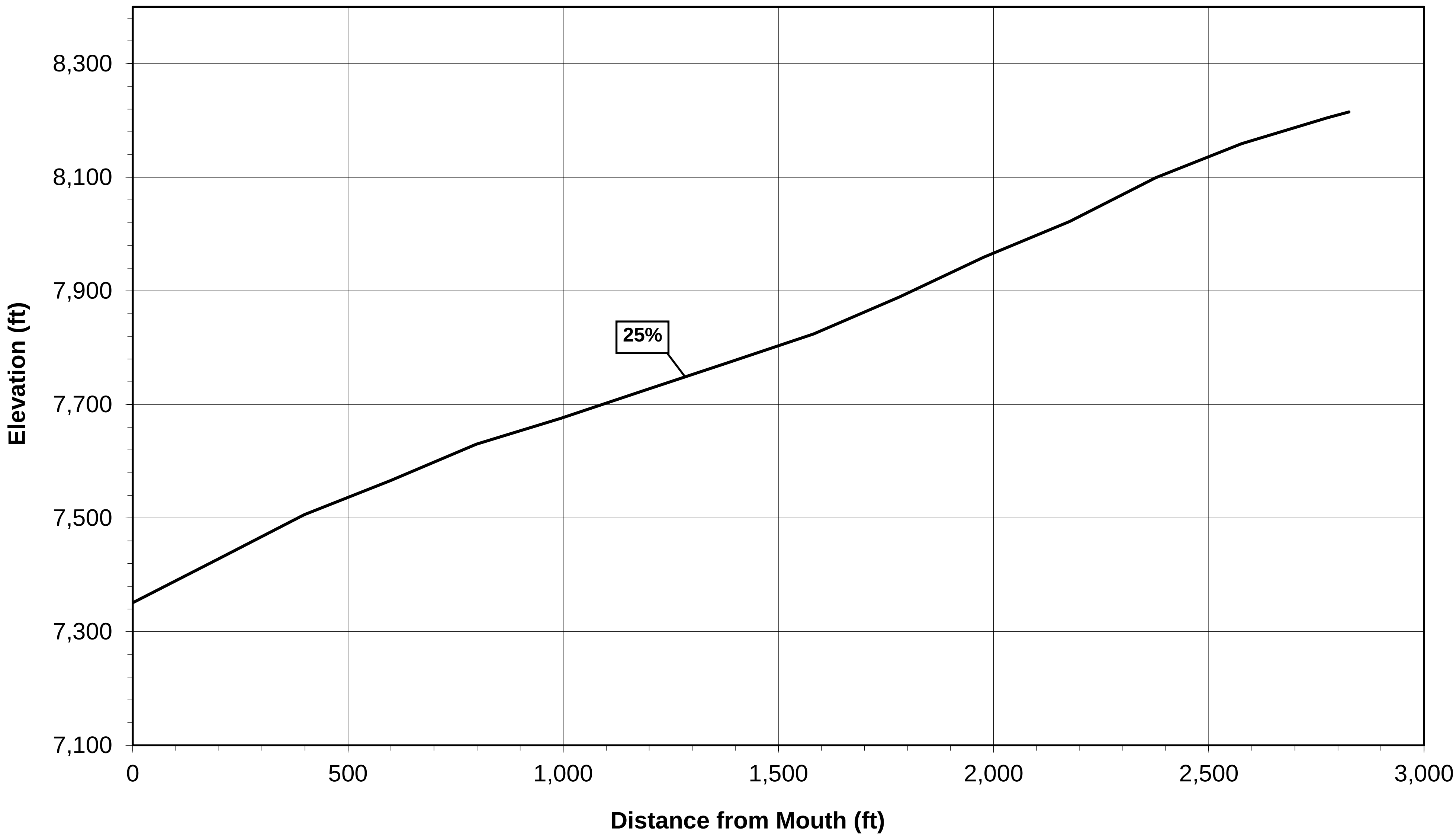

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.
Horizontal and vertical axes have been standardized to allow for graphical comparison of channel slopes.

