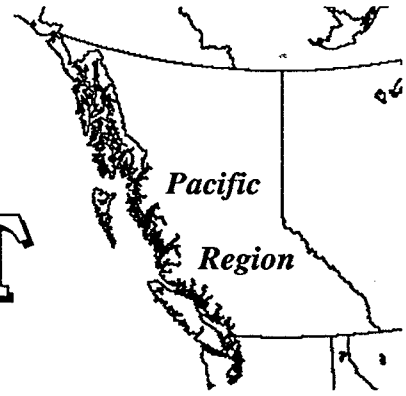
BVAEP Vancouver. Env. Can. Lib./Bib.
36 007 589

REF
PAES
91-1

SCIENTIFIC SERVICES DIVISION

REPORT



AIR QUALITY FORECAST SERVICE OPTIONS FOR AES IN BRITISH COLUMBIA

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September 9, 1991
Report PAES-91-1

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SECTION 1

EXECUTIVE SUMMARY

Canadians are concerned about contaminants in the air they breathe and are increasingly demanding information on the issue. The Atmospheric Environment Service (AES) now provides expertise to deal with some air quality issues, but its central role continues to be weather forecasting. Since air pollutant concentrations are closely linked to the weather, AES could provide an improved and visible service to Canadians by playing a leading role in forecasting the quality of the air.

This report explores how AES could help provide this service by both forecasting the ability of the atmosphere to disperse air pollutants as well as forecasting the *concentration* of those pollutants. The following topics are dealt with:

- existing air quality forecasting methods
- air quality forecasting programs in Canada and the United States
- an experimental carbon monoxide forecast in Vancouver
- types of air quality forecast services in which AES Pacific Region could become involved
- forecast service requirements.

The goals of an air quality forecasting service in British Columbia would be:

1. To forewarn the community of expected air pollution episodes, enabling those whose health may be adversely impacted to take appropriate action.

2. To provide regulators of emissions with information on expected air quality conditions.

3. To provide both the community and industry with an estimate of the duration of an existing air pollution episode for emission planning purposes.

4. To heighten community and industry awareness of air quality issues.

Considerable work has already been done in developing techniques to forecast air quality and atmospheric stagnation. These have generally involved automated approaches, with some techniques showing improvement with manual intervention. A number of jurisdictions have implemented air quality services and most include some aspect of forecasting air quality. These services all employ automated techniques as tools but are primarily dependent on people to coordinate and provide the service.

To test the feasibility of forecasting pollutant concentrations, AES Pacific Region conducted an experimental carbon monoxide (CO) concentration forecast program for three

sites in the winter of 1990-91. This experiment showed that it is possible to provide a useful service and that poor forecasts of CO concentrations were generally the result of poor weather forecasts.

Taking into account the unique characteristics of topography and population centre locations in British Columbia, the types of air quality forecast services in which AES could become involved can be summarized as:

- ***A regional stagnation forecast.*** This air quality service would estimate the large-scale capability of the atmosphere to disperse pollutants. It would rely heavily upon automated methods to calculate synoptic scale stagnation potential.

- ***A local dispersion forecast.*** This is a forecast of the capability of the atmosphere to disperse pollutants produced locally. It could apply to the dispersion of any locally-produced pollutant, including those from residential wood burning, local industrial sources or motor vehicles.

- ***A forecast of the long-range transport of air pollutants.*** This is a forecast of the probability that air quality in a town or city will be affected by an emitting source (generally industrial) situated well outside of the town. Though the mechanism for providing this service differs significantly from that necessary to provide a local dispersion forecast, the forecast products would be similar.

- ***An improved Ventilation Index.*** This is for the specific use of the B.C. forest sector. The forest sector currently uses the Ventilation Index to assess the impact of smoke from the prescribed burning of forest debris. However, improvements are needed to better reflect the ability of the atmosphere to disperse smoke from prescribed burning.

- ***A Lower Fraser Valley air quality forecast.*** This is a forecast of pollutant concentrations at specific locations throughout Greater Vancouver and the Lower Fraser Valley, and would be possible because of the high density air quality monitoring system already in place in the region. This forecast could be used to calculate an Air Quality Index for day 1 and 2.

The AES operational requirements of providing these types of services range from 0.1 person-years for providing an improved ventilation index service for the forestry sector to 0.5 person-years for a local dispersion forecast service for four municipalities.

SECTION 2

REVIEW OF AIR QUALITY FORECASTING METHODS

INTRODUCTION

This section reviews some air quality forecasting methods outlined in a number of papers dealing with real-time forecasting of atmospheric dispersion or air quality. Information in this section can be used as a starting point to develop tools to forecast air quality in British Columbia.

NATIONAL WEATHER SERVICE STAGNATION FORECASTS

Bailey [1] discusses stagnation forecasting in the National Weather Service during the 1970s. The term "stagnation forecast" is used to avoid possible misunderstanding that these meteorological forecasts imply high levels of air pollution. The NWS used (in 1977) a simple box model as the basic atmospheric dispersion model. In this model a given volume of air is assumed to be available into which pollutants can be dispersed and diluted. Box dimensions are mixing height (from the morning radiosonde observation), wind speed through the mixed layer (from both the morning radiosonde and computer-forecast boundary layer winds) and cross-wind diameter of the area (usually ignored, but probably important in B.C. valleys).

This simple model is subjectively modified in the 18-24 hour forecast period by the air pollution meteorologist to take into account the effects of:

- Weather (onset or change in precipitation)
- Changing winds
- Frontal passages and air mass changes
- Diurnal winds, heat island effects, and terrain.

Beyond the 18-24 period, only synoptic scale systems are used to estimate how the dimensions of the model box might change. Synoptic features that would diminish the box dimensions and thus favour stagnation are:

- Warm core highs and ridges, slow moving systems with weak surface gradients.
- Vorticity minima, negative vorticity advection, and other features producing areas of subsidence or large-scale stability.

- Frontal trapping (supposedly the stable region ahead of an active frontal system).
- Large-scale cold air trapping (supposedly cold air pooling in valleys, or simply very stable and motionless arctic air masses).
- Stability indices favouring stable airmasses.
- Light surface winds.
- Warm air advection aloft.
- Nocturnal clear conditions, cloudy daytime conditions.

The forecasts were a man-machine mix, with the NWS computer generating simple 24, 36 and 48 hour stagnation forecasts which were subsequently modified by an air pollution meteorologist.

Numerically, the following NWS criteria were used to identify stagnation episodes[2]:

- The morning mixing depth must be $\leq$ 500 metres and the observed mixing layer wind speed must be $\leq$ 4 m/s.
- The product of the forecast afternoon mixing depth and the forecast afternoon mixing depth must be $\leq$ 6000 m^2/s and the forecast average wind speed must be $\leq$ 4 m/s.
- The thirty hour forecast of tomorrow afternoon's mixing depth and average wind speed must meet the same criteria as above.
- The observed and forecast (12, 24 and 36 hour) 500 millibar relative vorticity must be $\leq 0.25 \times 10^{-4}$ sec^{-1}.
- The observed and forecast vorticity changes should not exceed 0.3×10^{-4} sec^{-1}.
- The affected area must be no smaller than an area equivalent to a 4° latitude square (about the size of Nebraska).
- There must be no significant precipitation or frontal passages expected within the next 36 hours. (POPS must be less that 40%).
- Forecast winds at a site must not exceed 5 knots and/or no more than three individual hourly speeds must not be forecast to exceed 8 knots within a 24 hour period.

A subjective analysis of each computed stagnation area was then made by the national air pollution meteorologist at the National Meteorological Center (NMC).

CANADIAN METEOROLOGICAL CENTRE STAGNATION FORECAST

In the early 1970s the Canadian Meteorological Centre[3] (CMC) modified an NMC stagnation area analysis and forecast model by Gross[4] for Canadian use to take into account a number of different synoptic situations; the warm anticyclone, the arctic inversion, sea/lake breeze inversions, the "St. Lawrence River Valley Effect" (only applied to two grid points in winter when residual cold air remained in the valley with warm overrunning), and the Alberta chinook effect (chinook warming over arctic air east of the Rockies).

The CMC version was less detailed than the NMC model in that two of the most important small scale parameters - mixing heights and mixing winds - were ignored. Only those forecast data types of the NMC model that could be obtained directly from the CMC main weather forecast model (3 level baroclinic at the time) were used in forecasting stagnation. Specifically, except for precipitation amounts, only 500 and 850 millibar vorticity, temperature and winds criteria were used. A revised stagnation forecast program today could make use of more types of data and increased precision now available from the CMC forecast models.

Appendix 2 contains an example of the western Canadian output of the CMC model.

FORECASTING POLLUTION EPISODES

Tarde and Scheinpflug[5] described the synoptic scale meteorology associated with high carbon monoxide (CO) concentrations in Colorado Springs. They note that this is an example of an urban area that does not follow the "textbook" case of a strong, stable upper and surface ridge producing stagnant boundary layer conditions conducive to high CO levels. Though CO still exceeds the National Ambient Air Quality Standards (27 days since 1982), there have been no exceedances due to strong surface anticyclones recorded in Colorado Springs. Rather, CO standards are exceeded when a short wave ridge running ahead of a short wave trough pushes across the Rocky Mountains. A frontal wave is usually associated with the short wave trough. This situation results in:

- a stable layer of air near the ground due to descending air ahead of and in the ridge accentuated by warm overrunning ahead of the frontal wave.

- overrunning cloud pushing up to the short-wave ridge. This limits surface heating and maintains the stable layer of air near the ground. (High albedo snow cover does the same thing).

Most high-pollution events occur in Colorado Springs in this synoptic situation during December and January when the sun's declination and hence the amount of mixing due to insolation is low.

Mesoscale effects play a large part in producing high CO levels in Colorado Springs.

These mesoscale effects (largely produced by topography and/or urban heating) are always partially controlled by synoptic scale systems. Overnight drainage winds occur in the north-south oriented valley where the city is located. The highest recorded CO levels occur with a weak pressure gradient, light overnight drainage winds, and what is thought to be an urban heat island effect over the city resulting in atmospheric convergence in the downtown core. On high albedo or cloudy days this effect sometimes occurs in the daytime, and, combined with high emission rates at these times, high CO levels have been observed. The mixing height (defined as the top of the drainage flow) during a non-high pollution event is usually between 200 and 500 metres. During periods of high CO values the mixing height varies from 20 to 100 metres.

The implication drawn from this paper is that the accumulation of carbon monoxide (and presumably other pollutants) is unique to each site, and broad-brush "textbook" approaches will have problems giving useful results.

AN AIR QUALITY FORECAST MODEL

Edson and Johnson[6] described a short term composite air quality forecast system for a single emission source based on three models; an empirical statistical model, a Gaussian dispersion model and a persistence model.

The empirical statistical model is made of a short term and a long term submodel. The meteorological parameters used in each submodel are:

1. Short Term Submodel:

   a) Surface and plume level winds
   b) 850 mb wind
   c) lapse rate up to 100 metres
   d) surface inversion thickness (from 1200 Universal Coordinated Time [UTC] sounding)
   e) instantaneous surface heating rate
   f) inversion surface breakthrough temperature

2. Long Term Submodel:

   a) 700mb and 850 mb winds (presumably the 12 UTC winds)
   b) surface inversion at 12 UTC (presumably the height, thickness and intensity)
   c) MSL pressure from 4 NWS stations (for computing geostrophic wind)
   d) T_{850mb}-T_{700mb} (presumably the observed 12 UTC difference)
   e) 700mb-500mb thickness change (presumably the forecast change)

The data from today is compared to data from the previous 45 days (60 days for the long term model) to arrive at the closest historical matches. Average and maximum SO_2

concentrations from these meteorologically similar days are then printed for the short term submodel. For the long term submodel the actual dates that match are printed, allowing the meteorologist to select the best historical case along with its associated SO_2 concentrations.

The Gaussian model uses a modified form of the Gaussian dispersion equation to quantify SO_2 concentrations along the centreline of a plume. Historical data are also incorporated into this model so that it is partially empirical.

A persistence-type forecast (called an extrapolation model) uses SO_2 concentrations from the previous few hours as a forecast concentration for the next hour.

The final composite forecast SO_2 concentration is a weighted average of the three forecast methods discussed above. The weighting amounts can be subjectively changed according to operational requirements or to refine the forecast as the meteorologist gains additional experience with the system.

OZONE CONCENTRATION FORECASTING

Clark and Karl[7] used regression techniques in an attempt to link meteorological and air quality variables to maximum one-hour ozone concentrations at 27 rural and urban areas in the northeast U.S. clustered mainly along and near the coast of New England, with a few located further west. Independent meteorological variables assessed included the heights, temperatures, relative humidities and winds from the 700 and 850 mb levels, sea level pressure, and boundary layer wind (all available from the Limited Fine Mesh [LFM] model) and trajectory information. Current and historically averaged ozone data were also used as independent variables. The variables deemed most important as predictors for maximum 1 hour ozone concentrations in each of the 27 regression equations (with the number of times each predictor was selected in brackets) were:

1. Maximum surface temperature	(19)	(higher temperature implies higher ozone)
2. Sea level pressure	(9)	(higher pressure implies lower ozone[a])
3. Length of backward trajectory to source	(9)	(longer trajectory implies lower ozone)
4. Boundary layer u wind component	(7)	(westerly winds implies higher ozone)
5. Average daily maximum ozone	(7)	
6. Boundary layer relative humidity	(7)	

Maximum surface temperature and sea level pressure rarely appear together in any one of these regression equations. Ozone concentrations were higher with westerly wind components

[a] This is a somewhat surprising result since high sea level pressure generally implies a surface ridge exists. This in turn suggests sunny, warm and stagnant conditions, all favourable for ozone production.

in some stations (eg. when air masses came from the Midwest) as compared to northerly winds (air mass from eastern Canada). No stability indicators were used directly as independent variables.

Using the regression equations for predicting ozone concentrations at the 27 sites using an independent data set gave only "mediocre" results. The most important information applicable to forecasting air quality in British Columbia is perhaps that maximum surface temperature is one of the most important parameters in forecasting ozone concentrations.

Prior *et al*[8] also used regression techniques to forecast ozone concentrations in St. Louis, but examined only five variables:

1. 6-9 AM wind speed
2. Forecast maximum daily temperature
3. 6-9 AM average ozone level
4. 6-9 AM average NO_X level
5. 9 AM solar radiation intensity.

