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Skyline Mine Subsidence Study

Changes in Stream Channel Characteristics and Hydraulic Parameters Related to Surface Subsidence

Research Work Unit 4301
Forestry Sciences Laboratory
Rocky Mountain Research Station
Logan, Utah

Final Report April 17, 1998

In Cooperation with:
Arco Coal Company/Canyon Resources LLC
Skyline Mine
and
Manti-Lasal National Forest
Region 4, U.S. Forest Service

SKYLINE MINE SUBSIDENCE STUDY

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Introduction

Underground coal mining has been associated with adverse environmental impacts because of subsidence. Subsidence can cause loss of productive land (Guither,1986), damage to underground pipelines (Hucka et al., 1986) and above ground structures (Kaneshige, 1971), decreased stability of slopes and escarpments (Shea-Albin, 1992), contamination of groundwater by acid drainage (Emrich and Merritt, 1969), and dewatering of streams (Cifelli and Rauch, 1986; Dixon and Rauch, 1990) and groundwater supplies (Stoner, 1983; Matetic and Trevits, 1992).

One of the major concerns regarding the longwall mining of coal is the effect on hydrologic conditions. Surface and subsurface cracking associated with mining subsidence can alter and create preferential flow paths, thus causing dewatering and rerouting of surface water and groundwater (Mather et al., 1969; Sells et al., 1992). Many of these effects are short-term but appear to be dependent on the characteristics of the overburden (Whittaker et al., 1979). Studies in Appalachia have shown that loss of water was much less and streamflow recovered within one year when mixed sedimentary overburdens were at least 500 ft (152 m) in depth (Tieman and Rauch, 1987; Dixon and Rauch, 1990). Of the more than 70 references to hydrologic impacts of underground coal mining recently compiled by Kadnuck and Fejes (1994) only two were from the western states. These two studies represent overviews and modeling efforts and present no new field data. Rather rapid closure of surface tension cracks has been measured at undermined sites in the Wasatch Plateau (DeGraff and Romesburg, 1981), thus indicating that this region may respond differently to subsidence than other lithologies.

Another potential impact on surface drainages in steep terrain is the alteration in channel and drainage morphology resulting from subsidence. Such changes could affect channel erosion, sediment delivery and routing in streams, and riparian habitat. While speculation exists concerning such morphologic changes associated with subsidence, these impacts have not been substantiated in controlled studies.

This study was initiated in 1992 in cooperation with Utah Fuel Company and the Manti-LaSal National Forest to address the effects of longwall mining and related subsidence in the Wasatch Plateau on hydrology, channel condition and habitat changes in perennial and intermittent reaches of a mountain stream. The initial phase of this study will continue through 1997 to assess the cumulative effects of longwall mining oriented approximately perpendicular to the stream channel and proceeding in a downstream direction. Interim reports covering results thru 1994 was submitted March 31, 1995, and May 27, 1997. This report updates the earlier report and contains results thru 1997.

Site Conditions

The Skyline Mine is located in the Upper Huntington Creek drainage on the Manti-LaSal National Forest about 27 miles east of Price, Utah (Figure 1). Huntington Creek flows into Electric Lake just downstream of the mine and eventually discharges into the San Rafael River, part of the Colorado River Basin. Much of the current mining activity is in the upper coal seam under Burnout Canyon. The next canyon south of Burnout is James Canyon. Both James and Burnout Canyons are predominantly west facing. Only very minimal mining will occur under James Canyon and this should not cause any subsidence near the stream channel. Thus James Creek can be used as an uncalibrated control in our investigations. The entire drainage areas of Burnout and James Canyons are 1,166 and 1,075 acres respectively. Surface elevation in the area ranges from 8,575 to 9,860 feet (2,614 to 3,005 m). Two and possibly three extractable coal seams exist in the Blackhawk Formation at depths of 600 to 800 feet (183 to 244 m). The formation is composed of marine sedimentary rocks, sandstones and mudstones. Bedrock dips to the west and numerous springs discharge from the west facing slopes of Burnout and James Canyons. The bentonite associated with the mudstones of the formation imparts a swelling characteristic to the lithology, thus most tension cracks in this area tend to close quite rapidly.

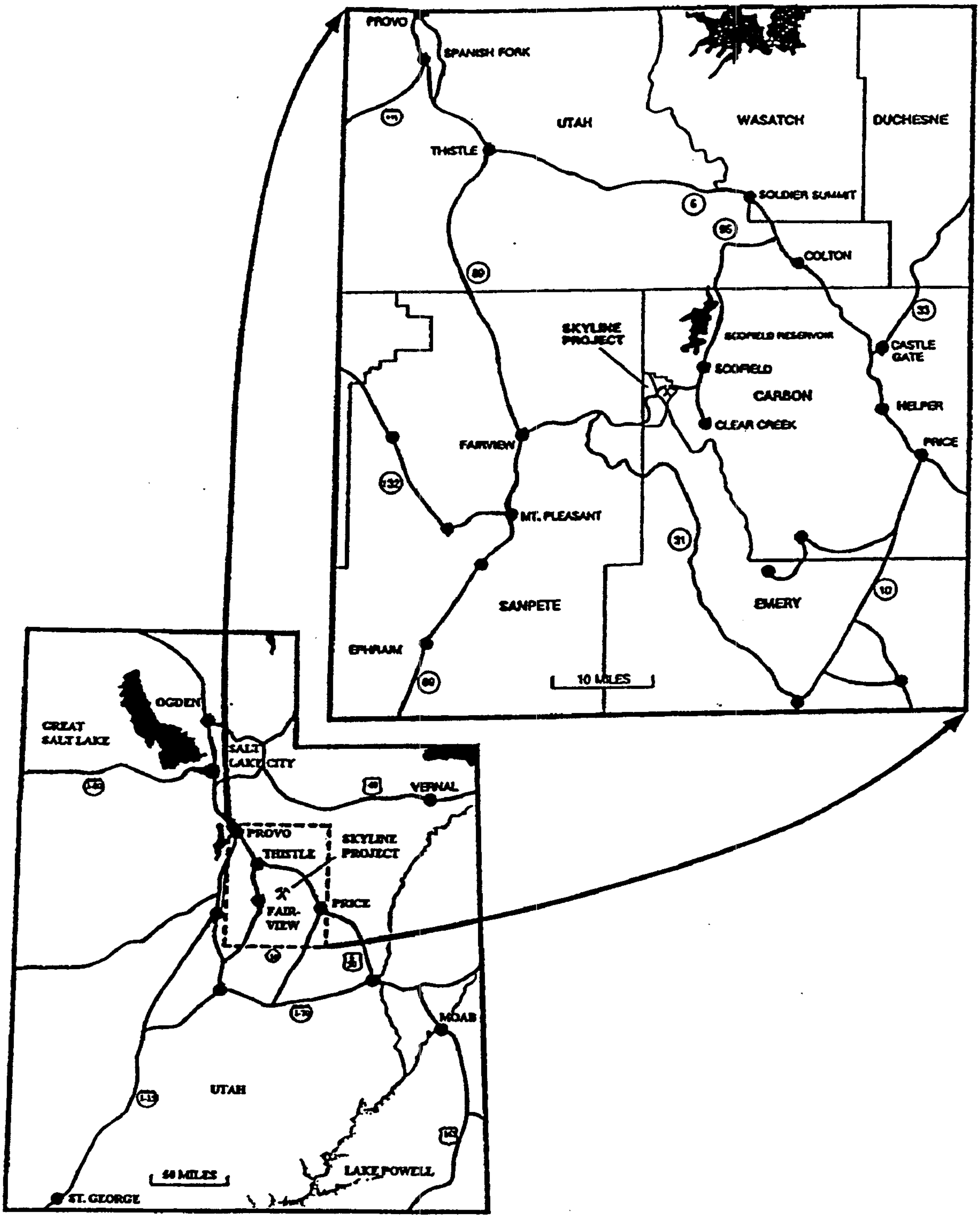


Figure 1. General location of the Skyline Mine in central Utah

Six panels of coal are proposed to be mined in the upper coal seam under Burnout Canyon. These are all oriented approximately perpendicular to the stream channels (either the main reach of Burnout Creek of the South Fork) and coal extraction in each panel takes about one year (Figure 2). Mining started at the top of the watershed (panel 5L) in 1991 and coal from panels 6L and 7L were removed during 1992-1993 and 1993-1994, respectively. Panel 8L was mined in 1995-'96 and panel 9L also in 1995-'96. Panel 10L will not be mined. The company now plans to initiate mining in the second seam of coal starting from the top of the drainage and progressing downslope. Approximately 2 million tons of recoverable coal are located in the seams below Burnout Canyon.

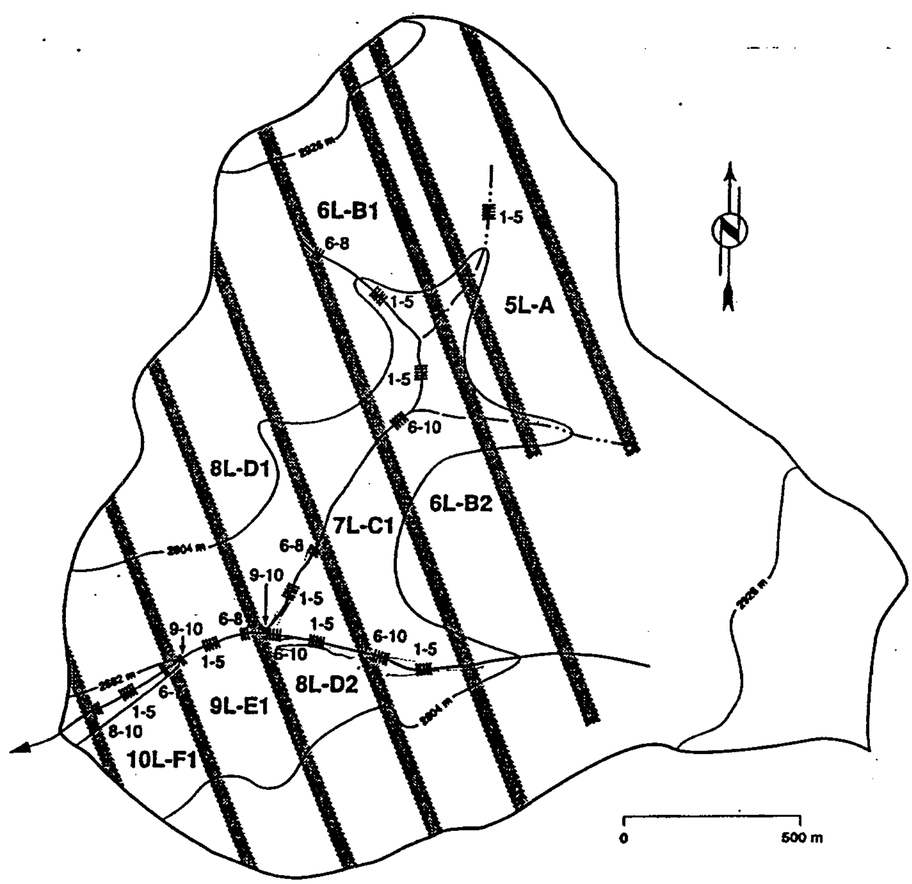


Figure 2. Map of Burnout Canyon showing the locations of documented cross-sections in relation to longwall mining panels. (Note: the darkened areas are support walls between mined panels.)

Mean annual precipitation is 30 to 35 inches (762 to 889 mm) with much of the precipitation occurring as winter snowfall. The snowpack is typically at a maximum in early April. Average water equivalent in the snowpack on April 1 is 21.5 inches (546 mm) according to the Mammoth Cottonwood SNOTEL station at 8,800 feet (2,682 m). This station is located approximately 4 miles northwest of the mouth of Burnout Canyon. Rainfall from May through September is 7 to 10 inches (178 to 254 mm) each year (Jeppson et al., 1968). Peakflows in these drainages are caused by peak snowmelt, episodic, convective summer storms or frontal storms.

Federal Coal Lease Laws and the Manti-LaSal's Forest Plan state that the hydrology of perennial streams must be protected from any impacts of underground mining. Thus, Utah Fuel Company is required to monitor the effects of coal mining on subsidence and hydrology and to prevent subsidence that would damage or substantially reduce flow in perennial streams. Up until now it has been the Forest's policy not to allow mining under perennial channels. The long-term findings of this cooperative investigation will have application to future longwall coal mining in the Wasatch Plateau which contains an estimated 6.4 billion tons of coal reserves. The Skyline Mine is one of the largest underground coal producers in the U.S. and it contributes substantially to the economy of Price, Utah, and the surrounding area.

Methodology and Instrumentation

Documented channel cross-sections were surveyed with an engineer's level at various locations along both Burnout and James Creeks in 1992, 1993, 1994, 1995, 1996 and 1997 (Harrelson et al., 1994) (Platt et al.,1983). Cross-sections in Burnout Creek were located in sets corresponding to the zones of maximum subsidence (compression) and maximum tension over each longwall panel. A typical subsidence profile which indicates the zone of maximum subsidence or compression (near the middle of each panel) and the zones of maximum tension (near the inflection points along the subsidence profile) is shown in Figure 3.

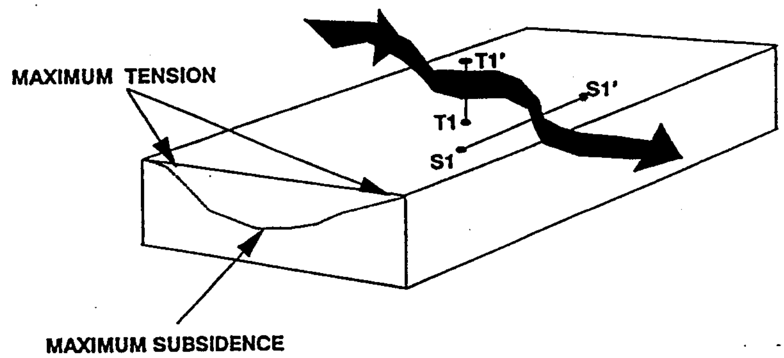


Figure 3. A typical subsidence profile showing the locations of maximum subsidence and maximum tension above each longwall panel and respective documented cross-section panels.

Burnout Creek flows approximately perpendicular to longwall panels 7L, 8L, 9L, and 10L (Figure 2). Ten cross-sections were monitored for each of these panels: 5 in the region of maximum subsidence and 5 in the region of maximum tension. Stream reaches above panel 5L and 6L were not necessarily oriented perpendicular to the underlying panels, thus, five tension zone cross-sections could not always be located (the last number on the I.D.# indicates subsidence/tension status: numbers 1-5 represent subsidence cross-sections and 6-10 tension cross-sections; see Table 1). For panel 5L, cross-sections were placed only in the zone of maximum subsidence since initial subsidence had already occurred in that panel prior to the 1992 survey. Table 1 lists the 73 cross-sections surveyed in Burnout Creek with respect to the underlying coal panel. Locations of these cross-sections are given in Figure 2.

In James Creek, the drainage directly to the south, five documented cross-sections were established in 1992 in each of four stream reaches. These four reaches were selected as representative geomorphic units comparable to documented reaches in Burnout Creek. Thus, **James Creek serves as an uncalibrated control to assess the natural temporal variability of channel geometry.** These cross sections were installed to help analyze effects of extreme events (floods, droughts, etc.) from effects of subsidence on channel cross-sectional changes in neighboring Burnout Creek. The 20 documented cross-sections are listed in Table 1 and their approximate location is shown in Figure 4.

.**Table 1.** List of documented cross-sections in Burnout and James Creeks.

Burnout Creek:

5L-A-1	6L-B1-1	6L-B2-1	7L-C1-1	8L-D1-1	8L-D2-1
5L-A-2	6L-B1-2	6L-B2-2	7L-C1-2	8L-D1-2	8L-D2-2
5L-A-3	6L-B1-3	6L-B2-3	7L-C1-3	8L-D1-3	8L-D2-3
5L-A-4	6L-B1-4	6L-B2-4	7L-C1-4	8L-D1-4	8L-D2-4
5L-A-5	6L-B1-5	6L-B2-5	7L-C1-5	8L-D1-5	8L-D2-5
	6L-B1-6	6L-B2-6	7L-C2-6	8L-D1-6	8L-D2-6
	6L-B1-7	6L-B2-7	7L-C2-7	8L-D1-7	8L-D2-7
	6L-B1-8	6L-B2-8	7L-C2-8	8L-D1-8	8L-D2-8
		6L-B2-9	7L-C2-9	8L-D1-9	8L-D2-9
		6L-B2-10	7L-C2-10	8L-D1-10	8L-D2-10
9L-E1-1	9L-E1-6	10L-F1-1	10L-F1-6		
9L-E1-2	9L-E1-7	10L-F1-2	10L-F1-7		
9L-E1-3	9L-E1-8	10L-F1-3	10L-F1-8		
9L-E1-4	9L-E1-9	10L-F1-4	10L-F1-9		
9L-E1-5	9L-E1-10	10L-F1-5	10L-F1-10		

James Creek:

W-1	X-1	Y-1	Z-1
W-2	X-2	Y-2	Z-2
W-3	X-3	Y-3	Z-3
W-4	X-4	Y-4	Z-4
W-5	X-5	Y-5	Z-5

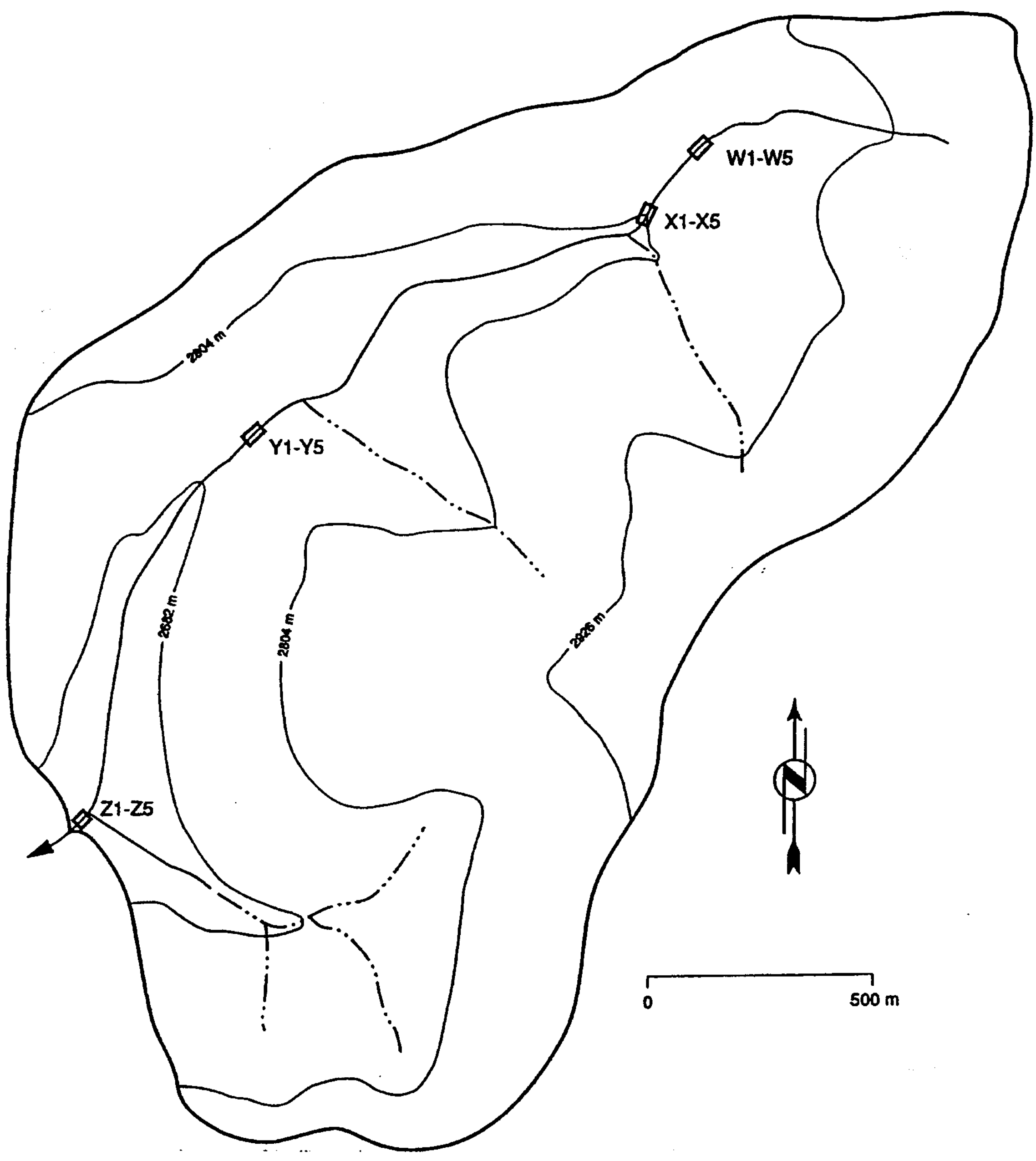


Figure 4. Map of James Canyon showing location of documented cross-sections.

Longitudinal profiles of both Burnout and James Creeks were surveyed each year with a hip chain and engineer's level. Survey points were taken in the channel thalweg at 10 m intervals along the stream. Significant kickpoints or channel steps were surveyed in addition to the 10 m intervals. In Burnout Creek, both the main channel and the South Fork were surveyed upstream of the highest elevation cross-section. Since only intermittent stream flow occur in the upper reaches of the Main Channel of Burnout Creek above 1700 m, channel characteristics were not measured much beyond this point in 1996 and 1997. The summaries presented here contain only measurements below the 1800 m distance for the Main Channel of Burnout.

Samples of streambed sediment were collected in every pool within Burnout and James Creeks. Pools were selected as the sampling unit since they are the depositional environment in channels and should most quickly reflect temporal changes, especially silting, related to erosion, channel adjustment, and flow regime. Sediment samples were transported to the laboratory where they were dried, organic matter was hand removed, and samples were sieved for particle size analysis. The following particle size classes were determined: <0.05 mm, 0.05 - 0.125 mm, 0.125 - 0.25 mm, 0.25 - 0.50 mm, 0.5 -1.0 mm, 1.0 - 2.0 mm, 2.0 - 4.0 mm, 4.0 - 8.0 mm, 8.0 - 16.0 mm, 16.0 - 32.0 mm and >32mm. At each measured pool ($\geq$ 0.5 m in length), the predominant formation element (e.g., rook, woody debris, bank slough) was noted for all years prior to 1996. Formation elements were not used in this report.

Dimensions of each pool were measured in the field so that pool volume could be calculated. For pools lengths $\geq$ 1 m, three sets of measurements were made for each pool for each year 1994 thru 1997: widths and maximum depths (based on baseflow conditions) at the lower, middle and upper portions of the pool. For these large pools, pool volume was estimated by averaging the cross-sectional areas of the two half-ellipses that comprise the lower and upper halves of each pool and then multiplying this value by one half of the pool length (L/2). Thus the volume (V) of the pool is computed as:

$$V = \pi/4\ [L/2\ (W_u/2 \cdot D_u + W_m/2 \cdot D_m) + L/2\ (W_m/2 \cdot D_m + W_d/2 \cdot D_d)]$$

$$= \pi/16 \cdot L \cdot (W_u \cdot D_u + 2W_m \cdot D_m + W_d \cdot D_d)$$

where, W_m is the middle width of the pool, W_u is the width at the upper end of the pool, W_d is the width at the lower end of the pool, D_m is the depth at the middle of the pool, D_u is the depth at the upper end of the pool, D_d is the depth at the lower end of the pool, and L is the length of the pool. These dimensions are shown schematically in Figure 5. For small pools (> 0.5 m and < 1 m in length), only mid-pool dimensions were measured. Thus, volumes of these small pools were calculated as a half of an elliptical cross-section assuming an average pool length of 0.75 m. The minor over-estimation in pool volume (because the presumed tapered "tails" of small pools would be considered to have the same depth as at mid-pool) would be compensated by the fact that more pools were in the upper portion of the length distribution (>.75<1.0 m).The formula used to calculate small pool volume (V_s) is:

$$V_s = \pi/2\ (W/2 \cdot D) \cdot 0.75\ \text{m}$$

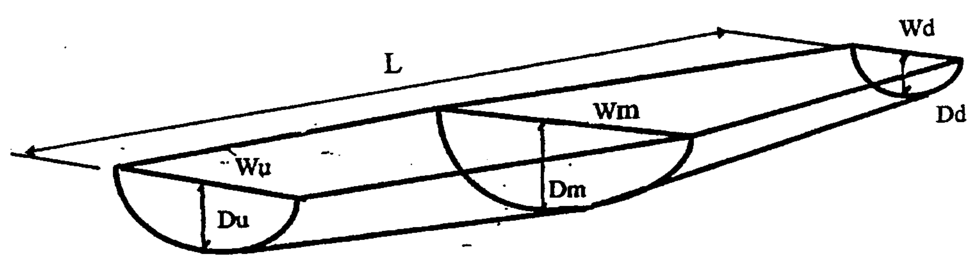


Figure 5. Schematic of large pool dimensions used in calculating pool volume.

A precipitation storage gage and a tipping bucket rain gage were installed near the upper divide between James and Burnout Canyons. The tipping bucket rain gage is only operated during the snow-free period (approximately June through October). The Company also maintains a rain gage at the mine site.

The Company installed five Parshall flumes in various reaches of Burnout Creek to monitor streamflow during the snow-and ice-free seasons. The 9-inch flume installed in the lower reach of Burnout Creek is of greatest interest in this study. This site is the same as where pre-mining water quality samples were collected from 1981 to 1991. In summer 1992, a recorder was installed at this flume. Prior to 1992, instantaneous flow was measured at the time of water quality sample collection. The Company also installed a flume in the lower reach of James Creek.

Channel Characteristics

Channel features were surveyed along the entire study reaches of both Burnout and James Creeks each year from 1992 thru 1997. Channel units were qualitatively classified as cascades, riffles, runs, glides, and pools in approximate order of decreasing unit stream power. A total of about 1,700 m of channel was surveyed in both Burnout and James Creeks. In analyzing the results from the first three years of the study, it became apparent that inconsistencies arose in distinguishing between riffles and runs in the field and in pool formation elements. Thus, in our analysis we have lumped riffles and runs into one type of channel unit and pools are not classified as to formation element. The habitat implications of runs and riffles are very similar therefore we can justify combining these characteristics. *Unfortunately, classifying channel characteristics is subjective and personal bias often distorts the results.* Different observers classified these characteristics in three of the six years covered by this report, thus year-to-year difference might well be a result of classification inconsistencies. However, in any one year both the James Canyon control area and Burnout were classified by the same individual to maintain within-year consistency between Burnout and the control area. All channel features are presented as lengths or as the percentage of length of the system (or portion of the system).

James Canyon (Control Area):

James Canyon has not been extensively subjected to mining and consequent subsidence, thus yearly differences in channel characteristics here result from a combination of natural causes (normal yearly variation), grazing, timber harvesting and observational error. There was a small portion of James Creek undermined in 1995 between cross sections X and Y(at about 2200 M). Mine survey data indicates about one-third meter subsidence occurred at this location. Beyond that small subsidence no other changes as a result of this mining have been observed.

James Creek serves as basis for judging the meaningfulness of changes that occur in Burnout. **Differences in Burnout that substantially and consistently exceed changes in James Canyon can reasonably be attributed to mining and subsidence.**

The percentage of the entire measured channel in James Canyon that was classified as rills and riffles over the six-year period varied between 71.8% and 83.5%, as cascades from 2.4% to 22.7%, as glides from 0.4% to 11.0%, and as pools from 1.6% to 6.0% (Figure 6). It is worth noting that the percentage of the entire length classified as pools decreased every year to a low of 1.6% in 1997. The number of pools varied between 18 and 45/km (Figure 7), and their total volume between 4 and 17 m^3 (Figure 8). The only trend apparent was as increase in the percentage of cascades apparently at the expense of runs and riffles which probably results from classification error. The number of pools decreased greatly in 1995 through 1997, and consequently total volume. Average pool volume varied between 0.25 and 0.12 m^3 over the six year period (Figure 9).

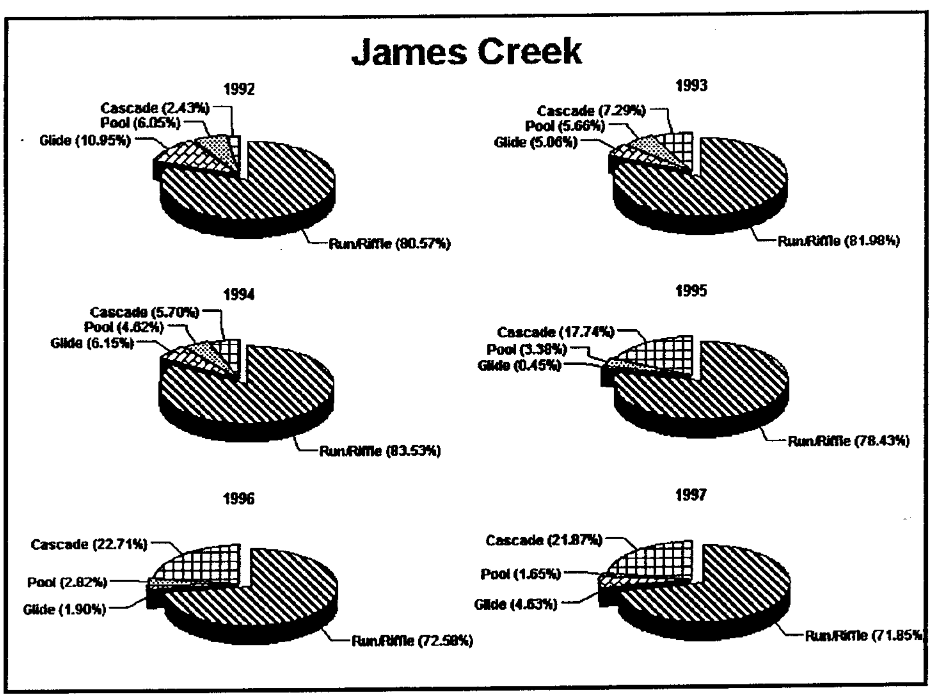


Figure 6. Distribution of channel elements in James Creek for 1992 through 1997.

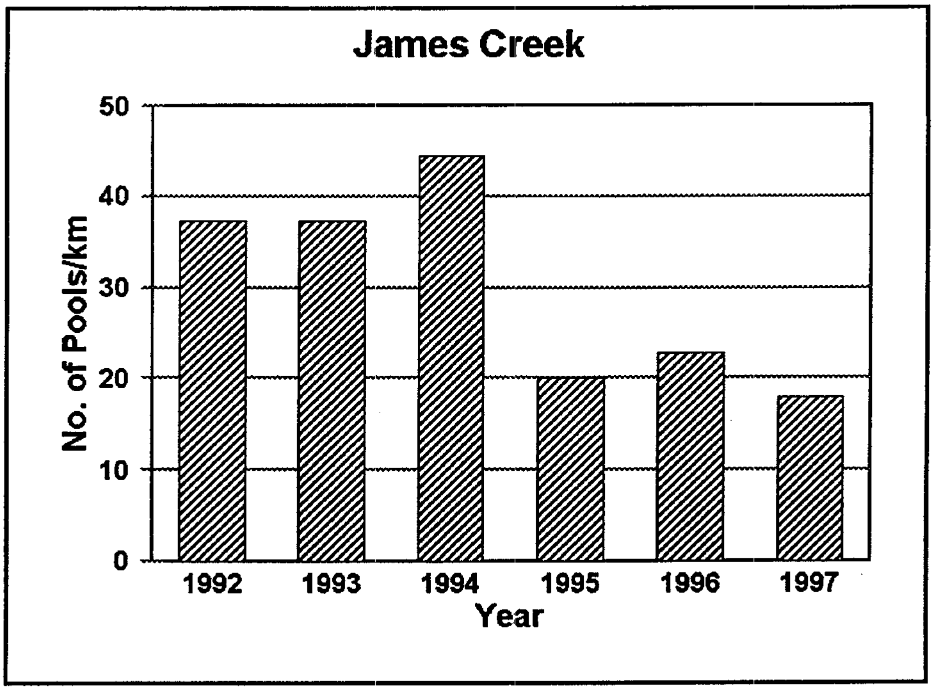


Figure 7. Total pool density in James Creek for 1992 through 1997.

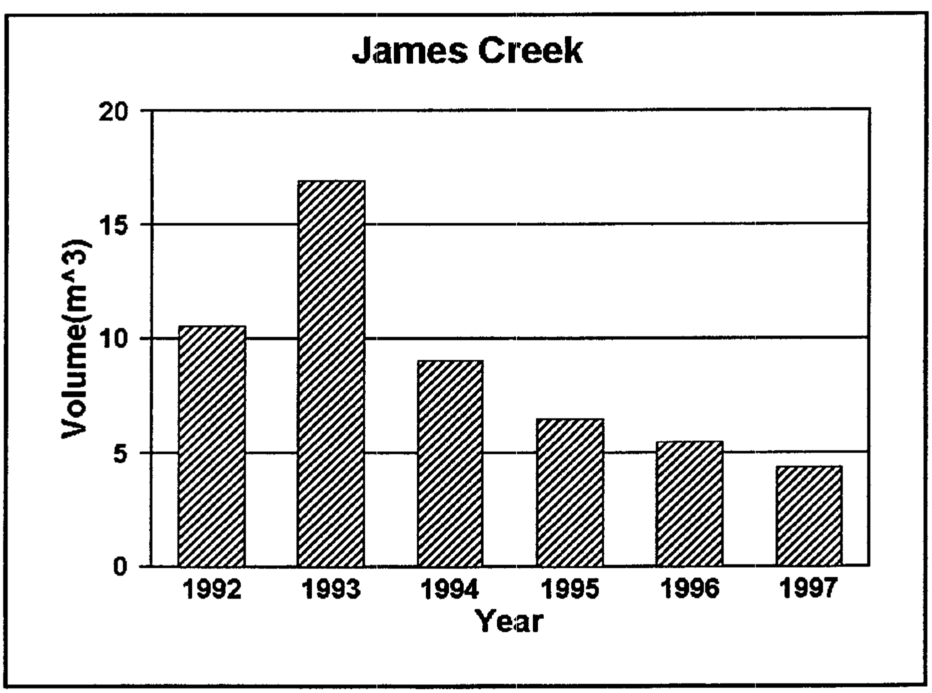


Figure 8. Total pool volume in James Creek for 1992 through 1997.

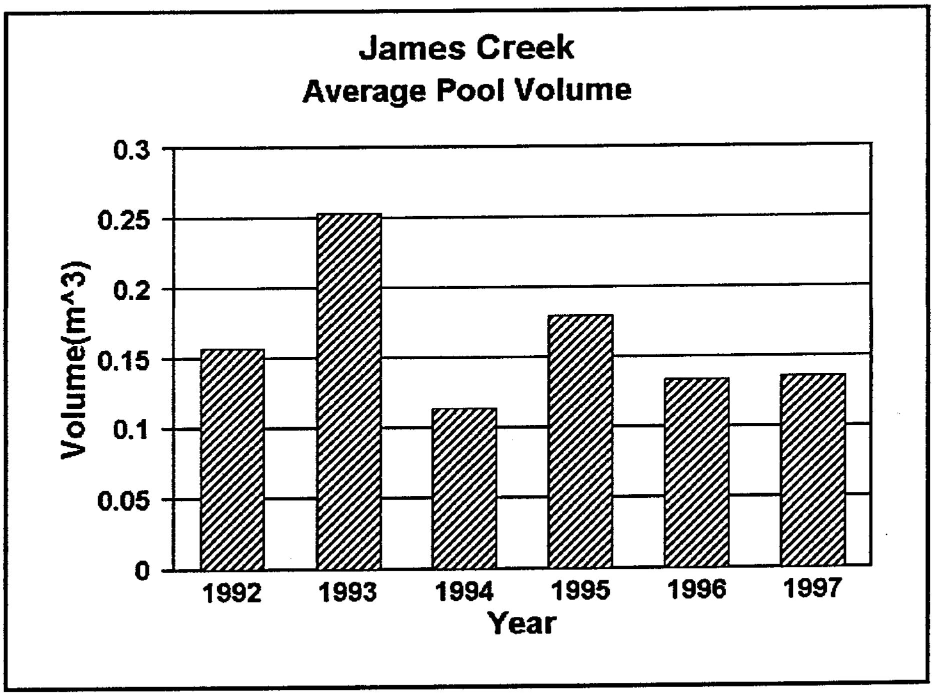


Figure 9. Average pool volume in James Creek for 1992 through 1997.

These data were subsequently broken into Upper James (1000 to 1800 m) and Lower James (0 to 1000 m) for further analysis of channel characteristics because of the apparent differences in steepness of the channel. The Upper James (Figure 10) consisted of a much greater percentage of channel length occupied by cascades than Lower James (Figure 11), and less length in runs/riffles and glides in all but the first year. Pool numbers were generally greater in Upper James than in Lower James; however, number of pools in both reaches decreased substantially in 1995 through 1997 (Figure 12 and Figure 13). Total pool volume varied four-fold in Upper James (from 1.2 to 4.7 m^3), and approximately six-fold (2.6 to 12.1 m^3) in Lower James (Figures 14 and 15). Average pool volume in Upper James varied between 0.08 and 0.20 m^3, and in Lower James between 0.14 and 0.42 m^3 (Figures 16 and 17. Average pool volume in the gentle reach of Lower James changed very little from 1944 on.

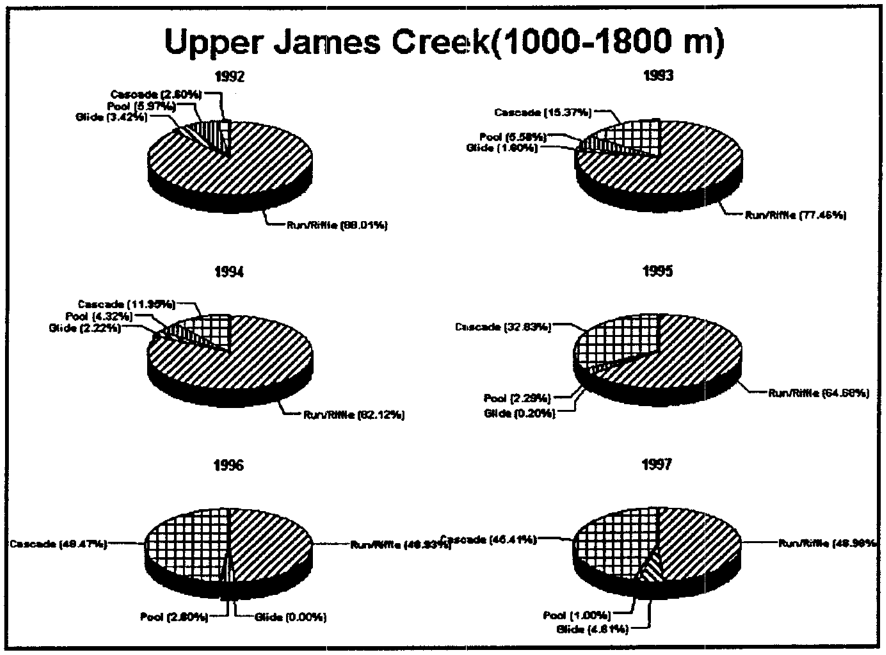


Figure 10. Distribution of channel elements in the upper reach of James Creek for 1992 through 1997.

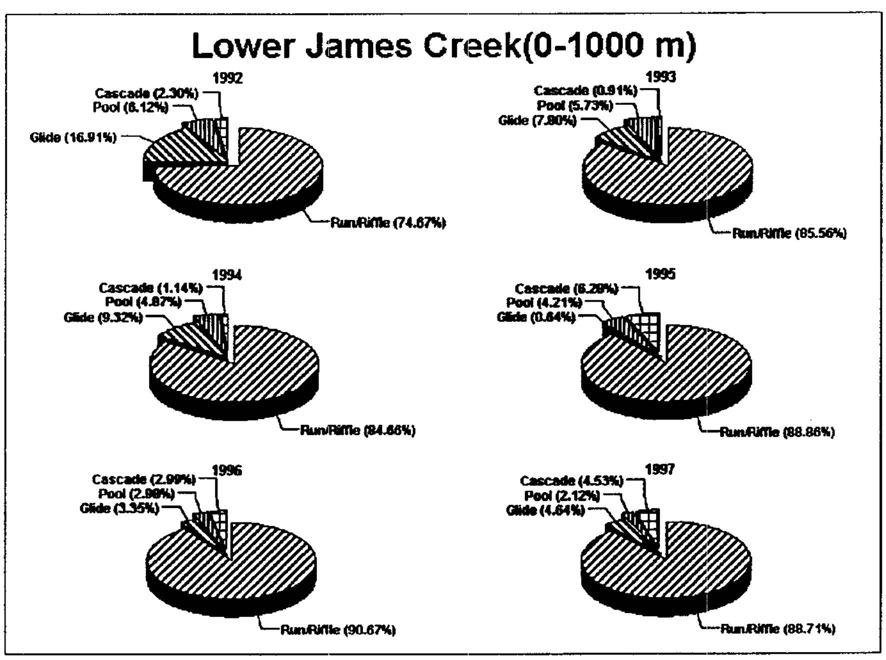


Figure 11. Distribution of channel elements in the lower reach of James Creek for 1992 through 1997.

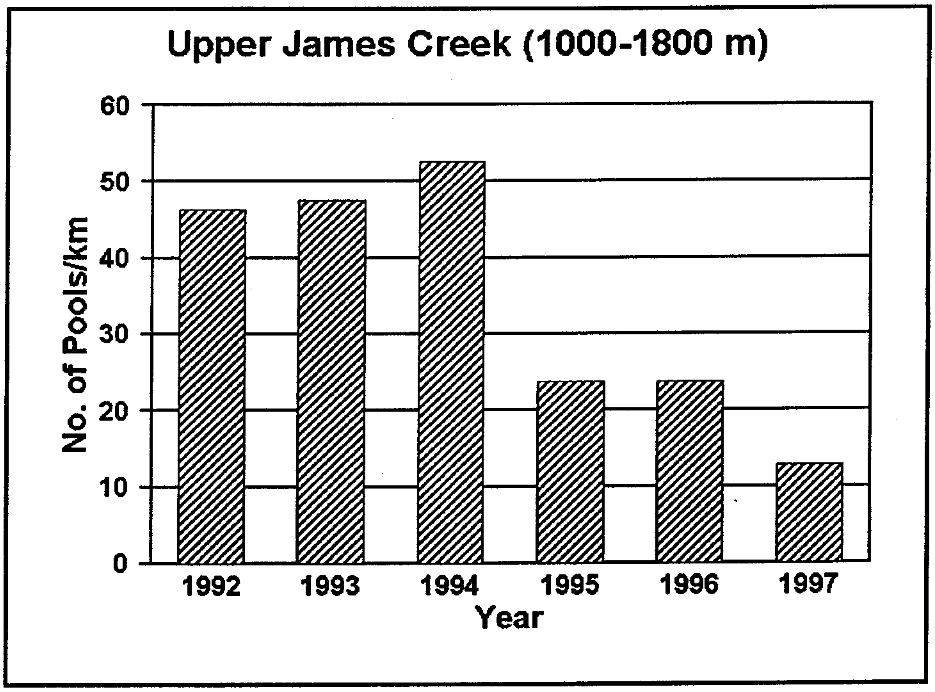


Figure 12. Pool density in the upper reach of James Creek for 1992 through 1997.

