BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

HAT CREEK PROJECT

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THE DESIGN OF A METEOROLOGICAL CONTROL SYSTEM FOR THE HAT CREEK PROJECT

SYSTEM ENGINEERING DIVISION

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THE DESIGN OF A METEOROLOGICAL CONTROL SYSTEM FOR THE HAT CREEK PROJECT

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SUMMARY

This document gives an in depth description of the meteorological control system (MCS) to be utilized with the Hat Creek project, a proposed 2000 MW coal-fired electric generating station. The MCS is basically a means of predicting adverse meteorological conditions in advance of their occurrence so that measures can be taken to avoid the high ground-level sulphur dioxide (SO_2) concentrations which might otherwise occur under these conditions. Meteorological forecasting combined with air quality modelling techniques are used to make the advance predictions. The measures to be taken to avoid high concentrations involve reduction in SO_2 emission rate, either through reducing load on the powerplant or by switching to an alternate fuel which is both lower in sulphur and higher in heating value, thus resulting in a lower consumption rate .

The MCS will be extensively automated, in that the air quality model will be computerized and the stack gas monitors, ground-level concentration monitors and meteorological monitors will all be "real-time" connected to a central computer facility. The sytem will, however, include a staff meteorologist as part of the forecasting and interpretation. The powerplant operators can on any given day select a *preferred control strategy; that is, a sequence of specific emission* reduction steps, each causing a greater reduction than the previous step. The control decision model (part of the MCS) will then establish if any of the steps need to be taken, and if it is determined that control is necessary, it also specifies which step needs to be taken for each hour in the upcoming forecast period. Forecasts will be updated every 8 hours and will cover a 41-hour period in the future.

MCS reliability should be greatly enhanced by MCS operation during early years of the project when the powerplant will operate at partial load. During this period SO_2 emissions are much less and are

not expected to result in ground-level concentrations greater than proposed guideline values under any meteorological conditions. However, the MCS will still provide predictions of ground-level concentrations which can compared to measured values and used to improve prediction accuracy. When fully operational, the powerplant with the proposed MCS is not expected to result in concentrations in excess of the proposal guideline values.

SECTION 1.0 - INTRODUCTION

British Columbia Hydro and Power Authority (B.C. Hydro) proposes to construct a coal-fired electric generating station in the upper Hat Creek Valley, approximately 200 km northeast of Vancouver, British Columbia. This document is intended to provide design information for a meteorological control system (MCS) to be used to maintain ambient sulphur dioxide (SO_2) concentrations within recommended guidelines in the area surrounding the project site.

1.1 ENVIRONMENTAL PROTECTION PHILOSOPHY

B.C. Hydro proposes that strategies to control the air quality effects of the proposed Hat Creek Project be based on control of ambient contaminant concentrations rather than through continuous emission rate limitations. In this mode of operation, excesses of ambient concentration objectives would be avoided by a temporary reduction in emissions during those meteorological conditions that could produce concentrations above the specified objectives. Crucial to the success of such an approach is the development of:

1. Ambient concentration objectives that insure protection of the environment.

2. A system of predicting possible excesses of these ambient objectives before they occur to allow time for a temporary emission control measure to be taken.

Extensive analyses have been conducted by B.C. Hydro to develop and recommend concentration guidelines which will prevent adverse effects on public health or welfare. These included detailed examination of available literature on health effects of the various pollutants and an examination of similar guideline development conducted by various

1.1 ENVIRONMENTAL PROTECTION PHILOSOPHY - (Cont'd)

government agencies in both Canada and the United States. Table 1-1 shows the ambient concentration guidelines recommended by B.C. Hydro along with the pollution control objectives published by the British Columbia Pollution Control Bureau (PCB), for mining, smelting and related industries.

TABLE 1-1

AMBIENT SO_2 CONCENTRATION GUIDLINES
RECOMMENDED BY B.C. HYDRO AND AMBIENT SO_2 CONCENTRATION
CONTROL OBJECTIVES PUBLISHED BY THE PCB
(μg/m³)

SO_2 Concentrations	B.C. Hydro	PCB Range
1-hour maximum	None	450 to 900
3-hour maximum	665	375 to 665
24-hour maxmimum	260	160 to 260
Annual arithmetic average	50	25 to 50

The Hat Creek Project will emit several contaminants from a number of sources, but analyses conducted by Environmental Research and Technology (ERT), Inc.[1] have identified the major point of emission to be the powerplant stack and the primary pollutant to be SO_2. As a result, the MCS has been designed specifically to control ambient ground-level SO_2 concentrations resulting from the burning of Hat Creek coal in the main boiler system. However, the MCS will have an effect on the emission rate of the other contaminants since all control actions utilized by the MCS result in a reduced coal consumption rate which will generally result in lower particulate, nitrogen oxides and trace elements emissions.

(b) Syncrude Canada Ltd.

The Athabasca tar sands development in Alberta, Canada is utilizing an MCS to control hydrogen sulphide and SO_2 concentrations. They are currently operating the system in the "reactive" mode which differs from the B.C. Hydro "predictive" mode approach. In the reactive mode, control actions are initiated when a measured value crosses a predetermined threshold value. In the predictive mode, it is the advance warning that such an event may be about to occur that triggers the control action. The reactive mode can be effective when there is little plume travel time between the points of emission and impact. Since operations have only been proceeding since August of 1978, there is insufficient data available to draw conclusions on the effectiveness of the system in use at the tar sands.

(c) Ontario Hydro

Ontario Hydro is currently operating a predictive-mode MCS for their Lakeview station near Toronto. This system utilizes meteorological forecasts to predict upcoming SO_2 episodes. Reduction in load is the primary control action, since fuel switching is not practical for their operation. Since the station is located very close to a major metropolitan area and therefore many other SO_2 sources, it is very difficult to assess the effectiveness of the MCS.

The Lambton station near Sarnia, Ontario, also utilizes an MCS based on meteorological forecasts. Here the primary control action is to switch to low sulphur coal. They are currently operating between 60 and 70 fuel switches per year. The Lambton station MCS is viewed by Ontario Hydro to be overly conservative and requiring more fuel switches than necessary to meet the control objectives.[5]

(d) Cominco

Cominco is currently developing an MCS for control of emissions from their smelter near Trail, B.C. The MCS will operate on meteorological forecasts and will curtail emissions by reduction in production rate. The program is still in the development stage.

(e) Afton Mines Ltd.

Afton Mines Ltd. operate a smelter operation in the vicinity of Kamloops, B.C. They utilize a reactive mode MCS to control emissions. The system involves three SO_2 monitors such that if any one of the monitors registers a concentration greater than a pre-set level, operations at the smelter must be reduced or shut down regardless of the wind direction or the influence on these monitors from other SO_2 sources.

(f) Tennessee Valley Authority (TVA)

Load shifting is being demonstrated by the Tennessee Valley Authority as a feasible, reliable form of dynamic emissions control for meeting air quality standards. In September 1969, TVA began operating an intermittent SO_2 control program at their Paradise Steam Plant in west-central Kentucky. Plant-generating load reductions reduce emissions whenever plume dispersion is unfavourable. These conditions are identified by on-site meteorological measurements which measure adverse atmospheric dispersion characteristics. The TVA program includes extensive pre-operational field studies to monitor maximum ground level concentrations and collect added information about plume characteristics through helicopter and mobile ground measurements. This information is combined with output from a critical plume dispersion model to establish nine meteorological and plume dispersion criteria which in turn determine when critical conditions threaten standards and require emissions reductions.

1.3 EXISTING MCS EXPERIENCE - (Cont'd)

The TVA program has demonstrated the effectiveness of these emissions control techniques. During the first 39 months of this program, there were 41 days requiring reduction of the generating load. The magnitude of the reduction ranged from 26 to 960 MW with an average of 454 MW. The average duration of the reduction was 3.6 hours, with a minimum of 24 minutes and a maximum of 5.8 hours. Frequency distributions of measured SO_2 concentrations before and after implementation of TVA's SO_2 control program at the Paradise Steam Plant demonstrate that although Kentucky's ambient standards were violated before the program was begun, but they were not voilated after the initiation of this program.

TVA has emission control programs at two other plants and plans to perform studies at six additional plants.

(g) American Smelting and Refining Company

The American Smelting and Refining Company (ASARCO) has demonstrated the effectiveness of a program for emissions control by curtailing smelter operations. ASARCO has installed a system that includes 18 SO_2 monitoring stations at their El Paso smelting complex. The system enables ASARCO to curtail operations to reduce or eliminate unacceptable SO_2 concentrations. A real-time method of monitoring and forecasting concentrations has been developed to enable ASARCO to achieve preventive curtailment by reducing the time lag between detection and reversal of an upward trend in SO_2 concentrations. ASARCO curtailment programs for dynamic emissions control at their El Paso and Tacoma complexes have substantially reduced their air quality violations.

SECTION 2.0 - THE HAT CREEK METEOROLOGICAL CONTROL SYSTEM

2.1 APPLICABILITY OF THE MCS APPROACH TO HAT CREEK

The proposed Hat Creek Project would be located in a remote setting that is relatively free from the influences of other SO_2 sources within a radius of 25 km. The location of the powerplant stack, the height of emission and the subsequent rise of the plume in the atmosphere insure that low ground-level concentrations will be maintained under normal (most frequent) atmospheric conditions. In an analysis of alternative SO_2 control systems for the Hat Creek project,[1] ERT estimated that intermittent control measures need be taken during only 280 hours per year (approximately 3 percent of the time). In addition, a benefit/cost analysis conducted by B.C. Hydro[2] has shown that the cost of installing stack gas scrubbers at the powerplant is more than an order of magnitude greater than the total cost of utilizing the MCS approach. For these reasons, although space provision will be made for the possible addition of a scrubber system at a later date if necessary, the current plans for the Hat Creek project call for utilization of an MCS as the primary SO_2 control system. Additional measures to be taken by B.C. Hydro to control ambient SO_2 concentrations include the location of the plant high above the valley floor and the use of a tall (244 m) multi-flue single stack to assist in plume rise. Both of these measures have been undertaken solely to reduce ground-level contaminant concentrations.

2.2 MCS GENERAL DESCRIPTION

The operation of the MCS centers around the use of a computer model to simulate atmospheric behaviour and air quality concentrations. The model is given a forecast of future meteorological and plant operating conditions and then calculates concentrations which will occur under those conditions. The predictions are then compared to guideline levels to determine if it is necessary to take a suitable control action

Inputs to the model can be divided into two groups: those involving the meteorological conditions, and those involving the emission conditions (emission rate, stack exit temperature, exit velocity and other parameters). The forecast of meteorological conditions to be used as model input will be based on data from a number of sources. Most important among these is the on-site meteorological monitoring network. Combining this with information on larger-scale atmospheric patterns (synoptic-scale data), meteorological trends can be recognized and their influences on future meteorological conditions can be characterized. On-site air quality data in the form of measured concentrations of various contaminants in the Hat Creek area can also be used to identify trends in meteorological and air quality patterns. All of these sources of information will be used by the forecasting function of the MCS to predict for future time periods a set of specific parameters (e.g. wind speeds, wind directions, turbulence characteristics of the atmosphere, temperatures), which will affect plant operation.

The model also receives information regarding the operations of the powerplant. Specifically, operations personnel detail the projected operating conditions of the plant for the next period (number of boilers in operation, loads and any departures from normal operating conditions). The model then uses the input meteorological and operations information to determine if any high contaminant concentrations will occur in the immediate future. In addition to the projected operating conditions, actual operating conditions and measured emission rates for the previous period are provided to allow the model to make predictions of SO_2 concentrations over a period of the next 24 hours. Actual SO_2 emissions will be determined by stack gas monitors, and recorded.

2.2 MCS GENERAL DESCRIPTION - (Cont'd)

The model also is designed to provide a recommended control action to the decision-making group in powerplant operations control. There is an interaction between management of power production and the modelling function so that the effects of alternate approaches to the recommended action may be considered. Eventually, appropriate operating instructions will be implemented. These instructions will have environmental protection as the primary concern. Only under emergency power requirement situations would a predicted guideline excess not be responded to by a control action.

As part of a quality assurance program, actual operating conditions, including measured emission rates from stack monitors, will be recorded and provided to a model improvement function. In addition, the model improvement function will receive model predictions and measured concentrations. The purpose of this function is to compare model predictions with measured concentrations. In this way the model can be improved to ensure that its future performance is as accurate as possible.

2.3 SEQUENCE OF IMPLEMENTATION

In all the analyses of the need for control measures at the Hat Creek Project, the assumption has been made that all four units in the powerplant will be operating at full capacity. However, the powerplant will not operate at full load continuously and it will be constructed unit by unit so that it will not generate 2000 MW until it is fully comissioned. During this period of operation at less that 2000 MW SO_2 emissions will be at a reduced rate as well and consequently will pose appropriately smaller potential for concentrations in excess of the guideline levels. However, it will always be possible to operate the MCS and, in particular, to improve the model by checking predictions with measured values. During this period, considerable knowledge will be gained concerning the dispersion climatology of the Hat Creek area. Because of the reduced load, this

2.3 SEQUENCE OF IMPLEMENTATION - (Cont'd)

knowledge can be gained without risk to the environment, and can be used to ensure that when the plant has its full 2000 MW installed capacity, the MCS will be ready as a proven effective control measure. It will also be possible to record actual emission rates with stack gas monitors and improve prediction accuracy.

As meteorological data have been collected at the site by B.C. Hydro since 1974 and will continue to be collected for many years prior to the first unit coming on line, the forecasting function of the MCS will have an extensive data base. Because of this, correlation between synoptic-scale and local-scale meteorological parameters can be developed long before the MCS is actually put into operation. This will also ensure that when the installed plant capacity reaches 2000 MW, the MCS will be a well-tuned system capable of accurately estimating the effects of Hat Creek emissions on ground level concentrations.

SECTION 3.0 - DETAILS OF THE RECOMMENDED METEOROLOGICAL CONTROL SYSTEM

This section first presents an overview of the recommended MCS. In subsequent subsections of this major section there are detailed discussions of: the air quality and meteorological monitoring subsystem, data acquisition and communications facilities, and the predictive, control decision, and feedback subsystems.

3.1 OVERVIEW

The Hat Creek MCS program, which is summarized here and described in technical detail in this section, has been developed with the assistance of Environmental Research and Technology (ERT), who have over 5 years experience with MCS components and operating systems. In particular, the proposed MCS is based on extensive experience in the operation of similar systems to control ambient SO_2 concentrations in the environs of relatively isolated powerplant and industrial facilities in the central United States. These systems have been successfully designed and operated for areas of complex terrain and other complex conditions, e.g., multiple stacks, mixed fuels (coal, oil and gas), fuel switching, and load reduction. Uncertainties regarding system performance have been minimized, and the experience can be applied directly to the Hat Creek program. The design itself may be described in terms of a generic MCS, as shown in Fig. 3-1. This simplified block diagram shows each part of the generic MCS as either a constraint, a process, or as part of the control system. The demand for electricity is a constraint which acts on the process (generation of electricity) to produce contaminant emissions. The atmosphere acts upon the process emissions and will be the governing constraint, with given emissions, on ambient air quality.

The control system will operate in three control loops: an active control loop based upon well-calibrated predictions of ambient air quality; a feedback control loop which augments and backs up the

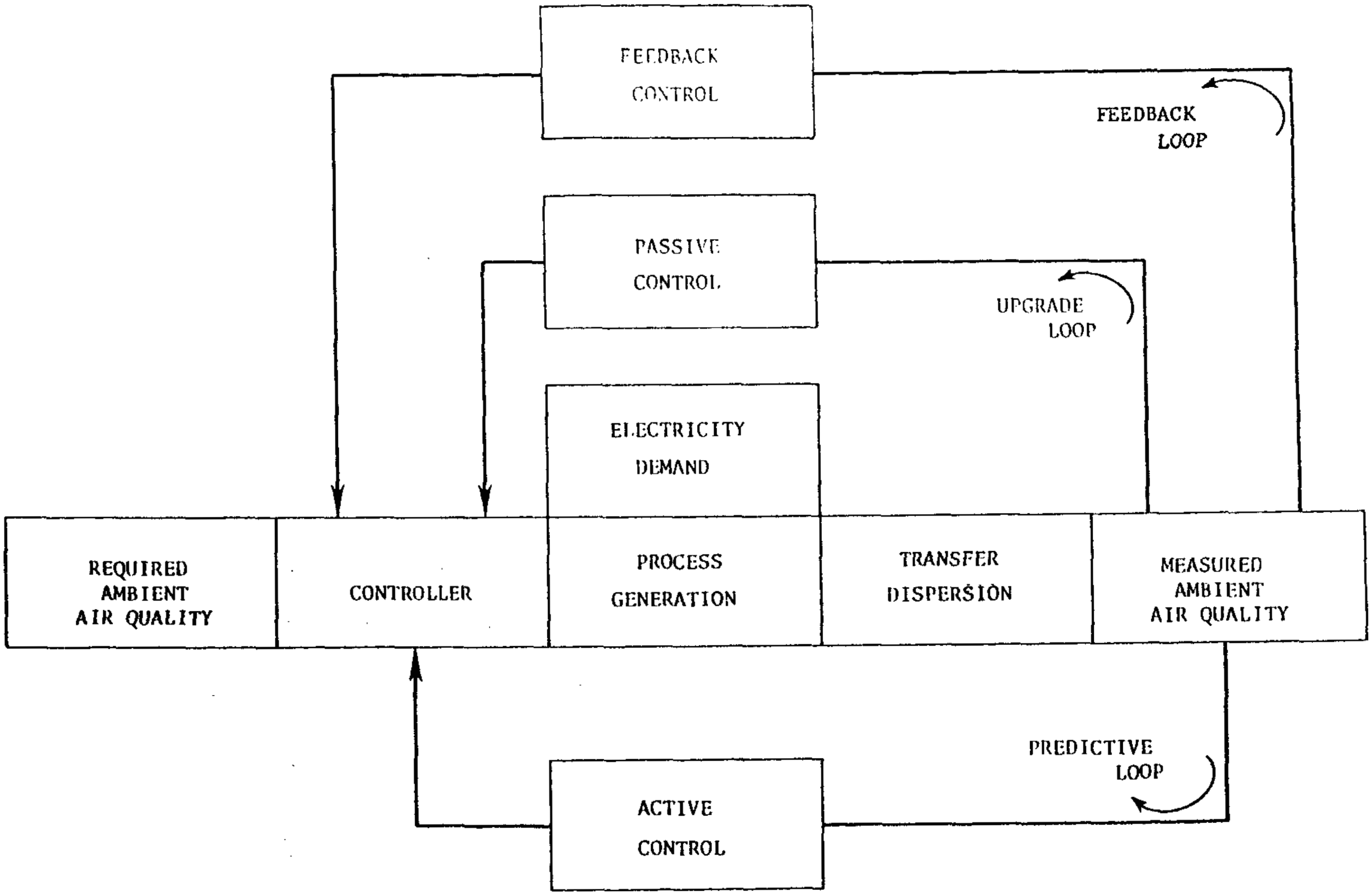

Figure 3-1 Conceptual Representation of a Meteorological Control System (MCS)

predictive loop; and a passive control loop whose primary purpose is to gather, analyze and apply data from the system to improve and optimize the system performance.

