Report Title: Review of Site C Climate Impacts
Issuer: Dr. Stanton E. Tuller
Date: March 25, 1991

NOTE TO READER:

INFORMATION CONTAINED IN THIS REPORT MAY BE OUT OF DATE AND BC HYDRO MAKES NO STATEMENT ABOUT ITS ACCURACY OR COMPLETENESS. USE OF THIS REPORT AND/OR ITS CONTENTS IS AT THE USER'S OWN RISK.

During Stage 2 of the Site C Project, studies are underway to update many of the historical studies and information known about the project.

The potential Site C project, as originally conceived, will be updated to reflect current information and to incorporate new ideas brought forward by communities, First Nations, regulatory agencies and stakeholders. Today's approach to Site C will consider environmental concerns, impacts to land, and opportunities for community benefits, and will update design, financial and technical work.

81669

REVIEW OF SITE C CLIMATE IMPACTS

Report Prepared for B.C. Hydro and Power Authority

Stanton E. Tuller
376 Beach Drive
Victoria, B.C., V8S 2M3

March 25, 1991

SYNOPSIS

Studies were carried out from 1976 to 1982 to investigate the existing climate of the Peace River Valley and to estimate the climate impact of the proposed Site C project. Studies concentrated on the summer growing season and the reservoir area. The major climatic effects would be an increase in fog, especially in late summer and fall, and the elimination of the lower terraces which have a favorable microclimate for agriculture. Changes in other climatic elements would be small and limited in extent. The estimate of small effects is based on three propositions: 1) the small size of the reservoir, 2) the modest predicted change in water temperature, and 3) the good mixing and diffusion within the valley.

Three to five years of additional wind speed and air temperature data from Ministry of Environment stations in the reservoir area have become available since completion of the earlier studies. Some limited air temperature data are available from stations below the dam. The climate data base is handicapped by short periods of record, limited spatial coverage, missing data, and a small number of recorded elements. The lack of fog and humidity data from within the valley is a major problem.

The major weaknesses of the climate impact assessment from a climatologist's point of view are the weak data base on which the fog and crop drying assessments are made and the limited spatial and temporal coverage.

It is strongly recommended that the three propositions involved in the small effect assessment be confirmed. High priority should be given to an analysis of the entire available wind record.

More detailed studies of fog and crop drying conditions based on additional data collected from within the valley should be undertaken. A decision on whether or not winter and downstream impacts need further treatment and selection of any further studies of the impacts of climate alterations on particular activities and phenomena should be made on the basis of the degree of concern and in consultation with consultants working in specific study areas.

TABLE OF CONTENTS

REVIEW OF SITE C CLIMATE IMPACTS
March, 1991

The purposes of this review are to:

1) outline previous work and reports that have been completed on the climate of the Peace River Valley in the Site C project area,
2) summarize the findings of the work on the expected climate impact of the project,
3) describe the climatic data which have become available since the previous studies were completed,
4) suggest some ways in which the climate impact analysis might be expanded or improved from a climatologist's perspective, and
5) make specific recommendations on additional studies to address the major weaknesses in the existing impact assessments.

I. REVIEW OF PREVIOUS STUDIES

Climate studies of the Site C project area were conducted during the period 1976 - 1982. The results were presented in a series of reports submitted to B.C. Hydro by Thurber Consultants Ltd. The final findings are summarized in (1). These studies included:

A. a literature review of the effects of small lakes and reservoirs on the climate of adjacent land areas,
B. investigation of the existing climate of the Peace River Valley through field studies and the use of B.C. Ministry of Environment data, and

C. assessment of the likely impact of the Site C project on climate including calculations of an approximate magnitude of expected effects.

A. Literature Review

The literature review indicated that small water bodies usually have only a modest effect on the adjacent climate. No studies of the changes in climate within a confined valley produced by the creation of a small reservoir were found. Most available studies were for water bodies much larger than the Site C reservoir. Some of the results of D.G. Schaefer's analysis of the regional climatic effects of the W.A.C. Bennett dam and Williston Lake (11) were extended using data collected after his report was issued. No information was found that would renounce Schaefer's conclusion of no regional effect (5,6).

