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Application of WRENSS to Southern Canada

by:

Kelly J. Loch

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND
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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled

APPLICATION OF WRENSS TO SOUTHERN CANADA

Submitted by: Kelly J. Loch

in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

Richard L. Rothwell
Supervisor

Robert H. Swanson

E S Chanasyk

Date____________________

DEDICATION

I dedicate this thesis to my parents,
Raymond and Jean Loch.

ABSTRACT

Application of WRENSS to Southern Canada

The WRENSS methodology (Troendle and Leaf 1980) was applied to watersheds in Southern Canada (45^{o} to 55^{o} N. Lat.) to test its applicability for streamflow prediction in ungauged watersheds. Four WRENSS regions were extrapolated northward from the continental U.S. on the basis of forest vegetation and climatic zones and 21 forested basins ranging between 0.4 and 144 km^2 were selected within these regions for testing.

Predicted streamflows were generated with a Fortran version of WRENSS (Bernier 1986) and regressed on actual recorded streamflows from historical data. Although regression of all data combined produced a coefficient of determination (r^2) of 0.94, regional results demonstrated a high degree of variability with r^2 values of 0.26 in region 6 to 0.44, 0.41, and 0.57 in regions 1, 4, and 5 respectively.

Further study of this variability revealed that the most important requirement for reliable WRENSS application to forested watersheds is good quality data. Specifically, data for a basin must be accurate and representative (temporally and spatially). In addition, an appropriate hydrologic

region must be selected through hydrological regionalization of a basin in terms of:

- i) water balance components of annual precipitation, streamflow, and evapotranspiration,
- ii) hydrological regime,
- iii) snowpack and wind redistribution characteristics, and
- iv) forest vegetation type.

Thirdly, specified guidelines for WRENSS application must be adhered to (i.e. snow versus rain dominated area application), and any possible basin characteristics (i.e. basin leakage) which may influence the water balance of a basin must be carefully considered to determine if WRENSS may be applied at all.

Based on the data used for this study, the applicability of WRENSS to predict streamflow in ungauged basins cannot be assessed. Poor quality data decreased the reliability of the results to the point where the suitability of methodology for this use is unknown. The results do not, however, preclude the use of WRENSS to predict changes to streamflow after harvesting; the original purpose of the methodology.

It was therefore concluded that application of WRENSS to other basins requires careful consideration of data quality, hydrologic regionalization, and other factors which affect the water balance. Further testing with good quality data would therefore be required to assess the applicability of WRENSS for ungauged basin estimation in Southern Canada.

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PROVINCE FOUR

Marmot Basin:	Approximately 80 km west of Calgary
Comprised of:	3 sub-basins: Twin 2.6 km^2, Middle 2.8 km^2 Cabin 2.1 km^2
Location:	50° 57' N. Lat. 115° 10' W. Long.
General Aspect:	East
Elevation range:	1585 to 2804 m.a.s.l.
Vegetation:	Primarily over-mature spruce-fir-pine stands: white spruce, alpine fir & lodgepole pine (Kirby & Ogilvie 1969).
Soils/geology:	Predominantly superficial deposits of till, outwash & talus. 5 soil types including luvisols, podzols, regosols, alpine, and organic (Jeffrey 1965).

DATA SUMMARY I: Precipitation: (i) 4 stn. avg.
Twin 1,3; Cabin 5; Con.5
(ii) (Confluence 5)

	1978			1979			1980		
	Pi	Pii	Q	Pi	Pii	Q	Pi	Pii	Q
J	32	23	6	21	14	5	48	34	3
F	16	10	4	67	48	4	39	26	3
M	62	33	4	38	19	5	67	41	3
A	89	54	7	83	59	5	37	29	14
M	114	84	49	64	50	50	134	122	98
J	84	64	182	50	44	109	121	114	148
J	62	51	81	25	25	40	47	44	34
A	77	63	30	64	59	16	111	105	28
S	82	66	22	30	22	10	114	102	36
O	46	29	20	31	20	8	33	24	29
N	79	54	11	17	14	5	65	43	11
D	36	21	8	131	95	4	94	91	8
T	779	552	424	621	469	261	910	775	415

Marmot Basin

DATA SUMMARY II: Precipitation: Alta. Environment Avg.

1974		1975		1976		1977		1978	
P	Q	P	Q	P	Q	P	Q	P	Q
132	5	28	6	14	5	30	6	36	6
36	4	76	4	86	4	15	4	15	4
67	4	38	4	36	4	75	4	5[illegible]	4
190	10	54	4	72	10	25	10	83	7
123	41	56	28	85	106	155	50	130	49
49	252	98	125	85	120	43	70	95	182
31	87	94	79	70	77	67	26	64	81
109	36	94	40	117	59	141	41	84	30
69	24	35	23	117	44	68	34	90	22
35	18	60	14	29	22	37	21	43	20
86	10	59	9	26	11	67	11	78	11
60	7	170	7	35	8	40	8	34	8
987	498	862	343	772	470	763	285	803	424

1979		1980	
P	Q	P	Q
21	5	49	4
70	4	37	3
29	5	59	3
86	6	42	14
75	49	161	97
55	109	144	148
31	40	50	34
73	16	111	28
31	11	121	36
29	8	33	29
20	5	62	11
135	4	103	8
655	262	972	415

TriCreeks Watershed: Approximately 40 km. southeast of Hinton

Location: 53° 09' N Lat. 117° 15' W Long.

Comprised of: 3 sub-basins:
Wampus 27.1 km^2
Eunice 15.6 km^2
Deerlick 13.6 km^2

General Aspect: North
Elevation range: 1262 to 1707 m.a.s.l.
Vegetation: Coniferous vegetation: lodgepole pine, white spruce and black spruce.

Soils/geology: Three till types with some glaciolacustrine deposits. Soils: Gray Luvisols and Eutric and Dystric Brunisols (Jablonski 1978).

DATA SUMMARY I: Entire basin: Precipitation data
Sacramento

	1974		1975		1976	
	P	Q	P	Q	P	Q
J	66	0	10	0	58	0
F	10	0	41	0	43	0
M	48	0	48	0	63	0
A	51	27	25	3	53	14
M	56	109	10	46	66	53
J	48	58	109	34	130	43
J	76	27	46	21	114	18
A	81	13	66	8	185	34
S	41	14	58	7	58	16
O	23	11	18	5	86	11
N	25	0	25	0	43	0
D	13	0	58	0	28	0
T:	538	259	514	124	827	189

TriCreeks Watershed

DATA SUMMARY II: Entire basin: Precipitation
Combined Snow course/
Sacramento/Rain Gauge

	1974		1975		1976	
	P	Q	P	Q	P	Q
J	61	0	10	0	58	0
F	114	0	41	0	96	0
M	129	0	69	0	150	0
A	145	27	96	3	53	14
M	56	109	28	46	66	53
J	48	58	63	34	114	43
J	74	27	71	21	43	18
A	81	13	56	8	140	34
S	48	14	48	7	51	16
O	23	11	18	5	86	11
N	25	0	25	0	43	0
D	13	0	58	0	28	0
TOT	817	259	583	124	928	189

TriCreeks Watershed

DATA SUMMARY III: Individual Basins: Wampus

	1974		1975		1976	
	P	Q	P	Q	P	Q
J	70	0	9	0	61	0
F	7	0	38	0	38	0
M	50	0	49	0	69	0
A	46	27	41	3	33	14
M	112	109	50	46	69	53
J	42	58	108	34	36	43
J	81	27	47	21	108	18
A	72	13	56	8	181	34
S	45	14	53	7	31	16
O	44	11	33	5	91	11
N	25	0	30	0	12	0
D	14	0	61	0	27	0
T	608	259	575	124	756	189

TriCreeks Watershed

DATA SUMMARY IV: Individual Basin: Eunice

	1974		1975		1976	
	P	Q	P	Q	P	Q
J	64	0	10	0	56	0
F	22	0	48	0	52	0
M	50	0	47	0	58	0
A	56	20	47	2	33	8
M	118	90	43	33	69	38
J	50	41	122	27	27	40
J	67	25	47	20	119	18
A	94	14	75	11	183	23
S	39	11	70	8	31	12
O	50	11	43	6	89	11
N	28	0	1	0	12	0
D	11	0	56	0	31	0
T	649	212	609	107	760	150

Spring Creek Watershed: 19.2 km southwest of Sturgeon Heights

Location: 54° 55' N Lat.
117° 50' W Long.

Comprised of: 5 sub-basins:
Wolverine Creek
Horse Creek
Rocky Creek
Bridlebit Creek
Spring Creek

Area: 112.2 km^2

General Aspect: West
Elevation Range: 650 to 850 m.a.s.l.
Vegetation: Predominantly aspen & black spruce; some white spruce. Approx. 25% of basin area are muskeg, swamp, or lake (MacIver (1966)).

Soils/geology: Glacial till and alluvial deposits.

DATA SUMMARY:

	1980		1981		1982	
	P	Q	P	Q	P	Q
J	24	0	11	0	144	0
F	13	0	11	0	31	0
M	42	1	4	1	26	0
A	13	13	12	26	11	3
M	56	4	36	9	12	19
J	100	14	24	2	17	1
J	59	3	88	0	158	6
A	75	1	3	0	107	20
S	50	3	20	0	23	1
O	11	1	17	0	11	1
N	4	1	9	0	12	0
D	108	0	0	0	10	0
TOT	555	41	235	38	562	51

PROVINCE FIVE

Watershed C:	40 km east of Vancouver BC
Location:	49° 30' N Lat. 122° 50' W Long.
Area:	0.44 km^2
General Aspect:	South
Elevation Range:	295 to 455 m.a.s.l.
Vegetation:	92% immature forest: predominantly western hemlock (Feller 1975)
Soils/geology: tills;	Basal and ablation soils, predominantly Humo-Ferric Podzols - shallow and coarse textured (Feller 1975).

DATA SUMMARY:

	1980		1981		1982		1983	
	P	Q	P	Q	P	Q	P	Q
J	101	122	110	105	470	418	422	408
F	333	314	281	237	529	497	332	292
M	208	211	250	201	132	152	220	134
A	175	123	347	314	234	168	143	120
M	157	68	141	110	58	32	99	70
J	163	129	285	202	53	10	178	100
J	95	78	76	46	182	112	287	215
A	115	39	37	8	122	41	51	13
S	186	100	152	16	112	36	132	85
O	97	46	424	337	218	122	181	87
N	571	488	362	331	334	272	560	498
D	507	533	282	263	281	272	152	113
TOT	2708	2251	2747	2170	2725	2132	2757	2135

Carnation Creek Watershed:

Location:	48° 54' N Lat. 125° 13' W Long.
Area:	10 km^2
General Aspect:	West
Elevation Range:	Up to 2500 m.a.s.l.
Vegetation:	Dense coniferous forest: western hemlock, western red cedar, Sitka spruce & amabilis fir (Hartman 1983).
Soils/geology:	Medium to coarse textured: gravelly loam to loamy sand (Hartman 1982).

DATA SUMMARY I: P: Carnation Ck. CDF
Q: Carn. Ck. Main Stn.

	1972		1973		1976	
	P	Q	P	Q	P	Q
J	352	474	538	556	437	448
F	433	481	213	192	457	377
M	548	608	269	269	374	333
A	252	271	68	90	117	138
M	34	61	170	139	176	134
J	41	19	132	124	94	82
J	153	123	42	20	74	61
A	33	11	22	7	106	55
S	118	40	68	10	81	70
O	61	12	323	228	203	139
N	321	248	452	423	143	155
D	543	663	663	680	342	402
TOT	*2889	3011	2960	2738	2604	2394

*(NOTE: P<Q)

Carnation Creek:

DATA SUMMARY II: P: Carnation Ck. Stn. A
Q: Carn.Ck. Main Stn.

