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Development of a toolbox for assessment of aquatic habitat impacted by peat harvesting

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Development of a toolbox for assessment of aquatic habitat impacted by peat harvesting

By

André St-Hilaire
Simon C. Courtenay
Andrew D. Boghen
Bernard Bobée
Vladimir Koutitonsky

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PROJECT TEAM

Environmental Sciences Research Centre:

Andrew Boghen, Ph.D.	Director
Christina Calder, B.Sc.	Research assistant

Fisheries and Oceans Canada:

Simon Courtenay, Ph.D.	Research Scientist

Université du Québec:

Bernard Bobée, Ph.D.	Director, Chair in Statistical Hydrology, INRS-Eau
André St-Hilaire, Ph.D.	Research Associate, Chair in Statistical Hydrology, INRS-Eau
Vladimir Koutitonsky, Ph.D.	Professor, ISMER

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1.0 INTRODUCTION

Peat harvesting is a very important industry in New Brunswick, valued at 64 million dollars in 1996 (J. Thibault, DNRE, pers. comm.). The usual methods used to harvest peat require a significant lowering of the water table, which is achieved by digging a network of ditches, thereby draining the bog and allowing the peat to dry. The nearby coastal water, estuaries or rivers are often used as recipients for the drainage water.

In order to avoid the release of high concentrations of peat fibres downstream of the harvested bogs in estuarine and coastal habitats, settling basins have been required at the downstream end of the network of drainage ditches. A number of studies (e.g. St-Hilaire and Bourgeois 2000, Ouellette et al. 1997) are currently underway to attempt to confirm that these settling basins are efficient and that the potential adverse impact of peat particles in coastal and estuarine environment is minimized.

As the peat industry continues to develop, habitat managers will be looking for efficient monitoring tools and tested methodologies to assess potential impacts. The objective of this report is to describe some useful monitoring tools pertaining to water quantity (i.e. flows) and water quality (i.e. suspended sediment concentrations).

These methods are implemented in a case study: A portion of a harvested bog, the St-Charles Plain, is draining into Mill Creek, which is a tributary of the Richibucto Estuary, located in southeastern New Brunswick. The Richibucto River and estuary has a drainage basin covering 1088.5 km^2 (Montreal Engineering Company 1969). Several rivers feed the shallow Richibucto Harbour, including the main Richibucto River, the St-Nicholas River and the St-Charles River via the Northwest Branch (Figure 1). Mill Creek, a small tributary of the Richibucto River, is located upstream of Rexton (Figure 1). It drains an area of 30 km^2, approximately half of which is located in the St-Charles Plain.

Over the years, Mill Creek has received large quantities of peat moss draining from an unnamed brook on its north shore, which will be called Malpec Brook in this study. The peat operation has been equipped with settling basins since 1994. Prior to this, large volumes of peat fibre drained into Mill Creek and settled near its confluence with Malpec Brook (Brylinsky, 1995).

The Richibucto Environment and Resource Enhancement Project (REREP) was initiated in 1995 by a number of local stakeholders, scientists and government agencies.

One of the objectives of REREP is to acquire essential scientific information to evaluate the health of the ecosystem. REREP has been involved in monitoring the recovery of the ecosystem in Mill Creek since 1996, two years after settling basins were installed.

The experience gathered through this monitoring study provides a strong basis from which habitat management tools related to potential impacts of peat harvesting can be developed and tested.

The methods described herein are divided in two categories :

- A methodology for high frequency monitoring of turbidity
- A basic method for the hydrological characterization of the receiving streams , including the transfer of information from gauged rivers.

2.0 METHODS

2.1 TURBIDITY MEASUREMENTS

Current regulations in New Brunswick require that peat harvesters measure suspended solid concentrations in their settling basins periodically by collecting water samples and having them subsequently analysed in independent laboratories. Suspended solids filtered from a known volume of water are dried and weighed to calculate suspended sediment concentrations. These spot measurements are insufficient to provide a detailed evaluation of sediment output downstream of the drainage network as hydrological conditions change throughout the year.

For a more complete understanding of suspended sediment dynamics, high frequency sampling is required. One method used to acquire high frequency observations is to measure suspended sediments indirectly, using turbidity as indicator. Turbidity can be defined as the optical property imparted to water by suspended sediments, as light is scattered and absorbed by the suspended particles rather than being transmitted in a straight beam (Wilber 1983).

Many different measuring devices exist to monitor turbidity, all of which rely on optical technology. The Optical Back Scatterometer (OBS) is one such instrument. OBS sensors measure turbidity by emitting an infrared (IR) beam, and detecting IR radiation scattered from suspended matter. Like other optical turbidity monitors, the response of OBS sensors depends on the size, composition, and shape of suspended particles (D&A Instruments, 2000). The gain (ratio of output signal to input signal) can vary widely for natural sediments. The concentration of sediment required to produce a particular OBS output can vary by a factor of about 100 depending on sediment type (D&A Instruments, 2000). The output signal of an OBS is usually a DC voltage, which is often translated in Nephelometric Turbidity Units (NTU) via a calibration curve provided by the manufacturer.

2.1.1 Calibration of OBS

The calibration provided by the manufacturer is often insufficient. The variability in OBS response requires that *in situ* calibration be performed. It also means that the resulting calibration curves are site specific. A calibration curve is established by taking a number of grab samples of water with suspended sediment concentrations covering the range of concentrations observed in the field. Once filtered and weighed, the measured suspended sediment concentrations from the samples are compared with the turbidity measurements recorded by the OBS at the time of sampling.

If instruments are deployed for a very short time, which may not be sufficient to collect a large numbers of suspended sediment samples for calibration, a laboratory calibration can be performed. The grab samples taken in the field are then supplemented by a number of samples designed in the lab, with *in situ* water and *in situ* sediments. In this case, calibration curves will be established *a posteriori*, and associated measurements of turbidity will be done in the lab once the OBS is recovered.