B. Existing Climate

Studies of the existing climate of the Peace River Valley (1,2,3,7) were designed to establish the background necessary to put projected climatic changes into perspective and collect data needed to assess the approximate magnitude of these changes. These studies focused on the Bear Flat and Attachie Flat areas because of accessibility and the agricultural importance of these two areas. Transect studies carried out in October, 1976, and February, May, July and September, 1977, investigated climatic profiles within the valley and the extent to which any present river effects were evident. B.C. Ministry of Environment stations located on the lower and upper terraces and plateau at Attachie Flat provided data on longer-term climate within the valley. Wind data from May, 1977, through 1978 and air temperature data from May, 1977, through 1980 were used.

C. Impacts

Calculations of an approximate magnitude of effect were made for a number of climatic elements. A ground surface energy budget model was used to estimate possible changes in monthly evaporation and sensible (convective) heat flux density created by replacing the present land use with the reservoir (1,8,9). Surface data from Fort St. John Airport and upper air data from Fort Nelson Airport were used as input data for the model. The approximate magnitudes of air temperature and humidity changes were determined by applying the computer model results to air masses of different mixing depths over the reservoir. The general results of this analysis were reinforced by calculations of temperature and humidity changes a parcel of air of given depth would experience as it moved across the reservoir (9). Mixing depths used in these calculations were those to the top of the upper terrace and to the top of the valley. Evaporation and humidity changes were used to determine the possible increase in fog density (1). The potential increase in the number of days with fog was computed using a combination of B.C. Ministry of Environment, Attachie Flat, air temperature data and Fort St. John Airport humidity, wind speed and fog data (10).

Detailed studies focused on the reservoir area and the May - September, growing season, period. The major concern at the time of the studies was the effects of climate on agriculture in the reservoir area. More reliable estimates of water temperature were also available for the summer season.

Although the studies outlined above were deemed sufficient to give an general idea of the direction and magnitude of the changes in climate expected from the Site C impoundment their results should not be viewed as exact predictions but as general indicators. Most studies had to use data collected outside the valley (e.g. Fort St. John Airport, Fort Nelson Airport). The lack of requisite data from the immediate area of concern somewhat compromises the applicability of the results.

A summary of projected climatic effects of the Site C reservoir is given in Table 1. The effects were usually deemed to be small and limited to the vicinity of the water body (confined mainly to the valley itself)(1). This coincides with the results of most other studies dealing with small water bodies. The major effect of the Site C reservoir would be to increase the density of fog during late summer and fall when the reservoir water temperature reached its maximum (1). The favorable agricultural microclimate of the lower terrace surfaces (13) was confirmed by the studies of valley climate. The overriding adverse effect of the project was deemed to be the elimination of this unique climatic resource (1).

The estimate of relatively small effects of the Site C reservoir was based on three propositions:

1) the small size of the reservoir (only two (1) to three (2) times the area of the present river;
2) the modest expected change in water temperature regime (14) and,

TABLE 1

Summary of Estimated Climatic Effects of the Site C Reservoir.

ELEMENT	TIME	EFFECT	ESTIMATED MAGNITUDE[a]	REFERENCE
Wind Speed	All year	Small increases	10%	12
Air Temperature				
Daily Maximum	Summer	Small Increases	<1°, likely <0.5°	1,9
Daily Minimum	Summer	Small increase near reservoir. Possible small decrease on occasion near valley sides.	<0.5°	1,9
Mean Daily	Summer	Slightly Lower	<0.5°	1,8,9
	Late fall, early winter	Slightly Greater	<0.5°	
Evaporation	May - July	Somewhat Lower	.15 gm/cm^2 day	1,8
	August - October	Greater	.15 gm/cm^2 day	
Humidity				
Mean Daily	May - October	Small Decrease	.12 mb (.012 kPa)	1,9
Nighttime	Late Summer - Fall	Increase	up to .5 mb (.05 kPa)	1,9
Rain and Snow	All year	No effect		1
Dew	Late Summer - Fall	Very small increase		1
Fog				
Frequency[b]	April - December	Increase	24 days, mixing depth 70 m 4 days, mixing depth 190m	12
Fog				
Density	May - October	Increase	.4 gm/m^2, mixing depth 70 m .15 gm/m^2, mixing depth 190m	1

< Less than.

[a] Maximum value of calculated effects to give an approximate idea of expected magnitude of change. Should not be thought of as an exact prediction because of the assumptions and data limitations involved in the calculations.

[b] Days/year. Includes days with saturated air but visibility greater than 1 km.

3) the generally good mixing within the valley which would readily dilute reservoir effects.