	1974		1975		1976	
	P	Q	P	Q	P	Q
J	477	562	293	368	439	448
F	536	509	211	198	465	377
M	508	651	260	273	377	333
A	188	294	115	139	122	138
M	221	204	131	159	181	134
J	95	95	68	63	96	82
J	106	72	21	26	79	61
A	2	11	216	163	110	55
S	36	15	6	35	85	70
O	116	69	696	620	209	139
N	473	491	746	815	151	155
D	542	526	478	601	334	402
TOT	*3300	3499	*3241	3460	2648	2394

*(Note: P<Q)

Jamieson Creek Watershed:

Location:	49° 20' N Lat. 123° 13' W Long.
Area:	2.9 km^2
General Aspect:	East
Elevation Range:	305 to 1310 m.a.s.l.
Vegetation:	Mature and overmature conif[illegible]rous species: weste[illegible] hemlock, weste[illegible] red cedar and Douglas-fir (Todd 1984).
Soils/geology:	Veneer till and lacustrine deposits Two main soil types: Humo-ferric and regosols (Todd 1984).

DATA SUMMARY I: Precipitation: 6 stn. avg.

	1975		1976		1977	
	P	Q	P	Q	P	Q
	376	92	433	185	266	135
	238	114	433	101	412	249
	356	139	259	111	368	134
	210	167	180	257	177	327
	192	574	221	549	242	263
	99	264	146	457	139	143
	14	117	134	385	89	46
	139	237	181	116	156	47
	105	367	150	112	263	168
	765	528	154	115	508	199
	1088	648	241	147	650	384
	502	462	458	345	538	422
T	4084	3709	2990	2880	3808	2517

Jamieson Creek Watershed

DATA SUMMARY II: Precipitation (Todd 1984)

	P	Q	P	Q	P	Q
J	244	92	409	185	241	135
F	251	114	409	101	378	249
M	358	139	409	111	353	134
A	216	167	180	257	178	327
M	196	574	165	549	229	263
J	107	264	122	457	127	143
J	10	117	135	385	76	46
A	96	237	163	116	140	47
S	102	367	147	112	249	168
O	673	528	140	115	480	199
N	993	648	236	147	625	384
D	572	462	432	345	485	422
T	3818	3709	2947	2880	3561	2517

PROVINCE SIX

Camp Creek Watershed:

Area:	33.9 km^2
Location:	49° 42' N Lat. 120° 00' W Long.
General Aspect:	East
Elevation Range:	900 to 1923 m.a.s.l.
Vegetation:	Interior Douglas-fir, Engelmann spruce, lodgepole pine.
Soils/geology:	Data not accessible.

DATA SUMMARY:
(Gauges outside of basin)

P: Peachland/Brenda Mines Stn.
Q: Camp Ck. Main Stn.

	1972		1973		1975		1976	
	P	Q	P	Q	P	Q	P	Q
J	107	3	39	126	4	93	3	3
F	110	3	45	4	105	4	64	3
M	71	5	55	4	68	4	27	4
A	55	10	2	6	24	6	29	6
M	21	136	33	26	37	54	44	66
J	82	116	31	11	10	52	38	30
J	27	24	5	4	31	12	41	11
A	46	10	7	3	67	6	117	10
S	33	7	34	3	1	5	9	20
O	20	7	76	3	78	4	36	7
N	24	5	172	3	113	3	12	4
D	91	5	82	2	99	4	48	4
T	687	331	581	73	759	158	558	155

Testalinden Creek Watershed:

Location:	40° 07' N Lat. 119° 35' W Long.
Area:	13 km^2
General Aspect:	South
Vegetation:	Lodgepole pine, Interior Douglas-fir.
Soils/geology:	Data not accessible.

DATA SUMMARY:
(Gauges outside of basin)

	1972		1973		1976	
	P	Q	P	Q	P	Q
J	68	2	28	2	32	2
F	43	2	53	2	35	1
M	47	5	58	2	38	2
A	53	8	[illegible]	3	31	4
M	46	[illegible]	[illegible]	6	44	16
J	76	4	[illegible]	4	45	9
J	30	[illegible]	[illegible]	2	33	4
A	47	[illegible]	[illegible]	1	178	3
S	28	[illegible]	66	1	18	2
O	18	2	64	1	22	2
N	35	2	94	1	12	1
D	38	2	49	2	19	1
T	529	125	550	27	507	47

INTRODUCTION

Watershed management "ensures that forest and other vegetative covers serve to protect and maintain water supplies to the fullest extent possible" (Davis 1966), for regime, quality and quantity. The prediction of water yield and changes in it are integral parts of watershed management.

Silvicultural practices can change the volume and timing of streamflow. Although silvicultural activities cannot increase the amount of precipitation falling upon an area, they can influence the distribution of rain or snow in both time and space on a local scale, and as well, they can reduce evapotranspiration and interception losses that normally occur from the forest canopy (Troendle and Leaf 1980).

Management decisions involving assessment of hydrological land use impacts require streamflow information. Ideally, land managers have actual streamflow measurements. Without recorded data, streamflow must be estimated. Modelling is one method that may be used to obtain streamflow estimates. Existing models are not always suitable for land use decision making however. This may be true if the model has been calibrated for a specific set of basin conditions and cannot be applied to different areas, if the model is too complex for frequent use, or if data requirements are not easily satisfied. In other cases, use of an incorrect model may provide faulty estimates of hydrological parameters or output that are not relevant to the land use managers' objectives (Haan et al. 1982).

An alternative approach for hydrological land use impact assessment is a methodology built upon model results. The results of numerous modelling simulations are compiled and assessed by functions which relate inputs and outputs. Such a methodology can be designed to allow assessment of a broad range of land use impacts on water yield. This is in contrast to models which are specific to areas from which the calibration data were obtained. A methodology also can be easier to apply because the complexities of the modelling are contained within functions describing the relationships between variables.

An U.S. example based on simulations done with two models, WATBAL (Leaf and Brink 1973) for snow dominated areas, and PROSPER (Goldstein and Mankin 1972) for rain dominated areas is WRENSS. WRENSS an acronym for "Water Resources Evaluation of Non-Point Silvicultural Sources", is a set of methodologies developed jointly by the United States Forest Service and Environmental Protection Agency. The methodologies were compiled in the late 1970s in a manual intended to aid the assessment of land use impacts on hydrologic parameters such as oxygen content, sedimentation and water yield. For purposes of this study however, "WRENSS" refers only to Chapter III of that manual (Hydrology) as the methodology to assess changes to water yield after forest harvesting. Furthermore, WRENSS as developed from WATBAL for snow-dominated areas was used as the primary focus of this study because of its potential applicability to southern Canada.

The WATBAL model is the primary routine of a model designed "to simulate the total water balance on a continous, year-round basis, and to compile the results from individual hydrologic sub-units into a composite overview of an entire watershed" (Leaf and Brink 1973). WATBAL receives daily inputs of precipitation from which daily evapotranspiration requirements, adjusted for available energy, are met. Soil mantle moisture requirements are then met to a specified level of field capacity, and excess inputs are then considered to be "water available for streamflow" (Leaf and Brink 1973b). WATBAL-predicted streamflow is therefore based on the climatic conditions of a specific basin; primarily the energy inputs.

WRENSS was developed by calibration of WATBAL to the climatic and hydrological characteristics of watersheds in different hydrologic regions of the U.S. Calibration involved fitting model output to historical streamflow records so that predicted streamflow equalled recorded streamflow for each basin. Each calibrated version had a set of parameters specific to the watershed used; for example: WATBAL-Hubbard Brook or WATBAL-Wolf Creek.

These WATBAL models calibrated for each basin were rerun numerous times with varied climatic inputs and watershed conditions to produce a wide range of outputs of water available for streamflow. From the simulations a good relationship was found between seasonal ET and precipitation on a regional basis.

The simulated output was therefore divided into seasonal components and presented as a series of nomograms to predict ET as a function of precipitation. These nomograms form the basis of WRENSS, and they represent evapotranspiration at a condition of maximum hydrological utilization defined as: (Troendle and Leaf, 1980):

> "the hydrologic state of the watershed in which complete hydrologic utilization is achieved. It may be thought of as, but is not necessarily the same as, a fully forested watershed with vegetation (primarily trees) capable of maximum evapotranspiration (ET) for the energy and water available".

For vegetation conditions in which less than maximum utilization is present, (e.g. thinned, immature stands) coefficients are included to modify the predicted ET values. These were developed with information from the WATBAL calibrations and from studies being carried out in Colorado at the time.

WRENSS was originally designed to estimate change in water yield resulting from forest harvesting, as opposed to estimating yield of ungauged basins. Use of WRENSS to estimate ungauged basin yield may be possible however (C.Leaf Pers. Comm. 1986), if the vegetative state of a basin is known. This application of WRENSS would be particularily valuable for much of Canada, since there are many ungauged basins.

Estimation with WRENSS of the "water available for streamflow"[1] in a basin is based on the water balance for a region with:

$Q = P - ET \pm S$ where:

Q = streamflow
P = precipitation
ET = evapotranspiration
±S = storage change (assumed = 0: longterm i.e. 10-15 years)

Precipitation as an input to the water balance is utilized twice:

1. To provide an estimate of ET as a function of precipitation (using the appropriate nomograph).
2. To provide a water balance component from which the estimated ET is subtracted to obtain "water available for streamflow" (i.e. $P - ET = Q$ assuming negligible storage change.)

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[1] "water available for streamflow" is the quantity of water that has passed through the evaporative zone and is potentially available for streamflow. It is a numerically generated value that may differ from "actual" streamflow according to basin storage conditions that influence flow routing. It is therefore equal to generated runoff adjusted for storage changes. (i.e. water available for streamflow = RO ± S)

Over a sufficiently long time period during which the change in storage approaches zero, ET subtracted from precipitation can provide a reliable estimate of water available for streamflow.

Data requirements for WRENSS are minimal, primarily:

a) watershed area, aspect, forest cover type, arrangement and density,

b) snowpack characteristics (i.e. snow density as it relates to possible redistribution), and

c) seasonal precipitation.

Although the data requirements are minimal, high standards of data quality are essential. Specifically, data should be accurate and representative. Accurate data are defined as those collected and tabulated according to procedures which minimize error due to instrumentation, sample size, human judgment, and environmental factors such as wind. Representative data are defined to be those descriptive of the temporal and spatial hydrological conditions of a basin. Data for WRENSS should include:

i) data that are collected and tabulated over a sufficiently long time period such that when used in a water balance calculation the change in storage approaches zero (i.e. large positive and negative fluctuations in storage balance out),

ii) precipitation data from a gauging network that represents the elevational and spatial range of a basin.

Good data are essential for the application of WRENSS. A model can be calibrated to poor quality data because application includes calibration, or adjustment of results to a standard, be it good or bad. Results are therefore fitted to the data, regardless of quality. WRENSS as a methodology does not provide the possibility for adjustment, thus poor inputs will produce poor outputs.

These requirements are essential because WRENSS is simple to use, has minimal data requirements, and is therefore subject to the danger of use as a "cookbook". WRENSS is intended to "complement sound scientific judgment, not replace it, and to insure reasonable evaluations where, because of a lack of experience, the judgment is less than optimum" (Troendle 1979).

The basic procedure to use WRENSS is:

a) Regionalization of a basin according to precipitation regime and type, climate, and physiography by comparison to descriptions in WRENSS for each hydrological region.

b) Division of the basin into homogeneous units of vegetation and aspect.

c) Calculation of yield for each of these units by the following:

    1) Input of seasonal precipitation.
    2) Adjustment of snow precipitation for redistribution between forest openings and adjacent uncut forest, with a snow retention coefficient.
    3) Prediction of evapotranspiration as as a function of the seasonal precipitation using the WRENSS nomogram for the appropriate region.
    4) Adjustment of ET with a cover density coefficient to represent the percentage of hydrologic utilization of the vegetation.

d) Area-weighting of water yields for each unit and summation to provide the total annual basin yield.