The main steps for calibration can be summarized as follows :

- Deploy OBS in the field
- Take as many 1L samples as possible, at the OBS sampling station, at the depth of deployment of the OBS, to cover the full range of turbidity encountered in the field. Water samples should be taken in duplicate.
- If grab samples are insufficient, supplement by designing samples using *in situ* water and sediments. Use sediments with similar granulometry to those encountered in the field, e.g. peat moss in this case.
- Samples must be filtered using 8 μm Millipore filters. Filtrate must be dried at constant temperature (75 °C, generally for 24 hours) and weighed. Divide the grab sample in at least two sub samples to make replicate measurements. If suspended concentrations are very high (i.e. > 500 mg/L), which often require longer filtering time, the number of replicates can be increased if sample volumes are decreased.
- A larger volume of water (i.e. > 2 L) is required for samples prepared in the laboratory. When turbidity measurements are made in a container, a sufficiently large volume of water is required to avoid interference of the emitted IR with the sides of the container. Lab samples must be constantly stirred to keep sediments in suspension, while turbidity is measured with the OBS.

- Calibration curves are established by regression between SS (mg/L) measurements and associated OBS measurements (V). This regression is often non-linear, but both linear and non-linear relationships can be tested for goodness of fit. As an example, equations 1 to 3 show some of the regressions used by LeBlanc et al. (2000) for the calibration of 3 OBS deployed in the Petitcodiac River (New Brunswick).

$$SS_{1098} = 3.0 * 10^{-5}. * NTU^{1.55} \quad (1)$$

$$SS_{1100} = 6.6 * 10^{-6} * NTU^{2} + 0.001 * NTU + 0.238 \quad (2)$$

$$SS_{1122} = 3 * 10^{-7} NTU^{2} + 0.0015 * NTU \quad (3)$$

Where :

SS : Suspended sediment concentration (g/L);
NTU : Turbidity measurement (NTU)

2.1.2 Field deployment of OBS

When deploying OBS sensors, care must be taken to have the sensor standing vertically in the water column, with the emitter pointing downstream. Most OBS found on the market are not self powered. A DC power supply (usually between 9 V and 15 V) is therefore required. Sensors produce a voltage as an output, which must be recorded by a data logger. Sampling frequency is usually programmed via the datalogger, and depends on the project, or on the limitations imposed by the size of the memory of the data logger. It is recommended to download data as often as possible (e.g. weekly).

2.2 HYDROLOGICAL ANALYSIS

2.2.1 Regional analysis

Turbidity measurements in the field are more useful if they can be associated with flow measurements. It is important to know, for instance, if high SS concentrations are associated with increased discharge after a rain event.

In most cases, habitat managers are confronted with a lack of basic hydrological information (i.e. there are very few or no flow measurements) about the river or stream into which the harvested bog is drained.

To alleviate this problem, a standard hydrological technique consists of transferring information from gauged rivers to ungauged systems.

In many cases it is of great interest to calculate the magnitude of high or low flow events with a certain return period (quantiles). This information enables the manager to compare daily flow measurements with extreme (high or low) events in order to evaluate the severity of current hydrological conditions in comparison with statistical information.

Such frequency analyses can be performed with data from gauged basins in the area. Flood and low flow quantiles are calculated for a number of stations with similar hydrological and morphometric characteristics. A regression equation can then be found between quantiles and the drainage area for a given region:

$$\log(Q_T) = a \log A + b \qquad (5)$$

where:

Q_T = Discharge with a return period of T;
A = Drainage basin area;
a,b = regression coefficient and constant.

El Jabi et al. (1994) have developed regression equations such as equation 5 for flood and low flow quantiles using data from 23 small (< 200 km^2) drainage basins in New Brunswick. These equations have been reproduced in the Results Section, and applied to the Richibucto sub-basins.

For a complete hydrological and suspended sediment budget, daily discharge measurements or estimates are often required. Since, in most cases, the water body of interest is not gauged, daily flows can be extrapolated from a nearby drainage basin using the ratio of drainage areas :

$$Q_u = Q_g \frac{A_u}{A_g} \qquad (6)$$

where:

Q_g, Q_u = daily discharge for the gauged and ungauged basins respectively (m^3/s);
A_g, A_u = Drainage basin area for the gauged and ungauged basins respectively (km^2).

2.2.2 Flood and low flow analyses

Prior to establishing a regression curve such as equation 5, frequency analyses must be performed. Flood and low flow analyses are done separately for individual gauged rivers. For this project and the case study of the Richibucto area, quantiles for flood and low flows were calculated with daily discharge from Environment Canada gauging station 01BS001 (Coal Branch at Beersville), which is the only gauging station located in the Richibucto drainage basin. The gauged area at station 01BS001 is 166 km^2, approximately 15% of the surface of the entire Richibucto watershed. The results of the frequency analyses can be compared with the regression results for that station.

Preliminary statistical tests must be performed on the time series of annual maximum and minimum prior to performing a frequency analysis. In our case study, The Wald-Wolofowitz test (Wald and Wolfowitz, 1943), was performed to test the independence of observations in the time series from the Coal Branch station. The Kendall test (Kendall, 1975) was used to verify stationarity (i.e. no trend in the time series). Associated p-values (p) were calculated and used to accept or reject the null hypotheses at a level of 5% ($\alpha = 0.05$)

Annual floods (i.e. maximum daily discharge) were identified for each year included in the time series (1965-1998). Different distribution functions were fitted to these data to determine the frequency of discharge events.

For low flows, the duration of an event is of great interest. Low flow analyses were therefore not limited to the annual minimum flow, but also included annual minima with duration greater than one day. This was done by calculating moving averages of daily flows for periods equal to the duration of interest. For our case study, we looked at low flow events with duration of 1 day, 3 days and 7 days by calculating moving averages (three days and seven days) on the time series and selecting the annual minima for each year.

Caissie (2000) used four (4) distribution functions to fit flood data from a station in southeastern New Brunswick (Environment Canada station 01BU002, Petitcodiac River): The Three Parameter Lognormal (LN3), the Two Parameter Lognormal (LN2), the Type 1 Extremal (Gumbel), and the Log-Pearson Type III (LP3) distribution functions. El Jabi et al.

(1994) used two different distribution functions (LP3 and LN2) for their regional study of floods in New Brunswick. In our case study, the same distribution functions used by Caissie (2000) have been tested. Two methods were used to fit the parameters of the distribution functions: the method of moments, and the method of maximum likelihood. A first crude estimation of the goodness of fit of the distributions was done using a Chi-squared test and complemented by visual examination.

It is sometimes difficult to select visually which of the distribution functions is best to establish quantiles. An objective quantitative statistical criterion, the Akaïke criterion (Akaïke 1978) was used in conjunction with a visual appreciation of the quantiles to select the most adequate distribution functions for floods and low flows.

