IMPACT OF CLIMATE ON RECLAMATION SUCCESS IN THE FOOTHILLS/MOUNTAINS REGION OF ALBERTA, CANADA[1]

by

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Abstract. The Alberta Research Council has conducted a reclamation research program near Grande Cache, Alberta in conjunction with the surface mining operations of Smoky River Coal Limited since 1972. Use of appropriate materials handling techniques and selection of suitable plant species combined with good management practices has resulted in the establishment of diverse plant communities that allow for different land use options. Climate was recognized as the most limiting factor to reclamation success in the region. Precipitation records were maintained on a growing season basis since the inception of the program. More recently, continuous monitoring equipment was installed to measure precipitation, air and soil temperature, wind speed and direction and relative humidity on a continuous basis. Frost-free period has ranged from 45 days to 112 days during the last five years. Soil temperatures at the 1 cm depth were found to exceed 46°C for several hours on consecutive days in areas characterized by a grass and legume cover. Measurement of the distribution and intensity of precipitation events indicates that the distribution of moisture can be somewhat less than effective for good plant establishment and growth. Prevailing winds are from the west and south. The data collected in the monitoring program are used to develop and refine operational reclamation procedures used in the area.

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Introduction

The Alberta Research Council has conducted a reclamation research program near Grande Cache, Alberta in conjunction with the surface mining operations of Smoky River Coal Limited since 1972. The development of effective materials handling techniques and selection of appropriate plant species combined with good management practices has resulted in the establishment of diverse plant communities that allow for different land use options (Macyk and Widtman 1987; Macyk 1985). Emphasis on materials handling techniques and revegetation concerns did not allow for any quantitative measurement of climate parameters in the early stages of the program. During the course of the study climate was recognized as the most limiting factor to reclamation success in the region. This paper provides a summary of the climatic parameters monitored, the results obtained and the relationship of these parameters to reclamation success.

Setting

The operations of Smoky River Coal Limited are located approximately 150 km north of Jasper in the Rocky Mountain Foothills. The three major surface mining operations are the No. 8, No. 9 and No. 12 Mine areas located adjacent to the Smoky River and Sheep Creek respectively. Elevations range from 1600 to 1800 m and the topography is steeply sloping.

Materials and Methods

Beginning in 1973 precipitation was measured each year during the period May 1 to September 30. This period varied by a few days annually on the basis of the time that researchers were on site. As the significance of the impact of climate on revegetation success became more apparent, and appropriate continuous monitoring equipment became available, a major program to evaluate additional parameters was implemented.

Temperature Measurements

During 1983 a study was initiated to determine the length of growing season and to provide air and soil temperature data. Two different types of monitoring equipment were installed. The Model TA51 Biophenometer (Omnidata International Inc.) is a miniature, battery operated growing degree day computer and chilling hour accumulator. Degree days above 5°C provide an estimate of the growth stage of a plant based on temperature measurements. For each day that the average temperature is one degree above the base temperature of 5°C, one degree day accumulates. One unit was located in the Sheep Creek Valley (elevation 1020 m) and another in the No. 9 Mine area (elevation 1850 m).

At No. 8 Mine, two Campbell Scientific CR21 (Campbell Scientific Inc.) units were installed to monitor soil and air temperature. The CR21 Micrologger is a battery powered microcomputer that can monitor signals from a wide variety of transducers recording a broad range of parameters. Air temperature and soil temperature at the 1 cm and 5 cm depths on the crown, north, south, east and west facing-slope positions were measured. Minimum, maximum and average temperatures at two-hour intervals were recorded for each of the locations.

Subsequently, three Model 824 Easylogger units (Omnidata International Inc.) which are 12-channel portable data recorders were installed. With this equipment the air and soil temperatures are measured at three-minute intervals and a minimum, maximum and mean value recorded on an hourly basis.

Precipitation

Precipitation is measured at various locations utilizing the Taylor Clear-Vu rain gauge (Taylor Instrument, Sybron Corporation). Tipping bucket rain gauges have also been installed at three locations in the mine area in conjunction with the Easylogger units.