WRENSS may be applicable to Canada because of similarities in physiography (Rowe 1977), and forest vegetation (Bowman 1970) to the northern

United States. Both countries are characterized by mixed hardwood and coniferous forests in the east, and coniferous forests in the west. The snow dominated climate of southern Canada is also similar to that of the northern U.S. Furthermore, Alberta Environment and the Alberta Forest Service have used WRENSS with reasonable success (D. Asquin Pers. Comm., 1985). Other successful and more extensive applications of WRENSS have been made by the Canadian Forestry Service (P. Bernier, Pers. Comm., 1985). Applications outside of Alberta, have been limited to British Columbia (Todd, 1984). The lack of extensive testing of WRENSS in Southern Canada, despite its potential benefits for land managers, has been due in part to a lack of good quality data.

The objective of this thesis was to examine the applicability of WRENSS for predicting streamflow in undisturbed and ungauged forested watersheds in Southern Canada.

METHODS:

Methods consisted of two main parts:

1) Preliminary testing through application of WRENSS to selected, undisturbed basins across Southern Canada, and comparison of the predicted to actual water yield.

2) Analysis of the requirements for reliable application of WRENSS.

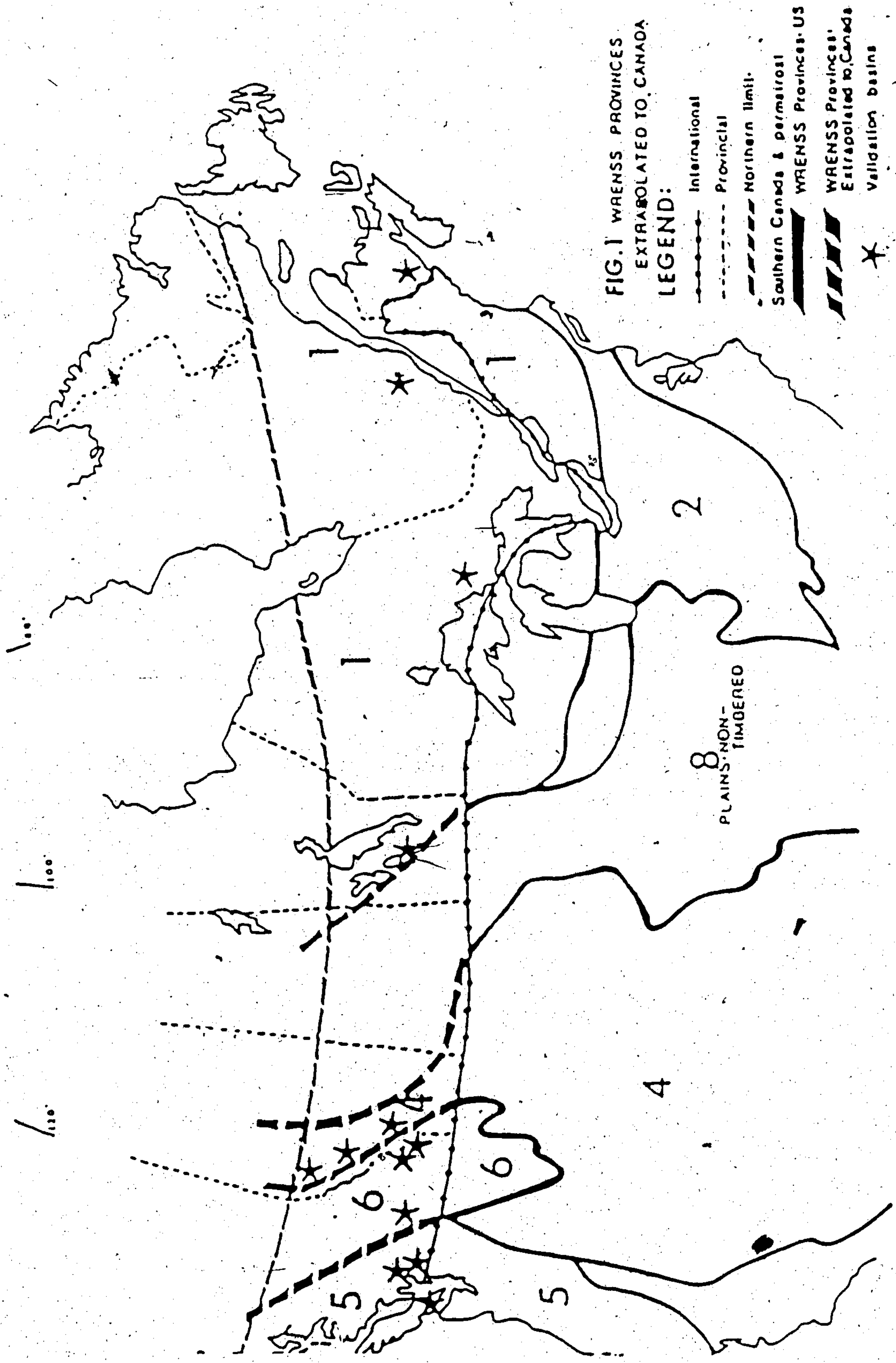
PART I:

The preliminary testing was initiated by selecting parts of Canada that are hydrologically and climatically similar to the continental U.S. "Southern Canada" was defined by the U.S./Canada border, and the middle of the Boreal forest region at approximately 55° north latitude which is also the southern edge of discontinuous permafrost (Rowe 1977) (Fig. 1).

Hydrological regions within Southern Canada similar to those in the continental U.S. were then delineated. Physiography (Bowman 1970), climate, and vegetation were used as indicators of regional hydrology to determine the regions most applicable to Canada. Four hydrological zones were extrapolated into Canada: (Fig. 1)

a) Province One - New England/Lake States
b) Province Four - Rocky Mountain/Inland Intermountain
c) Province Five - Pacific Coast Region of the Northwest province
d) Province Six - Pacific Coast Region of the Continental/Maritime province

Fig. 1 WRENSS PROVINCES EXTRAPOLATED TO CANADA



The selection of forested, test basins within these zones and collection of monthly precipitation and streamflow data for each were the next steps. A total of 21 basins including sub-basins of some major watersheds were selected, with 3 to 4 basins in each hydrological zone (Fig. 1; App.1,2). Most of the basins were research areas and were considered to have reliable long-term data (15 - 20 years). The basins ranged from 0.04 km^2 to about 150 km^2 in area to provide a good sample of basin sizes. Additional criteria defined for basin selection included:

1) Data availability: Long-term streamflow and precipitation records were required, to allow extraction of 4 to 5 years of predisturbance data. Short term and/or incomplete data sets were avoided.
Example: Data from recently established stations were not used.

2) Data reliability: Data sets were obtained from published sources where possible, and were checked for major gaps and inconsistencies.
Example: Data with many missing months of data were not used.

3) Data representativeness: Within each basin the location and elevation of precipitation gauges were checked to determine if the collected data represented the average precipitation (versus a high or low extreme) of the basin.
Example: Data collected from only one gauge in a basin were avoided.

4) Land use information: Since pre-disturbance data was required to represent baseline conditions as closely as possible, basins without known histories of major land use disturbances were preferred.

Comparison of simple water balances between Canadian basins and selected U.S. basins were also used in the selection process. This was done to increase the likelihood that the selected basins were correctly regionalized into the WRENSS regions. U.S. basins were chosen from those used to derive WRENSS, and from long-term basin studies described in the literature, and compared to the potential Canadian test basins to reveal any major differences in water balances.

The criteria established for the data used for the WRENSS application were considered to be idealistic. Data actually available for this study were very limited, (i.e. streamflow and precipitation from the same basin were not always available) and data quality standards were variable. In addition, specifications for WRENSS data requirements are not well documented. Given these limitations, it was recognized that it was not always possible to employ the standards fully in data collection. Subsequently, the following assumptions were adopted:

1) Precipitation data were assumed accurate and missing data estimated by using available long-term mean values or procedures such as the "Normal Ratio Method" (Hewlett 1982). Annual precipitation was assumed suitable for WRENSS application.

2) Precipitation data were assumed to have originated from relatively uniform gauging distributions; the arithmetic averages calculated were assumed to be areally representative.

3) Streamflow data were assumed accurate. Missing or questionable "winter" data (between water year onset: October 1, and spring run-off onset) were replaced with long-term mean values or assumed equal to zero (ie: frozen conditions). This was assumed because the proportion of winter flows on an annual basis is small for most intermittent and small permanent streams in snow dominated regions.

A FORTRAN version of WRENSS (Bernier 1986) was used to predict water available for streamflow. To standardize and simplify the application of WRENSS the following assumptions were made:

1) Seasonal precipitation regimes as specified for WRENSS (Troendle and Leaf 1980) were applicable to the Canadian basins.

2) The predominant basin aspect was assumed to be representative of the entire basin for all WRENSS predictions, unless otherwise specified.

3) Basal area data describing the vegetative cover of each basin were often not readily available. The vegetative state of all the undisturbed basins used was therefore assumed to exist at maximum hydrological utilization.

4) Vegetation type was assumed to be described by the predominant tree species for mixed softwood stands and mixed stands.

5) Due to limited information regarding the presence of snow scouring in each basin, it was assumed not to exist.

Preliminary analysis by simple linear regression was used to determine if a strong relationship existed between annual predicted (Qp) and annual actual (Qa) streamflow. A relationship was hypothesized even though predicted streamflow (Qp) represents the maximum, unrouted quantity of water available for streamflow and therefore should differ from actual streamflow (Qa) according to basin characteristics that affect storage; principally rate of groundwater movement.

Regressions were for all four hydrologic regions combined to provide information about WRENSS predictability for Southern Canada overall. Regressions were also calculated for each hydrological region to indicate predictability for individual hydrological zones.

In addition to the regressions, ratios of predicted (Qp) to actual (Qa) streamflow were calculated for each basin/year, and from all basins/region the mean Qp/Qa ratio for each region was calculated. Results are found in Appendix 4.

PART II: Secondary Analysis: Consideration of factors influencing WRENSS predictions

Preliminary testing of WRENSS on data from Southern Canada revealed a wide range of results in the regression analyses. A further examination of WRENSS was considered necessary. The second analysis was an evaluation of the data inputs and assumptions of WRENSS.

As with any model or methodology, data inputted into WRENSS directly affect the usefulness of the output, i.e. "poor data in = poor results out". Based on this, the factors considered to have the greatest effect on output from WRENSS were data quality and data representativeness. Assessment of these factors was done to establish guidelines for the reliable application of WRENSS based on examples from the preliminary analysis.

RESULTS AND DISCUSSION:

PART I: Preliminary Analysis

In the preliminary analysis of WRENSS, 21 Canadian basins with an average size of 33.1 km^2 were chosen. They represented four hydrological provinces, with the most northerly and southerly basins being Spring Creek, Alberta, and Nashwaak Experimental Watershed, New Brunswick (Fig. 1) respectively. Annual precipitation ranged from a maximum of 3628 mm in Coastal B.C. to a minimum of 451 mm in Northern Alberta. Annual streamflow ranged from 3139 mm in Coastal B.C. to 43 mm in Northern Alberta. Water balance comparisons (P, Q, ET) of these basins to U.S. counterparts were reasonable although the degree of similarity could not be readily quantified.

