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The Crested Butte Experiment: An Air Quality Analysis Scheme to Identify Particulate Impacts Associated with a Woodstove Replacement Program

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INTRODUCTION

Particulate air pollution problems have long been noted in Crested Butte, Colorado. Historical monitoring revealed frequent violations of Federal total suspended particulate air quality standards. Local sources of particulates were generally reorganized as woodburning and street emissions from sanding and unpaved roads. In 1988 a local regulation was passed requiring the replacement of all woodburning devices with new high technology, low emission wood stoves. An air quality study was designed to determine the changes in air quality due to this enmasse stove replacement program. This document describes the air quality study and the results of the woodstove replacement program on air quality.

HISTORY

The Colorado Department of Health's Air Pollution Control Division has been monitoring particulate concentrations in Crested Butte since 1974. Total suspended particulate (TSP) were measured until 1985 when a new fine particulate sampler was installed. This new sampler provided data for an anticipated change to the National Ambient Air Quality Standard total suspended particulates. The new standard would require the adoption of air pollution control programs in areas like Crested Butte that had been previously exempted from complying with particulate standards.

In 1987 the environmental Protection Agency adopted a new air quality standard for 10 micron and smaller particles (PM10). All areas of the country were evaluated to determine their probability of violating these new standards. Based on historical TSP information and new PM10 data, it was determined that Crested Butte had a moderately high probability of violating the new particulate standards.

Due to historical demonstrations of high particulate levels in Crested Butte [2,3] and the high expectation of not meeting the new standards, local concern for dealing with their air quality problems focused on control options. The two most obvious sources of particles pollution in Crested Butte were wood/coal burning and street sand/road emissions. Due to the obvious impacts wood burning had on visual, as well as small particulate air quality, local wood burning control plans were adopted. Regulations were passed requiring wood stove users to convert stoves to new high tech, low emission stoves by the winter of 1989.

The Air Pollution Control Division, in conjunction with the Town of Crested Butte, the Environmental Protection Agency and the Wood Heating Alliance, took advantage of the control program to perform a community wide Air quality experiment. This experiment was designed to demonstrate the potential Air Quality benefit of a mass upgrading of wood burning apparatus to state-of-the-art equipment. This paper contains the details of the air quality study which was designed to determine if the stove replacement project was successful in reducing particulate concentrations in Crested Butte. One phase of this study, the "In Home Testing" project is fully documented in another report.' The results of that phase of the project are summarized within this report and were used to build emissions inventories for modelling studies. One other portion of this study, the 1988/89 meteorological monitoring, was performed by an independent consultant who documented their results in another report.5

STUDY DESIGN

The primary concern was to determine if air quality was changed as the result of a mass replacement of wood burning devices in a community dominated by wood smoke emissions. Crested Butte offered a unique community to perform such an experiment based on the following criteria.

* Documented problems with particulate pollution.
* Isolated community considering pollution sources.
* Simple source mix dominated by wood smoke emissions.

* Community Desire to resolve air quality problems.
* Mechanism in place to stimulate the enmasse replacement of older woodburning devices,.

Because Crested Butte met all these criteria, it was judged to be an ideal location for this demonstration project. The key concept in the project involved the following stages.

1. Determine stove emission rates on a representative sample of existing stoves.
2. Determine appropriate measures of air quality and meteorology during base-line year.
3. Replace as many stoves as possible during the nonburning season.
4. Re-monitor air quality and stove emissions after the replacement program.
5. Compare the two seasons air quality with appropriate analytical techniques to determine if air quality was improved due to the replacement program.

Due to the complexities involved in comparing two air quality data sets, it was determined that an appropriate analysis would consist of four parallel analytical schemes. These schemes could each be completed relatively independently to ensure that failures in any of the separate schemes would not jeopardize the opportunity to analyze the difference between the before and after stove replacement air quality.

The four analytical schemes were:

I. Emissions Testing of typical in-use stoves prior to and after replacement of devices.

II Mathematical Modeling of the impacts of emissions impacts comparing the two seasons.

III. Ambient Monitoring including appropriate meteorological measurements to support modeling and air quality comparisons.

IV. Visibility Monitoring to include real time measurements and photographic representation of daily visual air quality.

Overview of Study Elements

The details of each of these phases of the project are described in subsequent chapters. However, a brief overview is included here to develop a better understanding of the project design.