The proposed Hat Creek MCS will utilize an extensive meteorological/air quality monitoring network and communications/computer facilities. B.C. Hydro currently has many of the necessary components in their operations weather forecast office in Burnaby, B.C. It is proposed that these facilities for data recording and communications be located at the Hat Creek site.

(a) The Proposed System

The organization of the proposed system is presented in Fig. 3-2. The information flow associated with the three types of control loop and their respective subsystems are shown in the figure as they operate using B.C. Hydro inputs: the active control loop or predictive subsystem, the feedback control loop or anticipatory subsystem and the passive control loop or upgrade subsystem.

A convenient point to enter the diagram is at the diamond labelled Load Demand. Under normal conditions, the load demand requires operation of some combination of boilers (fired with normal blended coal) to meet that demand which, in turn, produces the source emissions. The emissions are acted upon by the dynamical processes in the atmosphere and, as a consequence, are transported and dispersed. The air quality surrounding the Hat Creek plant will be monitored by an array of eight SO_2 monitors to establish actual ground level concentrations.

At the bottom of the diagram, the active control loop is depicted. Its effectiveness is dependent upon accurate emissions forecasts, meteorological forecasts and air quality modeling. Anticipated loads (schedule) are received from powerplant

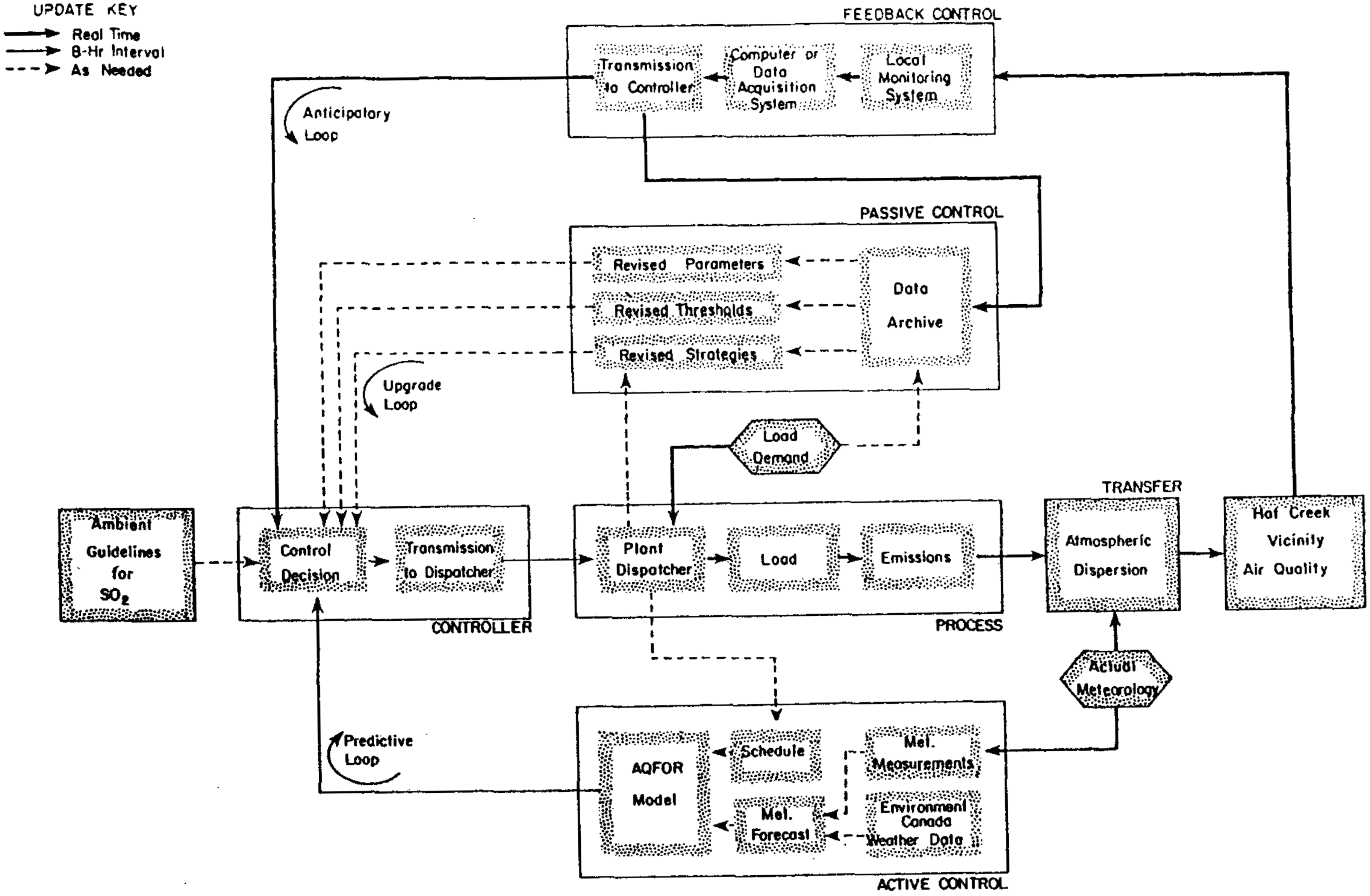

Figure 3-2 Schematic of Proposed Meteorological Control System

3.1 OVERVIEW - (Cont'd)

operation management, and actual meteorological observations are received from on-site measurements. Environment Canada meteorological data are currently obtained from the Atmospheric Environment Service by B.C. Hydro. In the MCS they will be combined with on-site data to produce a micrometeorological forecast for the Hat Creek environs. These data and predictions of meteorological parameters are prepared as input to the Air Quality Forecast (AQFOR) computer program which computes the projected concentrations of contaminants and determines necessary control actions as a function of time.

The feedback control loop in the B.C. Hydro system is depicted at the top of the diagram. The feedback loop operates in two modes: (1) it feeds observed meteorological and air quality data into the control decision AQFOR program to detect trends and to evaluate the impact of past history on future load reduction or fuel switching requirements; and (2) it provides warnings for concentration values above certain thresholds. Its effectiveness is assured by adequate sensors at strategic locations surrounding the plant. From experience in several programs, ERT has recommended that the feedback loop should include an experienced meteorologist as part of the direct interpretation process for observed data.

The passive control or upgrade loop provides for proper recovery, storage, statistical analysis and comparison of the various forecast and observed parameters to evaluate the accuracy and appropriateness of each part of the system. It uses this information to update the modelling assumptions and decision processes to optimize the system.

The Hat Creek Project is only a component of the entire generation facilities of B.C. Hydro. Of necessity, the MCS design described in this document must be specific to the Hat Creek

3.1 OVERVIEW - (Cont'd)

Project, but may in fact, when actually put into operation, be only a component of an MCS for the entire B.C. Hydro generation system. In this way the effects of meteorological parameters on all portions of the B.C. Hydro system may be taken into account. Fig. 3-3 shows a schematic diagram for this type of operation. The location of the Hat Creek MCS forecast centre at the central operations office in Burnaby will enable integration of this site specific system into the larger-scale system. The control subsystem block in the diagram is intended to include technically skilled atmospheric scientists from B.C. Hydro's offices in Vancouver, B.C.

The remaining paragraphs of Section 3.0 provide more detail about each of the subsystems and the facilities of the overall MCS for the Hat Creek plant.

3.2 MONITORING SUBSYSTEM AND FACILITIES

As part of the detailed environmental studies for the proposed Hat Creek Project, B.C. Hydro has instituted an ambient air quality and extended meteorological monitoring program. Currently, measurements are being taken at four sites in the Hat Creek area (see Fig. 3-4). These sites were located to satisfy several objectives:

1. To obtain accurate information on background air quality levels prior to plant start-up.

2. To collect meteorological data in sufficient detail to allow evaluation and design of a meteorological control system for the powerplant.

3. To collect pertinent meteorological and atmospheric turbulence data for the evaluation and design of cooling towers.

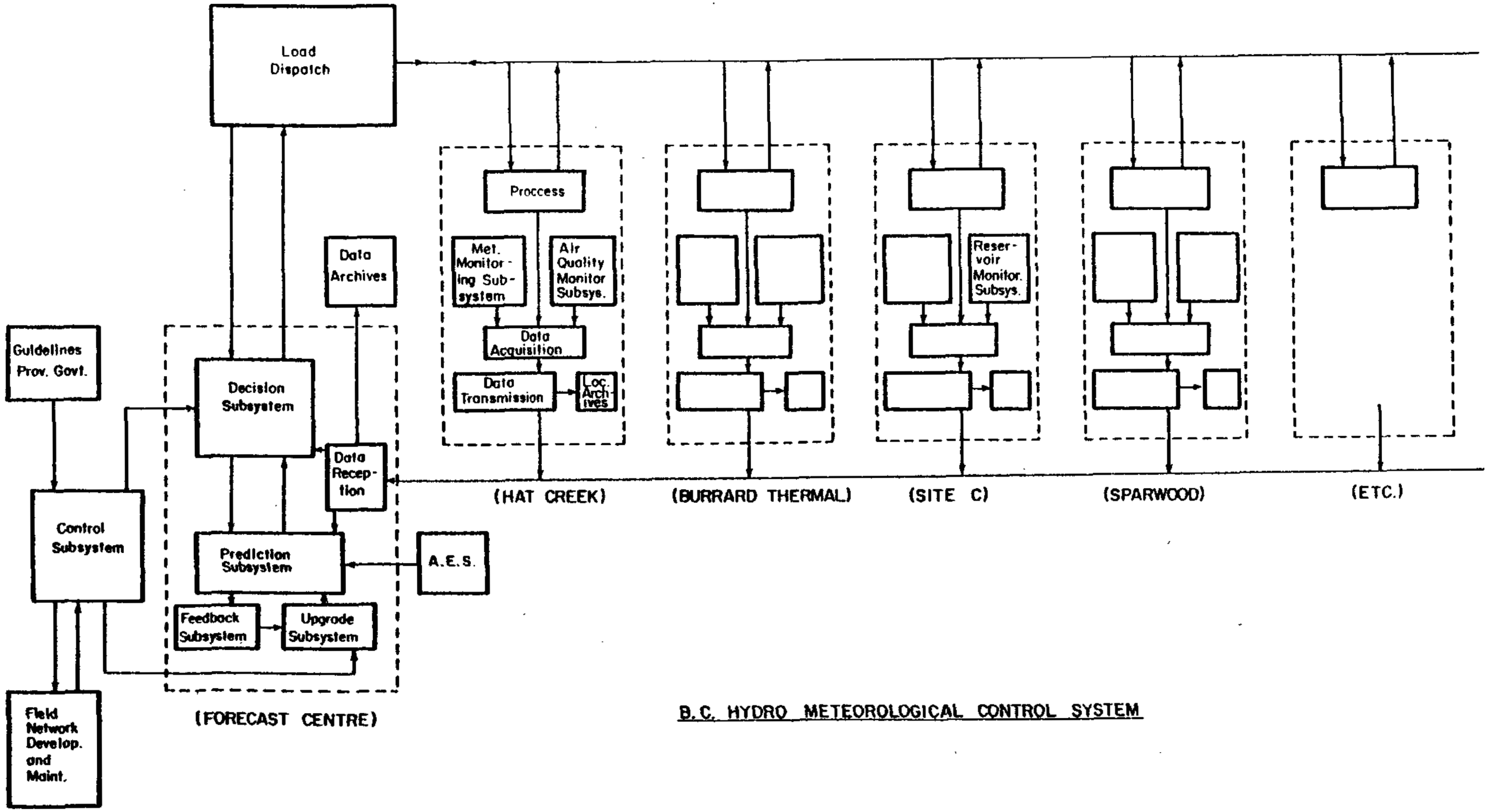

Figure 3-3 Flow Chart Showing Possible System-wide MCS for All B.C. Hydro Operations

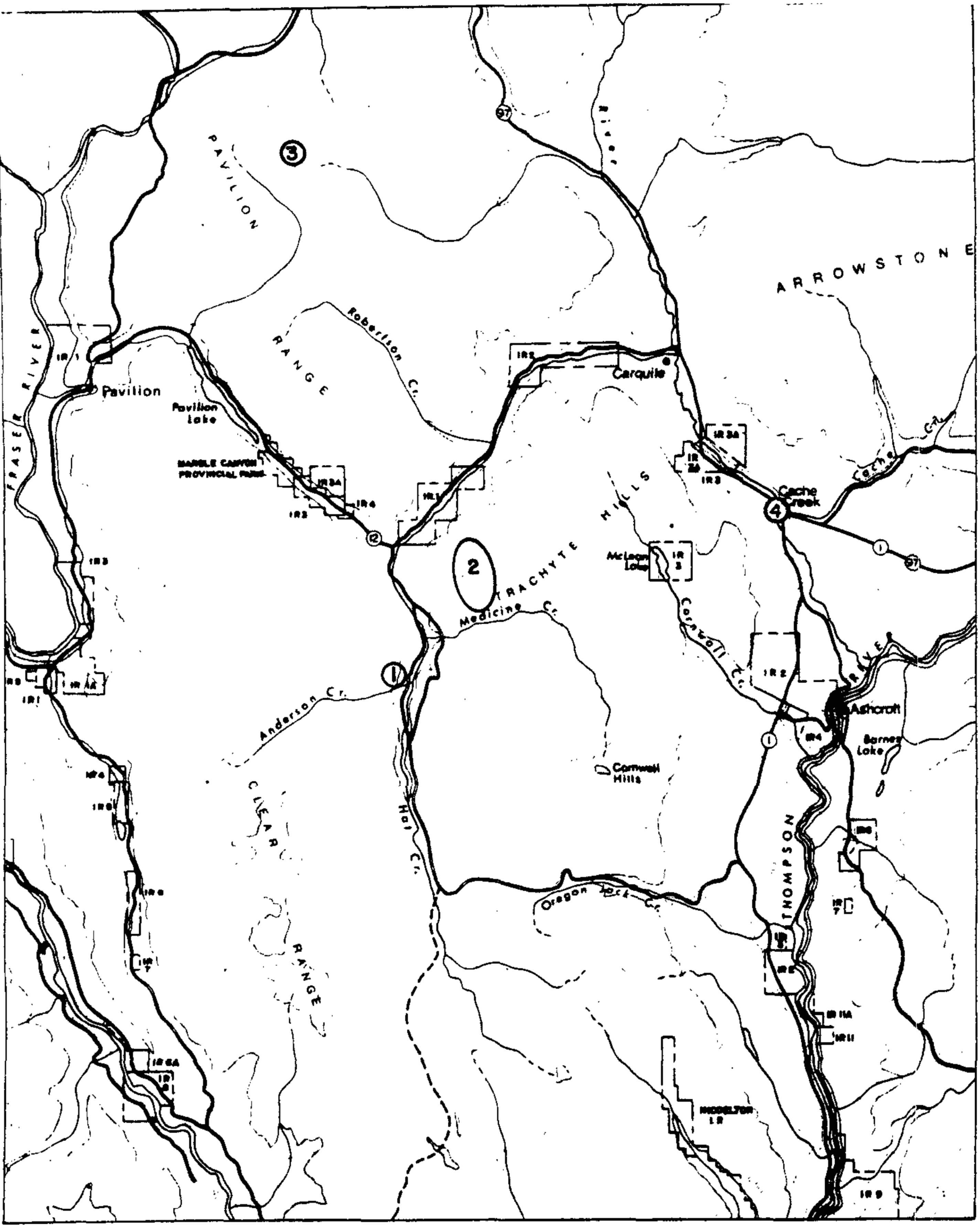

Figure 3-4 Meteorological & Air Quality Monitoring Stations in Full-Scale Monitoring Programme

1. Hat Creek Valley Site
2. Plant Site
3. Pavilion Mountain Site
4. Cache Creek Site

4. To collect meteorological data which will augment predictions of the effects of irregular terrain on contaminant dispersion in the vicinity of the proposed plant.