Other Parameters

Soil moisture is measured by the use of the SM898 Beckman soil moisture block. The LICOR LI-200 SB pyranometer sensor is used to measure solar radiation and the Vaisala HMP IIIA humidity sensor is used to measure relative humidity. Wind speed and direction is measured by the use of the Young Model 05102 wind monitor. All of these instruments are attached to the Easylogger units which measure the respective parameters at three-minute intervals and record minimum, maximum and mean values on an hourly basis.

Results and Discussion

Air Temperature

Detailed air and soil temperature data are available for 1984 to 1988. Experience had indicated that frost and/or snow could occur in any month of the year. The data obtained in 1984 indicated that indeed frost (temperature below 0°C) did occur in each month during the monitoring period. Length of frost-free period and killing frost-free period (temperature below -2°C) for 1984 to 1988 inclusive are illustrated in Figure 1. The length of killing frost-free period exceeded the frost-free period for all years particularly 1984 and 1985.

Another measure of growing season characteristics involves determination of the degree-days that accumulate. Degree-days above 5°C provide an estimate of the growth stage of a plant based on temperature measurements. The data in Table 1 compare the degree-days accumulated at the No. 9 Mine location with an elevation of 1800 m and the Sheep Creek site with an elevation of 1035 m.

The data indicate consistently higher values at the Sheep Creek location which is considerably lower in elevation. To put these data in perspective, the concept of degree-days is used in the definition of climatic zones in Alberta as illustrated in Table 2.

Both the Sheep Creek and No. 9 Mine sites fit the Climate Zone 5 category which represents most of the forested region of Alberta.

Soil Temperature

Soil temperature influences biological, chemical and physical processes in the soil and the growth and overall survival of plants. During the first year of the project, when plot establishment was underway, surface soil temperatures in excess of 50°C were recorded for bare soil materials when air temperature was greater than 25°C. Relatively dark soil materials comprised of soil and coal fines reached temperatures of 55°C and greater. One of the objectives of the monitoring program was to assess the relationship between air temperature, soil temperature and aspect and to apply the information to revegetation techniques and site management.

The data collected were analysed to relate air temperature and soil temperature at the 1 cm and 5 cm depths relative to different aspect, time of year and to some extent color