Emission Testing: A sample of forty six stove tests provided baseline emissions data characteristic of typical stoves being used in Crested Butte. Two stove testing procedures were used and emissions of the "fleet" of stoves were characterized. Wood use and other operating parameters were also recorded. During the second, post-replacement phase, 141 stove tests were performed. During the two seasons over 18,000 hours of stove operations were monitored to arrive at representative emission factors. A strict comparison of before and after emission characteristics was performed to compare the emission characteristics of the new high-tech stoves against already in use stoves. Emissions data was also used to support mathematical modeling of pre and post replacement impacts.

Mathematical Modeling - A two phased modeling approach was used to determine the impact of the stove replacement program. For both models, a detailed emissions inventory was created using stove emissions data, wood use, and a detailed count of the location and types of stoves in Crested Butte. Included in the inventory are also emissions from street sand or unpaved roads, tailpipe emissions from automobiles and other sources determined to be present in the community.

The first modeling approach is a simple rollback method. Emission inventories for both the pre-conversion and postconversion years were developed to represent typical conditions during the worst case period of air quality. A ratio of the measured air quality to the inventories total emissions was developed and compared to the actual air quality in the second year. In this approach care is taken to compare days of similar meteorological conditions. Of special interest are the high concentration, stagnation days, represented by a dominance of low wind speeds and a stable atmosphere.

The second modeling approach is a dispersion analysis. This more complex analysis utilizes the same emissions inventory but also develops a prediction of air quality based on the actual meteorology of selected days. Predicted air quality for these selected days is compared to actual measured air quality. A "calibration" of the inventory or model assumptions is made until acceptable predictions are acquired from the model. During the post conversion year, the model is again run for actual meteorological conditions using both the pre and post conversion inventories. A comparison is then made to determine how much change has occurred in the predicted air quality assuming that the stove replacement program had not occurred.

A verification of the model inventory was performed during both seasons using a separate technique *known* as Chemical Mass Balance Modeling (CMB). The CMB analysis is presented as a separate element of this study as it is a combination of modeling and atmospheric sampling methods. The CMB technique mathematically relates detailed chemical species data to sources. The chemical speciation is acquired from a detailed analysis of ambient particulate samples on selected days where air quality levels were elevated. Source profiles of representative pollution sources are then "matched" in the modeling process to determine the relative contribution each source makes to the overall pollution problem. In this study CMB analysis was used as a quality assurance check to ensure that all major sources were accounted for and that source mixtures did not vary between the pre and post stove replacement test.

Ambient Monitoring - A variety of particulate measurements was made during both wood burning seasons. Sampling for ten micron and smaller particles was performed using the EPA reference method samplers. A size fractionating sampler collected , particles of 2.5 microns and smaller (generally woodsmoke and tailpipe emissions) and 2.5-10 microns (generally fugitive emissions from unpaved roads and street sand) was also used. These samplers were located on the roof of the convenience store at Highway 135 and Whiterock Ave. The project design was established to collect at least thirty pairs of samples from the dichotomous particulate and PM10 sampler each of the two winter pollution seasons. A thirty meter meteorological tower collected wind and temperature information. Additional met data was acquired from a local NWS station.

Selected PM10 particulate filters were analyzed for their organic and elemental carbon content. Paired dichot filters were analyzed for trace element concentrations to support receptor modeling. Samples of road and sampling material were also collected for source characterization work.

Visibility Monitoring

Visibility measurements were made continuously using a nephelometer. Photographic records were made by both time lapse and 35 mm automated cameral systems. Thirty five millimeter slides were taken three times a day.

Hourly nephelometer data provided a direct measurement of the atmospheric loading due to fine particles. Past experience in mountain community studies indicates this measurement has a high correlation to wood burning patterns. Photographic information was used to relate visual air quality to particulate and nephelometer readings. The time lapse pictures also provide a visual impression of the impacts wood burning had on visual air quality during daylight.

RESULTS

While a comprehensive treatment of the results of this study is beyond the scope of this paper, it is worthwhile to present some comparisons of the two seasons air quality. Figure 1 depicts the average PM10 concentrations recorded on a monthly basis from the pre and post stove replacement programs. On the average, a forty percent reduction in PM10 was observed after the stove replacement program was completed. Figure 2 depicts the visual air quality as measured by light scattering and shows a fifty nine percent improvement in the second season. Meteorological evaluation of the two seasons indicates that there were slightly warmer conditions in the second season with an eight percent increase in average temperatures.6

Looking at the source nature of the particulates, Tables I and II present the chemical mass balance model results from the two seasons. The average results show the predominance of woodstove emissions, confirming that no unaccounted sources appeared to significantly impact overall air quality. Figure III presents the emissions inventory developed for the dispersion modeling. This inventory is based on the identified sources in area and stove emissions from the in house testing program.