5. To obtain air quality and meteorological data in specific areas of predicted maximum ambient contaminant concentrations.

6. To collect data at sites potentially influenced by all principal air contaminant sources of the project: the powerplant stack, the cooling towers and the coal mine.

7. To represent the major receptors of interest (especially human populations).

8. To obtain monitoring sites that are as permanent as possible.

Table 3-1 lists the variables that are measured at the four existing sites.

Details of the instrumentation and the data handling, maintenance and calibration procedures are given in documentation provided by ERT.[6]

When plant construction begins, an expanded aerometric monitoring network will be developed for MCS purposes. A suggested network is illustrated in Fig. 3- 5. Table 3-2 lists the variables to be measured. The final network design will be based on analysis of the data collected from the present four-station network and from further modeling studies based on data from a 100 m meteorological tower now in operation at the powerplant site.

TABLE 3-1

VARIABLES MEASURED AT EXISTING MONITORING SITES

	Site				
	Plant				
Parameter	Valley	Tower Base	Tower Top	Mountain	Mobile
Meteorological					
Temperature	X	X	X	X	X
Dew Point Temperature	X	X	X		X
Differential Temperature		X	X		
Precipitation	X	X		X	X
Evaporation		X			
Barometric Pressure		X			
Wind Speed and Direction	X	X	X	X	X
U-V-W Anemometer			X		
Bi-Vane	X				
Light Intensity	X				
Visibility	X				X
Fog Visiometer	X				
Air Quality					
Sulphur Dioxide	X				X
Nitrogen Oxides	X				X
Ozone	X				X
Carbon Monoxide					X
Total Suspended Particulate	X	X		X	X
Dustfall	X	X		X	X
Sulphation	X	X		X	X
Corrosion	X	X		X	X
Fluoridation	X	X		X	X

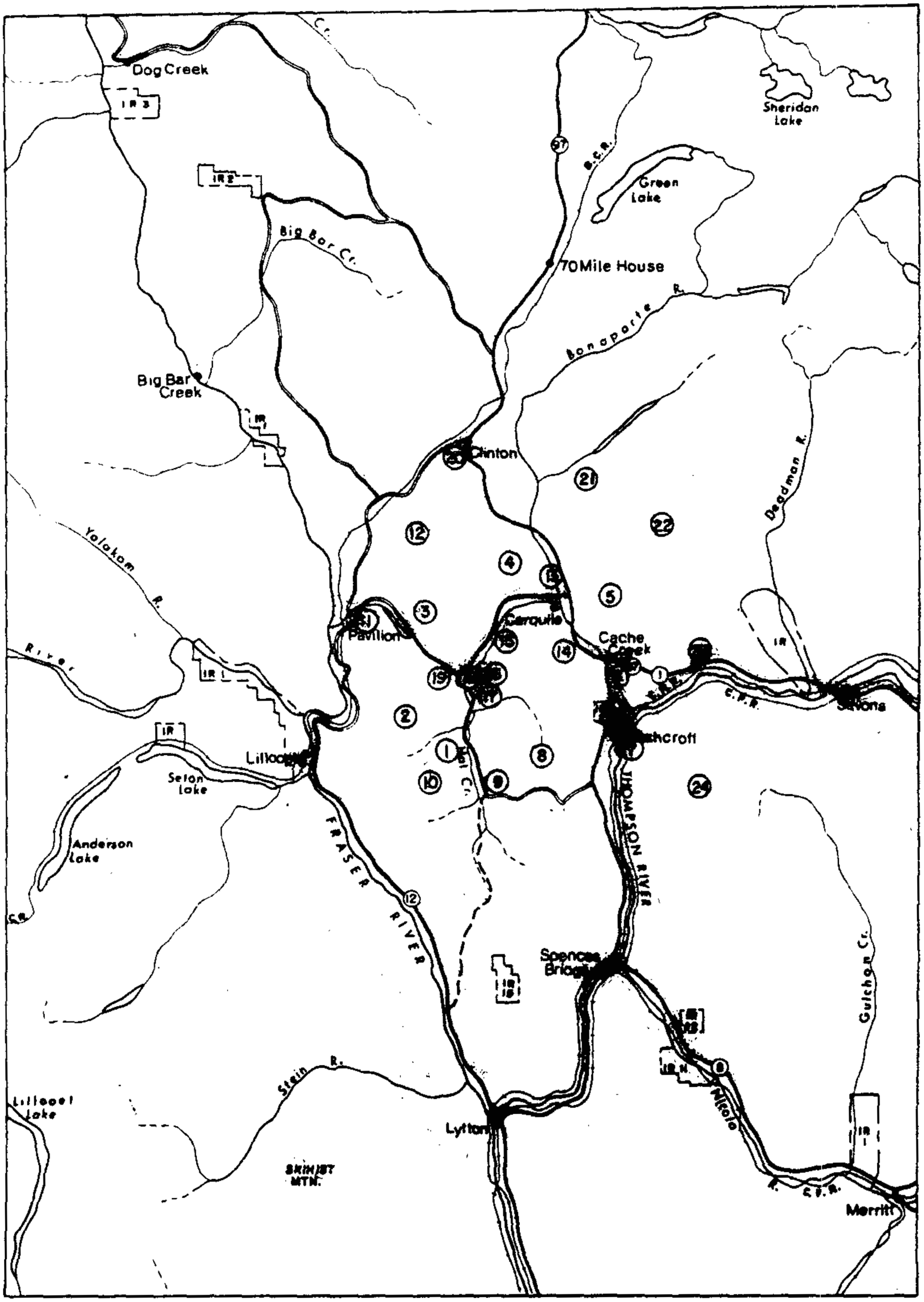

Figure 3-5 Proposed Monitoring Network to Support Hat Creek Project MCS Operations

TABLE 3-2

SUGGESTED MONITORING NETWORK FOR MCS OPERATIONS

	Site Number (See Fig. 3-5)																								
Meteorological	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16[1]	17	18	19	20	21	22	23	24	Mobile Station
Temperature	X											X				X[a]									X
Dew Point Temperature	X															X[a]									X
Differential Temperature																X[a]									
Precipitation	X											X				X[b]									X
Evaporation																X[b]									
Barometric Pressure																X[b]									
Wind Speed	X	X	X	X	X	X	X	X				X				X[a]									X
Wind Direction	X	X	X	X	X	X	X	X				X				X[a]									X
U-V-W Anemometer																X[c]									
Bi-Vane	X																								
Light Intensity	X																								
Doppler Radar (alt. minisonde or tethersonde)																X									
Air Quality																									
Visibility	X																								X
Fog Visionmeter	X																								
SO_2	X	X	X	X	X	X	X	X																	X
NO_x	X				X																				X
O_3	X				X																				X
CO																									X
TSP	X	X	X	X	X	X	X	X						X	X	X	X	X	X						X
Dustfall	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Sulphation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Corrosion	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Fluoridation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X

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[1] Site 16, located at the plant site, has a 100 m tower.

X[a] denotes parameters measured at top and bottom of tower.

X[b] denotes parameters measured only at bottom of tower.

X[c] denotes parameters measured only at top of tower.

3.3 DATA ACQUISITION AND COMMUNICATIONS

B.C. Hydro will arrange for provision and maintenance of a dedicated data acquisition system for the Hat Creek monitoring network and the MCS control centre. As part of the data acquisition system, B.C. Hydro will operate and maintain a data acquisition, storage and communications facility at Hat Creek.

(a) Communications Network Configuration

Fig. 3-3 shows the components and interconnections for the MCS network. The four basic components of the Hat Creek communication network are:

1. The MCS forecast centre, where the MCS calculations, forecasting and analysis are performed.
2. The Hat Creek computer site, which controls communications locally and collects the monitored data.
3. B.C. Hydro powerplant operations office, which provides scheduled emissions input to the MCS, and receives MCS output.
4. The various monitoring sites, shown as meteorological and air quality monitoring substations, and including local archives, used for local assessment of the monitoring system performance.

(b) Communications Links

The communications between the monitoring sites and the on-site computer centre will be by dedicated telephone data lines or a microwave system.

The communications between the Hat Creek computer and the MCS control centre will be by a dial-up phone line. The Hat

Creek computer will dial the telephone at the centre, send reports when a connection is established, and disconnect when the message is completed.

(c) Non-routine Conditions

Whenever a monitored concentration exceeds one of the predetermined warning levels, or a control action is indicated, operations will change to include more frequent reports. In the first case, a warning message will be sent by the computer to the MCS control centre to indicate the onset of high values, establishing the "warning state" for the network and initiating the regular printing of 2-minute reports. This procedure will continue until the end of the episode. The communications between MCS central and the system control centre will become more frequent with the shorter intervals between runs.

Procedural details are discussed further in following sections.

3.4 PREDICTIVE SUBSYSTEM

The proposed predictive system has been designed to comply with the guidelines for ambient SO_2 levels. As such, it is a sophisticated system. Evaluation of the system after months or years of operation may indicate that a less sophisticated system can be effective and is warranted. However, this report is based on the assumption that the proposed system is what is required to meet the ambient guidelines.

The predictive subsystem is the principal active control mechanism in the proposed MCS. The predictive subsystem uses meteorological forecasts and scheduled plant emissions as inputs to the air quality forecast model, AQFOR. The model, while predicting air quality, interacts with the control decision subsystem as described in Section 3.5, to produce not only predicted air quality at the chosen receptor points in the plant impact area, but also the recommended control actions.

In this section, the basis (the existing Hat Creek model) of the predictive model is briefly discussed, including the selection of a receptor grid, and the methodology for validation and upgrading of the model. This is followed by discussions of the meteorological and emissions forecasting operations which produce the inputs to the model, and a description of the operation of the model.

(a) AQFOR Model

(i) Model Theory

The AQFOR model will be based at first on the Hat Creek model[7] and other calculation routines to provide a system best suited to the specific application and with the flexibility required for real-time operation in an emission limitation program. Initially, basic component modules will include a multiple-source Gaussian diffusion model (using dispersion parameters developed from on-site data), a plume rise model and a terrain model. The influence of terrain on plume diffusion will be explicitly considered in the AQFOR model. In addition, the model is capable of handling stack-tip downwash, penetration of stable layers, reflection from ground surfaces and dispersion characteristics developed from on-site tracer studies. As the data base develops it may be possible to utilize statistical functions for predictions and completely eliminate the reliance on Gaussian diffusion.

(ii) Receptor Grid

The receptor points at which the AQFOR model predicts concentrations are carefully chosen to provide a nonbiased input for the control decision model. For single plant sources (as in the case of the Hat Creek plant) a radial receptor grid forming concentric circles will accomplish this purpose. Additional receptor points will be placed to coincide with the monitoring sites.

With the radial receptor grid, seven receptors along each of 16 radial directions (one for each wind direction), plus the monitoring receptors, would yield a total of 120 receptor points. The distance and number of receptor circles necessary for proper coverage can be readily modified as experience in operating the MCS accumulates.

(b) Validation and Upgrading

It is proposed that the system will include a systematic program to upgrade the reliability of the MCS in maintaining air quality standards. An essential part of the overall evaluation is the assessment of the accuracy of the air quality prediction system. A discussion of the validation methodology is given in Section 3.7. It is proposed to evaluate the performance of the MCS every 6 months to determine the necessity and extent of any upgrading.

(c) Forecasting Operations

Individual micrometeorological forecasts will be prepared for the region in the vicinity of the Hat Creek plant for each 1-hour interval in a 41-hour period after this forecast time. The 41-hour period is necessary because the longest averaging time to be considered is 24 hours and the forecast will not be updated for another 8 hours. This is combined with an additional 9-hour warning time necessary for fuel switching to give a total of 41 hours. Parameters to be forecast include wind direction, wind speed, mixing depth, atmospheric stability and plume dispersion coefficients. These forecast meteorological parameters are basic input to AQFOR. The following paragraphs describe the general theory and data to be considered, timing of forecasts, the specific meteorological calculations and verification of those calculations.

(i) General Considerations

The Hat Creek air monitoring network will be measuring data over a relatively limited region influenced by the powerplant and, as such, the region is considered to be on a scale between microscale and mesoscale. Since the forecast products generated by Environment Canada are generally for the synoptic scale (hundreds of miles), it will be necessary to predict the meteorological parameters on a representative scale for Hat Creek. Prognostic weather charts from Environment Canada depict the future locations of large-scale features of the atmosphere such as storms, fronts and high pressure systems. These products will be considered by the MCS forecaster to relate small-scale atmospheric motions to large-scale motions in order to develop forecasts of input data for AQFOR.

(ii) Timing

A meteorological forecast is generally most accurate and reliable for the first portion of the time period for which the forecast is valid. Thus, it is advantageous to schedule the beginning (more accurate, reliable) period of the forecast to coincide with the times of day when atmospheric parameters such as stability and mixing depth normally undergo changes, e.g., during the few hours after sunrise and sunset. Therefore, it is proposed to prepare a forecast and the recommended control strategy information three times each day, by 8:00 a.m., 4:00 p.m. and midnight. For each forecast, local meteorological data from the Hat Creek meteorological tower and air quality stations, and from data provided by Environment Canada, will be utilized in the forecast preparation.

(iii) Atmospheric Turbulence/Stability

The model AQFOR uses plume dispersion parameters to simulate the effects of atmospheric turbulence on plume growth and diffusion. In the detailed air quality analyses for the proposed Hat Creek Project (see, for example, Appendix B), these dispersion parameters were determined from estimates of atmospheric stability, which in turn is a surrogate for atmospheric turbulence. The Hat Creek meteorological tower is a platform for a u, v, w* anemometer. Standard deviations (σ_u, σ_v, σ_w) of the u, v, w wind measurements will provide more accurate estimates of plume dimensions and, therefore, will be used in the MCS program. In principle, σ_y (crosswind diffusion parameter) can be estimated from σ_u and σ_v, and σ_z (vertical) can be estimated from σ_w. In practice, it may be difficult to accurately measure σ_w. Therefore, an alternative approach should be available. It has been recommended

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* The east-west, north-south and vertical components, respectively, of the wind.

that σ_z also be estimated from the vertical temperature and wind shear data. These data will be available from the meteorological tower. Both approaches will be tested in the MCS.

(iv) Mixing Depth - Radiosondes and Acoustic Sounders

Mixing depths in the feasibility study conducted by ERT for the Hat Creek MCS, were determined by twice daily radiosonde at Vernon, B.C. However, the Vernon data have never been demonstrated to be representative of the Hat Creek site. In addition the Atmospheric Environment Service may discontinue the soundings at Vernon in the future. Therefore, it is recommended that some on-site measure of mixing depth be undertaken. There are various methods available for this including acoustic sounders, minisondes and tethersondes, however, the recent development of a doppler radar system provides an accurate cost-effective method for mixing depth assessment. It is proposed that such a system be utilized at Hat Creek, but it is also recognized that development of such systems will continue and the emergence of new technology is quite possible between the time of this writing and the time when equipment for the MCS is being purchased. Therefore, although some method of on-site mixing depth measurement will be employed, it is uncertain at this time which technology will be utilized.

(v) Wind Direction and Wind Speed

Three factors usually influence wind direction and speed - the large (synoptic) scale atmospheric pressure pattern over a region, the topography, and the proximity to a large body of water. For wind direction and speed, the major influences in the Hat Creek region are the synoptic-scale meteorological situation and nearby topography. These will provide the basis for the MCS predictions and the model input.

As part of the detailed environmental studies, an investigation of the synoptic weather conditions associated with relatively high predicted contaminant concentrations (3-hour average SO_2 concentrations greater than 655 $\mu g/m^3$) in the Hat Creek region was performed in an attempt to identify the meteorological conditions leading to these levels. From the cases examined (1975 data), several synoptic-scale patterns emerge:

1. Weak pressure gradient in the Hat Creek area, resulting from the absence of strong pressure systems or from a high pressure system centered over the area.

2. A large Pacific high pressure cell to the west and/or a well-developed low over Alberta.

3. A cyclonic storm system approaching the area from the west.

4. Wind directions between northwest, clockwise through south-southeast.

5. Light surface wind speeds, less than 2 $m\ s^{-1}$.

In general, potential problem situations are created by stable conditions with persistent critical wind directions and light speeds. This condition is relatively simple to forecast, since stable conditions usually occur during the evening or morning hours, and persistent wind conditions are generally associated with the approach of cyclonic or anticyclonic cells. This was the situation in 12 of the 15 cases examined. The remaining days involved a more difficult forecasting siutation, since the corresponding winds were very light and variable. Wind direction under such circumstances is difficult to predict, despite the tendency for flow to be channeled along the orientation of the mountain-valley system. In terms of an MCS, the greatest danger of exceeding criteria will occur during these meteorological conditions. From detailed examination of weather maps for 1975, it is estimated that forecast uncertainties associated with such difficult-to-forecast cases will require that MCS controls be enacted 25 percent to 50 percent more often than indicated by modeling results to ensure protection of the assumed ambient thresholds.