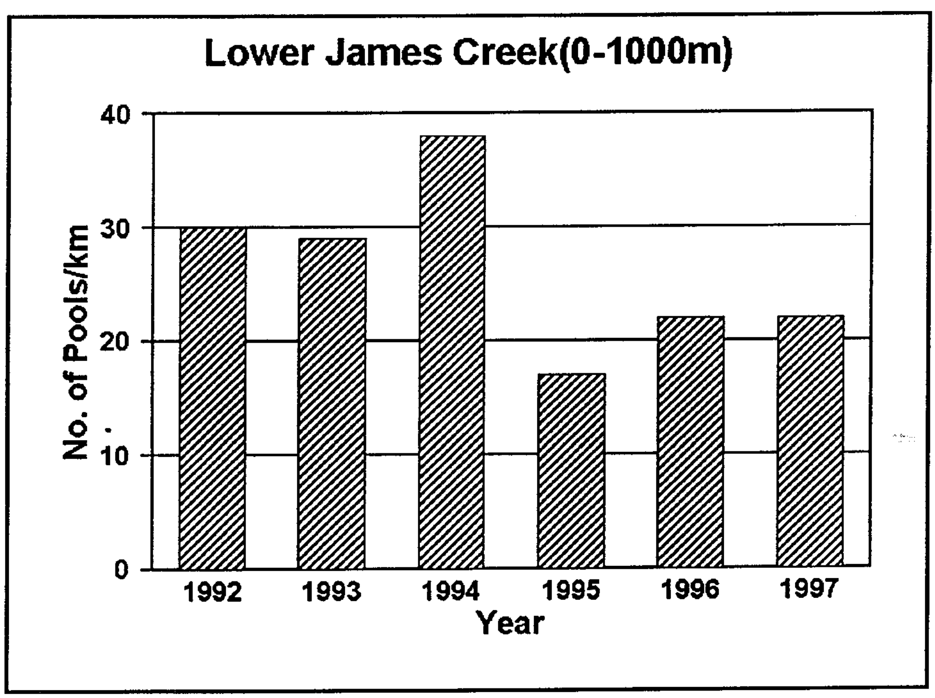


Figure 13. Pool density for the lower reach of James Creek for 1992 through 1997

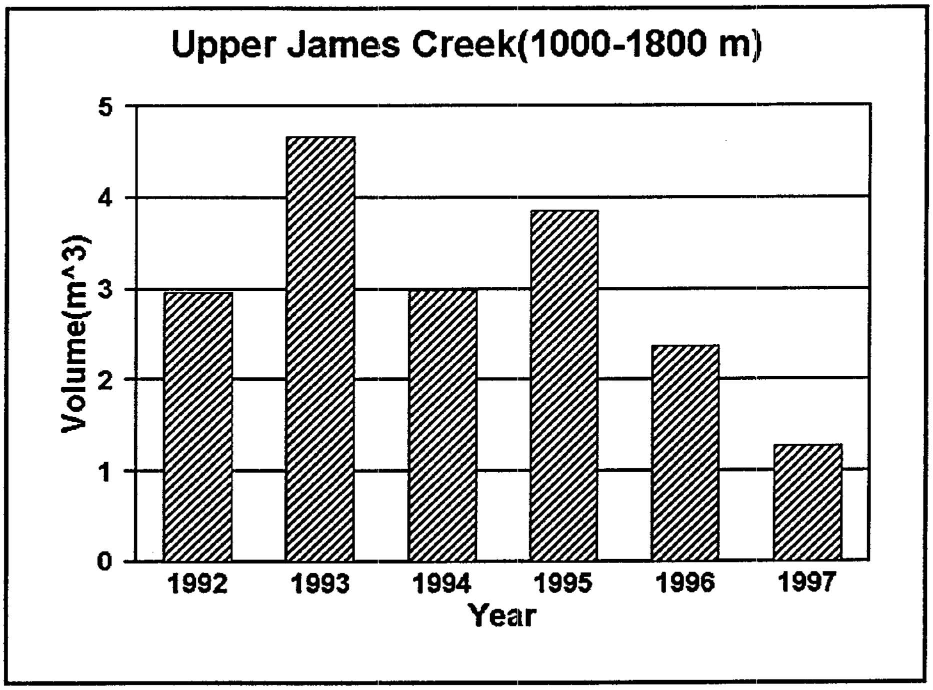


Figure 14. Total pool volume in the upper reach of James Creek for 1992 through 1997

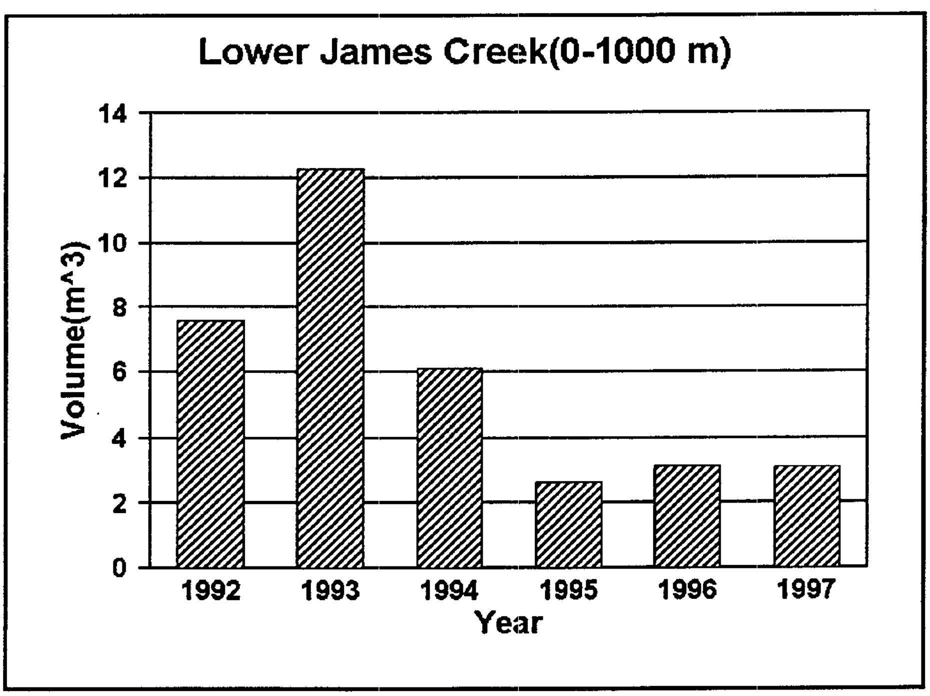


Figure 15. Total pool volume fore the lower reach of James Creek for 1992 through 1997.

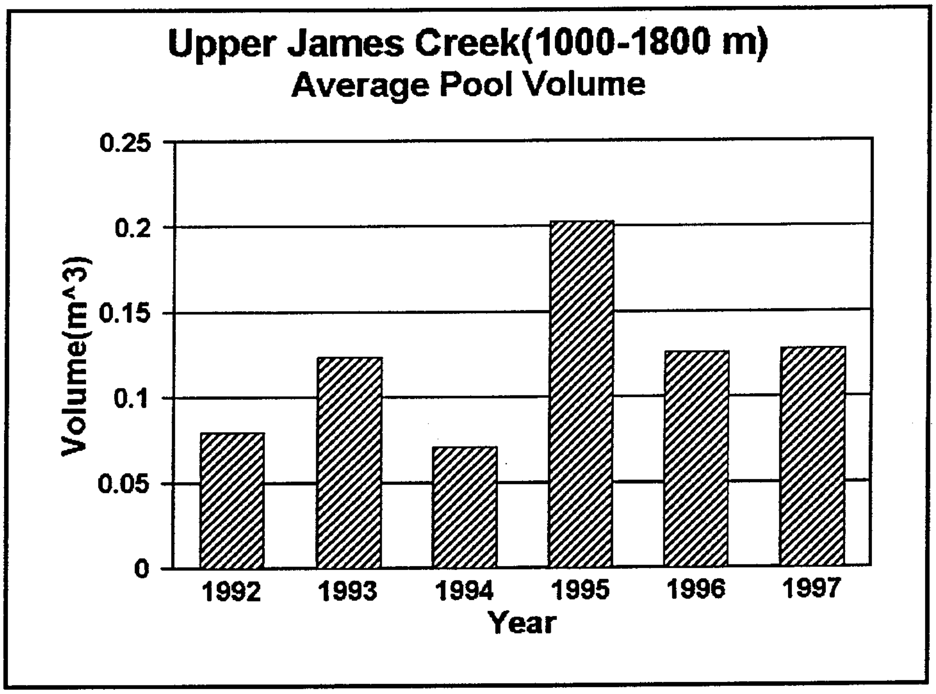


Figure 16. Average pool volume for the upper reach of James Creek for 1992 through 1997.

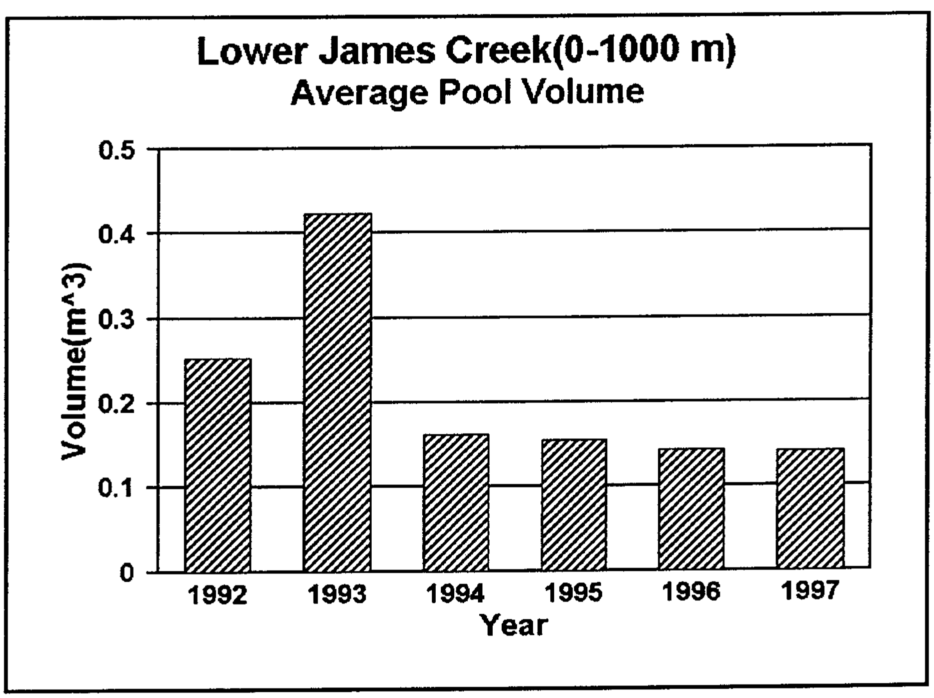


Figure 17. Average pool volume for the lower reach of James Creek for 1992 through 1997.

Burnout Main Channel:

For the entire main channel system in Burnout Canyon, the length of runs/riffles remained relatively constant throughout the 6-year period (Figure 18). The length of the channel in runs/riffles ranged from a high in 1993 of 88.3% to a low in 1995 of 79.7% and may easily be attributed to classification error. The percentage of channel in cascades increased greatly between 1994 and 1995 (from 3.3% to 15.2%), but then decreased to 8.1% in 1996 and again increased to 12.2% om 1997. This type of variability also could be caused by different observers classifying some of the steeper riffles as cascades. Pool length did not change appreciably during the six years, varying between 5.9% in 1992 and 2.5% in 1995. Such changes in pool length could well result from normal variations in sedimentation and flushing depending on variability in precipitation events from year to year.

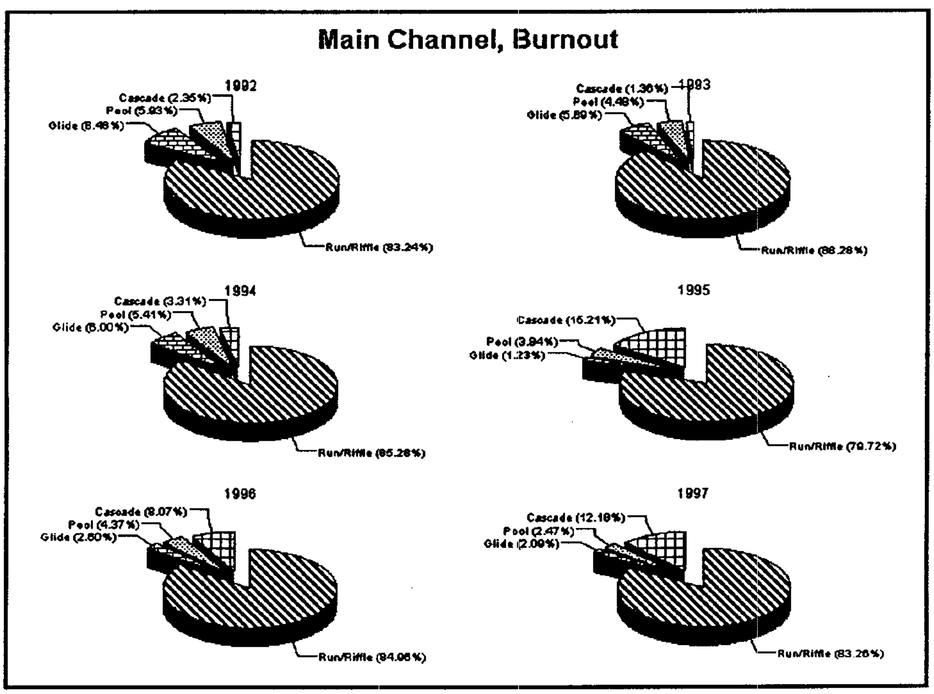


Figure 18. Distribution of channel elements in the Main Channel of Burnout Creek; 1992-1997

Total volume of all pool types in the Main Channel ranged between a high of 13.7 m^3 in 1993 to a low of 7.2 m^3 in 1997 (Figure 19). No consistent trend is apparent. The total number of pools, however, appears to show a gradual decline from a high of about 42/km in 1992 to a low of 24/km in 1997, with the exception of 1994 with 39 pools/km (Figure 20). Average pool volume, however, did not demonstrate a consistent trend. This varied from 0.13 m^3 in 1994 to 0.23 m^3in 1993 and 1995 (Figure 21).

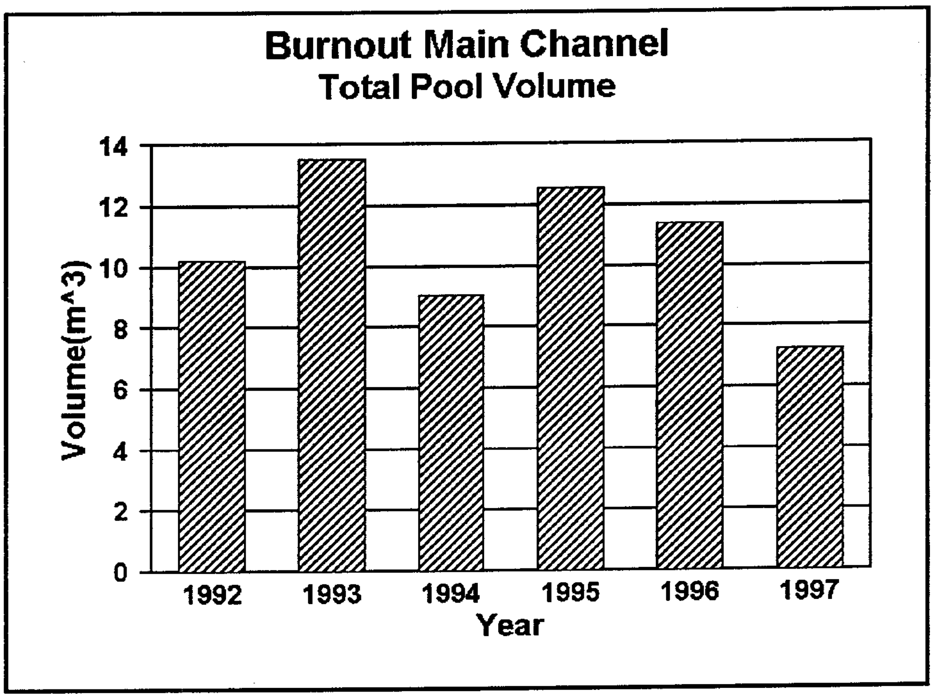


Figure 19. Total pool volume of all pools in the Main Channel of Burnout Creek; 1992-1997.

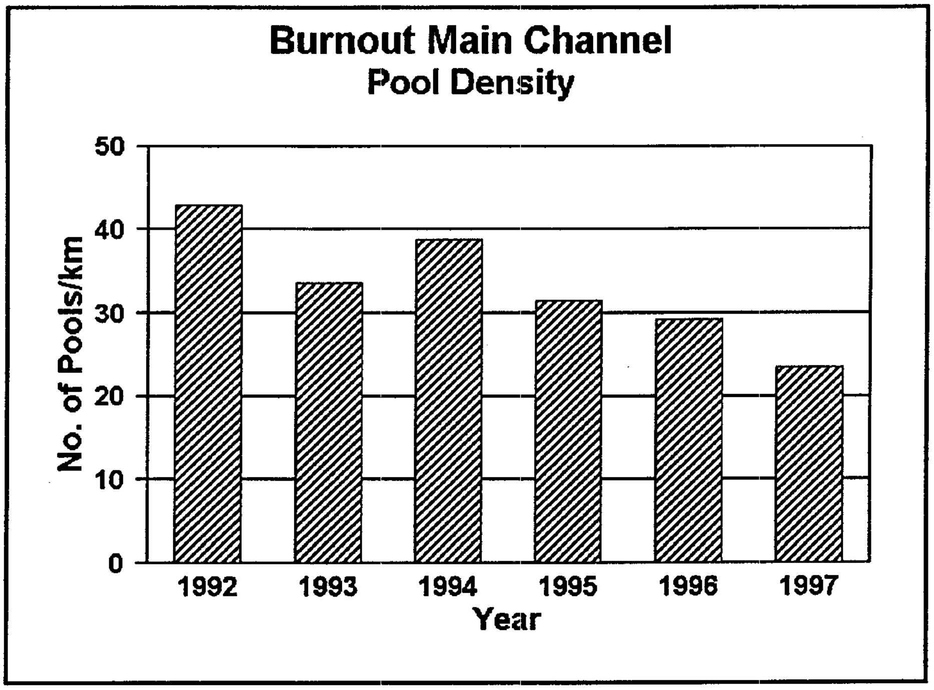


Figure 20. Pool density in the total Main Channel of Burnout Creek; 1992-1997.

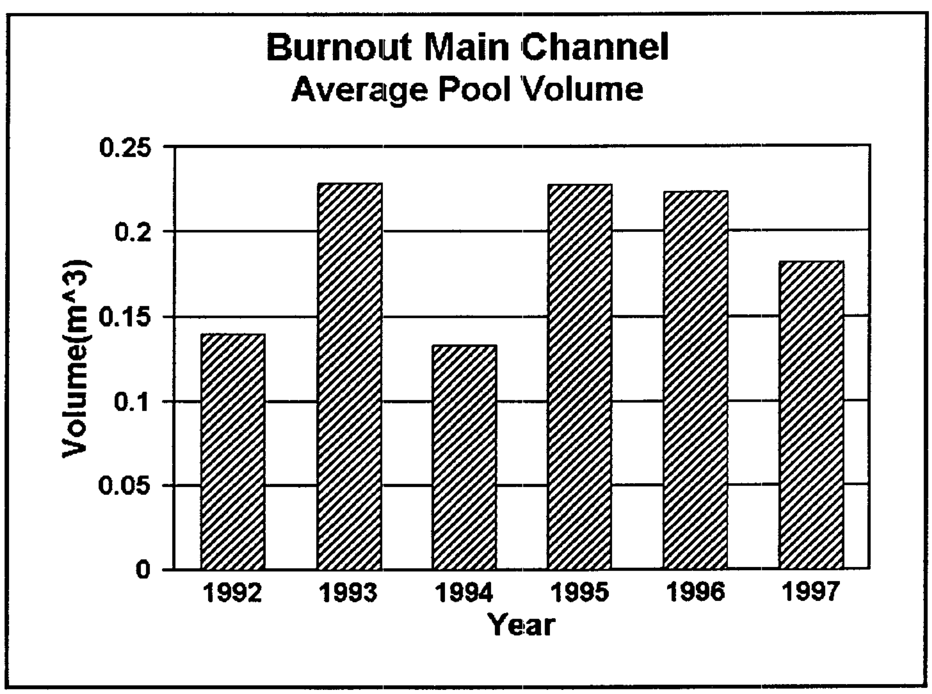


Figure 21. Average volume of pools in the Main Channel of Burnout Creek, 1992-1997.

South Fork Burnout:

Channel characteristics were also surveyed along ~640 m of the lower reach of the South Fork of Burnout Creek. Cascades increased progressively from 12.5% in 1992 to 53.6% in 1996, then dropped to 38.4% in 1997 (Figure 22). The proportion of stream channel classified as cascades in the South Fork was very much greater than in the Main Channel throughout the 6-year period, no doubt reflecting the greater steepness of the South Fork channel. Total volume of all pools varied greatly from a high of ~4.8 m³ in 1995 to a low of ~1.1 m³ in 1996 and 1997 (Figure 23). This precipitous decrease in pool volume in the South Fork differs markedly from the relatively small change that occurred in the Main Channel (Figure 19). Pool density in the South Fork remained approximately 70/km between 1992 and 1995, but then dropped greatly to ~30/km in 1996 and 1997 (Figure 24), reflecting the precipitous drop in total pool volume. Average pool volume in 1996 and 1997 was approximately the same, between 0.5 and 0.6 m³, as in 1992 and in 1994 (Figure 25).

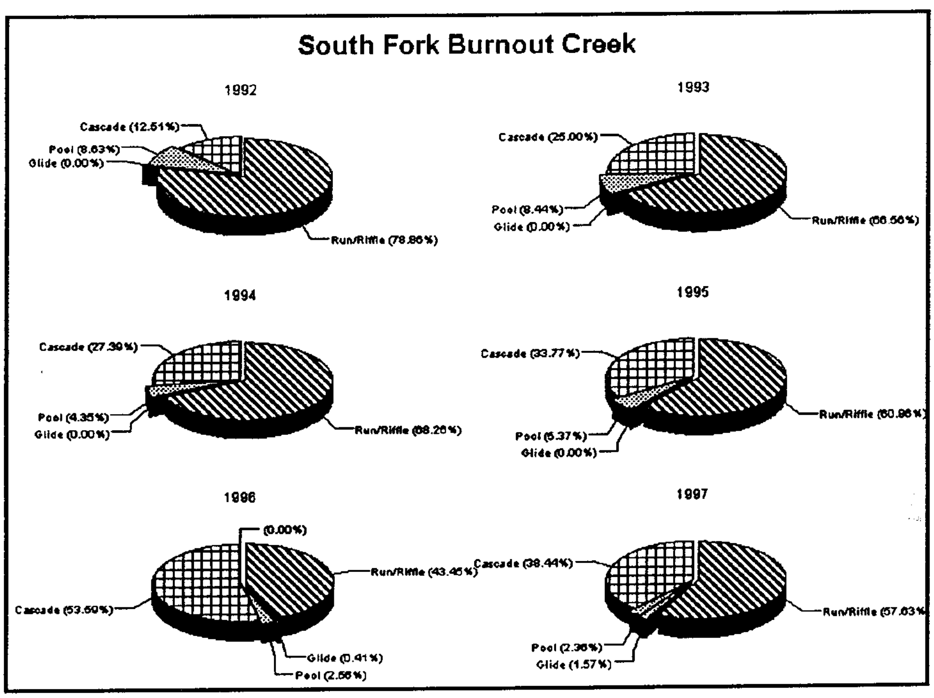


Figure 22. Distribution of channel elements in South Fork of Burnout Creek; 1992-1996.

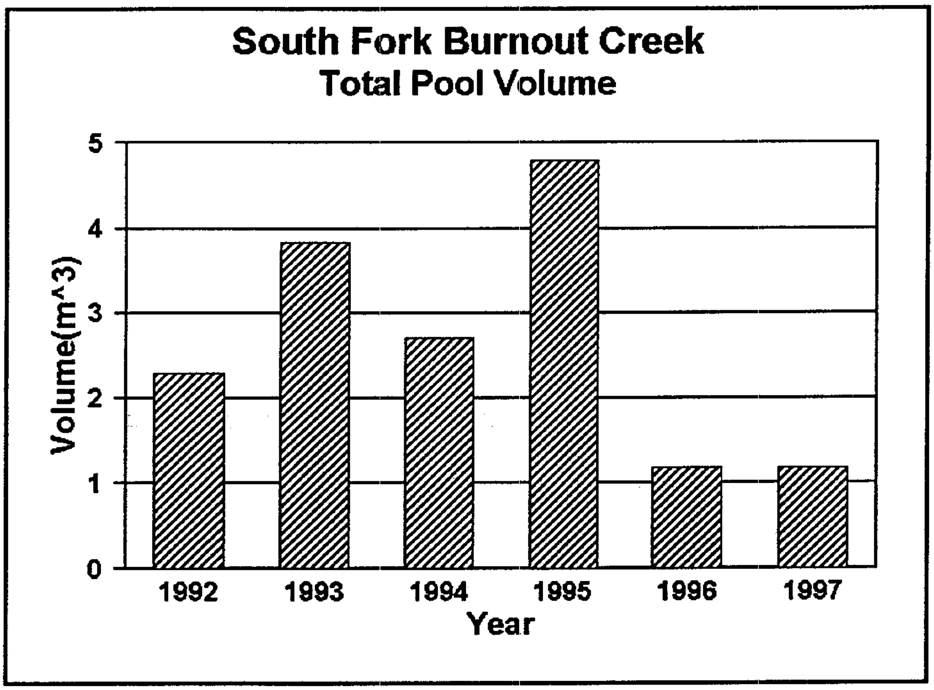


Figure 23. Total pool volume in the South Fork of Burnout Creek; 1992-1997.

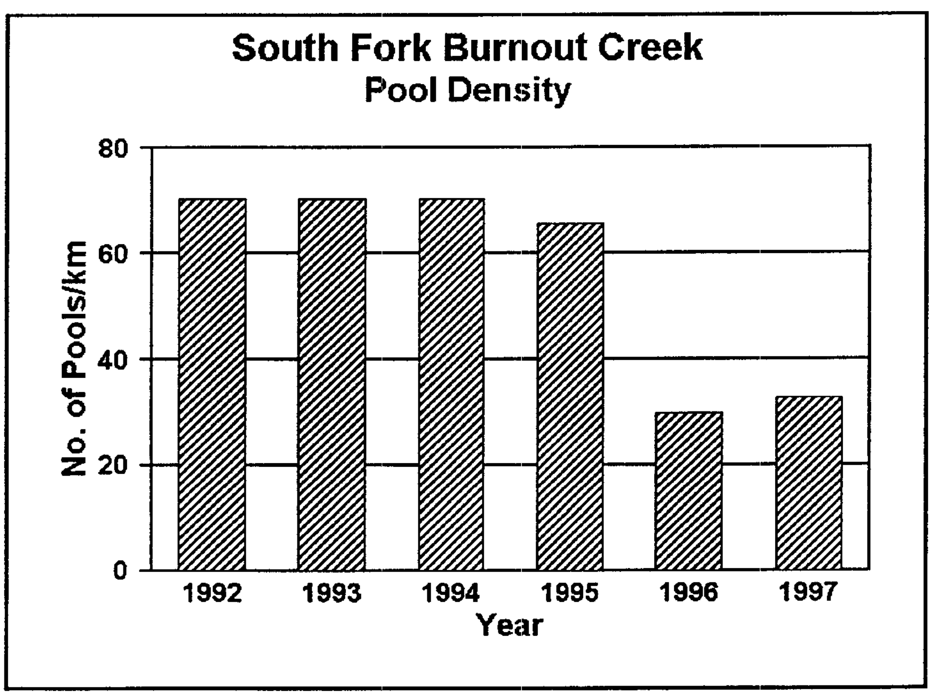


Figure 24. Pool density of all pools in the South Fork of Burnout Creek; 1992-1997

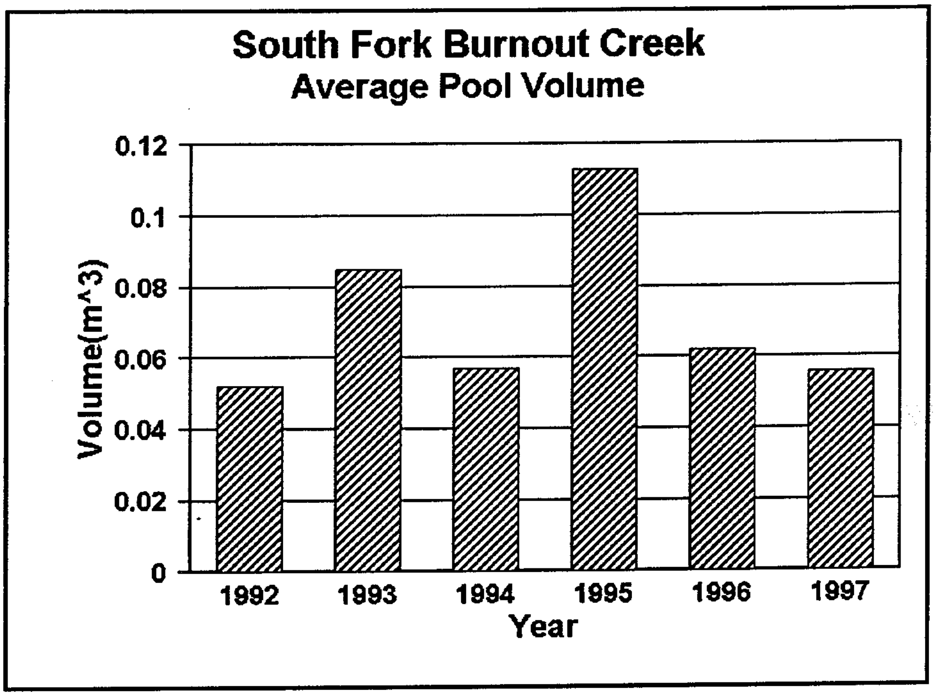


Figure 25. Average volume of pools in the South Fork of Burnout Creek, 1992-1997.

Changes over the 6-year period in stream channel characteristics within mining panels were evaluated separately since the panels were mined in different years: panel 7L in 1993-'94; panel 8L in 1994-'95; and panel 9L in 1995-'96. Panels 5L and 6L, in the upper reach of Burnout Creek beyond 1700 m, were not included in this analysis because they contained only intermittent stream flow and were not measured in beyond 1995. Sections of both the Main Channel and South Fork of Burnout crossed panels 7L and 8L. Subsidence was greater in the South Fork (0.5 to 4.5 feet) over panel 7L than in the Main Channel (0.0 to 1.0 feet) because of the presence of an intrusive dike in the latter. Only the lower reach of the Main Channel crossed panel 9L (Figure 2).

Panel 7L:

The proportion of the Main Channel length occupied by runs and riffles in panel 7L varied from 65.6% in 1995 to 89.6% in 1993, by cascades from 2.8% in 1993 to 25.9% in 1995, and by pools from 2.0% in 1997 to 8.5% in 1995 (Figure 26). Thus the length of cascades and perhaps pools appears to have increased the year following mining at the expense of runs and riffles in the Main Channel. In the South Fork section of panel 7L, runs and riffles ranged from 39.6% in 1996 to 79.6% in 1992, cascades from 10.6% in 1992 to 58.2% in 1996, and pools from 1.6% in 1997 to 9.7% in 1992 (Figure 27). Here, the percentage of cascades did not increase markedly until 1996, the second year following mining, again at the expense of the runs and riffles. However, the percentage of length occupied by pools in the South Fork had decreased prior to mining in 1994. The number of pools in the Main Channel of this panel remained fairly constant from 1992 thru 1994 (50 to 57/km) but then dropped to only 22/km in 1995, the year following mining (Figure 28). By 1996, pool numbers were back up to 52/km but then again dropped to 20/km in 1997. In the South Fork of panel 7L, pool numbers remained high (53 to 59/km) until 1996, the second year following mining, when they dropped to 32/km and by 1997 were only 25/km (Figure 29). Pool volumes in the Main Channel of panel 7L varied between ~1.6 m^3 and ~2.7 m^3, with the greatest volume measured in the year of lowest pool density, 1995 (Figure 30). Although total number of pools in this reach decreased by more than half in 1995 immediately following mining, these pools were more than twice as large (0.38 m^3) as the pools before mining (0.10 to 0.16 m^3), resulting in the high total pool volume for 1995 (Figure 31). Total pool volume in the South Fork varied between ~0.2 and ~1.5 m^3 (Figure 32), with the lowest volume corresponding to the lowest number of pools in 1996 and 1997. In contrast to the Main Channel in Panel 7L, average pool volume in the South Fork were lowest in 1997 (Figure 33).

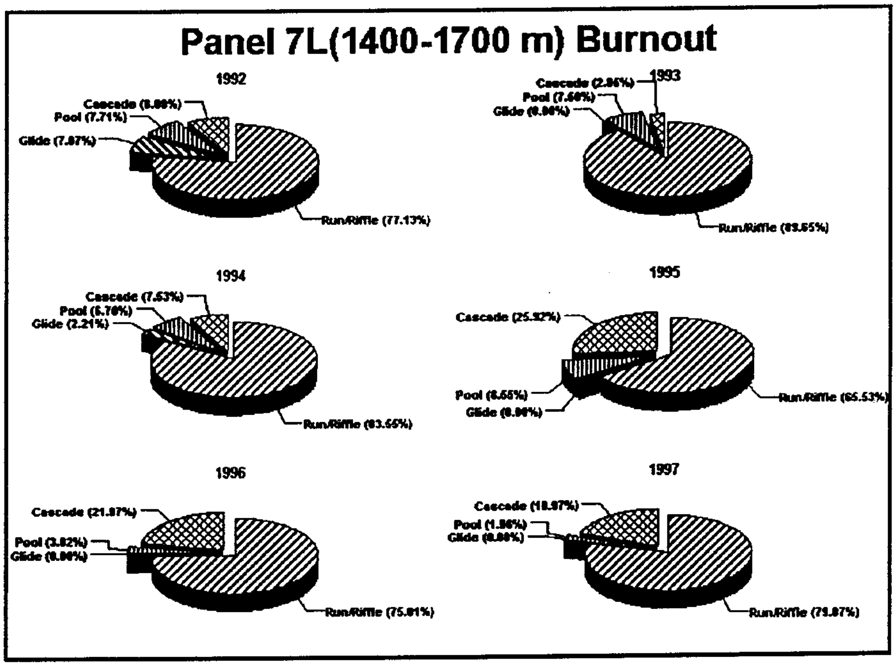


Figure 26. Distribution of channel elements in the Main Reach of Burnout Creek impacted by panel 7L (1400-1700 m) for all years

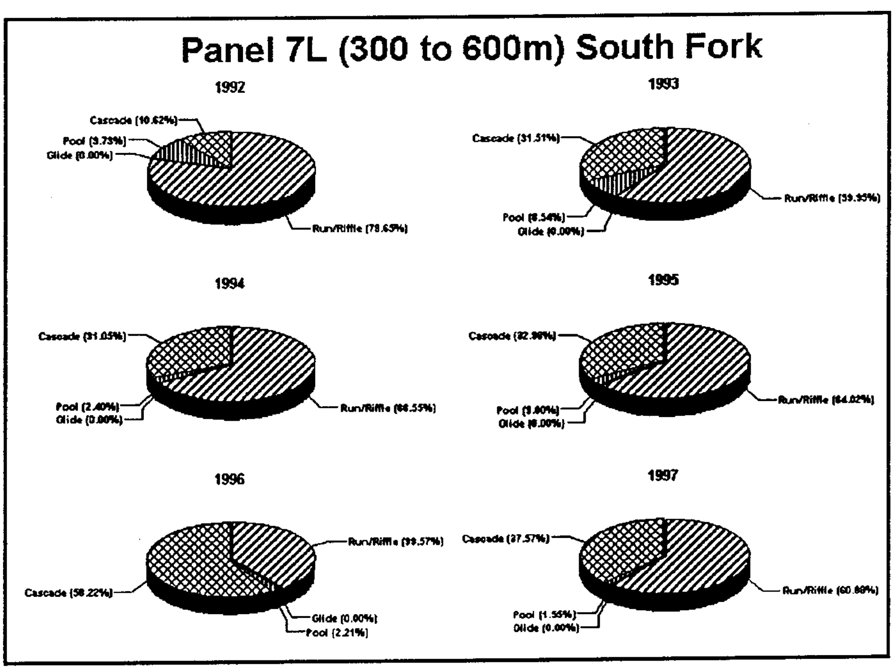


Figure 27. Distribution of channel elements in the upper reach of the South Fork overlying panel 7L for all years.

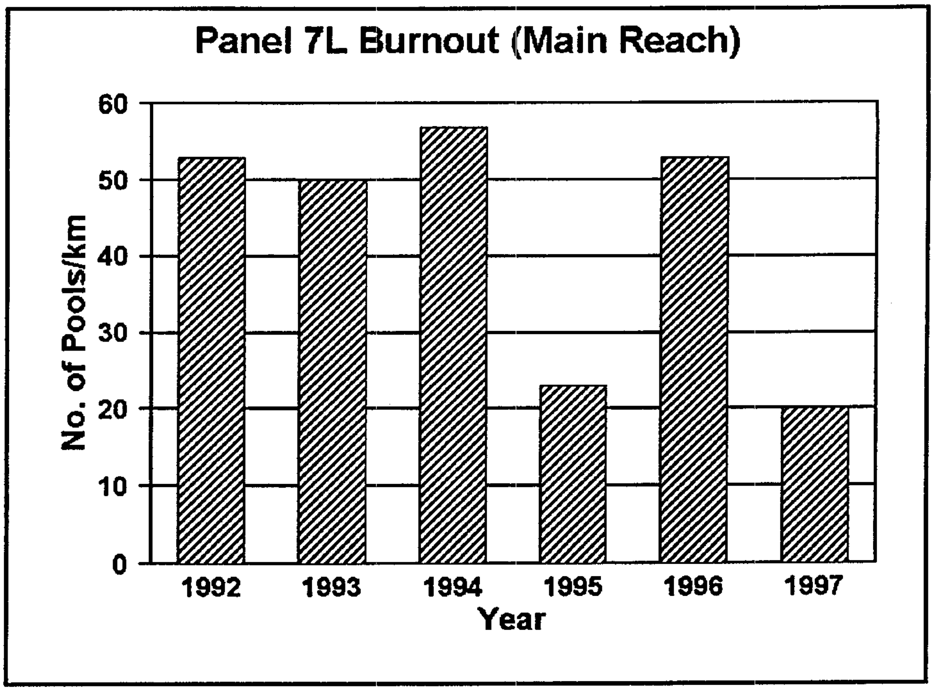


Figure 28. Pool density in panel 7L of the Main Reach of Burnout Creek; 1992-1997.

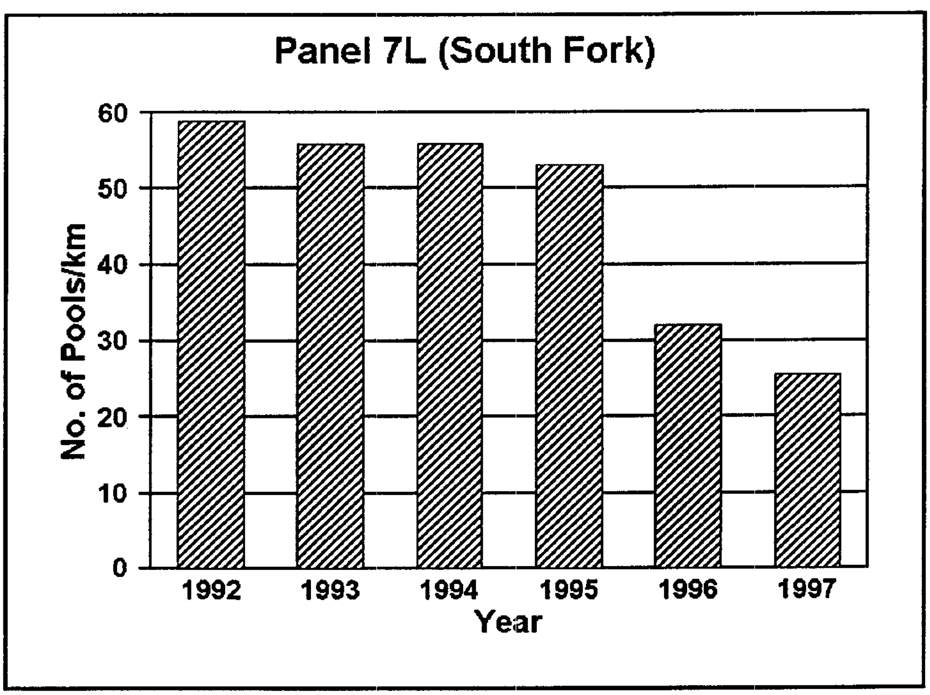


Figure 29. Pool density in the upper reach of the South Fork overlaying panel 7L for all years.

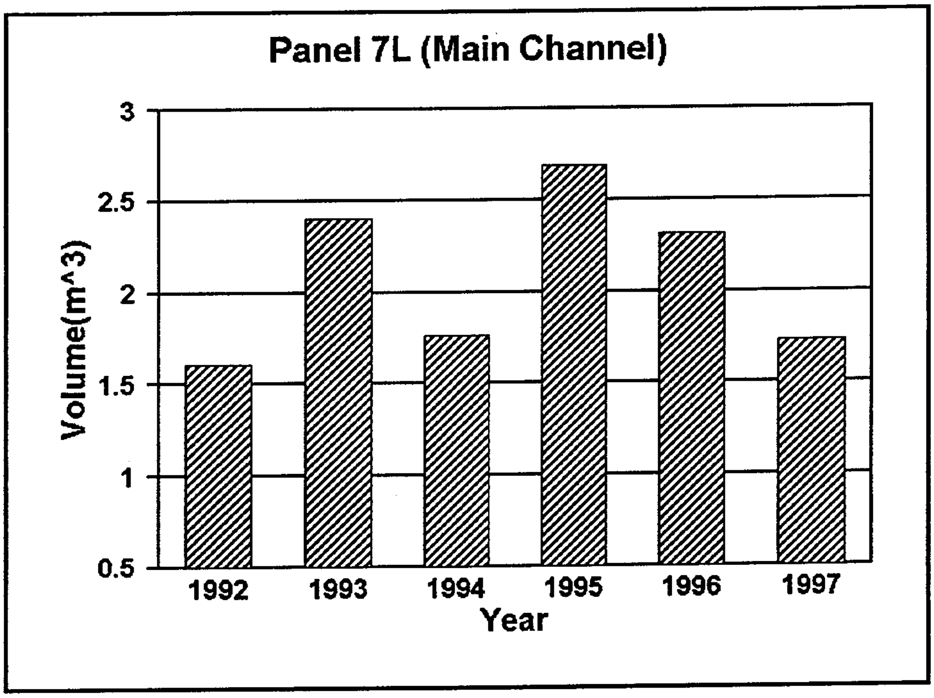


Figure 30. Total pool volume in panel 7L of the Main Reach of Burnout Creek for 1992-1997.

