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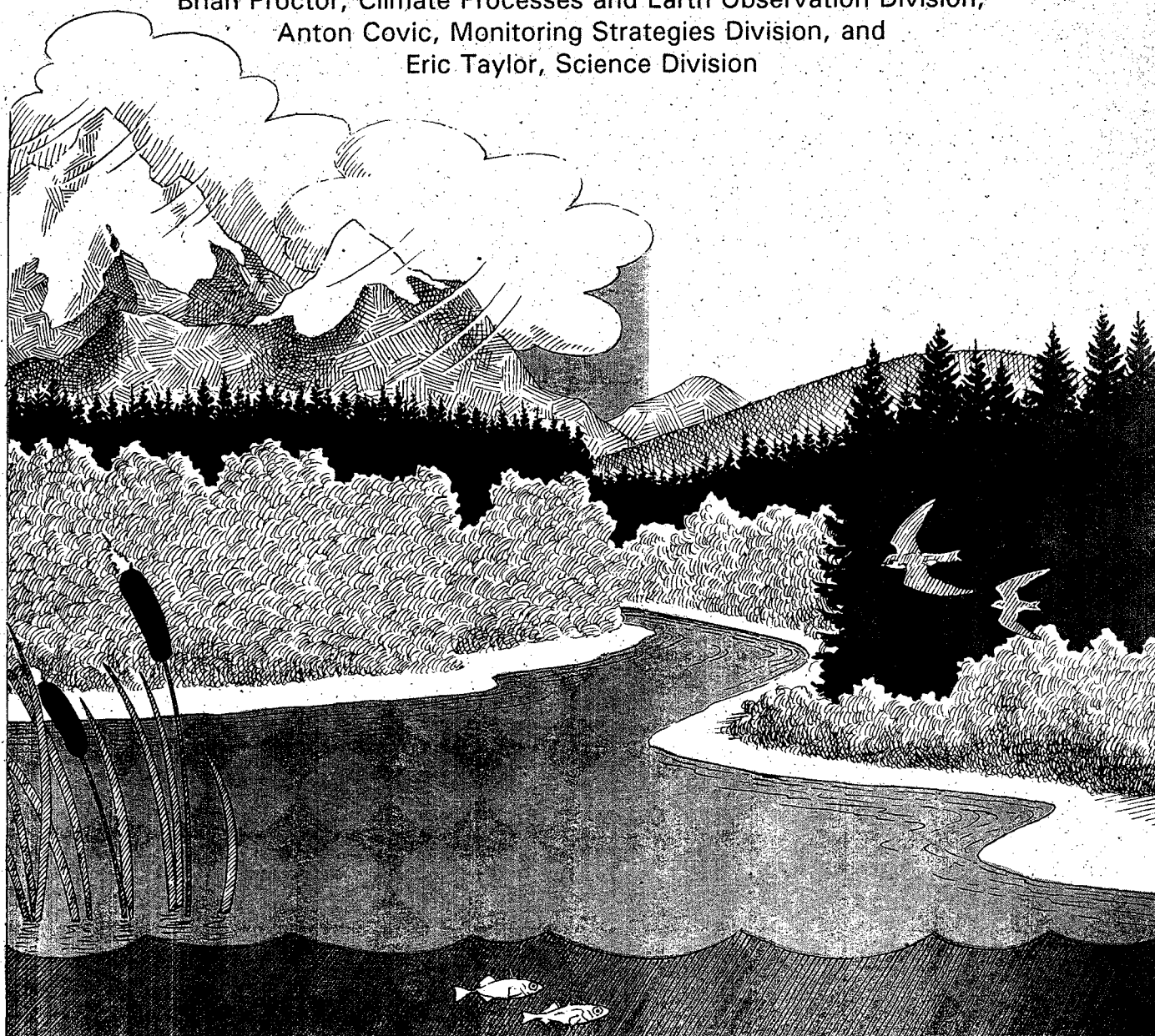
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Modelling Mountain Precipitation and Runoff  
on the British Columbia Coast