## FIGURE 20
## BASIN 41 LION GULCH CHANNEL PROFILE



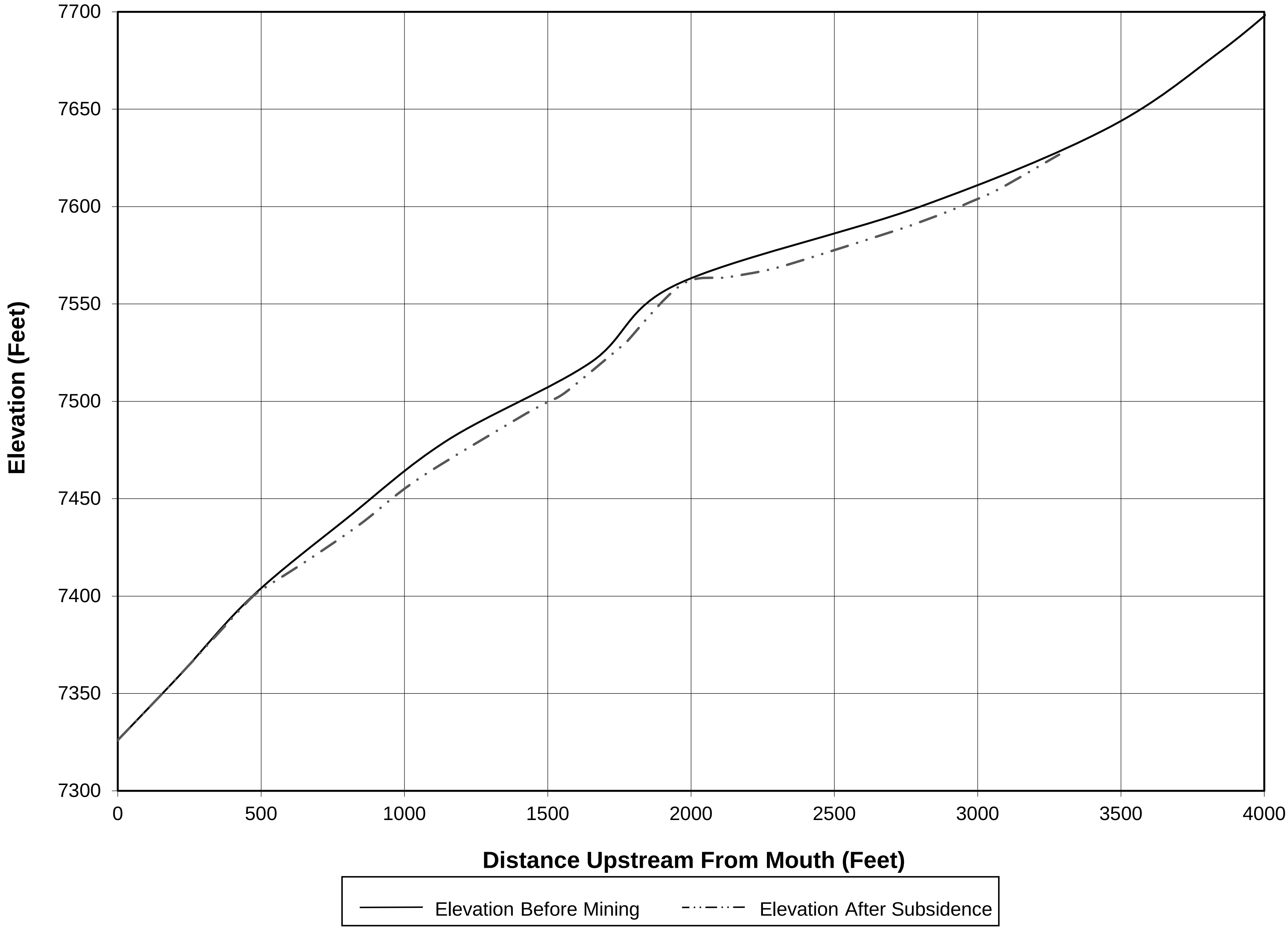

Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.

**FIGURE 20**
**BASIN 41 CHANNEL PROFILE**




Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.

# Figure 21
# Basin 3 - Horse Gulch Channel Profile Before and After Mining

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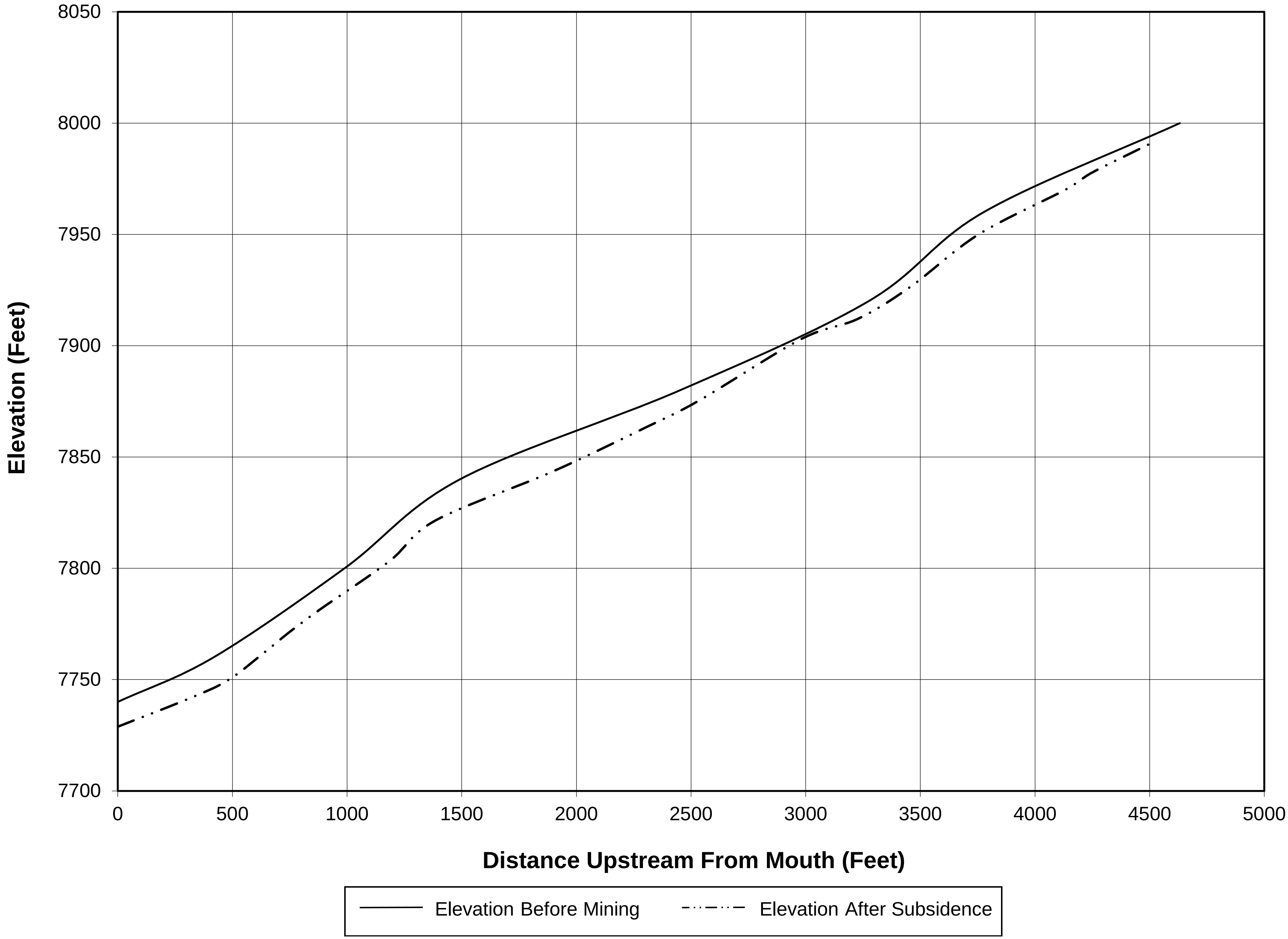
Basin 3.xlsx