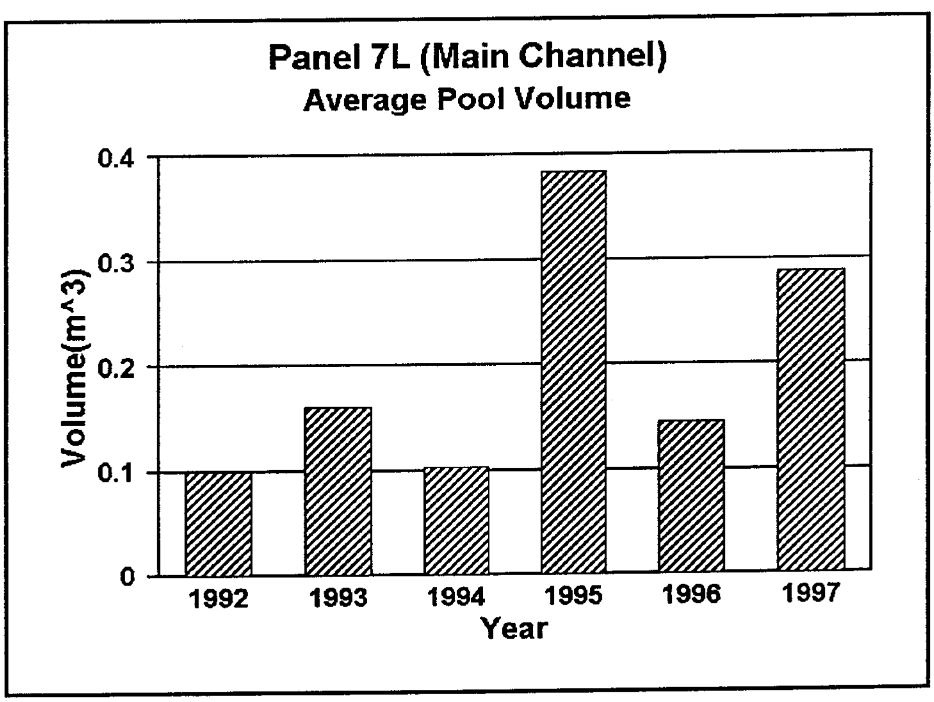


Figure 31. Average volume of pools in Panel 7L of the Main Reach of Burnout for 1992-1997.

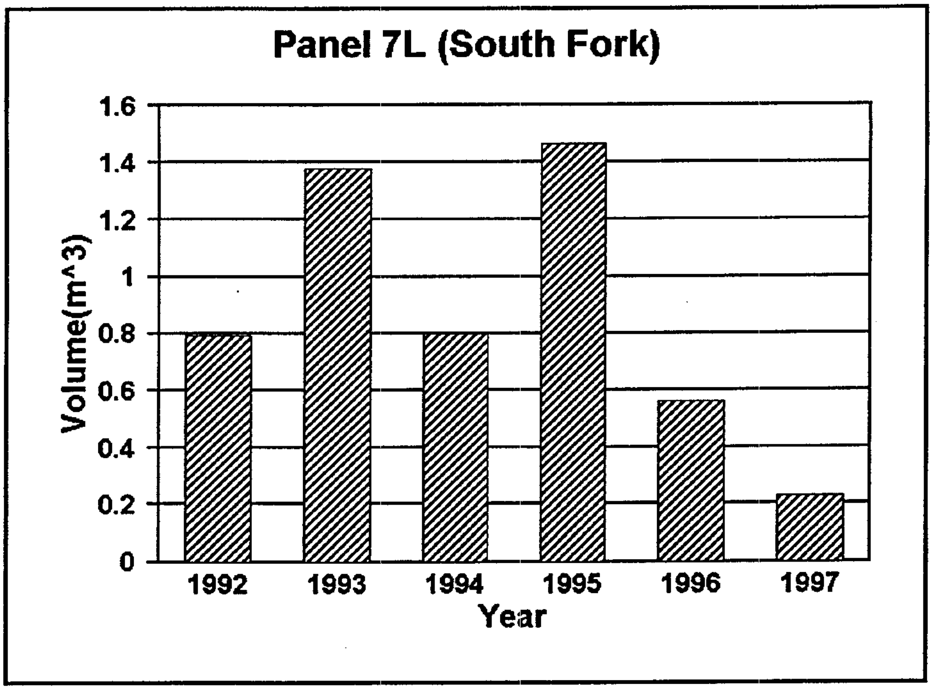


Figure 32. Total pool volume in panel 7L of the South Fork (300-600 m) for 1992-1997.

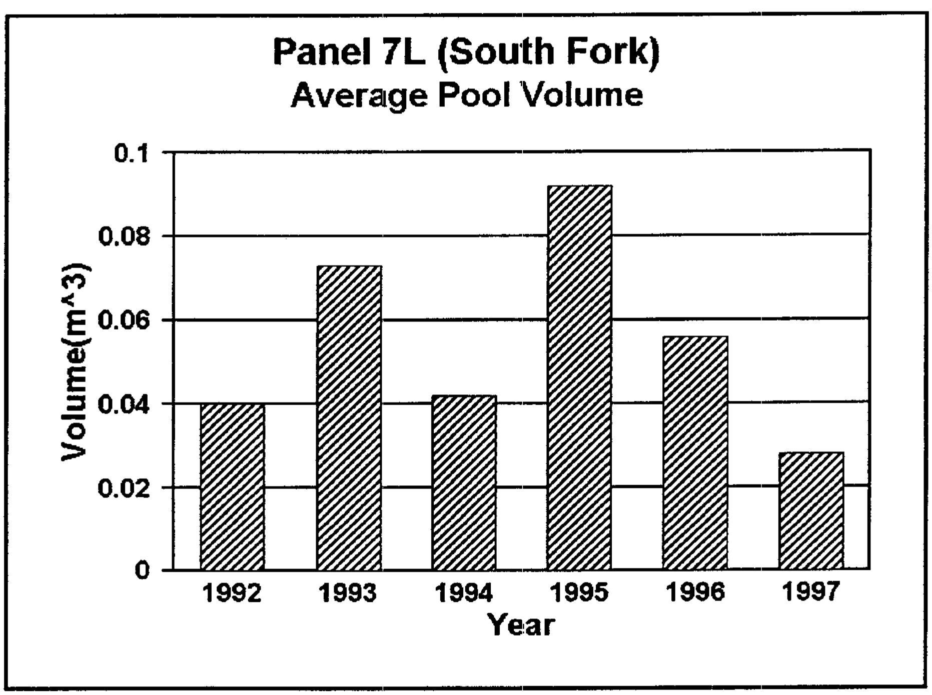


Figure 33. Average volume of pools in Panel 7L of the South Fork of Burnout, 1992-1997.

Panel 8L:

The proportion of channel length in the Main Channel section of panel 8L (mined in 1995-'96) occupied by runs and riffles decreased following mining from 89% to 77% (Figure 34), while that in the South Fork decreased consistently between 1992 to 1996 from 70% to 46%. but then increased to 55% in 1997 (Figure 35). The proportion of cascades in the Main Channel abruptly increased from 1.0% in 1994 to 12.9% in 1995, and then decreased to 6.1% in 1996 and then increased greatly to 18.2% in 1997. However, the proportion of cascades in the South Fork increased rather markedly and consistently between 1992 and 1996 (from 15% to 50%) with a corresponding decrease in runs and riffles, but then decreased to 39% in 1997. This suggests that as cascades increase, runs and riffles decrease, which could result from classification error. The proportion of Main Channel pools varied between 1.6% in 1995 to 7.2% in 1994, and in the South Fork from 2.8% in 1996 to 8.4% in 1994. A conspicuous decrease in channel occupied by pools occurred in the Main Channel in 1995 and in the South Fork in 1996.

The number of pools in the Main Channel varied between 12 and 20/km (Figure 36), and the total volume between 1.3 and 3.5 m^3 (Figure 37). In the South Fork, number of pools remained fairly constant (80 to 92/km) until 1996 when they decreased strikingly to only 28/km following mining (Figure 38). Pool volumes in the South Fork varied between ~0.6 and 3.3 m^3, with the lowest total volumes occurring in 1996 and 1997 when numbers were lowest (Figure 39). Average pool volume in the Main Channel was greatest in 1996, almost double that of preceding years (Figure 40). Greatest average pool volume in the South Fork occurred in 1995, then decreased by 1997 to about one-fourth this size (Figure 41).

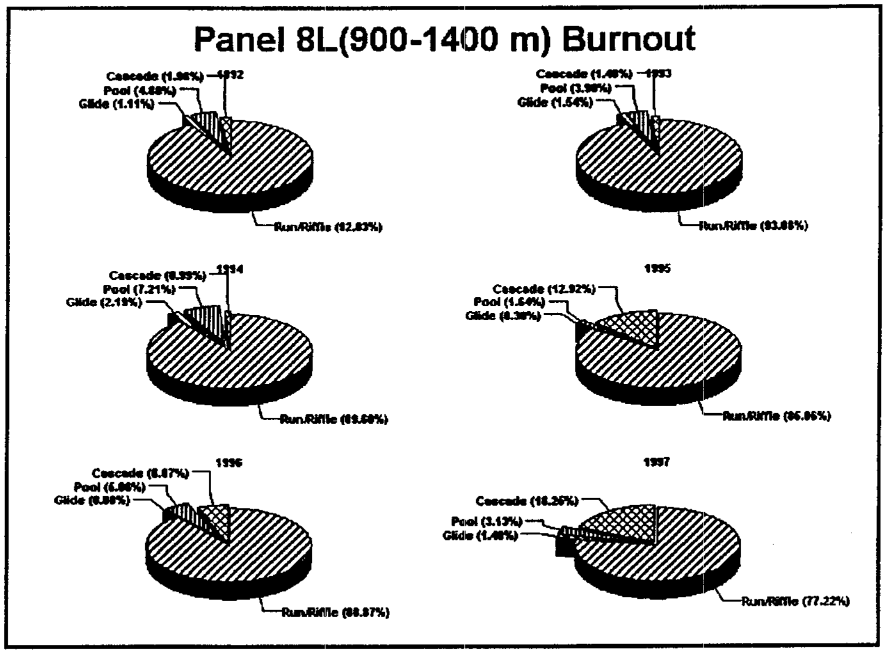


Figure 34. Distribution of channel elements in the Main Reach of Burnout Creek impacted by panel 8L (900-1400 m) for 1992-1997.

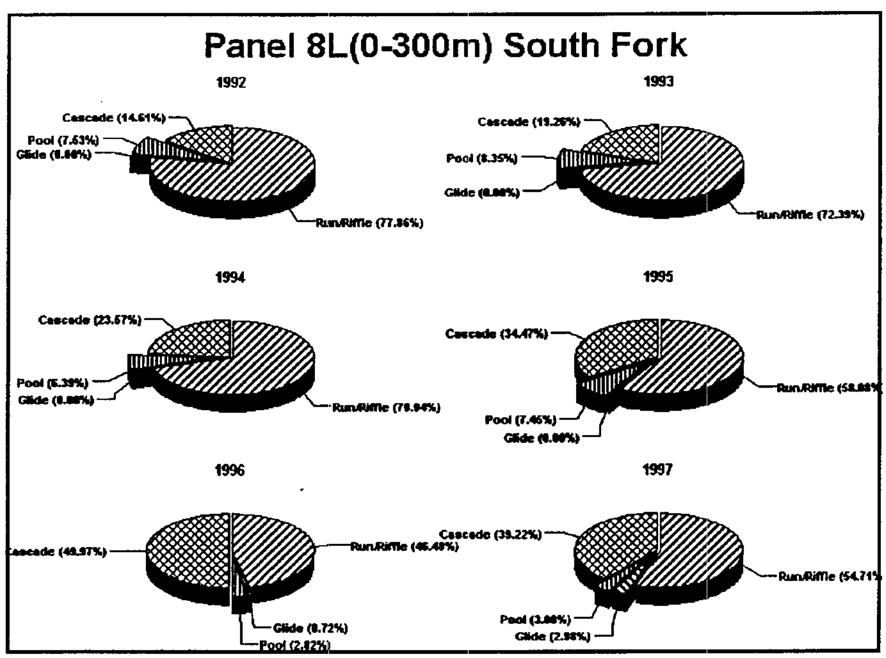


Figure 35. Distribution of channel elements in the Main Reach of Burnout Creek impacted by panel 8L (0-300 m) for 1992-1997.

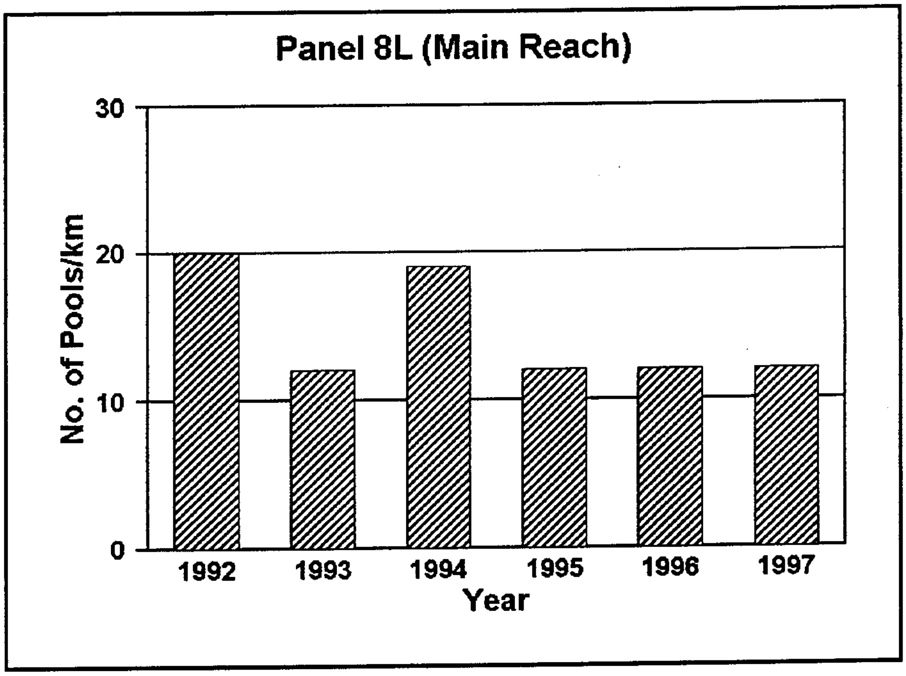


Figure 36. Pool density in the Main Reach of Burnout Creek impacted by panel 8L for 1992-1997

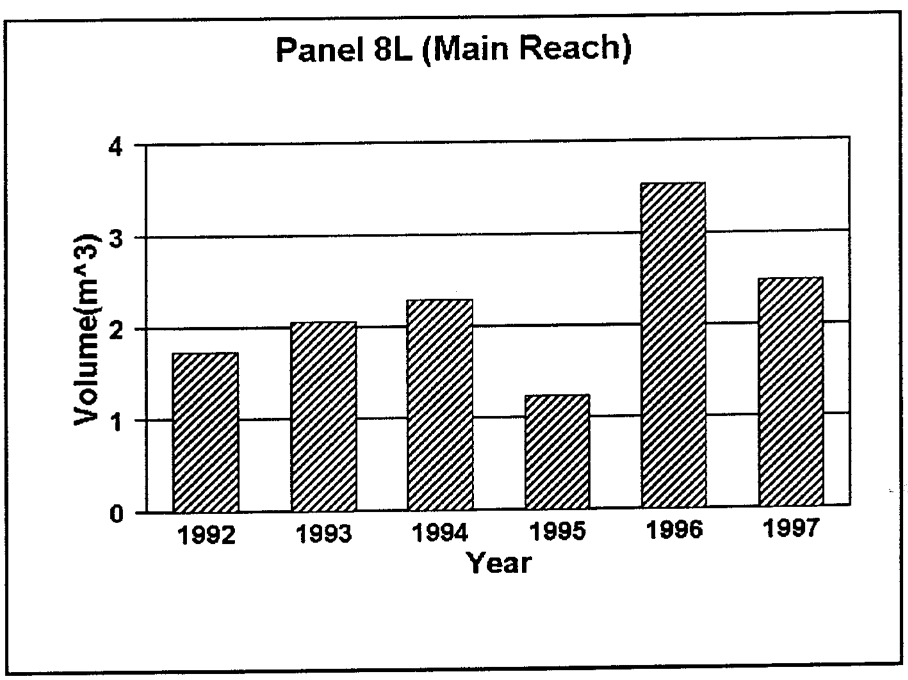


Figure 37. Total pool volume in the main reach of Burnout Creek impacted by panel 8L; 1992-1997.

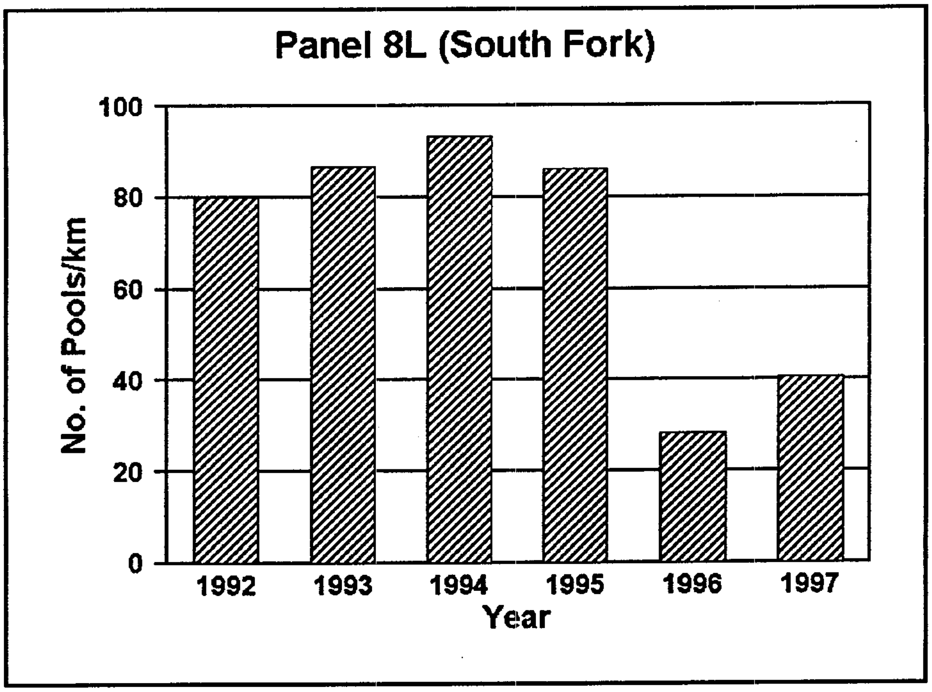


Figure 38. Pool density in the lower reach of the South Fork (0-300m) overlying panel 8L.

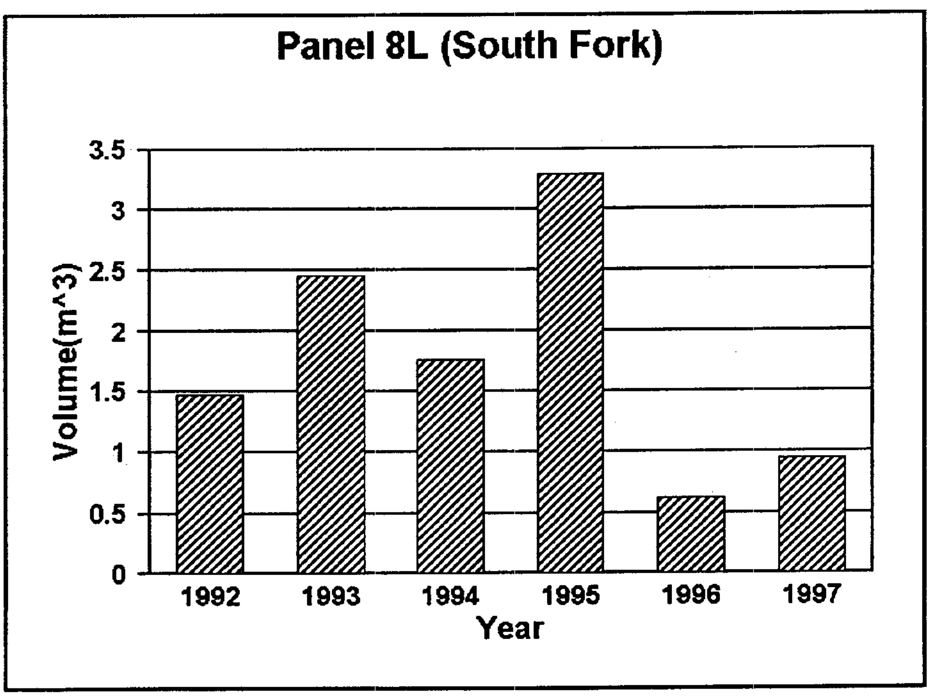


Figure 39. Pool volume in the lower reach of the South Fork (0-300 m) overlying panel 8L

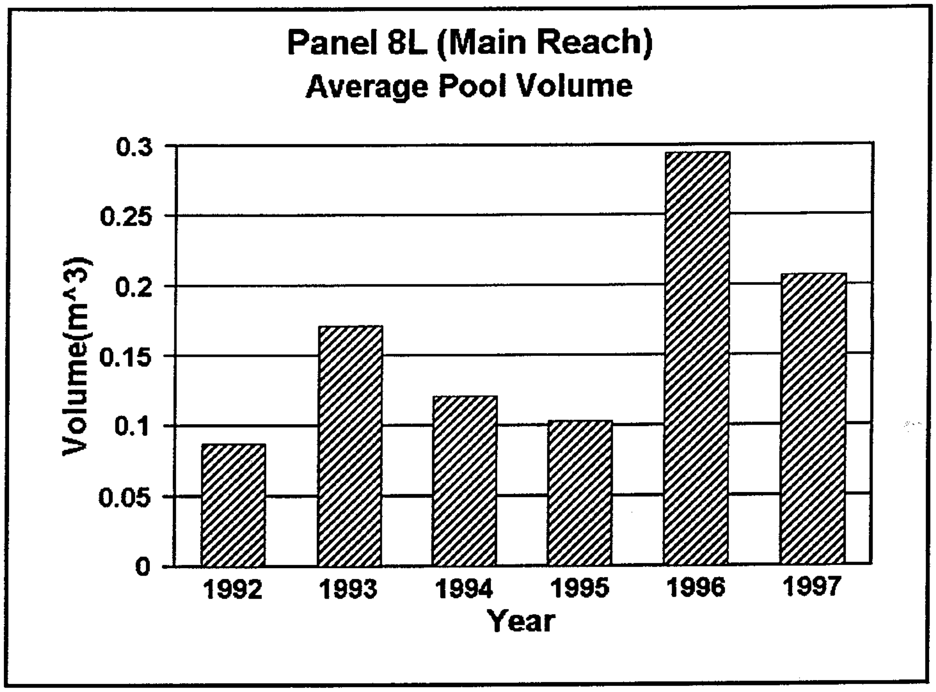


Figure 40. Average pool volume in the Main Channel of Burnout Creek impacted by Panel 8L (0-300 m) for 1992-1997.

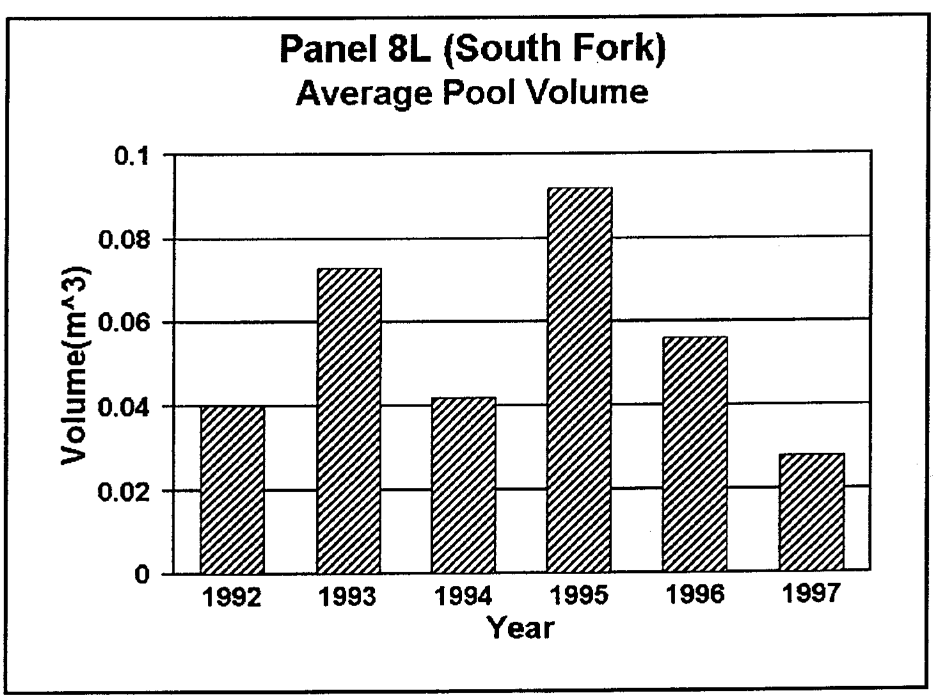


Figure 41. Average pool volume in the South Fork of Burnout Creek impacted by Panel 8L.

Panel 9L:

The proportion of channel length in panel 9L (mined in 1995-1996) occupied by runs and riffles varied between 80.6% and 87.8%, without showing any difference that could be attributed to subsidence (Figure 42). The proportion of channel in cascades varied between 0.0% and 9.8%, with a substantial increase occurring in 1995 and again in 1997, which might be attributed to classification error since it occurred at the expense of the proportion of glides. The proportion of channel occupied by pools was greatest in 1992 (6.6%) and then decreased to between 2.4% and 4.4% for the remaining years. Pool density in this panel varied between 23/km and 44/km (Figure 43) with the fewest occurring in 1997 following subsidence. Pool volume on the other hand decreased from ~2.1 m^3 in 1992 to ~1.0 m^3, and then increased to ~1.5 m^3 in 1994, 2.9 m^3 in 1996, and then decreased to 1.3 m^3 in 1997 (Figure 44). The timing suggests that the latter increase in pool volume might have resulted in part from the effects of subsidence and also higher stream flows in 1995 and 1996. Average pool volume was also greatest in 1996 (Figure 45).

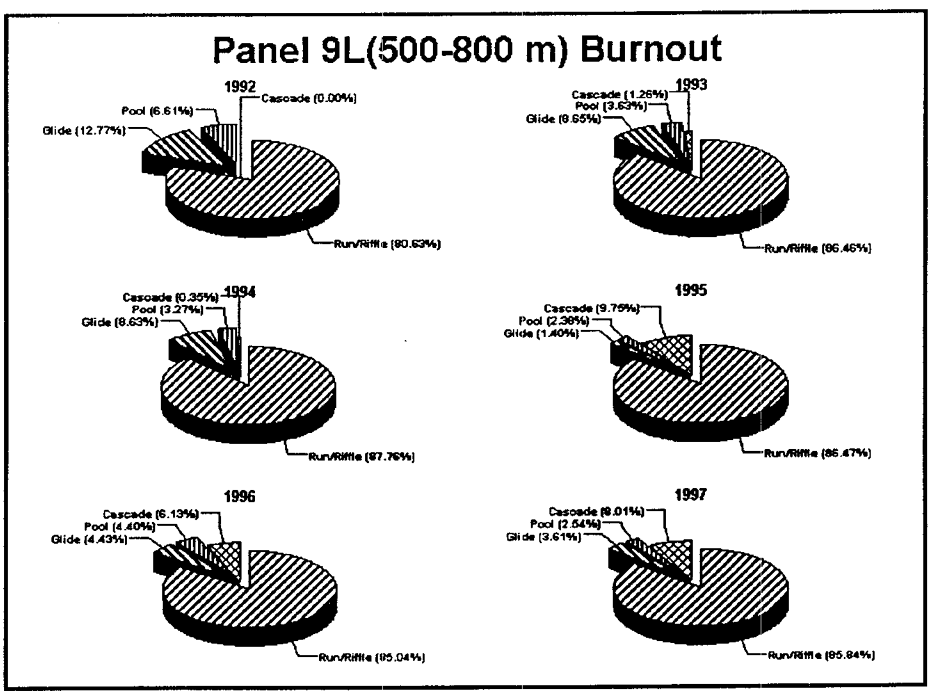


Figure 42. Distribution of channel elements in the Main Reach of Burnout Creek impacted by panel 9L (500-800 m) for 1992-1997.

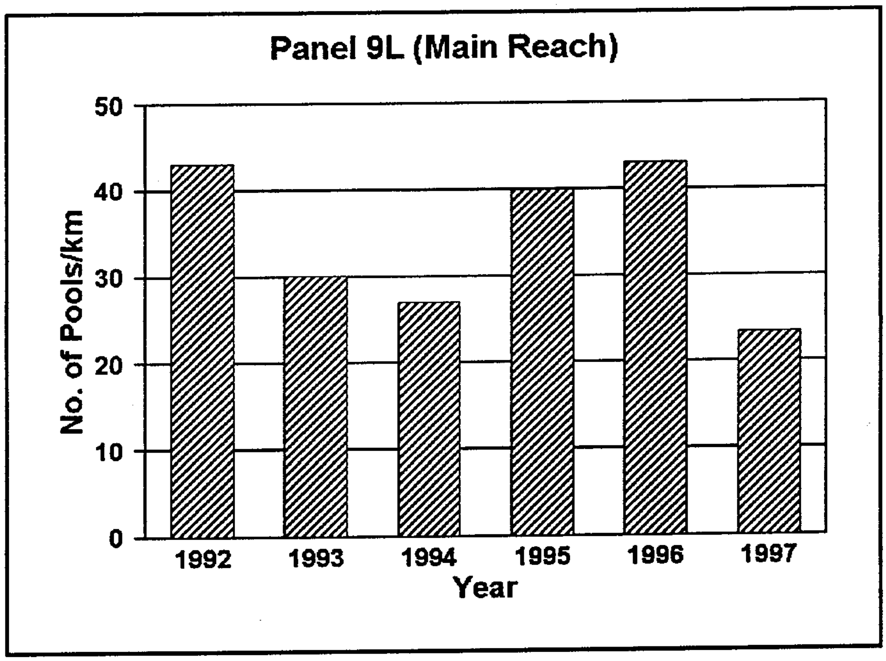


Figure 43. Pool density in the Main Reach of Burnout Creek impacted by panel 9L (500-800 m) for 1992-1997.

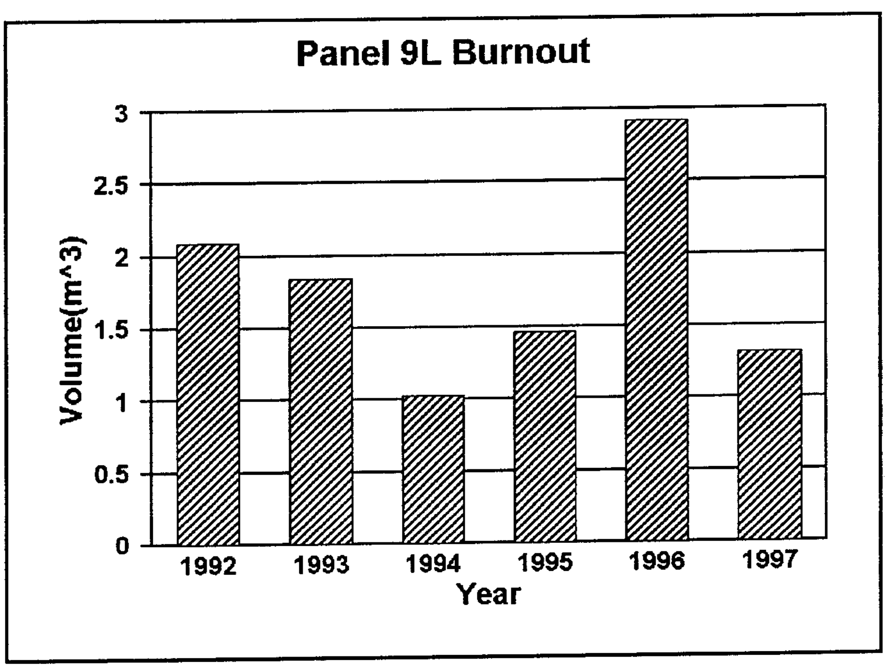


Figure 44. Total pool volumes in the Main Reach of Burnout Creek impacted by panel 9L for 1992 through 1997.

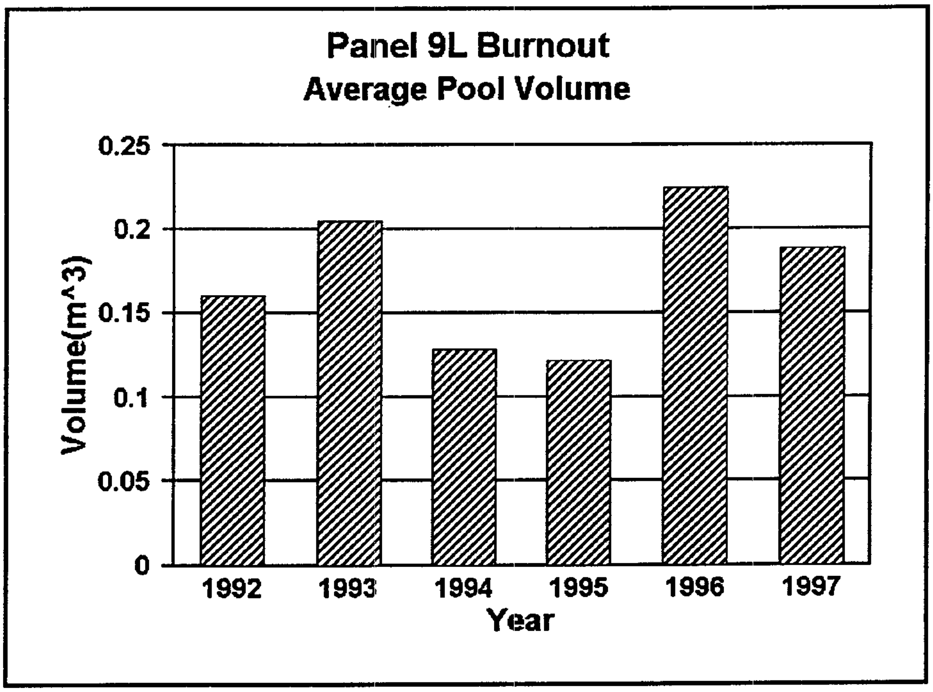


Figure 45. Average pool volume in the Main Reach of Burnout Creek impacted by Panel 9L for 1992-1997.

It appeared that many of the pools surveyed in 1994 were filling in with sediment. Some of the source of the sediment in this steep, incised reach may have been due to channel cross-sectional adjustment following subsidence, however, much of the sediment appeared to come from excessive animal use near the channel. While grazing has been assumed to be relatively constant during the 3-year period (based on grazing allotments), it was obvious from the field investigations that sheep congregated more heavily in the drainage bottoms of the upper perennial reaches of the South Fork during the dry summer of 1994. The steep side slopes that are directly connected to the channel in much of this reach are very susceptible to grazing and to the heavy elk use in the area. Many sheep and game trails were noted in sub-reaches that had some of the largest sedimentation in old pools.

Stream Flow Records:

Flumes were installed to measure variation in stream flow over the 1991 thru 1997 period on both the Main Channel and the South Fork of Burnout Creek. The flume on the Main Channel is close to the mouth of Burnout where it flows into Huntington Cr. at the head of Electric Lake. The South Fork flume is at its junction with the Main Channel of Burnout. These stream flow records should facilitate interpretation of channel characteristic changes that might be attributed to normal yearly differences in stream flow versus changes due to subsidence following mining.

Stream flow in the Main Channel varied over four-fold between years in June and July (from less than 1 cfs to over 4 cfs) but then by August flow tended to stabilize between about 0.3 and 0.6 cfs (Figure 46). Stream flow in the South Fork also varied over four-fold between years in June and July (from less than 0.1 cfs to over 0.4 cfs), and then decreased to between 0.01 and 0.05 cfs during August, September, and October (Figure 47). Unfortunately, mid-month measurements were not obtained for June in three of the sever years: 1991, 1993, and 1995. However, judging from the records available it appears that 1992 and 1994 were years of generally low stream flow and 1995, 1996, and 1997 were years of fairly high stream flow.

Stream flow in the flume at the Forest boundary in the James Canyon control varied at least as much as that in the lower channel of Burnout Creek (Figure 48).

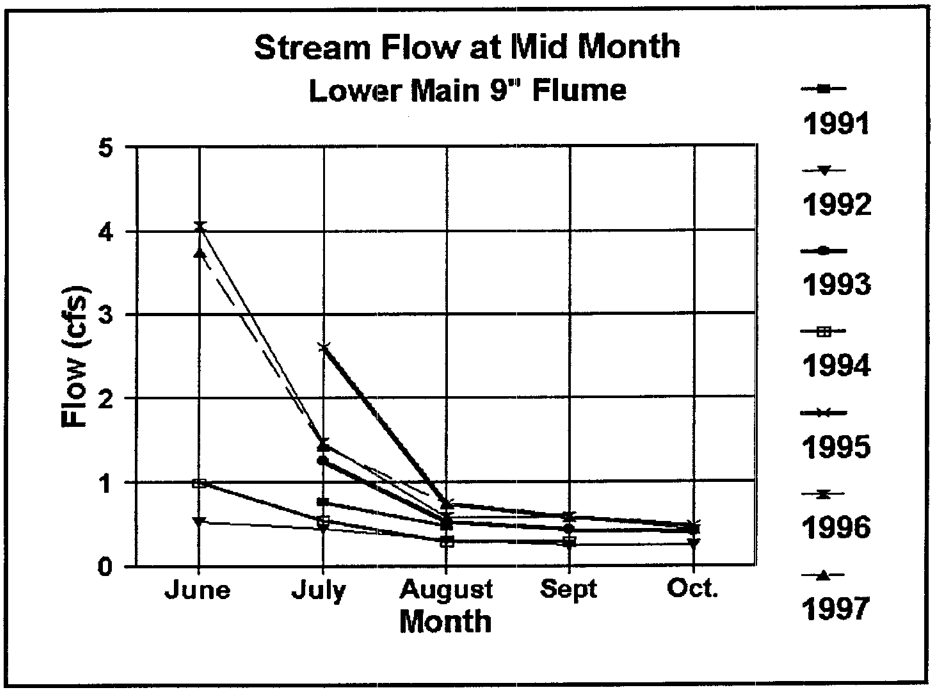


Figure 46. Stream flow records for Main Reach of Burnout Creek from 1992 through 1997.

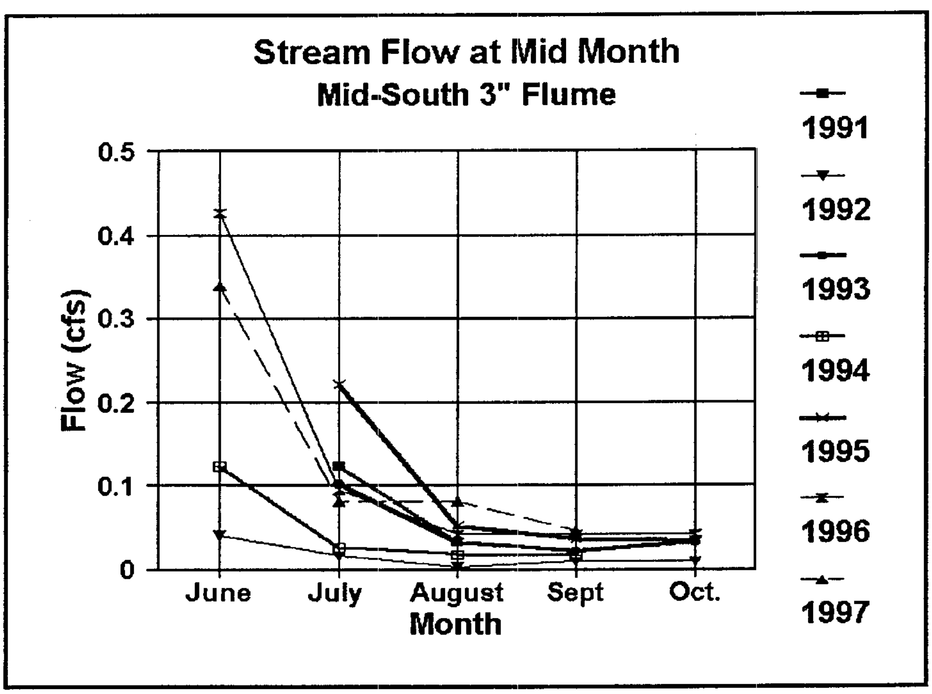


Figure 47. Stream flow records of the South Fork of Burnout Creek from 1992 through 1997.

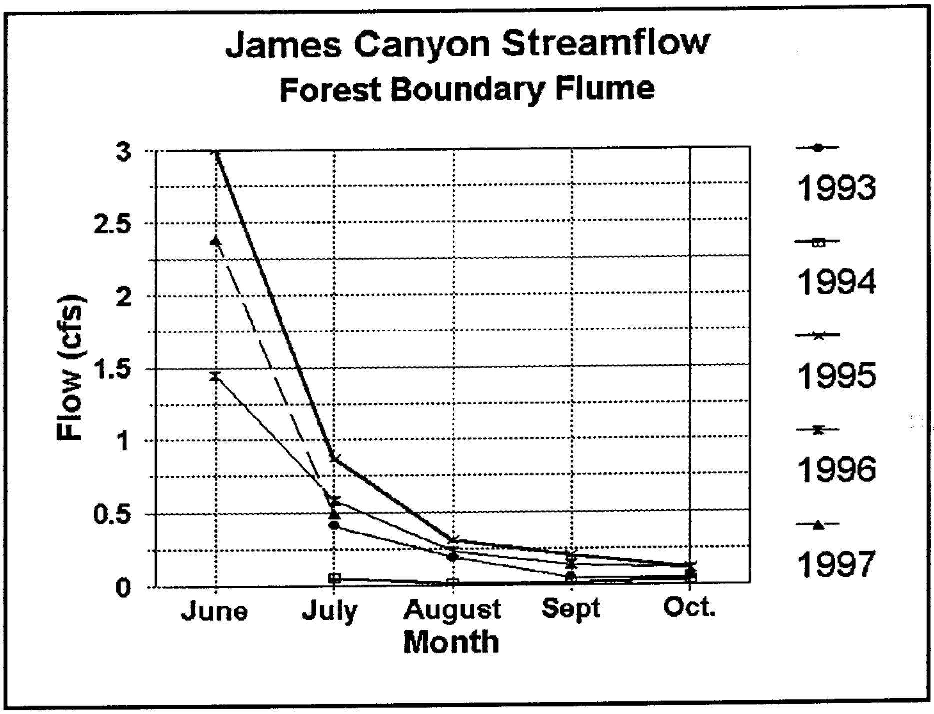


Figure 48. Stream flow records for the flume located at the Forest boundary in James Canyon, from 1993 through 1997.

CHANNEL CHARACTERISTICS DISCUSSION & CONCLUSION:

The James Canyon control area serves as a basis for judging whether a change in channel characteristics in Burnout might be attributed to subsidence following mining. If a substantial change in channel characteristics is markedly and consistently greater in Burnout than in James during the same time period, one can assume that the change results from subsidence, especially if the change is consistent in both the Main Channel and the South Fork of Burnout. To facilitate this comparison, the measured value for the year after change (X) is expressed as a percent of the value immediately prior to change (Y); thus percent change would equal 100(X/Y) - 100.

Following the 1993-1994 mining in Panel 7L, substantial changes occurred by 1995, but few can reliably be attributed to subsidence. For example, cascades in the Main Channel Panel 7L increased 244%, but they increased almost as much (+189%) in Upper James (Table 2) which is the comparable steeper section of the control. In the South Fork Panel 7L, the proportion of the channel in cascades did not increase nearly as much as in the James control suggesting, if anything, that subsidence negatively affected the proportion of cascades. By 1997, it appears that mining had a negative impact on the proportion of cascades since they did not increase nearly as much as in the James control (Table 3). The proportion of channel in pools, however appeared to have temporarily increased in both the Main Channel Panel 7L and in the South Fork Panel 7L compared to the control (Table 2). However by 1997, this difference was no longer evident (Table 3). The number of pools in the South Fork Panel 7L appear to have increased somewhat in 1995, but again this increase was temporary. Any increase in total pool volume in Panel 7L in 1995 also appears to have diminished by 1997. The inconsistencies in response between the Main Channel section and South Fork section of Panel 7L makes any generalizations regarding the effect of subsidence on channel characteristics in this panel difficult.