II. EXISTING CLIMATE DATA BASE

Climate inventory and impact assessment in the reports leading up to the B.C. Utilities Commission hearings in 1982 were based on Peace River climate station data recorded through 1980. Some additions to the record have been made since that time, improving the climate data base. There are also records from stations not used in previous reports that may be of limited use in more detailed, future analyses.

A. B.C. Ministry of Environment Stations

Both climate inventory and impact analysis made extensive use of a series of B.C. Ministry of Environment stations; opened in May, 1977; in the Attachie Flat area. Data from these stations include daily maximum, daily minimum and mean daily air temperature, monthly precipitation, and hourly wind speed and direction. Temperature data through 1980 and wind data through 1978 were used. According to the Ministry of Environment, additional wind data are now available from the plateau and upper terrace stations (Table 2). Additional temperature and precipitation data are available from the stations located on the upper and lower terraces.

Data from other Ministry of Environment stations, not used in

TABLE 2

B.C. Ministry of Environment
Attachie Flat Stations.

STATION LOCATION (Name)	Climatic Element	Date Terminated
PLATEAU	Temperature, Precipitation	October, 1980
(Attachie Up)	Wind	October, 1980
(Attachie SLS)	Temperature, Precipitation	Mid - 1984
UPPER TERRACE	Temperature, Precipitation	October, 1984
(Attachie Mid)	Wind	September, 1982
LOWER TERRACE	Temperature, Precipitation	March, 1984
(Attachie Low)		

previous studies, are available. These include:

Reservoir Area - The Rutledge transect, located on the north side of the valley between Farrell Creek and Lynx Creek, recorded air temperature and precipitation. All stations opened in May, 1977. The lower terrace (Rutledge Low) and upper terrace (Rutledge Mid) stations closed in March, 1984. The plateau station (Rutledge GTN) closed in October, 1980. The upper terrace and plateau stations have limited humidity data from mid-May 1977 to January 19, 1978 (15).

Downstream Area - In the Taylor area, stations near the river (Tay Curtis) and on the plateau (Tay Moore Up) ran from May, 1977, to October, 1980. A station on the terrace (Tay Moore Lw) ran until October, 1984. All stations recorded air temperature and precipitation over their whole record and humidity between mid-June and mid-December, 1977 (15).

Farther downstream, near the Clayhurst Ferry, Ferry Dr and Shipton Dr recorded temperature and precipitation from May 1977 to November 1979 (15).

All B.C. Ministry of Environment data are stored in their computer archives and are available on request.

B. Atmospheric Environment Service Stations

There are no Atmospheric Environment Service (AES) stations operating within the Peace River Valley with the exception of Taylor Flats which only observes precipitation, an element of little interest in climate impact assessment. Previous reports used Fort St. John Airport and other AES stations to try to assess if there was any measurable impact of the Williston Reservoir on the climate of the region (5,6,11) and to provide data for other analyses (1,8,9,10). The stations used in these studies (Fort St. John Airport, Fort St. James Airport, Baldonnel, Prince George Airport and Fort Nelson Airport) have continued to operate at least through the end of 1989. Particular data are available for a fee by request from the AES. Monthly data are published in the Monthly Meteorological Summary for selected stations, or from the Monthly Record of Meteorological Observations in Canada (currently on microfilm). In the past, personnel at Fort St. John Airport have been very helpful in providing small amounts of data from that station.

C. B.C. Hydro Stations

B.C. Hydro has collected air temperature and precipitation data at a number of stations in the Peace River drainage. Only one station is within the Site C project area; D-11, Halfway River near Farrell Creek; which began operation in October, 1980, and continues to the present. Sampling frequency is 15 minutes. The raw, unprocessed data are stored on Hydro's computer.

D. Data Utility

There are several limitations to the climate data base. Station density is low for an area with pronounced microclimatic variation and where interest in impacts is focused on a number of specific locations. Periods of record for stations within the valley are short. Missing data are common in the Ministry of Environment data. The records should be complete enough to give a general picture of the present climate of the area. Assessment of spatial variation within the valley is hindered by missing data combined with the relatively short periods of record. Difference in station exposure also limits comparability between some of the stations.