The best single variable was the morning ozone level, followed by the forecast maximum temperature. The best set of three variables was morning ozone level, forecast maximum temperature and morning wind speed. The morning NO_X level and solar radiation intensity did not usefully improve the regression equation.

A regression equation involving both linear and squared functions of the best three variables was then used and found to improve the predictive capability. This model was found to be useful for "average" ozone levels but the authors admit to a basic failure of the model to predict high ozone levels, when the need is most critical. Statistical methods are, of course, unable to predict extremes with any degree of skill. This paper subsequently discussed long-range transport and chemical transformations from regions of high emissions into the St. Louis area, an issue that is less relevant in British Columbia. Another variable that was noted to be of significance in extreme high level ozone episodes was the number of days duration of a stagnating high pressure system. The longer that the mix of precursor chemicals stayed in a stagnant boundary layer under sunny skies, the higher the ozone level rose.

Robeson and Steyn[9] used two independent variables to generate a conditional probability density function of ozone concentrations: the previous day's maximum ozone level and the day of the year. On average it was shown that today's maximum ozone level is dependent on yesterday's level and is higher in the summer months. The paper did not deal with any meteorological links to ozone concentration.

Kelly and Gunst[10] used transparent air bags filled with various concentrations of nitrogen oxides and hydrocarbons to examine the photochemistry and relationship between ozone, and other ambient chemicals in outdoor environments in and near Los Angeles. Ozone concentrations were sensitive to temperature, hydrocarbon concentrations and nitrogen oxide

concentrations. The relationship was not linear; if nitrogen oxide concentrations were artificially increased and the hydrocarbons decreased, dramatic drops in ozone production were found. This is presumably due to the scavenging effects of nitrogen oxides on ozone (this was not explicitly stated in the paper). An empirical regression equation linking maximum ozone concentrations to functions of nitrogen oxide and hydrocarbon concentrations and temperature was developed:

$$O_3(\max)=129+2.8[NO_X]-6.8\frac{[NO_X]^2}{[HC]}+19[T(ave)-21.1]$$

where $O_3(\max)$ = maximum daily ozone concentration
$[NO_X]$ = initial NO_X concentration
$[HC]$ = initial hydrocarbon concentration

An ozone forecasting program in British Columbia could make use of this and similar equations to provide initial estimates of daily maximum ozone concentrations.

DISPERSION INDICES

A number of indices have been devised to describe the dispersion capability of the boundary layer. Nikleva[11] described a Ventilation Index (VI) used originally by forestry agencies in the western United States. Its intended use was in the detection of situations conducive to the dispersion of smoke and to thus identify days when the prescribed burning of forest debris would not produce an air pollution event.

The VI is defined as:

$$VI=\frac{LU}{100}$$

where: L = Mixing height
U = Mean wind speed through the mixing layer

The mixing layer is defined as the layer of air next to the ground where active mixing takes place and is normally where the vertical lapse rate is close to dry adiabatic. A nomogram links VI values to indications of the dispersion capability of the atmosphere (poor, fair, good, excellent). No correlations were made of the VI to actual air pollutant concentration or visibility restrictions in this paper.

In Utah (in 1972) no prescribed burning was allowed when the VI was below 200, burning was restricted between a VI of 200 and 600, and burning was allowed for VI greater than 600. This index has been modified for use by the Pacific Weather Centre.

Another index was defined by Joukoff[12] in a report on the air pollution forecasting

program in Brussels. The Belgian Royal Meteorological Institute has established an Atmospheric Dispersion and Pollution Group[b] which issues a forecast of deteriorating atmospheric dispersion conditions. The goal is to provide up to 48 hours advance notice if possible. This allows for the reduction in SO_2 emissions in major industries in the country.

The three parameters most important in urban atmospheric pollution (particularly SO_2) in Brussels were determined to be:

1. surface temperature, which influences the intensity of anthropogenic emissions of pollutants or precursors (not mentioned in other reviewed papers)

2. wind speed

3. low level atmospheric stability

The Royal Meteorological Institute has designed a type of dispersion index called the Meteorological Pollution Potential Index (MPI). The revised version of this is defined as:

$$\frac{25-T}{\sqrt{V}\alpha}$$

where T = surface temperature (°C)
V = boundary layer wind speed (m/s)
α = 1000-700 millibar stability parameter

The 700-1000 mb stability parameter is defined[13] as:

$$\alpha=10\frac{H_d}{H}-9$$

where H is the 700-1000 mb thickness and the H_d is the 700-1000 mb thickness of a dry adiabatic atmosphere with the same surface conditions. The range of the MPI is from 0 (excellent dispersion potential) to infinity (no dispersion).

Shaw and Munn[14] described a simple urban model to estimate the pollution concentrations over a city. They show that the mean concentration over a city with uniform emissions over its surface is:

$$\chi=\frac{0.5QC}{LU}$$

[b] This group has recently been disbanded.

where χ = the mean concentration of the pollutant over the city (kg m^{-3})
Q = the unit area source strength of the pollutant (kgm^{-2} sec^{-1})
L = mixing height (m)
C = length of the city (m)
U = average wind speed in the mixed layer (m sec^{-1}).

This could be modified to become a dispersion index by setting Q to 1. This type of index could be of use in describing broad-scale dispersion capability in British Columbia.

Root *et al*[15] described the use of a much broader type of dispersion index (DI) to forecast SO_2 concentrations surrounding the Kennecott Copper smelter in Utah. Daily forecasts of SO_2 concentrations help dictate the emission rate from the smelter. Emission control staff initially attempted to forecast concentrations using a detailed and sophisticated dynamic dispersion model. However, this approach was abandoned due to the model's insufficient accuracy. It was replaced with an empirical approach to predictive modelling.

SO_2 concentrations were found to correlate best to synoptic-scale meteorological conditions, then to the vertical structure of the atmosphere, and least to local surface conditions. The DI is calculated by a meteorologist who objectively examines all data and enters the necessary observed and forecast data onto a worksheet. The entire daily operation takes 9 hours (8 hours for collection and identification of data, plotting upper air soundings, and surface data analysis, and 1 hour for entering data into the worksheet). The exact numerical structure of the DI is not given, but the following general statements were made:

Group I Parameters - Synoptic Scale Conditions. (Highest correlation to SO_2 concentration).

- Ridging aloft and high surface pressures were shown to be good predictors of SO_2 concentrations and so represent the greatest input into the DI.

- Low absolute vorticity, sinking air motions and warming aloft represent an intermediate contribution to the DI.

- Weak or no frontal activity allowed little mixing in the valley and represents a "maximum point addition" into the DI.

Group II Parameters - Vertical Structure of the Atmosphere. (Second highest correlation to SO_2 concentrations).

- Inversions characterized by strength (°C) and depth (m) are incorporated into the DI. (Inversions greater than 8°C and 1000 m deep receive the greatest point input.)

- Mixing layer conditions are represented by inputting a "clearing index" into the model.

- 500 mb wind speeds are also entered (presumably light upper winds will reduce

dispersion).

Group III Parameters - Local Surface Conditions (Least correlation to SO_2 concentrations).

Light wind speeds, a stable air mass, low surface heating and no precipitation are best correlated to poor dispersion. (The relative input of each of these parameters is not given in the paper).

The DI is defined as a dimensionless number based on the above measurements ranging from 0 to 80 (0 is the best dispersion, 80 is the worst). However, this objective index was found to improve if it was subjectively adjusted by a meteorologist. This adjustment consisted of an additional 0-20 points added by the meteorologist based on his determination of the dispersion capacity of the atmosphere. Thus the final DI ranged from 0-100 points.

A regression technique was used to link SO_2 concentrations to this dispersion index by use of a multi-ordered polynomial of the form:

$$Y = K_0 + K_1X + K_2X^2 + ... + K_nX^n$$

where: Y = maximum SO_2 concentration expected at a control station
K_i = numerical constants
X = Dispersion Index

Six separate regression equations are used (one for each 2 month period). The authors claim that accuracies produced by the model are superior to more sophisticated dynamic atmospheric diffusion models. In 1980 twenty four, thirty-six and forty-eight hour forecasts of SO_2 concentrations were being made daily. Additional information on the derivation and use of the Dispersion Index was requested from, but not provided by, Kennecott Copper Company in Salt Lake City.

SECTION 3

AIR QUALITY FORECASTING PROGRAMS

INTRODUCTION

This section reviews some current and past programs operated by various agencies responsible for the forecasting of air pollution or air pollution potential. These agencies often use automated techniques similar to those described in section 2 but rely heavily upon people to coordinate and provide the air quality forecasting service.

ONTARIO MINISTRY OF ENVIRONMENT

The Ontario Ministry of Environment presently operates an Air Quality Index Forecasting service seven days a week from its office in Toronto for all areas of Ontario. Four scheduled forecasts are issued daily with amendments as required. Three consulting meteorologists (two full time, one part time) are employed at the office and are responsible for acquiring air pollutant data as well as issuing forecasts of air pollution events. The annual operating costs of the program are approximately $250K; $120K for salaries, $80K for meteorological data acquisition, and $50K for air pollutant concentration data acquisition. (The latter is only a portion of the cost of this activity as the regulatory side of the Ontario Ministry of the Environment also uses the data and contributes funding.)

The forecast is based on the Ontario Air Quality Index (AQI). This index is similar to the Greater Vancouver Regional District Air Quality Index in that it reflects the pollutant with the most hazardous concentration. The forecast gives the probability of the AQI remaining below 32 (good to very good air quality) or climbing above 32 (moderate, poor or very poor air quality). The probabilities are descriptive rather than quantitative. For example, if the probability of AQI exceeding 32 is estimated by the meteorologist to be 40%, his forecast will state that there is a "slight possibility of moderate AQI levels".

Forecasts of the AQI are based on forecasts of the concentrations of those pollutants that are most often responsible for elevated AQI. A summary of the most important meteorological conditions for the forecasting of each pollutant's contribution to the AQI are given in Table 3.1.

An Air Pollution Alert System can order the curtailment of emissions if the AQI reaches certain levels and if meteorological forecasts indicate high pollution potential conditions will continue for at least 6 more hours. Table 3.2 describes the criteria used.

TABLE 3.1. Basic meteorological conditions associated with the pollutants most often responsible for elevated air quality indices in Ontario.[16]

POLLUTANT	SOURCES	MOST SIGNIFICANT METEOROLOGICAL CONDITIONS
Total Reduced Sulphate	Local Industry	Wind blowing from source to receptor
Sulphur Dioxide	Local Industry	1. Wind blowing from source to receptor, or calm winds. 2. Boundary layer stability. 3. Mixing height attaining the effluent plume level.
Ozone (May through September only)	Local sources	1. Stagnating high pressure centre. 2. Cloud-free warm sector. 3. Temperature ≥ 25°C. 4. Sunny skies.
	Long range transport of ozone and its precursors.	Similar to local sources plus: 1. Back side of a high pressure centre. 2. 1000 mb back-trajectories indicate that the air originated over industrialized states. 3. Sunny skies over trajectory path.
Total Suspended Particulate	Local Industry	1. Wind blowing from source to receptor, or calm winds. 2. Boundary layer stability. 3. Mixing height attaining effluent plume level.
	Local vehicle emissions. (During morning and sometimes evening)	1. Light winds (≤ 10kmh) 2. Low level inversion (elevated levels are usually observed near inversion break-up time)
	Long range transport	1. Stagnating high pressure centre. 2. Back side of a high pressure centre. 3. 1000 mb back-trajectories indicate that the air originated over industrialized states.

TABLE 3.2. The Ontario Air Pollution Alert System criteria[17]. The regulatory authority applies to owners of significant sources of air pollution in the community in which this AQI occurs.

AQI	ALERT	HEALTH EFFECTS	REGULATORY AUTHORITY
0-31	None	Little or none	None
32-49	Advisory Level	Probably little or none	Prepare to curtail operations
50-74	First Alert	Chronic respiratory disease symptoms accentuated	May be ordered to curtail operations
75-99	Second Alert	Not stated.	Further curtailment of operations
100+	Air Pollution Episode	Mild effects on healthy people. Serious effects on those with severe cardiac and respiratory disease.	All non-essential sources ordered to cease operations.

THE SEATTLE FORECAST CENTRE DISPERSION FORECAST PROGRAM

An Air Pollution Forecast was issued by the air pollution meteorologist at the Seattle Forecast Centre (SFC) in the 1970s. Instructions for the forecast preparation are in the appendix. This forecast relied mostly on a type of ventilation index similar to that now produced by the Pacific Weather Centre. The forecast of this index was based largely on upper air soundings, upper wind data and forecast maximum temperatures. The forecaster also considered the NWS stagnation forecast guidance for Washington. The forecast message, called a "Washington Dispersion Discussion", estimated the capability of the atmosphere to disperse pollutants and contained:

- a synopsis
- a maximum temperature forecast for today and tomorrow
- seven zone forecasts, each containing projections of the mixing height and the wind speed and direction through the mixed layer for today, tonight and tomorrow. Numerical ventilation index forecasts were not included.
- forecasts of the ventilation (poor through excellent) in all seven zones, obtained from nomograms of mixing height and wind speed.

Przywarty and Smith[18] report that NWS stagnation forecast guidance and the more widely distributed Washington Dispersion Discussion were discontinued during the 1982/83 budget cuts and have not been reinstated. With the growing concern of air pollution in the Puget Sound area, particularly with the wood smoke from forestry prescribed burning and wood burning appliances, the SFC now issues Air Stagnation Advisories only to the Washington State Department of Ecology on request (but not on circuit). The appendix contains a recent Air Stagnation Advisory issued by the SFC.

The Seattle Forecast Centre (and presumably all of the NWS) would like to distance itself from air quality forecasting since the number of telephone contacts rises astronomically when it is perceived that the NWS is implicated in the forecasting of poor air quality. This is because Washington State law now restricts the use of wood-burning appliances during air pollution episodes. Most callers complain that the air pollution episode should not have been declared in their particular neighbourhood for a variety of reasons, including:

- the wind is blowing from the sea or some sparsely inhabited area resulting in good air quality in their neighbourhood, or
- the wind is blowing out to a sparsely inhabited area and that any wood smoke that they produce will not have any impact.

THE PUGET SOUND AIR POLLUTION CONTROL AGENCY

The Puget Sound Air Pollution Control Agency[19] participates with the Washington State Department of Ecology in the forecasting of air pollution episodes. The main purpose of the Agency's work is the reduction in air pollution produced by wood burning appliances. The use of these appliances is restricted when an air pollution episode has been declared. The meteorological input into the forecast of an air pollution episode includes:

- the issuance of an internal (not for public consumption) Air Stagnation Advisory by the National Weather Service and/or
- indications that stagnant atmospheric conditions exist and that these conditions are forecast to persist for 24 hours.