For low flow frequency analysis, Caissie (2000) and El jabi et al. (1994) used the type III Extremal (T3E) distribution function. Many other distributions can be used for low flow analyses (Abi-zeid and Bobée, 1999). In addition, to the T3E distribution, we tested the LN3, LP3 , Halphen type B and gamma distributions on the low flow data from station 01BS001 (Coal Branch).

The frequency analyses and most statistical tests were done using the HYFRAN software (Bobée et al. 1999) developed at INRS-EAU.

3.0 RESULTS OF THE CASE STUDY

3.1 Basic Hydrological statistics at the reference station

From the time series of daily flows, the mean annual discharge at the Coal Branch hydrometric station as well as maximum annual flow and mean minimum annual flows for various duration were calculated (Table 1). The mean daily flow was found to be 3.65 m^3/s at station 01BS001 (1965-1998). The maximum recorded daily flow for the same period was 83.5 m^3/s, while the minimum was 0.065 m^3/s.

These statistics could be transferred to Malpec Brook using equation 6. In this specific case, however, it is recommended to wait until some discharge measurements are taken in Malpec Brook. Malpec Brook has a very small drainage area (4 km^2), and drains a harvested peat bog, which likely has a very different hydrological response than the largely forested watershed of the Coal Branch sub basin.

3.2. Flood and low flow frequency analysis

Prior to performing flood frequency analyses on data from station 01BS001, a Kendall test for stationarity was performed on annual maximum daily flow from Coal Branch data, which revealed that there is no significant trend in the maximum annual flow time series of station 01BS001 ($|K| = 0.667$, $p = 0.51$). Flood data were also found to be independent using the Wald-Wolfowitz test ($|U|=0.441$, $p=0.659$).

As described in section 2, flood data (annual maximum daily flows) were fitted with four different distribution functions (LN2, LN3, Gumbel, LP3) using the method of maximum likelihood (Table 2). A Chi-square test was performed for each distribution function as a first crude approach to verify if data were adequately represented by the function. Only two of the four distributions were appropriate (LN2 and Gumbel, Table 2). The Gumbel and LN2 distributions were compared visually (Figure 2) and using the Akaïke criterion (AIC). A lower value of AIC is found for a distribution that is more suitable for the sample (Akaïke, 1978). The AIC for the Gumbel and LN2 distributions were almost identical (281.9 and 281.7 respectively). The plots of observations and distributions confirm that any of the two distributions yield similar results (Figure 2).

Floods with return periods of 2, 5, 10, 20, 50 and 100 years were therefore calculated using the Gumbel and LN2 distributions from maximum annual discharge recorded at station 01BS001 (Table 3). The 100-year flood estimation is also given, but should be interpreted cautiously. Only 35 years of data were available from the Coal Branch station. Such a short time series does not allow for an accurate extrapolation to a return period of 100 years. A flood with a return period of two years was estimated to have a value of 43.7 m^3/s, while a 50 year flood was calculated to be between 86.8 m^3/s (LN2) and 89.3 m^3/s (Gumbel).

Low flow analyses were done for three different event durations: one day, three days and seven days. As for flood data, time series of annual low flows were tested for independence using the Wald-Wolfowitz test and for stationarity using the Kendall test. All three time series are made of independent observations, and showed no temporal trends (Table 4). Chi squared tests were also performed for the distributions fitted to the data (T3E, P3, Gamma, LN3 and Halphen type B). All distributions were adequate for the three samples, except for the Halphen type B, which was rejected as a distribution function for the 1-day and 7-day low flows (Table 5).

The same criterion used for floods (AIC) was used to select the best distribution to calculate low flow quantiles for each duration (Table 6). For all three time series, the Type 3 Extreme (T3E) and Gamma distributions are characterised by lower AIC than the other three (LN3 Halphen type B and P3). Low flows with return periods of 2 years, 5 years, 10 years and 20 years were calculated using the T3E and Gamma distributions (Table 7). A one-day low flow with a return period of two years was estimated to be 0.22 m^3/s (T3E, upper confidence interval =0.25 m^3/s, lower confidence interval =0.19 m^3/s), while a 7-day low flow with the same return period was estimated to be 0.25 m^3/s (T3E, upper confidence interval = 0.28 m^3/s, lower confidence interval =0.22 m^3/s).

3.3 Transposition of data to ungauged basins

Linear regressions (equation 5) using the drainage area as an independent variable were fitted to flood and low flow quantiles estimated by El Jabi et al. (1994) on 23 New Brunswick drainage basins with area < 200 km^2. Figures 3 to 12 show the regression lines for each quantile. The regression coefficients, constants and coefficient of determinations are reported in Table 8. R^2 values varied between 0.76 and 0.88. Lower coefficients of determination ($0.76 < R^2 < 0.79$) were found for low flow regressions, except for 7Q10 ($R^2 = 0.83$).

The regression equations (Table 8) were used to calculate quantiles for Malpec Brook, as well as six other sub-basins of the Richibucto watershed, which are of interest to REREP stakeholders. Malpec Brook is the smallest of the sub basins for which the calculations were done (4 km^2). A two-year flood was estimated at 1.16 m^3/s, while a 100-year flood was estimated at 3.41 m^3/s. A low flow with a one-day duration and return period of two years (1Q2) was estimated to be 9 L/s for Malpec Brook. A low flow with the same return period, but with duration of 7 days was estimated to be 14 L/s (Table 9).

Results of the frequency analysis for station 01BS001 (Table 3) can be compared with the estimated quantiles by the regression (Table 9). This comparison shows that the regression provided estimates of the same order of magnitude as the statistical quantiles, but tended to over-estimate low flows, and under-estimate floods. For instance, a two-year flood was estimated at 43.7 m^3/s using the frequency analysis, but had a value of 40.98 m^3/s when computed using the regression (Figure 13). The confidence intervals for regression estimates are systematically larger than the intervals computed for the frequency analyses (Figure 13). A 2-year low flow with a 7day duration (7Q2) was estimated by the regression to be 0.35 m^3/s at station 01BS001, but was only 0.24 m^3/s, according to Table 3.