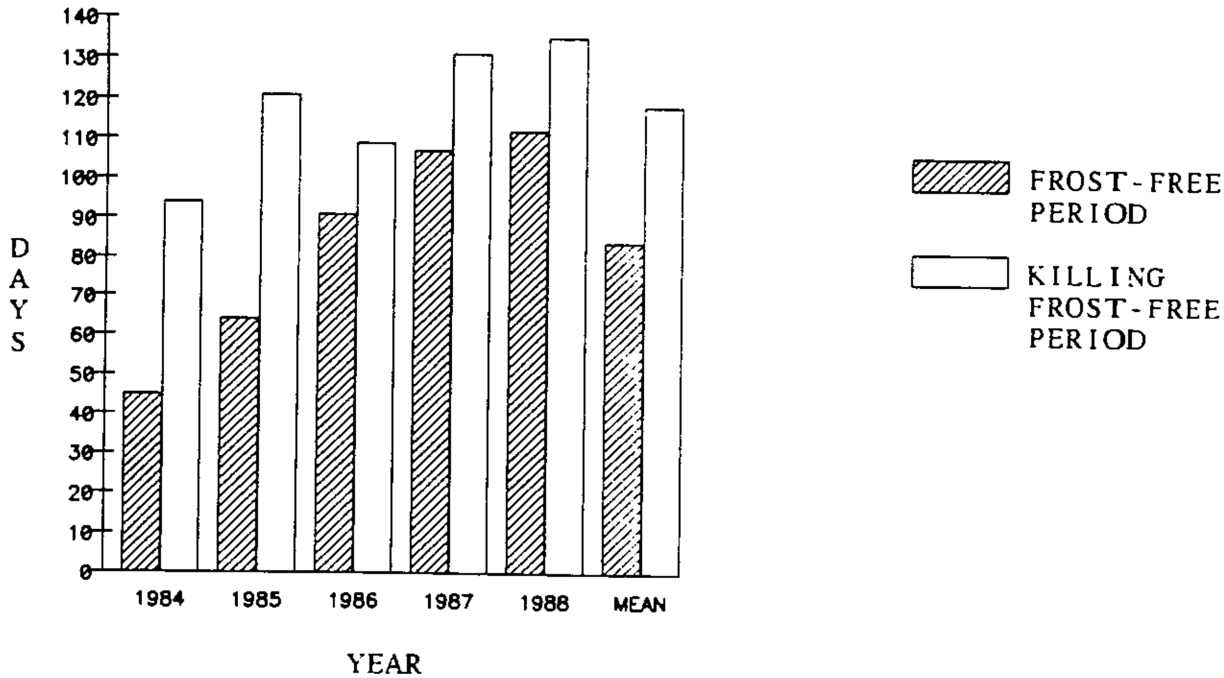

Figure 1. Frost-free and killing frost-free period for 1984 to 1988.

Table 1. Degree-days at the Sheep Creek and No. 9 Mine locations for 1984 to 1988.

Date	Degree-Days	
	Sheep Creek	No. 9 Mine
April 25 to October 3, 1984	919	-
April 10 to October 3, 1985	1023	846
April 15 to October 7, 1986	993	826
April 16 to October 7, 1987	1135	971
April 6 to October 7, 1988	1195	963
Mean	1053	902

Table 2. Degree-days and climate zones in Alberta.

Climate Zone	Degree-Days
1	>2200
2	1900-2200
3	1750-1900
5	<1750

of soil material in locations that had an established vegetation cover. The cover is comprised of a mixture of brome grass (Bromus inermis), creeping red fescue (Festuca spp.), crested wheatgrass (Agropyron spp.) and alfalfa (Medicago sativa). The extent of cover varied relative to aspect with the most dense cover occurring on the north-facing slope and the least dense cover on the south-facing slope and the crown position characterized by a dark soil surface material.

Soil temperatures at 1 cm on the north-facing slope were lowest and the range in temperature between minimum and maximum for a 24-hour period were lowest. Temperatures for the crown and south-facing positions were generally the highest and the range in temperature between minimum and maximum for a 24-hour period was greatest (Figure 2).

Relatively high soil temperatures and the length of time that they are sustained have a bearing on plant growth and mortality, especially tree seedlings.
Surface temperatures of 45 to 50°C can cause stem girdle which occurs when a complete circle of tissue is stricken with bark necrosis in the zone of the root collar causing a collapse of the non-woody stem tissues. Severe girdling of seedlings in the 45 to 50°C range depends on the severity of the soil drought (Day 1963).

Daubenmire (1943) showed that soil surface heating and drought can act interdependently to cause severe seedling mortality. Daubenmire showed that the heat sensitive seedlings of Engelmann spruce (Picea engelmannii) that were grown in moist soil began to suffer injuries at temperatures as low as 45°C when exposed for six hours. Heat injury may become serious for most coniferous species when surface