Only a limited number of elements were sampled. A major limitation is the lack of humidity data within the valley. Any attempt to refine the assessment of potential effects on fog, dew, crop drying or other moisture parameters would benefit from more humidity data. There is no quantitative information on current fog conditions within the valley. The limited amount and single location of wind speed and direction data and the lack of radiation data within the valley also compromise the analysis of the impact on all climatic elements.

Despite the shortcomings; the existing, expanded data base can be used in three studies. Wind speed data allow a check on the assumption of good mixing within the valley. Air temperature data provide a beginning for a study of existing downstream climate and climate impacts. The humidity data are likely too discontinuous to be of much direct use. Nonetheless, they should be inspected to see if they offer any new information.

III. POSSIBLE ADDITIONAL STUDIES

Suggestions of possible future work from a climatologist's perspective are given below. These are intended to stimulate thought and discussion on ways of addressing perceived weaknesses in the present impact assessments. Specific recommendations are given in section IV.

A. Expanded Climate Data Base

Some of the limitations of the existing climate data base can be overcome by a program of additional observations within the Peace River Valley. Such a program should concentrate on those elements for which little or no data are available and that will make the greatest contribution to impact assessment improvement.

1. Station Number and Locations

A network of 2 or 3 stations would be a reasonable compromise between cost, ease of data collection and handling, and utility of added information. Two stations should be located in the reservoir area. Two stations provide some information of spatial variation, allow cross checking of data and offer some compensation for the inevitable data loss at one station. If downstream impacts are determined to be of concern, a third station should be added to the network. Each station should be located in an open site on the land areas receiving the greatest reservoir impact, the upper terraces. Specific sites will depend on where access is granted. Recommended locations are: Attachie Flat (approximately 56°13'40"N, 121°25'45"W, elev. 1555 ft.) and the area just east of Dry Creek (approximately 56°7'15"N, 121°45'45"W, elev. 1615 ft.). These sites have easy access, are locations of previous data collection, are agricultural areas where climatic impact is of concern and are far enough apart to allow some assessment of spatial variation within the impact area. The area around Taylor is the best site for a downstream station because of its settlement density, economic importance and ease of access.

2. Elements

Each site should sample air temperature, humidity, wind speed and direction, and global solar irradiance. A data logging and retrieval system similar to that currently used in B.C. Hydro's Data Collection Platform network could handle data acquisition. It is beyond the scope of this review to recommend specific sensors, equipment and procedures. Care should be taken, however, to follow the Atmospheric Environment Service's evolving guidelines for electronic data collection to facilitate comparability with Fort St. John Airport data. The final processed data for impact analysis should include daily maximum and minimum air temperature; hourly air temperature, humidity (vapor pressure and dew point temperature), solar irradiance and wind speed and direction; and daily total solar irradiance.

In addition, fog frequency and, if possible, duration within the valley is necessary for an improved assessment of the impact on fog. Fog is more difficult to observe on a regular and continuous basis than are the elements listed above. Human observers or visibility sensors could be employed.

3. Length of Record

There are no precise rules on how long a record would be needed to obtain usable results and the axiom "some data are better than none" always applies. Practice and published research indicate that the long term mean can be reasonably approximated by a relatively short record; especially when a good, long-term reference station such as Fort St. John Airport is nearby. The Atmospheric Environment Service, for example, uses 5 or more years of data to adjust temperature and precipitation records to 30 year normals using the difference and ratio methods (16). The B.C. Ministry of Environment employs regression techniques to normalize records at temporary stations with only 3 years of data (13). Corotis et al. (17) and Justus et al. (18) found that one to two years of wind speed data could give a reasonable estimate of the long-term mean (e.g. 90% probability that the annual mean wind speed for 1 year will be within 10% of the long-term mean and one monthly mean wind speed will be within 18% of the long-term mean).

Longer records, however, would be needed to estimate expected, long-term frequency distributions and the probability of extreme and rare values (18). An unpublished analysis by S.E. Tuller and A.C. Brett, for example, indicated that between 50% and 90% of the total record length was necessary to adequately reproduce the long-term frequency distribution of wind power at 7 stations on the B.C. coast.

Although it would not be long enough to allow prediction of expected long-term frequency distributions and the probability of rare events, a record length of between 3 and 5 years should be adequate to fill the major gaps in knowledge of the existing climate of the Peace River valley and refine the estimates of climatic impacts of the Site C project.

4. Uses of the Data

Data from within the valley rather than the previously used Fort St. John data would increase the reliability of model assessments of the magnitude of climate impacts and would eliminate any criticisms about using nonrepresentative input data.