Table 2. Percent change between 1994 and 1995 in Panel 7L on the Main Channel and South Fork of Burnout Creek, and in the Upper James control.

STREAM ELEMENT	MAIN CHAN. PANEL 7L	UPPER JAMES		SOUTH FORK PANEL 7L	UPPER JAMES
Runs/Riffles	-22	-21		-4	-21
Cascades	+244	+189		+6	+189
Glides	-100	-91		0	-91
Pools	+28	-47		+25	-47
Pool Numbers	-60	-54		-7	-54
Pool Volume	+59	+27		+81	+27
Av. Pool Volume	+280	+186		+124	+186

Table 3. Percent change between 1994 and 1997 in Panel 7L on the Main Channel and South Fork of Burnout Creek, and in the Upper James control.

STREAM ELEMENT	MAIN CHAN. PANEL 7L	UPPER JAMES		SOUTH FORK PANEL 7L	UPPER JAMES
Runs/Riffles	-8	-40		-9	-40
Cascades	+152	+300		+21	+300
Glides	-100	+108		0	+108
Pools	-71	-77		-35	-77
Pool Numbers	-65	-77		-54	-77
Pool Volume	0	-60		-73	-60
Av. Pool Volume	+190	+73		-33	+73

Panel 8L was mined in 1995-1996, and data were evaluated for both the Main Channel section and for the South Fork section of this panel. (The data on changes in proportion of glides is not reliable because of the very small percentages involved.) The most relevant changes attributable to mining in the Main Channel is the increases in the proportion of channel occupied by pools as well as the number and volume of pools compared to the Upper James control (Table 4). These increases in pool attributes, however, did not occur in the South Fork Panel 8L. Although the proportion of runs and riffles decreased following mining, they did not decrease nearly as much as in Upper James, and thus probably increased somewhat following mining; this occurred in both sections of Panel 8L.

Table 4. Percent change between 1995 and 1997 in Panel 8L on the Main Channel and South Fork of Burnout Creek, and in the Upper James control.

STREAM ELEMENT	MAIN CHAN. PANEL 8L	UPPER JAMES		SOUTH FORK PANEL 8L	UPPER JAMES
Runs/Riffles	-9	-24		-6	-24
Cascades	+41	+38		+14	+38
Glides	+268	+2205		-----	+2205
Pools	+91	-56		-59	-56
Pool Numbers	0	-48		-53	-48
Pool Volume	+108	-67		-71	-67
Av. Pool Volume	+110	-37		-70	-37

Lower James most closely resembles the lower reach of Burnout Creek where Panel 9L is located; it is therefore used as the basis for determining possible changes here attributable to mining. Panel 9L was mined during 1995-1996, thus any effects of subsidence on channel characteristics should be noticed by 1997. Subsidence appears to have resulted in an increase in the amount of channel occupied by pools; although the actual increase was only +7%, Lower James experienced a decrease of 50% (Table 5). However, both the number of pools and the total pool volume appears to have decreased, especially when compared to increases in these attributes in Lower James. Although subsidence resulted in fewer pools, the average volume of these pools had increased substantially by 1997 (+50% in Panel 9L versus a -13% in Lower James). Thus mining caused fewer but larger pools in this panel. The actual length of channel in cascades in these lower reaches was small and the differences may well have resulted from classification inconsistencies.

Table 5. Percent change between 1995 and 1997 in Panel 9L of Burnout Creek and in the Lower James control.

STREAM ELEMENT	MAIN CHANNEL PANEL 9L	LOWER JAMES
Runs/Riffles	-1	-1
Cascades	-18	-25
Glides	+158	+625
Pools	+7	-50
Pool Numbers	-43	+29
Pool Volume	-13	+14
Av. Pool Volume	+50	-13

Whether mining has had an effect on channel characteristics along the entire monitored length of the Main Channel and South Fork channel of Burnout might be answered by comparing the relative differences between the 1993 data and the 1997 data in these channels with differences during the same period in James Canyon.

The response of the Main Channel to mining were not always consistent with changes in the South Fork. Whereas the proportion of the Main Channel occupied by cascades appeared to have increased, that in the South Fork may have decreased (Table 6). On the other hand, the total number of pools may have increased in both the Main Channel and South Fork drainages, but changes in pool volume were inconsistent.

The most reasonable conclusion regarding the effects of subsidence on stream channel characteristics in the Burnout drainages is that no meaningful differences occurred that can be attributed reliably to subsidence. Great year-to-year variability occurred in both the James Canyon control as well as Burnout Creek.

Table 6. Percent change between 1993 and 1997 in the entire Main Channel and the South Fork of Burnout Creek, and in their respective control reaches in James Canyon.

STREAM ELEMENT	BURNOUT CREEK	JAMES CANYON		SOUTH FORK BURNOUT	UPPER JAMES
Runs/Riffles	-6	-12		+13	-37
Cascades	+796	+200		+54	+195
Glides	-65	-8		------	+188
Pools	-45	-71		-72	-82
Pool Numbers	-30	-51		-36	-75
Pool Volume	-47	-77		-72	-74
Av. Pool Volume	-26	-44		-33	+4

Channel Cross-Section

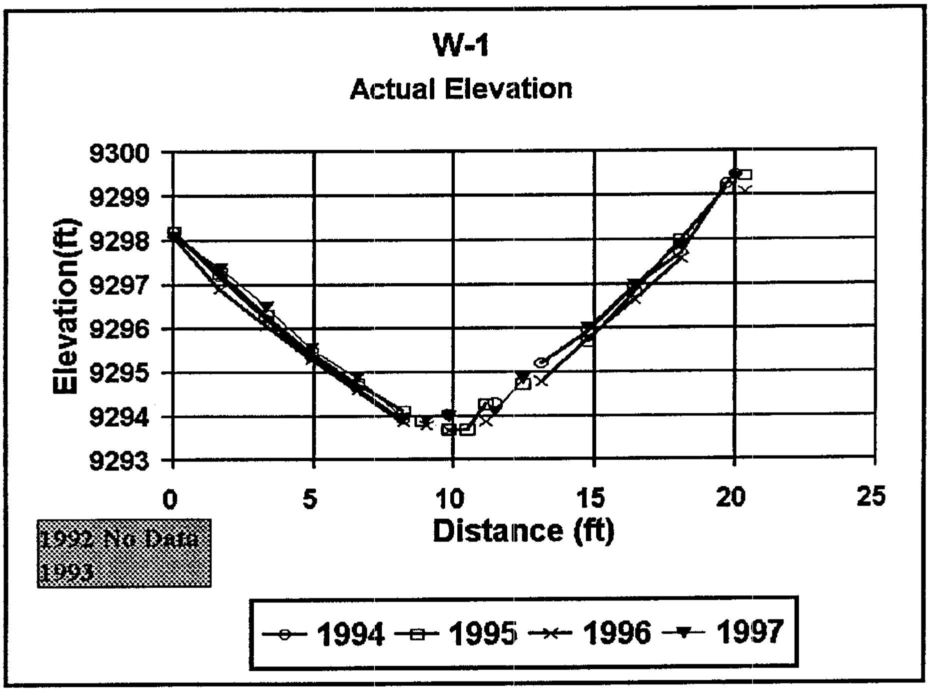
Scour and fill values are only meaningful directly for James Creek and the panel 10L cross-section in Burnout Creek that were not mined. For the subsided cross-sections, horizontal and vertical movement of either or both survey pins would introduce large errors in scour and fill calculations. Thus, it would be impossible to tell if a channel change was due to scour (or fill) or to subsidence. Therefore, in analyzing channel cross-sections that experienced subsidence, a routine to align yearly channel profiles by adjusting both vertical and horizontal axes was used. We could then align the major channel feature (e.g., thalweg) in a qualitative way to compare year to year channel changes.

Of the 73 channel cross-sections surveyed in Burnout Creek, we focus the majority of our attention on the cross-sections located above longwall panels 5L, 6L, 7L, 8L and 9L where mining and subsidence has already occurred from 1992 to 1997. Longwall mining and most of related subsidence above panel 5L had already occurred by early 1992, prior to our initial survey. Thus, documented cross-sections in this upper ephemeral reach of Burnout Creek were located only in the zone of maximum subsidence with the objective to monitor any residual subsidence or recovery of channel geometry. Subsidence in this monitored reach was approximately 5 feet and did not change appreciably after the 1992 survey.

Rather than describe changes in each of the 73 cross-sections monitored during the 6-year period, we selected cross-sections that typified the behavior of each set of cross-sections in zones of subsidence and zones of tension. Changes in these selected cross-sections thus represent changes in the stream channel and are discussed below.

James Canyon (Control Area):

Differences in cross-section profiles in James Canyon serve as a basis for determining the amount of cross-section changes in Burnout that might be attributable to subsidence. The differences between years in James Canyon cross-sections result from the normal yearly flux of cut and fill combined with minor differences in survey measurements. Figures 49 and 50



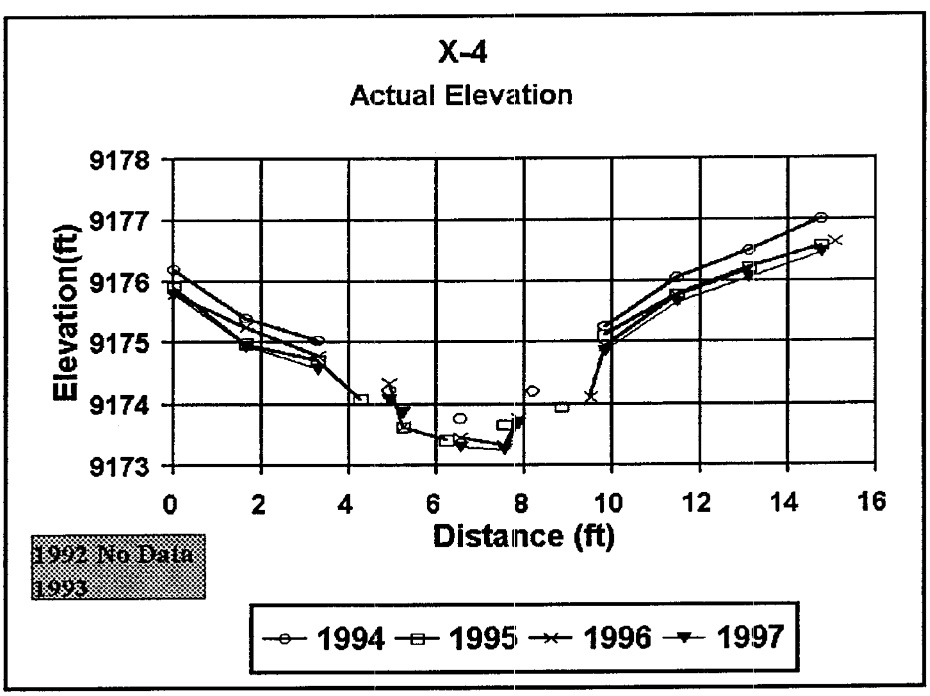
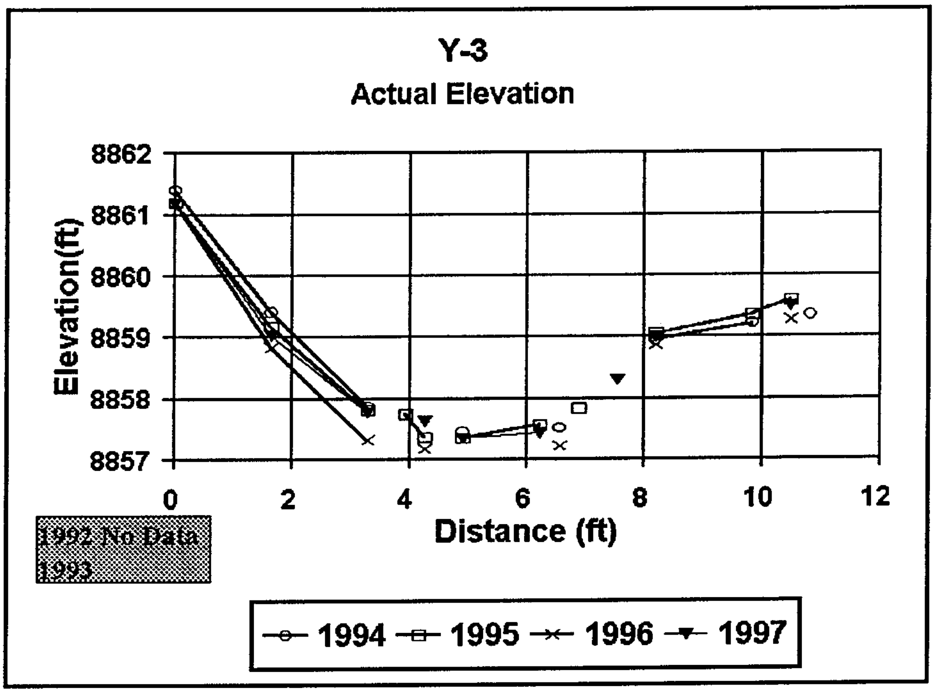


Figure 49. Examples of channel cross-section changes in the upper reach of James Canyon.



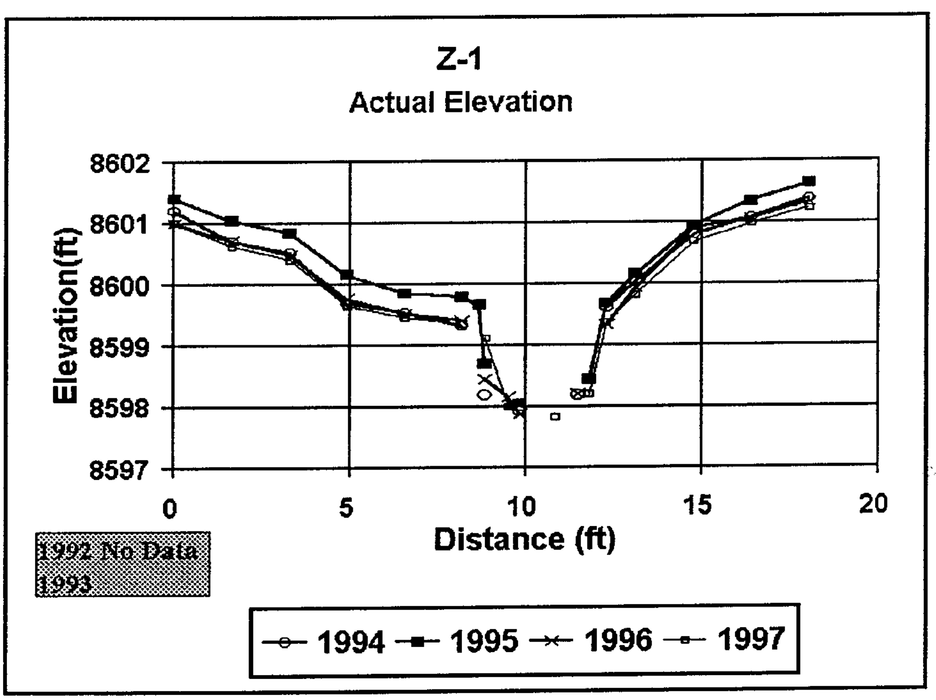
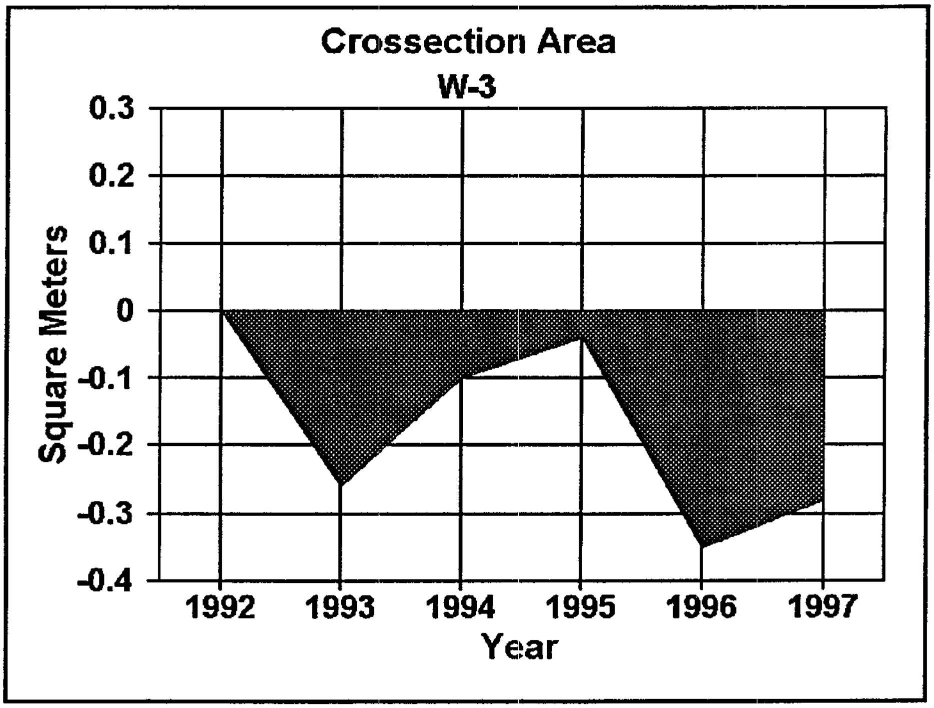


Figure 50. Examples of channel cross-section changes in the lower reach of James Canyon.



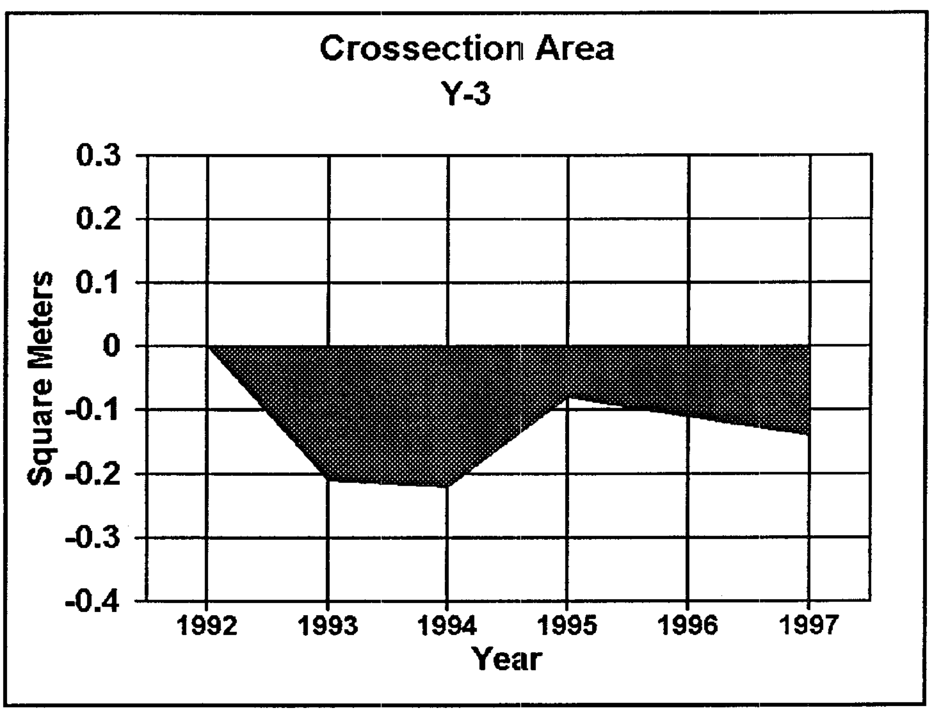


Figure 51. Examples of variations in cut and fill in the upper reach (W-3) and lower reach (Y-3) of James Canyon over the study period.

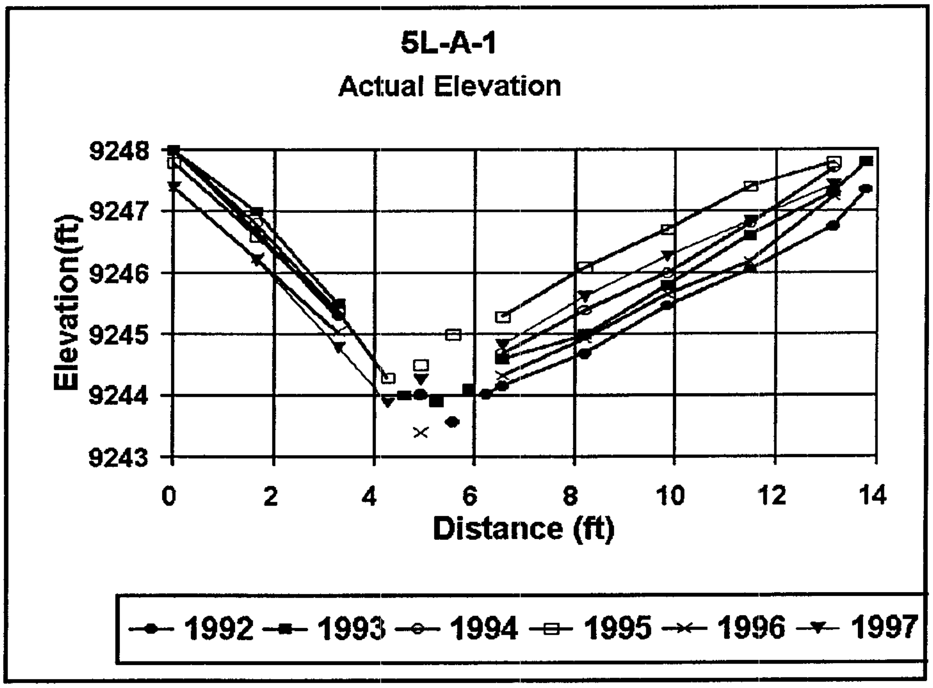
illustrate examples of cross-section profile differences in James Canyon between 1994-'97. Elevational differences between years in the profile of cross-section W-1 varied no more than 0.3 feet, cross-section X-4 varied nor more than 0.5 feet, cross-section Y-3 varied 0.6 feet, and cross-section Z-1 0.5 feet.

Distance between the staked ends (channel width) varied between 0.0 and 0.3 feet, which can be attributed to measurement error. Thus, we can assume that any cross-section elevational differences between years in Burnout that exceed ~0.5 ft. can be attributed to subsidence as well as any channel width exceeding ~0.3 feet.

Figure 51 shows the amount of channel cut and fill variation than can be expected to occur from normal erosion and deposition caused by yearly flux in stream flow. Between 1992 and 1993 both cross-sections W-3 and Y-3 lost over 0.2 m^2 in cross-section area. Deposition in subsequent years almost replaced this, but then section W-3 lost ~1/3 m^2 again in 1996. Almost 0.1 m^2 of this in W-3 was replaced in 1997, but Y-3 continued to lose. Obviously, substantial normal changes in cut and fill can be expected to occur yearly.

Panel 5L:

Two examples (5L-A-1 and 5L-A-5) of the changes occurring between 1992 and 1997 in the five cross sections in panel 5L are shown in Figure521. Both of these examples are in the zone of subsidence; however, this subsidence must have occurred prior to the installation of the cross-sections in 1992. The 1995 data appear to be an aberration, suggesting that the right side of the cross sections rose approximately 1 ft. but then fell again to approximately previous levels in 1996, which is an unlikely occurrence. The width of the 5L-A-5 channel (distance between pins) narrowed progressively by 1.0 foot between 1992 and 1995, but then widened by 0.6 feet in 1996, where it remained in 1997. This panel is located on the toe of a mass earth flow and the channel narrowing can be attributed to this slope movement.. The widening in 1996 is probably also related to movement within this zone.



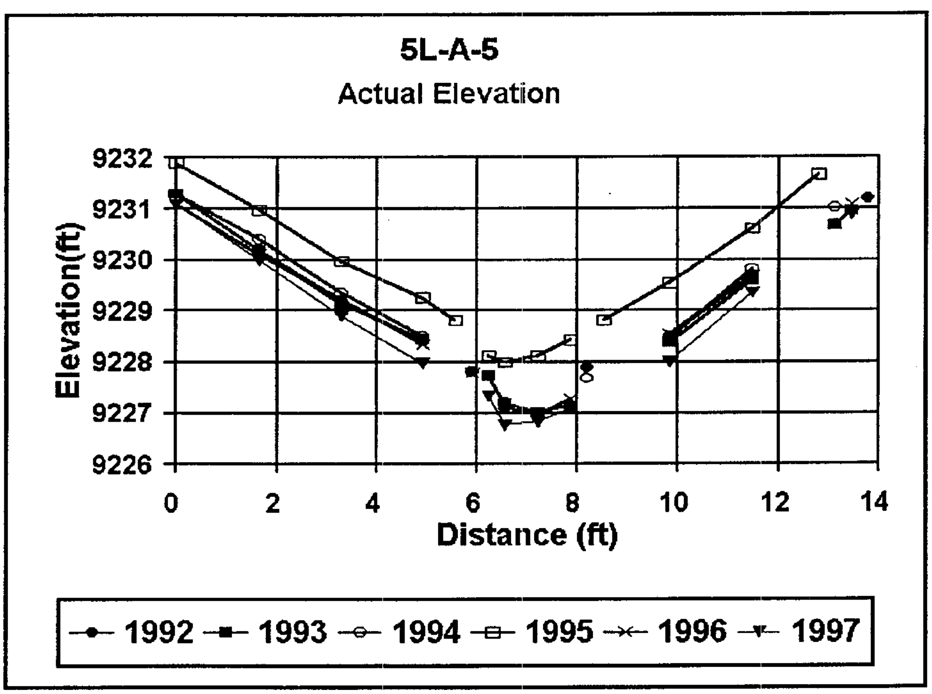
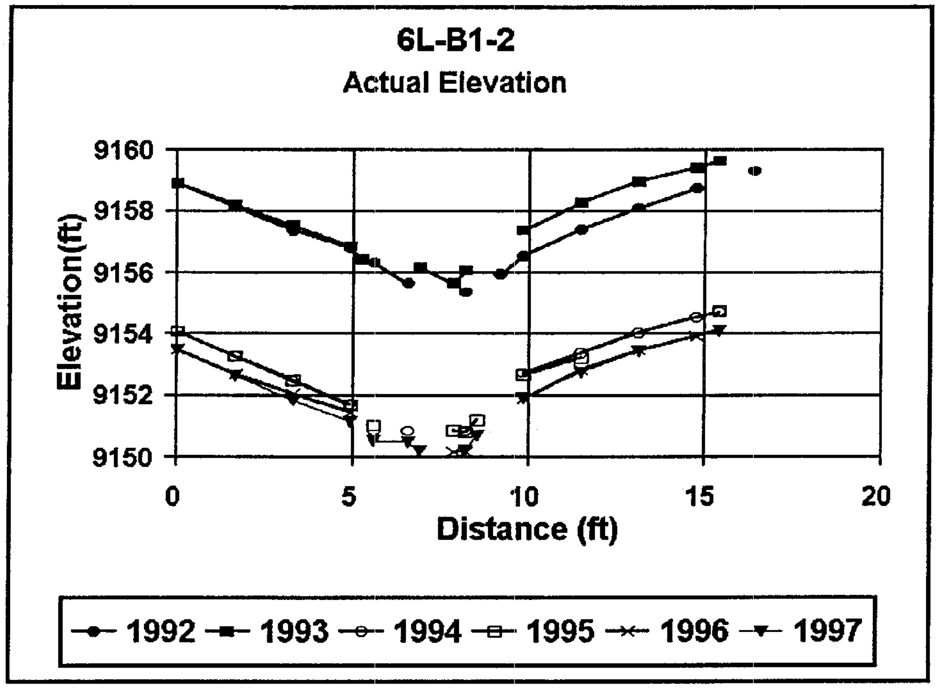


Figure 52. Examples of cross-section changes in the ephemeral reach of Burnout Creek.

Panel 6L:

Two reaches of the main branch of Burnout Creek overlying panel 6L (mined in late 1992 to early 1993) had cross-sections installed. The uppermost perennial reach of Burnout Creek (from about 2150 to 2450 m) had five cross-sections in the maximum subsidence zone and, because of the orientation of the panel, only three in the zone of maximum tension. Figure 42 shows an example of a cross-section in the subsidence zone (6L-B1-2) and one in the tension zone (6L-B1-7). The cross-sections in the subsidence zone dropped ~5.0 feet between 1993 and 1994, with possibly additional settling of 0.5 ft. by 1996. The channel narrowed by 1.0 feet at that time. The drop was less in the tension zone, ~ 3.2 feet between 1993 and 1994, with possibly some slight additional settling by 1996. The channel here narrowed progressively between 1992 and 1995 for a total of 1.5 feet.

In the lower reach of panel 6L, the effects of subsidence were not quite as noticeable. Cross-section 6L-B2-2 serves as an example of those cross-sections in the subsidence zone, and 6L-B2-6 an example for the tension zone (Figure 43). The cross-sections in the subsidence zone here dropped approximately 3.5 feet between 1993 and 1994, and settled perhaps an additional 0.5 feet by 1996. Subsidence in the tension zone, however, was much less (~1.5 feet) and appeared to occur gradually, with the major drop occurring between 1995 and 1996. The channel in the tension zone appears to have widened (~ 2.5 feet), whereas it didn't change in the subsidence zone.



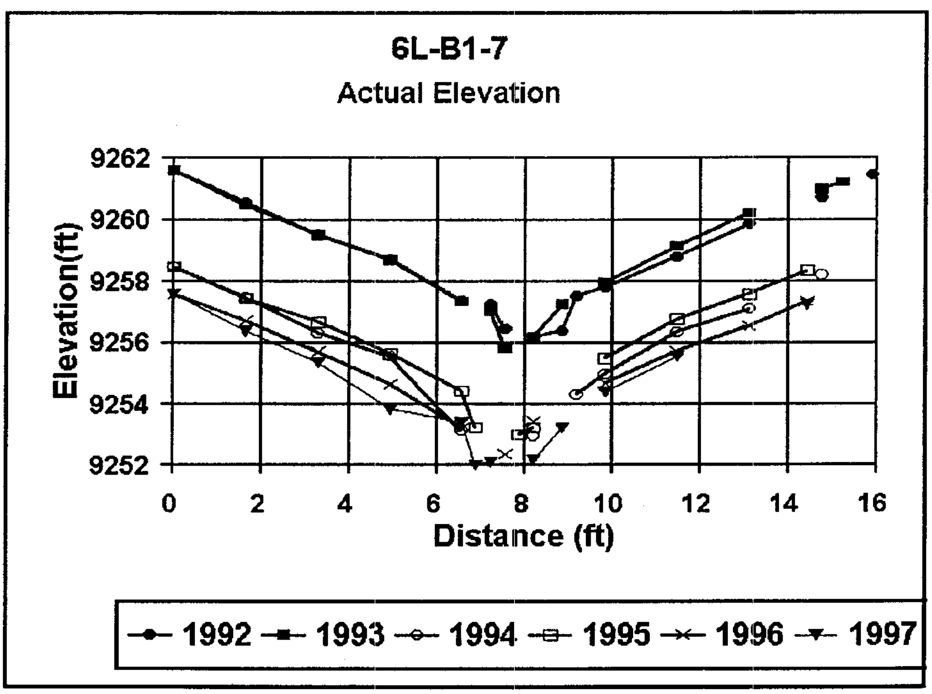
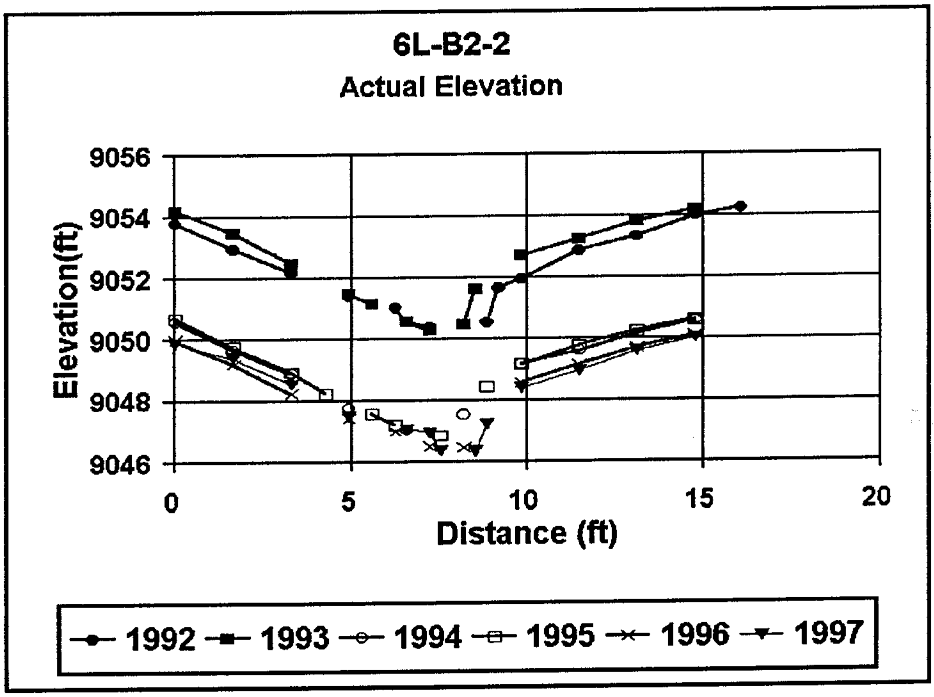


Figure 53. Examples of cross-section changes in the zones of subsidence (6L-B1-2) and tension



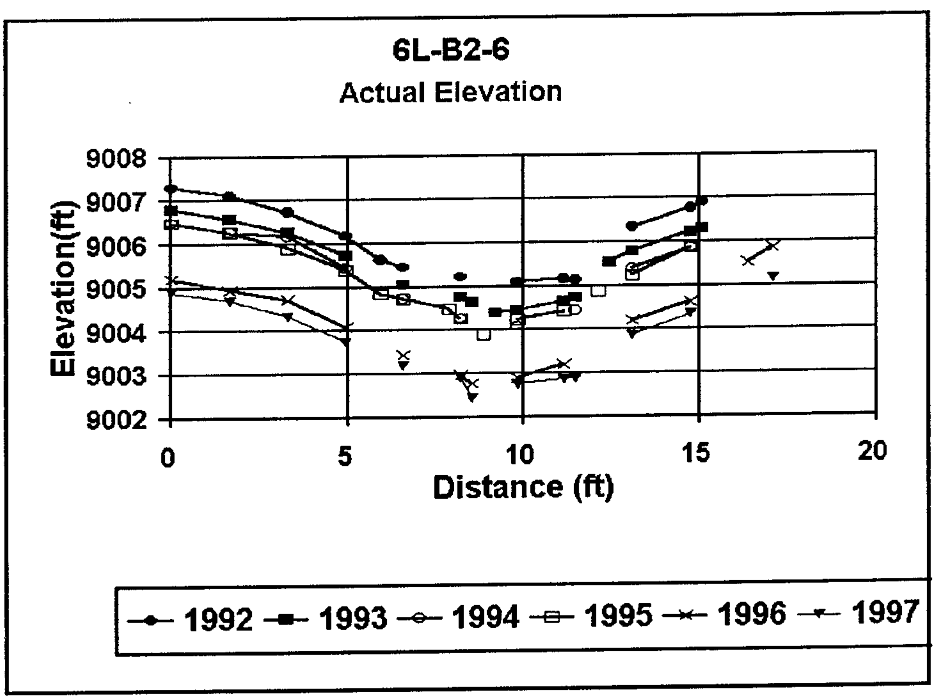
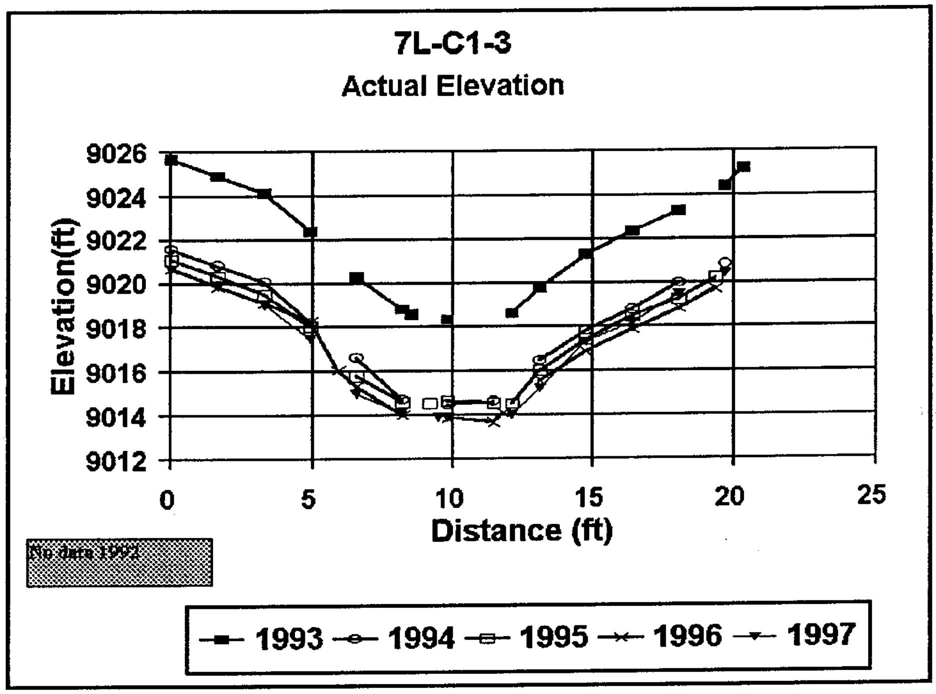


Figure 54. Examples of cross-section changes in the zones of subsidence (6L-B2-2) and tension (6L-B-6) of panel 6L in Burnout Creek.

Panel 7L:

Five maximum subsidence and five tension cross-sections were located above longwall panel 7L in the South Fork of Burnout Creek. Cross-section examples in this panel, mined in late 1993 and early 1994, are 7L-C1-3 for the zone of subsidence, and 7L-C2-8 for the tension zone (Figure 44). The cross-sections in the subsidence zone dropped 3.5 to 4.0 feet between 1993 and 1994, with very little further settling. The channel may have narrowed ~1.5 feet in the process. Cross-sections in the tension zone dropped comparatively little, between 1.5 and 2.0 feet, and more gradually, but the channel appears to have widened ~1.5 feet in this process.

Cross-section 7LC2-6 in the tension zone of the South Fork was used as an example of cut and fill changes (Figure 45). Following subsidence, a minor amount (<0.2 m^2) of deposition occurred in contrast to the erosion in James Canyon.



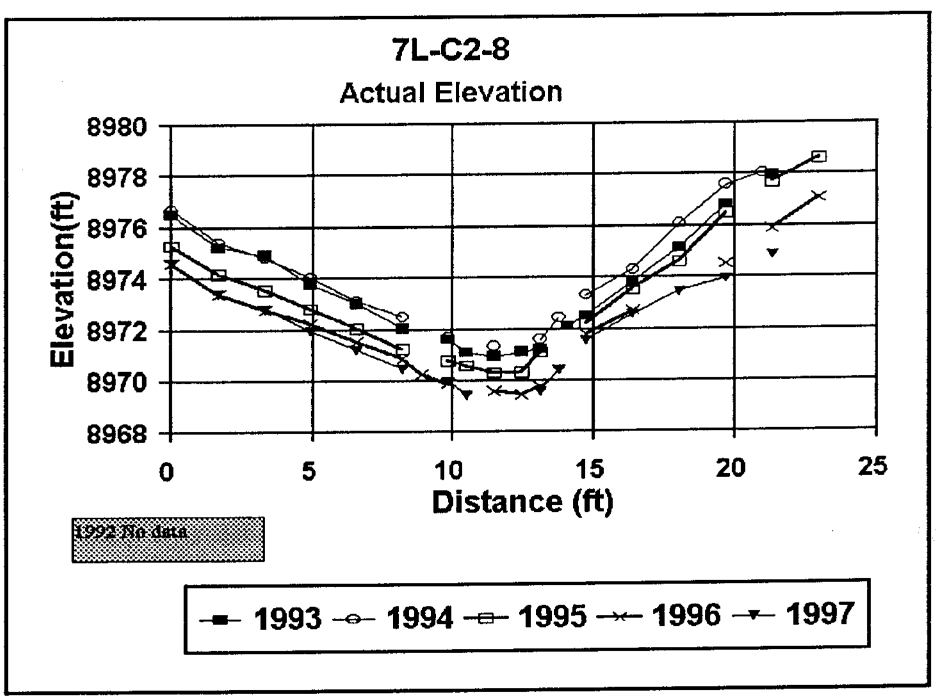


Figure 55. Examples of cross-section changes in the zones of subsidence (7L-C1-3) and tension (7L-C2-8) of panel 7L in the South Fork of Burnout Creek.

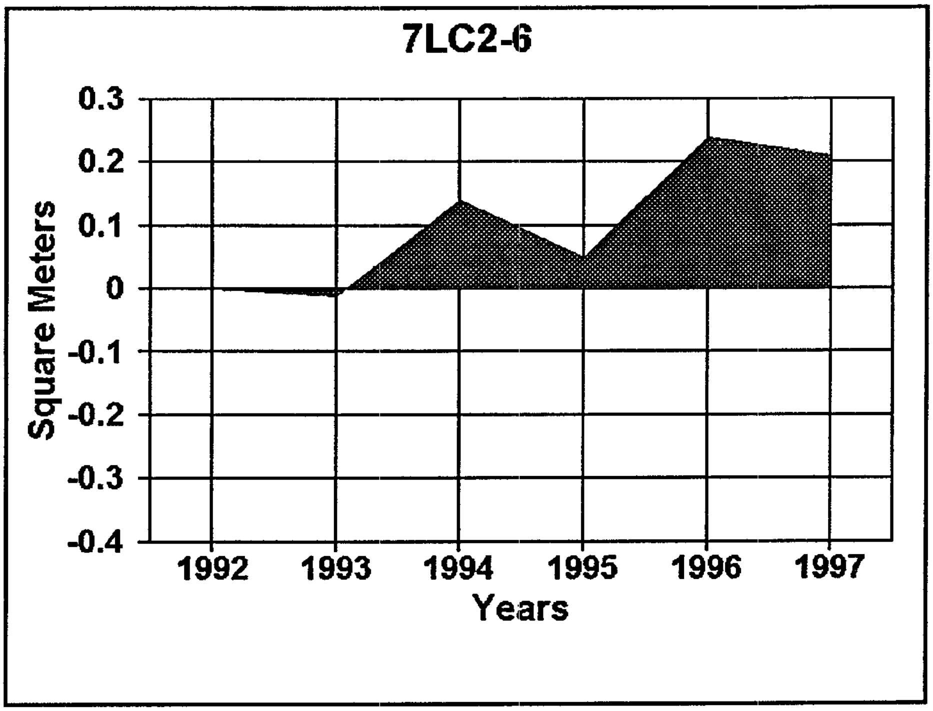


Figure 56. Example of cut and fill changes over the study period in tension zone of the South Fork section of panel 7L.

Panel 8L:

Four cross-sections are shown as examples of changes in panel 8L which was mined in 1995 and early 1996: two (8L-D1-3, subsidence; 8L-D1-9, tension; Figure 57) are in the Main Channel of Burnout, and two (8L-D2-4, subsidence; 8L-D2-10, tension; Figure 58) are in the lower reach of the South Fork. In the Main Channel the cross-sections in the subsidence zone dropped gradually, with ~1.0 foot in 1995, followed by an additional drop of ~ 0.5 feet in 1996, and an additional ~0.5 feet in 1997. The channel width did not change. The cross-sections in the tension zone of the Main Channel also dropped gradually, ~2 feet in 1995, with an additional drop of ~0.8 feet in 1996, and another ~1 foot in 1997. The channel width here decreased ~ 0.5 feet.