# Figure 22
# Basin 29 - Poison Creek Channel Profile Before and After Mining

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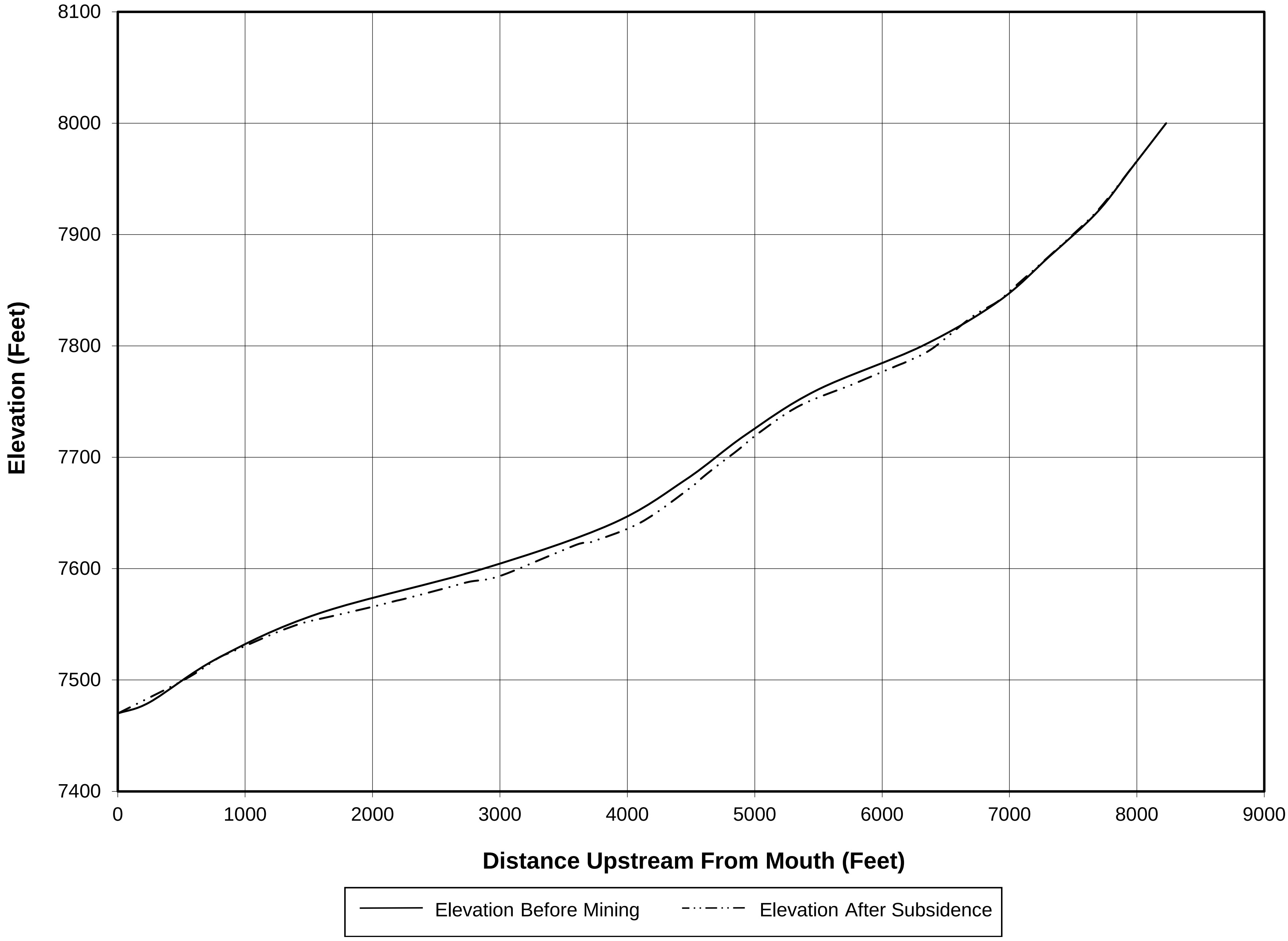
Basin 29.xlsx