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Anton Covic, Monitoring Strategies Division, and  
Eric Taylor, Science Division



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# Modelling Mountain Precipitation and Runoff on the British Columbia Coast.

by

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## Abstract

Model estimates of daily total precipitation and mean temperature were generated for 374 grid points over coastal British Columbia and eastern sections of the Gulf of Alaska for March and April of 1994. These estimates were obtained from the Regional Finite Element Model, an operational weather forecast model, run at the Canadian Meteorological Centre. A comparison of the modelled amounts with that measured at 7 Environment Canada climate stations suggested that the model was able to reasonably predict weekly total precipitation. Correlation coefficients between weekly modelled and measured precipitation ranged from 0.71 to 0.91 with all regressions significant at the 95% confidence level. These precipitation estimates were required as part of a larger project aimed at examining the effect of fresh water runoff on the current structure of near-shore areas. The precipitation estimates were used as input into a modified water balance model to yield discharges for 4 composite drainage basins. The resulting modelled discharges were within ~25% of the measured mean monthly amounts for the Nass and Skeena rivers. As such the techniques described offer interesting possibilities for working in ungauged or data sparse areas.

## 1. Introduction

The Federal Department of Fisheries and Oceans Institute of Ocean Sciences (IOS) is developing an operational ocean current model to be used in the prediction of oil spill trajectories in Hecate strait and Queen Charlotte Sound. (Figure 1). Fresh water runoff into the heads of mainland inlets is thought to have a significant short term effect upon the structure of ocean currents in areas directly adjacent to the British Columbia coast (Thompson, 1981). The effects of runoff and winds upon current structures can completely overwhelm tidally induced currents (Thompson, 1981). Large rainfall amounts can alter the current structure by affecting the local salinity distributions in near shore areas, particularly in the winter season.

IOS has requested that Environment Canada provide estimates of fresh water coastal runoff that could be incorporated into an ocean current model. This will enable IOS to improve the modelling of ocean currents and thus the forecasting of oil spill trajectories. This paper describes using modelled precipitation to estimate coastal runoff in these ungauged areas and compares the modelled results to measured quantities where available.

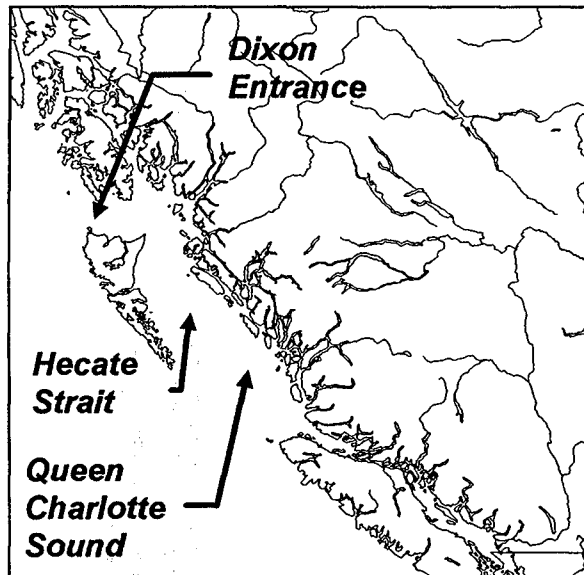


Figure 1. The area of interest on the British Columbia Coast.

## 2. Climatology of the British Columbia Coast

The outer coast of British Columbia has a maritime climate strongly influenced by the Pacific Ocean. The area, encompassing the west side of Vancouver Island, the Queen Charlotte Islands,

and the portion of the mainland lying north of Vancouver Island, has mild wet winters and cool foggy summers. Annual rainfall totals exceed 2500 mm in some areas of the outer coast (Phillips, 1990). Twenty-four hour rainfall amounts as high as 489.2 mm (at Ucluelet Brynnor Mines), have been recorded on the west coast of Vancouver Island (Phillips, 1990). Manning (1985) examined all climate stations for BC with at least 5 years of data for the period ending in 1983; the heaviest daily rainfall totals for the North Coast, Queen Charlottes, and West Coast of Vancouver Island were more typically between 125 and 200 mm. Average daily rainfalls for these areas in the fall-winter season are on the order of 6 (Cape St James) to 14 mm (Tofino).