5.0 DISCUSSION AND CONCLUSION

This report is a first step in developing a toolbox for hydrological and suspended sediment monitoring in the drainage network of a harvested peat bog. A methodology aiming at complementing the spot suspended sediment measurements required by current regulation has been described. This methodology has been initiated by REREP, in partnership with Fisheries and Oceans, Canada, Malpec Peat Moss and the New Brunswick Department of Natural Resources in our case study of Malpec Brook. Two OBS were deployed during the last week of March 2001, one in the outflow channel of the settling basins, and a second one further downstream in Malpec Brook. Turbidity measurements are being taken during the spring snowmelt flood, which is often the most important hydrological event of the year in the area. Water samples are taken bi-weekly during field visits at both stations to build a calibration curve for the two OBS. During the OBS deployment period, discharge measurements are taken weekly, to allow for further characterization of the hydrological behaviour of Malpec Brook. With these measurements, a verification of the adequacy of transferring daily flows from the only gauged station in the area (Coal Branch station 01BS001), will be done.

The statistical tools required for the characterisation of extreme hydrological events of the receiving stream or river were described and applied to the case study of Malpec Brook, on the Richibucto drainage basin. Regression equations developed by El Jabi et al. (1994) were used to transfer flood and low flow quantiles to Malpec Brook, as well as to other drainage sub-basins in the Richibucto watershed.

Some differences between quantiles calculated at station 01BS001 and the ones obtained by using equation 5 for the same station were observed. Many sources of error can account for the discrepancy. They include the error inherent to statistical quantile estimation (e.g. difference between observations and distribution functions in Figure 2) and potential errors in the estimation by the regression lines (see Figures 3 to 6). Also, it should be reminded that only one independent variable was used in the regression equations. A multiple regression, using a number of other morphometric parameters (e.g. mean elevation or mean slope of the drainage basin, Gravelius or shape coefficients; Llamas 1985) may explain a greater percentage of the variance for each quantiles.

Further investigations will be required for a complete assessment of the impact of peat on the estuarine habitat in Mill Creek. Core samples were taken at 10 stations along Mill Creek to quantify the amount of peat deposited in the area. Preliminary estimates showed that there might still be peat accumulating in Mill Creek (Ouellette et al 2001). If this is the case, the turbidity at the downstream station should show the presence of high suspended sediments, especially during important hydrological events (snowmelt, heavy rain). It would therefore be important to carry on the turbidity monitoring throughout the summer of 2001.

It would also be important to repeat the core sampling of previous years, at least twice during the summer of 2001. If peat continues to accumulate in Mill Creek, the volume of peat found in the core samples should reflect this increase.

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TABLES

Table 1. Discharge statistics, station 01BS001 (Coal Branch at Beersville)

Daily flows (1965-1998, n= 12540)	**Flow statistics (m^3/s)**
Mean	3.65
Median	1.53
Maximum	83.5
Minimum	0.065
Standard deviation (σ_t)	5.84
Annual floods (1965-1998, n=34)	**Flow statistics (m^3/s)**
Mean	46.0
Median	42.0
Maximum	83.5
Minimum	18.1
Standard deviation (σ_t)	14.7
Annual 1-day low flow (1965-1998, n=34)	**Flow statistics (m^3/s)**
Mean	0.223
Median	0.199
Maximum	0.438
Minimum	0.065
Standard deviation (σ_t)	0.093
Annual 3-day low flow (1965-1998, n=34)	**Flow statistics (m^3/s)**
Mean	0.236
Median	0.207
Maximum	0.483
Minimum	0.074
Standard deviation (σ_t)	0.097
Annual 7-day low flow (1965-1998, n=34)	**Flow statistics (m^3/s)**
Mean	0.255
Median	0.234
Maximum	0.510
Minimum	0.083
Standard deviation (σ_t)	0.102

Table 2. Chi squared (X^2) tests for the four distribution functions tested to fit the flood data from station 01BS001 (Coal Branch).

Distribution	X^2	Degrees of freedom	P value
Log-Normal (LN2)	9.76	4	0.08
3-paramter log Normal (LN3)	9.76	4	0.04
Type 1 Extreme (Gumbel)	9.76	4	0.08
Log-Pearson type III (LP3)	13.06	4	0.01

Table 3. Flood frequency analysis of Coal Branch flow data (station 01BS001)) using different statistical distributions. Floods shown in m^3/s.

Return Period T (years)	Distribution Function	Lower confidence interval (95%) (m^3/s)	Quantile (m^3/s)	Upper confidence interval (95%) (m^3/s)
2	LN2	38.8	43.7	48.6
	Gumbel	38.6	43.7	48.7
5	LN2	50.3	57.9	65.5
	Gumbel	50.4	58.3	66.1
10	LN2	56.8	67.0	77.3
	Gumbel	57.8	68.0	78.1
20	LN2	62.5	75.7	88.8
	Gumbel	64.8	77.2	89.7
50	LN2	69.4	86.8	104.0
	Gumbel	73.8	89.3	105.0
100	LN2	74.3	95.0	116.0
	Gumbel	80.4	98.3	116.0

Table 4. Results of the Wald-Wolfowitz test for independance and the Kendall test for stationarity on annual low flow with different durations at station 01BS001.

Low flow duration	Wald-Wolfowitz		Kendall	
	$\|U\|$	P value	$\|K\|$	P value
1 day	0.23	0.82	0.88	0.38
3 days	0.26	0.80	0.92	0.36
7 days	0.19	0.85	0.71	0.48

Table 5. Chi squared (X^2) tests for the four distribution functions tested to fit the low flow data from station 01BS001 (Coal Branch).