**Figure 23**
**Basin 32 - Deer Creek Channel Profile Before and After Mining**

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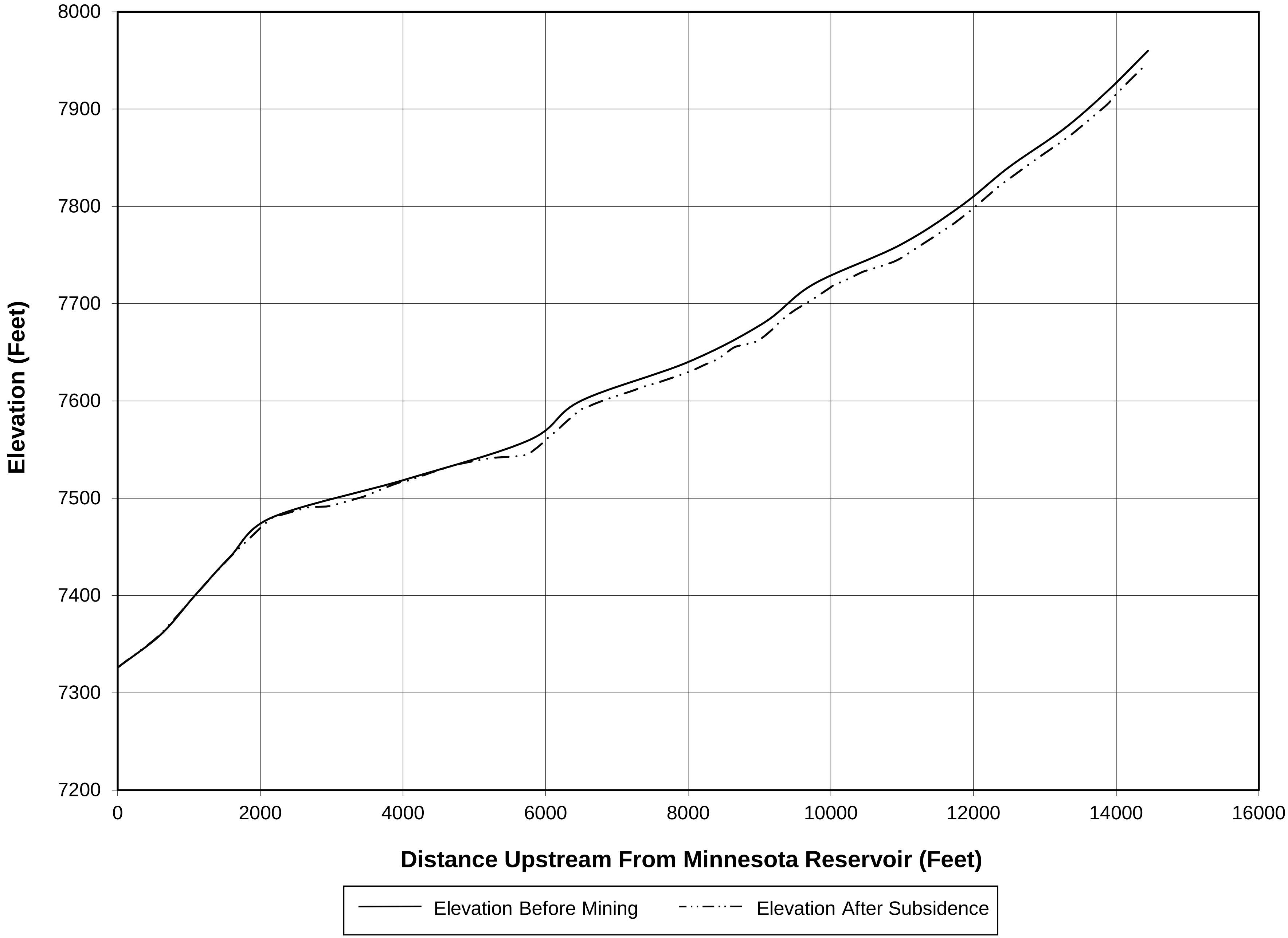
Basin 32.xlsx