Heavy precipitation tends to occur in the winter season and results from prolonged periods of moderate rainfall intensity associated with a succession of frontal systems moving off the Pacific Ocean (Phillips, 1990). This precipitation is widely spread but not evenly distributed, and is concurrent with an inability of the drainage basins to hold the precipitation (i.e. the basins are already saturated.) Consequently, large amounts of fresh water are discharged into the heads of the fjords and sharp salinity gradients can exist across small areas.

The effects of this fresh water on ocean currents in Hecate Strait, Dixon Entrance and Queen Charlotte Sound is not well understood and is the motive for this study.

### 3. Data

Estimating daily and weekly runoff necessitates good knowledge of the daily precipitation in the watersheds. There are about 30 climate stations in the region, but these are clustered mainly around populated areas near the coast or at lighthouse stations. All are low elevation sites, with the highest being 217 metres above sea level. Precipitation and temperature data from these climate stations would not be representative of the vast mountainous region where most of the runoff would originate. Therefore, a weather forecast model, the Regional Finite Element model (RFE), was used in this study to estimate the precipitation that occurred on a grid over the coastal mountains for the months of March and April in 1994.

RPN (Recherché en Prevision Numerique), the weather forecast model research division of Environment Canada, refined the mesoscale modelling of mountainous precipitation in a study of late spring intense orographic precipitation over the Canadian Columbia River basin. RPN ran the RFE on a high resolution window using 15 km grid spacing (Benoit et al., 1994) and forecasts of basin-wide precipitation were found to be realistic. However, the model overestimated precipitation at lower elevations, and underestimated precipitation at higher elevations. These errors were attributed to inaccuracies in model topography. The modelled precipitation was also shown to increase with increasing elevation on windward slopes as would be expected by theory (Spreen, 1947).

The RFE model output was used in the current British Columbia coastal study to estimate gridded precipitation amounts. Another benefit derived from the use of this weather forecast model was the ability to generate other physical fields, such as surface wind and heat flux, that IOS required for its ocean current model.

### 4. The Regional Finite Element Model

The RFE model used in this study (Mailhot et al., 1994) is a version of the model of Staniforth and Daley (1979) which includes a semi-lagrangian treatment of advection (Tanguay et al., 1989). The model allows for variable resolution sub-nesting capability which allows the model to be easily re-configured with the high resolution portion of the grid over any area of interest. In this study, the model was run on the standard grid spacing of 50 km. The model has been applied to a wide variety of meteorological phenomena and has been able to reasonably simulate future meteorologic fields with its prognoses (Benoit et al., 1994). Figure 2 shows the approximate domain of the model for this study.

Figure 3 shows the corresponding model topography and land sea mask. A distinct drawback of the model with a 50 km grid spacing is the model's topographic resolution.



Figure 2. Regional Finite Element Grid. 50 km grid point spacing. (G. Croteau, personal correspondence, 1994).

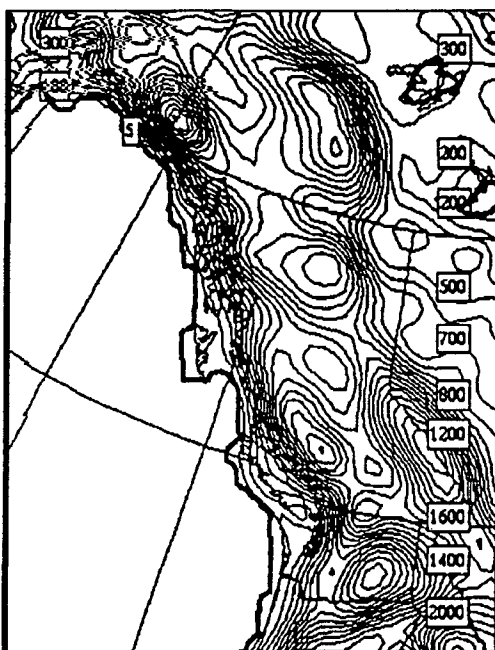


Figure 3. Regional Finite Element Orography (m) and Mask. (Adapted from CMC Reference Guide, 1993). The plotted contours are contours of model topography at 100 m intervals. The western most heavy line indicates where the model places the boundary between the ocean and land.