The latter "indications" are primarily derived from a radiosonde ascent (temperature, dewpoint and wind, up to 700 millibars) operated by the Washington Department of Ecology in Seattle on weekday mornings[c]. An analysis of temperature inversions and mixing depths is used to determine the expected dispersion capability of the atmosphere. The stagnation advisory is used in predicting the length and severity of an air pollution episode, but only the Department of Ecology can declare such an episode in any region of Washington. During such an episode any person who has an adequate source of heat without burning wood cannot burn wood in any solid fuel heating device.

A less severe "Impaired Air Quality" condition exists if meteorological conditions are conducive to an accumulation of air contamination concurrent with PM_{10} at an ambient level of 90 micrograms/m^3, measured over 24 hours. Restrictions on wood stoves are similar to that during an air pollution episode but certified low-polluting stoves are exempt from these restrictions.

PACIFIC WEATHER CENTRE

The Pacific Weather Centre provides a daily forecast of a modified Ventilation Index (scaled to the range 0-100) for fifteen "smoke-sensitive sites[d]" year-round. This forecast is primarily used for estimating the atmospheric dispersion of smoke produced by prescribed burning of forest debris and is not intended for other uses.

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[c] This sounding is only done when there are indications that stagnation conditions are expected to begin or are occurring. It is expected that an acoustic sounder (with appropriate software to analyze the data) will soon replace the radiosonde.

[d] These sites were identified in conjunction with the British Columbia Ministry of Forests.

The afternoon mixing depth is forecast by adjusting nearby morning radiosonde ascents to account for daytime heating. Wind speeds are defined as the average wind speeds observed during the morning radiosonde ascent below the calculated afternoon mixing height. This process of calculating the Ventilation Index has been almost entirely automated.

Inaccuracies arise when strong winds that often occur above a morning inversion (ie. a low level jet) are incorrectly assumed to remain unchanged when diurnal heating raises the height of the mixing height to well above the top of the morning inversion. In this case, the VI is very sensitive to forecast surface temperatures, with the VI occasionally changing dispersion category from poor to excellent with only a one degree change in forecast temperature, which is unrealistic.

Using 1000 millibar forecast winds to estimate the mixing layer winds may improve the utility of the VI. The numerical Stagnation forecast guidance issued by the NWS in the 1970s used the 3000 foot and 5000 foot forecast (FD) winds to estimate a mixing layer wind by interpolating or extrapolating these forecast winds to the middle of the forecast mixing depth.

Nanaimo City Council has requested that AES provide a daily ventilation index to the City in order to curb air pollutant concentrations. AES has declined to provide this service because the VI was specifically developed for forestry uses only.

CRANBROOK AIR QUALITY PROGRAM

The British Columbia Ministry of Environment (MoE) and the City of Cranbrook are developing a program[20] to address the air pollution episodes produced by wood burning appliances when the atmospheric dispersion is poor. A type of air quality index describes the atmospheric pollution due to PM_{10} concentrations. The description of this index is given in Table 3.3.

TABLE 3.3. Guidelines for assessing air quality in Cranbrook, B.C.

AVERAGE 24 HOUR CONCENTRATION OF PM_{10}[e]	INDEX	AIR QUALITY STATUS	ACTION
Zero to maximum desirable	0-49	Good	None
Up to maximum acceptable	50-99	Fair	None
Up to maximum tolerable	100-149	Poor	Residents urged to cease burning
Exceeding maximum tolerable	150+	Alert	Residents strongly urged to cease burning

[e] The quantitative concentrations of PM_{10} associated with these levels has yet to be defined by the B.C. Ministry of the Environment.

To obtain real-time PM_{10} concentrations, the MoE developed a regression equation relating PM_{10} concentrations in Cranbrook to the visual quality of ambient air as measured by a nephelometer.

The index in Table 3.3 is sometimes modified by the City of Cranbrook if the forecast meteorological conditions are expected to improve or worsen atmospheric dispersion. This forecast dispersion capability is provided in the form of a forecast ventilation index by the Southeast Interior Weather Office (Castlegar).

The final air quality status is provided daily at noon to the local radio station, local newspaper and the cable television station, along with requests to voluntarily curtail woodsmoke production, if applicable.

COMOX WOODBURNING REGULATION

The Town of Comox has instituted a similar voluntary burning restriction during the period October 1 to April 1. No instrumentation is being used to estimate PM_{10} values, but when visibility impairment and smoke odours indicate that the smoke concentration is sufficiently high and is expected to remain high, residents are requested to stop burning. The criteria for such a "No Burn" call, determined in consultation with the meteorologist at Canadian Forces Base Comox, are:

- Visibilities are significantly reduced by wood smoke.
- Wind speeds average less that 5 mph during the previous 24 hours.
- Cloud ceiling is less than or equal to 2000 feet.[f]
- A temperature inversion exists in the low levels.

WHITEHORSE AIR QUALITY PROGRAM

The City of Whitehorse passed a Wood Smoke By-Law in 1986[21] restricting the use of wood burning appliances. A nephelometer is used to estimate total suspended particulate (TSP) in Riverdale, the most affected subdivision of the city. If the TSP concentration reaches 120 micrograms/cubic metre for six continuous hours a critical situation is deemed to have been reached. This information, plus a forecast of dispersion conditions furnished on request by meteorologists at the Yukon Weather Centre, is used to determine whether the operation of wood stoves should be restricted in the Riverdale subdivision.

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[f] This criteria exists in the Town of Comox Wood Burning Regulations. However, information on cloud height was never requested by the Town during the winter of 1990/91.

Wind appears to be the most important parameter in dispersing smoke. Conditions will also improve if a strong frontal passage occurs in the valley and the stagnant air is displaced. However, many frontal passages are too weak and do not have much effect on the smoke concentration[22].

When a "No Burn Period" is announced on radio and television, any person who operates a wood stove is liable to a maximum penalty of $500 fine and/or six months in prison. Persons who have no other source of heat are exempt from this by-law.

SECTION 4

A CARBON MONOXIDE CONCENTRATION FORECAST FOR GREATER VANCOUVER.

INTRODUCTION.

AES Pacific Region (Scientific Services Division) conducted an experimental real-time carbon monoxide concentration forecast project for several locations in the Greater Vancouver area from November 1990 through to March 1991. This section describes the forecast procedure, the data required and some forecast issues.

Carbon monoxide is a colourless, odourless and tasteless gas which is produced from incomplete combustion of fossil fuels. It is a concern as an air pollutant because it reduces the ability of the blood to transport oxygen. Long term exposure to low concentrations may result in adverse effects in those suffering from cardiovascular disease. Ninety percent of man-made CO comes from motor vehicles. Other sources include fossil fuel combustion for heating and commercial operations.

AIR QUALITY DATA.

The air quality forecast was a day one and day two forecast of maximum carbon monoxide concentrations at three sites in Greater Vancouver. It relied upon the ambient air quality monitoring network of the Greater Vancouver Regional District (GVRD), a federation of 16 municipalities and 3 electoral areas in the Greater Vancouver area. This network consists of 179 samplers at 47 stations located in 14 communities. Each station is equipped to measure one or more of:

- Sulphur Dioxide
- Carbon Monoxide
- Ozone
- Nitrogen Oxides
- Wind
- Total suspended particulate
- Dustfall
- Coefficient of Haze
- Hydrogen Chloride/Fluoride
- Particulate metals (cadmium, chromium, copper, lead, manganese, zinc and/or nickel)

Data from 16 of the monitoring stations are available in real time in the GVRD air quality monitoring system (AQMS) computer via telephone modem. Data consists of hourly and daily average concentrations of pollutants and hourly average wind speed and direction. Only carbon monoxide (CO) concentrations and wind speed and direction from the AQMS were

used in the air quality forecast project.

AIR QUALITY FORECAST PROCEDURE

The carbon monoxide concentration forecast was prepared weekdays at 0800 for three sites in Greater Vancouver:

1. Robson Square in downtown Vancouver (site T1)
2. South Richmond (site T17)
3. Kensington Park in north Burnaby (site T4)

All weather data and forecasts available to meteorologists in the Pacific Weather Centre at 0730 PST were used in the preparation of the air quality forecast. All AQMS data available from previous days were used but the data from the current day was not accessed. This was because the carbon monoxide concentrations had at times already reached their peak by 0800.

The air quality forecast attempted to predict the following daily carbon monoxide concentrations for today and tomorrow for each of the three stations:

- One hour maximum concentration.
- Mean hourly concentration.
- Maximum three hour average concentration.
- Maximum eight hour average concentration[g].

FORECAST ISSUES

Forecasting carbon monoxide concentrations presented a number of challenges. Carbon monoxide is not emitted uniformly in space or time. Concentrations usually showed peaks at morning and afternoon rush hours, but the relative size of these peaks varied considerably in time and space. This likely was due mainly to meteorological conditions.

A complete report of this forecasting project will be produced in the future. Initial analysis of the data shows that:

- Meteorology is the most important factor in the departure from the regular diurnal variation of carbon monoxide concentrations. However, meteorological parameters affect the concentrations at different sites in different ways. For example, brisk southeast winds on very stable days will give relatively high CO levels in downtown Vancouver (station T1), though very low levels in Richmond (station T17).

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[g] The maximum three and eight hour average concentrations were calculated from the hourly data and were not supplied by the AQMS.

- Concentrations of carbon monoxide vary widely over a relatively small area such as Greater Vancouver.

- Topography appears to influence concentrations. For example, low flat areas (as opposed to hill tops) tend to have the highest concentrations. This may be because radiation inversions can develop more quickly and efficiently over low flat areas.

- Synoptic scale meteorological influences are important but can sometimes be overshadowed by mesoscale influences. For example, one of the highest carbon monoxide concentrations observed at site T17 was behind a cold front in very unstable air when a very low concentration would have been expected. In this case clear skies and almost calm winds behind the front probably produced a sharp and very shallow inversion for a brief period during rush hour causing high CO concentrations.

- With experience, a meteorologist can produce useful forecasts of trends in carbon monoxide concentrations.

SECTION 5

AIR QUALITY FORECAST APPROACHES FOR AES IN BRITISH COLUMBIA

INTRODUCTION.

Several agencies have shown interest in obtaining air quality or dispersion forecasts at a number of towns and cities in British Columbia. The complexity of an air quality forecast service for these towns and cities could range from a brief qualitative forecast of general dispersion potentials to quantitative forecasts of air pollutant concentrations.

This section looks at the distinctive air quality concerns in British Columbia and the types of air quality forecasts that could assist in mitigating these problems.

BRITISH COLUMBIA AIR QUALITY CONCERNS.

A report prepared for the British Columbia Round Table on the Environment and the Economy[23] concluded that air quality problems are generally localized and that air pollutants do not generally originate from distant sources. These sources can be characterized as follows:

1. Local emissions - emissions of pollutants from near ground level, primarily by wood burning appliances, field and yard burning, motor vehicles and some local industry.

2. Longer range transport of air pollutants - emissions from the prescribed burning of forestry debris or from high industrial smokestacks. Pollution from these sources must be transported by the wind to the populated area to be a problem. The distance these pollutants travel in British Columbia is probably less that 150 kilometres in general.

The dispersion mechanisms of these two source categories of air pollution differ. Smoke from hot prescribed burns and sometimes high smokestacks generally has sufficient buoyant energy to push through any shallow inversion formed near the ground due to radiative cooling. This allows the smoke to mix throughout any mixed layer above the inversion and to be transported to other locations. However, emissions from motor vehicles, residential wood stoves and smouldering prescribed burns do not have this buoyancy and can be trapped and can accumulate below any shallow ground-based inversion.

The pollution from biomass burning is one of the most serious health concerns in many cities and towns in British Columbia. Whether it be from wood stoves or forestry practices, this pollution contains particulates, carbon monoxide, formaldehyde, nitrogen oxides, polycyclic aromatic hydrocarbons and chlorinated dibenzodioxins and dibenzodfurans. All of

these have health impacts on humans and some are carcinogenic[24]. It is believed that human health is impacted more seriously by smoke from wood stoves, backyard burning and tee-pee burners in British Columbia than from smoke from prescribed burning[25]. Specifically, it is estimated that in British Columbia interior towns and cities the PM_{10} concentrations from smoke originating from residential wood stoves frequently exceed 50 micrograms per cubic metre, while the PM_{10} concentrations from smoke associated with prescribed burning rarely exceeds this value, even on days that are categorized as "very smoky".

Allowing for these and other considerations, five possible approaches for providing air quality forecast services in British Columbia are defined:

1. A regional stagnation forecast
2. A local dispersion forecast.
3. A forecast of the longer range transport of air pollutants.
4. An improved Ventilation Index.
5. A Greater Vancouver air quality forecast.

The following describes the rationale behind deciding on these categories and some initial approaches to providing the air quality forecast.

REGIONAL STAGNATION FORECAST

This is the probably the simplest and most straight forward approach to forecasting air quality. It will, however, likely be of limited value in a mountainous province like British Columbia. It would require that AES (probably CMC) develop an improved version of the CMC stagnation forecast guidance model to predict synoptic scale stagnation in the low levels. The regional forecasts, with or without manual interpretation, could then be disseminated to provincial, regional or municipal authorities for input into any local air quality services.

Using the NWS and CMC stagnation forecast guidance programs as models, the synoptic features that appear to be important for producing stagnation at towns in British Columbia would be:

- Slow moving and persistent cold high pressure systems in winter with stable airmasses and weak pressure gradients. This is probably the most important synoptic feature (particularly in the B.C. interior) in the accumulation of residential wood smoke in small cities and towns and in the accumulation of gaseous pollutants (particularly carbon monoxide) in large cities.

- Warm ridges during summer and fall with stable airmasses and light winds. This appears to be important in elevated smoke levels from local field, yard and forestry burning throughout the province and high ozone levels in Greater Vancouver and the Fraser Valley.

- Slow moving and weak weather systems with weak surface gradients and stable airmasses; weak or absent frontal activity.

- Light synoptic-scale surface winds.

- Warm air overrunning cool stagnant air.

This information could be used to tailor (either manually or automatically) a CMC synoptic scale stagnation forecast guidance to a specific region.

Likewise, the converse or absence of any of these features would likely lead to a reduction in stagnation.