# Figure 24
# Basin 35 - Dry Fork Channel Profile Before and After Mining

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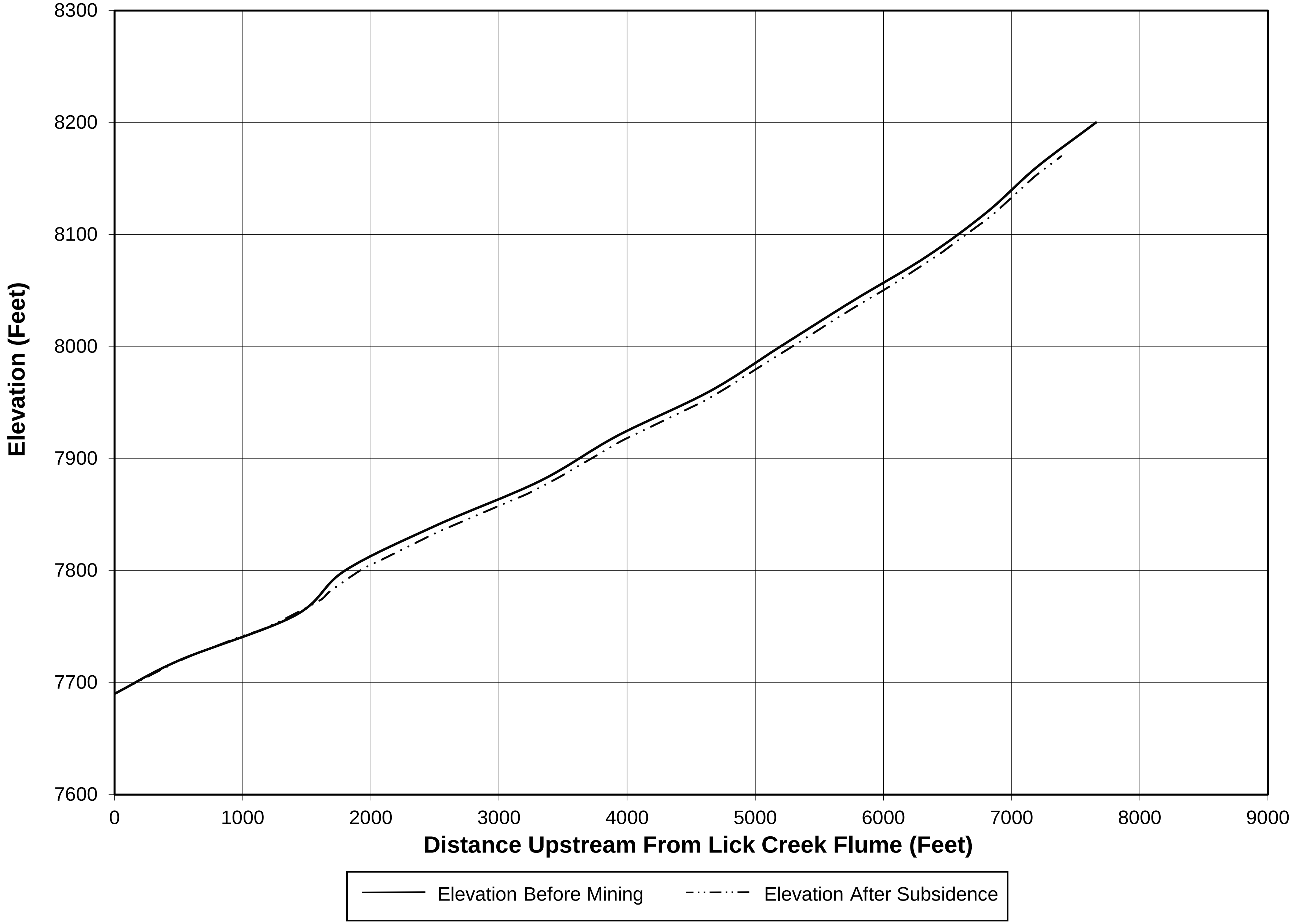
Basin 35.xlsx

# Figure 25
# Basin 36 - Lick Creek Channel Profile Before and After Mining

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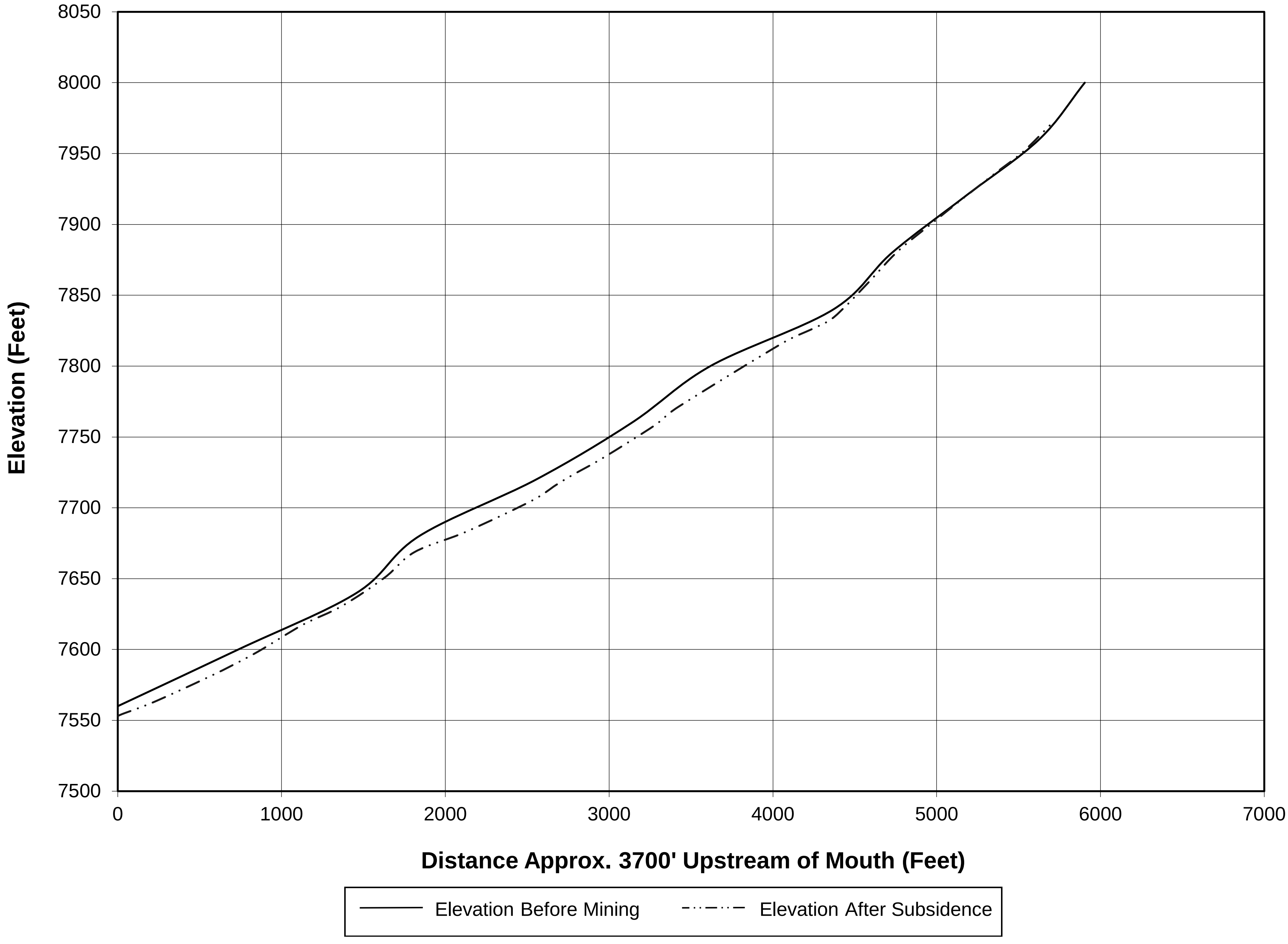
Basin 36.xlsx