## 5. Quantitative Precipitation Forecasts

Quantitative Precipitation Forecasts (QPFs) are forecast six hour total precipitation amounts in 6 hour time steps out past 48 hours and include assessments of both stratiform and cumuloform precipitation. Forecasts are made every 12 hours. Condensation processes in the model (at resolvable scales) are used to account for the formation of stratiform precipitation (Benoit et al., 1994). The large-scale condensation processes are represented by an isobaric condensation process that removes moisture when

the relative humidity exceeds a threshold saturation point. The scheme allows for the simplified description of two micro-physical processes:

- evaporation of precipitation as it falls through unsaturated layers below a cloud deck; and
- formation of liquid/solid precipitation phases with subsequent freezing/melting of falling precipitation.

The model also addresses convective processes. Deep convective processes are handled with a Kuo-type convective parameterization (Mailhot et al., 1989). Cumuloform convection is driven by the total moisture accession resulting from the convergence of moisture and surface evaporation, and exists in the presence of deep layers with conditional instability. In this type of scheme the moisture is partitioned in a parameterization scheme into a portion used to humidify the environment, with the remainder of the moisture allowed to fall as precipitation after contributing to the heating of the environment. Evaporation of convective precipitation is not allowed (Benoit et al., 1994).

## 6. Rainfall Estimation

Temperature and precipitation forecasts were obtained for 374 grid points shown in figure 3 from the Canadian Meteorological Centre (CMC) for each operational run of the RFE. Twenty-four total precipitation amounts were generated for each Greenwich day, i.e. 00 UTC to 24 UTC at every grid point over the model domain. These amounts were obtained by taking the individual 6 hour precipitation amounts and summing them. A significant QPF forecast error tends to occur in the first 6 hour time period. During this time step the parameterization equations used to obtain precipitation are too wet resulting in the model being biased towards forecasting too much precipitation. A rule of thumb in operational meteorology is not to use the first 6 hour time period in any new forecast. Therefore, the first 6 hours from the current forecast run was replaced with the 12 to 18 hour precipitation amount from the model run obtained 12 hours previous. This new amount was then summed with the 6 to 12 hour, 12 to 18 hour, and 18 to 24 hour intervals from the current run to get a daily amount. The following equation summarizes this procedure:

$$QPF_{total} = \sum_6^{24} QPF_i + \frac{18}{12} QPF_{Previous\ Forecast\ Run}$$

This daily total precipitation is then used as input into a runoff model. (The model accepts climate data in standard Atmospheric Environment Service format.) The forecast 24 hour precipitation data was treated as pseudo-climate station at each grid point, where the grid point elevation became the station elevation.

A mean surface temperature was also calculated for each pseudo-climate station at 00 UTC. This temperature was defined as the numeric mean of the forecast surface temperature at 12 UTC (an approximate minimum temperature) and the forecast surface temperature at 00 UTC (an approximate maximum temperature). This mean temperature was then used as input into the runoff model.

## 7. Runoff Model

The estimate of the daily and weekly fresh water runoff into Hecate Strait, Dixon Entrance and Queen Charlotte Sound was made by using a water balance model. Input to this model was the forecast precipitation and temperature data obtained from the Regional Finite Element Model during March and April 1994. The precipitation and temperature data were estimates for grid squares of 50 kilometres by 50 kilometres throughout most of British Columbia. Each grid square was separated into seven elevation bands in order to estimate temperatures more precisely. The central coast was then divided into four watershed regions from 51°N to 54°N along the British Columbia coast (figure 4). The main contribution to the runoff is from the Nass - Skeena basins. Table 1 shows the runoff results using the water budget model.