A LOCAL DISPERSION FORECAST

One practical air quality forecast service for British Columbia would be 24 and 48 hour *local* dispersion forecasts for towns and cities which have significant local pollutant emissions. This type of forecast would be applicable to any town in British Columbia. The presence of an air quality monitoring system would be necessary in the verification and thus the quality of the forecast product and could be made a mandatory prerequisite for such a service. The main aim of a local dispersion forecast would be to predict the ability of the lower atmosphere to disperse locally produced pollutants. To be useful, such a local dispersion forecast should be site specific and take into account both the synoptic features of the atmosphere and the particular mesoscale parameters important for each location.

In addition to the synoptic features used to tailor the CMC stagnation forecast guidance, smaller scale features that would be used as input for the local dispersion forecast would be:

- Local clear conditions which tend to produce sharp, shallow inversions (overnight in summer; or anytime in winter when radiative cooling is not significantly offset by daytime heating).

- Light or calm site winds.

- A constricting valley, with the town at the valley bottom.

- A non-urban location. Urban heat islands tend to discourage the formation of shallow nocturnal inversions. However, horizontal convergence produced by the heat island effect could tend to concentrate pollutants in the urban centre in some cases. This would be a site-specific parameter.

- Other atmospheric features linked historically to poor local dispersion.

The local dispersion forecast status could be characterized by one of four terms; excellent,

good, fair or poor. In Table 5.1 definitions are proposed for the local dispersion potential associated with each term. They are meant to apply to a populated area producing significant local emissions from such sources as wood stoves or motor vehicles. The maximum desirable, maximum acceptable, and maximum tolerable levels are defined by Environment Canada for a number of air pollutants[h].

TABLE 5.1 Proposed category definitions for a local dispersion forecast for an urban or semi-urban area with significant local emissions.

Excellent Dispersion:	Rapid dilution of pollutants. The concentrations should remain below the maximum desirable level or fall below this level within an hour or so.
Good Dispersion:	Moderate dilution of pollutants. The concentrations should remain below the maximum desirable level or fall below this level within six hours.
Fair Dispersion:	Marginal dilution of pollutants. The concentrations may remain above or rise above the maximum desirable level but should remain below the maximum acceptable level or fall below this level within several hours.
Poor Dispersion:	Little dilution of pollutants. The concentrations may remain above the maximum acceptable level or rise above this level within several hours and may rise above the maximum tolerable level over a longer time period (several days, for example).

The primary rationale behind defining the local dispersion status in this way is that it is a direct measurement of atmospheric dispersion and is verifiable when a monitoring system is in place.

The 24 and 48 hour local dispersion forecast could contain the best and the worst dispersion expected for each forecast day or alternately the expected dispersion at particular times of the day, such as early morning and late afternoon.

[h] British Columbia has a similar system of concentration guidelines, defined as *desirable, interim* and *maximum* levels.

FORECASTING THE LONGER RANGE TRANSPORT OF AIR POLLUTANTS

Another option important for some British Columbia towns is a forecast of the potential of a fixed source (generally industrial) to degrade the air quality at a "pollution sensitive" site, such as a town or city, that is some distance from the source. An example of this would be the forecasting of the air quality at Castlegar, which suffers from air pollution created by the Cominco smelter in Trail twenty-nine kilometres to the south. This type of forecast could also provide emission regulators with useful information.

The synoptic features that would be important for producing poor air quality due to longer-range transport of pollutants originating at a fixed point and that could be a basis for a related air quality forecast are similar to those necessary for stagnation and local dispersion forecasts would include:

- Slow moving and persistent cold high pressure systems in winter with stable airmasses and weak pressure gradients.
- Warm ridges during fall (and perhaps summer) with stable airmasses and light winds.
- Mixing layer winds blowing from the source to the populated area.
- Light or calm surface winds at the pollution-sensitive site.
- A constricting valley to impede the lateral dispersion of the transported pollutant.
- Weak or absent frontal activity.

Criteria for producing poor air quality from a distant source would be unique for each town or city. Since the source is fixed and the meteorological events conducive to poor air quality are already known from experience, an air quality forecast service such as this should be less complicated than others.

Analogous to the local dispersion forecast, the long-range air quality potential forecast status could be characterized by one of four terms; no impact, slight impact, moderate impact, severe impact. Table 5.2 gives proposals of definitions of these terms. They are meant to apply only to selected populated areas affected by a single remote significant pollution source.

Similar to the local dispersion forecast, the 24 and 48 hour forecast of the long-range air quality potential status could contain the best and the worst status expected for each forecast day or alternately the expected status at particular times of the day, such as early morning and late afternoon.

TABLE 5.2 Air quality potential categories for a pollutant-sensitive site vulnerable to emissions from a distant industrial source.

No impact:	No air pollutants will reach the pollutant-sensitive site from the emitting source.
Slight impact:	Air pollutant concentrations from the emitting source should remain below the maximum desirable level.
Moderate impact:	Pollutant concentrations from the emitting source may rise or remain above the maximum desirable level during the time period but should remain below the maximum acceptable level.
Severe impact:	Pollutant concentrations from the emitting source may rise or remain above the maximum acceptable level during the time period and may rise above the maximum tolerable level.

THE VENTILATION INDEX AND PRESCRIBED BURNING

Prescribed burning is used to clear forest debris for silviculture after harvesting and to remove understorey growth for hazard abatement and wildlife enhancement. Burning debris piles is a related forestry burning practice that produces significant amounts of smoke. These activities can occur throughout the province at any time of the year, though the preferred time is in the fall or spring.

The forest industry has been using a variation of the Ventilation Index (VI) as described by Nikleva[11] to determine whether meteorological conditions are conducive to the dispersion of smoke from prescribed burning. The VI is a practical instrument when dealing with relatively hot fires (which easily break through shallow ground-based inversions) in a rural setting. The VI has been accepted by the B.C. Forest Service[26] to the extent that burning permits are restricted when both the VI and ambient smoke levels (as measured by visibilities) are below certain limits. Table 5.3 describes these limits and the restrictions.

The current version of the Ventilation Index is a fundamental part of the Smoke Control Forecast now issued daily by the Pacific Weather Centre. As the use of the Ventilation Index for managing smoke and timing prescribed burning is gaining acceptance in British Columbia, its continued use should be encouraged.

Table 5.3 Restrictions to prescribed burning imposed by the B.C. Minister of Forests as a function of the Ventilation Index (scaled to 1-100) and the prevailing visibility[26].

Ventilation Index	Restrictions	
	Visibility < 20 KM	Visibility > 20 KM
67-100	*No restrictions*	*No restrictions*
35-66	*Burning only with permission of Regional Duty Officer*	*No restrictions*
0-34	*No Burning Allowed*	*No Burning Allowed*

The Ventilation Index algorithms could be improved to better reflect the capacity of the atmosphere to disperse prescribed burning smoke. Some approaches to improving this index are now described.

1. The procedure used to forecast the average wind speeds through the mixing layer could be improved. As mentioned in section 3, this average wind could be estimated from the 1000 and 850 millibar geostrophic wind speeds abstracted from the CMC weather forecast model (currently the Regional Finite Element model). Alternately, the mixing layer wind could be predicted from the forecast low level winds produced by CMC for various airports in British Columbia. Topographic effects for each individual case could also be used to adjust the mixing layer wind speed. Determining the mixing layer winds in this way should make the VI less sensitive to small changes in surface temperature.

2. The constricting effects of topography could be included in the index to make it applicable both over flat terrain and within a valley. This could be done by redefining the Ventilation Index to:

$$VI = \frac{LUW}{100}$$

where: L= Mixing depth (m)
U= Mean wind speed through the mixed layer (m/s)
W= Valley width (km)

This value of the VI could again be scaled to the familiar 0 to 100 range. *W*, the valley width, could have a maximum value of the expected horizontal cross-wind dispersion of a smoke plume after about 12 hours. This value would be near 20 kilometres.

3. Verification of the smoke dispersion capabilities of the VI is an essential part of improving its usefulness. Historical VI values could be compared to prevailing visibilities

during the burning seasons to obtain better VI interpretation and to perhaps improve its formulation.

Other questions should continue to be asked as part of any regulation governing prescribed burning, such as:

- Will the mixing layer wind carry the smoke to a populated area?
- Will the targeted populated area be seriously impacted because of its location near or at the bottom of a constricted valley?
- Are any other pollution sources expected to degrade air quality during the lifetime of the proposed prescribed burn?
- Is the air quality in the populated area already degraded because of previous or current air pollutant sources (including prescribed burns)?
- Will the smoke impact on other provinces, territories or countries?

Information that would help answer these questions could be part of any revised Smoke Control Forecast.

FORECASTING AIR QUALITY IN GREATER VANCOUVER.

Forecasting air quality in Greater Vancouver is a special case and could go further than simply forecasting the potential of the atmosphere to disperse local emissions. There are a number of reasons for this:

- Through the Green Plan, Canada has committed itself to providing, by 1993, public advisories on days when ground-level ozone levels are expected to become excessive.
- Greater Vancouver is significantly larger in population (pollutant receptors) and area than any other urbanized region of the province.
- The great number and concentration of motor vehicles in Greater Vancouver results in more noxious gaseous pollutants being produced there than any other area of B.C.
- A sophisticated real-time air quality monitoring system, one of the best[27] in North America, is in place in the region, allowing for the monitoring of pollutant concentrations and verification of concentration forecasts.
- It has been estimated that, with a business-as-usual attitude to emissions, the air quality in the lower mainland will become worse than that in Los Angeles by the late 1990s[28].

There is a unique opportunity here to produce a more detailed and usable air quality forecast product by forecasting concentrations or categories of concentrations of specific air pollutants.

The air quality forecast services for Greater Vancouver could be broken into two subsets: forecasts of the concentration of ozone and forecasting the concentrations of other types of air pollutants. It is felt that ozone should be dealt with as a separate forecasting issue since:

- tropospheric ozone is perceived by many to be the principal air quality problem in the Greater Vancouver area.

- ozone is not emitted by any source but is produced photochemically by interactions between other gases. This is not the case with most other pollutants.

- the ozone forecasting problem is on a larger scale in both time and space than that of other air pollutants in the lower mainland since it takes several hours for the photochemical reactions to cause concentrations to reach moderate levels. Gaseous precursors and ozone can move significantly in that time. Therefore different approaches would be needed in the forecasting of ozone in contrast to other gases.

- significant statistical and other work have been completed by workers in the Atmospheric Sciences section at the University of British Columbia on the relationship between tropospheric ozone and meteorological factors in the Lower Mainland[29]. Specifically, the best statistical predictors of today's maximum ozone concentration in the lower mainland have been shown to be yesterday's maximum ozone concentration and today's forecast maximum temperature. All of this work can be drawn upon in setting up such a forecasting service.

- the Greater Vancouver Regional District (GVRD) would support[30] an ozone forecasting program in the area.

Ozone is only a concern between May and September (when more of the public is involved in outdoor recreation and when agricultural crops are the most vulnerable) under specific meteorological conditions in the lower mainland. The forecasting of tropospheric ozone could be a cooperative effort between the AES, the B.C. Ministry of Environment and the GVRD. Preliminary discussions with GVRD suggest that any daily ozone forecast could be delivered to them for their endorsement, and then included in their noon Air Quality Index message to the media. The forecast could begin as a general day one and day two forecast of tropospheric ozone in the western Fraser Valley where the concerns are most acute. It could ultimately cover all of the Lower Mainland and the forecasts could become site-specific.

The synoptic meteorological criteria associated with peak ozone events are the same as those associated with stagnation events and poor dispersion of local emissions as described earlier in this paper. Since ozone is produced photochemically, critical site-specific inputs to

such a forecast should include yesterday's maximum ozone concentration and maximum forecast temperatures at each site (an indirect measurement of irradiance and sea-breeze intrusion). One further step would be required: the translation of this forecast into an estimate of pollutant concentration using real-time and historical pollutant concentration data. This concentration forecast could be transposed into a pollutant category if required.

Ozone forecasts could be produced for a number of sites throughout the Lower Mainland, each having different weighting of each criteria. Criteria for predicting ozone concentrations at different sites could be determined by comparing meteorological conditions and ozone concentrations during the summers of 1988, 1989 and 1990. Once these criteria have been determined, the forecast procedure eventually could largely be automated with a system to determine the ozone concentrations of the 25 or so GVRD and B.C. Ministry of Environment air quality monitoring sites.

Similar forecast techniques could be used for gases (and particulates) building on the experience gained in operating the ozone forecasting program.

SECTION 6

BRITISH COLUMBIA AIR QUALITY FORECAST PROGRAM REQUIREMENTS

INTRODUCTION.

This section estimates the minimum data, research and resources required for AES participation in an effective seven day-a-week air quality forecast service in British Columbia.

The five forecast options as described earlier are:

1. A regional stagnation forecast
2. A local dispersion forecast.
3. Forecasting the longer range transport of air pollutants.
4. An improved Ventilation Index.
5. A Greater Vancouver air quality forecast.

The requirements laid out in this section are based upon a number of assumptions:

- The main motivation for producing any air quality forecast is:
  - to forewarn the community of expected air pollution episodes, enabling those whose health may be adversely impacted to take appropriate action.
  - to provide regulators of emissions with information on expected air quality conditions.
  - to provide both the community and industry with an estimate of the duration of an existing air pollution episode for emission planning purposes.
  - to heighten community and industry awareness of air quality issues.
- The forecast office will have access to all meteorological information now available to the Pacific Weather Centre and other relevant information from CMC.
- Any air quality forecast services will be provided as an addition to the regular weather service performed at the forecast office. The geographical area of interest will be included in the area of responsibility of the forecast office.
- The air quality forecast procedure will not be automated initially and will rely upon the meteorological skills of the forecaster, although computer support will be required.

This does not mean that many (or most) of the functions of the air quality forecaster could not be automated in the future.

- Research and development will be done in-house by AES. Some or all of this research could be done outside AES if the necessary financial resources are available. Only general research and development requirements are outlined in this report. Detailed research and development cost estimates are not provided.

- Pollutant concentration data and any necessary additional meteorological data acquisition will be the responsibility of the B.C. Ministry of the Environment or the local municipality.

REGIONAL STAGNATION FORECAST REQUIREMENTS

Regional stagnation forecasts would be issued for individual districts, valleys or large urban areas. These forecasts would be based upon an automated stagnation forecast guidance produced by CMC (or perhaps produced locally). The forecast could be short and could list the current stagnation potential as well as the forecast 24 and 48 hour stagnation potential forecast for each area. The requirements below are based on the provision of a stagnation forecast service to an arbitrary four discrete areas.