Any assessment of impact requires a knowledge of existing conditions. The present impact assessments for moisture parameters such as fog, humidity and crop drying are greatly limited by the lack of quantitative data on existing conditions. Actual fog, humidity and solar irradiance data would fill this void and also allow more representative projections of expected impacts.

Any changes in the magnitude of expected climate impacts, with the possible exception of fog, is expected to be small, however.

Improvement that does occur will simply be in the magnitude of impact and in the confidence that can be placed in this estimate. New data will not alter the current assessment of the direction of change (increase or decrease). Once additional data are collected, the public will expect that they be utilized. This may necessitate reanalysis of even those impacts of only marginal concern.

A problem identified during the literature review was a lack of good before and after studies of climatic effects in the immediate vicinity of small reservoirs located in narrow valleys. If a couple of stations measuring air temperature, humidity and solar irradiance could be maintained for a period of 10 to 12 years both before and after impoundment; the data would be useful in future impact assessments. This would have no effect on evaluation for Site C but would be a useful investment in the planning for any subsequent hydroelectric projects in the province.

B. Climate Impact

A review of previous reports suggested some improvements and verifications that could be made to the climatic impact assessment.

1. Assumptions Behind the Small Impact

The three assumptions inherent in the estimation of generally small effects need to be confirmed. B.C. Hydro design engineers should be asked if there are any substantial alterations to the planned size of the Site C reservoir. Water temperature change projections given in (14) (2.5°C up to 3.2°C) should be verified by either water quality consultants or B.C. Hydro engineers.

The assessment that climatic impacts will be small was heavily dependent on the assumption of good mixing and dilution within the valley as indicated by the 1977 - 1978, B.C. Ministry of Environment, Attachie Flat, wind speed data. The times of greatest concern are those when stable thermal stratification within the valley (night and winter) and low wind speeds combine to limit mixing depth and direct dilution of reservoir effects. The additional 3.5 years of upper terrace wind speed data provide a more complete picture of wind speed and direction within the valley. Additional wind observations might further extend the record. An analysis of the existing, expanded wind record and any additional observations that become available should be given the highest priority. Such a study need not be complicated but should involve a simple frequency analysis of wind speeds at those times of the day and year that are of concern for practical impacts. Comparison with the wind speeds concurrently measured at Fort St. John Airport will help relate valley stations' short periods of record to the longer term climate of the region (see 7 for an example of this approach). A summary of wind directions, stratified in terms of times of interest and by wind speed classes should also be prepared to identify the areas most likely affected by advection from the reservoir.

Recent literature should be reviewed to determine what new information and case studies have been published on the effects of small water bodies on adjacent climate.

2. Decision on Expanding Area and Time Coverage

The present impact assessment focused on the reservoir area and the summer growing season. It needs to be decided whether or not there is now sufficient interest and concern to justify more detailed analyses of downstream and winter impacts. There appears to be enough B.C. Ministry of Environment station data in the Taylor and Clayhurst Ferry areas to give an idea of the existing air temperature climate of the downstream, valley bottom area. An estimate of changes in other climatic elements could be made using Fort St. John Airport data. However, a reliable assessment of the magnitude of these impacts requires the collection of additional climatic data (see section III.A) plus good predictions of changes in water temperature and river levels. Water temperature change is the most important control of climatic impacts in the downstream area. Assessment of climate changes can only be as good as the water temperature predictions on which they are based. Given the small size of the river, climate impacts are likely to be small in magnitude unless water temperature changes are large, limiting the need for extensive analysis.

The present impact assessments treated winter in only brief and conditional terms. An expanded winter impact assessment depends on the availability of information on whether or not the reservoir freezes and the timing of freeze-up and break-up. Earlier reports used conditional statements such as "if the reservoir is frozen" when addressing winter climate impacts. Although (1, pg. 29) states that B.C. Hydro expects "in an average year most of the reservoir would be ice covered by mid-winter" a more specific projection of ice timing and extent is needed if more precise assessments of winter climatic effects are required.

3. Expanded Frequency Analysis

Climatic impacts of the Site C project present a general magnitude of change (Table 1). Environmental alterations are not uniform over time but are composed of periods of greater and lesser effect. A deficiency in the present impact assessments is that little attention was given to frequency of occurrence (10 is an exception). It is desirable that any future climatic descriptions and impact assessments present not only mean values but also the frequency distributions employing class intervals that are significant for practical impacts. Although existing and any new data available in the near future will not be sufficient to give a reliable estimate of long-term frequency distributions there is still value is computing and presenting the distributions based on available data.