The best water balance comparisons were in regions 1, 4, and 5 (Table 1). Precipitation and evapotranspiration matched well in region 1, while streamflows averaged 44% higher in the Canadian basins. Region 4 demonstrated good matching with differences of 13 - 27% between the water balance components. Region 5 with the largest water balance components compared more poorly than regions 1 and 4, with only modest agreement

TABLE 1: WATER BALANCE COMPARISON: US & CAN BASINS

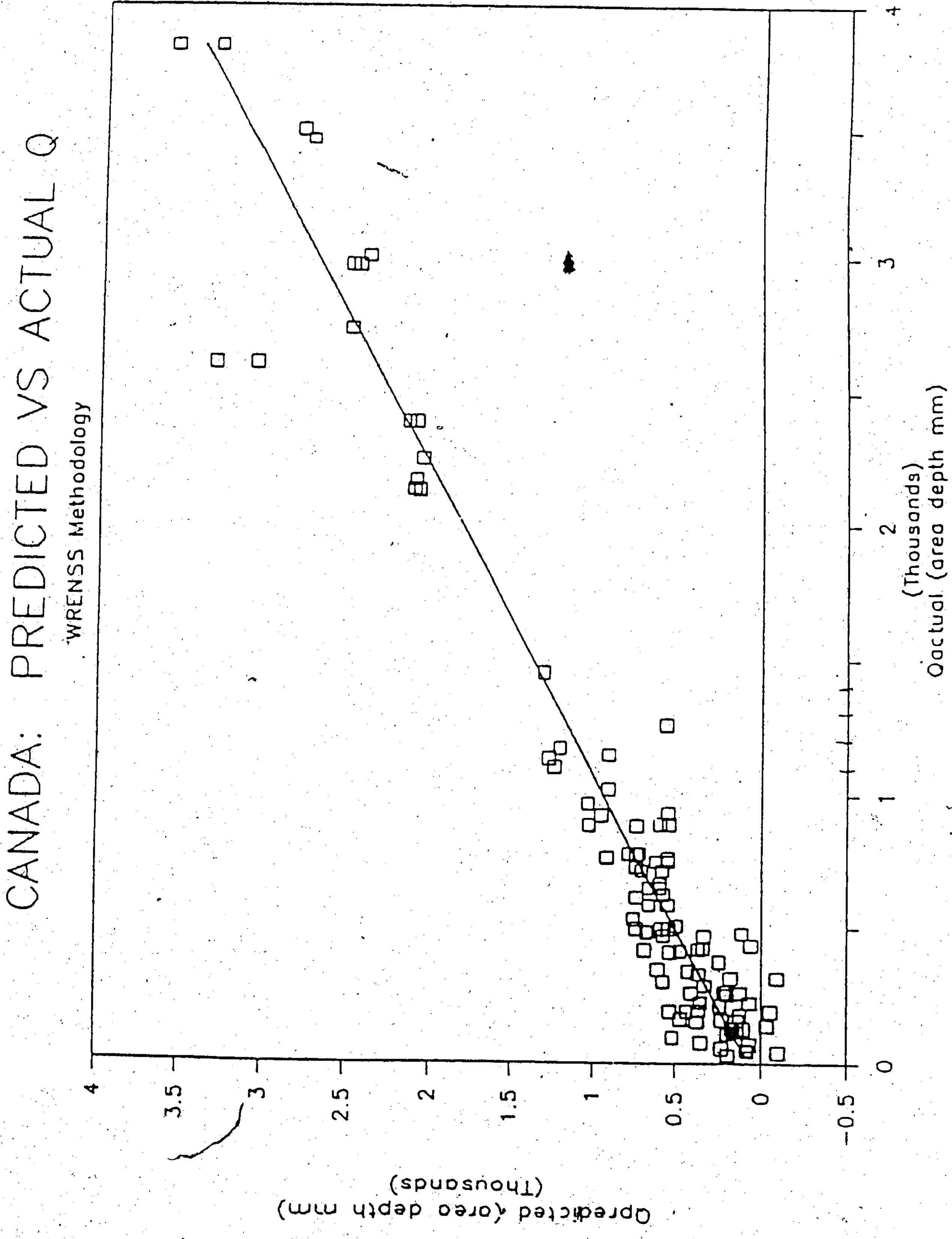
BASIN	AREA (km^2)	PPT (mm)	Qact (mm)	Qpred (mm)	ET (mm)
REGION 1					
Hubbard Brook	31.0	1295	809	807	486
Marcell	0.1	787	178	-	610
Central NH	0.2	1219	889	-	330
MEAN &	10.4	1100	625	-	475
STD DEV		(274)	(389)		(140)
Nashwaak	11.0	1290	863	748	427
Bassin Volees	5.0	1636	1053	1120	583
Turkey Lks	11.0	1119	789	676	330
MEAN &	9.0	1348	902	848	447
STD DEV		(264)	(136)	(238)	(128)
REGION 4					
Beaver Ck	310.0	489	67	86	422
Fraser	2.9	559	305	-	254
Wagon Wheel	0.8	533	155	-	378
MEAN &	106.2	527	176	-	351
STD DEV		(35)	(120)		(87)
Marmot Ck	9.0	790	367	355	423
Spring Ck	112.0	451	43	92	408
Tri Creeks	56.0	701	191	296	510
MEAN &	59.0	646	200	248	447
STD DEV		(176)	(162)	(138)	(55)
REGION 5					
Bull Run	274.0	3073	2139	2561	934
HJ Andrews	0.6	2388	1549	-	839
Doug fir area	1.0	2286	1448	-	838
MEAN &	91.9	2582	1712	-	870
STD DEV		(428)	(373)		(55)
Carnation Ck	10.0	2818	2714	2315	104
Wat C	0.4	2734	2172	2079	562
Jamieson Ck	3.0	3535	3035	3022	500
MEAN &	4.5	3029	2640	2472	389
STD DEV		(440)	(436)	(491)	(248)
REGION 6					
Skyland Ck	20.7	1270	660	560	610
C.Snow Lab	10.2	1778	1092	-	686
MEAN &	15.5	1524	876	-	648
STD DEV		(359)	(305)		(54)
Camp Ck	34.0	646	179	352	467
TestalindenCk	13.0	529	66	140	463
MEAN &	63.7	554	339	203	360
STD DEV		(82)	(137)	(132)	(182)

(differences of 17 to 54%) between actual flow, precipitation and ET components. The poorest comparisons were in region 6 where large differences in precipitation (64% lower), flow (61% lower), and ET (44% lower) were found.

The large differences in region 6, and for some locations in region 5, indicated noteable climatic differences between the selected Canadian basins and U.S. counterparts. However only one basin, Trapping Creek in region 6, was initially eliminated from regression analyses based on these comparisons. For this basin, P - Q gave an estimate of ET of only 200 mm, almost 70% lower than its U.S. counterpart, and less than half of that normally expected for a forested region. According to Anderson _et al._ (1976) the annual potential evapotranspiration average of eight major forest types found in North America is 675 mm.

Results of simple linear regression of actual and predicted streamflows for all hydrological provinces combined were strongly related (Fig. 2), with a r^2 value (Table 2) of 0.940. The high correlation was due in part to the differences between the hydrologic regions that caused a clustering of data points.

Fig 2. Predicted versus Actual Streamflow: Canada



For all data combined, the mean predicted flow was 879 mm, with confidence limits ($p<0.05$) of 441 to 1317 mm. The mean actual flow was higher at 1071 mm, with confidence limits ($p<0.05$) of 834 to 1308 mm.

Table 2: Simple linear regression of predicted flows (WRENSS) versus actual flows for hydrological provinces extrapolated to Southern Canada.

PROV	b_o	b_1	r	r^2	Se	n(a)	Fcalc
All	108.81	.852	.970	.940	206.0	93	37.95**
One	345.39	.527	.663	.440	165.8	42	5.59**
Four	100.08	.756	.639	.408	122.7	28	4.23**
Five	747.08	.646	.752	.566	344.8	16	4.26*
Six	171.66	.687	.513	.263	128.8	7	1.48

n(a) = total number of WRENSS runs completed for the region. This number includes runs with 2 - 3 annual values for each basin, and sub-basin.
(**$p<.05$; *$p<.10$)

Lower evapotranspiration rates in Southern Canada than in the U.S. could partially account for the higher streamflows. The mean difference between actual and predicted flows was 24 mm, with maximum and minimum values of 735 and -692 mm and a standard deviation of 249 mm. Hydrologically this indicates the range of flows in the four regions is wide (i.e. some locations have extremely small flows, others have large flows).

Coefficients of determination (r^2) for individual hydrologic regions were less favorable, ranging from poor to moderately good (Table 2; APP. 3). These regression results demonstrated weaker relationships and increased variability between predicted and actual flows. This was emphasized by the "best" results from hydrologic regions 1, 5, and 4. Coefficients of determination for provinces 1, 5, and 4 respectively were 0.440, 0.556 and 0.263 with standard errors of 166 mm, 345 mm, and 123 mm.

The mean differences and standard deviations between actual and predicted flows for regions 1, 5, and 4 were 8 ±209 mm, 249 ±393 mm, and -41.0 ±125 mm. This indicated high variability and unreliability in the estimates.

The poorest results occurred in hydrologic region 6 where the r^2 value was 0.263 (not significant). The small sample size of 7 years (2 basins) of data contributed to this poor correlation but was not entirely responsible for all of it. The mean difference between actual and predicted values for this region was -19 mm with a standard deviation ±121 mm. It was noted however, that the small mean differences between predicted and actual flows for all four regions did not indicate that the WRENSS predicted values were generally similar to the actual streamflow values. The small mean occurred because there were large positive and negative differences that balanced out when added together arithmetically.

PART II: CONSIDERATIONS FOR APPLICATION OF WRENSS

A: DATA QUALITY

One possible cause for the variability of results in regions 1,4, and 5 and the unreliable results for region 6 was the quality of precipitation and streamflow data used for testing WRENSS. Further investigation revealed four types of data quality problems.

1. Inaccurate precipitation and streamflow data.
   Example: Tri-Creeks watershed.
2. Spatially unrepresentative precipitation data.
   a) Areally;
      Example: Testalinden Creek and Camp Creek.
   b) Elevationally:
      Example: Marmot Basin.

3. Temporally unrepresentative precipitation data.
   Example: Spring Creek Watershed.
4. Basin leakage.
   Example: Les Bassins des Eaux Volees

EXAMPLE 1:

Inaccuracy in data from Tri-Creeks was caused by discontinuities in streamflow data and multiple gauge errors in precipitation data.

Streamflow records in snow-dominant areas are often discontinuous because channel icing prevents measurement of winter flows. Data for snowmelt (i.e. the rising limb of the hydrograph) at Tri-Creeks were missing and therefore were extrapolated. This is particularily critical for hydrological comparison of two snow dominant areas because over half of the annual flow in these areas occurs from snowmelt, and thus any errors in extrapolation can be very serious. Without data from this part of the hydrograph, comparison of two snowmelt dominant watersheds is impossible. Thus if the extrapolated estimates differ greatly from what could be actually measured, the comparison of WRENSS predictions to these actual flows will be erroneous.

Differing catch by different types of gauges increased the error in precipitation data used from Tri-Creeks. Streamflow prediction in the initial assessment was based on precipitation data combined from: snow course data for winter, (approximately November to February), Sacramento gauge data for the transition periods between snow and rain precipitation in the fall and spring (March, April, September and October), and standard rain gauge data for the summer (May to August). Comparison of the streamflow predictions based on this composite data set to predictions based on Sacramento gauge data alone indicated overprediction. The ratio of Qp/Qa for the composite data was 1.92 compared to 1.21 for the Sacramento gauge data set.