The South Fork cross-sections in the subsidence zone (8L-D2-4) dropped ~3.0 feet in 1995, with no further settling. Cross-sections in the tension zone (8L-D2-10) dropped ~2.0 feet in 1995, with a further drop of ~ 1.0 feet in 1996. Neither set of cross sections showed appreciable change in either width or shape.

Cut and fill measurements in the Main Channel (Figure 59) did not show differences in either erosion or deposition patterns in excess of those found in the control area.

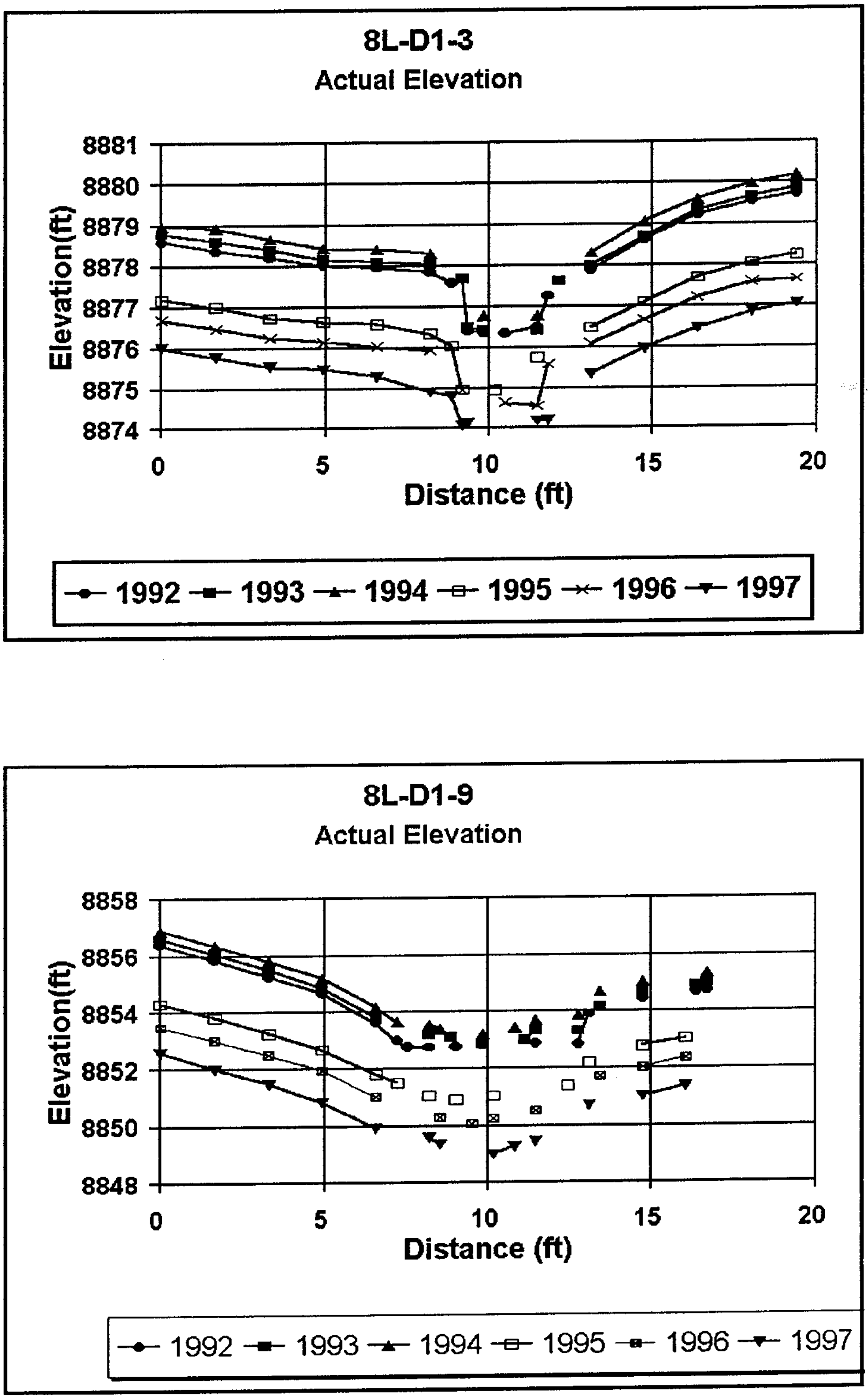
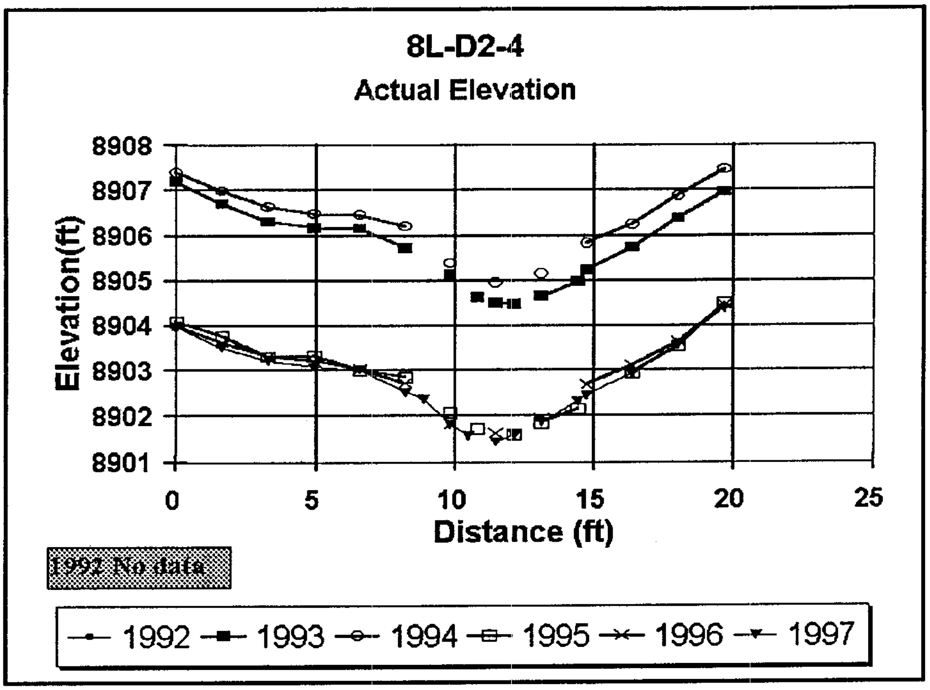


Figure 57. Examples of cross-section changes in the zones of subsidence (8L-D1-3) and tension (8L-D1-9) of panel 8L in the Main Channel of Burnout Creek.



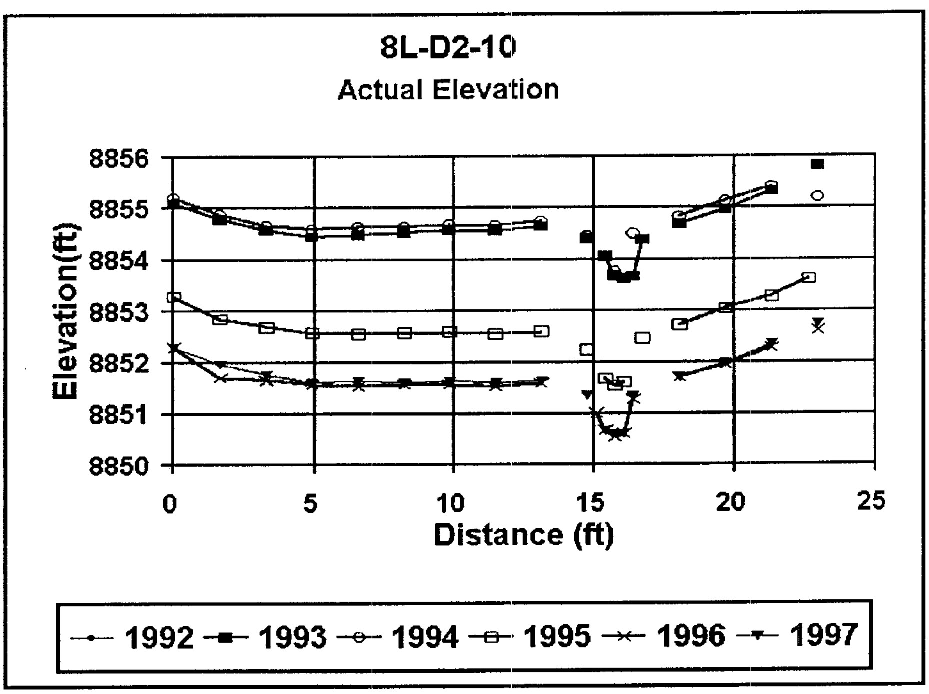


Figure 58. Examples of cross-section changes in the zones of subsidence (8L-D2-4) and tension (8L-D2-10) of panel 8L in the South Fork of Burnout Creek.

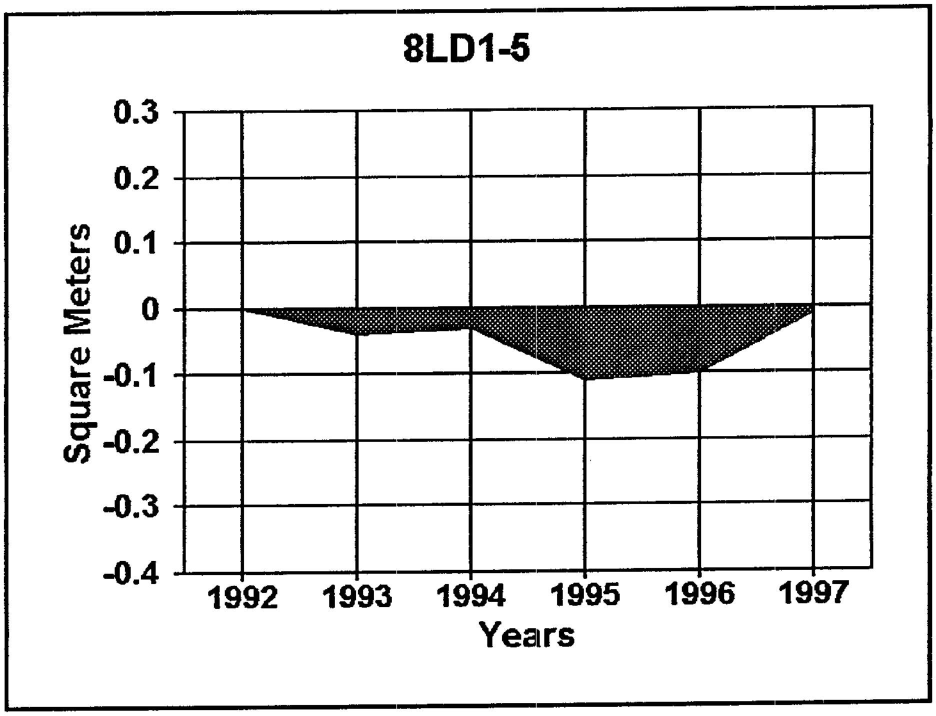
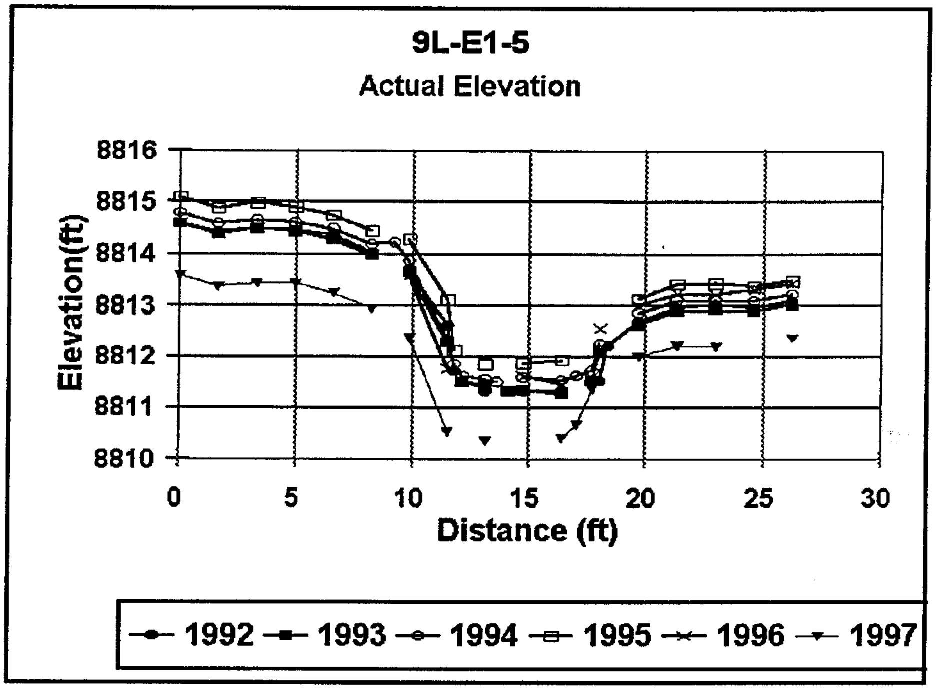


Figure 59. Example of cut and fill changes over the study period in the subsidence zone in panel 8L of the Main Channel of Burnout.

Panel 9L:

Panel 9L was mined in 1995 and 1996. Cross section 9L-E1-5 is used as an example of changes in the zone of subsidence, and cross section 9L-E1-8 of changes in the tension zone (Figure 60). Data collected in 1996 had not yet been affected by mining. By 1997, however, a drop of ~1 foot had occurred in the subsidence zone and a little over 1 foot in the tension zone. No change was noted in channel width. Some channel deposition occurred (Figure 61), especially in contrast to the channel erosion in the James Canyon control (Figure 51).



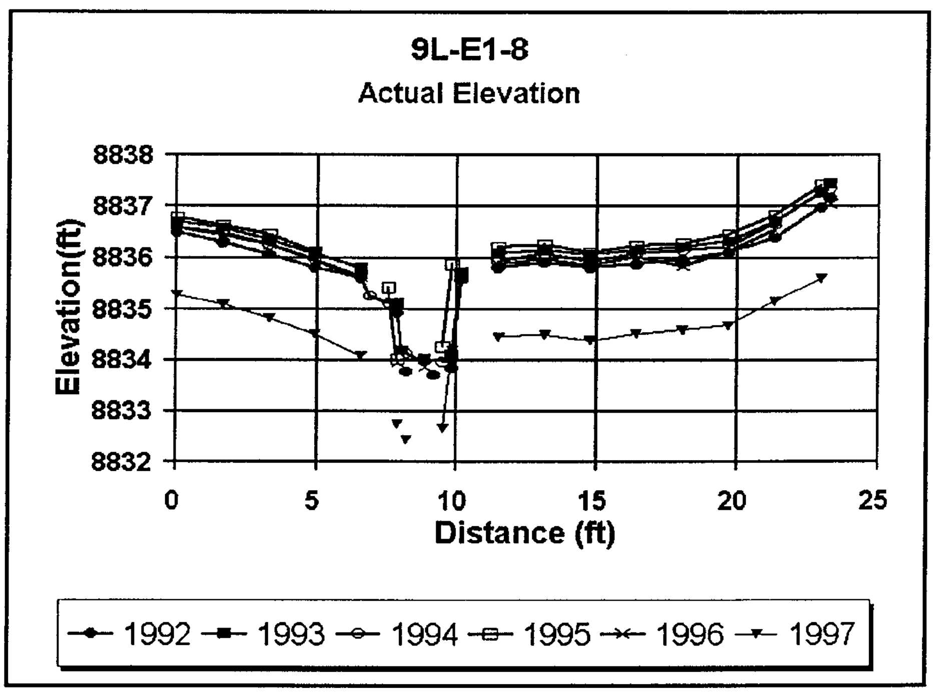


Figure 60. Examples of cross-section changes in the zones of subsidence (9L-E1-5) and tension (9L-E1-8) of panel 9L in Burnout Creek.

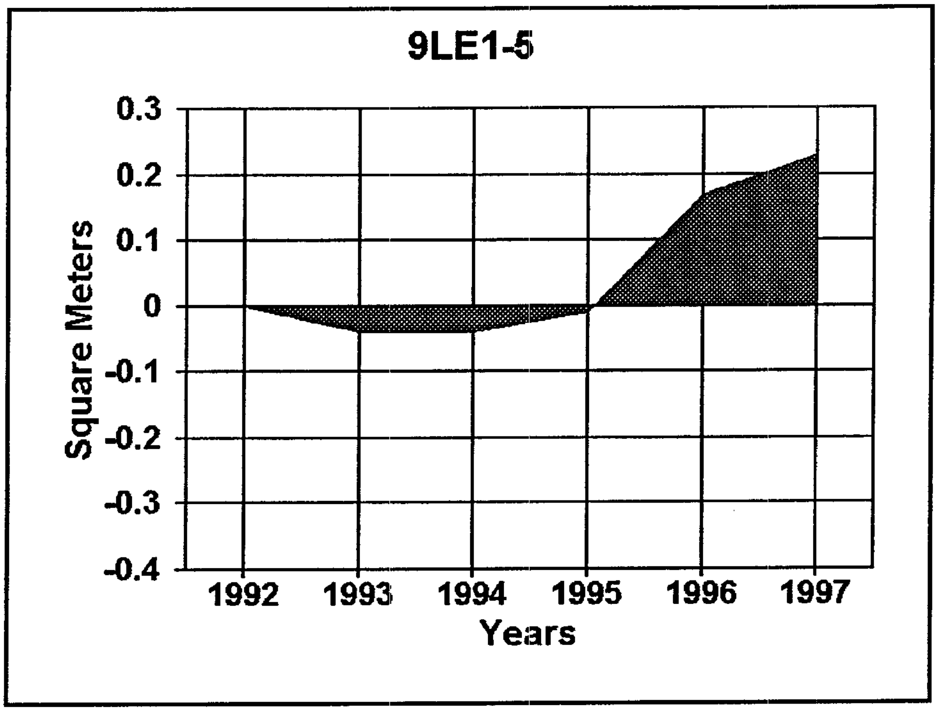
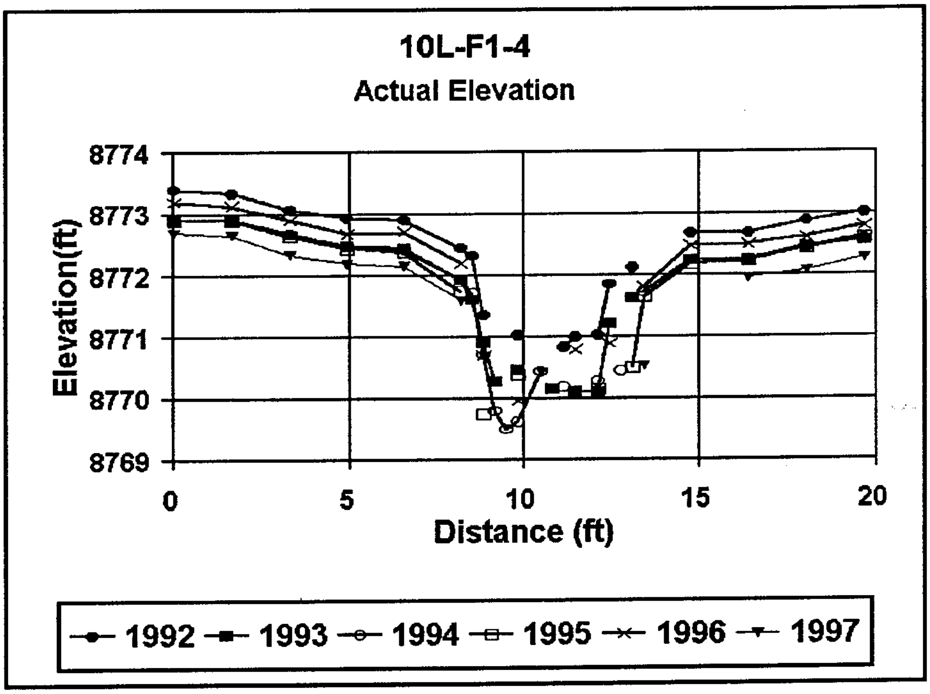


Figure 61. Example of cut and fill changes over the study period in the subsidence zone in panel 9L in Burnout Creek.

Panel 10L:

Panel 10L was not mined, therefore no changes beyond what might be expected from measurement error plus normal channel movement should be evident. The reason for the up to 1.5 feet differences in the thalweg area of cross-section of 10L-F1-49 (Figure 62) are caused by normal channel fluctuations caused by erosion and deposition or possibly some survey error. Changes in cut and fill in cross-sections here were considerably less than in the James Canyon control (Figure 63).



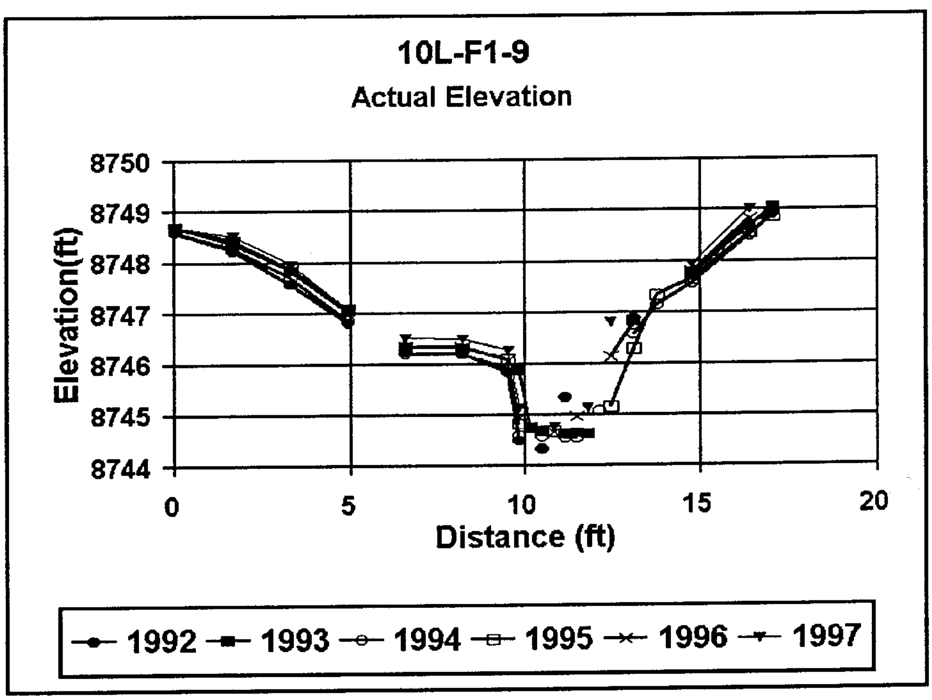


Figure 62. Examples of cross-section changes in the zones of subsidence (10L-F1-4) and tension (10L-F1-9) of panel 10L in Burnout Creek.

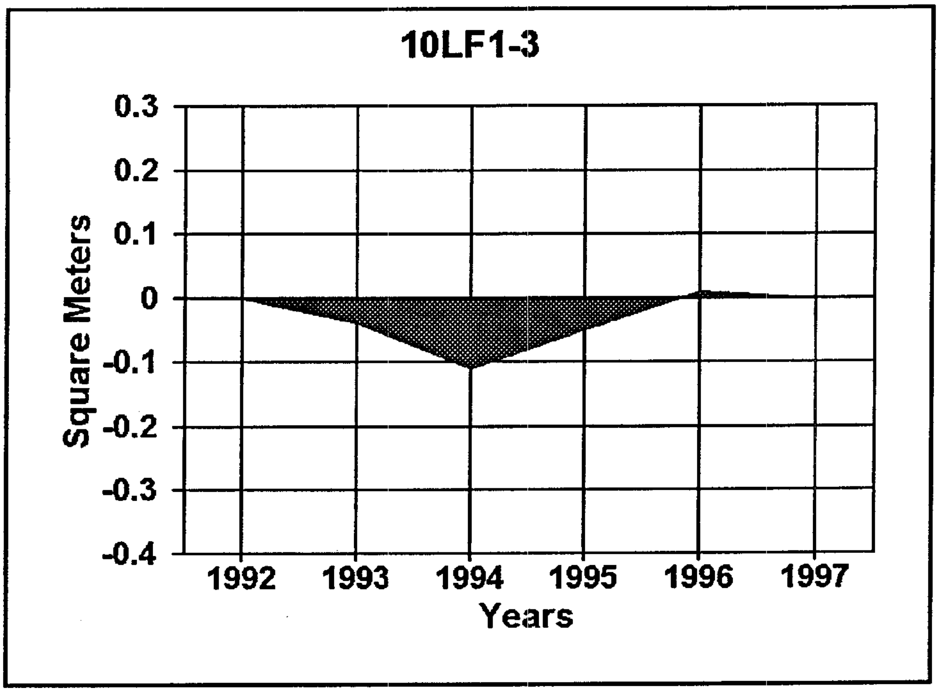


Figure 63. Example of cut and fill changes over the study period in the subsidence zone in panel 10L in Burnout Creek.

CROSS-SECTION CONCLUSIONS:

Subsidence following mining on Burnout Creek resulted in elevation drops of between approximately 1.5 to 5.5 feet in the zones of subsidence in the mined panels, but of only about 1.5 to 3.2 feet in the tension zones. If channel width changed in the subsidence zone, it usually was a narrowing of up to ~ 1.5 feet. Changes in channel width in the tension zone of a panel usually resulted in a widening of up to ~2.5 feet, but in some cases the width narrowed at least 1.5 feet. Thus the effect of subsidence on both channel drop and channel width varied considerably.

Amount of erosion and deposition in Burnout Creek attributable to subsidence did not appear to exceed that caused by normal processes in the James Canyon control area.

Longitudinal Channel Profiles

The longitudinal profile of both Burnout and the James Canyon control were surveyed by the use of a hip chain for distance along the thalweg and an engineer's level for elevational differences. The hip chain, with an estimated inherent measurement error of 10%, plus channel routing changes at the lower stream gradients, resulted in highly questionable data. In addition, the 1995 profile survey in Burnout (main channel) was obviously distorted (probably by unrecognized equipment failure) and has been removed from any comparisons. The channel profiles in 1996 and 1997 were surveyed by a licensed, professional surveyor while the earlier surveys were by nonprofessional with questionable training. In 1996 and 1997 the distances up-channel measured by hip chain were periodically adjusted to known survey position distances to partially compensate for inherent errors involved using a hip chain. The 1996 and 1997 elevation measurements were periodically tied to known elevation benchmark to verify accuracy. The 1996 and 1997 longitudinal profile data, therefore, are believed to more accurately represent the actual channel profile then the data obtained in earlier years where these controls were not employed.

Profile of the entire reach of James Canyon is shown in Figure 64, and of the lower and upper sections of James Canyon are shown in Figure 65. The differences in profiles between years is suggestive of the amount of error involved in the method selected to measure longitudinal profiles. Figure 66 shows enlarged 200 meter sections of Lower James Canyon (0 to 200 m) and of Upper James Canyon (1300 to 1500 m) controls for 1995, 1996, and 1997 to better illustrate the yearly variation of channel profile measurements attributable to a combination of natural fluctuations and measurement error. Stream profile elevation differences between these years in the lower reach of James Canyon are as much as 5 feet, and in the upper reach of the Canyon as much as 15 feet. The upper portion of James Canyon at about the 2050 to 2400 m distance lies over panel 8L which was mined in 1995-1996. The stream profile measurements do not show any effect that can reliably be attributed to subsidence (Figure 67).

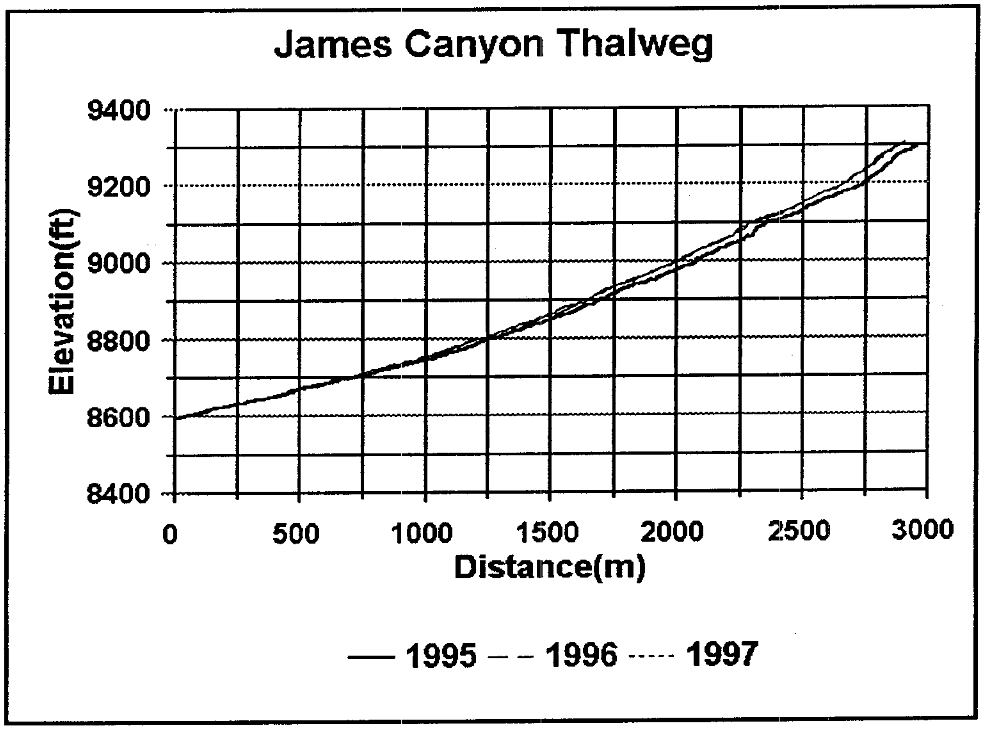
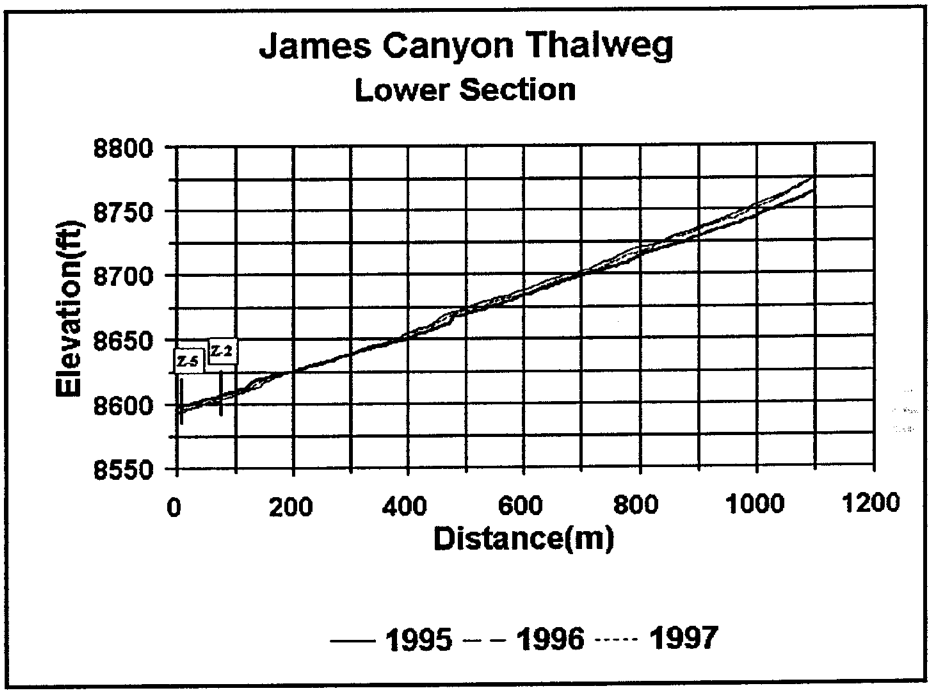


Figure 64. Longitudinal channel profile of the entire James Canyon reach, 1995-1997.



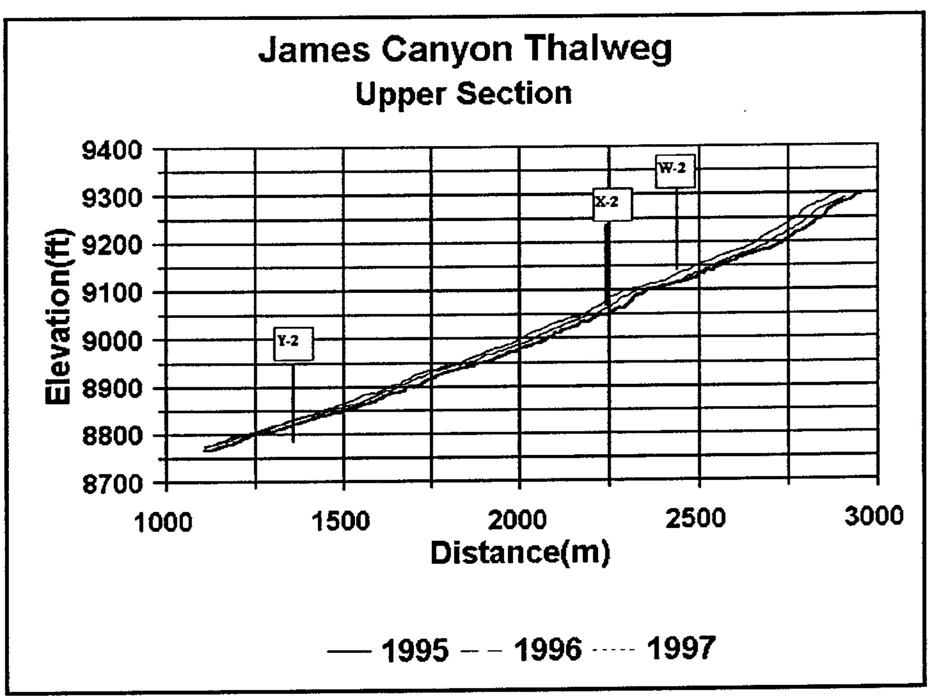
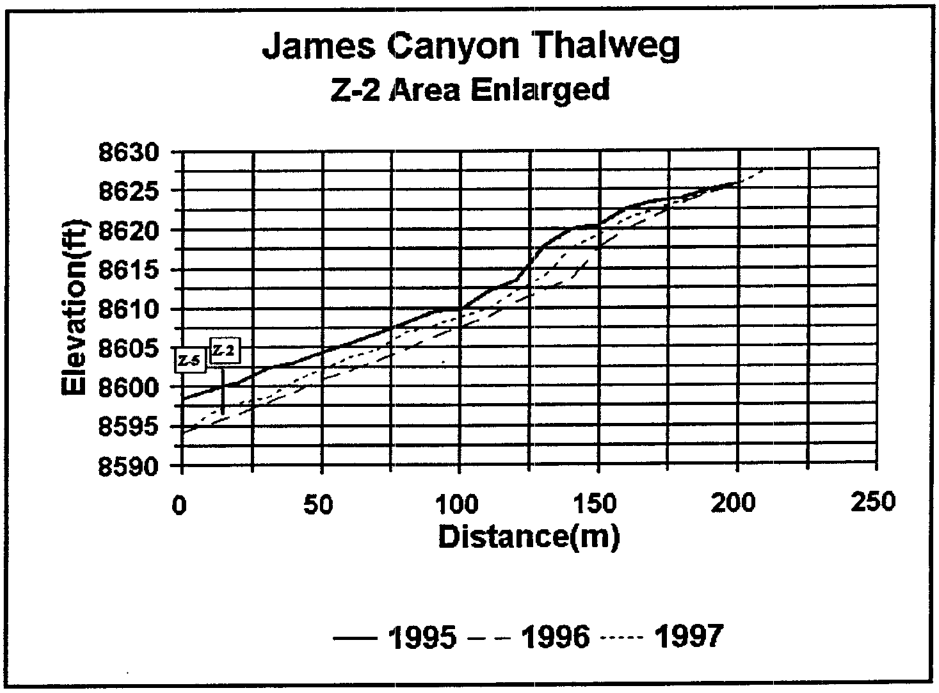


Figure 65. Longitudinal channel profile of the lower (0-1200 m) and upper (1000-3000 m) sections of James Canyon, 1995-1997.



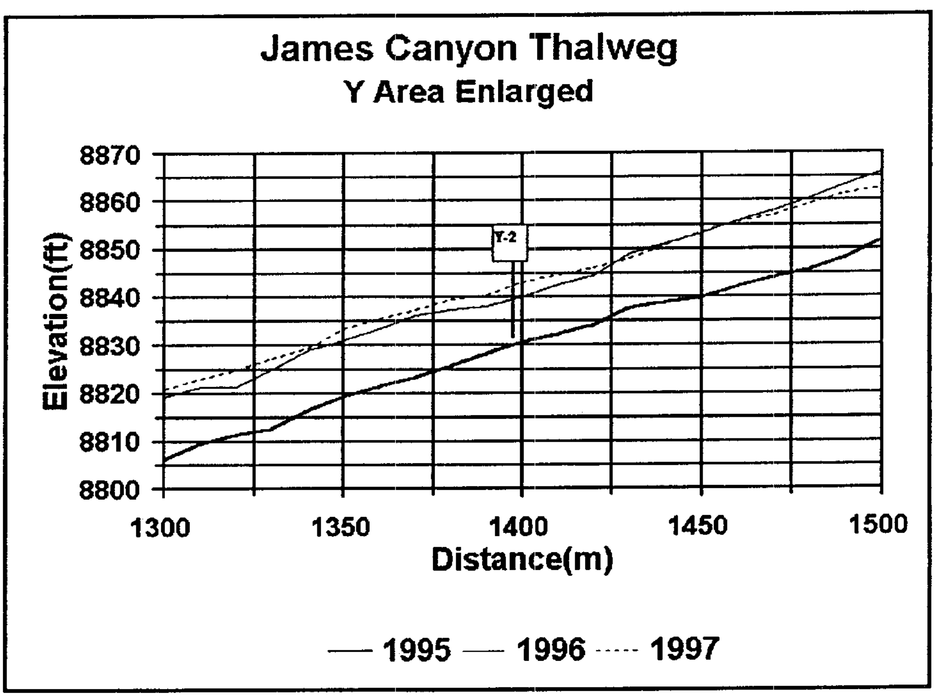


Figure 66. Longitudinal channel profile of the lower (0-200 m) and upper (1300-1500 m) sections of James Canyon, 1995-1997.

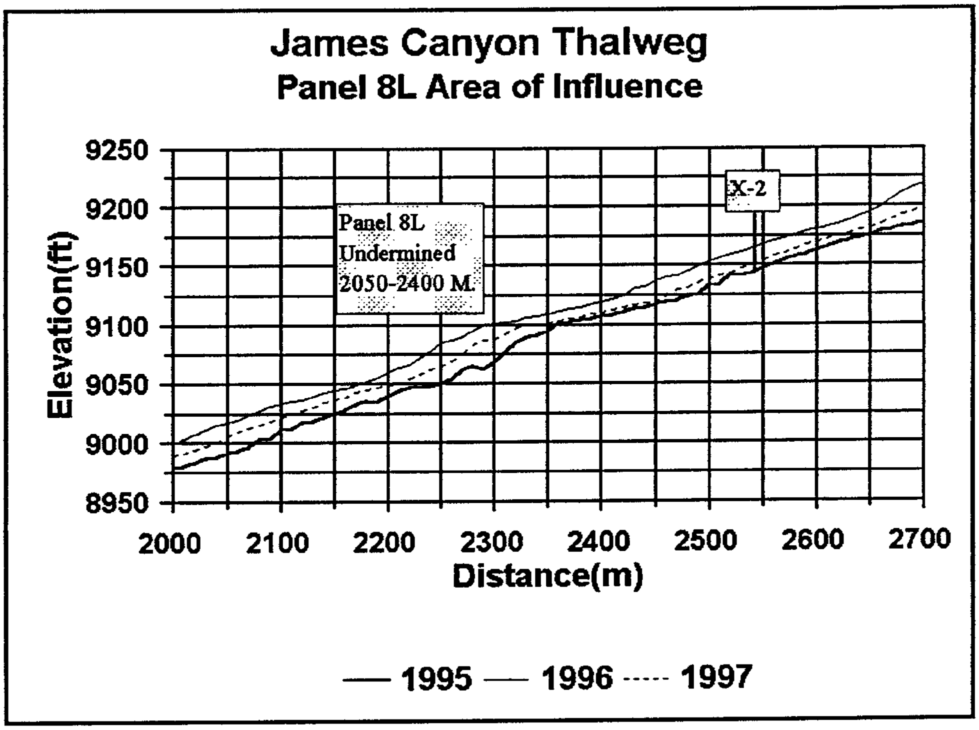


Figure 67. Longitudinal channel profile of the section of James Canyon underlain by Panel 8L, 1995-1997.

Because of the small magnitude of any vertical changes that occurred in the longitudinal profile of the main channel of Burnout Creek, it is difficult to assess any possible gradient changes related to subsidence (Figure 68). Even when examining specific reaches of Burnout Creek that were impacted by subsidence, significant changes in longitudinal profiles are not evident (Figure 69, 70, and 71). In the reach above panel 6L (1700 to 2370 m), mined in 1992-'93, some minor deviations between 1992 and other measurement years were noted but these tended to impact only very localized gradients. Some shifting of channel steps was apparent, but overall, the diverse character of the stream profile was preserved. (Note the vertical scale differences in Figures 68 through 71.) Where the vertical scale was expanded, a minor drop of ~ 1 foot appears in the panel 9L section between 1996 and 1997 in this panel mined in 1995-'96 (Figure 70), but this difference was well within the year-to-year variability of the sampling method. Generally, profile differences were as great before subsidence as were those measured following subsidence..

This would indicate that changes measured from year to year were caused primarily by natural channel changes, measurement bias, and measurement error. Also, it should be remembered that subsidence due to mining (between 1993 and 1994) in reach above panel 7L was minimal (<1 foot) because of the existence of an intrusive dike.

Changes in the South Fork (Figures 72 and 73) also cannot be attributed to subsidence. Gradient and roughness (steps) in the lower 500 m of this reach do not appear to have been appreciably affected.