1. Administrative requirements.

   a) If CMC is to produce the automated synoptic scale stagnation forecast guidance, agreement between Pacific Region and CMC must be reached on the provision of an version of this for British Columbia.

   b) Agreement should be reached between AES, B.C. MoE and/or the B.C. Union of Municipalities on the need for, and utility of, a regional stagnation forecast and on the design of a forecast service.

   c) AES, B.C. MoE and/or the B.C. Union of Municipalities should agree on the locations for which the regional stagnation forecasts are to be provided.

2. Initial capital and research requirements.

   a) If CMC is to produce the basic stagnation guidance, they must upgrade their present stagnation forecast computer program to enable it to interact with the current operational models and to take advantage of fields and resolution now available.

   b) Research into defining stagnation in British Columbia (as a function of, for example, vertical temperature and wind profiles, and surface conditions) and any relation to large-scale dispersion of pollutants would be required.

c) Analysis of the improved CMC synoptic scale stagnation forecast guidance would be required to determine if it is of sufficient quality and resolution to be used directly as a regional forecast in British Columbia without manual intervention.

d) Research into analysis of the synoptic meteorological situations leading to stagnation episodes would be required in order to determine stagnation forecast procedures[i]. This work would include data analysis and forecast procedure description and documentation.

e) A system to provide near real-time vertical profiles of the temperature and wind field in the lowest thousand metres of the forecast region would be useful but not necessary. Reliable vertical profiles could be obtained from a portable radiosonde unit.

3. Operational requirements.

a) If the CMC synoptic scale stagnation forecast guidance was found to be of sufficient quality and resolution, software developed in the research phase of this project would be run daily to produce and transmit a totally automated regional stagnation forecast for selected British Columbia sites. Little or no manual intervention would be needed. *The remainder of this section assumes that the CMC guidance would have to be modified manually.*

b) The meteorologist providing the stagnation forecast must be knowledgable and experienced in synoptic and mesoscale meteorology and in the provision of a weather service.

c) It is estimated that, for each individual stagnation forecast, it would take the meteorologist up to 30 minutes per day (for the first of four sites) to:

i) access the automated synoptic scale stagnation forecast guidance and analyze the current and expected stagnation potential.

ii) produce and disseminate a 24 and 48 hour site-specific stagnation forecast. This equates to 0.1 of a person-year per site for a year-round operation. Additional sites would require 0.05 PY.

In summary, a stagnation forecast service for four individual locations or regions would

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[i] If the CMC synoptic scale stagnation forecast guidance proves to be useable directly as regional stagnation forecasts, this research time could be used to write software to convert the CMC guidance to regional stagnation forecast products.

require 0.3 person-years[j] AES operational time.

LOCAL DISPERSION FORECAST REQUIREMENTS

A local dispersion forecast program would include site-specific local dispersion forecasts for individual cities or towns. The forecast could include a measure of the current air quality as well as the forecast 24 and 48 hour local dispersion forecasts for a site. The total resources outlined below assume that a local dispersion forecast will be issued for four individual sites.

1. Administrative requirements.

   a) The town or city should have requested an air quality forecast service.

   b) An agreement should have been reached between AES and the B.C. Ministry of Environment on the provision of an air quality forecast service (because of federal/provincial jurisdictional considerations).

   c) The town or city (or the MoE) should be prepared to participate (financially and/or with manpower) in any air quality monitoring effort.

   d) The town or city (or the MoE) should be prepared to participate in any operational real-time air quality assessment process and to make full and effective use of any air quality forecast service, including disseminating the forecast product if required.

2. Initial capital and research requirements.

   a) A real-time weather station taking weather observations for most (preferably all) of the day must be located near to the town or city.

   b) An ambient air monitoring system must be put in place. This system should consist of at least one monitoring station providing hourly average concentrations of the pollutant(s) under consideration and hourly winds. This system must be accessible in real-time by the office providing the air quality forecast. Costs for such a system would depend upon the type of pollutant to be measured. As an example, the estimated cost for one complete monitoring station for sampling PM_{10} concentrations, including the sampler, datalogger, heater, modem and phone lines varies from $20K (using a nephelometer which measures light scattering in a chamber) to $50K (using a Rupprecht and Patashnick Company Tapered Element Oscillation Microbalance [TEOM] Series 1400 PM_{10} Monitor). Similar costs would be expected to be incurred for each additional monitoring station on the network.

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[j] Required only if the CMC guidance does not prove to be of sufficient quality and resolution to produce a totally automated regional stagnation forecast product.

c) Analysis of the local dispersion of pollutants at each site (including computer modelling if necessary) would be required in order to determine and document air quality forecast procedures. Specific research of this type would include data analysis, forecast procedure identification and documentation. Since this research would require pollutant and meteorological data, an historical data set of at least one year of hourly pollutant concentrations and hourly winds from the stations in the network must be available.

d) A system to provide near real-time vertical profiles of the temperature and wind field in the lowest thousand metres would be useful but not a necessity. Reliable vertical profiles could be obtained from a portable radiosonde unit.

3. Operational requirements.

a) The meteorologist providing the local dispersion forecast must be knowledgable and experienced in synoptic and mesoscale meteorology and in the provision of a weather service.

b) Since the meteorologist will be involved in the provision of a real-time weather service, it is estimated that, for each individual site specific local dispersion forecast, it would take the meteorologist up to an hour per day to:

i) access the air pollutant data

ii) draft a 24 and 48 hour site-specific local dispersion forecast

iii) confer with field personnel, including representatives of the city or town and the Ministry of Environment.

iv) finalize and distribute the air quality forecast product.

This equates to approximately 0.2 of a person-year for a year-round operation. Residential smoke pollution is only a concern in the winter months, so that this figure would be reduced by up to two thirds for a smoke dispersion forecast product.

c) Each additional local dispersion forecasts in the same region would require an extra 15-30 minutes for these tasks. Therefore each additional site forecast would require .05 to .1 of a person-year for year-round operation.

d) Once the ambient air monitoring system is in place, the time required to operate and maintain this system would be minimal, provided the system is reliable. However, it is assumed that it would not be AES's responsibility to maintain such a system.

e) It is assumed that the town or city would provide personnel to participate in the air quality monitoring and forecast activity. This assumption is made because regulating local emissions (primarily residential wood smoke, perhaps bee-hive burners) would be a major reason for producing a local dispersion forecast and the city would have the emission-regulating authority. The related duties for this municipal representative would include:

   i) analyze the current air pollutant data

   ii) confer with the air quality meteorologist on the air quality

   iii) determine the status (for example: poor, fair, good, excellent) of the current and future air quality based on the air quality forecast, and disseminating this status locally to the media.

   iv) determine and then enforce (if necessary) the required emission regulations.

   It is estimated that the time required to complete these duties would be two hours per day.

In summary, a local dispersion forecast service, based on four site forecasts, would require 0.5 person-years of AES operational time.

REQUIREMENTS FOR PRODUCING A FORECAST OF THE LONGER RANGE TRANSPORT OF AIR POLLUTANTS

A forecast of the effects of the longer range transport of air pollutants on a site could take the form of a description of current air quality and a 24 and 48 hour forecast of the expected air quality impacts of the pollutants. In the following requirements, the source of pollutants is assumed to be an industrial emitter, but other types are possible. The term *air quality forecast* in this section refers to the forecast of air quality at a location affected by the longer range transport of air pollutants. These requirements are based on the provision of this type of forecast service to two distinct sites in B.C.

1. Administrative requirements.

   a) An air quality forecast service should be requested by the impacted town or city (or the B.C. MoE)

   b) The B.C. MoE and AES should agree to the provision of an air quality forecast service.

   c) The air quality forecast data should be made available to not only the public but to the

polluting industry and other interested agencies.

d) The town or city should be prepared to participate in any air quality monitoring effort and to participate in any operational air quality assessment and make full and effective use of any air quality forecast product.

2. Initial capital and research requirements.

a) A real-time weather station taking continuous hourly observations must be located near the affected town. A second weather station should be located near the pollution source.

b) An ambient air monitoring system similar to that described in the local dispersion forecast requirements must be in place.

c) If the rate of emissions from the source varies significantly with time, near real-time emission rate data should be available to the forecast office.

d) As with the local dispersion forecast, research into the specifics of the long-range transport of air pollutants at each site would be required. Again, a historical data set of at least one year of hourly pollutant concentrations and hourly winds from the stations in the network should be available.

e) An upper air system to provide real-time vertical temperature and wind data for the lowest several thousand metres would be very useful.

3. Operational requirements.

a) The meteorologist must have the same qualifications as described for a local dispersion forecast.

b) It is estimated that, for each site-specific air quality forecast, it will take a meteorologist up to one hour per day to:

i) access the air pollutant concentration and emission data

ii) draft a 24 and 48 hour site-specific air quality forecast

iii) confer with field personnel, including representatives of the Ministry of Environment, the city or town and the industrial emitter and

iv) finalize and distribute the air quality forecast product.

This would correspond to 0.2 of a person-year for a year-round operation.

c) Each additional site-specific air quality forecast in the same general area will require an additional 15-30 minutes, corresponding to an additional .05 to .1 person-year for year-round operation.

d) As in the local dispersion forecast, it is assumed that the operation of the ambient air quality monitoring system would not be labour intensive, and that it any case, AES would not be involved in its day-to-day operation.

e) The town or city would not be required to participate to the same extent as a local dispersion forecast because there would be no local emission regulations to invoke. However, a municipal representative could be responsible for:

   i) analyzing the current air pollutant data

   ii) conferring with the air quality meteorologist

   iii) determining the status (for example: poor, fair, excellent) of the current and future air quality and distributing this status locally to the media.

   It is estimated that the time required of the municipal employee will be less than 1 hour per day.

In summary, this type of air quality forecast service, based on two site forecasts, would require 0.3 person-years of AES operational time.

REQUIREMENTS FOR PRODUCING AN IMPROVED VENTILATION INDEX FOR THE FORESTRY SECTOR.

The current version of the Ventilation Index is computer-produced at the Pacific Weather Centre for 15 smoke-sensitive sites in British Columbia. Requirements for producing an improved Ventilation Index forecast are as follows.

1. Administrative requirements.

a) AES, the B.C. Ministry of the Environment and the B.C. Forest Service must agree on the need for revising the Ventilation Index.

b) The B.C. Forest Service, B.C. Ministry of Environment and/or Forestry Canada should be willing to contribute resources to revising the Ventilation Index, particularly providing PM_{10} and other pollutant concentration data for the verification of the dispersal capabilities of the Index.

c) The B.C. Forest Service or the B.C. Ministry of Environment should be willing to

contribute resources to the monitoring of smoke concentrations and smoke dispersion to facilitate the future improvement of the Ventilation Index. Future improvements could include acquiring wind forecasts from the B.C. Forest Service wind model.

2. Initial capital and research requirements.

An improvement in the Ventilation Index will require the following steps.

a) The theoretical definition of the Ventilation Index should be revised (perhaps as described earlier in this paper) to better reflect the ability of the atmosphere to disperse pollutants. The researcher(s) required to revise and verify the Ventilation Index must be knowledgable in both synoptic and mesoscale meteorology and aware of the interest of the B.C. Forest Service and the B.C. Ministry of Environment in smoke pollution from prescribed burning.

b) The quality of the meteorological data input into the Ventilation Index (such as mixing layer winds) must be improved.

c) The smoke dispersion capabilities of the revised Ventilation Index should be verified. Appropriate corrections to the Index should then be made. To do this, ground level smoke of PM_{10} concentration data, visibility impairment data (or related data) and both upper air and surface meteorological data from at least one smoke-sensitive site for one fire season should be available. An upper air system at the site to provide real-time vertical temperature and wind data for the lowest several thousand metres close to the site would be essential to this verification.

d) Software to calculate the revised Ventilation Index must be developed.

e) Software to produce an air quality forecast that incorporates the revised forecast Ventilation Index and the mixing layer wind for each smoke-sensitive site and any other specific location throughout the province where prescribed burning is planned must be developed.

3. Operational Requirements

a) The meteorologist required to produce and disseminate the smoke control forecast must be knowledgable in synoptic and mesoscale meteorology, as well as forestry meteorology and smoke issues.

b) The three regional Smoke Control Forecasts (which include the current Ventilation Index issued for 15 smoke sensitive sites) are currently issued once daily by the Pacific Weather Centre (a computerized version is issued during the rest of the year). Initially at least, the revised Ventilation Index should continue to be distributed in a similar manner, with software producing a first guess at the Index and the

meteorologist correcting this when necessary. Consultation between the meteorologist and field personnel is an essential part of the smoke control program. During the fire weather season these operations will take approximately 1 hour per day or 0.1 person-year for a six-month fire-season.

In summary, this type of air quality forecast service would require 0.1 person-years of AES operational time.

REQUIREMENTS FOR PRODUCING A TROPOSPHERIC OZONE AND OTHER POLLUTANT FORECAST FOR GREATER VANCOUVER AND THE LOWER FRASER VALLEY.

This section will detail the requirements for a producing daily forecasts of concentrations (or classes of concentrations) of tropospheric ozone and/or other noxious gases at specified locations in the Greater Vancouver Regional District and the Lower Fraser Valley.

1. Administrative Requirements

a) The GVRD must request that AES participate in an air quality forecast service that includes forecasts of concentrations of ozone and/or other noxious gases.

b) Agreement must be reached between AES, GVRD and the BC Ministry of Environment over the structure of the air quality forecast service, particularly the content of any noxious gas concentration forecast including the gas type(s) to be forecast, the locations for which the forecasts will be applicable and the length of the forecast valid period.

c) Agreement must be reached between the same parties on which agency or agencies will be responsible for producing the daily forecast and how it will be disseminated or used.

d) GVRD and/or the BC Ministry of Environment should be willing to contribute resources to the air quality forecast service and to participate in any air quality assessment process.