## Figure 26
## Basin 37 - Deep Creek Channel Profile Before and After Mining

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Basin 37.xlsx

**FIGURE 27A**
**Basin 39 - South Prong Channel Before and After Mining - Full Extent**

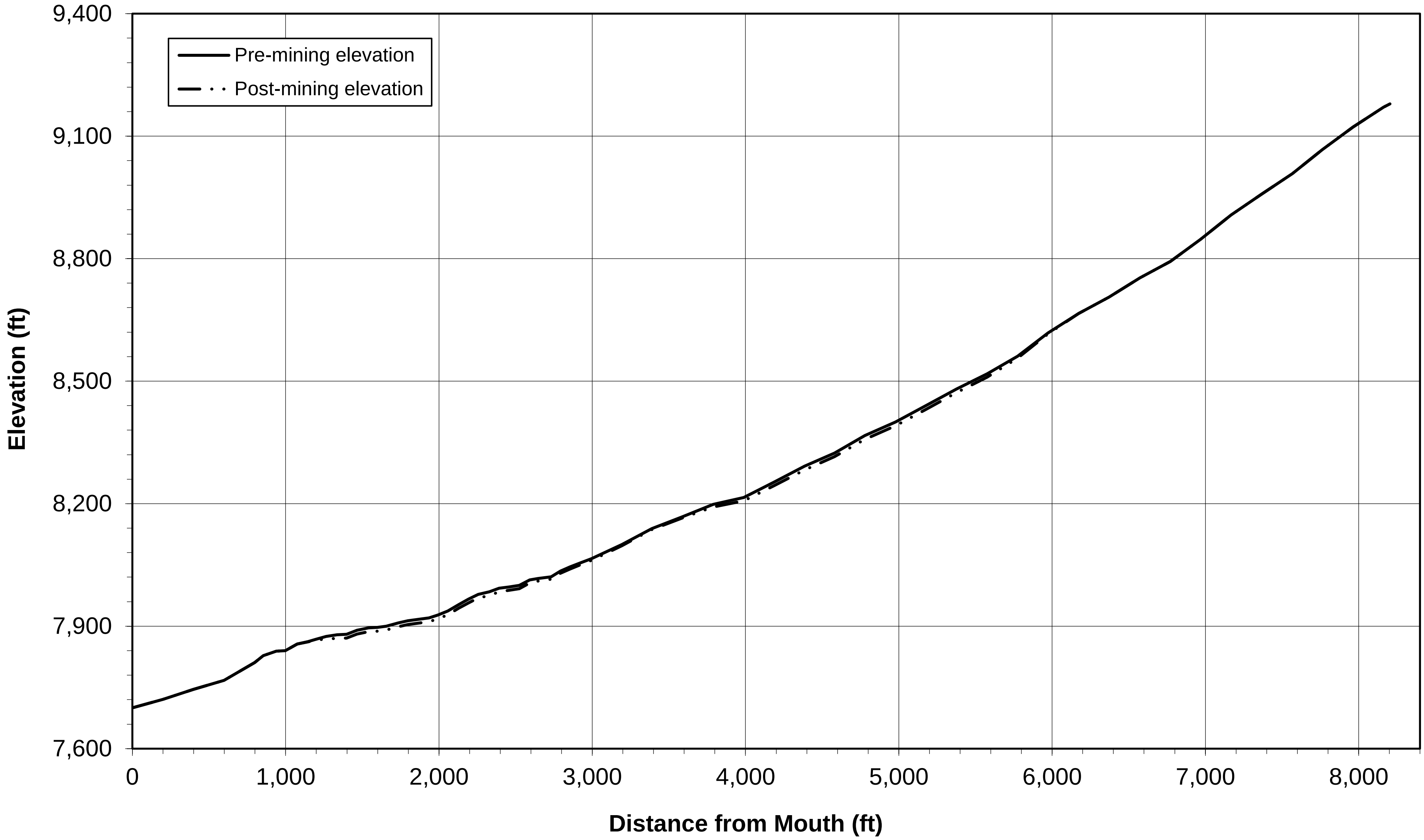
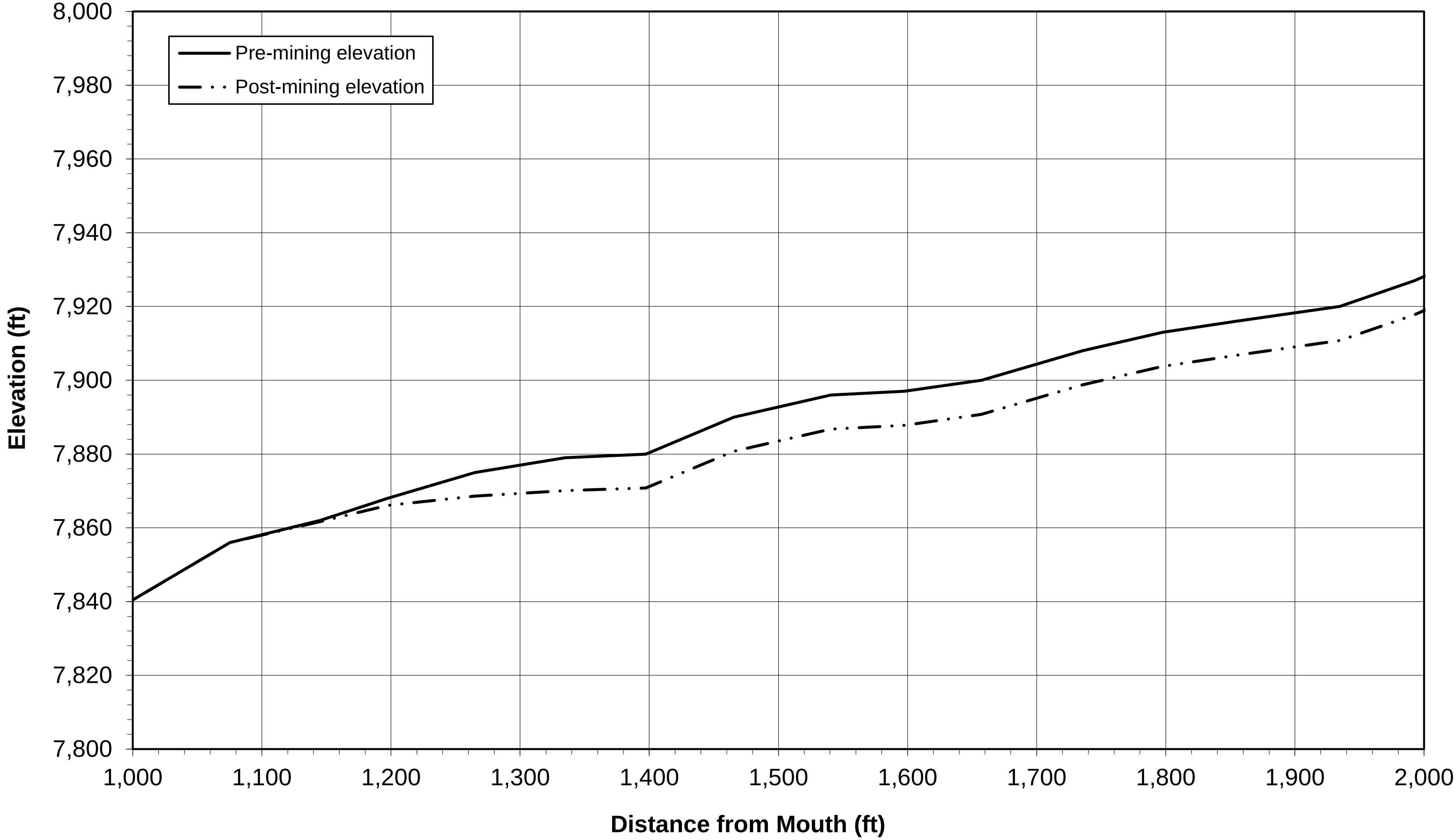
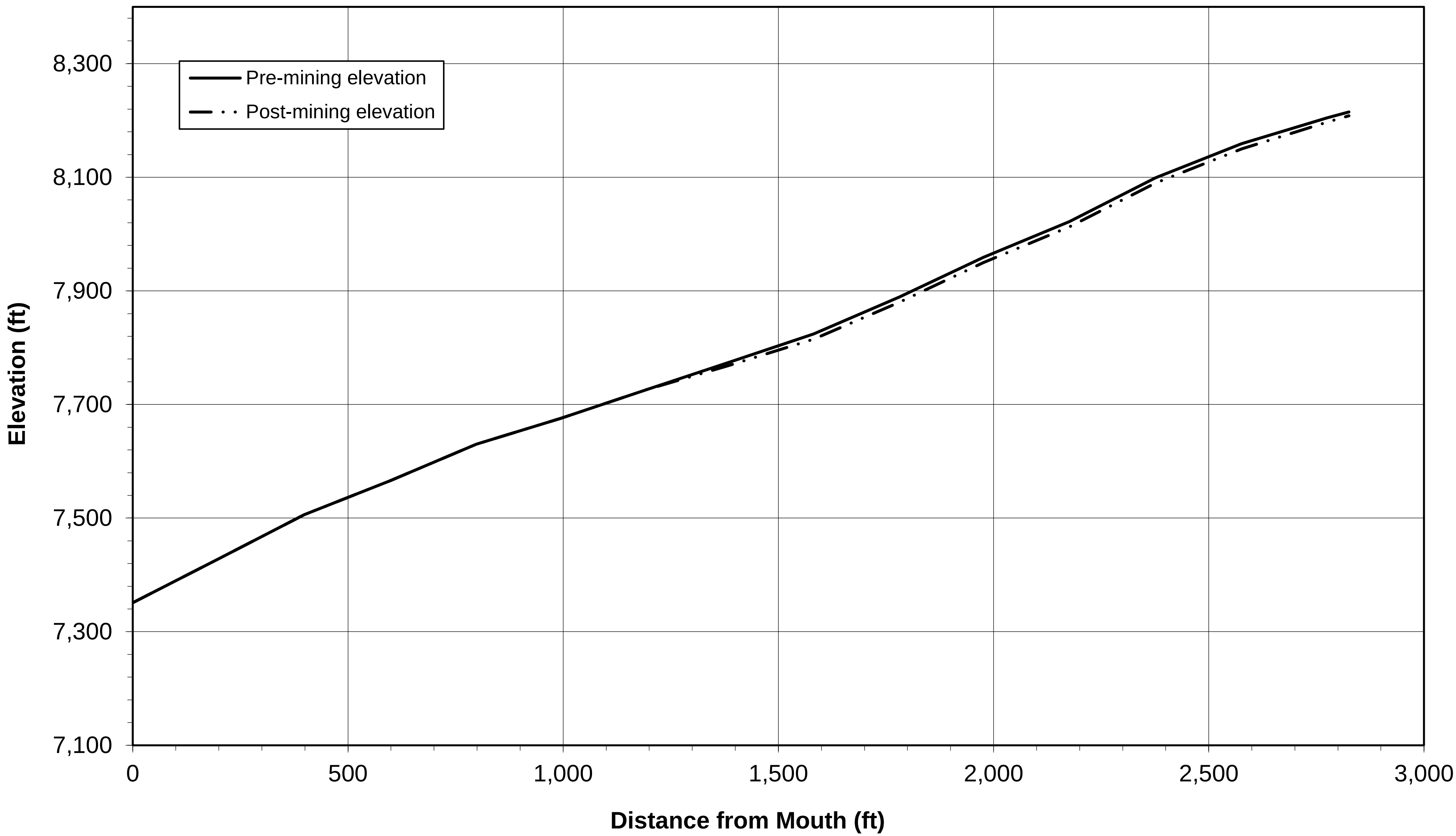