INSERT

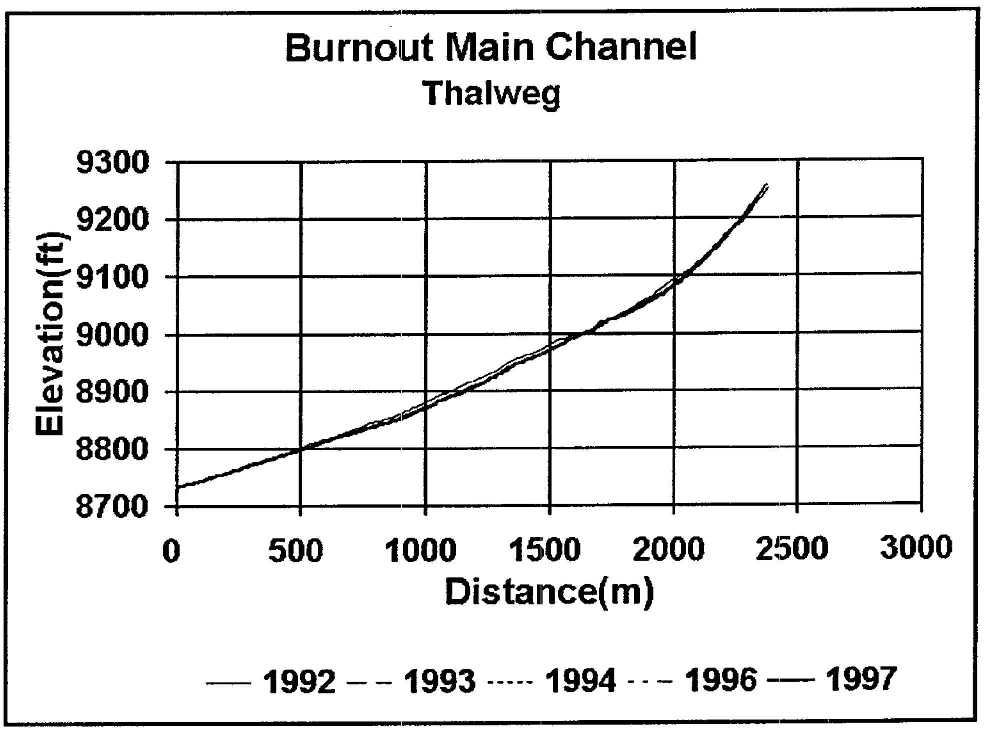
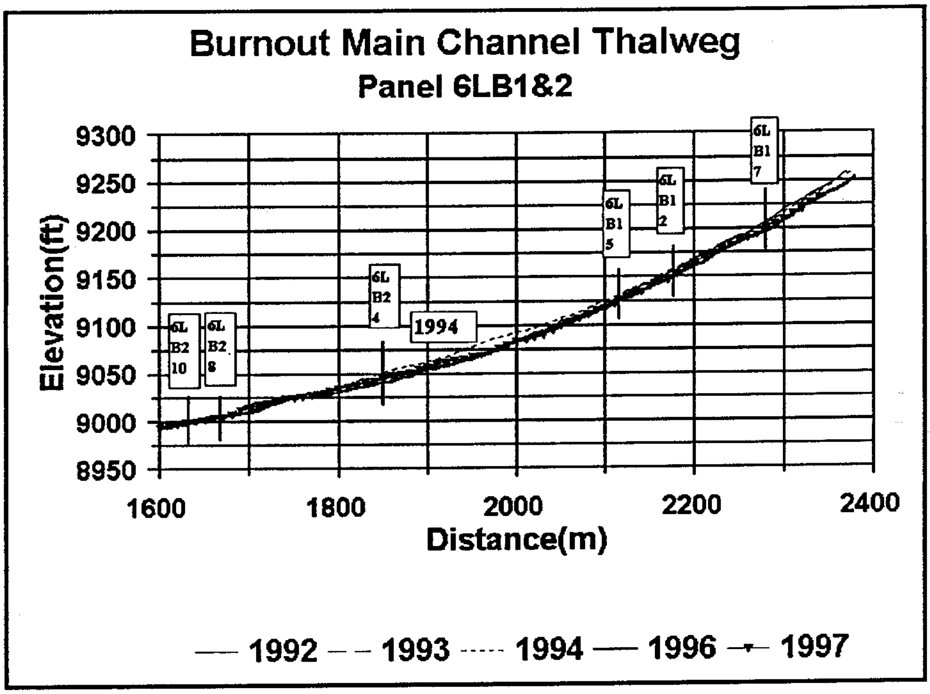


FIG 68

Figure 68. Longitudinal profile of the entire main channel of Burnout Creek, 1992-1997.



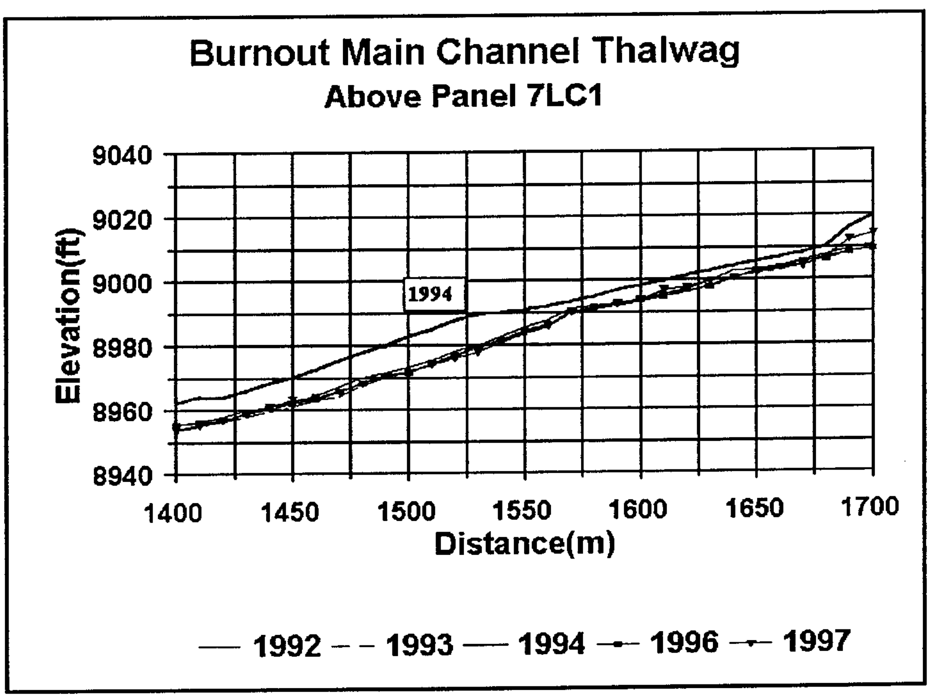
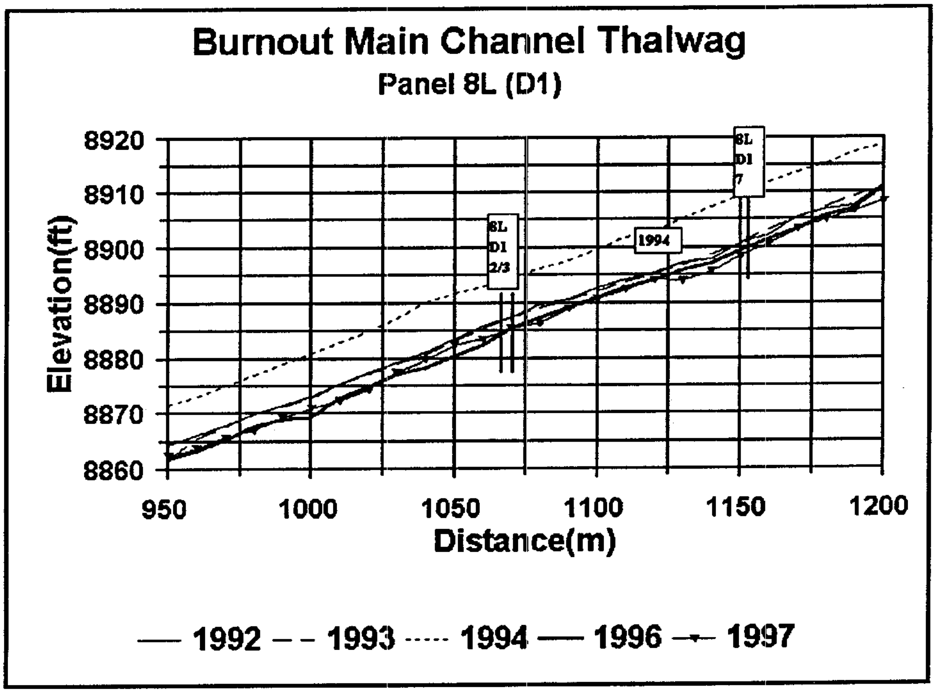


Figure 69. Longitudinal channel profile in panel 6L and the 7L portion of the main channel of Burnout Creek, 1992-1997.



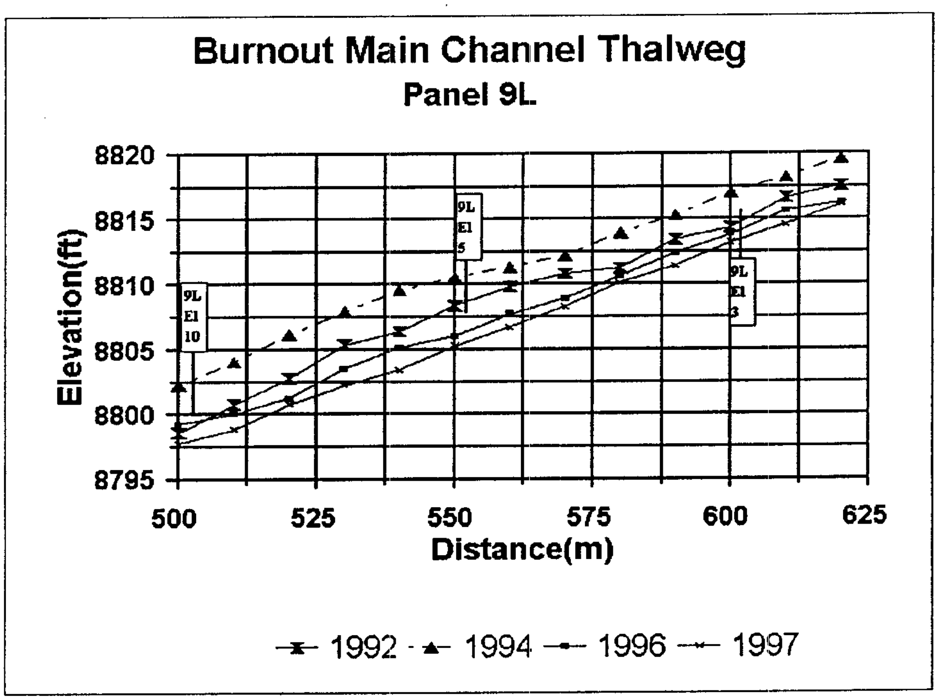


Figure 70. Longitudinal channel profile in panel 8L portion of the Main Channel, and panel 9L of Burnout Creek, 1992-1997.

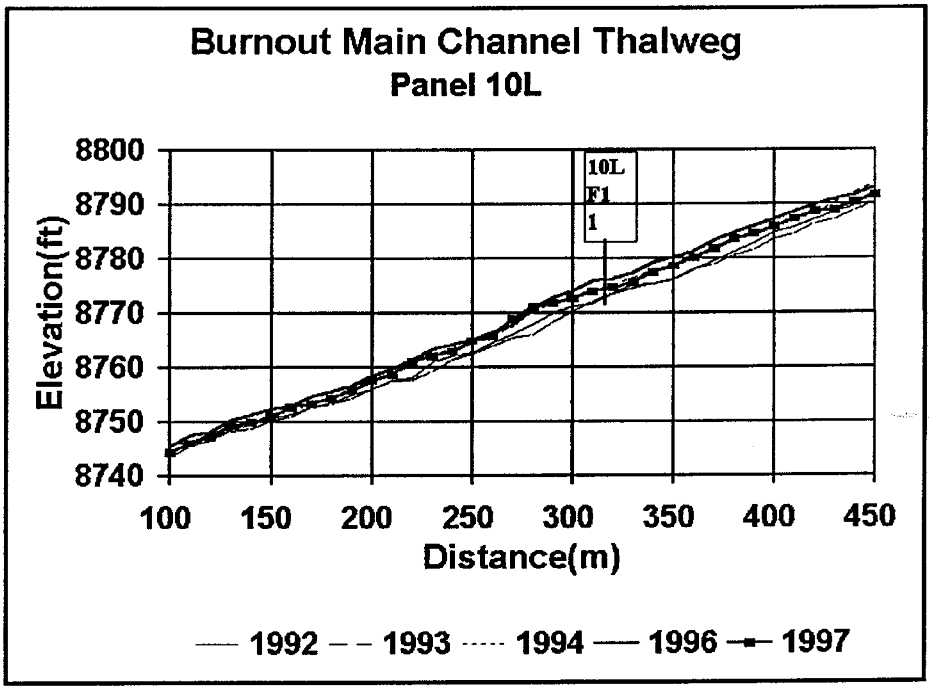


Figure 71. Longitudinal channel profile in panel 10L portion of the Main Channel of Burnout Creek, 1992-1997.

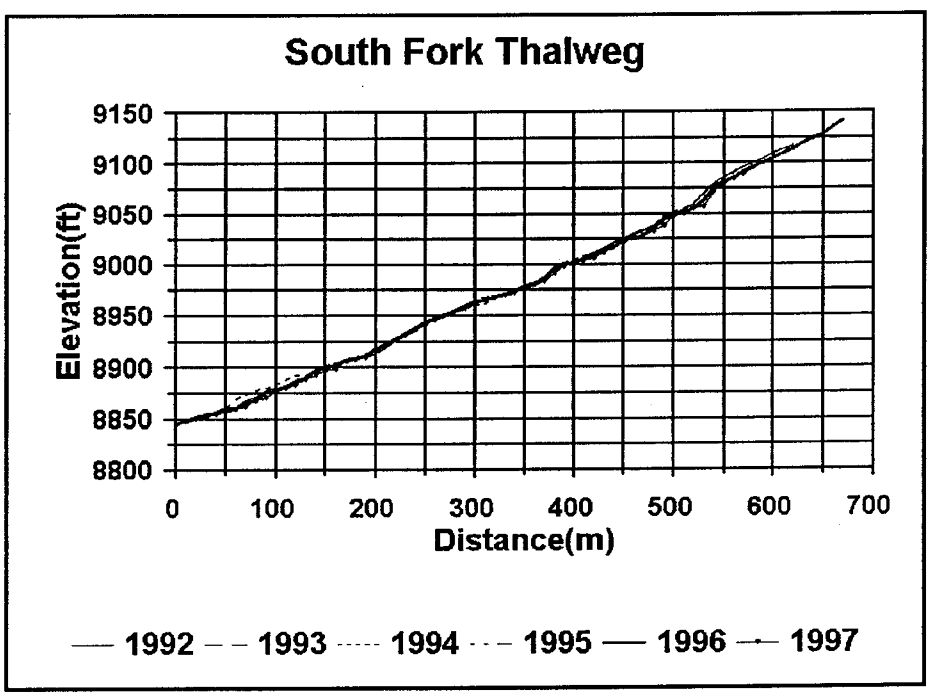
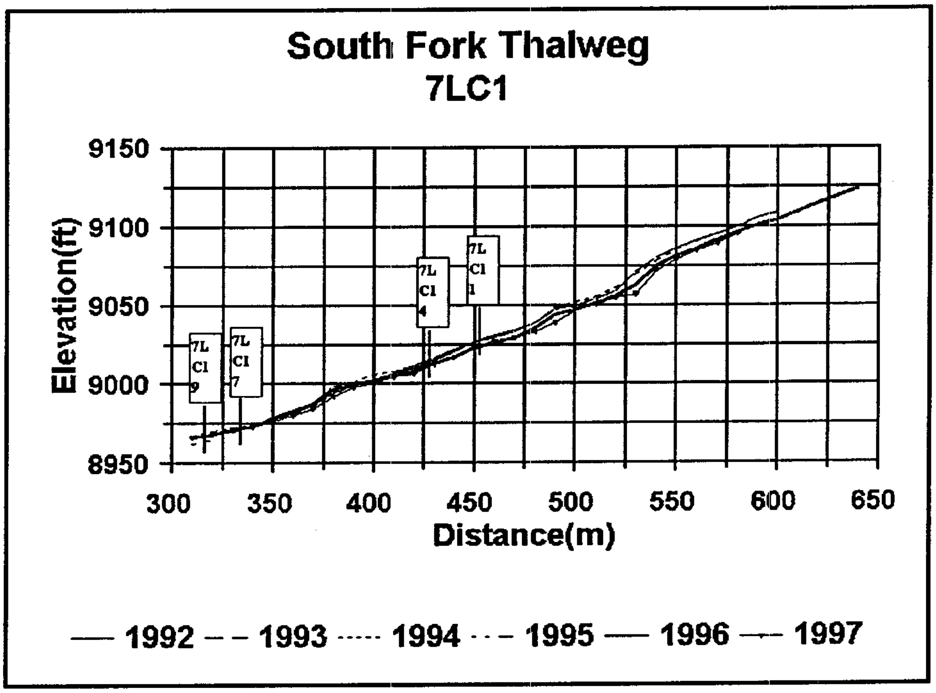


Figure 72. Longitudinal channel profile of the South Fork of Burnout Creek, 1992-1997.



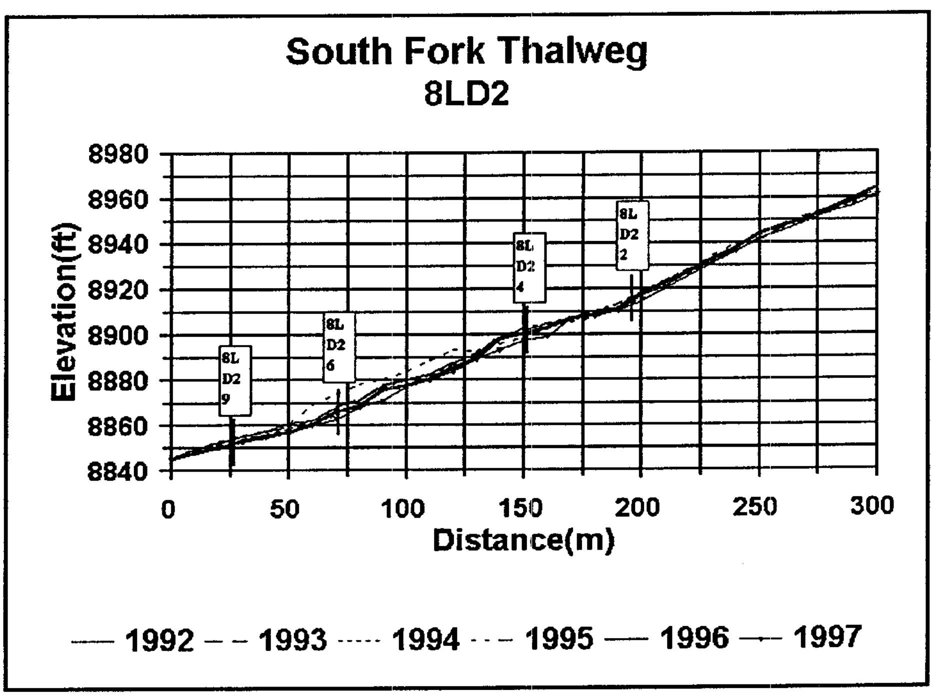


Figure 73. Longitudinal channel profile of the panel 7L and panel 8L portions of the South Fork of Burnout Creek, 1992-1997.

Longitudinal Channel Profile Conclusions:

Overall, channel profile surveys with the techniques used have not been very useful for interpreting impacts related to specific regions of subsidence in this study area. More careful and detailed measurements will be needed for such data to be of use in interpreting subsidence impacts.

Effect of Flood Routing on Potential Channel Erosion/Sedimentation

We evaluated possible impacts of changes in channel shape and localized longitudinal gradient due to subsidence, grazing, or natural geomorphic processes on the potential for future channel erosion and sedimentation within Burnout Creek. The procedure involved an estimation of channel runoff for each of the first three years (1992, 1993, and 1994) assuming a design flow; survey years 1995 and 1996 were not used in this analysis. The design flow is based on a 6-hour storm that produces a total precipitation excess of 1.02 inches. Runoff is generated using the SCS method and channel flow is routed by the Muskingum method. The drainage basin is partitioned into 5 sub-drainages to focus on discrete components that have been impacted by mining. A schematic of Burnout Canyon basin with the sub-drainages and channel segments used in the calculations for routing design peak flows is given in Figure 74. Areas of the sub-drainages range from 92.1 to 223.1 acres. Average sideslope gradients used in the SCS runoff prediction method ranged from 22 to 28% in the various sub-drainages and an average curve number of 60 was used throughout. Calculated design peakflows ranged from 0.88 m^3/s in the uppermost sub-drainage to 3.80 m^3/s in the lower portion of the study reach. These values seem to represent a moderate to extreme instantaneous peak flow for this watershed based on channel morphology.

For each of the 73 documented cross-sections in Burnout Creek, a flow depth is calculated in 1992,1993, and 1994 for the design storm. This calculation involves a discharge value derived from the runoff analysis, an assumption for Manning's roughness coefficient (n=0.04-0.05 for natural stream channels), channel gradient obtained from the localized longitudinal profile (just above and below each measured cross-section), and the shape of each cross section. The channel cross-section was surveyed each year and changes related to subsidence, grazing, or natural geomorphic processes are reflected in the flow depth calculations. We rearrange Manning's equation and iteratively input different water depths to minimize f_x as follows:

$$f_x = Q - 1/n \, A \, R^{2/3} \, S^{1/2}$$

where, Q is the discharge, R is the hydraulic radius defined as channel cross sectional area (inundated by water) divided by the wetted perimeter (R = A/P), S is the channel gradient, n is

Manning's coefficient, and f_x approaches zero value when the desired depth is obtained. This calculation is repeated for all cross sections in Burnout Creek to address any downstream effects of the morphometric changes occurring in the upper reaches of the drainage. Values of both wetted perimeter (P) and R are then calculated and compared for all three years throughout the drainage since these both relate to the potential for channel erosion and subsequent sedimentation at high flows.

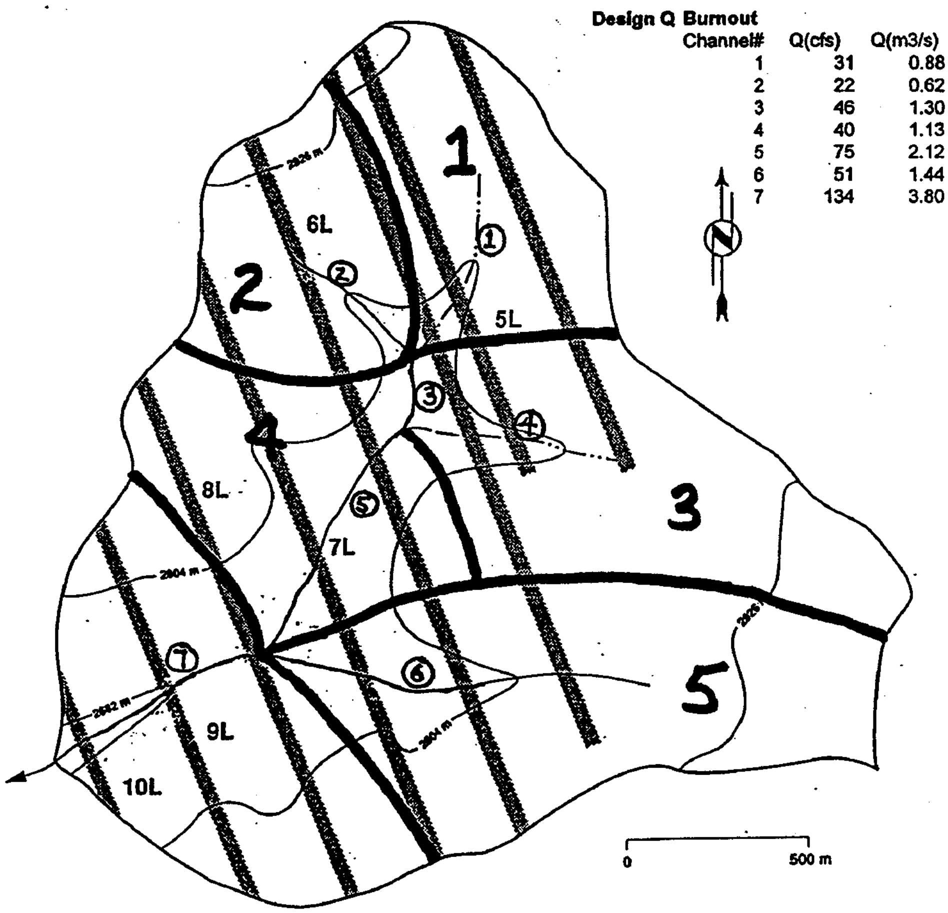


Figure 74. Sub-drainage and channel segments in Burnout Canyon used in peak flow routing.

For the most part, channels are somewhat armored on the bottom, but virtually unarmored and poorly vegetated along the channel sides (at heights that would be inundated by stormflows). Thus, channel erosion potential could be viewed to be directly proportional to the wetted perimeter of the channel (P) exposed to a given stormflow. On the other hand, P is inversely proportional to average shear stress along the channel bed (τ_0) described by :

$$\tau_0 = \gamma RS$$

where γ is the specific weight of water, R is the hydraulic radius (R = A/P), and S can be approximated by the channel gradient. Thus, as wetter perimeter (P) decreases, the channel becomes more "efficient" in routing water and the shear stress (which causes bed sediment transport) increases. Conversely, hydraulic radius is directly proportional to shear stress along the channel bottom. Several factors can influence the value of R: (1) the basic geometric shape of the channel and (2) the overall "smoothness" of the channel profile. These factors are, of course, also determinants of P. For example, given the same bankfull width, the wetted perimeter (P) of rectangular channel is 1.137 times that of a semi-circular channel and P of a triangular channel is 1.287 times that of a semi-circular channel. In the interpretation of our results, we should be aware that an increase in P could be interpreted as an increase in the potential for the streambanks to erode and a likely increase in suspended sediments transport due to the high silt content of the soils. This is especially true in the upper channel where streambanks are largely unvegetated, partly due to grazing pressure. However, a decrease in P would result in increased shear stress at high flows along the channel bottom and would increase the potential for channel downcutting and bedload sediment transport.

In the mining-impacted portion of main channel of Burnout Creek, only the reach overlying panel 6L was surveyed for cross-sectional changes. Two sets of cross-sections (6L-B1 with 8 cross-sections and 6L-B2 with 10 cross-sections) were located in this reach from about 1700 m to 2450 m upstream. Only a few significant changes in P values were found between 1992 and 1993 when the majority of the subsidence occurred (Figure 75). Percentage change in P values less than about 5-10% are not considered to be very significant because of the potential for cross-section measurement discrepancy from year to year. All of the three cross-sections which had changes in P values in excess of 10% between 1992 and 1993 were in the upper reach of 6L-

B1, which experienced the most subsidence (4.0 to 4.5 feet) along the main channel. One of the cross-sections was in the zone of maximum tension and the other two were in the zone of maximum subsidence from 2210 to 2230 m. Examples of changes in channel geometry that generate these changes in P are shown in Figure 76. Only one cross-section in this impacted reach (6L-B1) experienced a >+10% change in P during this same period. Additional channel adjustment occurred between 1993 to 1994 in the 1700 to 2400 m reach. By 1994 there was greater evidence of decreases in P in this upper reach (6L-B1) compared with trends in the lower portion of the reach (6L-B2) (Figure 77). Of the 18 surveyed cross-sections in the upper reach, 6 had P declines in excess of 10% and all but 3 cross-sections experienced some decrease in P from 1992 to 1994 (Figure 76). Both subsidence and tension cross-sections exhibited these decreases. Differences in percentage change in P between the 18 cross-sections in panel 6L and the 30 cross-sections downstream (panels 8L, 9L, and 10L) were statistical tested ($\alpha = 0.05$) for 1992-93, 1993-94, and 1992-94 survey data. In all cases, mean change in %P was greater in panel 6L than in the lower portion of the channel, however, this difference was significant for the 1993-94 and 1992-94 data; not for the 1992-93 data because of the high variability in this post-subsidence data set.

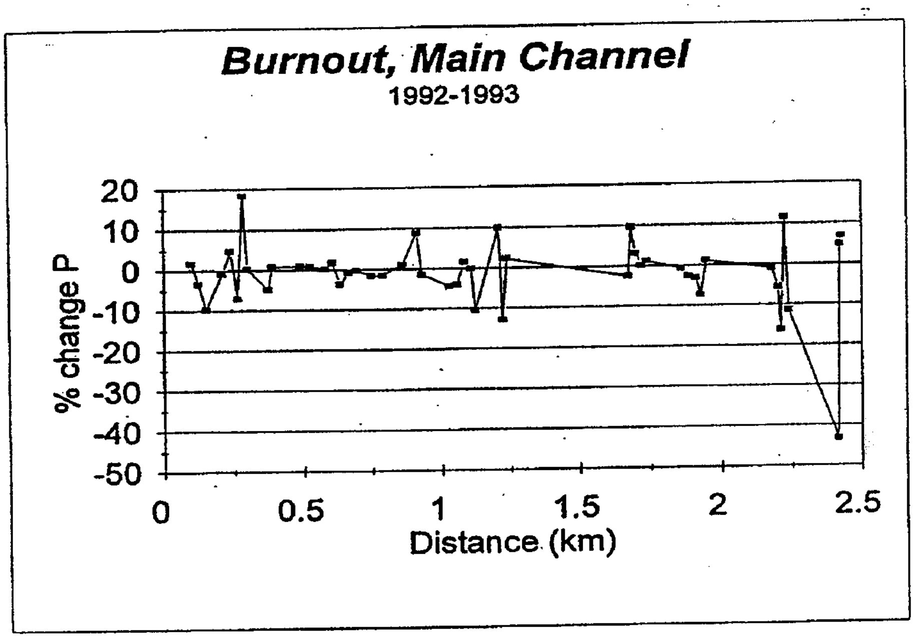


Figure 75. Percent change in wetted perimeter from 1992 to 1993 along the Main Channel of Burnout Creek.

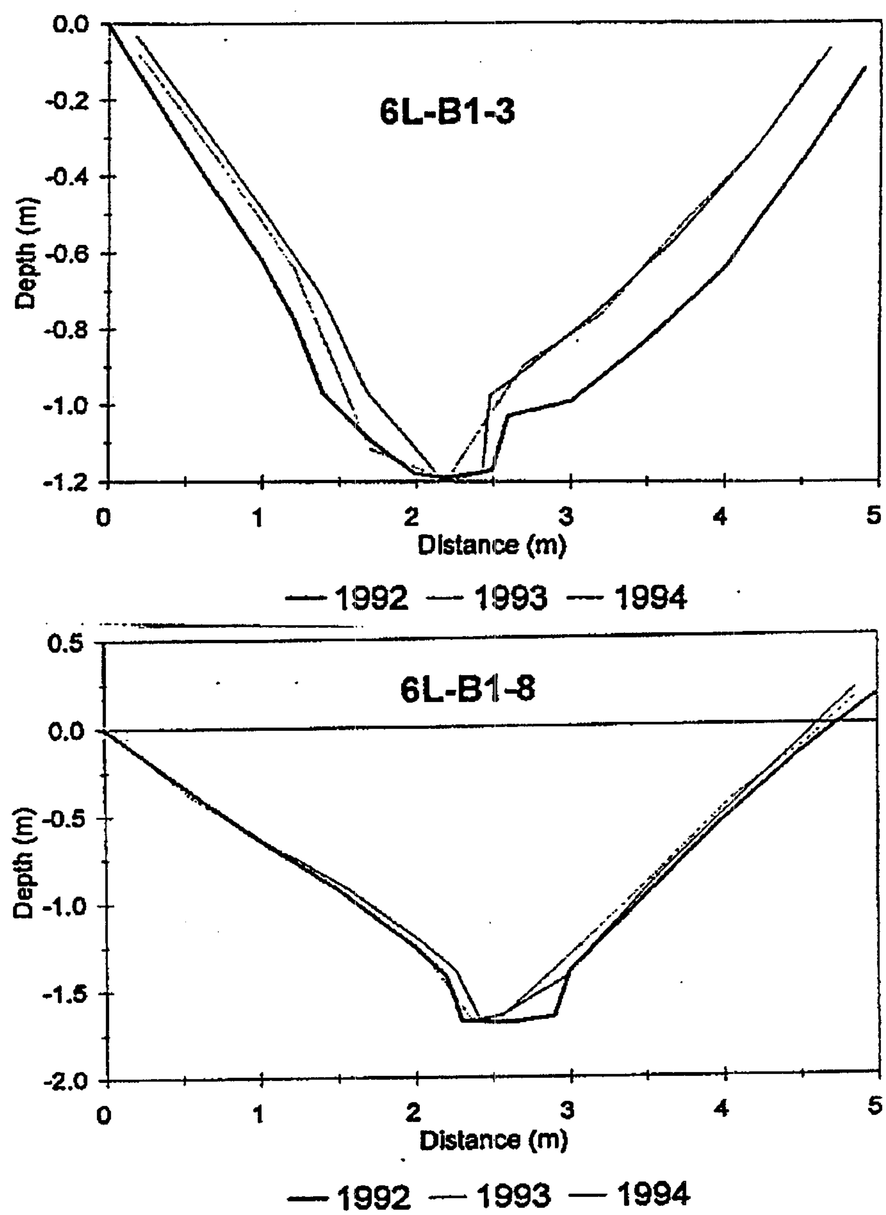


Figure 76. Examples of increases in hydraulic radius (R) and decreases in wetted perimeter (P) with time at cross-sections 6L-B1-3 and 8.

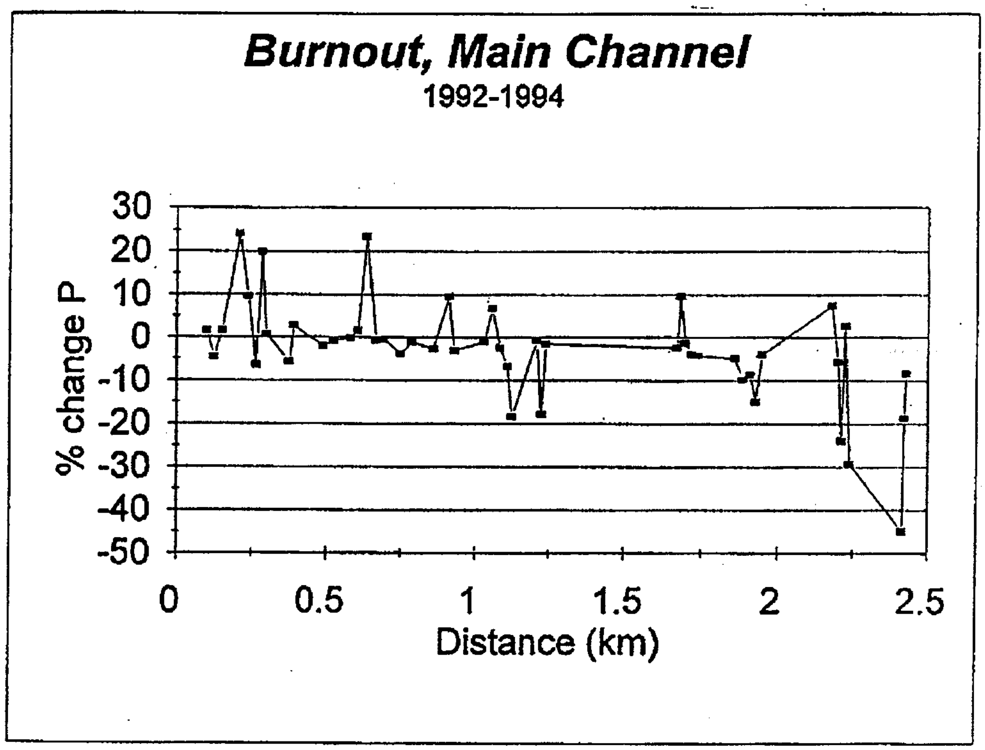


Figure 77. Percent change in wetted perimeter from 1992 and 1994 along the Main Channel of Burnout Creek.

As anticipated, changes in R followed somewhat of an opposite pattern as those for P. From 1992 to 1993, a few scattered increases in R were noted in the impacted (1700 to 2450 m) reach (Figure 78). The mean change in R from 1992 to 1993 was not significantly different between the 18 cross-sections above panel 6L (2.46%) and the 30 cross-sections in the lower portion of the channel (1.78%). Between 1992 and 1994 more increases in R were noted in this reach, but not quite to the extent as those calculated for P (Figure 79). The mean change in R from 1993 to 1994 was significantly different between the cross-sections above panel 6L (4.28%) and those in the lower reaches (1.11%). Examples of increases in R with time are shown for two cross-sections in Figure 76. Given the downstream variability in R changes from year to year, the trend of increase R in the upstream reach is not as notable as the respective temporal change in calculated P.

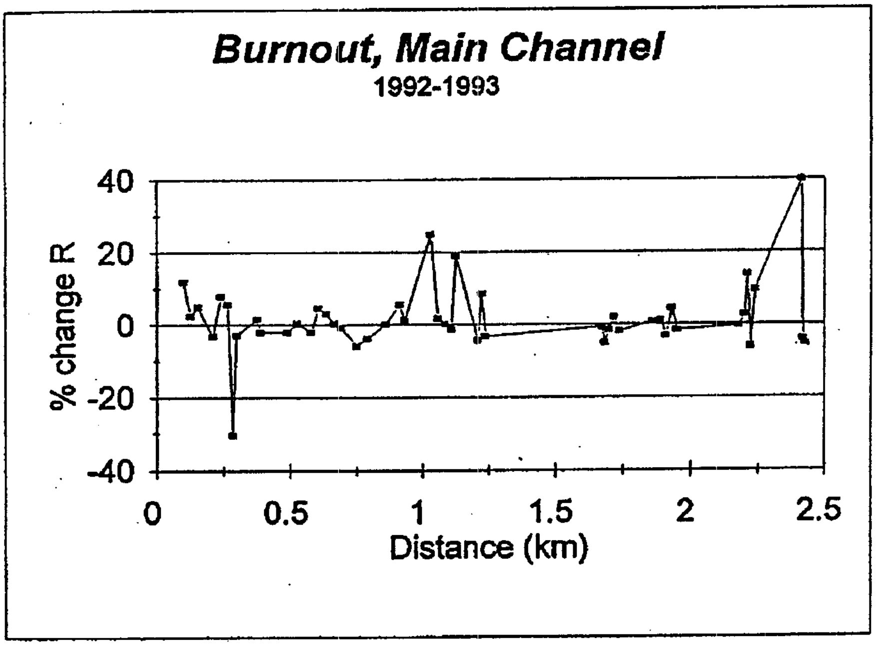


Figure 78. Percent change in hydraulic radius from 1992 to 1993 along the Main Channel of Burnout Creek.

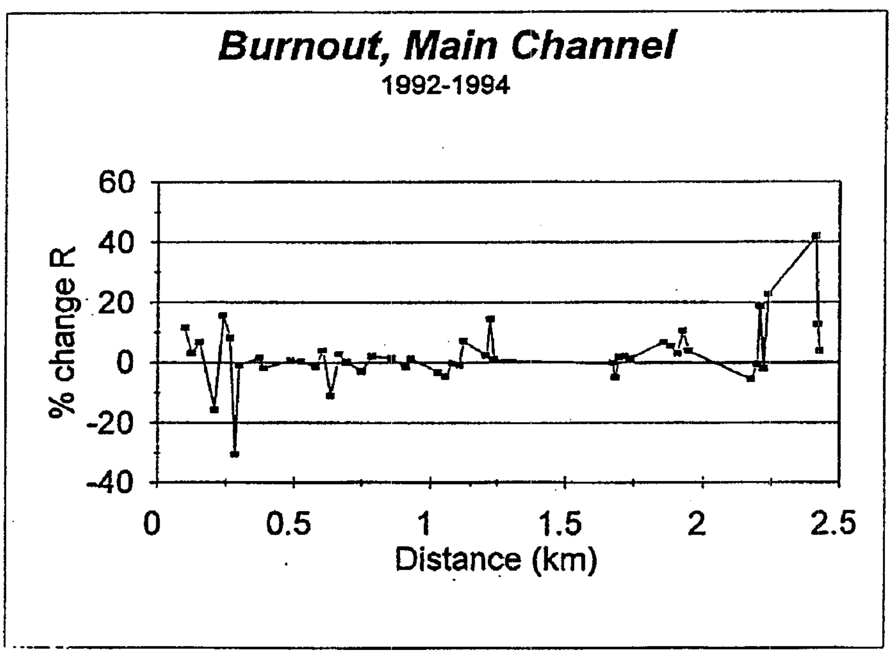


Figure 79. Percent change in hydraulic radius from 1992 to 1994 along the Main Channel of Burnout Creek.

Changes in hydraulic characteristic of the South Fork channel in the vicinity of panel 7L (cross-sections located between 290 and 450 m) were less apparent than changes above panel 6L in the main reach of Burnout Creek. None of the yearly comparisons (1992-93, 1993-94, or 1992-94) showed significant differences in percent change in P or R between the impacted and non-impacted reaches of the South Fork. Since mining occurred in panel 7L in late 1993 and early 1994, changes between the 1993 and 1994 cross-section surveys and flood routing simulations should provide insights into any mining-related changes. Eight of 10 cross-sections above panel 7L experienced decreases in wetted perimeter (P) between 1993 and 1994. Unlike in the main channel (above panel 6L), these decreases were generally very small (only 2 of the profiles exceeded 10%, Figure 80). In addition, 8 of the 10 cross-sections above panel 8L (not mined) experienced decreases in P during this same period (Figure 79). Hydraulic radius (R) increased slightly during the 1993 to 1994 period for most cross-sections, although only one of these increases was greater than 5% (Figure 81). The apparent increase in R in the upper reach of the South Fork between 1993 and 1994 was in the range of variability in R values calculated in the lower portion of the reach, thus the changes cannot be directly attributed to subsidence.

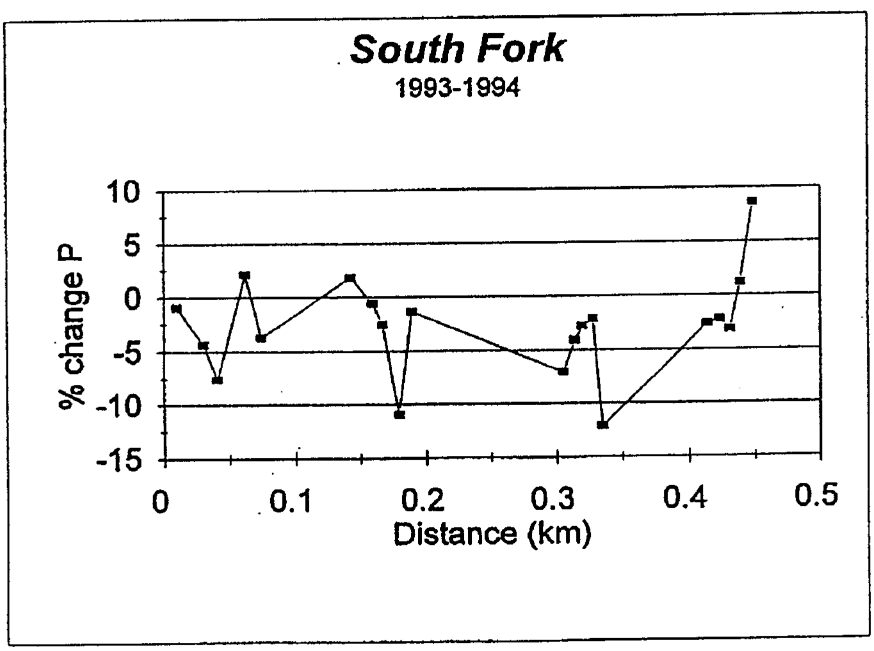


Figure 80. Percent change in wetted perimeter in the South Fork, 1993-1994.