CONCLUSIONS

A detailed analysis and comparison of seasons is beyond the scope of this paper. However, it is clear that the second season had significantly cleaner air and that meteorological differences were not significant enough to cause the improvements. Lowered stove emissions in the second year are attributed to cleaner woodstoves and an reduction in the number of woodburners.

A detailed follow up study needs to be performed after the current stove population has had a few years to age. The air quality measurements should be supplemented with radio carbon dating of the particulates to confirm the wood smoke contribution to the particulate levels. Finally, atmospheric soundings and better automated photography would enhance the evaluation of air quality as it relates to visibility impacts.

REFERENCES

1. P. Donahue, N. Chick, S. Burns, Annual Quality Assurance Report 1989, Colorado Department of Health, Air Pollution Division, Aug. 1990, pp. 11.

2. Colorado Air Quality Data Report 1989, Colorado Department of Health, Air Pollution Control Division, Sept. 1990, pp. 63.

3. Colorado Air Quality Data Report 1986, Colorado Department of Health, Air Pollution Control Division, July 1987, pp. 68.

4. D. Jasma, Field Performance of Woodburnina and Coalburning Appliances in Crested Butte. Colorado, Virginia, Polytechinic Inst., Dept. of Engineering, Feb. 1991.

5. Crested Butte Winter Study November 1988 - March 1989, Meteorological Data Report, RTP Environmental Associates, Inc., Boulder, Colorado, August, 1989.

6. G. Kenniston, Crested Butte Woodstove Replacement Study, Ambient Monitoring Report, Colorado Department of Health, Air Pollution Control Division, October, 1990, pp 10.

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MONTHLY AVERAGE PM.10 CONCENTRATIONS

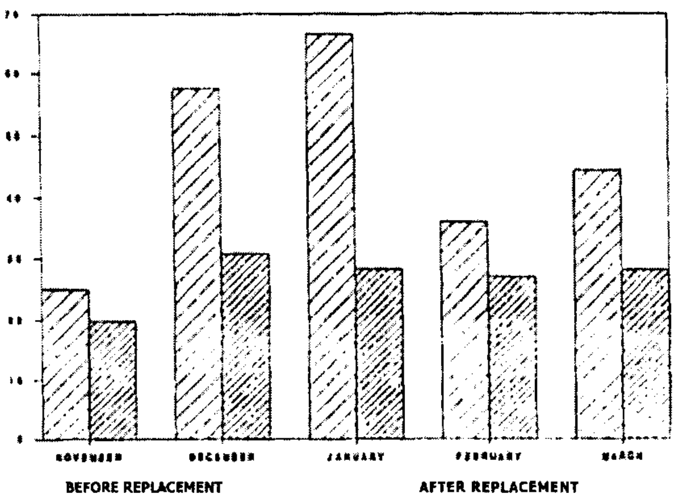

Figure 1
Monthly average PM10 concentrations.

MONTHLY AVERAGE LIGHT SCATTERING

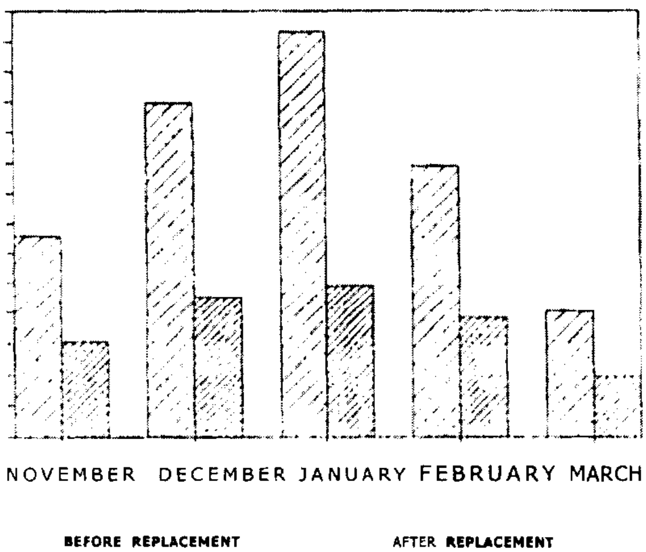

Figure 2 Monthly average light scattering values.