Duration Distribution function	Fitting Method	X^2	Degrees of freedom	P value
1 day low flow				
Type 3 Extremal (T3E)	Method of moments	2.71	4	0.75
3 Parameter log-Normal (LN3)	Maximum likelihood	1.29	4	0.86
Pearson type 3	Maximum likelihood	0.82	4	0.94
Halphen Type B	Maximum likelihood	10.24	4	0.04
Gamma	Maximum likelihood	1.29	5	0.94
3 day low flow				
Type 3 Extremal (T3E)	Method of moments	1.76	4	0.88
3 Parameter log-Normal (LN3)	Maximum likelihood	0.82	4	0.94
Pearson type 3	Maximum likelihood	0.82	4	0.94
Halphen Type B	Maximum likelihood	0.82	4	0.94
Gamma	Maximum likelihood	0.82	5	0.98
7 day low flow				
Type 3 Extremal (T3E)	Method of moments	6.00	4	0.31
3 Parameter log-Normal (LN3)	Maximum likelihood	8.35	4	0.08
Pearson type 3	Maximum likelihood	8.35	4	0.08
Halphen Type B	Maximum likelihood	10.24	4	0.04
Gamma	Maximum likelihood	8.35	5	0.14

Table 6. Akaïke (AIC) criteria for the distributions fitted to the three samples of low flows with different duration

Duration Distribution function	AIC
1 day low flow	
Type 3 Extremal (T3E)	-64.25
3 Parameter log-Normal (LN3)	-62.61
Pearson type 3 (PT3)	-62.80
Gamma	-64.76
Halphen type B	-62.97
Gamma	-64.76
3 day low flow	
Type 3 Extremal (T3E)	-61.42
3 Parameter log-Normal (LN3)	-60.80
Pearson type 3 (PT3)	-60.96
Halphen type B	-60.97
Gamma	-62.96
7 day low flow	
Type 3 Extremal (T3E)	-57.23
3 Parameter log-Normal (LN3)	-56.65
Pearson type 3 (PT3)	-56.78
Gamma	-58.78

Table 7. Low-flow Frequency analysis of Coal Branch (Station 01BS001) using different statistical distributions. Flows shown in m^3/s

Low flow duration (days)	Return period (years)	Distribution function	Lower confidence interval (95%) (m^3/s)	Quantile (m^3/s)	Upper confidence interval (95%) (m^3/s)
1	2	Gamma	0.18	0.21	0.24
		T3E	0.19	0.22	0.25
	5	Gamma	0.12	0.14	0.17
		T3E	0.11	0.14	0.17
	10	Gamma	0.09	0.12	0.14
		TE	0.09	0.11	0.13
	20	Gamma	0.07	0.09	0.12
		T3E	0.05	0.08	0.11
	50	Gama	0.05	0.07	0.10
3		T3E	0.03	0.06	0.08
	2	Gamma	0.19	0.22	0.25
		T3E	0.20	0.23	0.26
	5	Gamma	0.13	0.15	0.18
		T3E	0.12	0.15	0.18
	10	Gamma	0.11	0.13	0.15
		T3E	0.09	0.11	0.14
	20	Gamma	0.08	0.10	0.13
		T3E	0.06	0.09	0.11
	50	Gamma	0.01	0.08	0.11
7		T3E	0.04	0.06	0.08
	2	Gamma	0.21	0.24	0.27
		T3E	0.22	0.25	0.28
	5	Gamma	0.14	0.17	0.20
		T3E	0.13	0.16	0.20
	10	Gamma	0.11	0.14	0.17
		T3E	0.09	0.12	0.15
	20	Gamma	0.08	0.11	0.14
		T3E	0.07	0.10	0.12
	50	Gamma	0.07	0.09	0.12
		T3E	0.04	0.07	0.09

Table 8. Regression coefficients and coefficients of determination caculated for floods with return periods of 2 years (F2), 10 years (F10), 20 years (F20) and 100 years (F100), one day low flows with return periods of 2 years (1Q2), 10 year, (1Q10) and 20 years (1Q20), as well as 7-day low flows with return periods of 2 years (7Q2), 10 year, (7Q10) and 20 years (7Q20).

Quantile	Regression constant (A)	Regression coefficient (B)	Coefficient of determination (R^2)
F2	-1.174	0.956	0.88
F10	-0.509	0.913	0.85
F20	-0.326	0.901	0.83
F100	0.0094	0.88	0.80
1Q2	-6.07	1.002	0.79
1Q10	-6.34	0.904	0.79
1Q20	-6.49	0.896	0.76
7Q2	-5.47	0.865	0.79
7Q10	-6.07	0.891	0.83
7Q20	-6.16	0.879	0.79

Table 9. Flood and low flows (m^3/s) for sub-basins of the Richibucto watershed, evaluated using equation 5 (regression between area and quantiles).

		Flood return periods					
Sub-basin	**Area**	**2**	**10**	**20**	**100**		
Malpec Brook	4.00	1.16	2.13	2.52	3.41		
Gaspereau Creek	30.00	7.98	13.41	15.46	20.13		
Mill Creek	30.00	7.98	13.41	15.46	20.13		
Bass	139.00	2.40	54.39	61.56	77.61		
Station 01BS001	166.00	40.98	63.96	72.23	90.74		
Molus	175.00	43.10	67.12	75.75	95.05		
St.Charles	225.75	54.98	84.69	95.29	118.92		
		Low flow duration and return periods					
Return periods	**Area**	**1Q2**	**1Q10**	**1Q20**	**7Q2**	**7Q10**	**7Q20**
Malpec Brook	4.00	0.009	0.006	0.005	0.014	0.008	0.007
Gaspereau Creek	30.00	0.069	0.038	0.032	0.080	0.048	0.042
Mill Creek	30.00	0.069	0.038	0.032	0.080	0.048	0.042
Bass	139.00	0.324	0.153	0.126	0.301	0.188	0.162
Station 01BS001	166.00	0.387	0.179	0.148	0.351	0.220	0.189
Molus	175.00	0.408	0.188	0.155	0.367	0.230	0.199
St.Charles	225.75	0.527	0.237	0.195	0.457	0.289	0.249