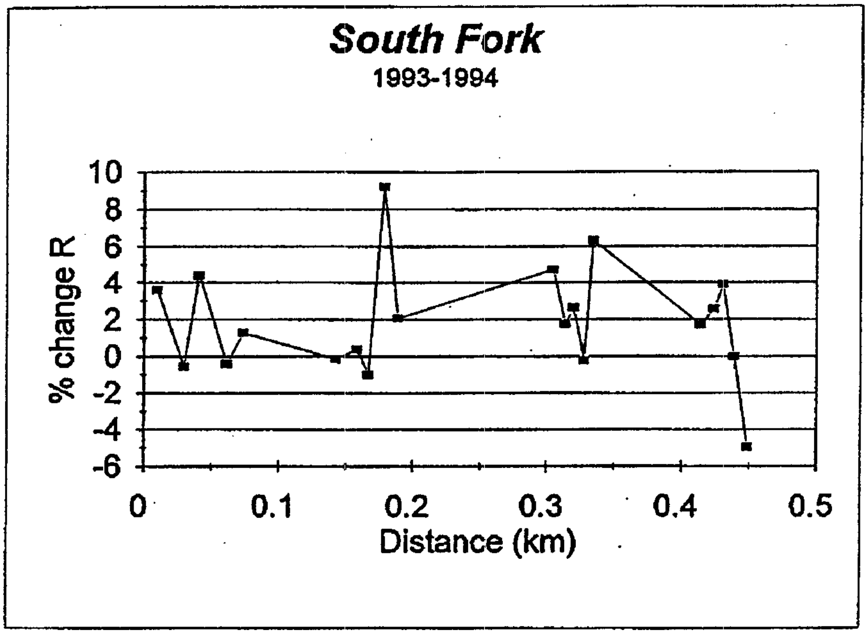


Figure 81. Percent change in hydraulic radius in the South Fork, 1993-1994.

Flood Routing Conclusions:

The overall findings of this hypothetical flood routing study in the main channel of Burnout Creek show that possibly channel bottom scour (and thus bedload sediment) would increase immediately following mining because of localized channel adjustments. This potential for increase in scour appears to be concentrated in the upper reaches (above 1990 m) and does not extend into any of the lower portions of the drainage where fish habitat is important. On the other hand, the significant decreases in P measured in numerous crossections in the 1700 to 2450 m reach indicate that bank erosion in this upper portion of the drainage may actually be less during peak flows. This would potentially result in decrease suspended sediment during peak flows. Since suspended sediment is transported much greater distances compared with bedload sediment, the relative impacts of these potential reductions would be experienced at very different spatial scales: i.e., increased bedload transport would likely have a localized impact (e.g., scouring and subsequent localized deposition) and decreased suspended sediment transport would reduce sediment loads into receiving water bodies (i.e., Upper Huntington Creek and Electric Lake). In the next section we discuss the spatial and temporal distribution of bed sediment in pools throughout Burnout Creek and the relationship of sediment distribution to our hypothetical hydraulic calculations.

It should also be stated that these hydraulic calculations and subsequent inferences are strongly dependant on cross section results. If cross sections are in error then these inferences will also be in error.

Sediment Characteristics of Pools

Sediment characteristics in dynamic equilibrium environments throughout Burnout Creek and the James Canyon control were evaluated by sampling and analyzing bottom sediments from every pool in the system during 1992, 1993, 1994, 1995, 1996, and 1997. Samples were collected from the middle of each pool using a small scoop. They were then dried and sieved to characterize sediment size classes. Changes in composition of sediments in pools should reflect erosion and sediment transport processes in the near vicinity or from upstream. Prolonged increases in fine sediment composition of pool bottoms are known to be detrimental to fish habitat (Phillips et al., 1975).

James Canyon:

Median particle size (D_{50}) in James Canyon pools ranged from a low of ~ 4.5 mm in 1992 to a high of ~ 17 mm in 1994, or approximately a four-fold difference over the 6-year period (Figure 82). The variation among pools of this median particle size is shown in Figure 83 for both 1994 and 1997. Median particle size ranged from < 0.1 to ~ 60.0 between pools. These data show the extreme natural variation that occurs in particle size both between years and also between pools distributed along the stream channel.

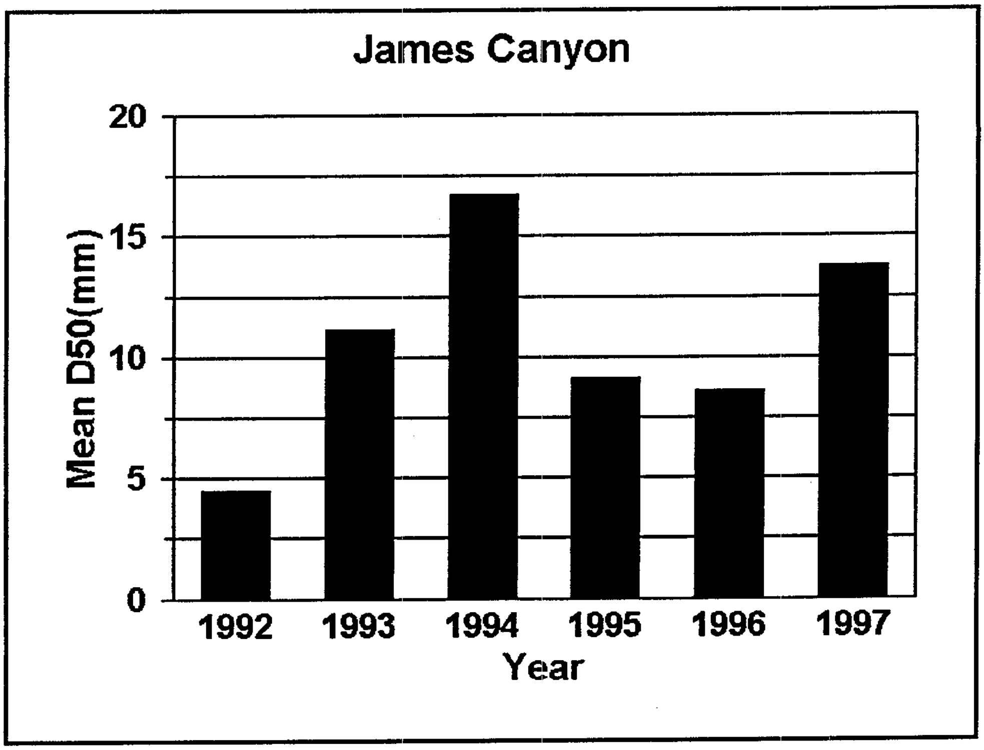
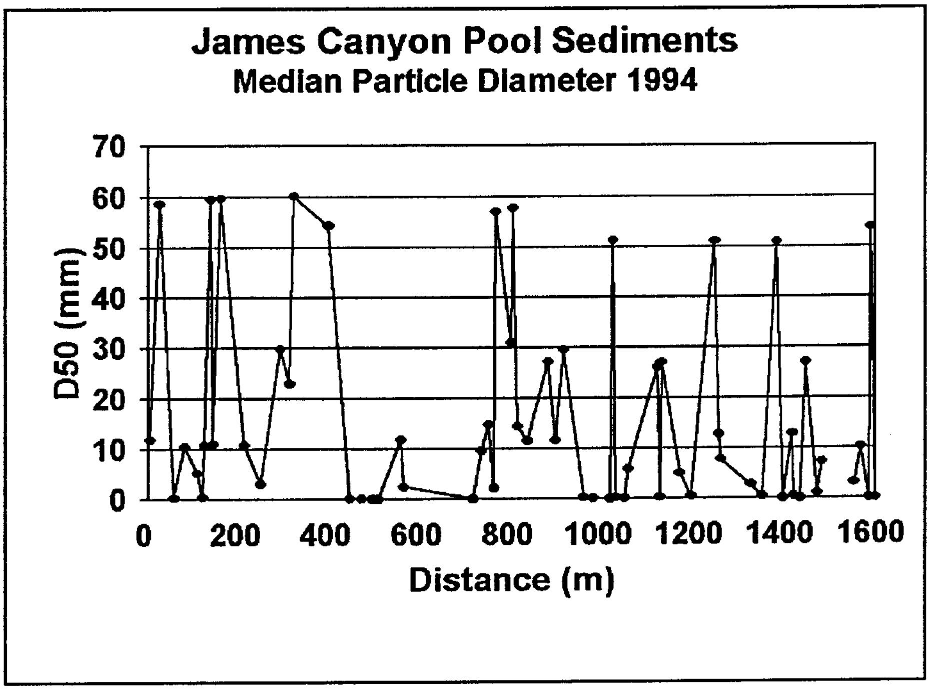


Figure 82. Changes over the study period in median particle diameter (D_{50}) of pool sediments in James Canyon, 1992-1997.



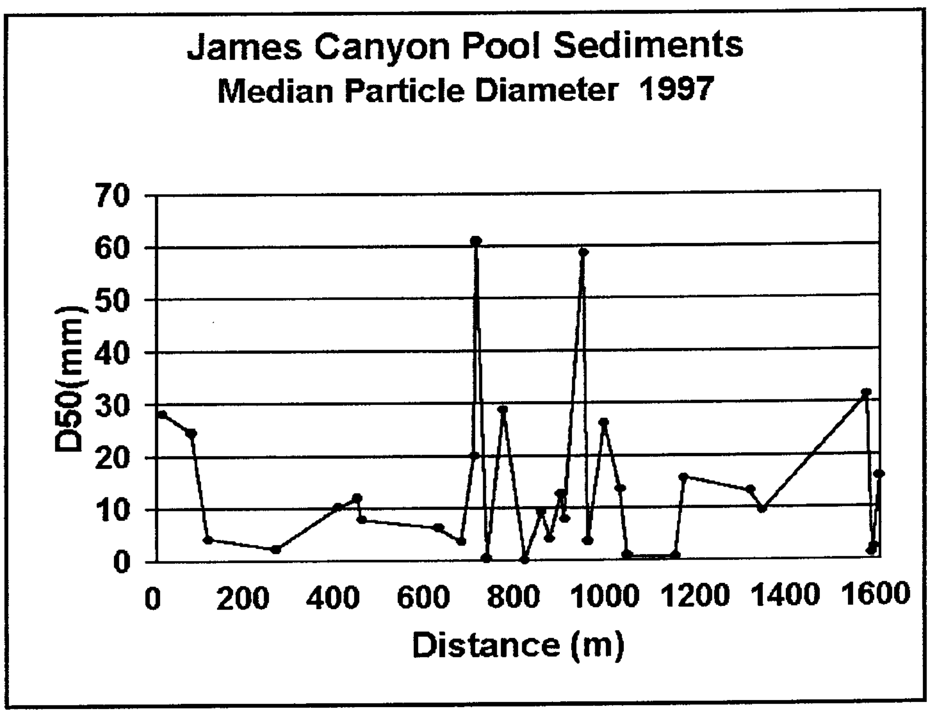


Figure 83. Distribution of median particle diameter (D_{50}) of pool sediments along the channel of James Canyon in 1994 and in 1997.

The fine sediments so detrimental to fish habitat ranged from a high of ~ 72% in 1992 to a low of ~ 34% in 1997 (Figure 84), or a two-fold difference attributable to normal variation. The variation in fine sediments among James Canyon's pools varied between < 1% to > 80% in both 1994 and 1997 (Figure 85).

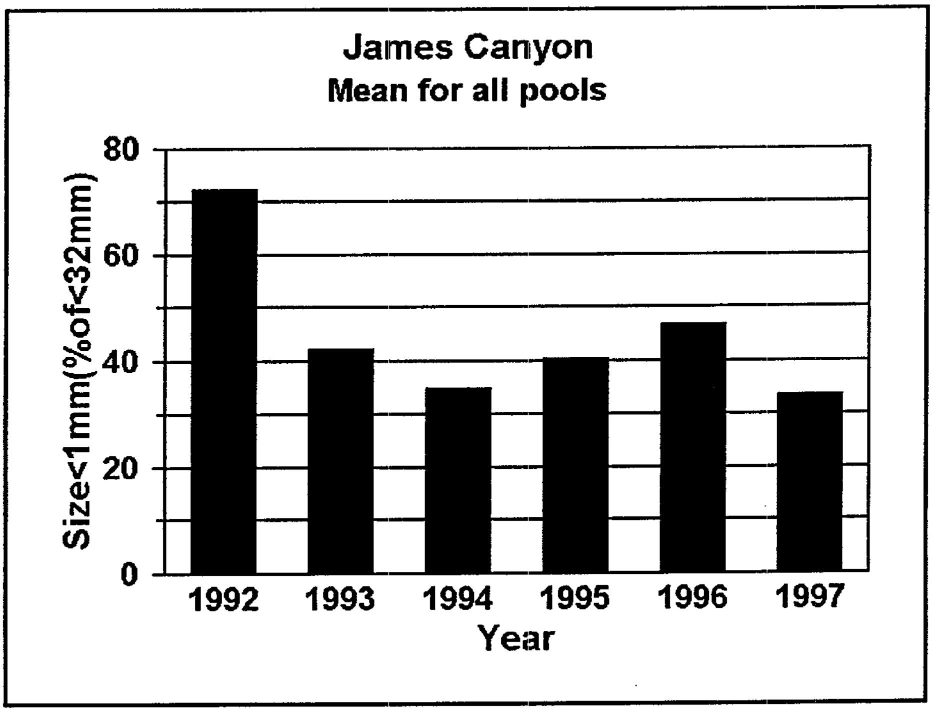
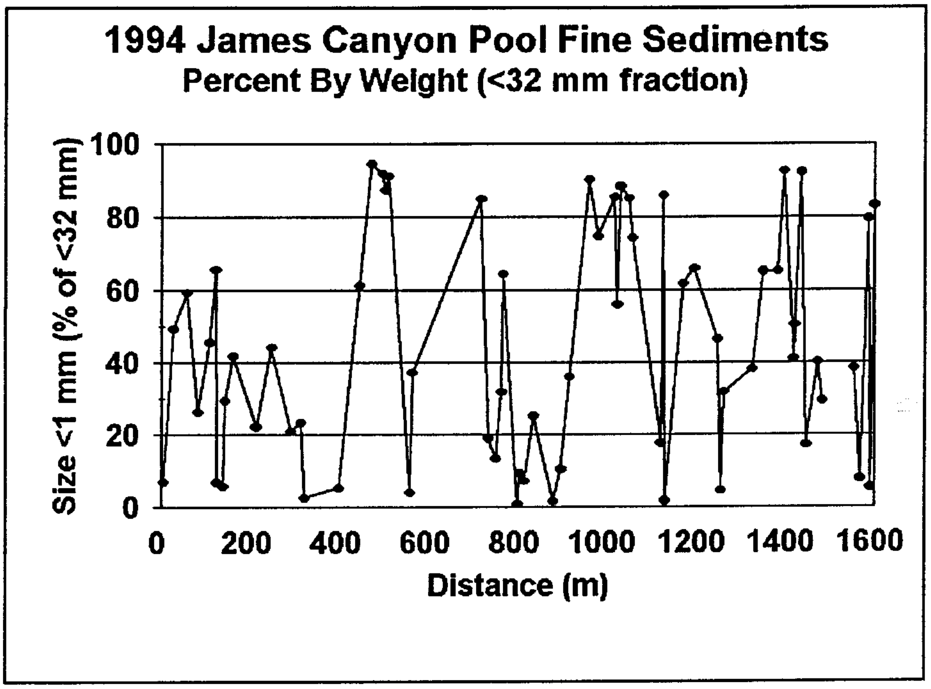


Figure 84. Changes over the study period in pool fine sediments (< 1 mm size) in James Canyon, 1992-1997.



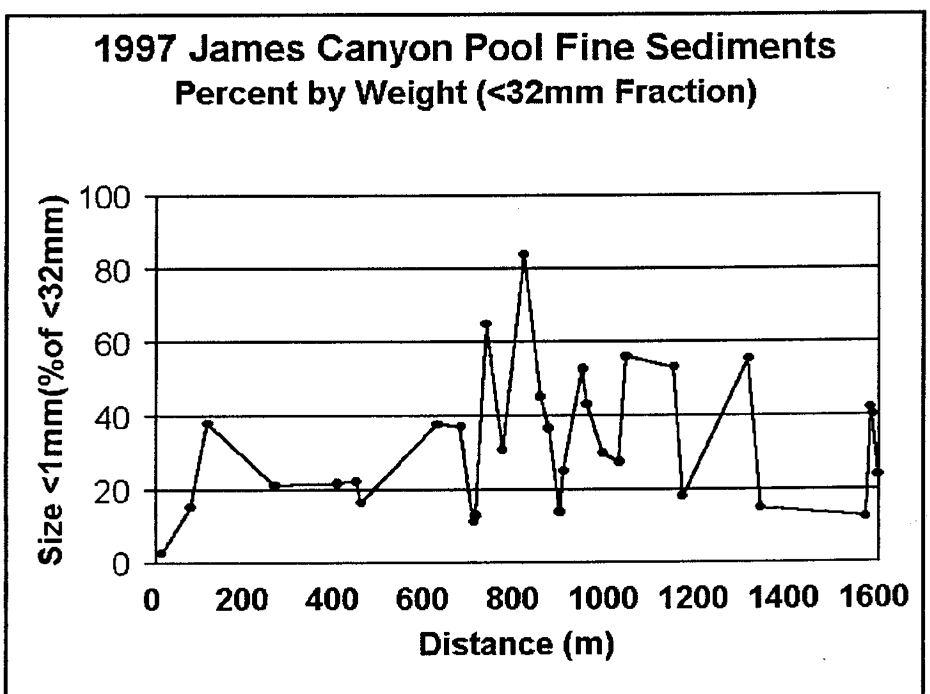


Figure 85. Distribution of fine sediments in pools along the channel of James Canyon in 1994 and in 1997.

Burnout Creek:

Two reaches of Burnout Creek were analyzed for changes in sediment composition: the Main Channel and the South Fork. The yearly variation in median particle size in the Main Channel (Figure 86), ranging between ~ 9 mm in 1993 to ~21 mm in 1997, was slightly less than that in the James Canyon control. The variation in mean particle size among pools was about the same in both the Main Channel (Figure 87) and in James. The fine sediments < 1.0 mm in size decreased in the Main Channel from a high in 1992 of ~ 54% to a low in 1995 of ~30% (Figure 88), a pattern of change similar to that in James Canyon. The variation of fine sediments among pools in 1994 and 1997 is shown in Figure 89.

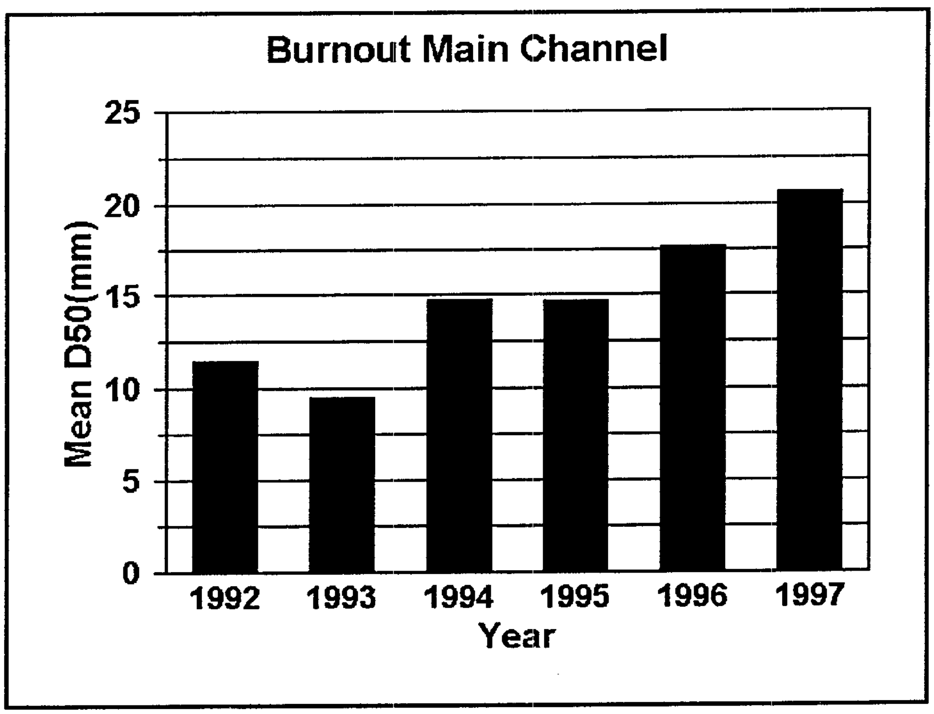
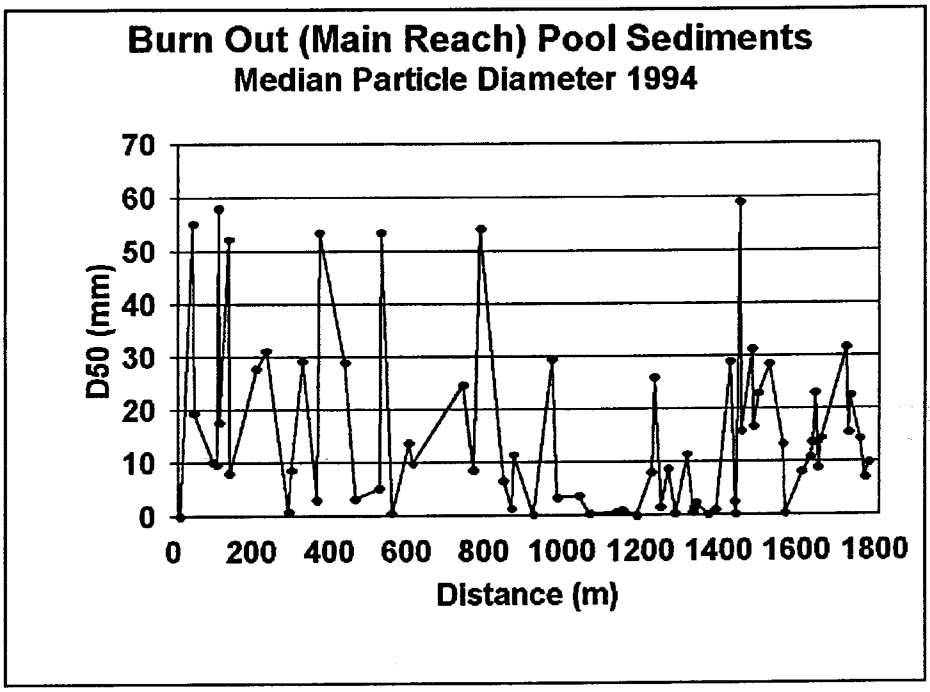


Figure 86. Changes over the study period in median particle diameter (D_{50}) of pool sediments in the Main Channel of Burnout Creek, 1992-1997.



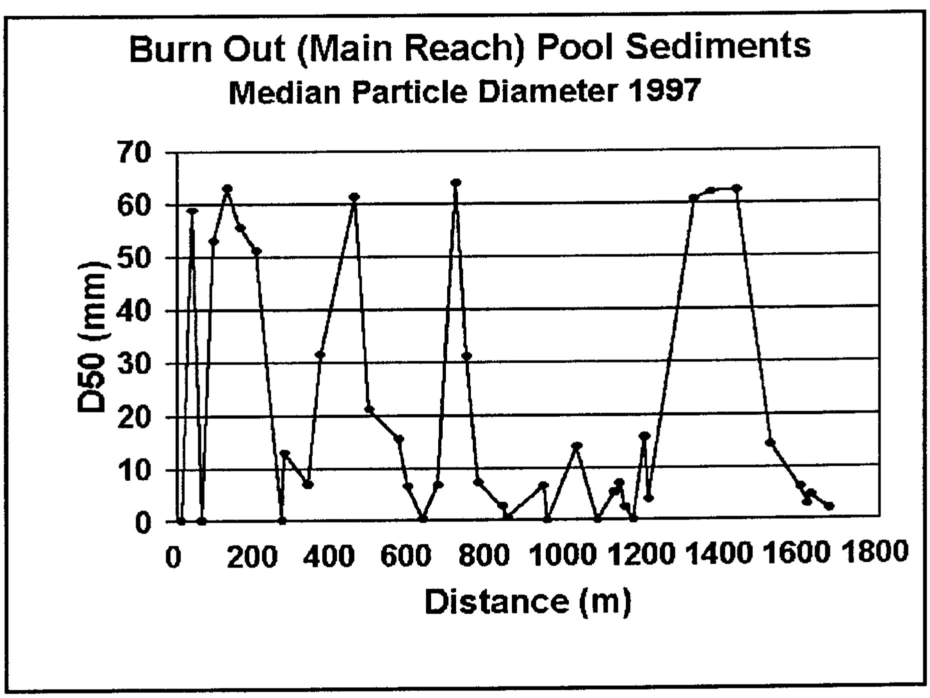


Figure 87. Distribution of median particle diameter (D_{50}) of pool sediments along the Main Channel of Burnout Creek in 1994 and in 1997.

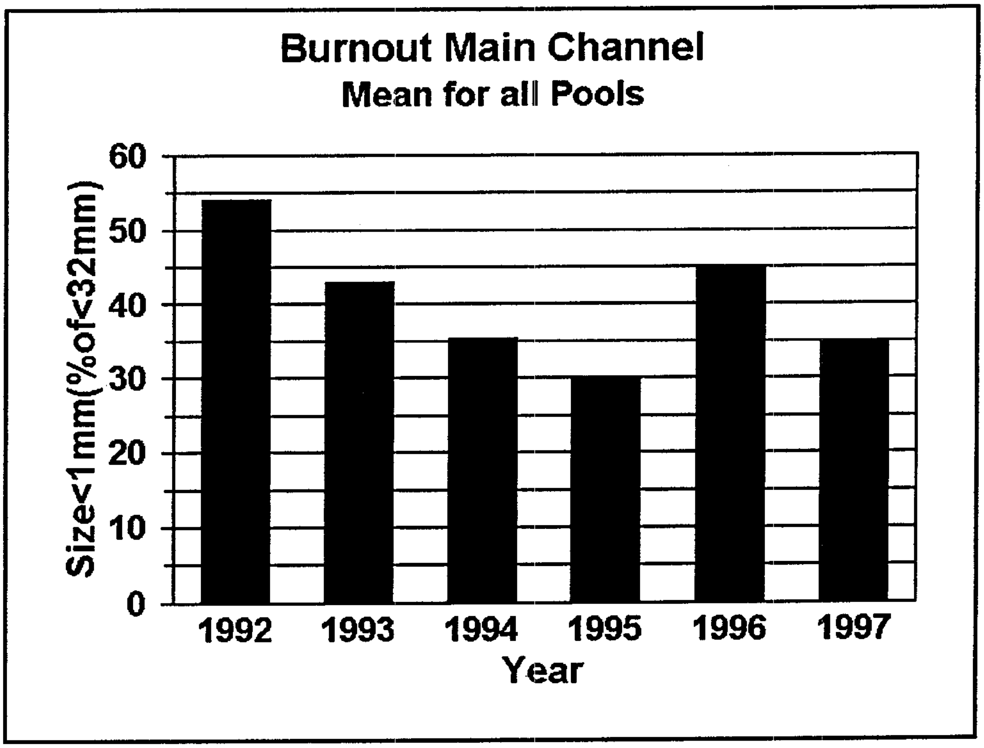
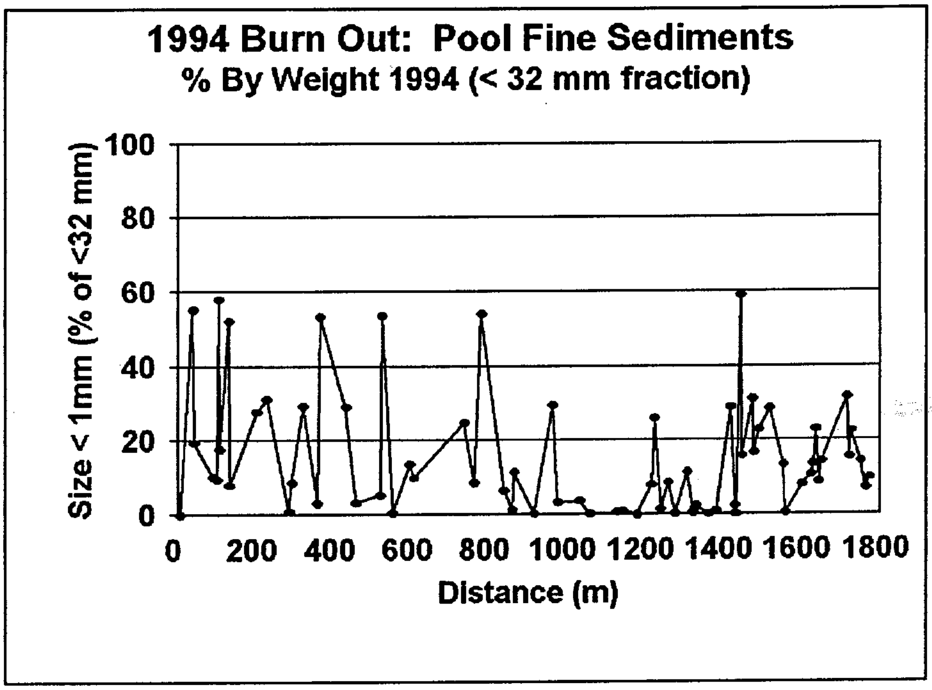


Figure 88. Changes over the study period in pool fine sediments (< 1 mm size) in the Main Channel of Burnout Creek, 1992-1997.



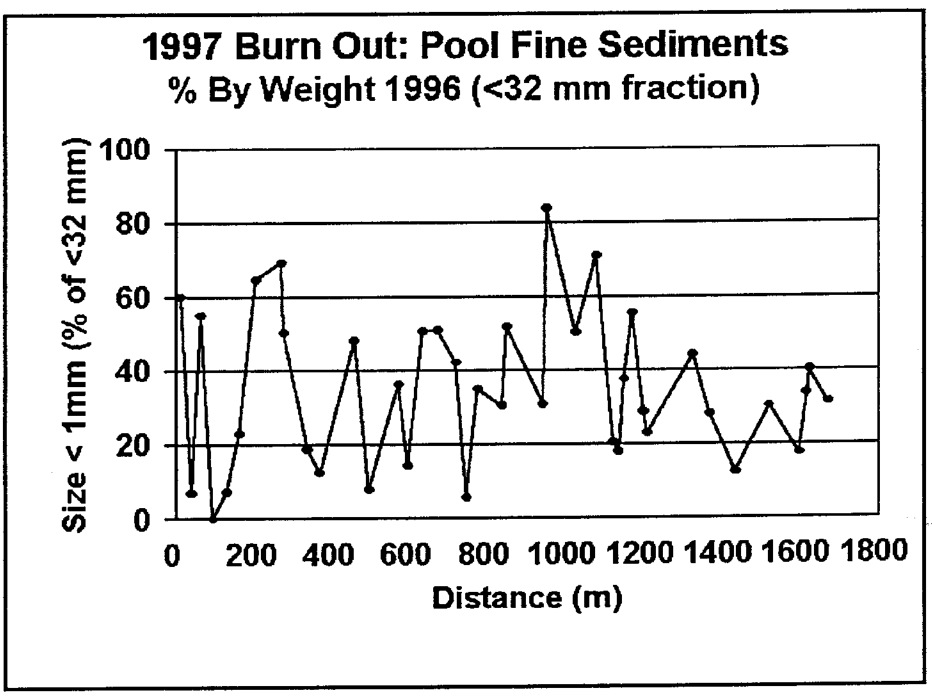


Figure 89. Distribution of of fine sediments in pools along the Main Channel of Burnout Creek in 1994 and in 1997.

Changes between years in the mean particle size in the South Fork did not match what occurred in the Main Channel. The largest median particle size occurred in 1994 with 1996 being almost as large but then decreased again in 1997 (Figure 90). Differences in median particle size among pools in the South Fork was considerably less in 1997 than in 1994 (Figure 91). Differences between years in fine sediments (Figure 92) showed a somewhat similar pattern as in the Main Channel of Burnout and in James. The highest proportion of fine sediments occurred in 1992, and the lowest in 1994. The variation of fine sediments among pools in the South Fork is shown in Figure 93.

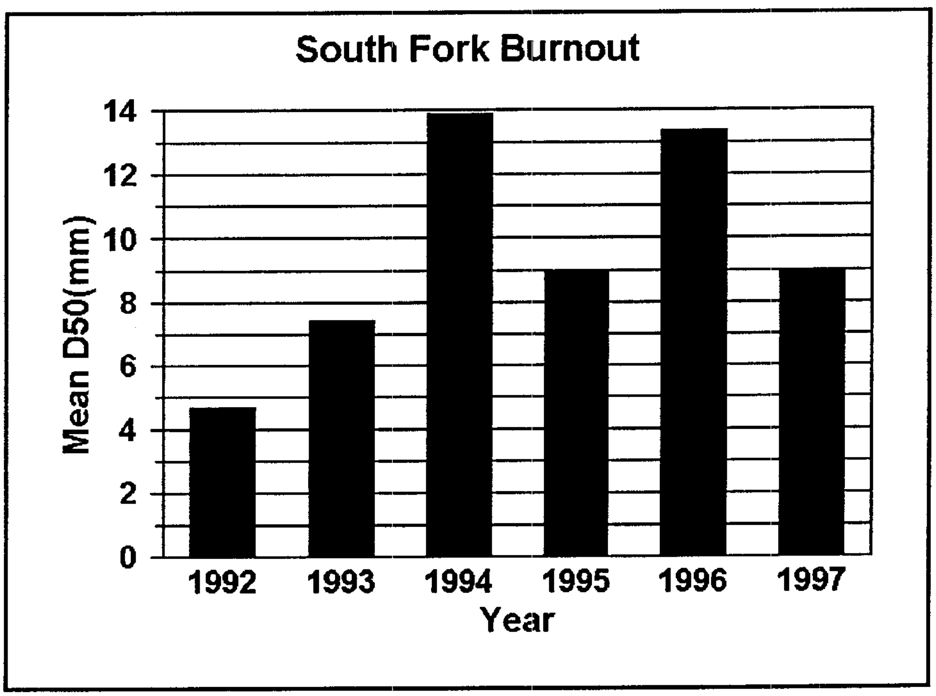
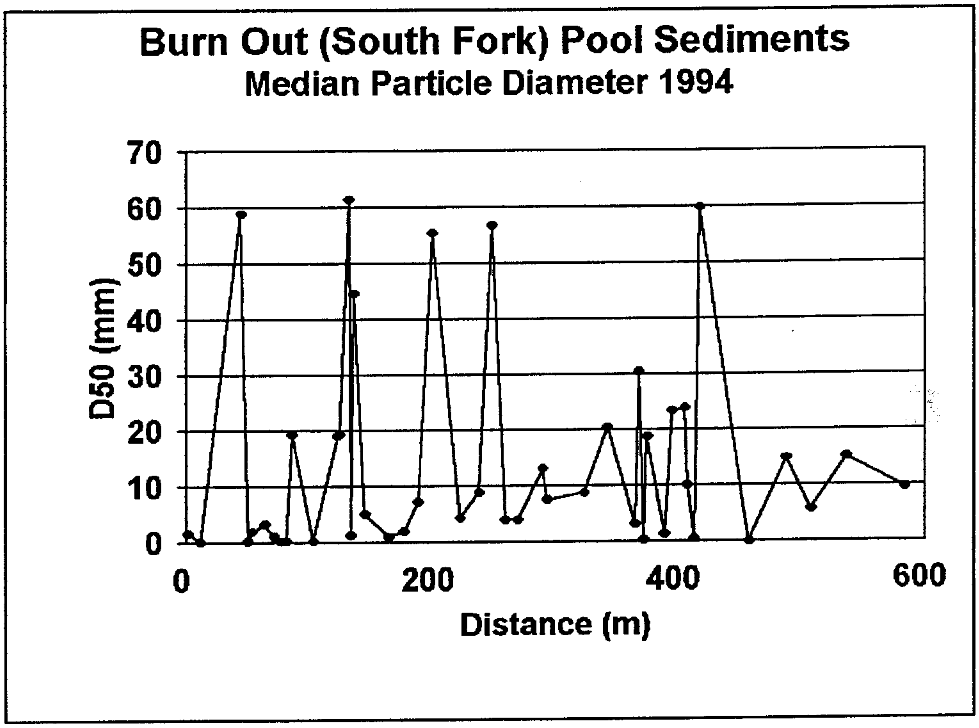


Figure 90. Changes over the study period in median particle diameter (D_{50}) of pool sediments in the South Fork of Burnout Creek, 1992-1997.



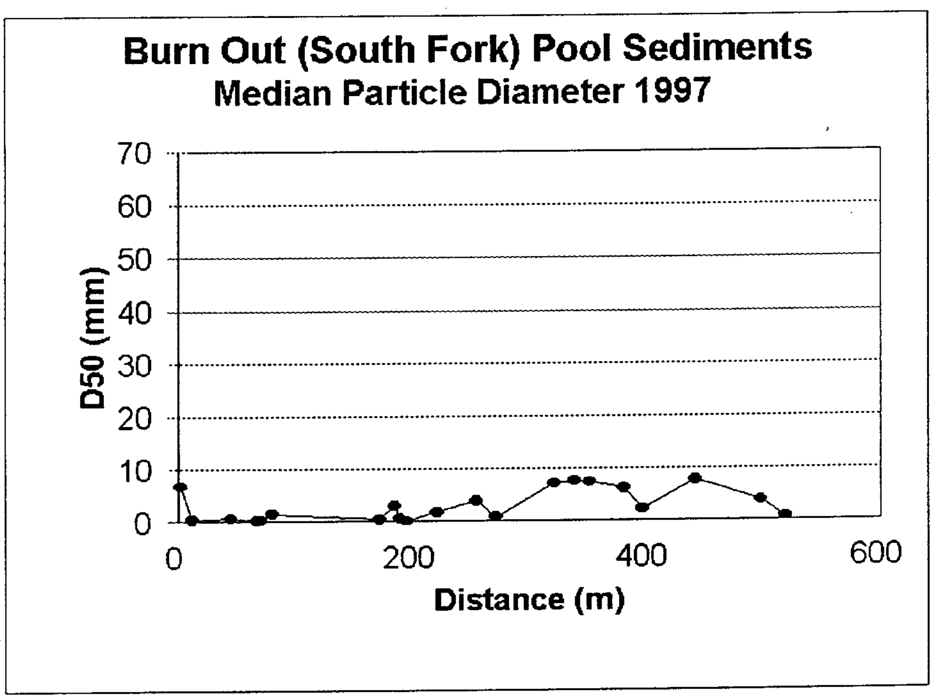


Figure 91. Distribution of median particle diameter (D_{50}) of pool sediments along the South Fork of Burnout Creek in 1994 and in 1997.

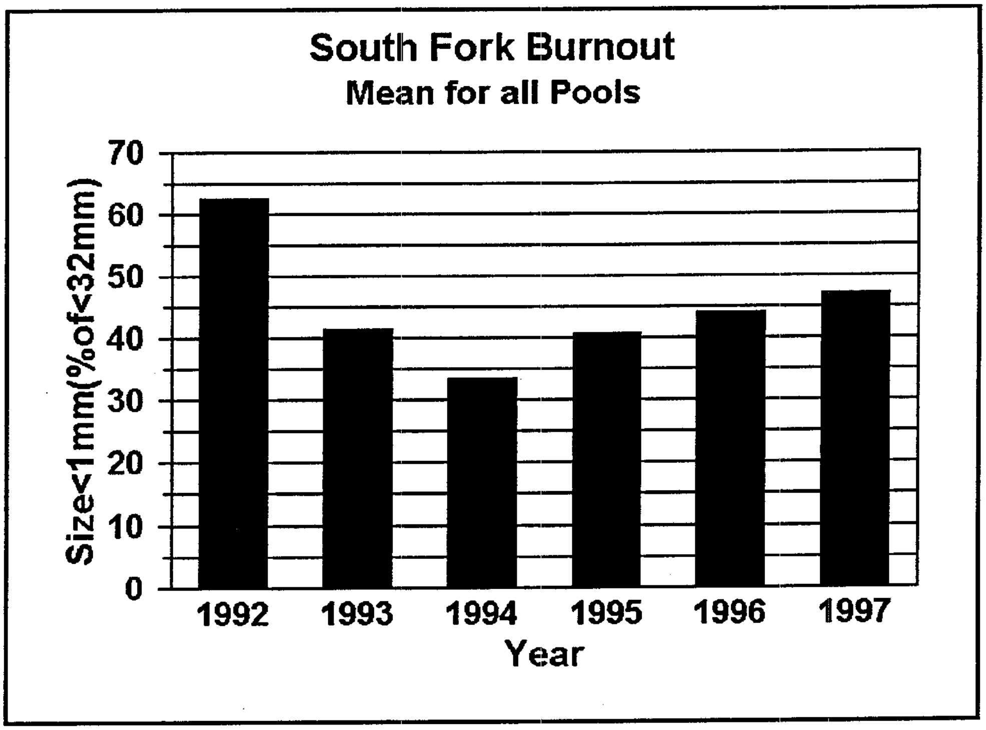
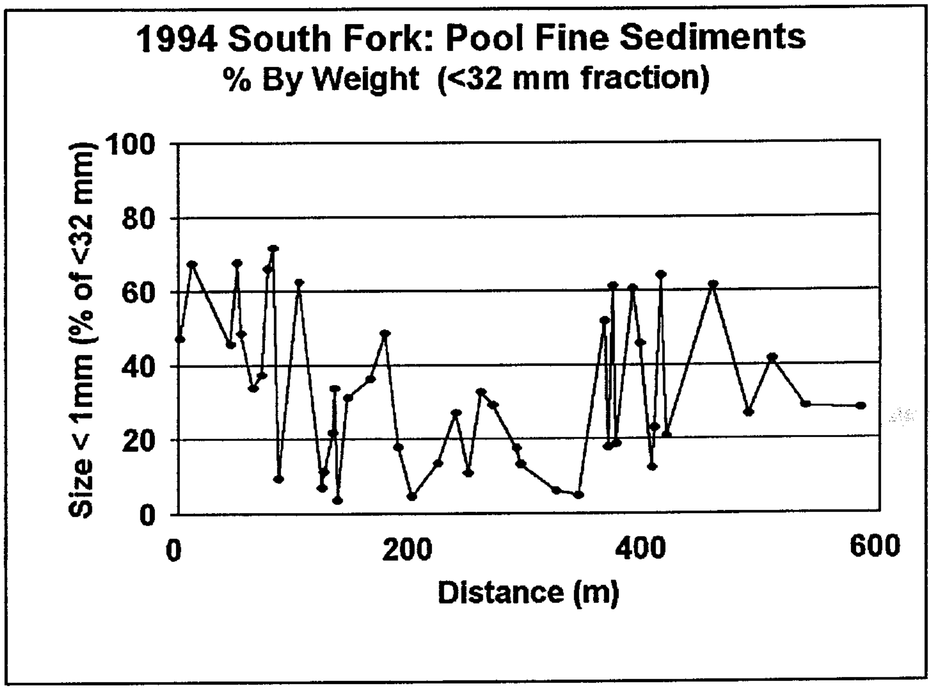


Figure 92. Changes over the study period in pool fine sediments (< 1 mm size) in the South Fork of Burnout Creek, 1992-1997.



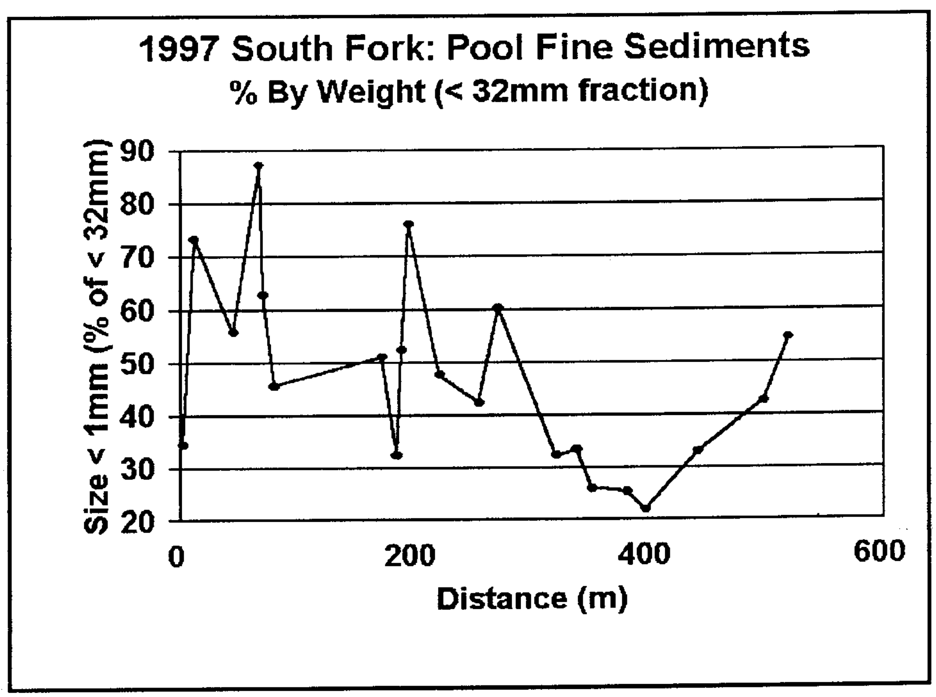


Figure 93. Distribution of fine sediments in pools along the South Fork of Burnout Creek in 1994 and in 1997.