Table 1. Estimated runoff for the period March 9-April 26, 1994 on the central and northern B.C. Coast. Four watersheds have been defined along the coast, from 51°N to 54°N. No runoff estimates are made for the period March 1-8 since runoff in this period is dependent on precipitation and temperature information for days prior to the modelling period. All runoff is expressed in cubic metres/second ( $\times 10^9$ ) of water.

Time Period (1994)	Watershed			
	Nass/ Skeena	Kitimat/ Kemano	Bella Coola	Kilbella/ Sheemahant
March 1-8	n/a	n/a	n/a	n/a
March 9-15	1.13	0.61	0.98	0.22
March 16-22	0.95	0.38	0.69	0.17
March 23-29	0.95	0.24	0.41	0.13
March 30- April 5	2.88	0.51	1.34	0.27
April 6-12	1.49	0.42	0.94	0.23
April 13-19	1.81	0.75	1.51	0.36
April 20-26	3.21	0.65	1.68	0.36

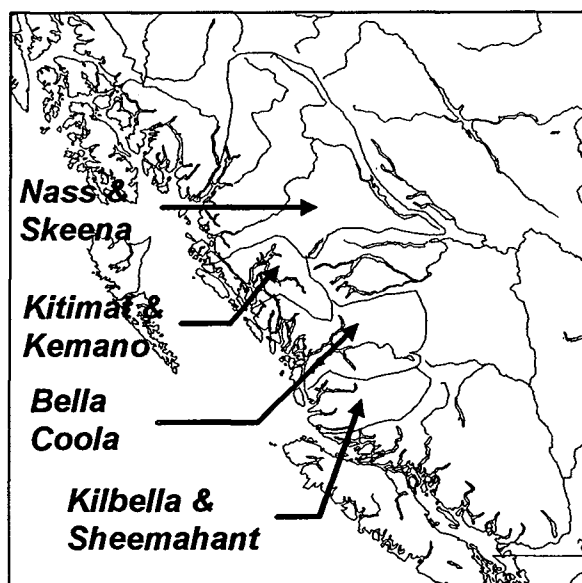


Figure 4. Watershed divisions used for the runoff water balance model.

The assumptions made in using the water balance model to estimate runoff were as follows:

- Evapotranspiration was assumed to be zero throughout the modelling period. This assumption should not induce significant errors since the months of March and April are generally cool, wet months on the Central and north Coasts of British Columbia;
- Infiltration and percolation (or water storage due to these processes) was assumed to be zero;
- Water storage took place only in the form of snow;
- Snow melt was estimated by a degree-day

method (Gray, 1970);

- Snow was initially assumed to be on the ground for all elevations above 250 metres above sea level and snowmelt was assumed for these areas for temperatures above freezing. Below approximately 250 metres, it was assumed that the only snow on the ground was snow that fell during the modelling period;
- The timelag of snowmelt or rain reaching the coast was assumed to be two days per grid square for interior locations. This corresponds to a velocity of 25 km/day (in an east-west direction); and
- Runoff from grid squares immediately adjacent to the coast is assumed to take place on the same day as the precipitation and/or snowmelt event.

## 8. Discussion

### a. Modelled Precipitation

In order to assess the applicability of the modelled results a comparison of the modelled precipitation accumulated in one week intervals was done with seven Environment Canada climate station sites. These sites are shown in table 2. The grid point chosen was simply the nearest adjacent point. Appendix 1, shows the weekly accumulated measured and modelled precipitation at each of the sites listed in table. 2.

Table 3 shows the resulting regressions

between the measured precipitation at each site, accumulated on a week by week basis, versus the modelled precipitation (also accumulated on a weekly basis) for the nearest available grid point. All the correlations obtained were significant at the 95% confidence level. The corresponding scatter plots are shown in Appendix 2.