Gauging errors occur because each gauge type varies in its ability to catch different forms of precipitation. One example of this is the gauge efficiency of the M.S.C. standard rain gauge (Bruce and Clark 1966) when used along the Foothills of Alberta. In spring, precipitation is a mixture of rain and snow (Longley 1972) and gauging error or undercatch with the standard gauge can be up to 45% for snow and between 7 and 14% for rain (den Hartog 1975). Most gauges undercatch because they cause turbulence in the airflow, and this results in varied precipitation fallout in the vicinity of the gauge (Gray 1970); particularily for lighter precipitation such as snow.

EXAMPLE 2a:

Precipitation data for Testalinden and Camp Creeks were not spatially representative. Data for the Interior of B.C. were extremely limited. Precipitation data used for these basins were from single stations that were nearby but not in nor at the same elevations as Testalinden and Camp Creeks. These data were assumed to be reasonable approximations of total precipitation in each basin. The high Qp/Qa ratios for Testalinden and Camp Creeks however suggested this assumption was incorrect with ratios for Testalinden Creek of 3.37 and Camp Creek of 2.59 (APP.4). Precipitation measured at the stations probably were underestimates because precipitation is strongly influenced by elevation. In mountainous areas where gauging is limited, this problem is common.

Spatially representative precipitation data should be collected from an adequate number of gauges uniformly distributed within a watershed. A good network of gauges is particularily important in mountainous basins where precipitation gradients are strong.

EXAMPLE 2b:

Some of the data from Marmot Basin were not representative elevationally. Practical constraints of establishing and maintaining a precipitation gauging network often limit location of gauges to sites easily accessed such as near streamflow gauging stations. Precipitation data from low elevation gauges in mountainous areas usually underestimate average values because precipitation increases with elevation. In Marmot Basin rainfall increases about 120 mm over an elevational rise of 1200 m (Storr 1967).

Comparisons of streamflow predictions were made using data from a single low elevation station versus a four station average that included higher elevation stations. The four stations used included Confluence 5 at low elevation, Cabin 5 at mid-elevation, and Twin 1 and Twin 3 located at upper elevations. The Qp/Qa ratio for the single station (Confluence 5) (Table 4) was 0.46 compared to 0.90 obtained with the 4 station average. The low ratio for the single station estimate clearly demonstrated that serious data quality problems are introduced by using elevationally unrepresentative data.

Table (3) Marmot Basin Data: Qp/Qa Ratios

Year	Qp/Qa^1	Qp/Qa^2
1978	0.80	0.24
1979	0.75	0.31
1980	1.14	0.82
	x=0.90	x=0.46

Legend: Qp/Qa: predicted flow/actual flow
Source: 1 (4 station average)
2 (Confluence 5 alone)

EXAMPLE 3:

Results from Spring Creek basin provided a good example of the problem that can occur when using short term precipitation data with WRENSS. Predictions using annual precipitation data were compared to predictions made with an 18 year precipitation average. The ratio of Qp/Qa was reduced from 1.81 using annual data to 0.90 using the long-term mean (Table 4). The latter provided a more reliable precipitation value for a basin because it reduced and integrated the high variability possible with annual values. Long-term streamflow values also reduced variability because changes in storage approach zero when averaged over a long enough time period.

Table 4: Spring Creek: Longterm mean precipitation value

BASIN/LOC/ YEAR	P(mm)	Qa(mm)	Qp(mm)	Qp/Qa
Spring Ck AB				
1980	556	41	114	2.78
1981	237	37	-82	-2.22
1982	561	50	243	4.86
MEAN	451	43	92	1.81
LONGTERM	P(mm)	Qa(mm)		
MEAN	519	98	88	0.90
(#yrs)	(18)	(7)		

EXAMPLE 4:

Basin leakage, negative or positive, can affect streamflow predictions based on water balance calculations. Comparison of actual flows from basins with leakage to WRENSS predicted flows is therefore subject to error. Application of WRENSS is not recommended for these types of basins unless specific hydrogeological or surface flow information is available and appropriate adjustments can be made.

Basin leakage is very difficult to detect and quantify. Two basins of Les Bassins des Eaux Volees may have been influenced by water transfer due to beaver damming (P. Bernier Pers.Comm. 1986). The loss of water from either basin would reduce Qa and therefore inflate flow ratio comparisons of

Qp/Qa. However, since the mean Qp/Qa ratios for the two basins were only slightly greater than 1 (Bassin 6: 1.06 and Bassin 7a: 1.09: APP.4), the differences between the predicted and actual values was small, and the degree of variability was high, no conclusions could be made about the presence or influence of basin leakage in Les Bassins des Eaux Volees.

B: REGIONALIZATION

Along with the requirements for good quality data, application of WRENSS requires selection of the correct hydrologic region from those defined in the methodology. To meet this requirement, the hydrological characteristics of regime, water balance, and vegetation of a basin must be matched to those of a WRENSS region. This process is called regionalization.

For preliminary application of WRENSS to southern Canada, regionalization was conducted according to the WRENSS handbook by using descriptions of snowpack type and characteristics of wind redistribution of snow. In addition to the requirements specified by WRENSS, regionalization also included vegetation zonation, location within northwardly extrapolated U.S. regions, and some comparison of water balances. From further study of the preliminary results, it was noted that regionalization of a Canadian basin should also include comparison of hydrological regime to those of the WRENSS regions.

From preliminary results, Nashwaak Watershed was an example of a basin correctly regionalized. In Table 5, water balance components of P, Qact and ET of Nashwaak were similar to the U.S. Region 1 (+/-20%), given that gauging error for measurement of the water balance components can be highly variable. Comparison of hydrological regime for Nashwaak Watershed and the three U.S. basins also supported this hydrological regionalization. Annual hydrographs of the four basins indicated definite similarities in runoff pattern including snowmelt dominance.

TABLE 5: Water Balance Comparison: U.S. Region 1 and Nashwaak Basin

Basin	PPT (mm)	Qact (mm)	ET (mm)
U.S. Region 1:			
Hubbard Brook	1295	809	486
Marcell, Minn.	787	178	610
Central N.H.	1219	889	330
Mean	1100	625	475
(+/-20%)	880-1320	500-750	380-570
Canada Region 1:			
Nashwaak Basins	1290	863	427

The latter characteristic is required as WRENSS predictions based on WATBAL are for snow dominated runoff areas. A "snow dominant" regime is characterized by a dominant runoff peak that occurs during snowmelt season (R. Swanson Pers.Comm. 1987). In some regions, although rainfall may actually account for a higher proportion of total annual precipitation, if there is one dominant runoff peak during the snowmelt season the area is considered to be snow dominant.

Correct regionalization of Nashwaak Watershed was also indicated by similar vegetation types. Forest cover at Nashwaak includes a mixture of hardwoods and softwoods and the basin is totally forested (Dickison and Daugharty 1982). This is similar to the mixed forests of the U.S. basins.

Three examples of basins from the preliminary results incorrectly regionalized were the basins used to represent Region 5. The most important evidence of incorrect regionalization was the lack of snow dominance in the hydrological regimes of Carnation Creek, Watershed C, and Jamieson Creek. In these cases, although water balance comparisons were reasonably similar, the differences between the WRENSS Region 5 regimes and those of the Canadian representatives were too great to provide any useful conclusions about the applicability of WRENSS in that area of southern Canada.

Based on these and other examples found in the data used, regionalization of a Canadian basin should ideally be done by matching the following basin characteristics to the corresponding U.S. region to the best degree possible:

1. Water Balance Components: The relative quantity and proportion between the components, and total of ET estimated by P - Q should be reasonably similar.
2. Regime: The annual pattern of timing of runoff should be similar to U.S. counterparts. (A snowmelt peak should be present if the snowmelt portion of WRENSS is used.)
3. Vegetation: Vegetation should be similar to the U.S. region, and the state of hydrological utilization should also be similar. This is particularily important for areas with mixed or predominantly deciduous vegetation because the largest species differences in ET are found between coniferous and deciduous trees.

C. FACTORS GOVERNING CORRECT APPLICATION OF THE METHODOLOGY: BASIN WATER BALANCE CHARACTERISTICS

Along with requirements for data quality and correct regionalization, reliable prediction of ungauged flow should include careful consideration of basin characteristics which may affect storage changes in snow, soil, or groundwater. This is necessary when WRENSS is used to estimate annual yield, as opposed to change in yield, because streamflow is calculated as the difference between precipitation and the WRENSS estimated ET.

i) CLIMATIC EVENTS AFFECTING THE SNOWPACK AND RESULTANT AVAILABLE PRECIPITATION

Climatic events such as "Chinook" or foehn winds are not accounted for in the WRENSS methodology. Chinook winds greatly affect snowpack ablation in some areas of southern Canada. Along the East slopes of Alberta, and in parts of southwestern B.C., Chinook winds occur with great frequency (Golding 1981) and the resulting precipitation (i.e. snowpack) available for streamflow is greatly reduced. Measurements at nineteen Chinook sites along the East slopes of the

Rockies indicated evaporative losses during January to March of up to 223 mm in the open areas above treeline, and 135 mm in forested areas (Golding 1977). Without adjustment to precipitation for such losses, large errors could occur in WRENSS predictions of water available for streamflow for Chinook prone areas in southern Canada.

ii) BASIN STORAGE

WRENSS does not allow for basin storage carryover as part of the water balance equation. The methodology was designed to be used with long-term hydrologic data over which period basin storage carryover approaches zero or is very small (i.e. positive and negative changes balance out to zero). Streamflow predictions based on short-term data (e.g. 1 year) are therefore incorrect applications of WRENSS. The example from Spring Creek clearly demonstrated the error introduced from using short-term data.

WRENSS streamflow predictions also require the assumption of long-term values because streamflow is strongly influenced "both by events in past months, and current ET and precipitation" (Swift et al. 1975). The impact of this would be particularily pronounced in dry periods after years of high precipitation. In the short-term, predicted flows would be low due to reduced precipitation inputs while actual streamflows would be maintained by stored water from previous precipitation. In the long-term, with the effect of storage on streamflow assumed to be negligible, the predicted streamflow would be more representative of average conditions in the basin.

The size of basin storage can also impact WRENSS predictions. Basins with large storage capacities would be less likely to have a change-in-storage term equal to zero, when compared to basins with small storage capacities that facilite rapid output (i.e. runoff) from inputs (i.e. precipitation). Those with large storage capacities include basins with large areas of deep organic soils or clay textured soils.

These storage related factors may have influenced results from the basins with high storage capacities, such as Turkey Lakes Watershed, and Les Bassins des Eaux Volees. In regions with an older geologic history as in the Canadian Shield, soils are more well developed than in areas of more recent glaciation such as the Rockies. Spring Creek as a basin with deep organic soils, is an example of the former. Due to the greater storage capacities of the soil mantle in these basins, actual streamflow would tend to be lower than in basins with lower storage capacities, but also more sustained during precipitation deficit periods.

The water available for flow predicted for such areas would be based only on the quantity of precipitation inputted and not for quantities going into storage. Predicted water available for streamflow would therefore tend to be greater than actual. During times of low precipitation when slow release of stored precipitation from the deep soils would be maintaining actual streamflow, water available for streamflow could be negative. This would occur because the nomogram estimates of evapotranspiration would exceed the incoming precipitation.

This was observed in the preliminary results for Spring Creek (1981) for which predicted water available for flow when precipitation was below normal, (APP.2) was negative. Since this basin consists of about 25% swamp and lake (McIver 1966) with low relief, poor drainage and "good detention storage" (McIver 1966), the influence of storage carryover is clearly demonstrated for this basin.

SUMMARY OF REQUIREMENTS FOR WRENSS APPLICATION FOR BASELINE STREAMFLOW PREDICTION

Further study of the requirements for reliable WRENSS application produced the following recommendations:

1. Accurate and representative data should be used in WRENSS. Procedures to promote accuracy should include data sampling to minimize instrumentation error and human error. The data should be examined for missing values and corrected for environmental factors such as wind.