2. Initial capital and research requirements[k].

a) In 1990, the GVRD air quality monitoring system consisted of 179 samplers of gas,

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[k] These requirements, along with the personnel requirements, assume that AES will accept responsibility of the daily production of forecasts of ozone and/or other noxious gas concentrations.

particulate, wind, temperature and rainfall data at 47 stations. All stations do not measure all types of data. For example, only three sites measure temperature. This system is now being upgraded to include temperature and wind sensors at more sites. This process should continue. Since these data would be useful to AES, costs could be shared among the two agencies. AES is currently working with GVRD to install some additional temperature sensors. Wind sensors are already in place at 12 sites and it is not critical that additional sensors be initially put in place. However, three additional wind sensors would be useful. Temperature sensors should be installed in at least 2 additional sites in the system to improve spatial temperature monitoring.

b) Real time hourly air quality, temperature and wind data from the GVRD air quality monitoring network must be available at the forecast office at all times. (Communication problems currently hamper data acquisition.) Data formats different than those currently available on the GVRD air quality computer may be required. (GVRD responsibility).

c) Software should be developed in the AES forecast office to display the GVRD air quality and meteorological data.

d) Research (including computer modelling if required) would be necessary for gas concentrations forecasts:

   i) For an ozone forecasting service, further research into the relationships between ozone concentrations throughout the GVRD, emissions and concentrations of ozone precursors, and meteorological data must be completed in order to produce an initial ozone forecasting approach.

   ii) For other noxious gas forecasting services, similar research would involve examining relationships between the gas emissions/concentrations and meteorological data to produce a particular gas concentration forecast.

   The personnel involved in this research must be familiar with synoptic and mesoscale meteorology affecting Vancouver and have an acceptable knowledge of the ozone (or other pollutant as applicable) chemistry issues. Scientific Services Division has begun work on implementing an air quality model for the Lower Fraser Valley.

e) Statistical procedures applicable to the forecasting of ozone concentrations in the Fraser Valley should be reviewed and updated.

3. Operational Requirements

a) The meteorologist involved in the operational forecast of ozone (or other pollutant) concentrations should be knowledgable and experienced in synoptic and mesoscale meteorology and in the provision of a weather service.

b) It is estimated that, for the ozone (or other pollutant) concentration forecast for the *first* site it will take a meteorologist up to one hour per day to:

i) access the GVRD air pollutant concentration and meteorology data

ii) draft a 24 and 48 hour site-specific gas concentration forecast

iii) confer with field personnel, including representatives of the Ministry of Environment and/or the GVRD and

iv) finalize and distribute the air quality forecast product.

This would correspond to 0.2 of a person-year for a year-round operation. Additional sites will require about 15 minutes (.05 person-years) each. Since ozone is only a problem in the Vancouver area between May and September, this time will be reduced for ozone concentration forecasting. Similar reductions would be expected for carbon monoxide forecasts.

SECTION 7

AIR QUALITY FORECAST SERVICE OPTIONS

Table 7.1 summarizes the air quality forecast service options based upon the forecasts components dealt with in the previous two sections.

TABLE 7.1. Options for providing air quality forecast services in British Columbia.

Air Quality Forecast Service Option	*Possible Forecast Components*	*Description of Service*	*AES Operational Person-Years*
OPTION 1: **METEOROLOGICAL STAGNATION/ VENTILATION FORECAST**	Regional Stagnation Forecast	An automated synoptic scale stagnation forecast guidance (provided by CMC or produced locally) would be tailored for individual locations or regions in British Columbia.	0.3[1]
	Improved Smoke Control Forecast	The current smoke control forecast, accepted and used by the forestry sector in British Columbia as a measure of the ability of the atmosphere to disperse smoke from forestry burning, would be improved by developing an updated version of the ventilation index.	0.1
OPTION 2: **AIR POLLUTANT CONCENTRATION FORECAST**	A local dispersion forecast. (Four site forecasts).	A daily forecast of the expected concentrations or concentration categories of pollutants produced locally by such sources as residential heating (wood smoke) or motor vehicles would be produced.	0.5
	Forecasting the longer range transport of air pollutants. (Two site forecasts).	A daily forecast of the expected concentrations or concentration categories of pollutants caused by the impact of a distant source of pollutants on a city or town would be produced.	0.3
	Greater Vancouver air quality forecast. (Three site forecasts).	A daily forecast of air pollutant (such as ozone) concentrations or concentration categories at several locations in Greater Vancouver would be produced. This is feasible because the GVRD already has an excellent air pollutant monitoring system in place.	0.3

[1] Required only if the CMC guidance does not prove to be of sufficient quality and resolution to produce a totally automated regional stagnation forecast product.

Option 1 in Table 7.1 deals only with ability of the atmosphere to disperse pollutants. Option 2 goes one step further and encompasses those approaches dealing with air pollutant concentrations.

CONCLUSION

British Columbians are becoming increasingly reluctant to accept poor air quality. They are becoming more aware of the health risks, the deterioration of visibility and the hazards threat to agriculture associated with air pollution. AES could contribute a useful and visible service to British Columbians in this field by providing improved air quality forecasts to the public. Significant benefits to the public could be realized. The ongoing costs to AES of this type of service are not high.

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12 HR FORECAST FOR

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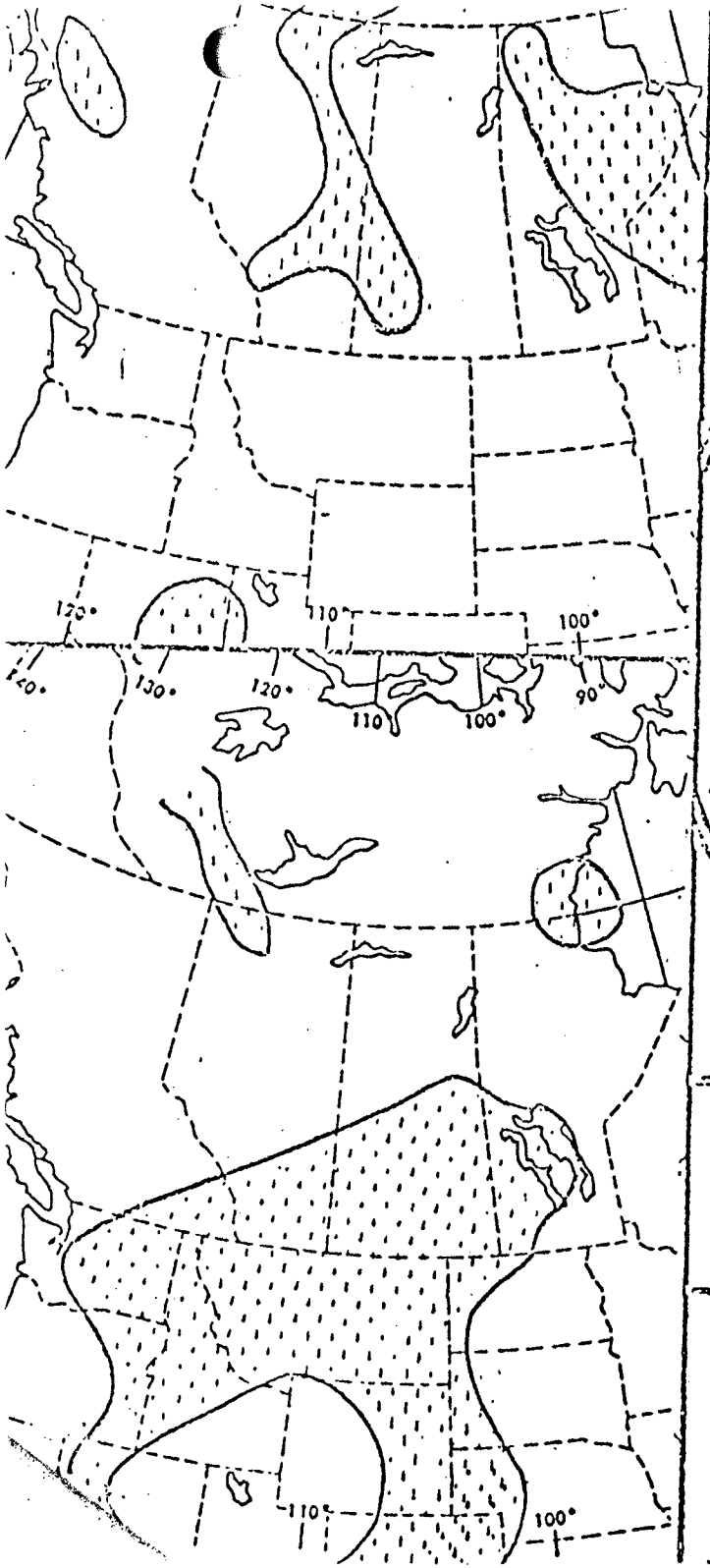