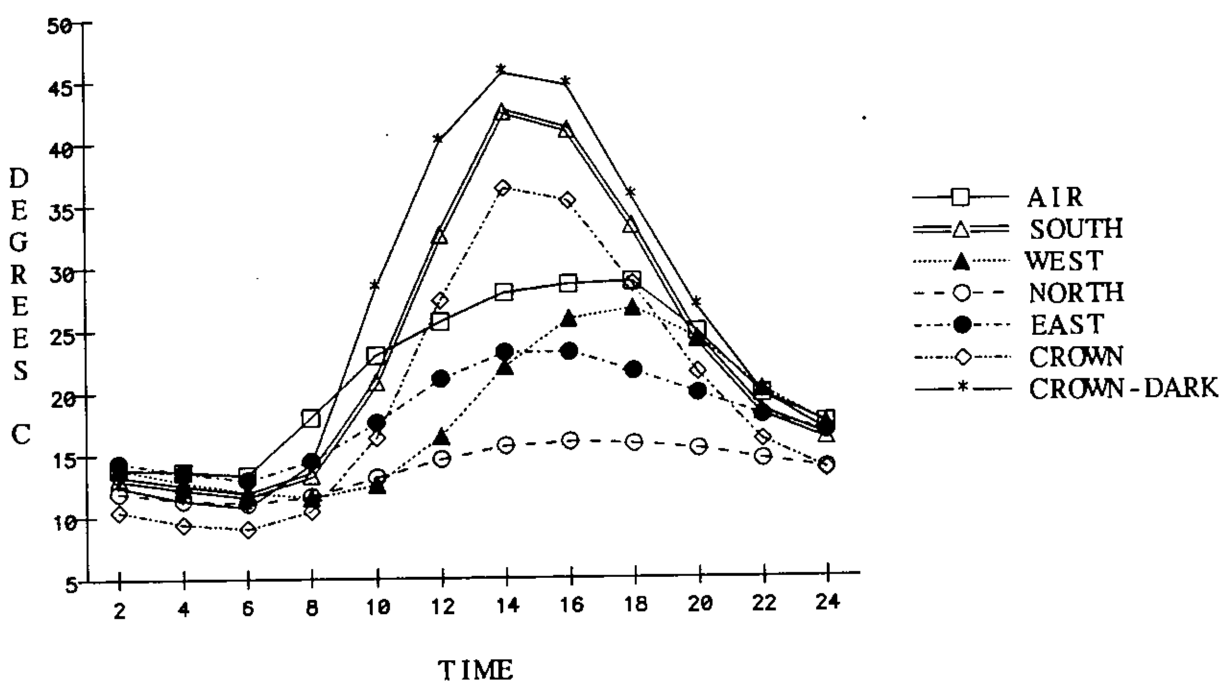

Figure 2. Mean temperature (2 hr interval) at 1 cm depth on different aspects at No. 8 Mine for July 9, 1985.

temperatures in the 50 to 60°C range are reached for periods of a few minutes up to several hours. However, the severity of the injuries in this temperature range is not only dependent on high temperature but also upon limited moisture supply (Day 1963).

The soil temperature data were scrutinized to assess the occurrence of relatively high surface temperatures with surface values being represented by the 1 cm depth and the length of time that these temperatures persisted. For example, mean temperatures in excess of 40°C were reached on three successive days (July 30 to August 1, 1985 inclusive) and these temperatures were sustained for at least six hours on each of the days. During this time temperatures reached maximum values of 52°C with mean values of 46°C being sustained for two to four hours. It is important to note that these high temperatures occurred on the south-facing slope and on the crown position with a less dense vegetation cover and darker soil material than that which occurred on other aspects. These relationships were illustrated in Figure 2.

These data indicate that high surface temperatures are most likely to impact vegetation establishment, growth and survival on the south-facing slopes and at positions where the surface soil is relatively dark.

Additional data were collected to get an indication of the relationship between temperatures that occur at the soil surface and at the 2 and 5 cm depths under a grass/legume cover and under a grass/legume cover with alder.

The temperatures that occurred under cover including a grass/legume and alder cover were considerably lower than those under a grass/legume cover. This is one of the major reasons why tree seedlings more readily become established and thrive in areas with an existing grass/legume and shrub cover.

Precipitation

Precipitation for the May 1 to September 30 period or the approximate growing season was monitored throughout the program and the results presented in Figure 3.

The precipitation total for a growing season is important, however, distribution of rainfall throughout the season is critical for effective plant establishment and growth. Tipping bucket rain gauges were installed to assess the distribution and intensity of rainfall events at different locations.

The data presented in Table 3 provide a rainfall summary for three sites at each of the No. 8 and No. 9 Mines in 1987. The data indicate that the total values for the period were relatively uniform however, large differences did occur over short distances for individual days or rainfall events. For example, for the July 6 to July 8 interval the sites at No. 8 Mine which are about 400 m apart had totals ranging from 8.0 to 17.0 mm. Similar variability was noted for the sites at No. 9 Mine.