In the beginning stages of the MCS, forecasts of critical meteorological conditions will be conservative in order to account for the inherent inaccuracies in both air quality and meteorological predictions, since even a very small number of underpredictions may limit the effectiveness of the MCS.

An additional means for improving meteorological forecasts for an MCS at the Hat Creek plant will be provided by commencing MCS operation at the same time as startup for the first 500 MW generating unit. The construction schedule calls for staggered installation with one new unit going into service each year. This provides an important advantage in that the relationships between plant emissions, meteorological conditions, and ambient air quality can be studied, and forecasting procedures refined, during plant development.

(vi) Emissions

Plant SO_2 emission projections will be prepared for 1-hour intervals for 41 hours as basic input to the predictive model. The emissions projections will be derived from the projected load, coal consumption, and coal sulphur content. In addition, SO_2 emissions from real-time stack gas analyzer output will aid in the forecast of future emissions over the 41-hour period and will be used directly in the feedback control component of the MCS (see Section 3.6). Expected plant load will be provided to the MCS control centre three times daily prior to preparation of the AQFOR input (see below).

(d) Operation of the Model

(i) Preparation of Input

The AQFOR is used on the 8-hour schedule coinciding with revised meteorological forecasts and emissions schedules. All input to the (stand-alone) computer program consists of: (1) model parameters, (2) observed data, and (3) forecast information. Data required by the system consists of actual boiler loads and SO_2 emission rates for each of the previous 24 hours, actual SO_2 concentrations and meteorological conditions measured at each monitoring site for each of the previous 24 hours and the desired plant operations strategies for the subsequent 41 hours.

The 24-hour historical data and data describing the meteorological forecast and boiler operations schedules are submitted with the model parameters with each scheduled AQFOR run.

(ii) Predictive Model Output and Control Decision Model Recommendations

The output of the AQFOR is the inclusive set of SO_2 concentrations computed for each specified receptor point, for each hour (for 24 hours past to 41 hours future) for the desired plant operation schedule and each alternate mode involved in emission reductions. This information is archived for use by the control decision model, which analyzes these computed results in terms of the required air quality guidelines. The control decision model, its algorithm, operation and final output, are described in the following sections.

3.5 CONTROL DECISION SUBSYSTEM

(a) Control Action Criteria

The control decision model (a module of AQFOR) provides the means by which the active, passive and feedback loops are closed. The interaction of observed conditions, predicted conditions and air quality guidelines produces recommended actions designed to result in compliance with these guidelines. The model operates in "real-time" making use of two distinct dynamic forms of information: monitored concentrations and model predictions.

(c) Control Strategies

The previous sections have been concerned with the theoretical and computational basis for the control decision model. In this section, the actual specification of control strategies as input to the model is discussed, including examples of an actual strategy which might be used for the Hat Creek plant.

The specification of the "switchmode strategy" is accomplished by entering into the computer the control operations making up each successive step in the cutback sequence. Operations currently implemented are:

REDUCE -	reduce the load on a specified boiler to a specified load value (or by a specified percentage of maximum load)
SWITCH -	switch a specified boiler from one fuel to another
SET -	set a specified boiler to a given load value
CUT -	cut load on a specified boiler to zero.

The operating switchmodes for Hat Creek include fuel switching in the winter and load reduction the rest of the year.

A sample load reduction strategy might reduce generation in 50 MW steps, resulting in five stages of cutbacks:

Step 0	No reduction, each unit at 500 MW
Step 1	One unit reduced to 450 MW
Step 2	One unit reduced to 400 MW
Step 3	One unit reduced to 350 MW
Step 4	One unit reduced to 300 MW*

---

* The air quality studies have indicated a reduction to 60 percent load would be sufficient to protect the guidelines.

This is only one possible strategy from a complete set which might be used. In operations, several sets will be established for different times of the year. A given set will be selected for operation during certain periods. This set will then be archived for use in the model. At any time, Hat Creek plant personnel need only specify which strategy is operative on the current day. Additional strategies may be implemented at any time, requiring only the entering of information.

The control decision model has been designed to provide as much freedom for plant operation as possible, consistent with air quality guidelines. The plant operations manager will have the responsibility to adjust loads as he sees fit among the various boilers, with due regard to the MCS recommended operating conditions.

The control decision switchmodes are determined by a simple control table which permits specification of load reduction or fuel switching. When calculating switchmodes, the control decision model always maintains operations within the plant schedule, which is input with each run. This automatically compensates for maintenance shutdowns and planned output reductions.

(d) Model Output

(i) Output Formats

Operation of AQFOR produces a table of maximum SO_2 concentrations by time period as shown in Fig. 3-6. For this example, the periods are 3 hours each. Similar tables can be produced to show maximum concentrations for other time periods. In the table, each row represents one of the given emission reduction steps with the top row ALT #0, representing the given (no reduction) conditions. Within each box, the maximum concentration

Operating switch mode alternative number

Forecast time number

```
 96 1091     ERT AIR QUALITY FORCAST PROGRAM                 VERSION   1.4  (750423)
            MAXIMUM CONCENTRATION OVER ALL RECEPTORS
+----+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
IALT I  PERIOD I  PERIOD I  PERIOD I  PERIOD I  PERIOD I  PERIOD I  PERIOD I  PERIOD I  PERIOD I  PERIOD I
I #  I    1    I    2    I    3    I    4    I    5    I    6    I    7    I    8    I    9    I   10    I
+----+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
I    I       1 I       1 I       1 I       1 I       1 I       1 I       1 I       1 I       1 I       1 I
I  0 I   0.143 I   0.105 I   0.105 I   0.143 I   0.143 I   0.143 I   0.143 I   0.143 I   0.143 I   0.143 I
+----+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
I    I       1 I       1 I       1 I       1 I       1 I       1 I       1 I       1 I       1 I       1 I
I  1 I   0.128 I   0.094 I   0.094 I   0.128 I   0.128 I   0.128 I   0.128 I   0.128 I   0.128 I   0.128 I
+----+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
I    I       1 I       1 I       1 I       1 I       1 I       1 I       1 I       1 I       1 I       1 I
I  2 I   0.114 I   0.083 I   0.083 I   0.114 I   0.114 I   0.114 I   0.114 I   0.114 I   0.114 I   0.114 I
+----+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
I    I       1 I       1 I       1 I       1 I       1 I       1 I       1 I       1 I       1 I       1 I
I  3 I   0.099 I   0.073 I   0.073 I   0.099 I   0.099 I   0.099 I   0.099 I   0.099 I   0.099 I   0.099 I
+----+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
I    I       2 I       1 I       1 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I
I  4 I   0.095 I   0.062 I   0.062 I   0.095 I   0.095 I   0.095 I   0.095 I   0.095 I   0.095 I   0.095 I
+----+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
I    I       2 I       1 I       1 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I
I  5 I   0.095 I   0.062 I   0.062 I   0.095 I   0.095 I   0.095 I   0.095 I   0.095 I   0.095 I   0.095 I
+----+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
I    I       2 I       1 I       1 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I
I  6 I   0.095 I   0.062 I   0.062 I   0.095 I   0.095 I   0.095 I   0.095 I   0.095 I   0.095 I   0.095 I
+----+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
I    I       2 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I
I  7 I   0.100 I   0.064 I   0.064 I   0.100 I   0.100 I   0.100 I   0.100 I   0.100 I   0.100 I   0.100 I
+----+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
I    I       2 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I
I  8 I   0.103 I   0.070 I   0.070 I   0.103 I   0.103 I   0.103 I   0.103 I   0.103 I   0.103 I   0.103 I
+----+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
I    I       2 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I
I  9 I   0.104 I   0.066 I   0.066 I   0.104 I   0.104 I   0.104 I   0.104 I   0.104 I   0.104 I   0.104 I
+----+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
I    I       2 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I
I 10 I   0.099 I   0.062 I   0.062 I   0.099 I   0.099 I   0.099 I   0.099 I   0.099 I   0.099 I   0.099 I
+----+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
I    I       2 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I
I 11 I   0.099 I   0.062 I   0.062 I   0.099 I   0.099 I   0.099 I   0.099 I   0.099 I   0.099 I   0.099 I
+----+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
I    I       2 I       1 I       1 I       2 I       2 I       2 I       2 I       2 I       2 I       2 I
I 12 I   0.095 I   0.062 I   0.062 I   0.095 I   0.095 I   0.095 I   0.095 I   0.095 I   0.095 I   0.095 I
+----+---------+---------+---------+---------+---------+---------+---------+---------+---------+---------+
            MINIMUM OPERATIONS PERMISSIBLE FOR EACH PERIOD:
 MODE      0,        0,        0,        0,        0,        0,        4,        4,        3,        0,
```

No change

Receptor at which the maximum SO_2 concentration is forecasted to occur.

Forecasted maximum SO_2 concentration in ppm.

Maximum Cutback

Figure 3-6 ERT Air Quality Forecast Program AQFOR predicted concentrations for any receptor or monitor site, as shown in Fig. 3-8. This shows the concentrations for receptor 4 for every period of time and for every step of cutback. This type of output may be used in model verification, since forecasts for particular monitoring sites can be compared to actual observed values.

(ii) Analysis of Output

The MCS meteorologist in the control centre will analyze the model output using his experience and professional judgement. The forecaster has the option to override the model recommendations when the situation warrants. In these instances, he will document his rationale for overriding the model output. For example, his experience may indicate that the model has been overly conservative under certain weather conditions and therefore specified a cutback that may not be needed. For each forecast, a discussion will be prepared by the forecaster which will describe the general synoptic weather situation and its influence on the meso and microscale dispersion in the power station region. Included will be the technical reasons for transmitting a control plan different from that indicated by model output. This man-machine mix, with the control centre meteorologist analyzing and interpreting the model output, has been demonstrated to be very effective in attaining the objectives of similar MCS progams.

```
 96   088      ERT AIR QUALITY FORCAST PROGRAM
************************************************
VRT  :   RECEPTOR JUST FINISHED:      26
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
VRT  :   RECEPTOR JUST FINISHED:      27
   -8    0    0    0    0    0    0    0    0    0
   -8    0    0    0    0    0    0    0    0    0
   -8    0    0    0    0    0    0    0    0    0
   -8    0    0    0    0    0    0    0    0    0
   -8    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0    0
```