**FIGURE 27B**
**Basin 39 - South Prong Channel Before and After Mining - Critical Reach**

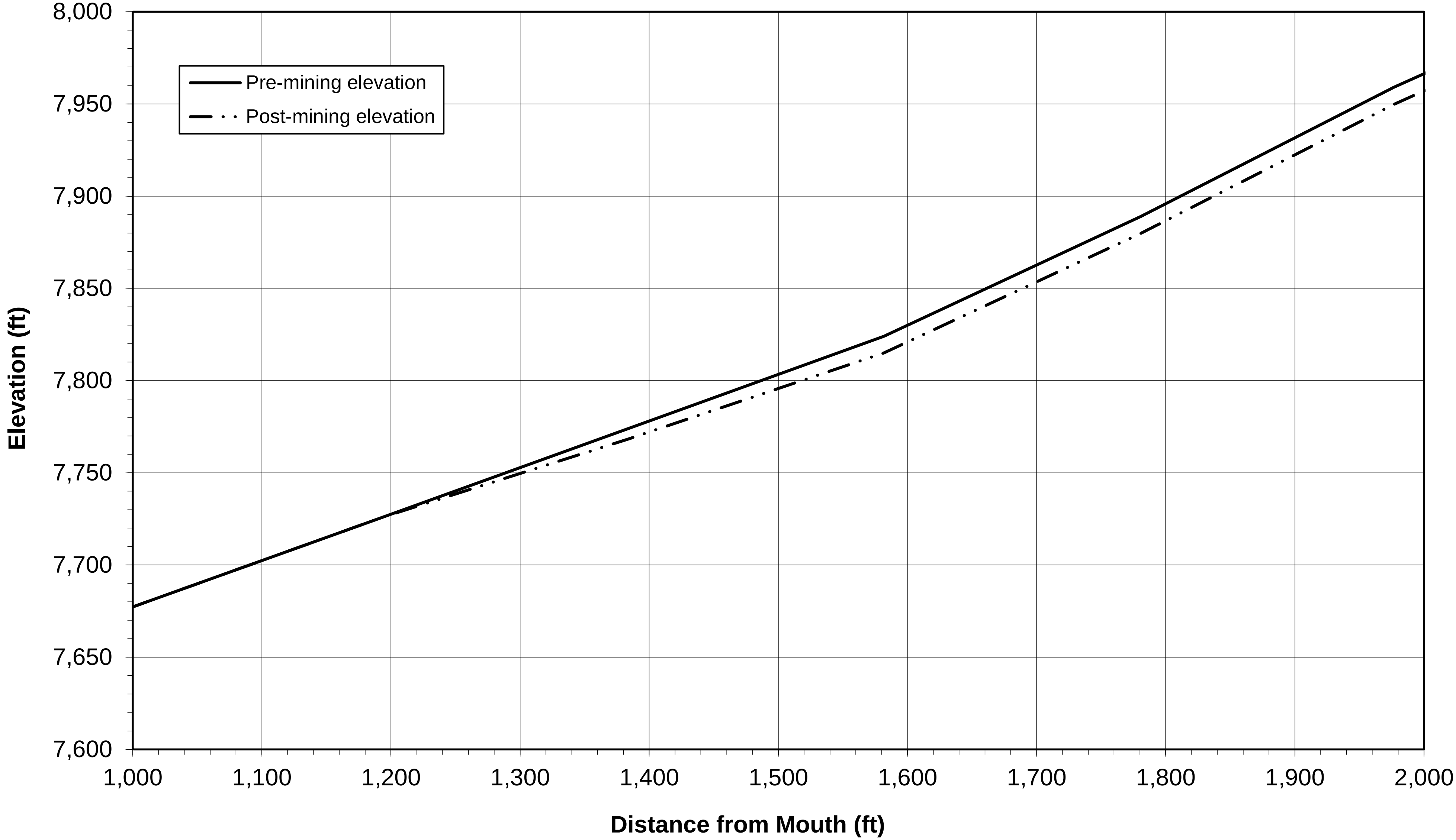


## FIGURE 28A
## Basin 41- Lion Gulch Channel Profile Before and After Mining - Full Extent




Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.

**FIGURE 28B**
**Basin 41- Lion Gulch Channel Profile Before and After Mining - Critical Reach**




Notes: Slope indicated for lowest reach of channel potentially affected by subsidence.