FIGURES

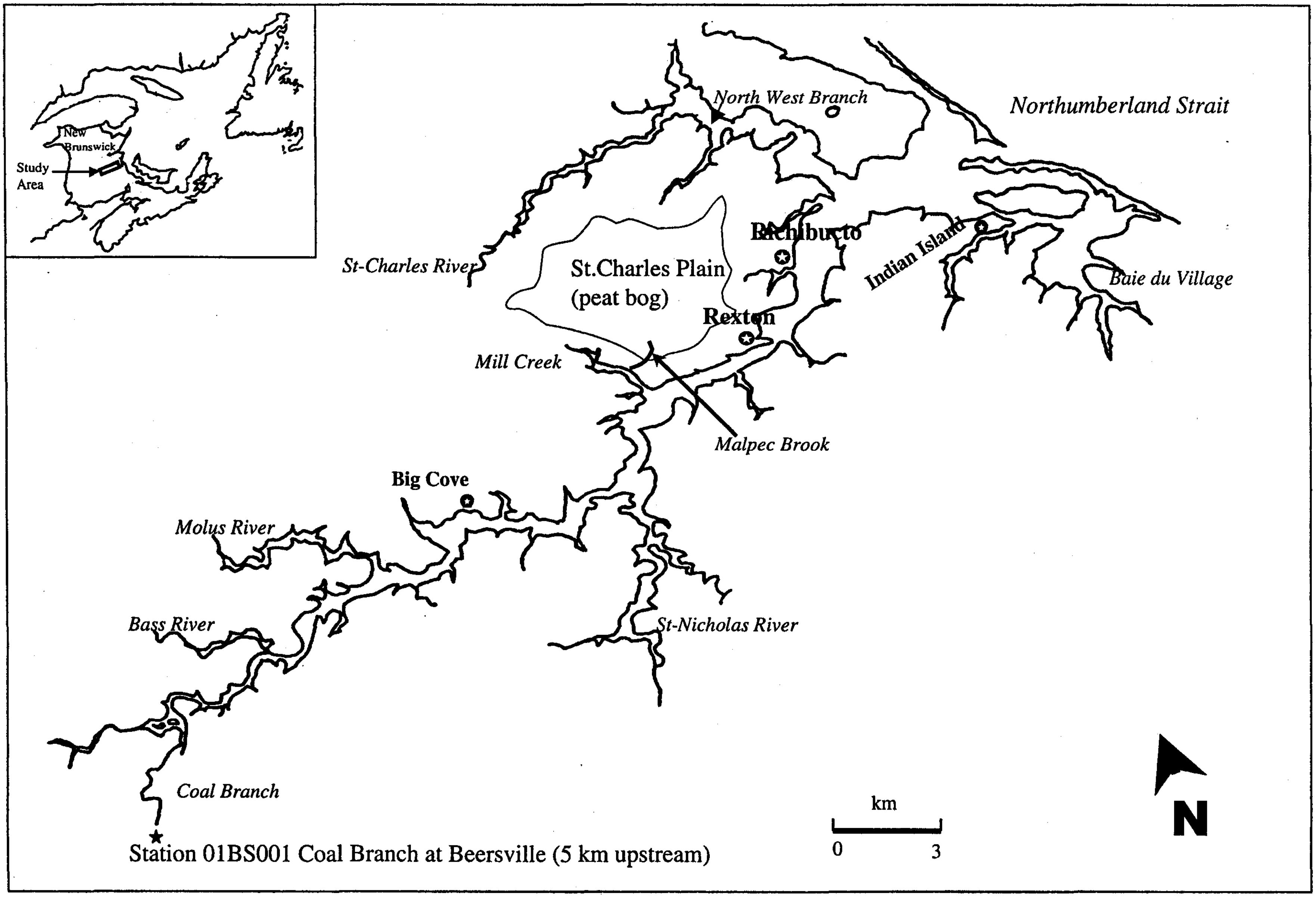

Figure 1. Richibucto Estuary, showing the location of Malpec Brook and Mill Creek

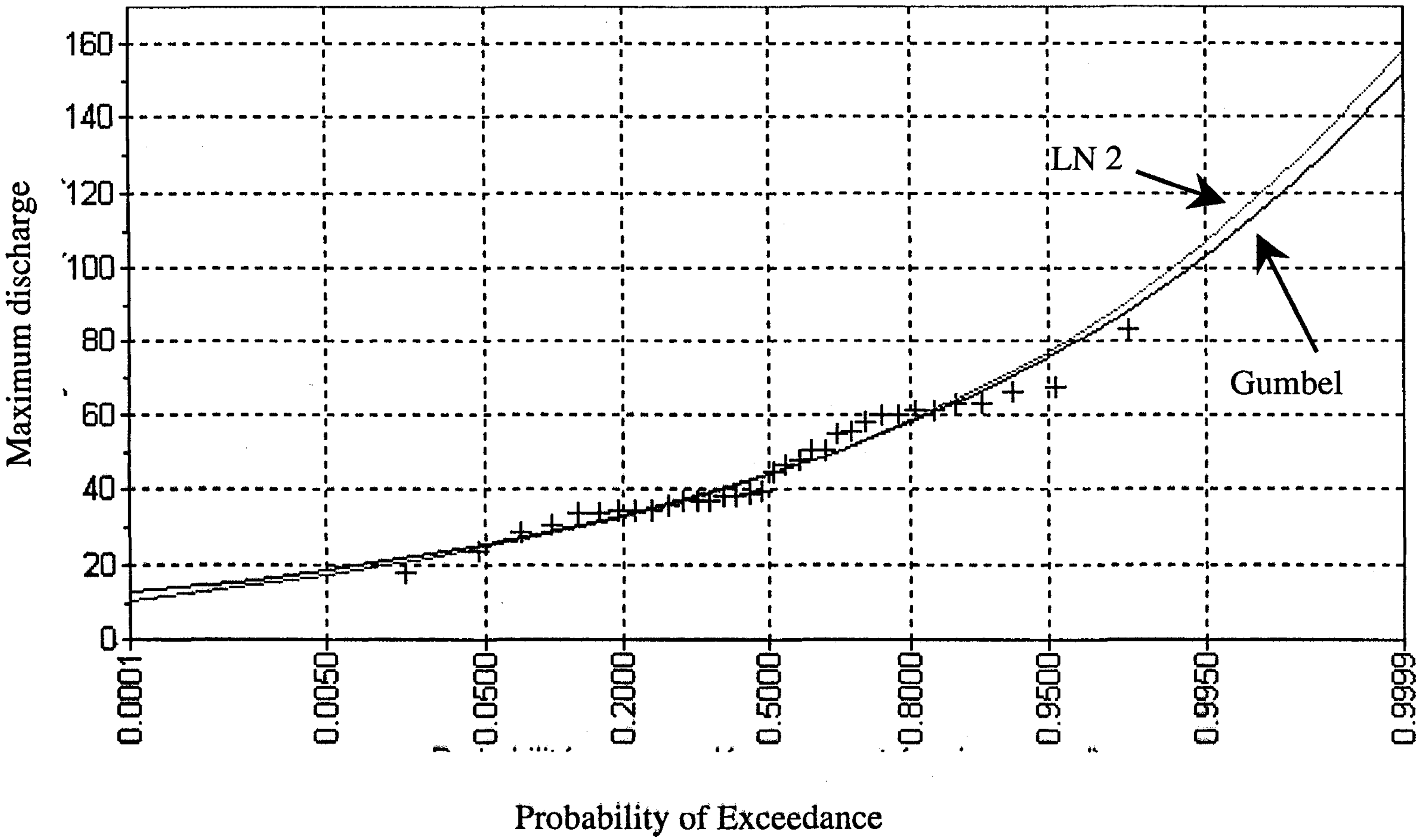

Figure 2. Comparison of Logmormal (LN2) and Type 1 Extreme (Gumbel) distribution functions with annual flood observations