Depending upon specific location, 58 to 36% of the total rainfall in 1987 occurred between July 8 and August 18 with the bulk of this occurring in August. It is important to note that only 50 to 60 mm occurred

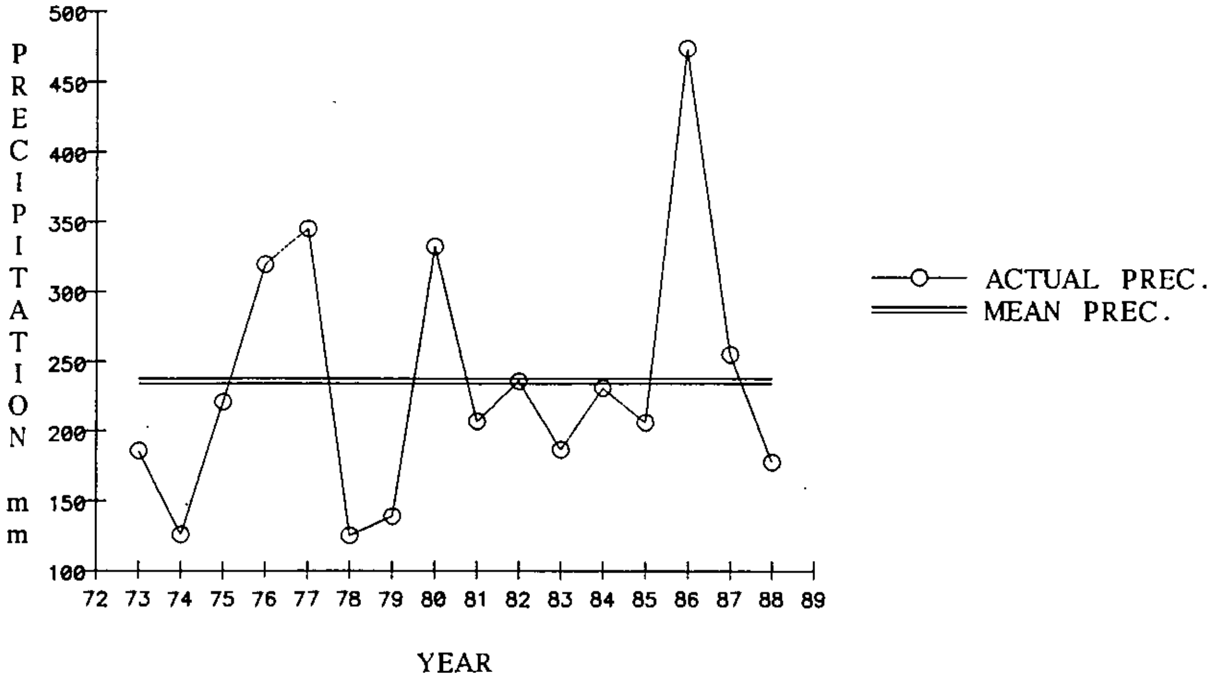

Figure 3. Precipitation for growing season at No. 8 Mine for 1973 to 1988.

Table 3. Precipitation data (mm) summary for 1987.

	Location					
	No. 8 Mine			No. 9 Mine		
Date	I	II	III	A	B	C
April 30 to June 1	30.6	20.2	22.1	18.3	19.1	20.2
June 1 to July 6	28.7	35.8	38.0	31.7	32.0	41.6
July 6 to July 8	12.6	17.0	8.0	9.8	8.0	3.0
July 8 to July 18	155.0	143.2	140.6	149.3	151.0	145.3
August 18 to September 21	27.6	34.3	30.0	25.8	19.0	24.0
September 21 to October 7	14.0	14.7	15.4	14.2	11.0	17.7
Total	268.5	265.2	254.1	249.1	240.1	251.8

between April 30 and July 6 which suggests that a severe moisture deficit occurred during that time. This deficit was evident in the relatively poor growth of vegetation and lack of germination of newly seeded areas in the spring of 1987. This phenomenon of relatively low rainfall values in the spring and fall has occurred for several years in which records have been maintained.

Very often the distribution of the rainfall has been somewhat less than effective for good plant establishment and growth, and the intensity of precipitation was such that a major portion of the water was lost through runoff. Table 4 provides an indication of the distribution and intensity of rainfall that occurred in the months of June, July and August in 1988.