C. Applications

Climate, like all aspect of the physical environment, is of no practical importance in itself. It is only when considered in reference to something else that climate takes on importance.

A local climatic change can affect countless human activities and natural phenomena. It is impractical and in some cases unfeasible to treat all of these. The areas of greatest concern will vary over time. Their identification and the determination of their relative significance involves input from a variety of sources. The people best able to rapidly identify these concerns are the individual consultants working in specific fields. Therefore, it is recommended that consultants be asked to identify areas of secondary climatic impact that are important in their specific study areas. The final decision on which future studies need to be undertaken should be made on the basis of the degree of concern. Design and conduct of the selected secondary impact studies should involve close liaison between the climate consultant and the other consultants to insure that the final results best meet the actual need.

From a climatologist's perspective, there are two practical applications of great public concern in which the original impact assessments were somewhat weak and a third that is important because of its pervasive influence on many impacts. These are where the greatest improvements can be made in the present assessments.

1. Fog

One of the most significant local effects of the Site C reservoir was deemed to be the increase in fog, especially during the late summer and early fall (1). Fog has been of special concern because of its impact on crop drying but it could also have effects on transportation and recreation.

Improved assessments are hampered by a lack of humidity and fog data for the Peace River Valley. The existing, expanded, Attachie Flat, upper terrace wind speed record would allow some improvement in the determination of mixing within the valley so that the previous assessments might be refined slightly. Collection of additional humidity and, especially, fog (visibility) data would allow a much more justifiable assessment by both establishing a picture of the current fog situation within the valley and allowing better modelling of future impacts.

2. Crop Drying

This was perhaps the greatest agricultural concern at the 1982 hearings. The general consensus was that it would be better to simply build crop driers than to collect data needed for an improved assessment of deterioration in drying conditions (12).

The existing, expanded record of both air temperature and wind speed from the Attachie Flat, upper terrace station would allow some refinement of the assessment by improving the analysis of the frequency of warm, windy conditions that favor drying and cool, calm conditions that hinder it. The lack of valley radiation and humidity data hinder more precise analyses. Collection of humidity and radiation data from within the valley would allow better quantitative assessments of both current and projected crop drying conditions.

3. Wind

There has been concern expressed that an increase in wind speed created by the change in surface roughness might increase wind chill on domestic animals in the valley (12) and have an adverse effect on the recreation potential of the reservoir area (DPA, 1989 open house summary, pg. 4).

The existing, Attachie Flat wind speed and direction record can be used to determine the mean wind speed conditions and the areas that will be most affected by any wind speed alterations. The record is too short to allow a proper assessment of long-term frequency distributions and the recorded hourly run of wind dampens the gusts, limiting analysis of dangerous, wind gusts. A detailed analysis of this wind record would, nonetheless, be useful and assessments would be somewhat improved by additional wind data from within the valley.

IV. RECOMMENDATIONS

The B.C. Utilities Commission (12, pp. 161 - 162) concluded that "Both the Ministry of Environment and the Ministry of Agriculture and Food agreed with results of the climatic impact study done by Hydro's consultant. The major area of controversy was not the impact of the project on climate, but rather the effect of the climatic impacts on agriculture, the dominant issue being the effect of the expected increase in fog on crop drying. The impacts of the project on climate and the consequent effects on agriculture are uncertain, they are likely relatively small and limited in extent. Nevertheless the Commission recognizes that they could be significant to some farmers in the Valley.

There appears to be general acceptance of the results of the previous Site C project, climate impact assessment. Concern and controversy involve the projected magnitude of change not the direction of change.

From a climatologist's standpoint, two weaknesses in the present climate impact assessments are the lack of a firm foundation for the fog and crop drying predictions and the limited areal (reservoir area) and temporal (growing season) coverage. In addition, it is necessary to verify the assumptions on which the prediction of only a small change was base. The following specific recommendations, in order of importance, are made to address these climate concerns. Selection of secondary impacts that might need further treatment requires the input of other consultants who are more aware of the present feelings of the population in the affected area.