Figure 3-7 Typical Printout Describing the Nature of Potential Air Quality Violation

```
 1  1029     ERT AIR QUALITY FORECAST PROGRAM     VERSION  1.0 (750312)
********************************************************************************
         CONCENTRATIONS FOR RECEPTOR NUMBER:      4          TIME ------>
+----+-------+------+------+------+------+------+------+------+------+------+
|ALT | PERIOD|PERIOD|PERIOD|PERIOD|PERIOD|PERIOD|PERIOD|PERIOD|PERIOD|PERIOD|
| #  |   1   |  2   |  3   |  4   |  5   |  6   |  7   |  8   |  9   |  10  |
+----+-------+------+------+------+------+------+------+------+------+------+
|    |      4|     4|     4|     4|     4|     4|     4|     4|     4|     4|
|  0 |  0.000| 0.000| 0.008| 0.008| 0.032| 0.032| 0.132| 0.132| 0.132| 0.132|
+----+-------+------+------+------+------+------+------+------+------+------+
|    |      4|     4|     4|     4|     4|     4|     4|     4|     4|     4|
|  1 |  0.000| 0.000| 0.007| 0.007| 0.028| 0.028| 0.118| 0.118| 0.118| 0.118| INCREASING
+----+-------+------+------+------+------+------+------+------+------+------+ STEPS OF
|    |      4|     4|     4|     4|     4|     4|     4|     4|     4|     4| CONTROL
|  2 |  0.000| 0.000| 0.007| 0.007| 0.025| 0.025| 0.104| 0.104| 0.104| 0.104| STRATEGY
+----+-------+------+------+------+------+------+------+------+------+------+
|    |      4|     4|     4|     4|     4|     4|     4|     4|     4|     4|     |
|  3 |  0.000| 0.000| 0.006| 0.006| 0.021| 0.021| 0.090| 0.090| 0.090| 0.090|     |
+----+-------+------+------+------+------+------+------+------+------+------+     v
|    |      4|     4|     4|     4|     4|     4|     4|     4|     4|     4|
|  4 |  0.000| 0.000| 0.005| 0.005| 0.018| 0.018| 0.075| 0.075| 0.075| 0.075|
+----+-------+------+------+------+------+------+------+------+------+------+
|    |      4|     4|     4|     4|     4|     4|     4|     4|     4|     4|
|  5 |  0.000| 0.000| 0.005| 0.005| 0.018| 0.018| 0.075| 0.075| 0.075| 0.075|
+----+-------+------+------+------+------+------+------+------+------+------+
|    |      4|     4|     4|     4|     4|     4|     4|     4|     4|     4|
|  6 |  0.000| 0.000| 0.005| 0.005| 0.018| 0.018| 0.075| 0.075| 0.075| 0.075|
+----+-------+------+------+------+------+------+------+------+------+------+
|    |      4|     4|     4|     4|     4|     4|     4|     4|     4|     4|
|  7 |  0.000| 0.000| 0.005| 0.005| 0.018| 0.018| 0.075| 0.075| 0.075| 0.075|
+----+-------+------+------+------+------+------+------+------+------+------+
|    |      4|     4|     4|     4|     4|     4|     4|     4|     4|     4|
|  8 |  0.000| 0.000| 0.005| 0.005| 0.018| 0.018| 0.076| 0.076| 0.076| 0.076|
+----+-------+------+------+------+------+------+------+------+------+------+
|    |      4|     4|     4|     4|     4|     4|     4|     4|     4|     4|
|  9 |  0.000| 0.000| 0.024| 0.024| 0.017| 0.017| 0.073| 0.073| 0.073| 0.073|
+----+-------+------+------+------+------+------+------+------+------+------+
|    |      4|     4|     4|     4|     4|     4|     4|     4|     4|     4|
| 10 |  0.000| 0.000| 0.000| 0.000| 0.003| 0.003| 0.011| 0.011| 0.011| 0.011|
+----+-------+------+------+------+------+------+------+------+------+------+
|    |      4|     4|     4|     4|     4|     4|     4|     4|     4|     4|
| 11 |  0.000| 0.000| 0.000| 0.000| 0.003| 0.003| 0.011| 0.011| 0.011| 0.011|
+----+-------+------+------+------+------+------+------+------+------+------+
|    |      4|     4|     4|     4|     4|     4|     4|     4|     4|     4|
| 12 |  0.000| 0.000| 0.000| 0.000| 0.003| 0.003| 0.011| 0.011| 0.011| 0.011|
+----+-------+------+------+------+------+------+------+------+------+------+
|    |      4|     4|     4|     4|     4|     4|     4|     4|     4|     4|
| 13 |  0.000| 0.000| 0.000| 0.000| 0.003| 0.003| 0.011| 0.011| 0.011| 0.011|
+----+-------+------+------+------+------+------+------+------+------+------+
|    |      4|     4|     4|     4|     4|     4|     4|     4|     4|     4|
| 14 |  0.000| 0.000| 0.000| 0.000| 0.003| 0.003| 0.011| 0.011| 0.011| 0.011|
+----+-------+------+------+------+------+------+------+------+------+------+
|    |      4|     4|     4|     4|    4||     4|     4|     4|     4|     4|
| 15 |  0.000| 0.000| 0.000| 0.000| 0.003| 0.003| 0.011| 0.011| 0.011| 0.011|
+----+-------+------+------+------+------+------+------+------+------+------+
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FIGURE 3-8 CONCENTRATIONS FOR A PARTICULAR SENSOR SITE & FOR EACH STEP OF THE CONTROL STRATEGY.

3.6 FEEDBACK (EMERGENCY CONTROL) SUBSYSTEM

(a) Threshold and Rate of Change

The "Feedback" subsystem in the operational meteorological control system is the mechanism which provides current feedback as to the effectiveness of the MCS. If the predictive subsystem were 100 percent accurate, there would be no need for the feedback subsystem, since all episodes would be correctly forecast, and control measures would be applied to prevent excesses. In actual operations, however, the accuracy of the predictive model, though high, is less than 100 percent, and control action measures must occasionally be taken based on current air quality levels, and on rates of change in these levels.

Two forms of feedback control exist in the proposed system: (1) a long-term, overall estimate of future emissions limits required to protect averages of current concentrations which also trail into the past; and (2) a short-term analysis of instantaneous concentrations and the rate at which they are changing.

The long-term model necessarily requires a history of actual concentrations everywhere in the significant impact area. Since SO_2 data will be measured at only a relatively small number of sites (5 to 10), the remaining receptor concentrations must be calculated, making use of known emissions and meteorological conditions. Moreover, the computation requires an update to the meteorological forecast, since any future control action invoked to offset current trends depends critically on meteorological conditions. For these reasons, the long-term feedback model has been incorporated into the scheduled computation of air quality, and operates automatically as a part of the control decision (switchmode selection) model. This is accomplished as follows:

3.6 FEEDBACK (EMERGENCY CONTROL) SUBSYSTEM - (Cont'd)

1. For each receptor point, hourly-averaged concentrations are determined for the past 24 hours using either available monitoring data, or by calculation, using known emissions and known meteorological conditions.

2. For each receptor, currently uncompleted trailing averages are computed, beginning with the oldest (least recent) hours.

3. The concentration limit which must be met during the remainder of the averaging period (in the future) to avoid crossing the cutback threshold is computed.

4. This concentration limit is used to determine whether, and to what extent, future control action will be required.

The results from the model are that both short-term values of current concentrations as well as long-term (24-hour) trends are considered.

Although an essential part of the "long-term" operations scheduling, the computational trend analyses procedure has the disadvantage that it normally operates only on the forecast schedule, i.e., once every 8 hours. For the intervening time, the short-term analysis is required.

(b) Episode Coverage

"Instantaneous" surveillance of monitored air quality is provided by the real-time data acquisition system. If the measured SO_2 concentration at any site in the monitoring network exceeds a preset threshold value for a 1-minute sample, the monitoring system enters the "warning stage". At this point, the following actions occur:

3.6 FEEDBACK (EMERGENCY CONTROL) SUBSYSTEM - (Cont'd)

1. For each (1-minute) sampling period, current readings for all sensors in excess of a preset value are printed at the computer centre.

2. As long as the warning state prevails, the computer dials the readout printer and prints, on the even minute, the current reading for all sensors in the monitoring network.

The onset of an episode is thus immediately flagged and reports begin appearing at 2-minute intervals at the MCS centre within 2 minutes after the onset of the warning state. The forecaster on duty must first verify that the warning readings are real, (i.e., not due to instrument malfunction) and, if real, activate the control decision model based upon the latest revised schedule of emissions and meteorological forecast. Once the necessary cutback steps have been computed, these are then relayed to powerplant operations, using voice communication with plant personnel to discuss current events and trends.

When the next full forecast is available, (which may be immediate because of the alarm condition) the computational model is then used to provide a long-term projection.

3.7 UPGRADE SUBSYSTEM - METHODOLOGY AND PROCEDURES

One important part of the operational MCS is the capability for refinement or "upgrade" based upon accumulated experience with the system. The purpose of this section is to define the actual procedures involved in the upgrading process.

(a) Upgrade Approach

Initially, physical processes are predicted with deterministic models, using the most logical values for system parameters. From the beginning of system operation, comparison of predicted versus observed values enables the long-term accumulation of error statistics, which may be used as the basis for model refinement. As the statistical data base grows, and strong correlations between observed and predicted quantities are developed, the statistical basis of the model becomes more dominant. After a long period of time, with a mature, stable statistical data base, it may be expected that the prediction portions of the model can become largely statistical in nature.

It is important, in the system upgrade process, that the modeler-meteorologist be a part of the logic - i.e., no modification of the model be incorporated without a thorough scientific review of the data, and establishment of reliable empirical relationships upon which model revisions are made. For this reason, no automatic real-time "corrections" are incorporated into observed or predicted quantities in any monitoring or modeling system. Dynamic "front-end" error-correction schemes have a strong tendency to become unstable, producing unrealistic results and errors which are often difficult to detect. Human judgement is required for the initial effort in a careful evaluation of the predicted and observed data, to develop a high-quality statistical data base. The model refinements may then be developed from this data base.

(b) Data Archives

The most important single element of the upgrade subsystem is the data archive, in which original data representing all observed and predicted quantities are preserved. This archive contains, as a minimum, histories of the following quantities:

1. 1-hour averaged SO_2 concentrations at each monitoring site.

2. Observed meteorological conditions covering the same period of time.

3. Actual load on each boiler, covering the same period of time.

4. 41-hour forecasted meteorological conditions, for each forecast time.

5. Actual measured SO_2 emission rates.

6. Scheduled boiler operations (i.e., load).

7. 1-hour averaged SO_2 concentrations predicted by the air quality forecast model using forecast meteorological conditions and scheduled operation.

8. A log of cutback operations.

The archive, once developed, must be structured into categories by meteorological condition, plume rise, etc., to enable the meaningful error quantities to be generated. The number of categories is large and hence the time required to develop statistically significant populations for each category is long - from months for the most frequent occurrences to years for the rare events.

(c) Routine System Upgrades

The continuing process of data shorage, verification and evaluation leads to system upgrades which are by nature, "routine" in that they involve modifications to model inputs rather than to the theoretical basis of the model or the software by which is is implemented. Changes of the latter type are of a long-term nature, occurring only after extensive periods of research and experience with the system.

Routine upgrades are of basically three types:

1. Revison of forecast model parameters.
2. Revision of control decision thresholds.
3. Revision of cutback strategies.

(i) Forecast Model Parameters

These parameters describe the plant engineering characteristics, fuel properties, stack parameters, etc., as well as the coefficients used in the equations describing the dispersion process itself. These quantities are supplied to the AQFOR and may be readily modified as warranted by engineering considerations, or by statistical review of the data as described above.

(ii) Control Decision Thresholds

The backbone of the control decision model, as described in Appendix A, is the cutback threshold curve which determines, for each running averaging period, the averaged concentration at which control is required. These values thus determine the general degree of conservatism built into the control decision model; i.e., the general level of the curve provides the built-in safety factor with respect to the applicable standards, and the shape controls the relative sensitivity of the control decision model to short-term or long-term effects.

Optimization with respect to the trade off between probability of violation and plant MCS operating costs, however, may only be done after a review of overall system performance after a number of months of operations. For example, if experience shows a tendency to cut back too soon and too often, a less conservative curve may be used. Conversely, in the event of excesses due to insufficient degree of control, a more conservative curve may be entered. The effect of revised cutback curves may be established "offline" by rerunning the control decision model with appropriate case studies drawn from the data archive.

(iii) Strategies

The third form of "routine" system upgrade is the adoption of new switchmode strategies, as discussed in Section 3.5. This form of update occurs whenever plant engineering or operational conditions warrant, making sure that it is always current with respect to the most desirable mode of operation determined by plant personnel.

3.8 RELIABILITY OF SYSTEM COMPONENTS

(a) Introduction

The ultimate reliability of the MCS will be measured by its ability to prevent excesses of the ambient SO_2 guidelines. This in turn will depend on the reliability of four generalized components: (1) air quality monitoring; (2) meteorological forecasting; (3) emissions forecasting; and (4) air quality modeling. The meaning of the first three components is self-evident. By air quality modeling, we mean the algorithms and methodology which are used to relate meteorological inputs, emission rates, source data, terrain, and location factors to current and future air quality in the vicinity of the source. Each of the MCS components identified above are considered individually in this section with respect to their effect on overall MCS reliability.

(b) Assessment of Air Quality Monitoring Reliability

Every meteorological control application must have a monitoring network to verify that the required air quality is being maintained through the operation of the MCS. Also, real-time air quality monitoring must be available as one input to the decision to control emissions. In addition to these uses of monitoring data, they are also used during the definition phase of the MCS and later when the forecast models are calibrated and periodically upgraded. It is essential, then, to understand reliability with respect to the data produced by a monitoring network.

Monitoring network data will be employed during every important state of an MCS: (1) development of the system; (2) operation of the system; and (3) historical review of the system. Reliability, however, may be usefully defined without considering the specific application of the monitoring network.

The following sources of uncertainty in a monitoring system will contribute to a degradation of system reliability:

1. Instrumentation accuracy limits.

2. Percentage data capture statistics.

3. Information transfer error.

4. Insufficient and/or inappropriate sampling locations.

3.8 RELIABILITY OF THE SYSTEM COMPONENTS - (Cont'd)

Proper choice of SO_2 monitoring instruments depends on many factors. For purposes of evaluating a system for an MCS application, it is important to consider sensitivity, lag time and response time, interferences, accuracy, calibration drift and maintenance requirements. These are described in Appendix H of the detailed air quality studies.[6]