"Representative" data should describe the hydrological conditions of a basin temporally and spatially. Representative data should include:

(i) data for a sufficiently long time period such that change in basin storage approaches zero (i.e. positive and negative fluctuations in storage cancel out), and
(ii) precipitation data from a gauging network that represents the elevational and spatial variability in a basin.

2. Regionalization of a basin based on similarities of water balance proportions (P, Q,

and ET), hydrological regime (including general pattern and snowmelt dominance), and forest vegetation when compared to the WRENSS regions.

3) Identification of basin conditions which may affect the water balance and are not accounted for in WRENSS estimates of water available for streamflow. These conditions include basins prone to climatic events which reduce precipitation available for streamflow (i.e. Chinooks) and basins with large carry-over storage capacities that do not allow the change-in-storage term to approach zero. The use of WRENSS for basins with these types of conditions is not recommended.

CONCLUSIONS

Application of WRENSS to Southern Canada for predicting streamflow yielded highly variable and unreliable results. Some comparisons of predicted and actual streamflows were good, but others were very poor. Regression analysis of predicted on actual streamflows demonstrated very good correlation for all data combined but highly variable results for individual regions (r^2 values between 0.26 and 0.56). Ratios of predicted to actual streamflow ranked by the magnitude of difference from 1, ranged from poor in all the Region 6 basins, to very good for Marmot Basin and Les Bassins des Eaux Volees in Regions 4 and 1 respectively.

Further examination of these results indicated that WRENSS must be carefully used for predicting streamflow because the prediction of flow is more sensitive to factors which influence the water balance than is the prediction of change in flow.

From further study of factors affecting the water balance and thus WRENSS predictions, the most important consideration for the correct use of WRENSS was found to be the quality of data used. In particular, precipitation data must be accurate and representative in both time and space.

A second important consideration is the selection of the correct hydrologic region through regionalization of a basin in terms of the water balance components, hydrological regime, and vegetation. Incorrect selection of the hydrologic region will yield poor WRENSS estimates.

A third important consideration for the use of WRENSS is the identification of other basin conditions which affect the water balance; primarily climatic events affecting the snowpack and basin storage (i.e. carry-over storage). If unique hydrological conditions in a basin are not accounted for in WRENSS, use of WRENSS is not recommended.

Given current data availability and quality, it is unlikely that extensive application of the snow dominant portion of WRENSS for the prediction of streamflow from ungauged basins is possible at this time in Canada. However, application of the methodology to individual basins is likely to be possible if the three established requirements are satisfied. In particular, this seems to be likely for the following basins since very good ratios of predicted to actual flows were calculated (App. 4): Nashwaak Watersheds, Les Bassins des Eaux Volées and Marmot Creek. Further study recommended for these basins, would include the comparison of WRENSS predictions made with long-term precipitation data to long-term actual streamflows. This is in contrast to the comparisons of annual predicted and actual values carried out in this study. It should also be noted that the outcome of this study also does not preclude the use of WRENSS for its intended use to predict change in water available for streamflow after forest harvesting.

For any future applications of WRENSS to predict annual yield, the criteria established from this study are very important, although difficult to adhere to. For example, accurate and representative data are not always readily available. The data used in this study are representative of that commonly available for Canadian watersheds. As well, regionalization done only according to the location of a basin within a region should be avoided. The hydrologic regions serve as guidelines to particular hydrological conditions, but individual basin characteristics such as the annual water balance and annual hydrograph should be closely examined. These also serve only as guidelines because precipitation quantity may be reasonably extrapolated while regime may be more difficult to extrapolate (C.Leaf Pers.Comm.1986).

According to Jeffrey (1961) "many watershed studies are initated with the idea that results obtained from them will be representative of a much larger area, usually a vegetation type, physiographic region, or climatic zone. However experience has shown that it is very difficult to extrapolate data from control watershed experiments to such areas even after calibration". This is supported by Leaf (Pers.Comm.1986) in that "even within the geographic area of province four as an example, there are some areas for which hydrological characteristics cause WRENSS to be inapplicable to particular basins". Application of WRENSS should therefore be undertaken only after the basin has been correctly regionalized and checked for any basin characteristics that may not be handled well by WRENSS, and only after accurate and representative data have been obtained.

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APPENDIX ONE: BASIN INFORMATION

Abbreviations Used:
Q = streamflow P = precipitation (Pi = station 1)
(Pii = station 2) T, TOT = annual totals

PROVINCE ONE

Nashwaak Experimental Watershed:		Approximately 50 km northwest of Fredericton, NB.
Comprised of:	Hayden Brook	46° 17' N Lat. 67° 02' W.Long.
	Area:	6.6 km^2
	Narrows Mtn.	46° 17' N Lat. 67° [illegible] W Long.
	Area:	3.9 km^2
General Aspect:	South	
Elevation range:	195 to 478 m.a.s.l.	
Vegetation:	Totally forested: mixed hardwoods and softwoods (Dickison and Daugharty 1983)	
Soils/geology:	Basins underlain by argillite; overlain by glacial till (Dickison and Daugharty 1983)	
DATA SUMMARY:	H.B.=Hayden Brook N.M.=Narrows Mountain	

	1975 (mm)			1976 (mm)			1977 (mm)		
		NM	HB		NM	HB		NM	HB
	P	Q	Q	P	Q	Q	P	Q	Q
J	89	26	29	136	53	55	85	30	39
F	43	12	13	162	91	107	83	14	15
M	82	15	15	89	52	67	72	40	42
A	80	95	88	64	273	276	68	189	195
M	94	271	241	146	172	195	64	120	164
J	112	78	87	63	25	35	247	138	134
J	85	18	23	154	23	34	49	26	36
A	31	8	11	98	69	47	92	14	17
S	135	15	15	65	23	28	155	15	16
O	83	21	15	221	121	137	119	91	103
N	148	69	51	57	67	87	98	62	68
D	157	49	61	197	69	72	146	52	55
Tot	1139	677	649	1452	1038	1140	1278	791	884

Les Bassins des Eaux Volees:	80 km. north of Quebec City, Quebec
Comprised of:	Four basins: 5, 6, 7, 7A Basins used: 6, 7A
Area:	6 (3.9 km) 7A (1.2 km)
Location:	47° 25' N Lat. [illegible]1° 00' W Long.
General aspect:	East
Elevation range:	560 to 1000 m.
Vegetation:	95% commercial forest: Balsam spruce, white birch, white pine.
Soils/geology:	Glacial material ranging between 0 and 18 m.; soils predominantly orthic ferro-humic podzols.

DATA SUMMARY:

	1970				1971			
	#6(mm)		#7a(mm)		#6(mm)		#7a(mm)	
	P	Q	P	Q	P	Q	P	Q
J	44	35	40	21	90	25	86	13
F	156	31	159	14	154	18	145	9
M	97	24	89	12	85	18	76	9
A	93	31	86	16	76	21	82	9
M	130	217	129	292	141	225	140	290
J	144	124	152	142	82	87	78	75
J	257	87	225	82	137	79	129	43
A	126	113	135	83	274	131	260	93
S	170	93	179	91	139	103	137	89
O	135	110	137	106	105	94	105	83
N	134	66	124	50	102	54	99	37
D	37	39	36	20	129	38	125	19
Tot	1523	970	1491	929	1514	893	1462	769

	1972				1973			
	#6(mm)		#7a		#6(mm)		#7A	
	P	Q	P	Q	P	Q	P	Q
J	116	27	109	12	97	63	97	15
F	146	18	128	7	105	42	106	26
M	170	20	157	7	86	46	79	25
A	47	18	43	8	135	110	129	101
M	120	231	124	364	148	312	138	353
J	111	205	122	213	171	196	172	155
J	205	141	215	131	211	186	192	129
A	240	146	251	128	152	131	160	65
S	127	88	135	76	131	115	160	68
O	185	117	186	131	156	115	153	76
N	114	64	110	51	118	68	120	45
D	185	60	168	40	285	70	280	46
Tot	1766	1135	1748	1168	1795	1454	1786	1104

Turkey Lakes Watershed: 60 km. north of Sault Ste. Marie, Ontario

Comprised of: 20 sub-watersheds:
Total area: 11.1 km^2
Basins used: #31 34 39 47 49
Area: Areas (km^2): 31(.06) 34(.63) 39(.17) 47(.04) 49(.19)

Location: 47° 03' N Lat. 84° 25' W Long.

General Aspect: North
Elevation range: 244 to 644 m.a.s.l.
Vegetation: Great Lakes-St. Lawrence Lowland Forest Region (Rowe 1972): sugar maple, yellow birch, white spruce, white pine.
Soils/geology: Stony, basal till underlies surficial till; soils predominantly Orthic Humo-Ferric Podzols.

DATA SUMMARY I: Entire Basin

	1981		1982		1983		1984	
	P	Q	P	Q	P	Q	P	Q
J	18	19	71	24	44	55	125	26
F	58	20	47	16	31	17	37	25
M	94	72	92	18	43	66	41	29
A	75	270	88	175	95	153	48	201
M	71	73	19	218	140	124	52	91
J	306	168	51	15	50	72	106	19
J	32	32	74	9	89	13	113	19
A	92	13	94	5	75	7	95	14
S	52	6	139	41	160	12	175	34
O	136	26	170	165	161	75	149	81
N	45	30	73	129	121	73	144	150
D	85	24	121	85	141	54	143	96
Tot	1064	753	1039	900	1150	721	1228	785

Turkey Lakes Watershed

DATA SUMMARY II: Individual Basin #31

	1981		1982		1983		1984	
	P	Q	P	Q	P	Q	P	Q
J	18	0	71	8	44	20	125	7
F	58	0	47	2	31	5	37	16
M	94	0	92	23	43	41	41	13
A	75	0	88	157	95	100	48	135
M	71	33	19	78	140	54	52	39
J	306	146	51	4	50	23	106	8
J	32	5	74	3	89	4	113	7
A	92	3	94	1	75	2	95	3
S	52	0	139	21	160	5	175	22
O	136	17	170	99	161	39	149	46
N	45	13	73	70	121	42	144	79
D	85	6	121	46	141	13	143	45
TOT	1064	223	1039	512	1150	348	1228	420

Turkey Lakes Watershed

DATA SUMMARY III: Individual Basin #34

	P	Q	P	Q	P	Q	P	Q
J	18	5	71	42	44	41	125	19
F	58	24	47	50	31	28	37	40
M	94	112	92	54	43	85	41	27
A	75	189	88	279	95	156	48	203
M	71	51	19	143	140	96	52	70
J	306	147	51	10	50	46	106	17
J	32	25	74	6	89	11	113	39
A	92	9	94	3	75	4	95	9
S	52	2	139	42	160	9	175	37
O	136	22	170	135	161	69	149	79
N	45	24	73	94	121	75	144	107
D	85	22	121	79	141	35	143	86
TOT	1064	632	1039	937	1150	655	1228	733

DATA SUMMARY IV: Individual Basin #39

	1981		1982		1983		1984	
	P	Q	P	Q	P	Q	P	Q
J	18	0	71	0	44	0	125	5
F	58	0	47	0	31	0	37	6
N	94	0	92	0	43	65	41	9
A	75	235	88	140	95	142	48	204
M	71	48	19	195	140	109	52	61
J	306	144	51	2	50	37	106	4
J	32	16	74	0	89	1	113	3
A	92	2	94	0	75	1	95	1
S	52	0	139	21	160	1	175	28
O	136	10	170	124	161	62	149	74
N	45	27	73	82	121	50	144	100
D	85	0	121	57	141	17	143	42
TOT	1064	482	1039	621	1150	485	1228	537