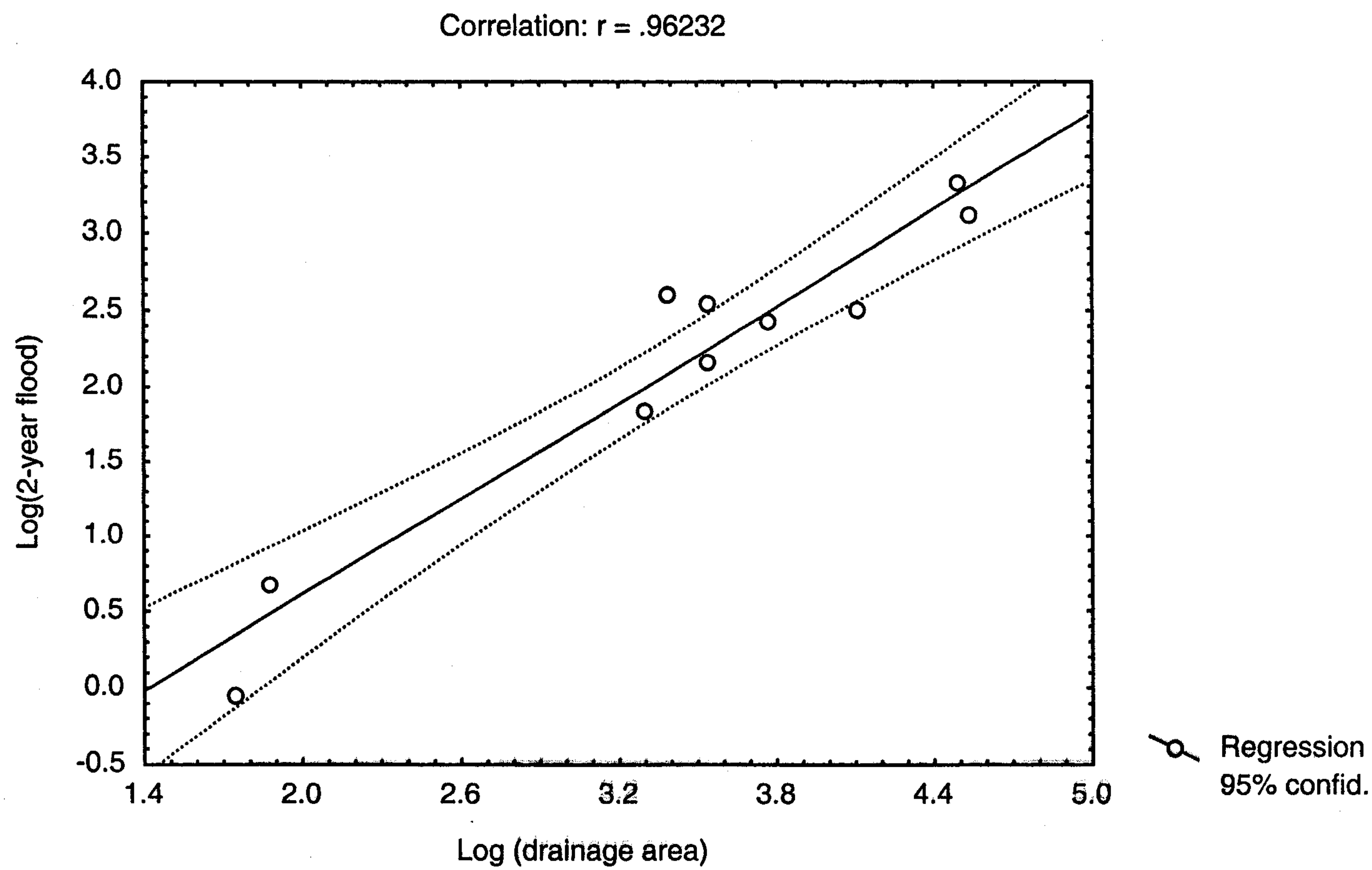

Figure 3. Regression between two year flood discharge (F2) and drainage area (from El Jabi et al. 1994)