A. Verification of Assumptions Behind Small Impact

It is essential that the assumptions on which the current prediction of only small changes in climate is based be verified (section III.B.1). This includes confirmation of the expected size of the reservoir and water temperature changes and a study of all available wind data from within the valley. Presently available, Attachie Flat, wind data are adequate to verify the assumption of good average diffusion and mixing within the valley. If more wind data become available these can be incorporated to add further confirmation. Recent literature should be reviewed to ascertain if any relevant studies have been published since the previous impact assessment.

B. Fog and Crop Drying

Fog and crop drying assessments should be expanded (sections III.C.1&2). Both are hindered at present by inadequate quantitative information of the existing fog, humidity and solar irradiance within the valley. Fog has several adverse effects and definitely needs to be addressed. Poor crop drying conditions could be compensated by crop driers (12) and is a lesser priority. Refinement of the estimated effects relies on collection of additional data from affected areas recommendations C and E).

C. Fog Observations

A program of fog (visibility) observations should be established within the Peace River Valley to determine current fog frequency and duration (section III.A.2). This will establish the baseline of existing conditions from which a projected impact can be determined more reliably.

D. Inspection of Existing Humidity Data

The B.C. Ministry of Environment's limited, within-valley humidity data should be obtained and inspected to determine their utility. It is unlikely that these short records of relative humidity observations at specific times of the day will be of much direct applicability. This should be investigated, however.

E. Observation Program

An observation program to run at least 3 to 5 years within the Peace River Valley should be established to measure air temperature, humidity, solar irradiance, and wind speed and wind direction (section III.A). Simultaneous observations of humidity, solar irradiance and wind are needed to improve the analysis of crop drying impacts. Wind speed and humidity are needed for better fog predictions and will aid the assessment of changes in humidity.

These data will allow use of within-valley input data in calculations of the approximate magnitude of effect on other climatic elements as well. The result will be more reliable, justifiable estimates of the magnitude of change.

It must be cautioned, however, that the results using improved data are not likely to differ much from the present assessments with the possible exception of fog and crop drying. A number of assumptions and approximations must still be used in the calculations, limiting the effectiveness of input data improvements. Anticipated changes are more sensitive to surface (water temperature) conditions than they are to atmospheric conditions. It makes little sense to improve the atmospheric inputs unless reliable water temperature predictions are also available. However, from a strictly climate point of view; additional, quality data will put projected impacts on a much firmer foundation.

F. Decision on Winter and Downstream Analyses

A decision needs to be made on whether or not detailed consideration needs to be given to winter and downstream impacts (section III.B.2). From a simple climate perspective the present report is deficient because of the cursory treatment given to this season and area. From a practical standpoint, the impact on human activities is not as great as reservoir area and growing season effects. Thus, the decision must be made on the basis of the degree of concern for the secondary impacts of the climatic alterations not on the benefit of improving coverage of the climate impact assessment itself.

Expansion of studies to cover winter and downstream impacts requires reliable ice cover and water temperature predictions and would benefit from additional winter humidity data in the reservoir area and air temperature, humidity, wind speed, fog and solar irradiance data in the downstream area.

G. Impoundment Effect Study

A program of observations in the reservoir area should be established to run 10 to 12 years both before and after impoundment (section III.A.4). The benefit of this program would be the establishment of a case study that would provide the basis for the assessment of climatic effects of future projects.

H. Summary and Decision on Implementation

Currently available wind, air temperature and humidity data not used in the previous assessments should be obtained and used to assess the assumption of good mixing within the valley, the air temperature pattern below the dam and whether the limited humidity data are of any use. Other recommended studies require the collection of additional data from within the valley.

Completion of the steps recommended above, along with subsequent analyses, would provide a comprehensive climate impact assessment based on a solid foundation of within-valley data. In a practical sense, however, the present impact assessment is a reasonable evaluation of anticipated climatic effects. People are more concerned with the secondary impacts of climate alterations than with the climate changes themselves. Any decision on whether to invest more time and expense in improving the climate impact assessment should be based on the degree of concern and the perceived necessity of more precise, justifiable estimates of the magnitude of change. There is no question, however, that the recommendations given above will improve the climate impact assessments themselves and make them easier to defend.

V. CONCLUSIONS

Previous studies indicated that the Site C project should produce only small, localized changes in climate. The small size of the reservoir, the limited alteration of water temperatures and the good diffusion within the valley limit the magnitude of effect. Fog is the element that is likely to experience the greatest change.