The lag time of a monitoring network is the time between the occurrence of the concentration and the time that this value is displayed for use by MCS personnel. With telemetered data, short-term averages (say, 2-minute averages or instantaneous concentration values) are usually available for examination before a 1-hour or 3-hour averaging period has transpired. In these cases, the lag time is not a constraint on the system.

The percentage of useful data capture depends upon the combined downtime of the sensors and associated data capture and transmission components. Sensor downtime includes time periods of instrumentation, calibration and maintenance, as well as identifiable data sets of inaccurate measurements. A well-designed system will attempt to minimize these sensor downtime contributions by providing automatic instrument calibration, remote sensing of possible instrument malfunctioning and generally, remote control of the instrumentation. Thus, real-time monitoring and telemetry of information provides mechanisms for substantially enhancing data rates. If the system involves telemetry such as telephone line usage, the data capture rate will depend additionally upon the downtime of this telemetry system and the remote recording devices. If the system requires any real-time data processing, the downtime of the data processing equipment must also be considered.

For the Hat Creek MCS, the remoteness of several of the monitoring sites may require the on-site generation of power to run the instruments. Special attention must be given to the selection of reliable generators. Real-time data displays will immediately indicate monitor problems and greatly enhance overall system reliability.

(c) Assessment of Meteorological Forecasting Reliability

The purpose of every MCS is to eliminate the occurrence of excesses of air quality guidelines by reducing contaminant emissions during periods when weather conditions are not conducive to adequate dispersion. Identification of these poor dispersion periods must be accomplished with some advance notice, since there are practical limits to the speed with which emission reduction orders can result in lower emissions from the stack. Furthermore, there is a significant "ventilation time" before the emissions can travel from the stack to beyond the important influence distance of the source. The requirements for advance warning of impending poor dispersive periods means that, in practice, the MCS must include some form of meteorological forecasting.

Certain local weather events, e.g., wind shifts, particularly demand prior recognition, since measured air quality levels alone would not generally provide a warning of such changes. Without forecasting, contaminant concentrations could rise rapidly in these situations, before any curtailment action could be effective.

The principal role of meteorological forecasting in the context of MCS programs is in support of air quality predictions. Actual MCS operations should include routine analysis of measured contaminant concentrations and concurrent meteorological conditions. Such continuous review procedures will improve forecasting methods to reflect accumulated experience.

In general, the essential requirements of meteorological forecasting for MCS are as follows:

1. The forecast lead time and updating intervals must be appropriate to the methods of emission reduction and their associated practical time constraints.

2. The relationship between synoptic-scale weather patterns and critical meteorological parameters at the site must be understood, as well as the consequences of forecast uncertainties in the prediction of air quality levels.

3. Forecast verification procedures must be included as part of the MCS.

For the Hat Creek plant, a lead time of at least 2 hours and a maximum of 8 1/2 hours will be required for lower-sulphur coal to reach all the boilers in operations. During the summer months when load reduction is the preferred control action, a 20 percent curtailment would be effected within minutes. It is assumed that the MCS would be operated to protect ambient guidelines for 3 and 24-hour average periods. Thus, forecasts must be prepared for a period of at least 33 hours during the winter. Based on this requirement, continuous meteorological support is essential. Periodic updating (e.g., every 8 hours) of the meteorological and air quality forecasts would compensate for the natural increase in uncertainty that accompanies extended predictions. Such revisions can greatly improve control system reliability.

The weather variables that the MCS meteorologist must forecast are those that influence or are closely related to the dispersive capacity of the lower atmosphere. These include wind speed, wind direction, stability, or direct estimates of atmospheric turbulence mixing depth, and, to a lesser extent, cloudiness, temperature and precipitation. In general, the most important parameters are those required as input to the MCS air quality prediction model.

Predictability of wind direction is generally good, especially when well-defined synoptic pressure systems are present in the vicinity of the MCS source. The accuracy of forecasts decreases with increased lead time and is generally more difficult for regions of complex terrain. Large high-pressure systems over the area of interest are often associated with light and variable winds; wind direction predictions are least reliable under these conditions.

Wind speed is more difficult to forecast. It varies diurnally, with generally higher values during daylight hours. Wind speeds also depend on the strength of the synoptic pressure gradient, surface roughness and terrain channeling effects. Forecast reliability for this parameter also decreases with length of forecast time.

The stability in the lowest kilometres of the atmosphere is broadly related to its turbulence characteristics. An unstable condition is characterized by thermal convection, vertical eddy motions and good dispersion. A stable atmosphere is one with suppressed turbulence and weak mixing capacity. The standard deviation of wind components and vertical profiles of wind speed and temperature are good indicators of atmospheric stability. These are most reliably predicted with assistance from monitoring instruments placed at different levels (e.g., on a meteorological tower).

The atmospheric mixing depth is defined as the height of the atmosphere through which vertical mixing readily occurs. Its predictablity depends on the predictability of the maximum temperature, the vertical distribution of temperature in the lowest few kilometres, and the presence or absence of subsidence inversions associated with synoptic-scale anticyclones (high-pressure systems). The prediction of maximum temperature is routine and generally quite reliable. The reliability of a temperature forecast decreases with increased lead time and is affected by cloud cover, wind speed and direction, time of year, and local effects. Like atmospheric stability, the mixing depth depends on the vertical temperature structure of the atmospheric boundary layer. Temperature sounding data from Vernon presently provide the best means for estimating the mixing height near the Hat Creek project. The operation of the 100 m meteorological tower at the plant site and the recommended installation of a doppler radar or other device will provide additional information. The mixing height is limited by the elevation of the base of a subsidence inversion; the mixing height is intrinsically lower than or equal to the inversion base height. Successful prediction of an inversion base height is thus determined in part by the reliability of forecasting the movement and locations of anticyclones.

The determination of model input parameters is strongly related to the predictability of synoptic-scale weather systems. The prediction of the growth and movement of cyclones and anticyclones is routinely performed by the forecasters from Environment Canada. Meteorological forecasts can often be improved by the use of relevant real-time data gathered at the site. Pilot balloons, radiosondes, and on-site wind and temperature sensors are important sources of forecast inputs. It is obvious that the mix of Environment Canada guidance, on-site data collection, and forecasting experience and skill are important for MCS forecasting reliability. The reliability of these predictions varies with experience, forecasting lead-time requirements and the positions of large-scale weather patterns.

Meteorological forecasting in the context of an air quality prediction program requires a basic understanding of the relationship between local weather conditions and contaminant concentrations. This knowledge should be gained by additional diffusion analyses based on the aerometric monitoring programs.

In the beginning stages of the MCS, forecasts of critical meteorological conditions should be conservative in order to account for the inherent inaccuracies in both air quality and meteorological predictions, since even a very small number of underpredictions will limit the success of the MCS. With a 244 m stack and control thresholds set at 80 percent of the assumed 3 and 24-hour guidelines, switching to low sulphur coal has been predicted to be necessary for about 195 hours during the 4-month winter period. The use of this more restrictive set of control guidelines is recommended, at least during initial period after the powerplant reaches its full capacity as a measure to compensate for forecast uncertainties.

An additional means for improving air quality and meteorological forecasts for the MCS at the Hat Creek plant would be provided by commencing MCS operation at the same time as startup for the first 500 MW generating unit. The construction schedule calls for staggered installation with one new unit called into service each year. This provides an important advantage in that the relationships between plant emissions, meteorological conditions, and ambient air quality can be studied and forecasting procedures refined for several years before emissions reach the levels assumed in this analysis associated with all four units at full load.

(d) Assessment of Air Quality Modeling Reliability

Several air quality models have been developed to predict ambient pollution levels resulting from pollutant emission sources. These models fall into two general categories: (1) deterministic-atmospheric dispersion models which calculate concentrations based upon physical relations between emission and meteorological variables and effluent plume dispersion; and (2) statistical or empirical models based upon the determination of statistical relations between emission rates, meteorological conditions, etc., and air quality levels. The model, AQFOR, which will be used in the Hat Creek MCS, is a deterministic model.

The reliability of a model is defined by its ability to predict ambient pollutant concentrations from given meteorological conditions and emission rates. The best method for the evaluation of prediction model accuracy is a thorough analysis of the accuracy resulting from a large data set of predictions with the model. With a sufficiently large data set, the model reliability can be assessed over all weather conditions and observed emission rates. Such an evaluation procedure results in three benefits: (1) the model is immediately useful for operational application; (2) the expected accuracy of short-term forecasts can be evaluated within close limits; and (3) threshold pollutant concentrations for the reliable operation of an MCS can be determined.

To assess the reliability of an atmospheric dispersion model for a particular locale, i.e., an isolated MCS, a basic understanding of the relationship between meteorology, emissions and pollutant concentrations must be established. This can be determined through a joint meteorology - air quality monitoring program and a model validation program.

For some applications, a comprehensive verification program may be unnecessary. If it has been determined that high-pollutant concentrations rarely occur or occur only under certain well-defined weather conditions, then the model validation study need only concentrate on the occurrence of those particular adverse weather conditions and source emissions which cause high pollutant concentrations. The model reliability, then, must be carefully established for the emissions and meteorology which will produce concentrations above a threshold level.

The empirical plume equation to be initially used to estimate the down-wind dispersion of a pollutant from an elevated continuous point source is the double-Gaussian plume equation:

$$C = \frac{Q}{u\pi\sigma_y\sigma_z} \exp - \frac{y^2}{2\sigma_y^2} \left[\exp - \frac{(z-h)^2}{2\sigma_z^2} + \exp - \frac{(z+h)^2}{2\sigma_z^2}\right]$$

where C is the pollutant concentration at height, z

Q	is the source strength.
u	is the mean horizontal wind speed.
σ_y, σ_z	are the standard deviations of the distribution of concentrations in the y (cross-wind) and z (vertical) directions, and are functions of downwind distance, x, and atmospheric stability or turbulence.
h	is the effective source height.

The above equation forms the basis for a more general Gaussian plume model - it is generally integrated and otherwise modified to represent a more complex relationship between emissions, meteorology and concentrations.

The Gaussian form of a plume equation is convenient because of its simple analytical form. However, the Gaussian approximation must adequately describe the plume spread as a function of downwind distance and meteorological parameters. Several characteristics and assumptions of the Gaussian plume equation should be noted:

1. The equation requires use of plume shape parameters derived from field experiments (in this case, on-site tracer experiments).

2. The plume equation represents time-averaged concentrations, as determined by the details of the various field experiments.

3. The equation is representative of steady-state conditions. Its use is less valid when local wind speeds and direction and local turbulence rates are changing rapidly.

4. Calculations off the centreline are assumed to decrease symmetrically in the cross-plume and vertical directions, following Gaussian distributions in both cases. The measures of the plume spread, σ_y and σ_z, are related to downwind distance and to atmospheric turbulence.

5. The effective height of emission, h, is defined as the height of the plume centreline when the plume has reached neutral buoyancy conditions. For emissions from smokestacks, this height is the sum of the physical height of the stack and an incremental height related to the buoyancy and vertical momentum of the plume. It is also affected by local terrain.

In summary, the assumptions implied in the Gaussian plume equations represent idealized conditions seldom, if ever, realized in the real world.

The causes of errors in point source model calculations may be broadly grouped into three categories: inaccuracies in the representation of the atmospheric transport and dispersion process by the model, errors in the emissions data and errors in estimating meteorological parameters.

The dispersion parameters σ_y and σ_z are functions of downwind distance and atmospheric stability. It is assumed that the atmospheric stability is constant throughout the area of interest. However, changes in atmospheric mixing rates, which are parameterized by σ_y and σ_z, are possible with changes in surface roughness and thermal characteristics. For example, a pollutant plume traveling over a region may experience an increase in spread over rough terrain as compared to more gentle terrain.

The Gaussian point source model also assumes that wind speed and direction are constant throughout the area. Model calculations are particularly sensitive to errors in wind direction as noncentreline pollutant concentrations decrease exponentially away from the centreline. Wind direction persistence information is especially important for estimating concentrations over time periods of a few hours. As discussed in the previous section, wind direction will vary with a changing synoptic meteorological situation and also with terrain effects.

The Gaussian model is usually limited by the lack of treatment of transformation and removal processes in the atmosphere in addition to uncertainties in the emissions data. As formulated by the Gaussian model, the pollutant concentration is directly proportional to source emissions. Hence, uncertainties in the source strength and the temporal variability in emission rates will lead to uncertainties in the concentration calculation.