Sediment Characteristics Conclusions:

Although the two-fold variation between years in mean particle size (D_{50}) in the Main Channel and three-fold variation in the South Fork of Burnout Creek did not exceed that experienced in the James Canyon control area, the pattern of changes differed (Figures 82, 86, and 90). Mean particle size tended to increase progressively from initial lows in the early years to higher levels especially in the later years. The highest level in James Canyon was in 1994, but then decreased by ~1/2 in 1995 and 1996, but increased again in 1997. This suggests that subsidence may have resulted in an increase in the mean particle size.

The two-fold variation between years in percentage of fine sediments in Burnout did not exceed that in James Canyon. The pattern of change between years was the same in both drainages (Figures 84, 88, and 92). This suggests that subsidence had no detectable effect on the proportion of fines <1 mm in size in the mined drainage.

Riparian Survey

Two types of vegetation surveys were conducted in 1992 in both the upper and lower reaches of Burnout and James Creeks. The upper and lower riparian survey sites in Burnout Canyon are located in the middle of panels 9L and 10L, respectively. The upper and lower riparian reaches in James Canyon are located just downstream of cross-section group Y and just upstream of cross-section group Z, respectively. At each site, seven cross-sections were established perpendicular to the riparian complex so that the entire riparian area was traversed (Figure 94). Both ends of each transect were marked and photographed for future reference. A tape measure was stretched across each transect and spatial changes in riparian community types were documented. Riparian transect varied in length from 6.5 to 33 m depending on topography and drainage position. In general, riparian transect in the upper reaches were shorter than those in the lower reaches. A total of 15 riparian community types were identified in the four areas and common names are included in Table 7. Community designations closely followed those given by Padgett et al. (1989). **Because composition of riparian communities would be slow to respond to hydrologic or geomorphic alterations due to subsidence, these survey are**

intended to serve as benchmarks for future evaluation with re-measurements that may be appropriate if community change becomes suspect.

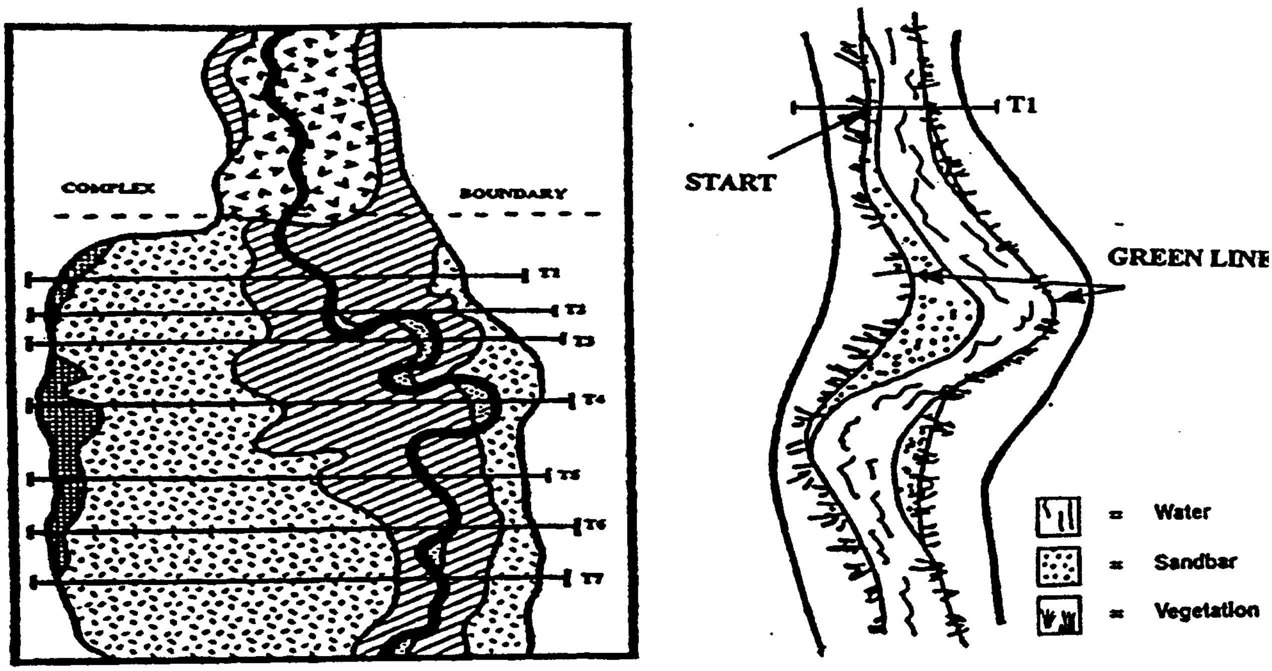


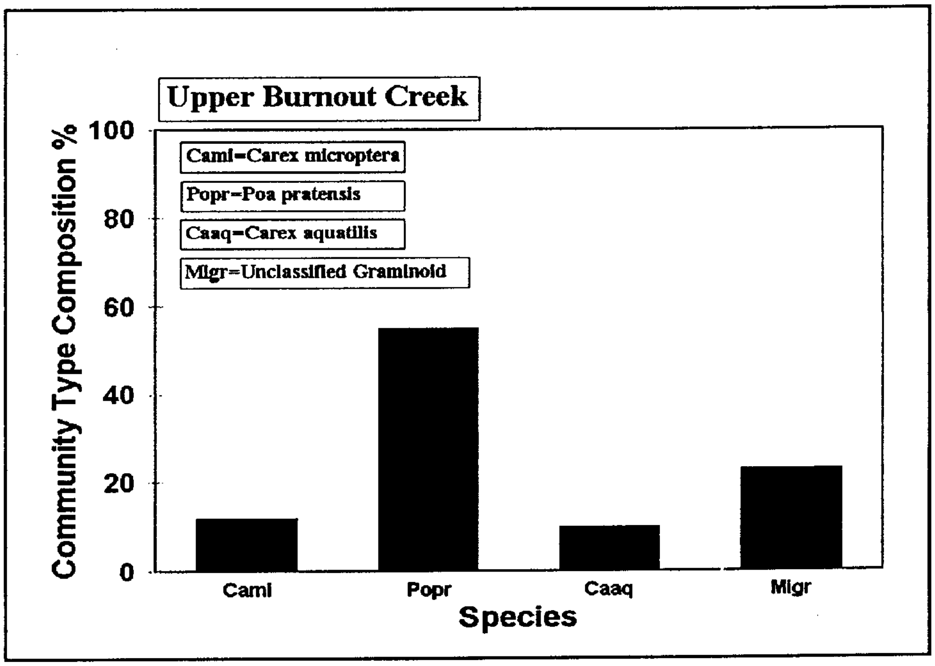
Figure 94. Example of vegetation transects and greeline survey at each riparian complex.

Riparian transects selected in the lower reach of Burnout Creek were dominated by four community types (Figure 95) -- *Carex microptera* (37%), *Artemisia cana*/unclassified graminoid (22%), *Artemisia cana/Poa pratensis* (17%), and *Poa pratensis* (15%). The riparian reach in the lower portion of James Creek was dominated (50%) by *Juncus balticus* (Figure 96), only a minor component of the vegetation complex in the lower Burnout Creek riparian reach. The other two most abundant vegetation community types in lower James Creek were *Artemisia cana*/unclassified graminoid (24%) and *Artemisia cana/Poa pratensis* (12%). The riparian reach in upper Burnout Creek had only four vegetation community types: *Poa pratensis* (55%), unclassified graminoid dominated (23%), *Carex microptera* (12%), and *Carex aquatilis* (10%) (Figure 95). *Poa pratensis* also dominated (55%) the riparian transects in upper James Creek. The other three community types were present, but were less abundant (Figure 96). Several other community types were also present, including *Deschampsia caespitosa* (11%).

Table 7. Scientific and common names of vegetation found in riparian areas.

	Latin Name	Common Name
Species encountered in veg. community types.	*Artemisia cana*	silver sage
	Carex aquatiles	water sedge
	Carex microptera	smallwing sedge
	Deschampsia caespitosa	tufted hairgrass
	Juncua balticus	Baltic rush
	Poa pratensis	Kentucky bluegrass
	Potentilla fruticosa	bush cinquefoil
	Other Groups of Species	
	Unclassified conifer	mixed conifers
	Unclassified deciduous trees	mixed deciduous
	Unclassified forb dominated	mixed forbs
	Unclassified graminoid dominated	mixed grasses
Other woody species encountered along greenline	*Abies lasiocarpa*	subalpine fir
	Picea engelmannii	Engelmann spruce
	Ribes spp.	gooseberry
	Symphoricarpos oreophilus	mountain snowberry

To assess vegetation condition directly along the stream edge, a "greenline" vegetation survey was conducted in each of the four riparian reaches (Figure 94). The greenline represents the first continuous vegetation encountered when moving away from the perennial water source. Oftentimes the greenline is at the water's edge. The greenline survey consisted of identifying vegetation community types encountered along both sides of the channel. Total length of the greenline survey on each side of the channel was about 100 m. In addition to assessing vegetation community types encountered along both sides of the channel. Total length of the greenline survey on each side of the channel was about 100 m. In addition to assessing community types, stem counts (both live and dead) were made for all trees and shrubs encountered within a 1-m wide strip with the left edge of the greenline (measured from the greenline away from the channel). This allowed woody vegetation to be expressed on a stems per unit area basis. A total



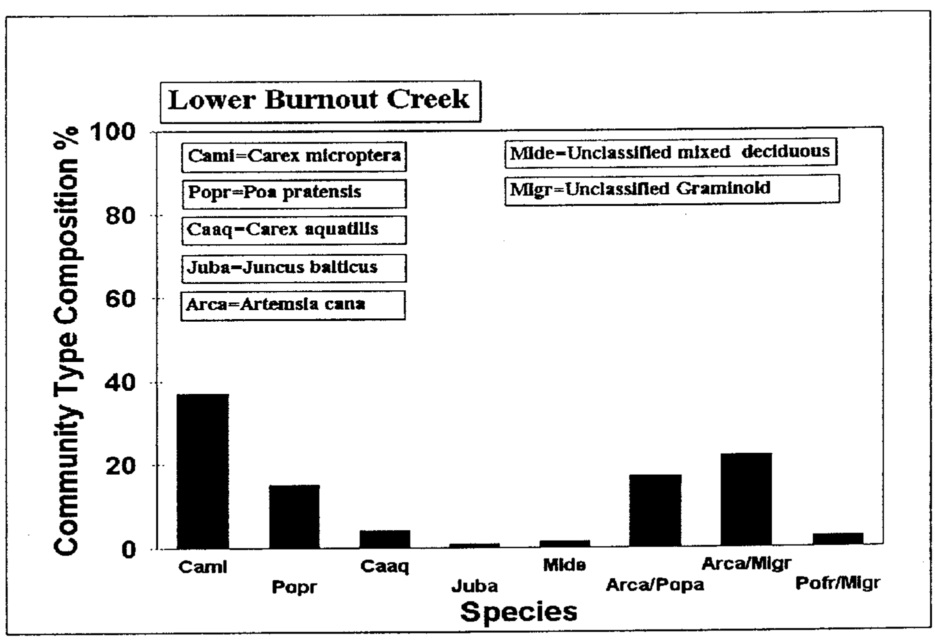
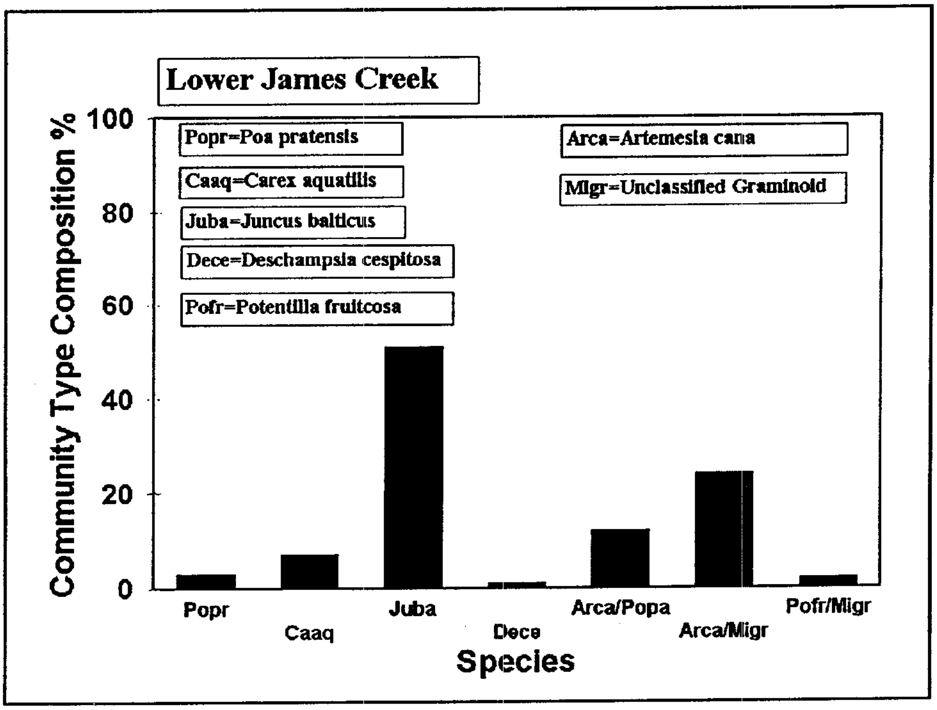


Figure 95. Vegetation community composition along transects for upper and lower riparian complexes along Burnout Creek.



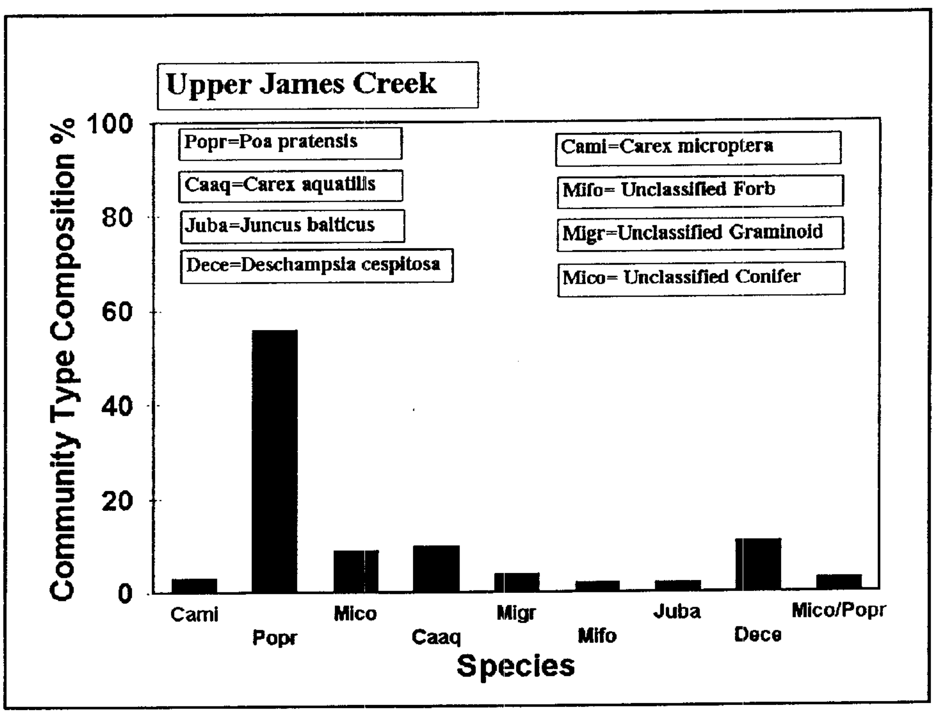


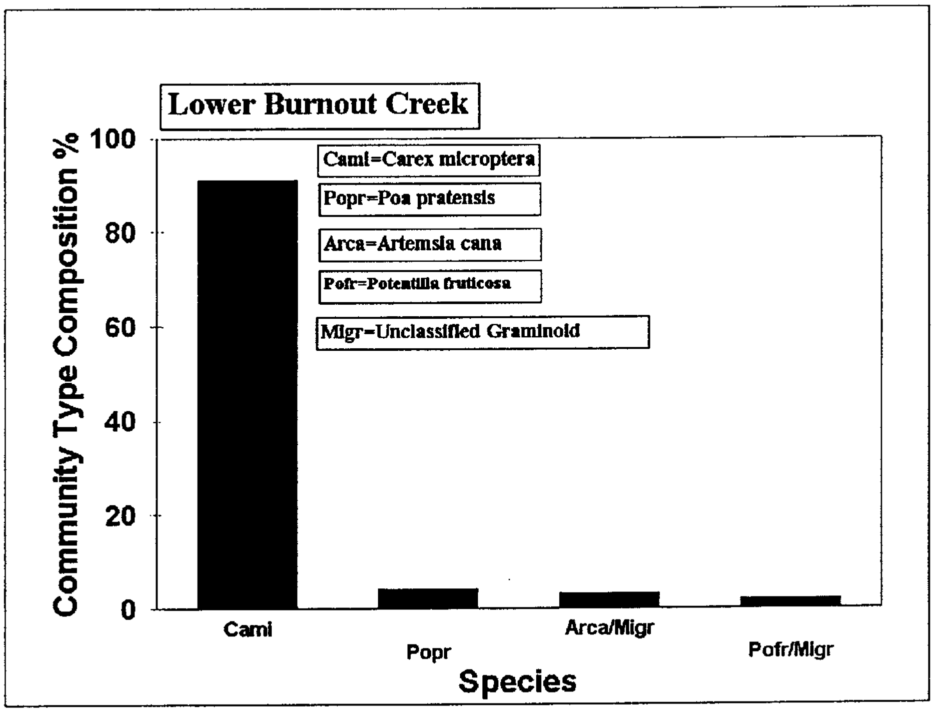
Figure 96. Vegetation composition along transects for upper and lower riparian complexes along James Creek.

of six species of woody plants were found and their common names are given in Table 7.

Along the greenline in lower Burnout Creek, *Carex microptera* comprised 90% of the vegetation community types (Figure 97). In the riparian reach in lower James Creek, *Juncus balticus* occupied 55% of the greenline; however, significant amounts of *Carex aquatilis* (24%) and *Deschampsia caespitosa* (20%) were present (Figure 98). More than 30 live *Potentilla fruticosa* plants and 10 live plants of *Artemisia cana* per 100 m of greenline were found in the lower portion of Burnout Creek. *Artemisia cana* was more abundant (16 live plants per 100 m of greenline) in the lower reach of James Creek; however, *Potentilla fruticosa* was less abundant (about 3 live plants per 100 m of greenline). In the riparian reach along the upper portion Burnout Creek, six community types were present -- *Carex microptera* (27%), *Poa pratensis* (23%), *Carex aquatilis* (18%), unclassified graminoid dominated (16%), unclassified conifer dominated (9%), and unclassified forb dominated (7%) (Figure 97). Most of these same community types occurred along the streambank of upper James Creek; however, *Deschampsia caespitosa* was most abundant (50%) (Figure 98). Englemann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) along with *Ribes* spp. were present in small numbers (<2.5 live stems per 100 m of greenline) in the upper reach of Burnout Creek. *Symphoricarpos oreophilus* was the dominant woody shrub (12.5 live plants per 100 m of greenline) in upper James Creek. More than six Engelmann spruce per 100 m of greenline were noted in the upper reach of James Creek.

As a part of the riparian survey, qualitative assessments of stream cover were made for: (1) overhanging banks, and (2) vegetation and rock cover. An assessment of streambank stability was made as well. Continuous estimates of each of these three parameters were made along the entire surveyed reach (approximately 100 m) in each of the four riparian survey areas. Overhanging bank cover was estimated as the degree of bank overhang above the perennial water course (including soil and sod material, but not overhanging vegetation) measured perpendicular to the bank in the following intervals: 0 = no overhang; 1 = slight overhang (0-5 cm); 2 = moderate overhang (5-10 cm); and 3 = large overhang (>10 cm). In-stream vegetative/rock cover was estimated as the relative amount of waterway shaded or protected by overhanging vegetation, vegetation in the channel, or rocks in the channel. Qualitative estimates were as follows: 0 = no cover; 1 = slight cover; 2 = moderate cover; and 3 = heavy cover. Photographs were taken of all cover classes to correlate with qualitative assessments. Streambank stability was qualitatively rated in one of four classes: 0 = stable; 1 = slightly unstable; 2 = moderately unstable; and 3 = highly unstable.

The greatest differences in overhanging bank cover between the two streams surveyed occurred in the lower reaches. The lower channel of James Creek was narrow with larger overhanging sod-covered banks than in Burnout Creek (Figure 99). In the upper reaches of both Burnout and James Creeks, either no or very small (0-5 cm) overhanging banks were most common (Figure 99). In-stream vegetation cover and bank stability were both averaged over the greenline based on a weighted linear distance occupied by various qualitative estimates. Average in-stream vegetative/rock cover was highest (1.98) in the lower riparian reach of James Creek and lowest in the upper reach of James Creek (Table 8). The higher cover in the lower reach of James Creek was due to plants hanging over the relatively narrow channel. In-stream cover index was intermediate in the lower (1.25) and upper (1.39) reaches of Burnout Creek. Qualitative estimates of streambank stability indicated that banks were least stable in the upper riparian reach of Burnout Creek (1.91). Bank stability in the other her reaches of the two streams ranged from 1.06 to 1.34 (Table 8).



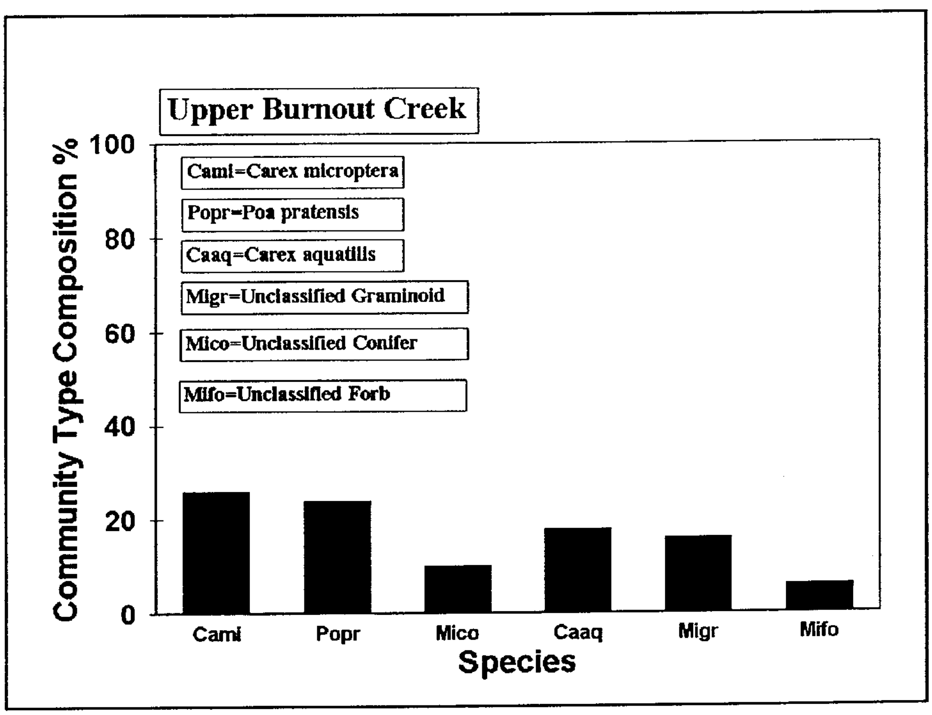


Figure 97. Vegetation communities along the greenline for the lower and upper riparian complexes along Burnout Creek

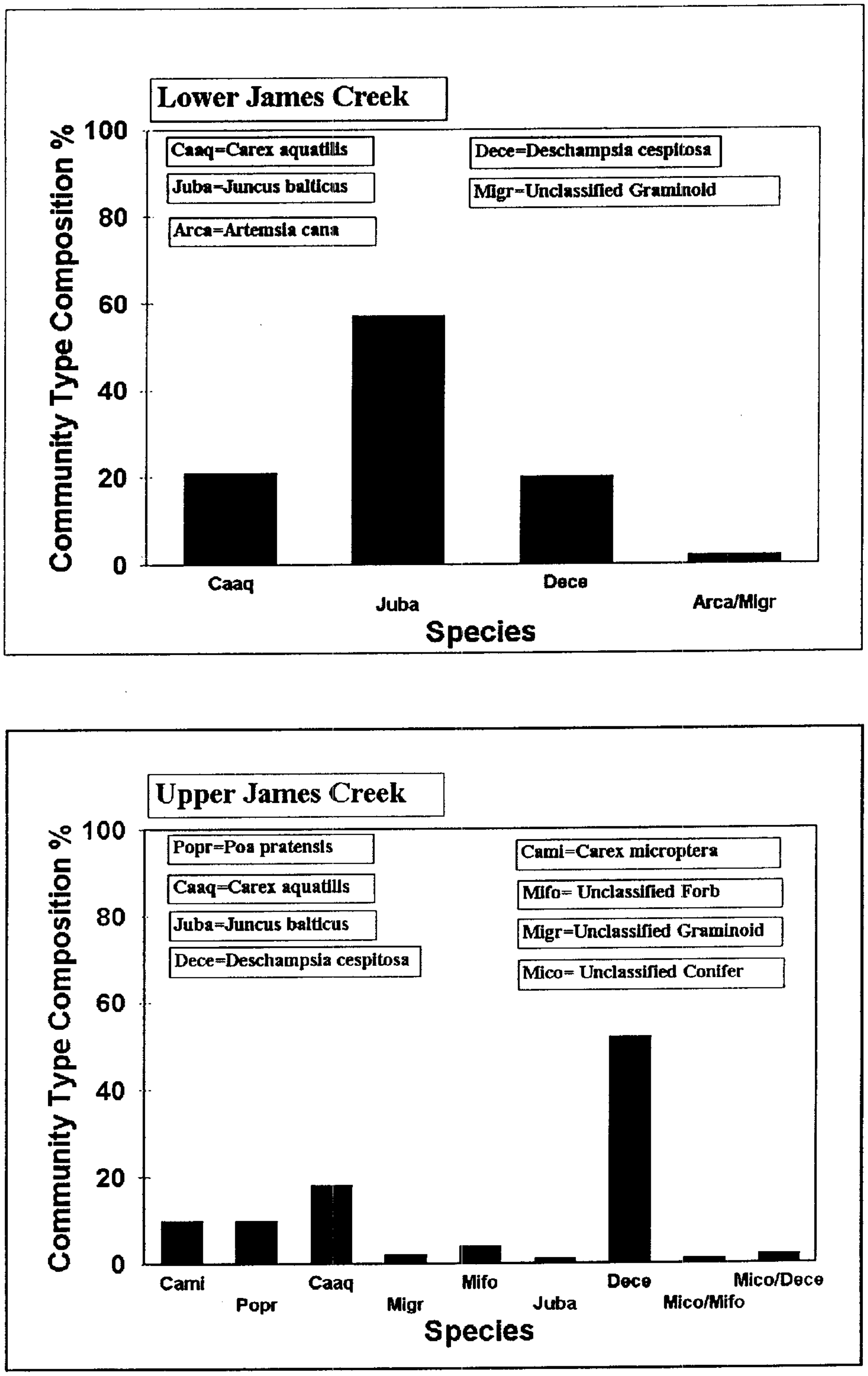


Figure 98. Vegetation communities along the greenline for the lower and upper riparian complexes along James Creek.

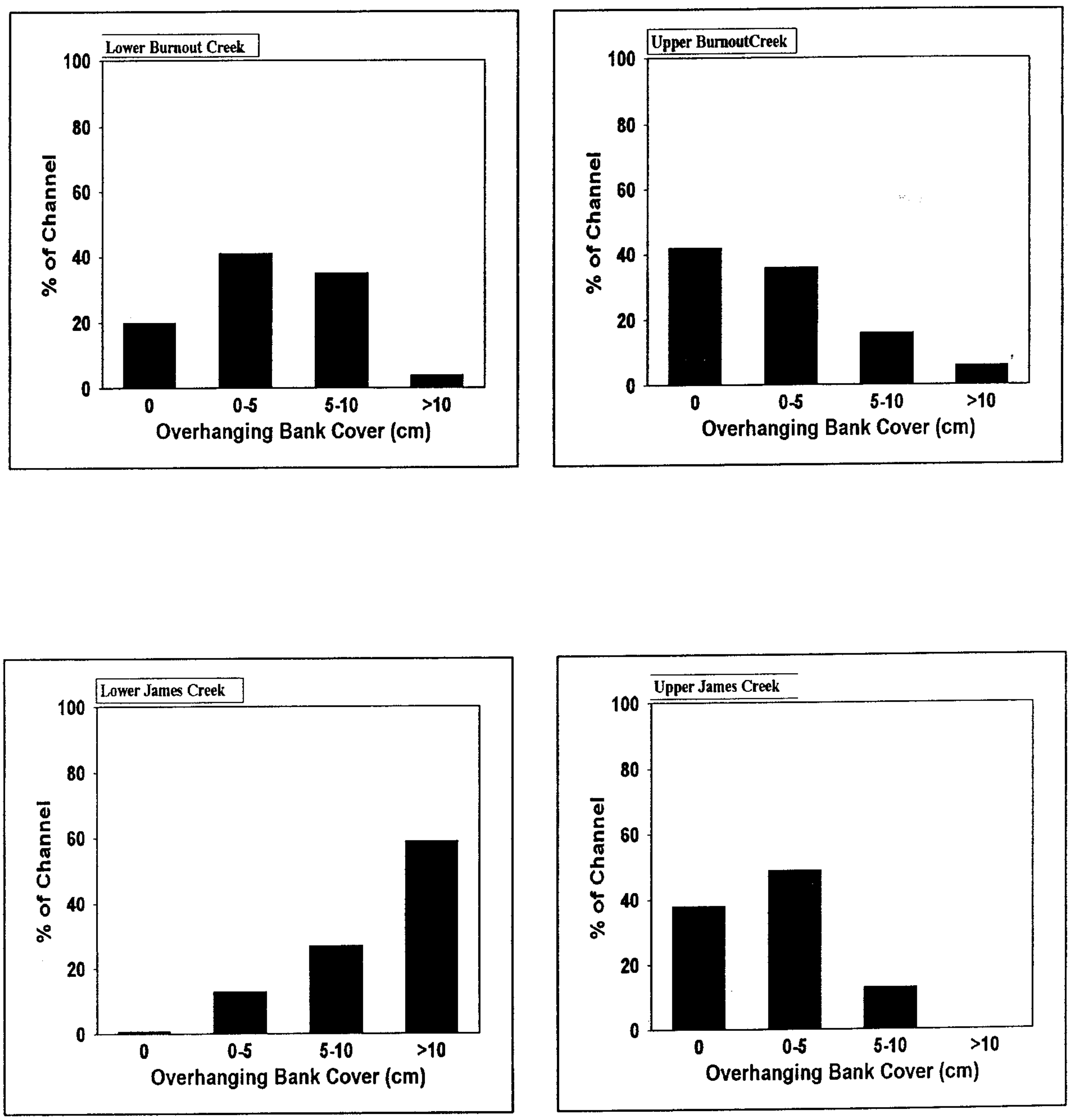


Figure 99. Degree of bank cover for various riparian reaches of Burnout and James Creeks.

Table 8. Qualitative estimates of bank stability and in-stream cover weighted by stream distance.

Reach	Mean Bank Stability Class	Mean In-Stream Cover Class
Lower Burnout Creek	1.34	1.25
Upper Burnout Creek	1.91	1.39
Lower James Creek	1.20	1.98
Upper James Creek	1.06	.98

Landslide Inventory

A comprehensive landslide survey was conduced along the monitored reaches of Burnout Creek in autumn 1992. Only landslides that were adjacent to the channel or visible from the channel were noted. Recent slides were defined as those that appeared to occur after 1980. For recent slides larger than 10 m^3, detailed measurements were taken on the numbers and sizes of soil pipes that may have contributed to failure initiation. For older slides it was impossible to accurately estimate failure dimensions, thus only relative position and size of these failures are shown in Figure 100. These data provide a background for comparison with post-subsidence landsliding frequency. In 1993 and 1994, surveys were conducted to document any new landslides that occurred along Burnout Creek.

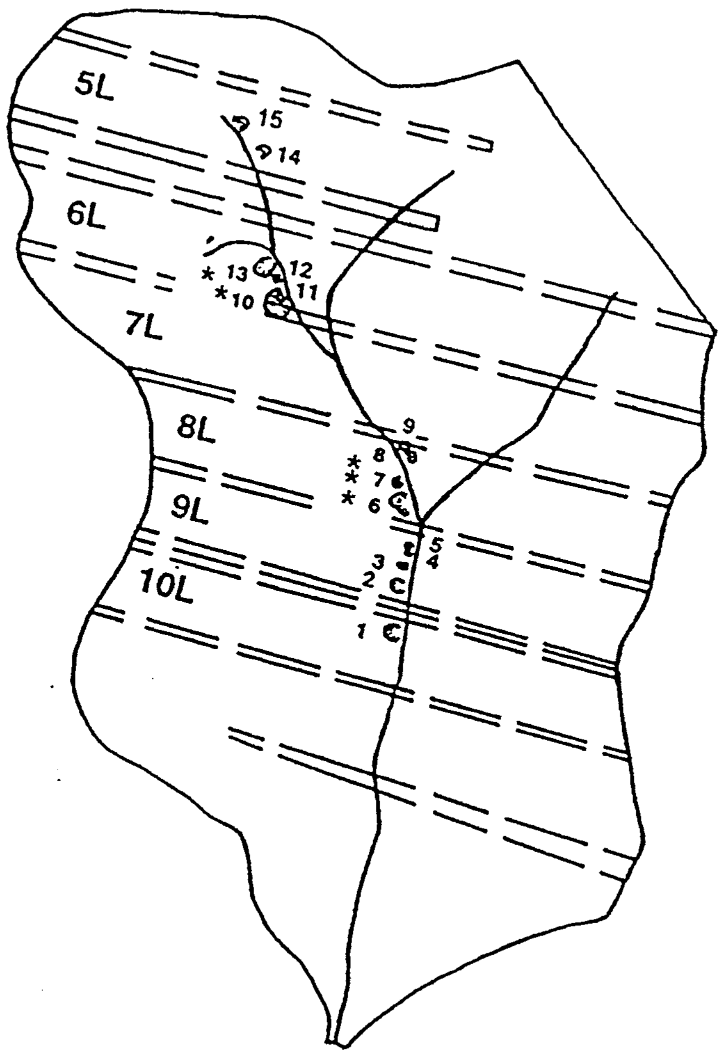


Figure 100. Location of landslides along Burnout Creek (* indicates old landslides).

Nine recent landslides occurred prior to mining along Burnout Creek. These ranged in size from 1.9 to 156 m^3. All but two of these failures were on approximately south-facing slopes (Table 9). Headscarps of six of these recent failures contained one or more soil pipes that are believed to be contributory factors in triggering these events (Blong and Dunkerley, 1976; Tsukamoto et al., 1982; Sidle et al., 1985). Soil pipes ranged in size from < 1 cm to 17 cm (Table 9). All but two of these recent landslides were translational failures (debris slides or avalanches); the remaining two were rotational slumps. The two largest failures (#11 and 12), located along the upper main channel of Burnout Creek, were associated with previous disturbances (Figure 100). Failure #11 was a localized slump/deep-seated slide that occurred in the eastern portion of a stabilized ancient slump block (failure #10). Failure #12 was associated with an old road cut and fill from a logging operation.

Table 9. Characteristics of recent, pre-mining landslides along Burnout Creek.

Land-slide #	Failure Type	Vol. (m^3)	Estimated Date of Failure	Aspect	Visible Pipes Present	# of Pipes	Pipe Diameters (cm)
1	Debris avalanche	32	~ 1990	S20°E	Yes	6	2,2,2,3,7,8
2	Debris avalanche	30	~ 1983-87	S22°E	Yes	4	2,6,7,4
3	Debris slide	7	~ 1983-87	South-facing	Yes	several	--------
4	Debris slide	1.9	~ 1990	South-facing	No		
5	Debris slide	5.6	~ 1990	South-facing	No		
9	Slump	7	~ 1983-87	NW-facing	No		
11	* Slump/ slide	135	~ 1983-84	S40°E	Yes	1	17
12	Debris slide	156	~ 1983-84	E15°S	Yes	3	6,6,5
14	Debris slide	10.5	~ 1988-90	NW-facing	Yes	1	1.5

* Within old landslide #10.

A total of five older landslides were noted. These were all very large, old (>50 years) slumps or combination slump/deep-seated slide failures. It is likely that some smaller "old" slides existed, but they were impossible to recognize in the field due to infilling of the scoured zone and revegetation. Approximate size and location of these old landslides are shown in Figure 100. Any future activation of these older slumps and deep-seated slides will be noted. All 14 landslides, both recent and old, were photographed.

In the post-mining surveys (1993 and 1994), only one new landslide (#15) was documented -- a small debris slide along the north-facing streambank in the upper ephemeral reach of Burnout Creek above panel 5L. This landslide was likely triggered by snowmelt in early spring 1993. It is located upstream of slide #14 and has similar dimensions and volume. Since subsidence had already occurred in panel 5L (mostly during late 1991 and early 1992), the initiation of this small failure was not associated with mining. None of the older landslides were reactivated during the 1992 to 1994 period. No recent landslides were noticed during 1996. Thus far, it appears that subsidence from underground mining has not increased the landslide potential along Burnout Creek. However, it should be understood that 1993 and 1994 were relatively dry years with only modest snowpacks. Thus, pore water pressures needed to initiate or accelerate landslides on unstable slopes may not have been present during this period.

Baseflow

Instantaneous baseflow measurements for sites CS-7, near the outlet of Burnout Creek, were summarized for the pre-mining period from 1981 to 1991. Flow measurements were excluded from the analysis if they were influenced by spring snowmelt runoff or by a storm event. Generally, data collected during the period from late June to late October were included in the analysis. The mean baseflow discharge for the 41 pre-mining measurements is 0.43 cfs; standard deviation is 0.28 cfs. A total of 49 baseflow data points were analyzed for the post-mining period from 1992 to 1994. These data represent actual flume readings taken throughout the summer and autumn of 1992 and 1994 (Figures 46 and 47). Again, storm events and snowmelt runoff were excluded from this data base. When weekly direct measurements were not available, baseflow was taken from the recorder (daytime values) at CS-7. The mean baseflow discharge for the 49 post-mining measurements is 0.40 cfs; standard deviation is 0.12 cfs. There was no significant difference between pre-mining and post-mining baseflows based on t-test comparisons (α=0.05).

Summary

This report analyzes channel changes and related hydraulic parameters in a mountain stream (Burnout Creek) that has been partially impacted by subsidence from underground coal mining. Comparisons are made between reaches of streams that have been subsided, the entire stream channel of the mined drainage, and an uncalibrated control stream in James Canyon. The James Canyon serves as a basis for judging whether a change in channel characteristics in Burnout might be attributed to subsidence following mining. Channel characteristics classified in the James Canyon control varied considerably between years, probably resulting from a combination of subjective classification differences between observers in different years combined with normal fluctuation attributable to variations in stream flow. However, changes in Burnout Creek that exceed those in James are attributed to the effects of mining.

Changes in channel characteristics was inconsistent between mined panels as well as between the Main Channel and South Fork. The most likely change in both sections of Panel 7L (mined in 1993-'94) was a temporary increase in the number and proportion of the channel in pools compared to the appropriate section of the James control. By 1997, however, this increase was no longer detectable. An increase in pools was also apparent in the Main Channel portion of Panel 8L (mined in 1995-'96), but not in the South Fork portion of this panel. In Panel 9L (mined in 1995-'96) subsidence appears to have resulted in an increase in the proportion of the channel occupied by pools, but not in the total number of pools. The pools here were fewer and larger.

The effect of mining on stream channel characteristics in the entire Burnout drainage between 1992 and 1997 appears to be a general increase in of pool numbers in both the Main Channel and South Fork, but changes in pool volume were inconsistent. The proportion of the Main Channel in cascades may have increased, but cascades decreased in the South Fork. Great year-to-year variability in measurements in the stream channel of the control area (James Canyon) obscure the reliable detection of other changes that may have occurred in Burnout.

Overall, channel profile surveys with the techniques used have not been useful for interpreting impacts related to specific regions of subsidence in this study area. More careful and detailed measurements will be needed for such data to be of use in interpreting subsidence impacts.

Changes in the cross-sections of the stream channel attributable to mining consisted largely of decreases in elevation and some changes in channel width. Drops of 1.5 to 5.5 feet in elevation occurred in zones of subsidence, whereas drops of only 1.5 to 3.2 feet occurred in the tension zones of mined panels. Any observed changes in width were usually a narrowing of up to ~ 1.5 feet in subsidence zones, and a widening of up to ~ 2.5 feet in tension zones. The amount of erosion and deposition measured by these cross-sections did not exceed that caused by normal processes in James Canyon. Here again we want to add a word of caution, not so much for the method, but for the number of different people doing this work from year to year. Further studies should try for more consistency. Actual techniques varied from year to year, resulting in data that presented problems during analysis.

Typically, during the summer or autumn after initial subsidence, some channel constriction was measured. However, one year later, some recovery to pre-subsidence geometry was observed. This so-called recovery could be related to fluvial reworking of the channel bottom, stress relief after subsidence, or even animal traffic. Changes in channel geometry (especially in the channel bottom) affected hydraulic properties: wetted perimeter often decreased after subsidence and, conversely, hydraulic radius increased (but not to the extent of the decreases noted for wetted perimeter). These hydraulic properties were calculated based on routing of design stormflow through the basin and allowing for temporal changes in channel cross-sections. Calculations for the impacted reach over panel 6L suggest that bed shear stress may increase during peakflows, thus causing potential increases in channel scour, bedload transport, and winnowing of finer bed material. On the other hand, the calculations indicate that channel erosion may be less because of the smaller wetter perimeter measured following subsidence. This potential for reduced channel bank erosion could decrease suspended sediment transport. Some of these predicted changes are partially confirmed by analyzing the substrate data collected from pools throughout Burnout Creek.

Although the two-fold variation between years in mean particle size (D_{50}) in the Main Channel and three-fold variation in the South Fork of Burnout Creek did not exceed that experienced in the James Canyon control area, the pattern of changes differed somewhat. Mean particle size tended to increase progressively from initial lows in the early years to higher levels especially in the later years. This suggests that subsidence may have resulted in an increase in the mean particle size. Subsidence had no detectable effect on the proportion of fines <1 mm in size in the mined drainage.

Riparian vegetation surveys were conducted in 1992 along the stream channel in Burnout as well as along the James Canyon control. These survey are intended to serve as benchmarks to compare with future remeasurements that may be appropriate to detect possible changes in riparian plant communities that might be attributed to mining.

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