The data indicate that intensity of rainfall was quite variable. For example, in June, 4 mm of rain was recorded in 24-, 42- and 48-minute periods and on one day in 21 hours and 51 minutes. Infiltration and runoff would vary with each of these events.

Wind Direction and Speed

Wind is a common phenomenon in the area. During the initial establishment phase of the study it seemed that the wind blew constantly and on many days disrupted normal field activities. Observations during the course of the study provided some evidence of the effect of wind on revegetation success. Strong winds during the winter months tended to blow snow cover off the mined and revegetated areas and wind chill levels had a devastating effect on newly planted or established tree seedlings.

Table 4. Rainfall data for June to August, 1988 at No. 8 Mine.

Date	Rainfall (mm)	Time Elapsed	Date	Rainfall (mm)	Time Elapsed
June 4	1	-	July 2	6	25 min
June 5	5	14 hr 29 min	July 4	5	20 hr
June 6	18	16 hr 48 min	July 5	2	14 hr 29 min
June 7	4	21 hr 51 min	July 6	2	28 min
June 8	2	26 min	July 11	14	4 hr 57 min
June 10	4	48 min	July 29	1	-
June 11	8	6 hr 53 min	July 31	5	6 hr 11 min
June 13	4	42 min			
June 20	1	-			
June 23	1	-	Total	25	
June 26	4	24 min			
June 27	1	-	August 1	11	19 hr
June 28	14	4 hr 31 min	August 4	3	3 hr 44 min
June 29	19	17 hr 25 min	August 15	4	6 hr 14 min
			August 16	9	17 hr 20 min
			August 18	4	8 hr 21 min
Total	88		August 20	1	-
			August 29	6	1 hr 5 min
			Total	38	

Wind is often considered to have a negative effect on vegetation growth especially in terms of its desiccating effect both on the plant itself and the soil medium.

During the month of July, 1988 the average wind velocity was 26.4 km/hr. To get an indication of the extremes that occurred maximum velocities above 70 km/hr were investigated. The data indicated that maximum velocities in excess 70 km/hr occurred on 11 days and the maximum velocity recorded was 89 km/hr. In August, 1988 a total of eight days had maximums in excess of 70 km/hr. The highest velocity measured was 128 km/hr.

Hourly wind data for the months of January and February, 1988 were assessed in detail to provide an indication of the potential impact of winds during winter months. In January there were 48 hours with wind in excess of 70 km/hr and 9 hours when wind velocities exceeded 90 km/hr. In February there were 98 hours with wind exceeding 70 km/hr and 32 hours when wind velocities exceeded 90 km/hr.

Daily wind velocity means were calculated from hourly data for six consecutive days in February, 1988 and are presented in Table 5.

In the No. 8 and No. 9 Mines a major portion of the reconstructed area is characterized by south and west-facing slopes. Knowledge of the direction of the prevailing winds is a useful parameter in selecting vegetation species and designing material replacement options. Table 6 provides an indication of wind direction for July, August and September, 1988.

Westerly winds were dominant during the period described in Table 6.

Table 5. Mean daily wind velocities and air temperature values for February 16 to 21, 1988

	Wind Velocity (km/hr)			
Date	Average	Minimum	Maximum	Temperature (°C)
February 16	51.5	32.4	78.2	-3.2
February 17	53.9	38.7	78.4	-0.5
February 18	50.8	32.5	71.5	1.6
February 19	52.2	32.5	73.0	-2.7
February 20	60.4	41.0	89.9	-2.4
February 21	68.1	49.2	77.5	-4.3

Table 6. Wind direction measured at No. 9 Mine in 1988.

	Hours of Wind			
Month	North	South	East	West
July	12	221	131	372
August	0	205	195	312
September	0	178	174	316

Conclusions

The results of the research program indicate that climate impacts revegetation success to a major extent. Extremely high soil temperatures do occur which affect the establishment of vegetation. Precipitation is variable over short distances and distribution during the growing season has resulted in moisture deficits during critical times. Relatively strong winds which prevail during the growing season and winter months affect the establishment, survival and growth of vegetation in the area.

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