The effective height (h) of a stack, which determines the centreline height in the Gaussian plume model, is computed as the sum of the physical stack height and the plume rise due to the vertical momentum and the buoyancy of the effluent. Plume rise is related to the dimensions of the stack, the effluent composition as temperature and heat flux, the wind speed above the stack, and atmospheric stability. Uncertainties in these parameters will affect the plume rise calculation.

The uncertainties in plume centreline heights can cause major errors in model calculations, particularly for cases where the distance between source and receptor is small. At large downwind distances, the importance of stack height decreases, thus reducing errors due to uncertainties in plume rise.

(e) Summary

Given the uncertainties in various MCS components, it is suggested that incorporation of certain design features in the MCS program for the Hat Creek plant will substantially improve the reliability of meteorological and air quality predictions, thereby minimizing the number of system failures, i.e., excursions of applicable ambient guidelines. These may be summarized as follows:

1. For fuel-switch mode, the control guidelines should initially be set at 80 percent of the assumed 3-hour and 24-hour regulatory guidelines to compensate for errors incurred due to forecast lead-time requirements. Fine tuning after start up may reduce the 20 percent margin.

2. MCS operation should commence concurrently with startup of the first 500 MW generating units to develop the skill of recognizing adverse dispersion conditions, to tailor the air quality forecast model, and to streamline system operations during the period when total emissions are substantially below those assumed in this analysis.

3. Conservative forecasting methods should be used, especially during the early phases of the MCS. It is estimated that control actions will be necessary about 25 percent to 50 percent more frequently than indicated by the modeling results to compensate for the difficulty in predicting certain meteorological events associated with relatively high ground level concentrations.

4. Staffing for the MCS should include a provision for continuous forecasting service by professional meteorologists. This is especially important during the months when fuel switching is the preferred control action, due to the large forecast lead-time requirements imposed by this emission reduction technique. Periodic updating and refinement of the meteorological forecasts is particularly helpful for improving 24-hour concentration estimates.

5. All aspects of the MCS program should be routinely evaluated to identify problems and suggest methods to improve reliability of site-specific meteorological forecasting and air quality predictions, and to enhance understanding of the effects of control actions on ambient concentration levels.

If these features are included in the design and operation of the MCS, it is reasonable to expect excellent reliability, i.e., few if any SO_2 concentrations greater than the assumed guideline criteria.

(f) Example of MCS Operation

An example of reliability for an operational MCS serves to illustrate the improvement of air quality control with accumulated experience. Since the summer of 1974, ERT has operated a system for a major chemical manufacturer in the midwestern United States. The program is intended to provide the chemical company with recommended plant operating conditions (emissions) for maintenance of federal 3-hour and 24-hour SO_2 standards on the basis of predicted dispersion conditions.

The manufacturing plant has two separate power houses approximately 2 km apart. Each powerhouse has five boilers. Emissions are exhausted through a total of eight stacks. The MCS procedures are complicated in that 10 boilers can operate at variable loads, and some are capable of operation with different fuels. Control actions are required relatively frequently. During the summer, emission curtailment orders are in effect about 5 percent of the time, 10 percent to 20 percent during the spring and fall and from 25 percent to 45 percent of the time during winter. Table 3-3 documents the performance of the MCS with regard to maintaining SO_2 levels below the 365 $\mu g/m^3$ (0.14 ppm) standard for 24 hours and the 1300 $\mu g/m^3$ (0.5 ppm) standard for 3 hours. During the "shakedown" year, the number of excesses dropped dramatically, and continual improvement was evidenced during the ensuing operational years. A similar reduction in measured 3-hour concentrations above the federal secondary standard (1300 $\mu g/m^3$ or 0.50 ppm) has occurred since implementation of MCS. In 1972, measured maxima above this threshold were recorded on 23 occasions; only one such value occurred in each of the years 1975, 1976 and 1977.

3.8 RELIABILITY OF THE SYSTEM COMPONENTS - (Cont'd)

TABLE 3-3

PERFORMANCE STATISTICS FOR ERT MCS AT A MAJOR MIDWESTERN CHEMICAL MANUFACTURING PLANT

	Measured Number of Threshold Exceedences					
	Before MCS		MCS "Shakedown"	Operational MCS		
Standard	1972	1973	1974	1975	1976	1977
3-hour secondary (1300 μg/m^3 or 0.5 ppm)	23	8	7	1	1	1
24-hour primary (365 μg/m^3 or 0.14 ppm)	22	11	6	2	1	0

Considerable effort has been expended to refine meteorological forecasting for the plant area by systematic verification procedures. Experience with the MCS has identified the specific weather situations that previously resulted in unexpectedly high ground level concentrations. Three model upgrade studies have been performed since system startup to incorporate realistic methods for simulating these conditions.

In addition, results of physical modeling experiments conducted in a wind tunnel have substantially improved air quality predictions for high wind speed conditions that produce plume washdown from the relatively low stacks. The statistics presented in Table 3-3 demonstrate the effectiveness of such studies in improving system reliability and reflect the accumulation of site-specific operational experience.

Interestingly, forecast verification records have shown that accuracy in forecasting weather parameters for this MCS has been consistently good throughout the program. Thus, the dramatic reduction in air quality violations with MCS is primarily related to an improved ability to simulate dispersion processes associated with particular meteorological events.

SECTION 4.0 - ALTERNATIVES FOR EMISSION REDUCTION

There are two primary measures which may be taken to reduce SO_2 emission rate if the forecasting/modeling element of the MCS predicts a concentration in excess of the guideline values: fuel switching and load reduction. These would generally not be used in combination, but rather as discrete alternatives. The usual preference will be to use fuel switching on one or more of the units in the winter months and use a load reduction scheme during the rest of the year. However, the flexibility of the control decision model allows many combinations of different control alternatives to be considered. Thus, if plant operators wished to consider the combined effects of load reduction on one or more units with fuel switching on other units, the MCS could provide an analysis of this strategy. The following sections discuss the operational aspects of each of the alternatives.

4.1 FUEL SWITCHING

Hat Creek coal can be generally described as a low-sulphur coal since the average sulphur content in the normal blended powerplant coal is less than 0.4 percent on an "as received" basis.* However, one zone (Zone D) of the deposit has a significantly lower sulphur content (0.25 percent as received) and it is proposed to use unblended "D" zone coal during fuel switching. In order to assess the application of this mode of MCS operation it is necessary to establish the quantities and qualities of the normal blended powerplant coal, and the lower sulphur MCS fuel. It is also necessary to establish the handling and storage procedures which will ensure appropriately effective fuel switching.

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* "As received" basis refers to inclusion of coal moisture content when computing component percentages. Alternatively, "dry basis" would mean without moisture considered.

4.1 FUEL SWITCHING - (Cont'd)

(a) Fuel Reserves

An extensive program has been conducted at the mine site to determine characteristics of the coal in the deposit. Over 200 holes have been drilled in a 150 by 150 m pattern and the cores have been analyzed for a number of parameters. Geological and geophysical interpretations of this drilling have led to the identification of four major coal zones (called A, B, C and D) with estimated reserves in a 35-year pit as shown in Table 4-1. Also shown in the table are the sulphur contents of each zone. The "D" zone coal clearly has the lowest sulphur content and is proposed for use in the MCS as the secondary, or low-sulphur fuel.

TABLE 4-1

HAT CREEK NO. 1 DEPOSIT ESTIMATED
RESERVES FOR PROPOSED 35-YEAR PIT[1]

Zone	Estimated Reserves in 35-year Pit (Mt)	Estimated Sulphur Content (%)[2]
A	77.5	0.71
B	57.2	0.80
C	60.4	0.41/0.5
D	149.1	0.31

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[1] Source: Hat Creek Project, Preliminary Engineering Composite Report, Appendix D, September 1978, updated by Paul Wier Co.[8]

[2] Dry coal basis.

Although the "D" zone coal is located beneath the other zones as they exist in the deposit, the zones are not steeply dipped, so that access to each of the zones is possible by removal of only the surficial materials. As a result "D" zone coal will be available from the first years of mining for use in blending to produce powerplant quality coal and by itself as an MCS alternative.

The results of an analysis of meteorological and projected emission conditions for the powerplant with all four units at full load made by ERT indicated that 130 hours of fuel switching would be necessary during the 4 winter months to ensure that ambient concentrations would never exceed 80 percent of the recommended short-term guideline levels. Because they had only used 1 year of meteorological data in making this estimate, ERT further recommended that, to plan for years where meteorological conditions might be less favourable than the year used in the study, the MCS should be prepared to undertake fuel switching as much as 50 percent more hours than had been predicted. Thus, 195 hours of fuel switching has been identified as a criterion for establishing maximum annual low-sulphur coal requirements for the MCS. At a maximum fuel consumption rate of 35 100 t/d (for low-sulphur coal), this corresponds to approximately 285 000 t/a of low sulphur coal. Over the course of 35 years this would mean approximately 10 million tonnes of "D" zone coal would be used as a secondary fuel if the plant always ran at full load. This represents less than 7 percent of the available reserves of "D" zone coal in the 35-year pit. The coal blending scheme has taken this "D" zone coal utilization into consideration so that overall fuel quality will be unaffected by the fraction of "D" zone coal that is being used for the MCS.

(b) Coal Blending

In order for the fuel switching mode of MCS operation to be an effective SO_2 control strategy, it is necessary to ensure acceptable coal sulphur content during normal operation as well as several shovels in the pit producing to a schedule based on predrilling of the deposit, the run-of-mine coal quality and properties entering the blending piles are planned to ensure that, with appropriate stacking and reclaiming, the blended product sent to the powerplant is within specified quality limits.

This mining/blending scheme is designed to minimize variations in coal quality as mined. Since the mining/blending scheme relates primarily to heating value, some variation in sulphur content of the blended product will occur. Precise information on the sulphur variability cannot be determined at this time, but a reasonable assessment has been made. The analysis to determine feasibility of the MCS approach conducted by ERT[1] assumed emissions from the plant could be characterized by continuous combustion of coal with a heating value of 14 650 kJ/kg (as received) and a sulphur content of 0.45 percent (as received). If all the sulphur is assumed to be converted to SO_2 this corresponds to an emission rate of 0.61 mmg of SO_2 per kilojoule in the fuel. Current B.C. Hydro estimates are that the normal blended coal will have an average heating value of 13 700 kJ/kg (as received) and sulphur content of 0.39 percent (as received). This would correspond to an emission rate of 0.57 mmg of SO_2 per kilojoule in the fuel if all the sulphur were converted to SO_2. It is estimated that at least 5 percent of the sulphur would not be emitted as SO_2 but would be further converted to SO_3 or remain in the ash.[9] Thus, ERTs analysis of MCS feasibility has already allowed for some variability in coal quality.

(c) Coal Storage

In addition to the two blending/storage piles at the mine there will be two storage areas at the powerplant. One of these will be a "live" storage pile of up to 95 000 t of coal (65 hours of full-load operation). The other will be a "dead" storage area for up to 1 200 000 t (30 days of full-load operation) which will normally contain 14 days supply. The purpose of these storage areas is to ensure that the powerplant will have reliable coal supply to meet production needs at all time.[8] A certain portion of both these stockpile areas will be reserved for low-sulphur coal. The actual quantity of low-sulphur coal to be stored in these piles will be determined by actual powerplant and MCS experience. ERTs analysis of the MCS system[1] concluded that the maximum duration of a single coal switching event was 45 hours in a single year based upon the 1 year of meteorological data analysed. Using the 50 percent factor to account for years where longer durations might occur, a value of 68 hours is anticipated to be the longest fuel switching event. This would require 100 000 t of low-sulphur coal if it occurs during full-load operations. The powerplant storage facilities described earlier would provide this, with an additional supply of "D" zone coal direct from the mine as necessary.

(d) Fuel Switching Operations

When a decision has been made to switch to low-sulphur coal because meteorological conditions have been predicted which may cause high ambient concentrations, it will be possible to immediately cease filling silos with normal coal, clear the system, and begin reclaiming low-sulphur coal from the live and/or dead storage areas at the powerplant. Instructions will be simultaneously given to the mining/blending area to prepare for delivery of low-sulphur coal directly up the overland conveyor to the powerplant. Normal coal enroute from the mine to the powerplant at the time of the initiation of the fuel switch will be diverted to storage. The mine will also produce and deliver low-sulphur coal to replenish the "MCS reserves" at the powerplant. In this way a continuous supply of low-sulphur coal will be ensured to meet the requirements of any MCS event.

4.1 FUEL SWITCHING - (Cont'd)

Coal reclaimed from the live storage area by a bucketwheel reclaimer will be conveyed through the powerplant coal handling system to the silos which feed the boiler pulverizers. The various powerplant conveyor belts and surge bins will not provide delay in the fuel switching operation. Low sulphur coal from the live storage area will start to fill the silos in less than 30 minutes. Meanwhile the normal coal remaining in the silos at the time the fuel switch was initiated will be drawn down. The silos each have a capacity of 8 hours supply. Thus, at worst, if the silos are full, it will take 8 hours of operation with normal coal before a given pulverizer will begin delivering low-sulphur coal to the furnace.

To allow the worst effective period for low sulphur coal to start reaching the furnace, it is necessary to have at least 8 1/2 hours of warning. The MCS has been designed to provide this much advance warning. In theory it will be possible to switch coal for any period of time. In practice it is not desirable to expose the powerplant to an excessive range of operating conditions in a short period of time. Thus, in actual operation of the MCS, even though the forecasting/modeling element has predicted an excess of only the 3-hour guideline concentration, the fuel switching will be such that a longer period of low-sulphur coal use will actually occur. In actuality the experience of other MCS operators indicates that the most common guideline concentration excess which must be avoided by MCS operation is a 24-hour average value. Thus, most fuel switching episodes at the Hat Creek Project are expected to be of the 8 to 24-hour range. Experience gained in the initial years of project operation will determine the needed switching times.