Turkey Lakes Watershed

DATA SUMMARY V: Individual basin #47

	1981		1982		1983		1984	
	P	Q	P	Q	P	Q	P	Q
J	18	0	71	6	44	9	125	9
F	58	0	47	2	31	2	37	14
M	94	0	92	9	43	40	41	8
A	75	0	88	151	95	148	48	187
M	71	57	19	158	140	98	52	38
J	306	145	51	1	50	17	106	6
J	32	7	74	5	89	2	113	9
A	92	7	94	1	75	0	95	3
S	52	0	139	37	160	8	175	49
O	136	42	170	99	161	62	149	71
N	45	33	73	72	121	36	144	80
D	85	10	121	49	141	8	143	27
TOT	1064	301	1039	590	1150	430	1228	501

Turkey Lakes Watershed

DATA SUMMARY VI: Individual Basin #49

	1981		1982		1983		1984	
	P	Q	P	Q	P	Q	P	Q
J	18	6	71	10	44	18	125	12
F	58	0	47	9	31	10	37	23
M	94	0	92	29	43	51	41	20
A	75	190	88	224	95	145	48	188
M	71	55	19	151	140	111	52	52
J	306	108	51	6	50	28	106	14
J	32	7	74	5	89	6	113	17
A	92	21	94	4	75	43	95	12
S	52	1	139	54	160	36	175	66
O	136	43	170	99	161	76	149	72
N	45	32	73	124	121	46	144	95
D	85	12	121	53	141	14	143	48
TOT	1064	475	1039	768	1150	584	1228	619

APPENDIX TWO:
(Actual (A) and Predicted (P) Streamflow Summary)

PROV	WATERSHED	YEAR	STREAMFLOW(P) (mm)	STREAMFLOW(A) (mm)
One	Nashwaak (N.B.)			
	Hayden Brook			
		1975	597	649
		1976	910	1140
		1977	726	884
	Narrows Mtn.			
		1975	597	677
		1976	910	1038
		1977	736	791
One	Bassin des Eaux Volees (Que.)			
	Bassin 6	1970	1036	970
		1971	1026	893
		1972	1277	1135
		1973	1307	1454
	Bassin 7a	1970	950	929
		1971	918	769
		1972	1207	1168
		1973	1242	1104
One	Turkey Lakes (Ont.)			
	(entire)	1981	618	753
	(aspects-	1982	596	900
	unified)	1983	705	721
		1984	784	785
	(entire)	1981	552	753
	(aspects-	1982	545	900
	1/3-2/3 div.)	1983	581	721
		1984	718	785
	Sub-basin 31	1981	520	223
	Sub-basin 34	1981	574	632
	Sub-basin 39	1981	588	482
	Sub-basin 47	1981	574	301
	Sub-basin 49	1981	574	475
	S.B. 31	1982	496	511
	S.B. 34	1982	549	937
	S.B. 39	1982	565	621
	S.B. 47	1982	549	590
	S.B. 49	1982	549	768

S.B. 31	1983	607	348
S.B. 34	1983	661	655
S.B. 39	1983	675	485
S.B. 47	1983	661	430
S.B. 49	1983	661	584
S.B. 31	1984	686	420
S.B. 34	1984	740	733
S.B. 39	1984	754	537
S.B. 47	1984	740	501
S.B. 49	1984	740	619

FOUR

Marmot Ck.(AB)			
(AB Env.Data)	1974	541	498
	1975	425	343
	1976	335	470
	1977	327	285
	1978	367	424
	1979	216	262
	1980	537	415
(Marmot Data)	1978	339	424
	1979	197	261
	1980	475	415
(Confluence 5)	1978	102	424
	1979	82	261
	1980	341	415
Spring Ck.(AB)	1980	79	41
	1981	-99	38
	1982	228	51
TriCks(AB)	1974	128	259
	1975	105	125
(Four)	1976	434	189
	1974	227	259
(Six)	1975	217	125
	1976	512	188
As Prov. 4			
(snow course/	1974	407	259
rain g./sacr.)	1975	167	124
	1976	535	189

As Prov. 6 (snow course/ rain g./sacr.)	1974	471	259
	1975	269	125
	1976	581	188
(Indiv.Basins)			
(Deerlick)	1974	178	313
	1975	140	153
	1976	353	223
(Eunice)	1974	237	212
	1975	194	107
	1976	370	150
(Wampus)	1974	193	259
	1975	158	124
	1976	363	189

FIVE			
Watershed C (BC)			
	1980	2053	2251
	1981	2092	2170
	1982	2070	2132
	1983	2102	2135
Jamieson Ck. (BC)			
(UBC Report Ppt.Data)	1975	3303	3709
	1976	2434	2880
	1977	3048	2517
(6 Stn. Ppt. Avg.)	1975	3571	3709
	1976	2477	2880
	1977	3296	2517
Carnation Ck. (B.C.)			
(Stn A)	1974	2786	3499
	1975	2725	3460
	1976	2134	2394
(CarnCk.CDF)	1972	2377	3011
	1973	2477	2738
	1976	2090	2394

SIX			
Camp Creek (BC)			
	1972	364	331
	1973	348	73
	1975	471	158
	1976	226	155
Testalinden Ck. (B.C.)	1972	143	125
	1973	191	27
	1976	87	47
	1976	76	483
	1977	36	222

APPENDIX 3:

Fig. 3 Predicted Versus Actual Streamflow Region: 1

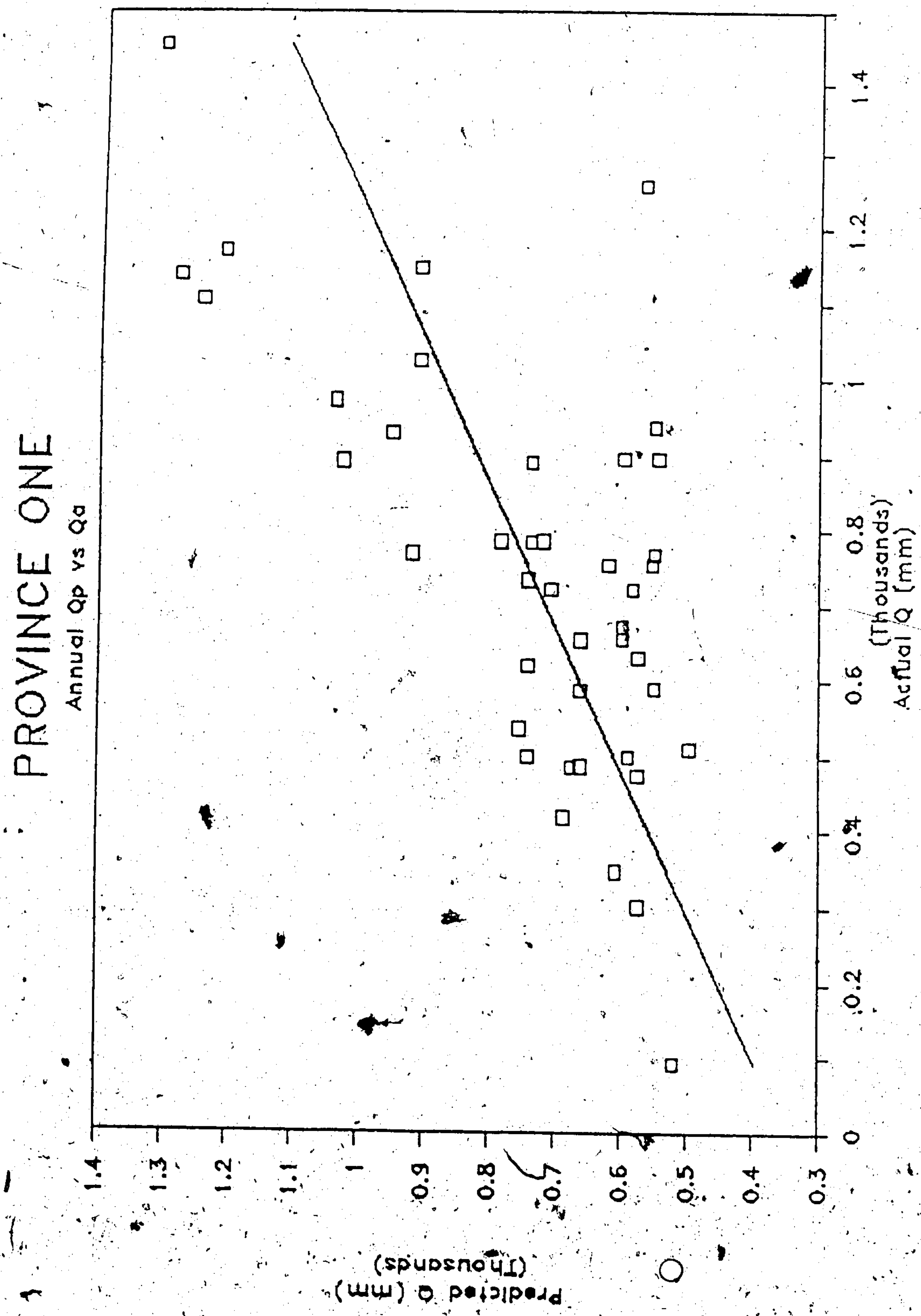


Fig. 4 Predicted versus Actual Streamflow Region: 4

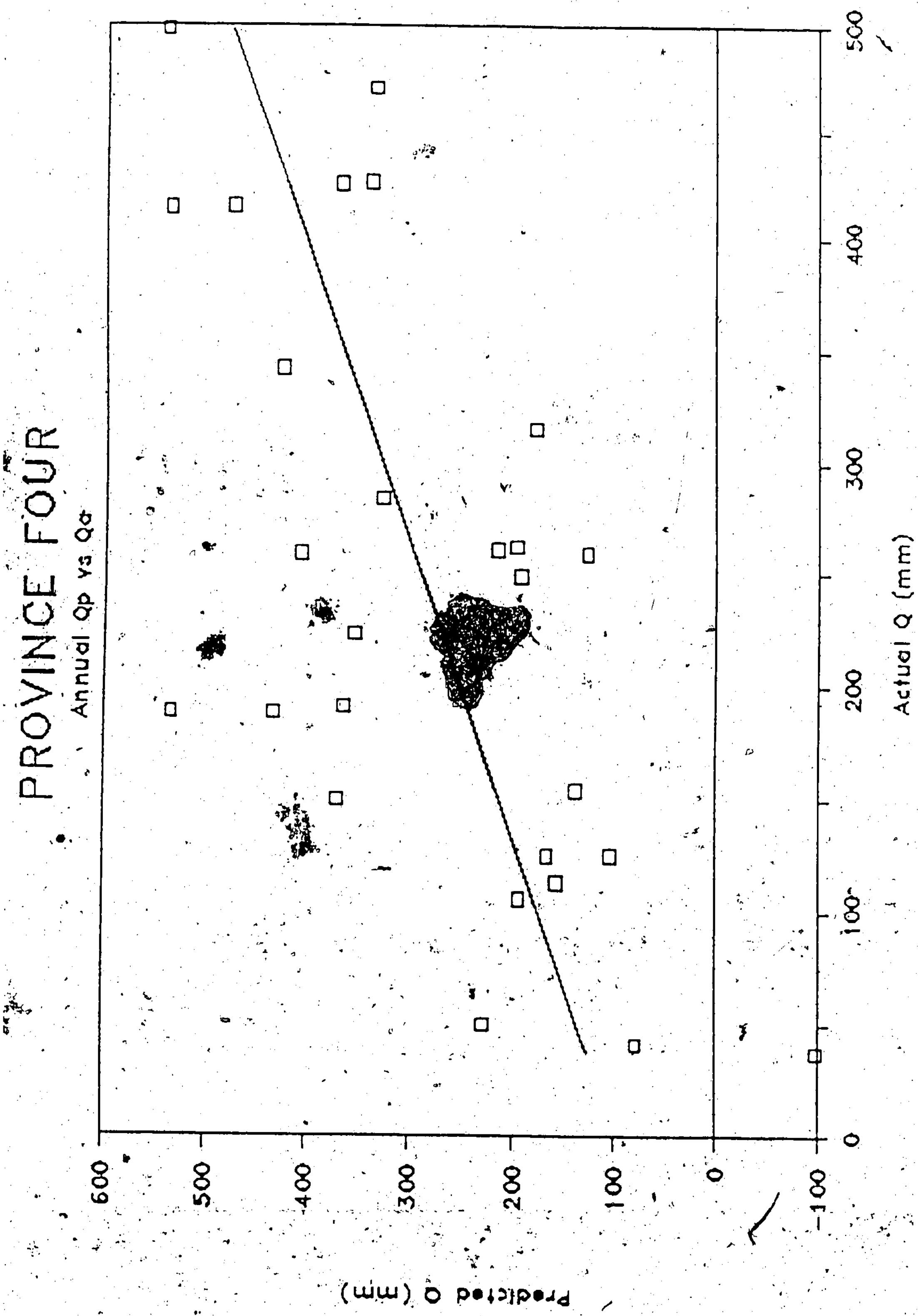


Fig. 5 Predicted versus Actual Streamflow Region: 5

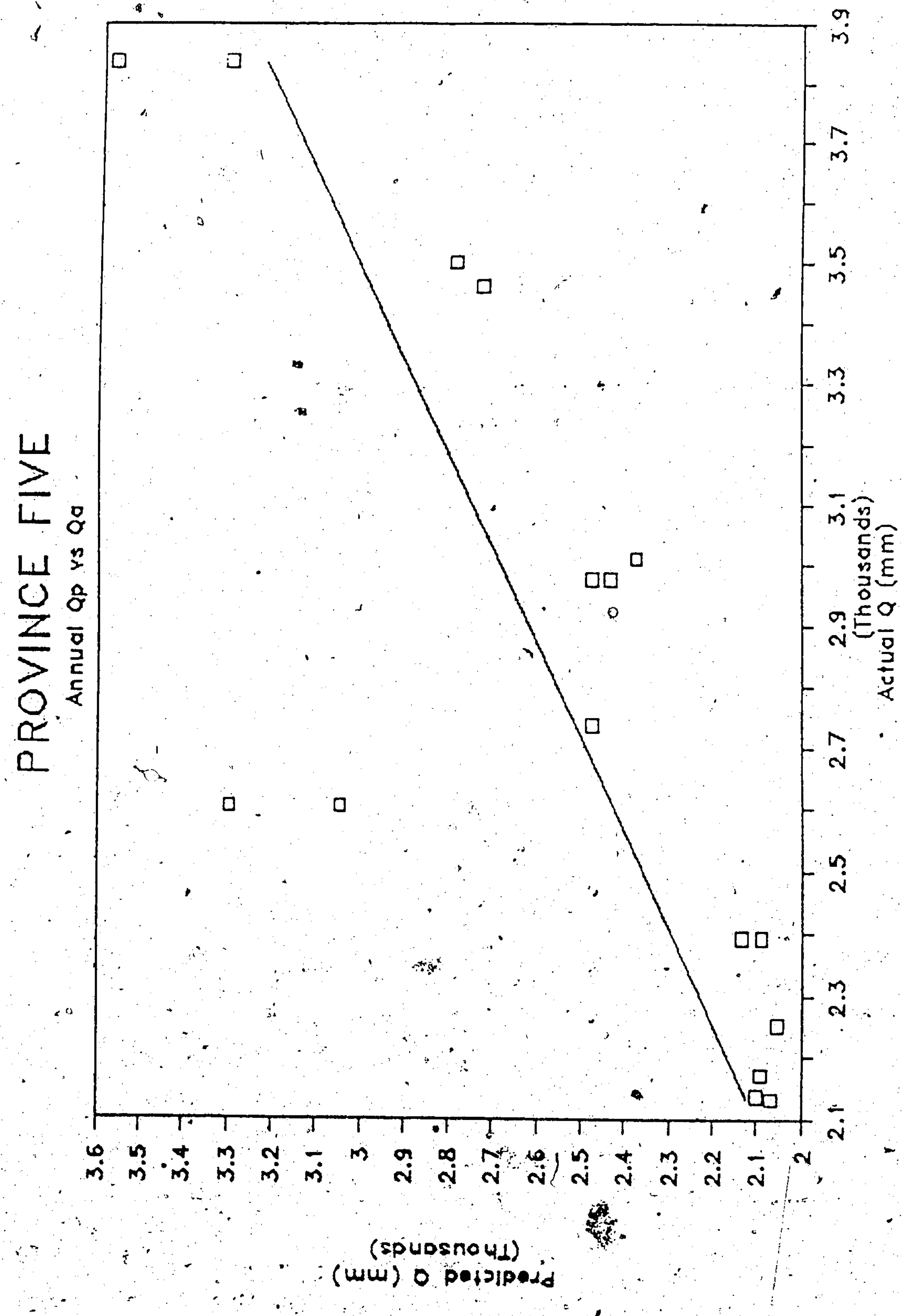
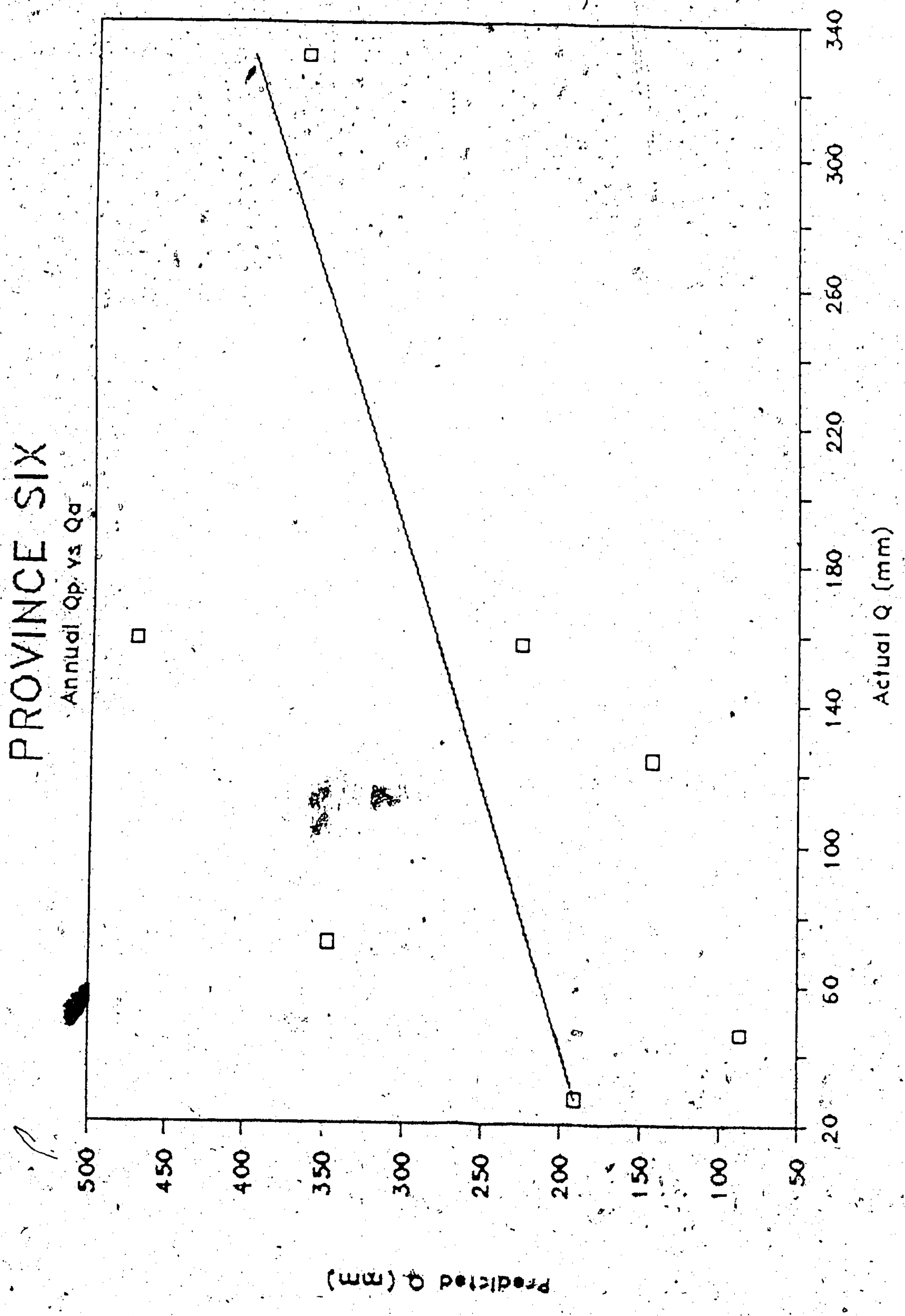


Fig. 6 Predicted versus Actual Streamflow Region: 6



APPENDIX 4: Ratios of Predicted to Actual Streamflow Ratios of Qp/Qa

Legend:

100(DIFFERENCE) = 1-(Qp/Qa)

VERY GOOD: DIFFERENCE $\leq$ 10%
GOOD: DIFFERENCE = 10 - 20%
FAIR: DIFFERENCE = 20 - 30%
POOR: DIFFERENCE $\geq$ 30%

PROV	BASIN	RATIO Qp/Qa	PRECISION RANKING
ONE	Nashwaak, N.B.		
	Hayden Brook	[illegible]84	GOOD
	Narrows Mtn.	0.91	VERY GOOD
	BASIN MEAN	0.88	GOOD
	Bassin des Eaux Volees,Que.		
	Bassin 6	1.06	VERY GOOD
	Bassin 7a	1.09	VERY GOOD
	BASIN MEAN	1.08	VERY GOOD
	Turkey Lakes,Ont.		
	Entire(Aspects unified)	0.87	GOOD
	Entire(Aspects divided)	0.77	FAIR
	Individual basins:		
	#31	1.23	FAIR
	#34	0.88	GOOD
	#39	1.11	GOOD
	#47	1.42	POOR
	#49	1.06	VERY GOOD
	BASIN MEAN	1.13	GOOD

FOUR	<u>Marmot, AB</u>		
	Alta.Env.Meth.	1.03	VERY GOOD
	4 Stn.Avg.	0.90	VERY GOOD
	BASIN MEAN	0.99	VERY GOOD
	<u>TriCreeks, AB</u>		
	Entire(Sacram)	1.21	GOOD
	Entire(Mixed)	1.92	GOOD
	Indiv.Basins		
	Deerlick	1.02	VERY GOOD
	Eunice	1.81	POOR
	Wampus	1.36	POOR
	BASIN MEAN	1.46	POOR
FIVE	<u>Carnation Ck BC</u>		
	Stn. A	0.93	GOOD
	CDF	0.86	GOOD
	BASIN MEAN	0.84	GOOD
	<u>Jamieson Ck BC</u>		
	UBC Report	0.98	VERY GOOD
	6 Stn. Avg.	1.04	VERY GOOD
	BASIN MEAN	0.98	VERY GOOD
	<u>Watershed C</u>		
	Entire	0.96	VERY GOOD
	BASIN MEAN	0.96	VERY GOOD
SIX	<u>Camp Ck BC</u>		
	Entire	2.59	POOR
	BASIN MEAN	2.59	POOR
	<u>Trapping Ck BC</u>		
	Entire	0.61	POOR
	BASIN MEAN	0.61	POOR
	<u>Testal Ck BC</u>		
	Entire	3.37	POOR
	BASIN MEAN	3.37	POOR