The model elevation is generally larger than the observed station elevation. This is due to topographic resolution and may explain the results that show that the modelled precipitation is generally higher than the observed precipitation. The only exception to this for the seven stations studied is Boat Bluff. Boat Bluff is historically known as a wet site, relative to those around it, and it is hypothesized that the increase in precipitation amounts must be due to local enhancement mechanisms and exposure regimes (E. Coatta personal correspondence, 1995.).

The over-forecasting of precipitation at a grid point is probably due in part to the model's topography which tends to underestimate high elevations and overestimate low elevations. The actual precipitation over high elevation areas will generally be higher than that at lower elevations, at least for Coastal British Columbia, due to orographic uplift of the airmasses (Bruce and Clark, 1966). As a result, for the stations examined in this study's inter-comparison, the model's topography is too high resulting in an over estimation of precipitation yields.

Table 2. Atmosphere Environment Program Climate Sites and Closest Regional Finite Element Grid Point.

	Latitude °N	Longitude. °W	Station Elevation. (m)	Model Grid Point Elevation. (m)	Latitude °N (model)	Longitude °W (model)
Port Hardy Airport	50.683	127.367	22	0	50.800	127.656
Bella Coola Airport	52.383	126.583	35	597	52.599	126.583
Boat Bluff	52.650	128.517	15	447	52.599	128.345
Dryad Point	52.183	128.117	4	267	52.150	128.345
Terrace Airport	54.467	128.583	217	909	55.399	128.345
Prince Rupert Airport	54.300	130.433	34	325	54.399	130.412
Ivory Island	52.267	128.400	15	267	52.150	128.345

Table 3. Linear least squares regression equations and correlation coefficients between measured precipitation (weekly accumulations) and model output (weekly accumulations) at the nearest grid point.

Climate Station	Regression Equation for Precipitation	Correlation Coefficient
Boat Bluff	measured = $-5.04 + 1.11 \times \text{modelled}$	$r = 0.91$
Dryad Point	measured = $3.67 + 0.53 \times \text{modelled}$	$r = 0.88$
Ivory Island	measured = $-1.60 + 0.61 \times \text{modelled}$	$r = 0.87$
Prince Rupert Airport	measured = $4.13 + 0.64 \times \text{modelled}$	$r = 0.71$
Terrace Airport	measured = $1.61 + 0.46 \times \text{modelled}$	$r = 0.84$
Bella Coola Airport	measured = $1.88 + 0.39 \times \text{modelled}$	$r = 0.74$
Port Hardy Airport	measured = $6.53 + 0.52 \times \text{modelled}$	$r = 0.81$



The relationships obtained between measured and modelled precipitation were statistically significant at the 95% confidence level, and the amount of the variance in the measured precipitation explained by the modelled precipitation ranged between 50.6% and 82.2% (these numbers were for Prince Rupert Airport and Boat Bluff respectively). The results of the modelling experiment indicate that model precipitation can be used to estimate actual precipitation falling at various coastal locations with some confidence (see figure 5.)