New data have become available since the completion of the previous studies. Wind data from Attachie Flat and air temperature data from two downstream areas are the most useful. Overall, however, the climate data base is still very limited.

The major weaknesses in the climate impact assessments are those for fog and crop drying and the neglect of winter and downstream effects. Both fog and crop drying are of major concern to local residents and the assessments were made without the benefit of good, within-valley data.

The most important additional study that must be undertaken is confirmation of the assumptions on which the estimation of only a small climate impact are based. This includes an analysis of whatever additional wind data are available. Correcting the weaknesses in the fog, crop drying, winter and downstream assessments requires the collection of additional fog, humidity, wind, and solar irradiance data from within the valley. It is felt that any new data and analyses will not seriously alter the current impact assessments that are based on sound climatic principles and were not seriously criticized in 1982. Their benefit would be to allow more comprehensive, reliable and justifiable assessments of the climate impacts of the Site C project. The question that must be answered is whether there is enough concern with climate itself to make the time and expense involved in refining the present assessments worthwhile.

REFERENCES

REPORTS PREPARED BY STANTON E. TULLER

Testimony Prepared for B.C. Utilities Commission

1) "Climate". Evidence of Stanton E. Tuller, Ph.D. Application foran Energy Project Certificate, Testimony and Supplemental Material, Volume 2, B.C. Hydro and Power Authority, July 20, 1981.

Earlier Summary Reports on Climate Inventory and Impact

2) Site C Physical Environment, Climate. Interim Report to B.C.Hydro and Power Authority, Thurber Consultants Ltd, July 8, 1977.

3) "Present Climate". Peace River Site C Hydroelectric DevelopmentPhysical Environment Impact Assessment, Thurber Consultants Ltd., March, 1979, pp. 7 - 39.

4) "Changes in Climate (with Proposed Project". Peace River SiteC Hydroelectric Development Physical Environment Impact Assessment, Thurber Consultants Ltd., March, 1979, pp. 66 - 90.

Specialized Reports Prepared for B.C. Hydro through Thurber Consultants Ltd. (Dates are not confirmed)

5) Extension of Schaefer's Ten Year Moving Averages of AirTemperature and Precipitation. March, 1981.

6) Long Term Trends in the Number of Days with Fog. March, 1981.

7) Analysis of Air Studies Branch Attachie Flat Upper Terrace WindData. May, 1981.

8) Surface Energy Budget Computer Model Analysis. July, 1981.

9) Summary of Calculations Used to Estimate the Magnitude of AirTemperature and Humidity Effects of the Site C Reservoir. July, 1981.

10) Potential Effects of the Site C Reservoir on Fog Frequency(Upstream from the Dam). May, 1981.

REPORTS BY OTHER AUTHORS:

11) D.G. Schaefer, Climatological Impacts of Peace River Regulationand a Review of the Possible Effects of Climatic Change on Agriculture in the Area. Report prepared for B.C. Hydro, June, 1976.

12) B.C. Utilities Commission, Site C Report, Report andRecommendations to the Lieutenant Governor-in-Council. May, 1983.

13) G.E. Cheesman and R.L Davis, The Agroclimate of the Peace RiverValley and a Comparison with Other Locations in British Columbia. Technical Report Presented to British Columbia Utilities Commission, B.C. Ministry of Environment, June, 1982.

14) G.F. Kennedy and M.C. Quick, "Water Quality". Evidence of Mr.G.F. Kennedy and Dr. M.C. Quick, Application for an Energy Project Certificate, Testimony and Supplemental Material, Volume 2, B.C. Hydro and Power Authority, July 20, 1981.

15) Catalogue of Provincial Climatological Stations, 1980. B.C.Ministry of Environment, December, 1980.

16) Atmospheric Environment Service, Canadian Climate Normals, 1951- 1980. Vol. 2 Temperature & Vol. 3 Precipitation. Atmospheric Environment Service, 1982.

17) C.G. Justus, K. Mani and A.S. Mikhail, "Interannual and Month-to-Month Variations of Wind Speed". Journal of Applied Meteorology, 18:913 - 920, 1979.

18) R.B. Corotis, A.B. Sigl and M.P. Cohen, "Variance Analysis ofWind Characteristics for Energy Conversion". Journal of Applied Meteorology, 16:1149 - 1157, 1977.