1. Shutdown of pulverizers (eight per boiler, seven on at full load).

2. Ignition of pilot and support fuel (oil).

3. Changeover of unit auxiliaries to station service supply.

The load reduction procedures may have an effect on many important operational parameters which are of continual concern to the operator. These include furnace stability, fouling and slagging of boiler heating surfaces, and thermal fatigue of turbine components due to changes of steam temperatures with changes of load. Quite apart from the possible economic penalty of load reductions, it is not desirable to operate the powerplant under continuously changing load conditions.

The use of load reduction as a control measure in the Hat Creek MCS will be to respond to distinctly defined MCS episodes. However, the actual operating conditions and loading of the powerplant units will vary for other reasons, such as normal maintenance outages (e.g. each of the four units is expected to be inoperative for 1 month per year for maintenance procedures). To recommend modified operating conditions to the powerplant, the MCS will need information on the current load of each unit, and on any planned changes in those loads in the near future. Powerplant operations would provide regular updates on this information to the forecasting/modeling element of the MCS.

REFERENCES

1. Environmental Research and Technology (ERT), Inc. 1978. Air Quality and Climatic Effects of the Proposed Hat Creek Project. Appendix C - Alternate Methods of SO_2 Control. Santa Barbara, California. ERT Document No. 5074-F-C April.

2. Lesnick, E.C. Benefit-Cost Analysis: Air Quality Control Systems. Prepared by Ebasco Services of Canada Limited. September, 1979.

3. Environmental Research and Technology (ERT), Inc. 1978. Modification and Validation of the Operating Version of AQFOR. Report to Dow Chemical Company, Michigan Division, Midland, Michigan. ERT Document No. P-3242 March.

4. Green B. *Second Validation Study of the AQFOR Dispersion Model* used in the Kincaid SCS. Report to Commonwealth Edison Company, by ERT, Concord, Massachusetts. ERT Document No. P-1902-820.

5. Personal communication, B.C. Hydro and Ontario Hydro.

6. Environmental Research and Technology (ERT), Inc. 1978. Air Quality and Climatic Effects of the Proposed Hat Creek Project, Appendix H. ERT Document No. 5074-F-H.

7. Environmental Research and Technology (ERT), Inc. 1978. Air Quality and Climatic Effects of the Proposed Hat Creek Project, Appendix B. ERT Document No. 5074-F-B.

8. Paul Wier Co. Report forthcoming.

APPENDIX A

CONTROL DECISION MODEL DESCRIPTION

A.1 ALGORITHM DESCRIPTION

The control decision model makes use of a three-dimensional computation space referred to as the C-K-T (concentration versus cutback versus time) space, defined as follows. In the following sections we refer to "cutback" as any reduction in emission rate of SO_2, whether via fuel-switching or load reduction.

Compute for each receptor the array of concentrations C (K,T) for time periods T = 1, 41 and operating modes K = 1, N, where K = 1 consists of the most desirable total plant configuration, and the ordering K = 2, ..., N corresponds to successive stages of emission reduction. These concentrations shall for this discussion be regarded as "instantaneous", i.e., 1 hour is the smallest time increment permitted in the system.

The concentrations may be represented in a three-dimensional space, which we shall call the C-K-T diagram, as shown in Fig. A-1. If a surface is passed through the points in this space, one obtains the representation of Fig. A-2, which shows isopleths of concentration above the value referred to as the "instantaneous" or (1-hour) cutback concentration (this value may in fact be the 3-hour guideline or a value somewhat less than the guideline to provide a "safety factor"). This area is thus "inaccessible" (i.e., above some unacceptable threshold value) for this receptor and this time period.

For each receptor, there is a similar C-K-T diagram which may contain within it an inaccessible region. If all such diagrams are superimposed, as shown in Fig. A-3, the result becomes the inaccessible region for the entire plant - i.e., that set of operating modes which

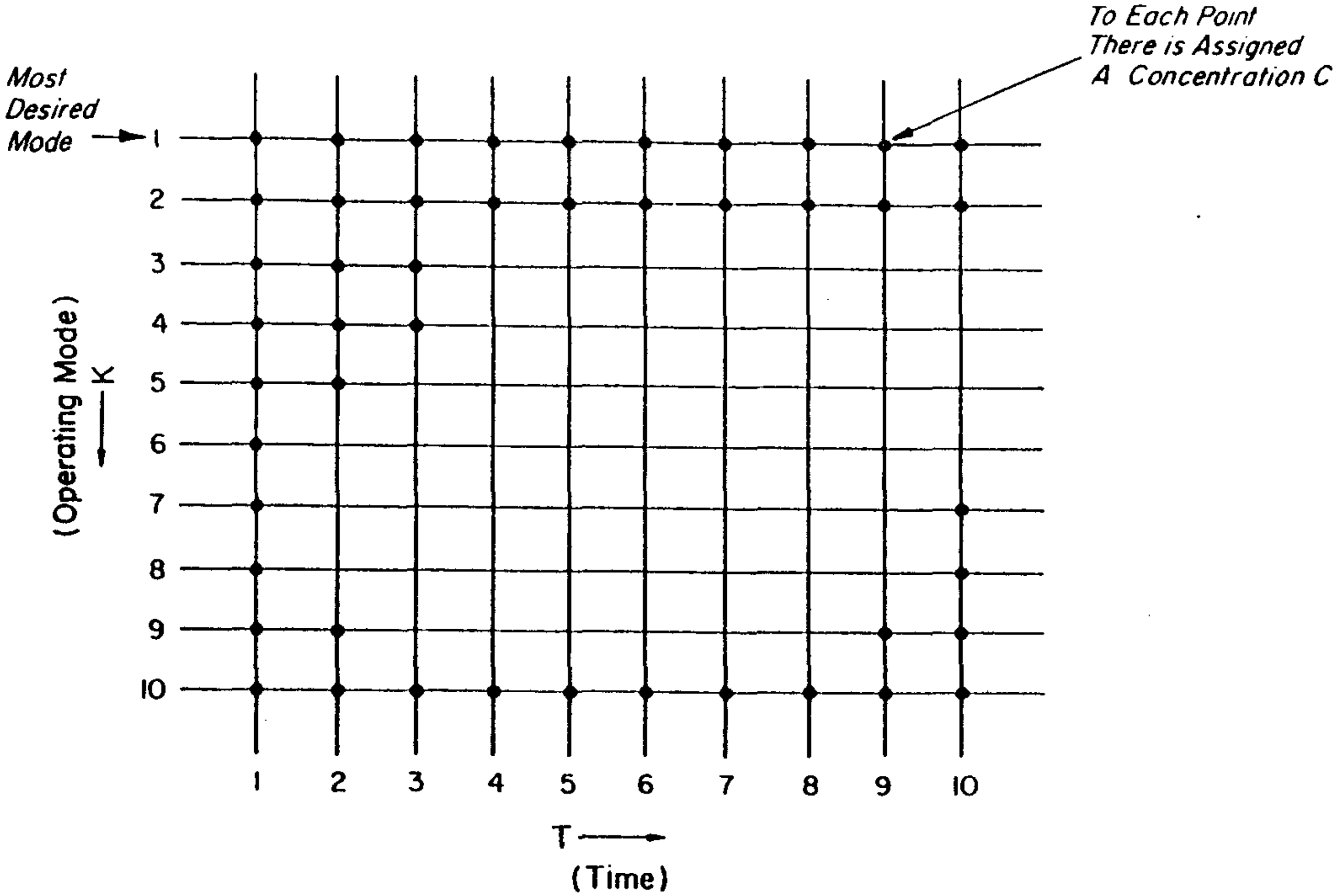


Figure A-1 C-K-T Diagram for one Receptor Represented as an Array of Discrete Points. Shown are possible ordered operating modes (9 stages of cutback) and 10 time periods.

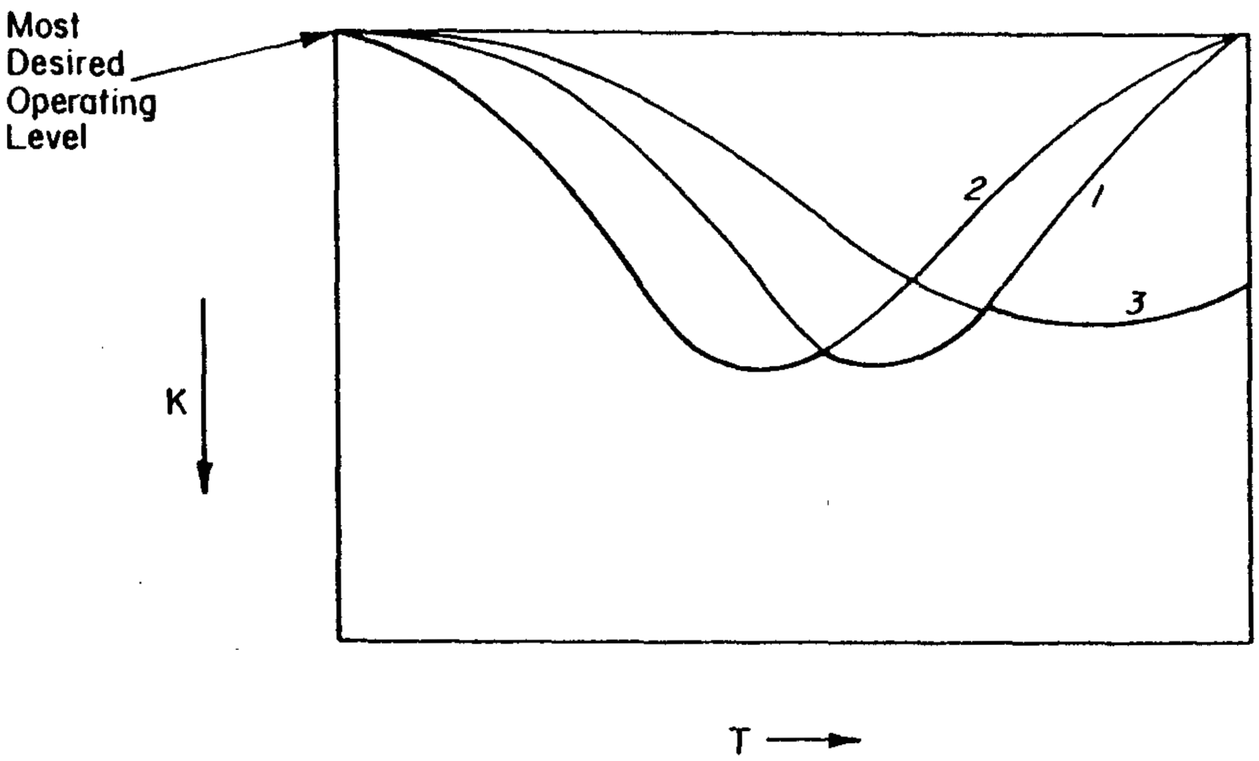


Figure A-3 Composite K-T Diagram for a 3-Receptor System. The overall plant inaccessible region is that which includes any inaccessible region for a single receptor (heavy line)

A.1 ALGORITHM DESCRIPTION - (Cont'd)

is inaccessible for at least one receptor - with respect to 1-hour average concentrations. Any projected plan of operation for the plant may be represented as a line along the surface of the C-K-T diagram. The plan is therefore viable with respect to the instantaneous (1-hour averaged) concentrations if an only if this line path does not enter the "plant inaccessible region".

Extension to averages of concentration performed over multiples of the fundamental 1-hour period requires the added consideration of the history of actual concentrations. The running average of period P, beginning at time T_o is given for a single receptor by:

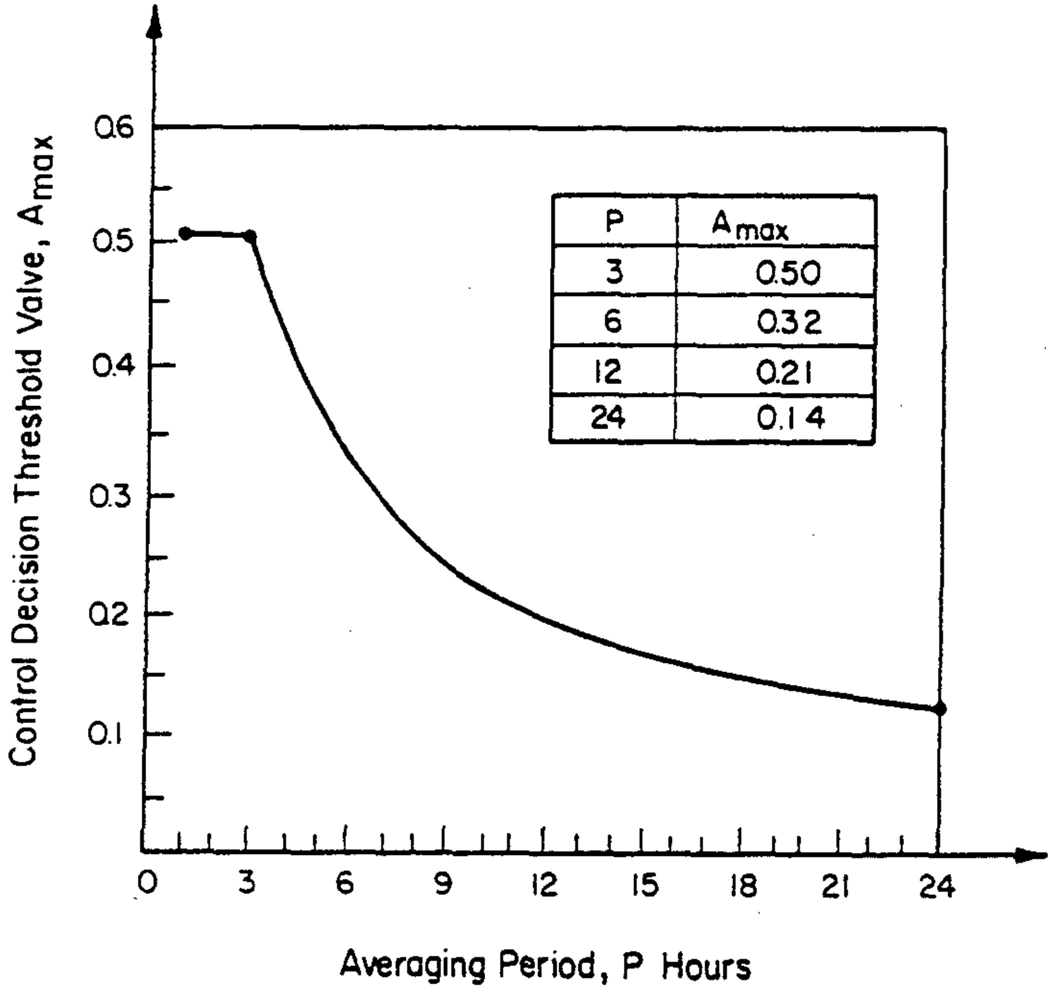
$$A(P,T_o) = \frac{1}{P} \int_{T_o}^{o} C_o(T')dT' + \int_{o}^{P+T_o} C(K',T')dl' \quad , T_o \leqq o$$

(1)

$$A(P,T_o) = \frac{1}{P} \int_{T_o}^{T_o+P} C(K',T')dl' \quad , T_o > o$$

where C_o (T) is the 1-hour averaged concentration observed for this receptor at time T ($T \leqq 0$) and the integral for $T > 0$ is a line integral performed along the projected plant operation path. For each averaging period P, there is a control decision threshold value A_{max} (P) as shown for example in Fig. A-4. The requirement for viability of any projected plan with respect to the averaging period P is thus

(2) $A(P,T_o) < A_{max}(P)$



P	A_{max}
3	0.50
6	0.32
12	0.21
24	0.14

Figure A-4 One Possible Control Decision Threshold Curve, Defining the Maximum Values of Running Averaged Concentrations

A.1 ALGORITHM DESCRIPTION - (Cont'd)

for all values of T_o on the range -P to 24-P. Using Equation (1), this requirement becomes

$$\frac{1}{P}\int_{o}^{P+T_o} C(K',T')dl' < A_{max}(P) - \frac{1}{P}\int_{T_o}^{o} C_o(T')dT', \quad T_o \leq o$$

(3)

$$\frac{1}{P}\int_{T_o}^{P+T_o} C(K'T')dl' < A_{max}(P) \qquad , T_o > o$$

The path integrals (i.e., the projected plan of operation) must therefore satisfy the dual criteria of compensating for past occurrences, while protecting against future occurrences. Note that Equation (3) makes the assumption that observed concentrations are available at the receptor for which the test is made. In actual fact, the field of receptors cover the entire area of plant influence, and only a few of the computation points coincide with monitoring sites. To overcome this problem, the concentrations C_o (T) must be computed using observed meteorological conditions and actual plant emissions applicable to the time T.

Define C_{Test} (P, T_o) as that constant concentration which, if maintained everywhere along the path, would just equal the effective control threshold as given by Equation (3). Thus

$$C_{Test}(P,T_o) = \frac{1}{P+T} \quad P.A_{max}(P) - \int_{T_o}^{o} C_o(T')dT' \qquad , T_o \leq o$$

(4)

$$C_{Test}(P,T_o) = A_{max}(P) \qquad , T_o > o$$

A.1 ALGORITHM DESCRIPTION - (Cont'd)

Then, Equation (3) becomes

$$(5)\quad \frac{1}{P}\int_{\max(0,\ T_o)}^{P+T_o} C(K',T') - C_{Test}(P,T_o) \quad dl' \quad < \quad o$$

Thus, if the values of C_{Test} are known, the necessary and *sufficient condition for viability of a projected plan with respect to* a given receptor is that C must be less than C_{Test}, averaged over the path. One sufficient condition is that $C(K',T') < C_{Test}$ for all points *on the projected path. This would be unnecessarily restrictive,* however, since it would limit operations to those modes for which concentrations are always less than the control decision threshold for the longest averaging period (e.g., the 24-hour standard of 0.14 ppm from Fig. A-4).

It is important to note, however, that even if the above conditon is not applicable everywhere on a projected path, it must be true on the average over the path. Fig. A-5 represents a simple example for the case in which concentrations are constant with T. Application of the 1-hour criterion defines the accessible region for this receptor to paths below A-A" in Fig. A-5. Economic considerations thus make the path A-A" the best "first choice" for a projected path, subject to maintenance of long-term average criteria.

In the example shown, the quantity C_{Test} is assumed to be 0.4 ppm for the averaging period P. The conditions of Equation (5) *make it impossible for the first choice level 0.5 ppm to be maintained* for the entire period; hence a revised path A-A'-B'-B" is indicated. Note that the path shown in Fig. A-5 is one of an infinite set of choices which may satisfy the condition of Equation (5), subject only to the requirement that the area between the path and C_{Test} before the cutback A'-B' must equal that after the cut. From the foregoing discussion it is clear that, if the concentration at any point along a

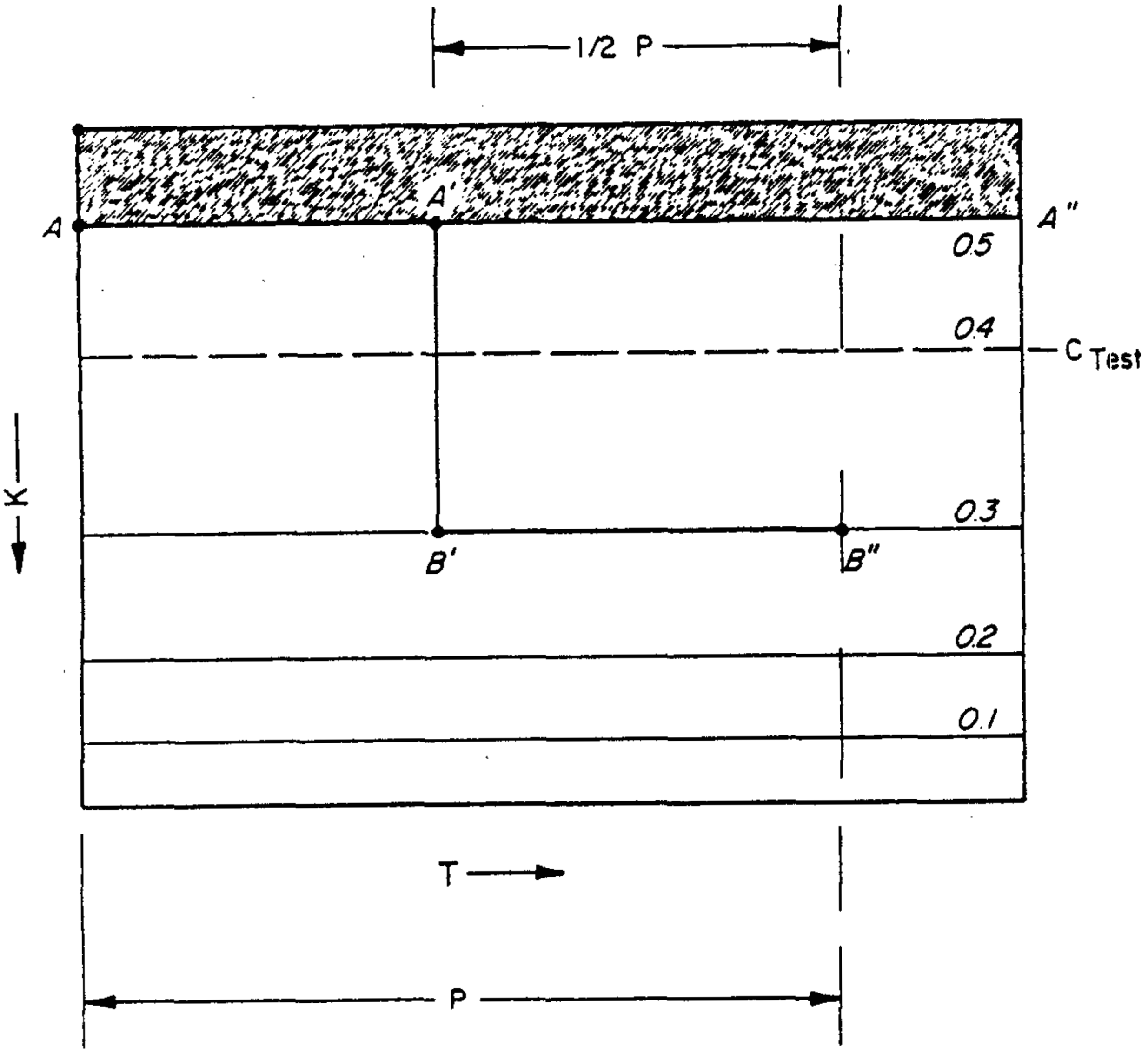


Figure A-5 Application of Averaging Criterion for Averaging Period P for a Single Receptor

A.1 ALGORITHM DESCRIPTION - (Cont'd)

projected plant-operations path exceeds the value of C_{Test} for any averaging period P and initial time T_o, a cutback will have to be made to satisfy Equation (5).

The algorithm for computation thus consists of the following:

1. Compute the C(K,T) array for each receptor.
2. Identify the inaccessible area for each receptor as that for which the 1-hour average concentrations exceed the specified guideline.
3. Identify the overall plant inaccessible area as the area which is inaccessible for one or more receptors.
4. Define the initial "first choice" projected path as that which produces minimum cutback and remains in the plant accessible area.
5. Compute the quantities C_{Test} (P,T_o) using Equation (4).
6. For each receptor in sequence, and beginning with the earliest value of T_o and moving forward, apply the test of Equation (5) for each period p under consideration, modifying the path as required to meet the criterion.
7. The path which results from the above steps will meet all the criteria for averaging periods from 1 hour on up to the longest period (24 hours) considered.

A.2 CUTBACK THRESHOLD

The algorithm described above is driven by the control point threshold curve, which determines, for any averaging period, the maximum predicted average concentration which will be allowed at any receptor before applying the next cutback step in the given switchmode

A.2 CUTBACK THRESHOLD - (Cont'd)

strategy. Fig. A-6 gives three possible cutback threshold curves, labelled A, B and C which are designed to protect the 3-hour and 24-hour SO_2 guidelines.

Each of the three curves of Fig. A-6 contain a "safety factor" in that they all lie below the guidelines themselves. The difference in the curves lies in their degree of conservatism: Curve A is the most conservative, since it cuts back at the lowest value for any averaging period, while curve C is the least conservative.

The trade-off between economic and air quality considerations is thus determined by the curve chosen: Curve A will be "safer" in MCS operation, but will result in higher plant cost due to more frequent cutback. Conversely, curve C will provide the least plant cost, but will provide a higher probability of excessive concentrations.

Optimization of the MCS for the particular requirements of a plant involves the best choice of threshold curve, and the adjustment of this curve is determined by "system experience". It is expected that a nominal curve (e.g. curve B) will be used initially, with modifications made as indicated during the first several months of system operation.

A.3 OPTIMIZATION OF CONTROL ACTION

An important consideration, as expressed in the fourth control action criterion, is the application of control measures during the time in which they will be most effective in reducing long-term averaged concentrations, and not at other times. This requires that in anticipating the need for control, the cutback of plant emissions at some time in the future should be carried out such that (1) long-term averages are protected at all receptors; and (2) the minimum total cutback is obtained.

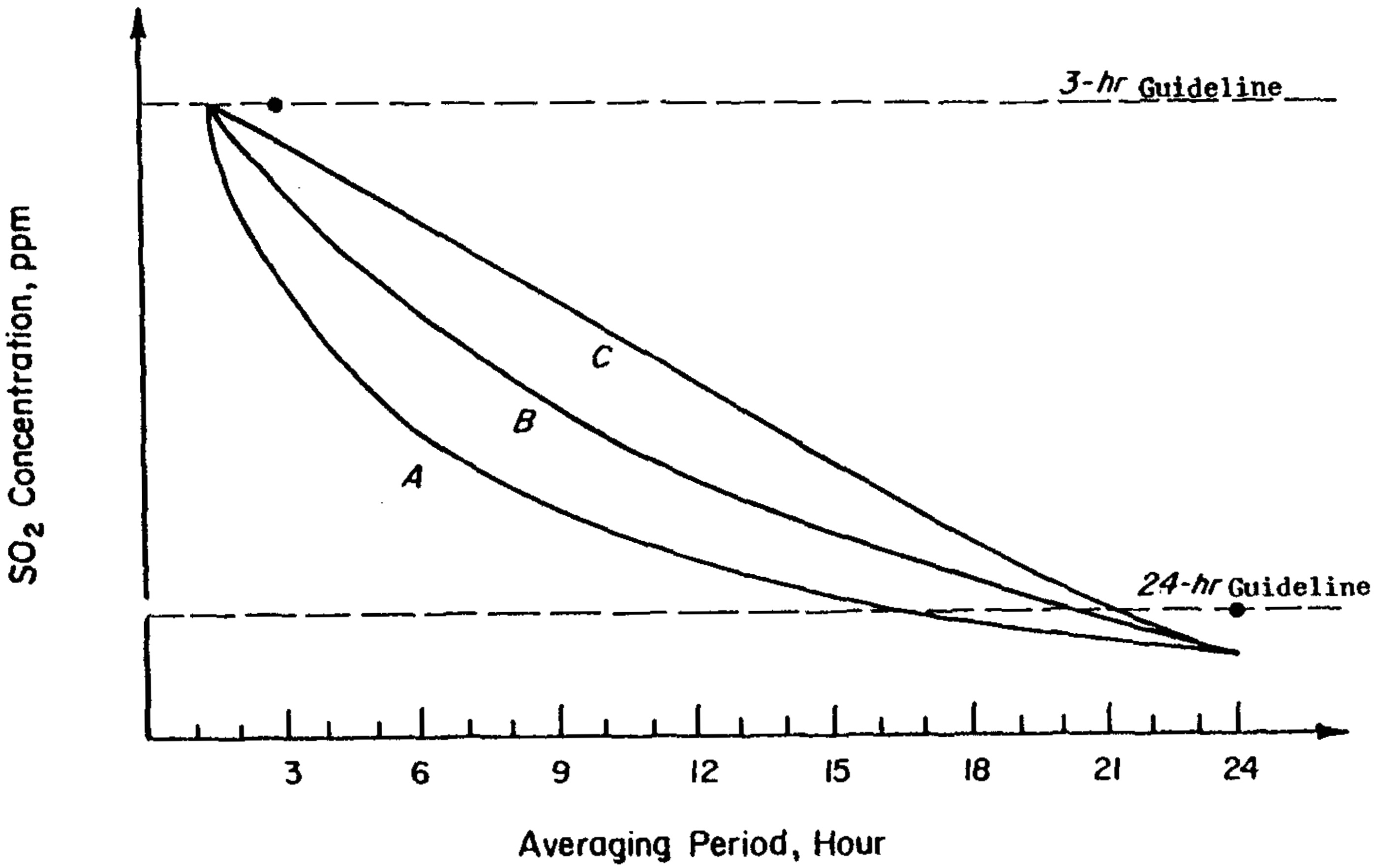


Figure A-6 Three Possible Control-Point Threshold Curves which Protect Both 3- and 24-Hour Standards, Ranging from Most Conservative (A) to Least Conservative (C)

A.3 OPTIMIZATION OF CONTROL ACTION - (Cont'd)

The first of these goals could be accomplished simply by reducing emissions - either immediately or at a time scheduled in the future - to a constant level such that all applicable long-term averages would be protected for all receptors, and retaining this level for the remainder of the forecast period. This approach, although practical for fuel-switching options would result in periods of unnecessary restriction during load reduction options.

The alternate approach, as implemented in the control decision model, provides for the maximum total generation by staging the cutback in successive steps, at all times keeping the "operation path" in the C-K-T space as close as possible to the forbidden or "plant inaccessible" region in that space. A simple example of the difference in the two approaches is shown in Fig. A-7, in which an eposide beginning at future time T_o is indicated by the shaded inaccessible region. In the simple approach, emissions are cutback at time T_o to a constant level for the remainder of the forecast period as indicated by path a-a". In the optimum approach, each step in the cutback strategy is instituted for the time period necessary to avoid crossing into the forbidden region, as indicated by path b-b'. The area between the two paths represents the total plant generation lost in using the former approach. The tremendous operating cost advantage of the latter approach justifies its added complexity.

A.4 COMPUTATIONAL CONSIDERATIONS

The numerical procedures used in selecting the operating schedule for a control action requirement are subject to computational instabilities which result from the generally complex relationship between the driving plant load and overall air quality as defined in terms of maximum averaged concentrations. The dependence of plume rise upon load, for example, makes it likely that a small reduction in load to satisfy a requirement at one receptor point will lower the plume

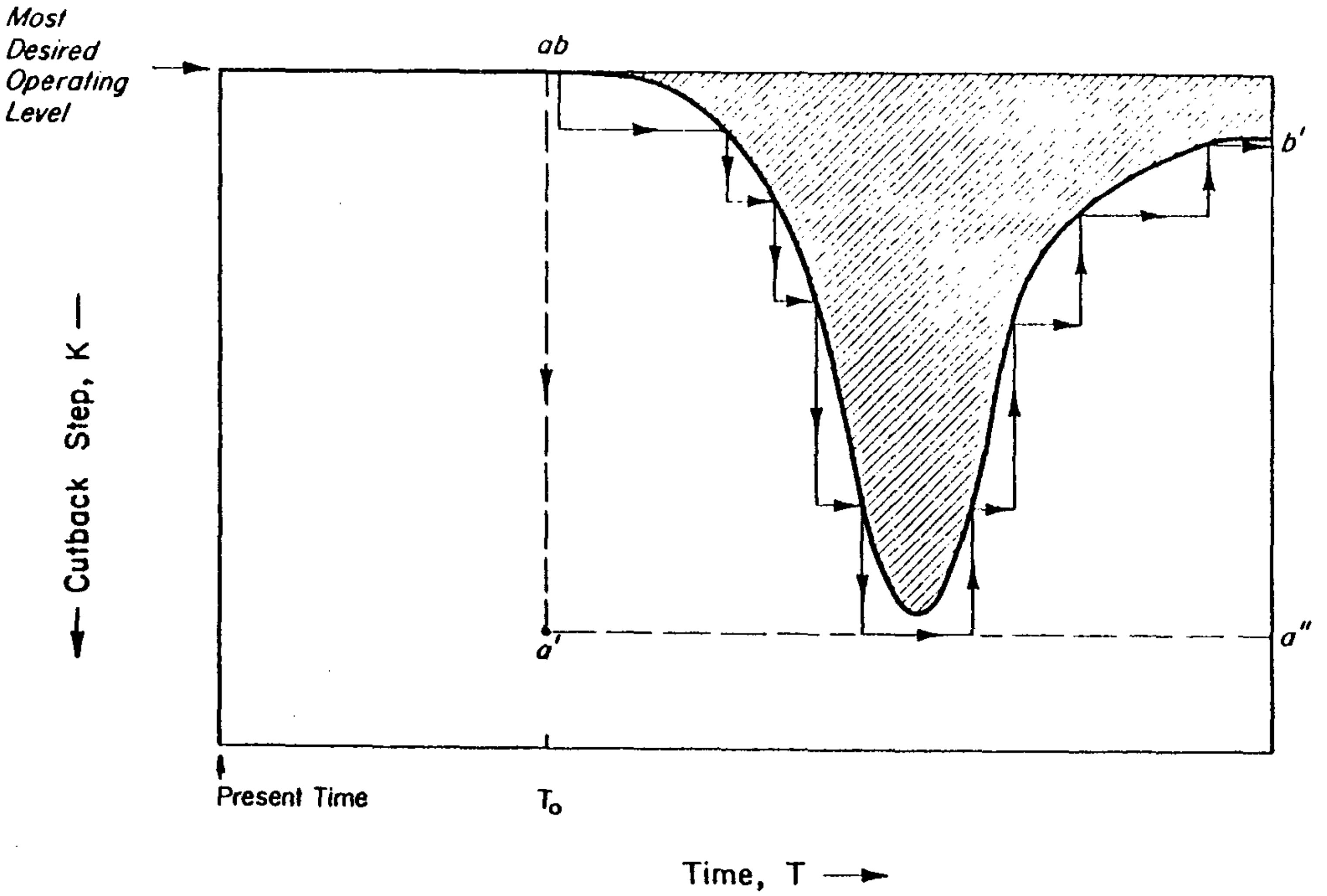


Figure A-7 Comparison of Two Alternative Cutback Strategies: Curve a-a'-a" reduces emissions to a constant level at some future time T_o, while curve b-b' performs successive stages of cutback to optimize the total select operations enough to cause excessive concentrations at another point. Iteration of incremental cutbacks under these conditions tends to force a solution which either shuts the plant down for a long period of time or which oscillates in time (a series of alternating on-off operations). This potential problem, inherent in the algorithm described here, has indeed been encountered in other cases where similar models have been employed, but has been effectively eliminated in the AQFOR proposed for the Hat Creek Project by the ordering of computations so that long-term trends are anticipated in the selection of the cutback schedule, eliminating the need for short-term corrections to protect the long-term averages. In addition to providing computational stability in the forecast of future operating schedules, the approach used allows for an automatic "trend analysis" procedure to be applied not only to currently monitored concentrations, but also to concentrations calculated at nonmonitoring sites using actual emissions and observed meteorological conditions. The operation of this trend-analysis model has been described in Section 3.7 in the discussion of the anticipatory subsystem.