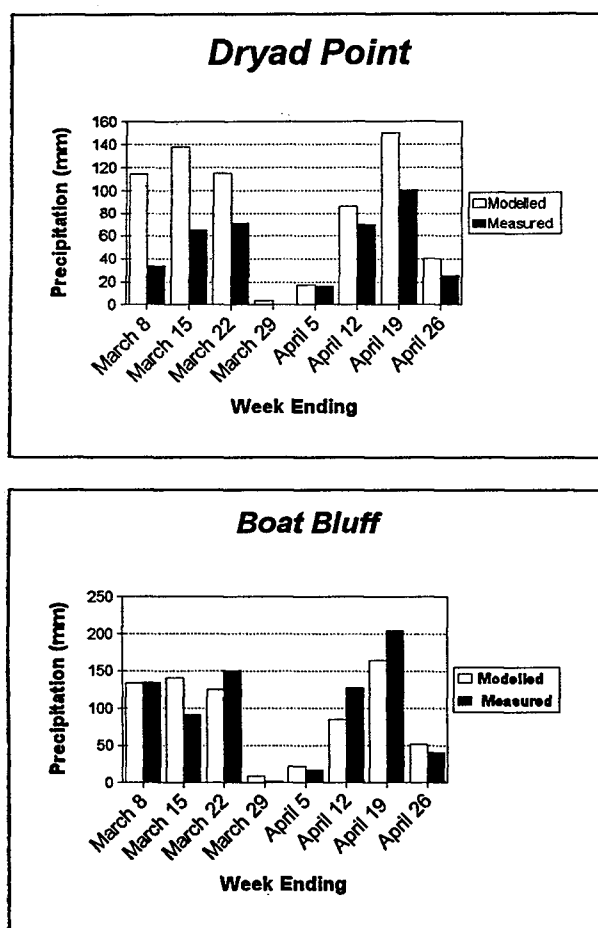


Figure 5. Weekly accumulated measured and modelled total precipitation for Boat Bluff and Dryad Point. Boat Bluff is only site in this study in which the regression equation indicates that the modelled precipitation under-estimates the measured precipitation. Dryad Point is a site more indicative of others in this study. Here, the modelled precipitation overestimates the measured precipitation by approximately 45%. In both instances, the correlations obtained were significant with 95% confidence.

A valid question to ask at this time is if the modelled precipitation falling at a grid point is not indicative at that falling at a low altitude station used for comparison, how representative are these modelled amounts for whole grid squares. No direct method exists to assess this assertion. Work done using the RFE on a 15 kilometre grid, and the Meso-scale Compressible Community Model in the east Columbia Basin of British Columbia suggested that the modelled precipitation gave more representative runoff amounts when compared to precipitation measured at valley bottom sites (W. Chin, personal correspondence 1995).

#### b. Runoff Model

In order to assess the applicability of the modelled temperature and precipitation results, a comparison was done between the modelled and measured runoff for the Combined Nass/Skeena watershed with historical discharges for each of the rivers in question (Environment Canada, 1988). The results are shown in table 4. The discharges obtained from the water budget model are similar to those given by historical values with a slight bias towards overestimation. Part of this difference can be likely attributed to the additional runoff amounts that other component streams contribute to the modelled basin total runoff that are not included in the measured discharge. Of importance is the fact that the results have similar orders of magnitude.

Table 4. Measured and modelled mean monthly runoff for the Nass/Skeena Composite River Basin. The monthly mean measured discharge is from the Historical Streamflow Summary for British Columbia to 1986 (Water Survey of Canada, 1988). The modelled discharge is simply the mean weekly discharges averaged over whole week cycles for each month.

Nass / Skeena Composite Drainage Basin			
Month	Mean Monthly Runoff ( $\times 10^9 \text{ m}^3/\text{s}$ )		Percent difference between modelled and measured runoff
	Measured	Modelled	
March 1994	0.73	1.01	27.8%
April 1994	1.77	2.17	18.4%

## 9. Summary

Modelled precipitation and temperature data for two months in early 1994 from the Regional Finite Element weather forecast model were used in estimating the precipitation input into watersheds on the north and central coasts of British Columbia. A comparison of the modelled amounts with that measured at 7 Environment Canada climate stations suggested that the model was able to reasonably predict weekly total precipitation. Correlation coefficients between weekly modelled and measured precipitation ranged from 0.71 to 0.91 with all regressions significant at the 95% confidence level.

The resulting precipitation estimates were used as input to a water balance model to estimate the freshwater runoff into the ocean adjacent to the coast. The North and Central Coasts of British Columbia were subdivided into 4 composite drainage basins. A direct comparison of the mean monthly modelled runoff for the Nass and Skeena composite basin with historical values yielded estimates within ~25% of those measured.

This runoff estimate will be used by the Institute of Ocean Sciences to improve the modelling of ocean currents in Hecate Strait, Dixon Entrance and Queen Charlotte Sound. These improvements will help refine the forecast of the trajectories and behavior of oil spills in the region.