Figure 3 from page 10 of original would not scan

Table I Summary of Crested Butte Chemical Mass Balance Model Source Contribution Estimates.
percent contribution +_ (uncertainty)

DATE & PM10 CONC.	GEOLOGICAL	WOOD	NITRATE	SULFATE	MOBILE	UNKNOWN
12-05-88	18.6	59.2	0.8		12.2	9.2
82 gg/m^3	(2.2)	(7.5)	(0.1)		(5.4)	
12-09-88	22.7	46.5	0.4		12.8	17.6
80 Ag/m^3	(2.7)	(6.4)	(0.1)		(4.7)	
12-17-88	21.3	46.1	0.3		12.7	19.6
75 pg/m^3	(2.5)	(6.4)	(0.1)		(4.6)	
12-29-88	3.1	66.2	0.5		10.9	19.3
110 Ag/m^3	(0.7)	(7.4)	(0.1)		(5.0)	
12-29-88	2.3	60.3	2.8	3.8	14.6	16.2
115 Ug/m^3	(0.5)	(7.2)	(0.4)	(0.4)	(5.5)	
12-31-88	2.7	86.1	0.8		1.3	9.1
112 pg/m^3	(0.5)	(7.6)	(0.1)		(0.4)	
01-02-89	4.5	61.7	0.4		12.9	20.5
89 jug/m^3	(0.9)	(7.3)	(0.1)		(5.3)	
01-04-89	3.8	71.5	2.7	2.3	13.9	5.8
64 ag/m^3	(0.7)	(9.0)	(0.4)	(0.4)	(5.9)	
01-14-89	10.5	59.0	0.5		14.7	15.3
112 gg/m^3	(1.2)	(7.2)	(0.1)		(5.7)	
01-16-89	11.8	71.5	2.6	3.3	1.6	9.3
9 0 Ag/m^3	(1.4)	(13.3)	(0.4)	(0.4)	(0.5)	
01-18-89	7.3	71.1	0.3		1.7	19.6
91 gg/m^3	(1.2)	(6.6)	(0.1)		(0.6)	
01-22-89	11.4	74.1	0.3		0.9	13.3
88 $_j$Ug/m^3	(1.6)	(6.8)	(0.1)		(0.4)	
01-22-89	5.9	77.2	2.8	1.9	9.9	2.3
8 3 Mg/m^3	(1.2)	(17.3)	(0.4)	(0.3)	(6.2)	
01-30-89	17.9	70.6	0.2		1.8	9.5
79 Ag/m^3	(2.4)	(13.2)	(0.1)		(0.6)	
Average	0.3	65.8	1.1	2.8	8.7	

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Table II Summary of Crested Butte Chemical Mass Balance Model Source Contribution Estimates.
percent contribution ± (uncertainty)

DATE & PM10 CONC.	GEOLOGICAL	WOOD	NITRATE	SULFATE	MOBILE	UNKNOWN
12-21-89 40 gg/m^3	28.4 (2.9)	66.8 (5.9)	1.9 (0.2)	2.8 (0.4)	2.3 (0.5)	1.9
12-24-89 33 Ug/m^3	20.7 (3.0)	75.0 (6.6)	3.0 (0.4)	2.5 (0.5)	2.9 (0.8)	4.7
12-27-89 62 gg/m^3	37.5 (3.2)	57.0 (5.0)	2.0 (0.3)	1.5 (0.4)	3.0 (0.7)	1.1
01-02-90 43 Ag/m^3	17.7 (1.2)	65.6 (5.6)	3.3 (0.4)	3.1 (0.5)	3.9 (0.7)	6.2
01-05-90 35 Mg/m^3	11.1 (1.5)	68.3 (6.4)	2.2 (0.3)	3.7 (0.6)	7.5 (1.3)	6.7
01-11-90 47 pg/m^3	14.7 (1.2)	62.9 (6.1)	0.3 (0.1)		0.9 (0.2)	21.1
02-24-90 44	60.1 (4.7)	46.2 (6.0)	1.1 (0.1)	2.0 (0.3)	2.1 (0.6)	12.2
03-16-90 41 Mg/m^3	62.8 (4.8)	28.9 (3.2)	0.4 (0.1)	4.3 (0.6)		3.5
03-20-90 48 Ag/m^3	67.0 (2.5)	28.4 (2.9)	0.6 (0.1)	2.4 (0.3)		1.5
* Average	21.7	65.9	3.4	2.1	2.7	

- This is the average of the apportionments made on the six filters collected In December, 1989 and January, 1990

NOTE TO EDITORS