CANADIAN WEATHER SERVICE

CMC

STAGNATION AREA FORECASTS

2

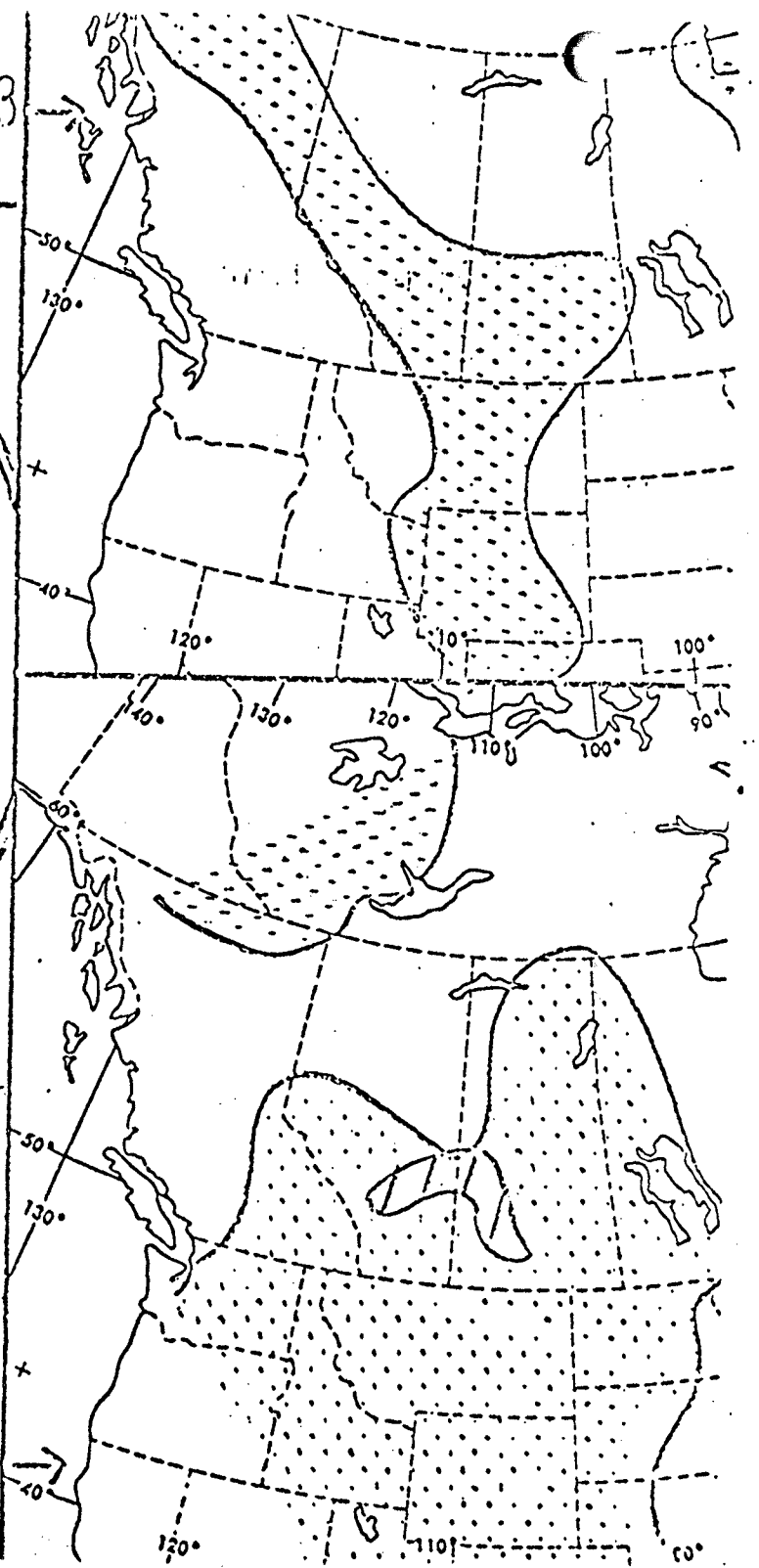
CHART NO. 33

24 HR FORECAST FOR

1200Z OCT 221973

36 HR FORECAST —— AND COMPOSITE////////

FOR 0000Z OCT 231973



12 HR FORECAST FOR

0000Z OCT 22 1973

CANADIAN WEATHER SERVICE

CMC

STAGNATION AREA FORECASTS

2

CHART NO. 38

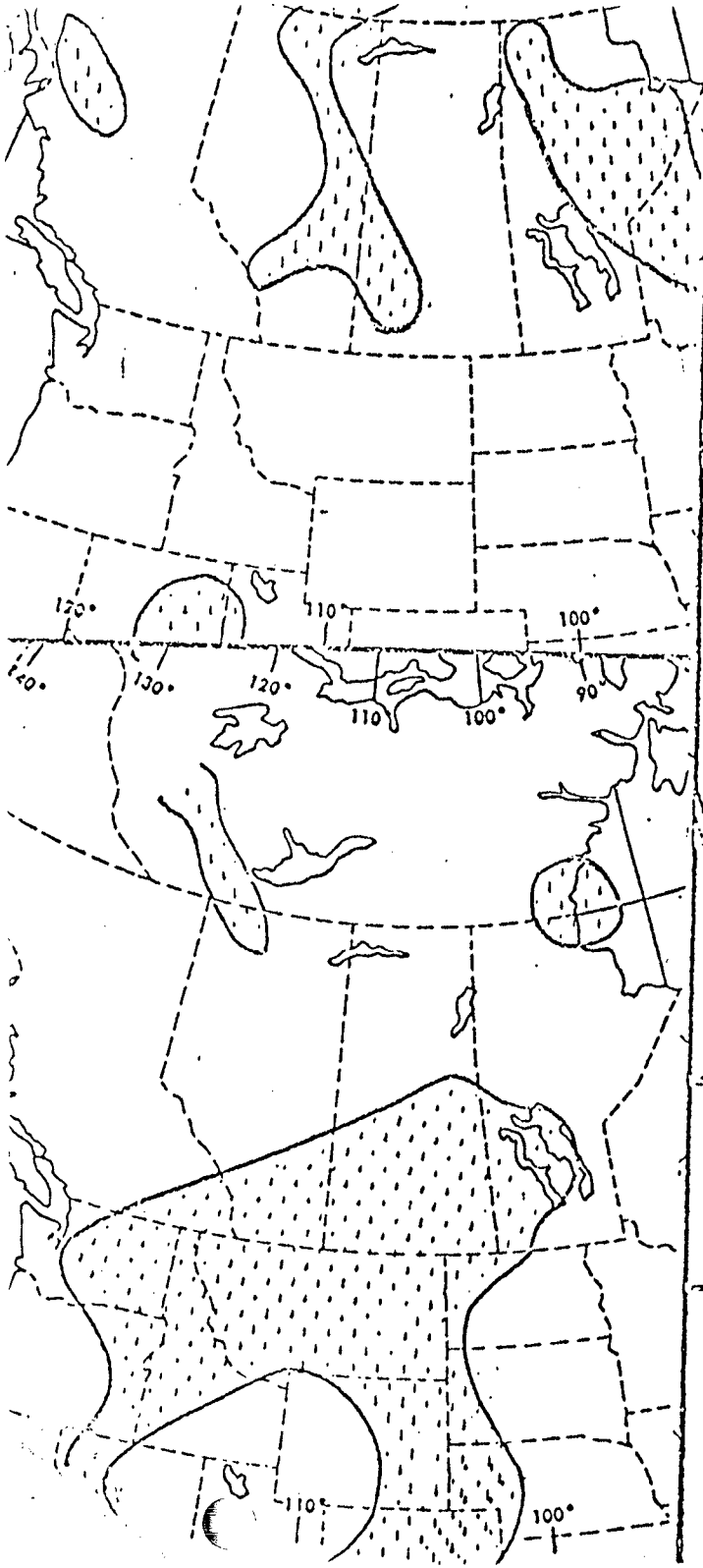
24 HR FORECAST FOR

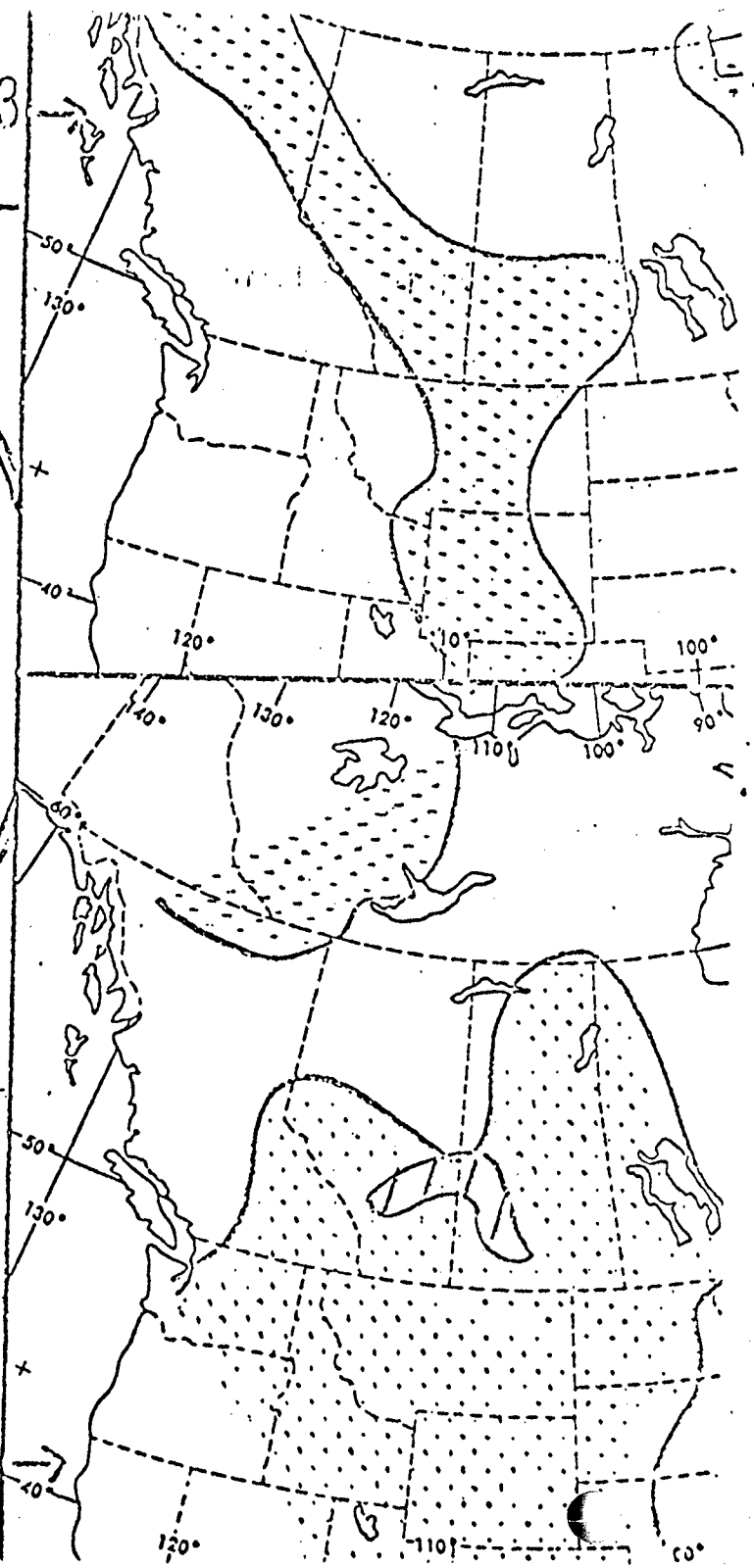
1200Z OCT 22 1973

36 HR FORECAST —— AND COMPOSITE ////////

FOR 0000Z OCT 23 1973

62-2140





PREPARATION OF THE AIR STAGNATION WORKSHEET AND THE POLLUTION FORECAST

COMPLETION OF THE AIR STAGNATION WORKSHEET PROVIDES THE DATA FOR THE MORNING AIR POLLUTION FORECAST WHICH IS DUE ON THE TELETYPE MACHINE BY 9 AM EACH WEEKDAY MORNING. THE FOLLOWING ELEMENTS ARE PROVIDED:

SYNOPSIS: A detailed description of the synoptic pattern as it pertains to the State of Washington during the next 48 hours. The FP-3 is usually the basic guidance.

FORECASTS OF MAXIMUM TEMPERATURES: For Seattle, Yakima, and Spokane. The time period is today and tomorrow. Forecast aids include soundings, FMUS 10, and the SEA FM2.

FAX MAP STAGNATIONS AREAS: Are depicted on Fax Map FO 74C, which can be found on the extra Forecaster desk.

ZONE FORECASTS: Are provided for the eight areas shown on the work sheet. Where situations warrant, zones may be lumped together. Forecast maximum mixing heights for afternoon together with mean wind speed and direction throughout the layer. This is followed by minimum mixing heights and transport winds for the next morning. The third and last entry is a forecast of maximum mixing height and transport wind for the following afternoon.

VENTILATION: is the product of the mixing height and the mean wind speed throughout the layer. Graphs for Eastern and Western Washington are prepared and can be found at the back of the Air Pollution Clip board. Category forecasts are made for all areas and usually vary between morning and afternoon. The time period of the forecasts is today and tomorrow. (? NOT TOO ?)

STATE FORECASTS: ~~are transmitted on the teletype~~ following the Ventilation forecasts. Use the latest FP1 tape.

AFTERNOON DISCUSSION: is made and transmitted on the teletype by 3 PM each weekday afternoon. This is the opportunity to make any changes to the morning forecast if required.

UPPER AIR SOUNDINGS: are the basic tool of the Air Pollution Forecaster. From this single diagram you can determine maximum mixing heights, minimum mixing heights, and a good approximation of the maximum temperature for the day. Input of maximum temperature forecasts for the following day will ~~permit~~ ~~permit~~ indicate a potential 36 hour maximum mixing height.

UPPER WIND DATA: will allow for the computation of the mean wind speed and direction through the mixing level. FD, FO22, and FOUS 60 forecast winds will provide 24 and 36 hour guidance for transport winds.

WD 6/25/74

*** MONTHLY VERIFICATION CMC**AIR STAGNATION FORECASTS***

.. SEPTEMBER...1973.

VERIFYING MEASURE	FCST LENGTH (VERIFYING TIME) 12HRF (00Z)	24HRF (00Z)	36HRF (00Z)	12HRF (12Z)	24HRF (12Z)	36HRF (12Z)
PERC OBS OF STAGN CORRECTLY FCST...	47.54	38.42	34.38	50.09	36.36	38.38
PERC FCSTS OF STAGN CORRECT.....	52.50	39.47	38.27	46.60	35.42	35.45
PERC OBS OF NO STAGN CORRECTLY FCST	74.33	64.84	66.91	70.08	65.44	63.56
PERC FCSTS OF NO STAGN CORRECT.....	70.36	63.82	63.08	72.92	66.36	66.43
PERFCOBS OF STAGN OR OF NO STAGN CORRECTLY FCST	64.31	54.96	54.75	63.23	55.48	54.93
PERC FCSTS OF STAGN OR OF NO STAGN CORRECT	64.31	54.96	54.75	63.23	55.48	54.93
BIAS.....	0.91	0.97	0.90	1.07	1.03	1.08
THREAT SCORE.....	33.24	24.17	22.12	31.82	21.86	22.59
HEIDKE SKILL SCORE.....	0.22	0.03	0.01	0.20	0.02	0.02
YULE COEFF OF ASSOCIATION.....	44.80	6.99	2.88	40.30	3.93	4.14
PERC OBS WHICH ARE STAGN.....	37.38	37.38	37.38	34.27	34.27	34.27

USE OF COMPUTER PRODUCTS IN AIR POLLUTION FORECASTING

THERE ARE A FEW, RELATIVELY NEW, COMPUTER PRODUCTS AVAILABLE WHICH CAN BE OF CONSIDERABLE HELP TO THE AIR POLLUTION FORECASTER. THE BIG ADVANTAGE OF THESE PRODUCTS IS THE LONGER RANGE ASPECT, A FACTOR WHICH IS USUALLY THE MOST DIFFICULT PART OF THE FORECAST. A BRIEF DESCRIPTION OF EACH PRODUCT, AND ITS POTENTIAL, FOLLOWS:

FOUS ~~60~~ 72:

PROBABLY THE MOST USEFUL OF THE COMPUTER PRODUCTS, IN THAT IT PROVIDES FORECASTS OF A NUMBER OF METEOROLOGICAL PARAMETERS. FORECASTS OF BOUNDARY LEVEL WINDS OUT TO 48 HOURS ARE PARTICULARLY HELPFUL. OTHER ITEMS OF USE AND INTEREST INCLUDE FORECASTS OF PRECIPITATION AMOUNTS, LIFTING INDEX FORECASTS, MULTILEVEL RELATIVE HUMIDITY FORECASTS, AND FORECASTS OF VERTICAL VELOCITY.

FMUS 10:

FORECASTS OF MAXIMUM AND MINIMUM TEMPERATURE FOR SELECTED CITIES OUT TO 72 HOURS.

FOUS 12:

PRECIPITATION PROBABILITY FORECASTS FOR SELECTED CITIES IN 12 HOUR SEGMENTS FOR A PERIOD OF 48 HOURS.

FO 22:

FORECASTS OF SURFACE WINDS FOR SELECTED CITIES IN 6 HOUR INTERVALS FOR A PERIOD OF 48 HOURS. DOES NOT INDICATE GUSTINESS.....

FOUS 50:

24 HOUR FORECASTS OF HEIGHTS, TEMPERATURE, AND DEWPOINT FOR SURFACE 850 AND 700 MB LEVELS. ALSO 24 HOUR FORECASTS OF K VALUES FOR STABILITY PURPOSES.

SATELLITE PICTURES:

NEW HIGH RESOLUTION SATELLITE PICTURES SHOULD PROVIDE BETTER LOCATIONS OF CLOUDS, TROUGHS, AND FRONTAL SYSTEMS.

6/26/74 WD

AIR POLLUTION WORKSHEET

MAX TEMPS

	YDA	FOUS 12 TDA	FOUS 12 TMR	FP4 TDA	FP4 TMR	FCST TDA	FCST TMR	FOUS 22 POPS		
SEA										
UIL										
YKM										
GEG										
ALW										
PDX										

FOUS 72 (00Z) BOUNDARY LAYER WINDS

	24HR	36HR	48HR
YVR			

	MIXG HGT	MEAN WND DIR	MN SPD	MIXG HGT	MEAN WND DIR	MN SPD	MIXG HGT	MEAN WND DIR	MN SPD
Coast & Northwest Interior									
Southwest Interior									
Northeast Wa & Okanogen									
Central Basin & Paloose Mtns									

SYNOPSIS:

DATE_____

Puget Sound									

VENTILATION WORKSHEET

DATE _____

Maximum Temperature Forecasts

YDA MAX	FOUS 12 TDA	FOUS 12 TMRW	SEA FP4 TDA	SEA FP4 TMRW	FCST MAX TDA	FCST MAX TMRW

POPS _____ UIL POPS _____

POPS _____ GEG POPS _____

ZONE FORECASTS

Heights in feet, Wind direction in degrees, Speed in knots

COAST	NW INTERIOR
PUGET SOUND	SW INTERIOR
NE WASH	OKANOGAN
CENTRAL BASIN	PALOUSE/BLUE MOUNTAINS

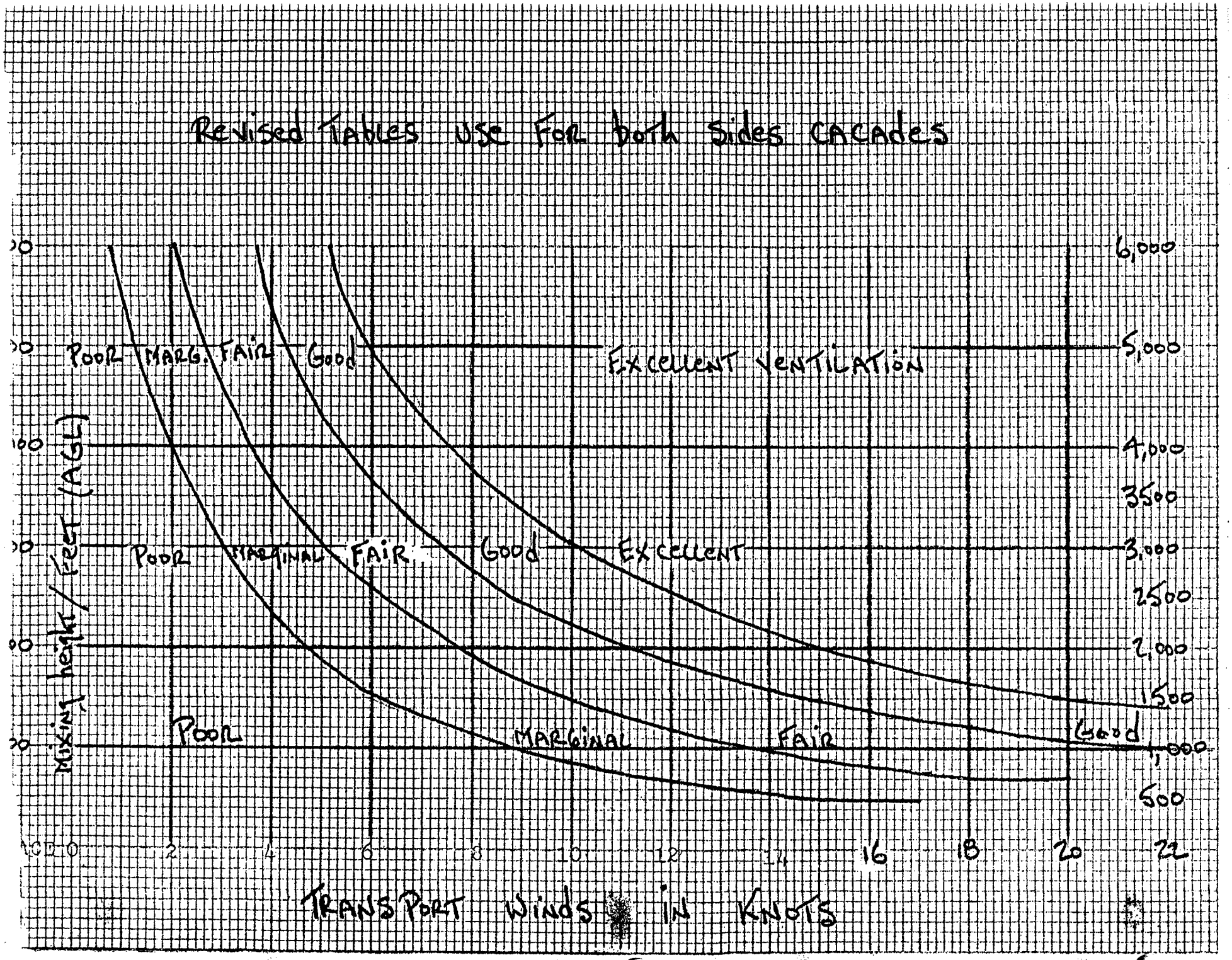
SYNOPSIS

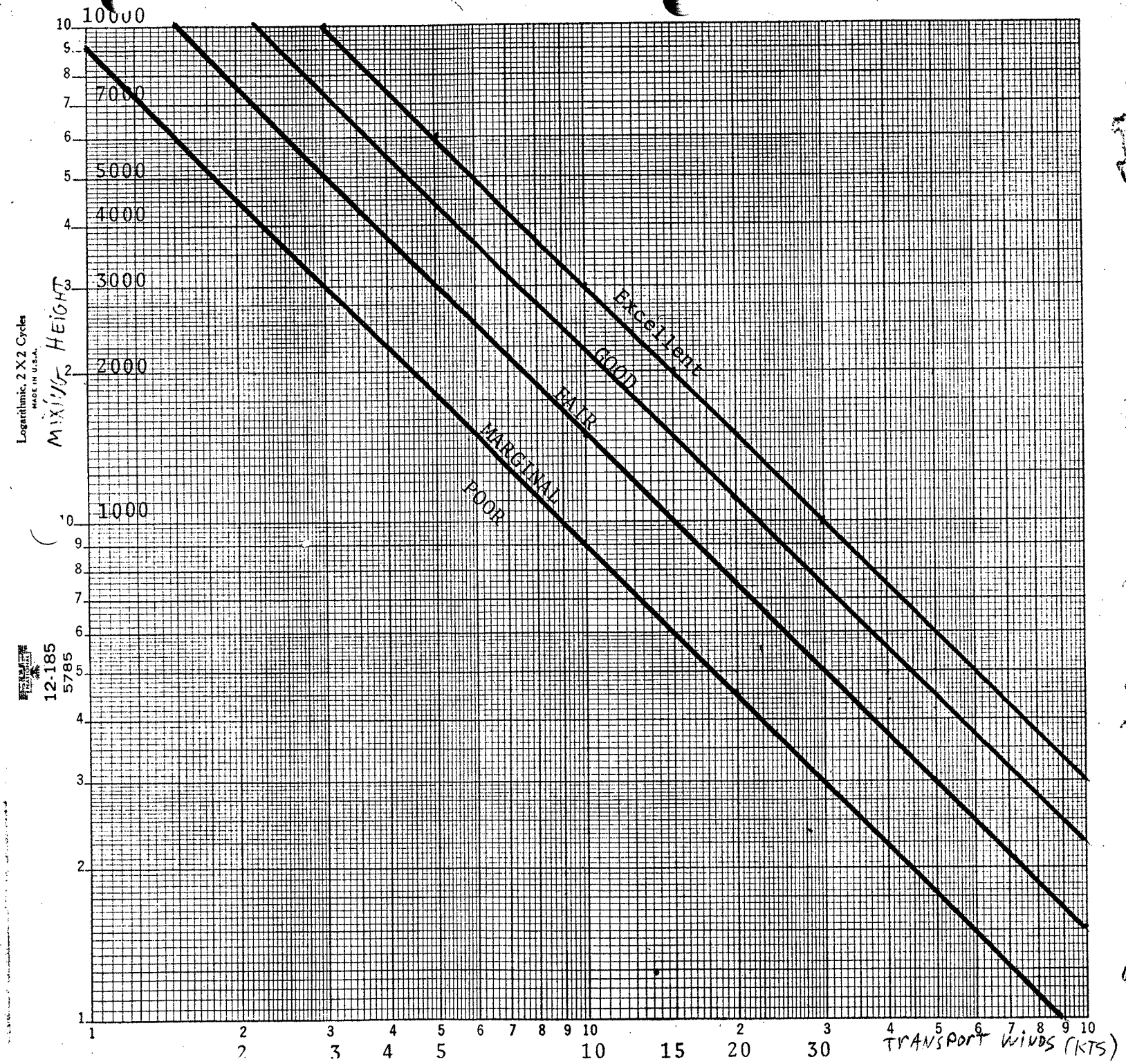
VENTILATION

PSAPCA AQI FOR TDA TMRW

EVT
SEA
TCM

_____ Early mrng FZ6 and Zones transmitted ?
_____ CNDN SL PRES TO ASARCO
_____ Call out and tape UIL and GEG 12Z raobs transmit on AP and Lcl Loop ckts.
_____ Reperforator on before 07:45AM
_____ Call ALW (0745P) Lcl AP discussion
_____ Transmit PB sounding (RAWARC & CG ckts)
_____ Call GEG (0815P) AP discussion
_____ Check AP Ckt for last min. data
_____ ALW 8-442-5470
GEG 8-439-3761 OR 3762
_____ 8:30am deadline for Forecasts on AP ckt
_____ 9am FZ6 transmitted on AP ckt
_____ 10am Zones transmitted on AP ckt
_____ 12pm CNDN SL PRES TO ASARCO
_____ 3pm FZ6 transmitted on AP ckt
_____ Afternoon Discussion (Forecast update) due on AP ckt by 3pm...


Revised Tables use for both sides Cascades
Poor
Marg.
Fair
Good
Excellent Ventilation
Poor
Marginal
Fair
Good
Excellent
Poor
Marginal
Fair
Good
Mixing height / feet (AGL)
6,000
5,000
4,000
3500
3,000
2500
2,000
1500
1,000
500
0
2
4
6
8
10
12
14
16
18
20
22
Transport winds in knots


10000
7000
5000
4000
3000
2000
1000
MIXING HEIGHT
Excellent
GOOD
FAIR
MARGINAL
POOR
TRANSPORT WINDS (KTS)
Logarithmic, 2 X 2 Cycles
MADE IN U.S.A.
12-185
5785

A lower atmosphere sounding unit began operating on the east shore of Portage Bay in Seattle during 1971. The Department of Ecology operates the station. Normal operation provides one slow ascent sounding to 700 millibars about 0700 local time each Monday through Friday except on holidays. This sounding is the primary source of lower atmosphere data in the Puget Sound Basin and is an essential basis for many forecasts including air stagnation forecasts. Each sounding is reasonably representative of the lower atmosphere in the entire Puget Sound area. The Agency makes regular use of the sounding in evaluating and interpreting air quality data and also enters the sounding in a computerized data base.

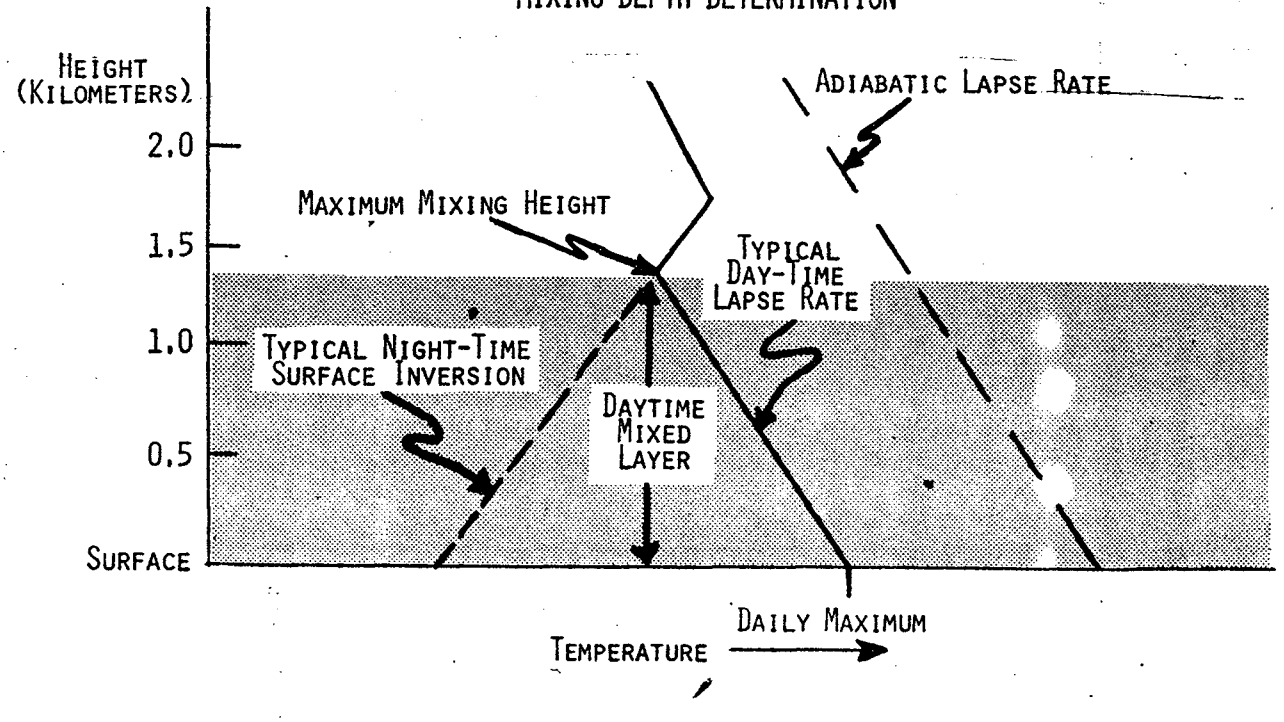
The figure below illustrates some key concepts. Temperature increasing with height is termed a TEMPERATURE INVERSION. A temperature inversion limits the height to which pollutants are mixed or dispersed vertically. The MIXING DEPTH is simply the height from the surface to the temperature inversion base. The mixing depth continuously changes responding to the daytime increase or nighttime decrease of surface temperature, and to other processes which modify the temperature at the ground or aloft.

On days with no temperature inversion, the mixing depth is unlimited and this contributes to rapid pollutant dispersion and good air quality. In contrast, a temperature inversion near the surface thick enough so that the daytime mixing depth will not exceed the depth of the inversion significantly restricts vertical dispersion. This stable condition is associated with higher concentrations of air pollutants.

Four soundings during 1979 are plotted and presented on the following pages. The temperature is represented by a solid line connecting actual data values enclosed by circles. The dewpoint temperature is represented by a dashed line connecting actual data values enclosed by triangles. The measured winds at several heights are plotted to the right of the sounding and also reported as numerical values in degrees/knots.

These soundings represent days on which pollutant levels were high and exceeded standards at many stations. Maximum OZONE levels for all stations were recorded on JUL 17. Maximum or second high 1 hour and 8 hour average CARBON MONOXIDE values were recorded for several stations on SEP 14 and NOV 14. Many stations recorded TSP values exceeding the 24 hour standard on JUL 17, OCT 12, and NOV 14. No TSP sampling was conducted on SEP 14. An Air Stagnation Advisory was in effect on OCT 12 and NOV 14.

MIXING DEPTH DETERMINATION



NNNN

↓↓A
ZCZC WBC599
ADMN RWRE 071430
NATIONAL WEATHER SERVICE SEATTLE WA
730AM PDT MON MAY 07 1979

MORNING WASHINGTON DISPERSION DISCUSSION

SYNOPSIS
WEAKENING SURFACE LOW PRESSURE CENTER AT 50N 130W MOVING SLOWLY EASTWARD. AIR MAASS COLD AND UNSTABLE. SCATTERED SHOWERS WESTERN WASHINGTON WIDELY SCATTERED SHOWERS EASTERN WASHINGTON TODAY. DIMINISHING SHOWER ACTIVITY TOMORROW.

MAXIMUM TEMPERATURE FORECASTS

	TODAY	TOMORROW
SEATTLE	52/57	52/57
YAKIMA	60/65	60/65
SPOKANE	52/57	52/57

ZONE FORECASTS

COAST AND NW INTERIOR	4000/200/10	700/220/07	3000/240/10
SW INTERIOR	5000/200/15	700/220/18	4000/240/15
CENTRAL BASIN AND PALOUSE/BLUE MTNS	UNL/220/10	500/230/05	UNL/240/10
NE WASHINGTON AND OKANOGAN	UNL/230/10	500/240/07	UNL/240/08

VENTILATION
ALL AREAS EXCELLENT DURING AFTERNOON POOR AT NIGHT.
HULL

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