## 10. Future Work

The results obtained in this study are promising in that the use of model output precipitation and temperature as input into a water balance runoff model yielded discharges similar to those measured. This presents interesting possibilities for working in ungauged or data sparse regions. The major limitation with the precipitation data appears to be the model's tendency to overestimate precipitation falling at low elevations. To verify this relationship and to determine if it also holds at higher elevations, it would be necessary to rerun the experiment for a longer time period to obtain a more extensive data set and also to verify versus a station at higher elevation.

One probable cause of this systematic precipitation error is likely the difference between model and actual topography. In order to assess the significance of these differences, the model should be rerun with smaller grid spacing (~25 km) to determine if the improved topography would result in improved precipitation estimates. Similarly, the model should also be rerun for smaller composite watersheds for which measured discharge records exist.

A second possible source of error which could explain this deviation between measured and modelled runoff could be the initial assumptions of zero evapotranspiration in the water balance model. In a recent water balance study on the North Coast of British Columbia, Beaudry and Sagar (1995) found evapotranspiration to be ~25% of the annual rainfall. Further, evaporation was found to be very significant even during the cool wet winter months. During these months nearly all of the evapotranspiration was in the form of evaporation. To assess the implications of the initial conditions made, the water balance model should be rerun with a new parameterization of input precipitation accounting for the effects of evapotranspiration.

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## Appendix 1.

Accumulated measured and modelled total precipitation (weekly basis) for seven Environment Canada climate sites indicated in Table 2.

Climate Station	Time Period ('94)	Measured Precipitation. mm	Modelled Precipitation. mm
Port Hardy Airport	March 2-8	46.7	60.3
	March 9-15	38.6	89.1
	March 16-22	67.2	79.3
	March 23-29	0.0	7.4
	March 30-April 5	24.2	16.1
	April 6-12	52.2	82.7
	April 13-19	31.0	76.8
	April 20-26	17.8	25.8
Bella Coola Airport	March 2-8	43.2	146.0
	March 9-15	74.8	133.2
	March 16-22	23.6	132.6
	March 23-29	0.0	11.0
	March 30-April 5	12.2	20.2
	April 6-12	71.6	88.9
	April 13-19	74.3	161.1
	April 20-26	11.4	56.5
Boat Bluff	March 2-8	133.9	132.8
	March 9-15	91.6	139.7
	March 16-22	150.4	124.3
	March 23-29	2.2	9.1
	March 30-April 5	16.6	21.6
	April 6-12	126.6	84.5
	April 13-19	204.5	164.8
	April 20-26	40.4	51.2
Dryad Point	March 2-8	33.6	114.4
	March 9-15	65.1	138.1
	March 16-22	70.8	115.1

	March 23-29	0.3	3.7
	March 30-April 5	16.4	17.7
	April 6-12	70.2	86.5
	April 13-19	100.5	150.0
	April 20-26	25.4	40.2
Terrace Airport	March 2-8	31.4	73.2
	March 9-15	38.4	64.0
	March 16-22	20.6	50.7
	March 23-29	0.0	10.5
	March 30-April 5	21.8	15.7
	April 6-12	24.8	38.9
	April 13-19	45.8	92.5
	April 20-26	5.8	36.6
Prince Rupert Airport	March 2-8	61.8	97.0
	March 9-15	34.9	110.3
	March 16-22	89.3	75.9
	March 23-29	0.0	20.5
	March 30-April 5	18.0	23.5
	April 6-12	46.5	39.7
	April 13-19	89.0	100.7
	April 20-26	10.1	27.0
Ivory Island	March 2-8	51.2	114.4
	March 9-15	51.9	138.1
	March 16-22	77.0	115.1
	March 23-29	0.2	3.7
	March 30-April 5	5.7	17.7
	April 5-12	78.6	86.5
	April 13-19	112.3	150.0
	April 20-26	18.8	40.2

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## Appendix 2

Scatterplots of measured vs. modelled precipitation for 7 Environment Canada Sites within the RFE study domain. Also shown are the linear least squares regression lines with 95% confidence limits.