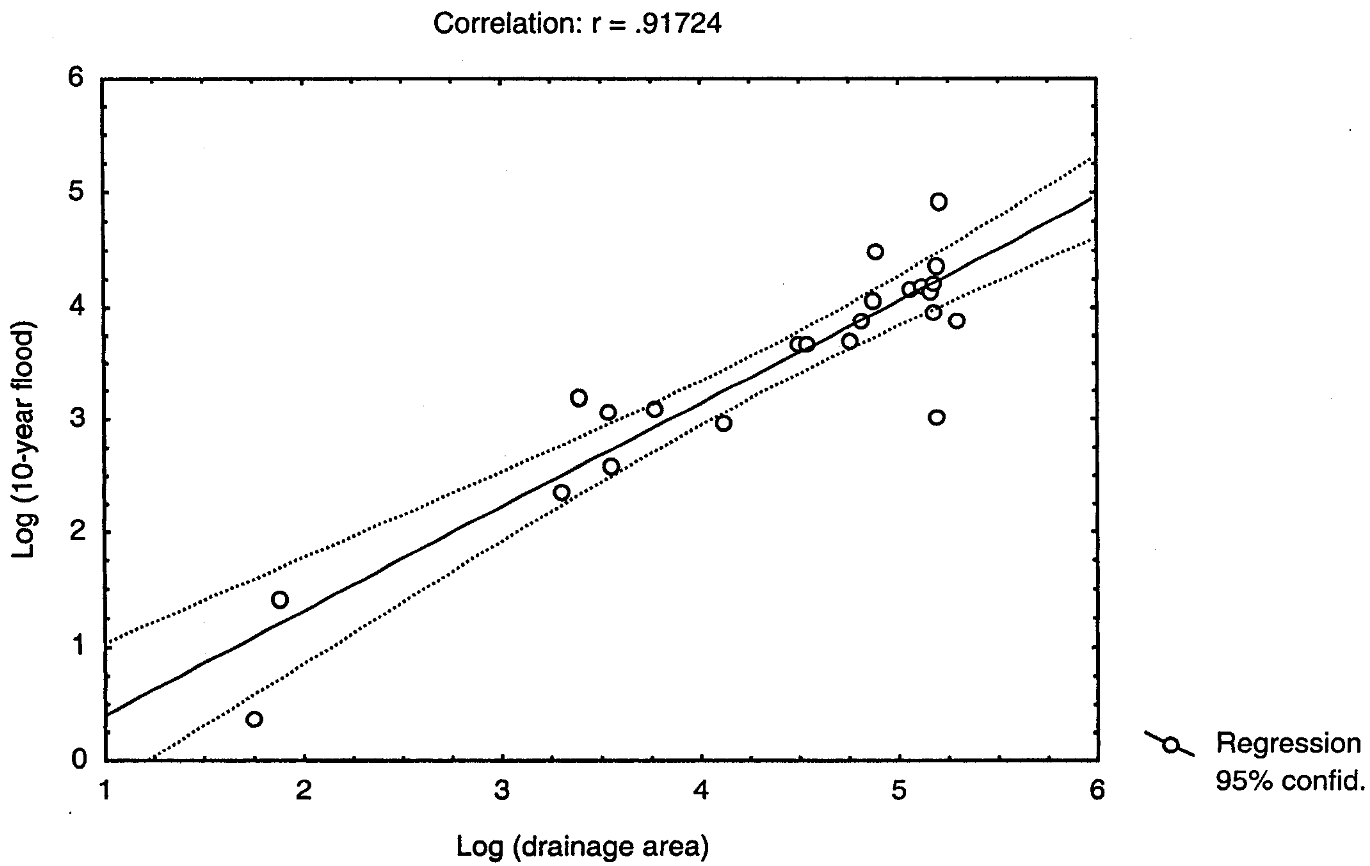

Figure 4. Regression between ten year flood discharge (F10) and drainage area (from El Jabi et al. 1994)

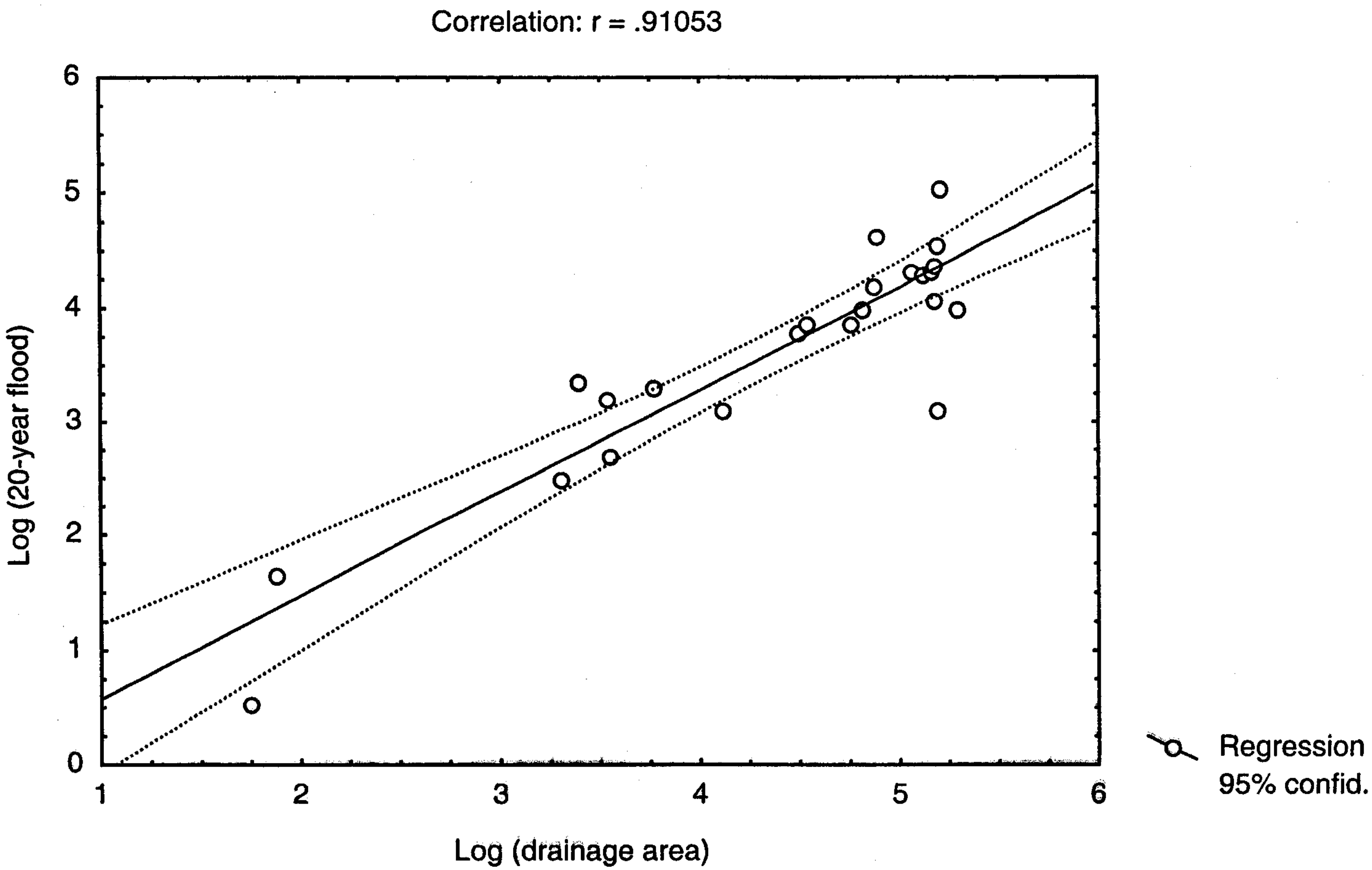

Figure 5. Regression between 20 year flood discharge (F20) and drainage area (from El Jabi et al. 1994)

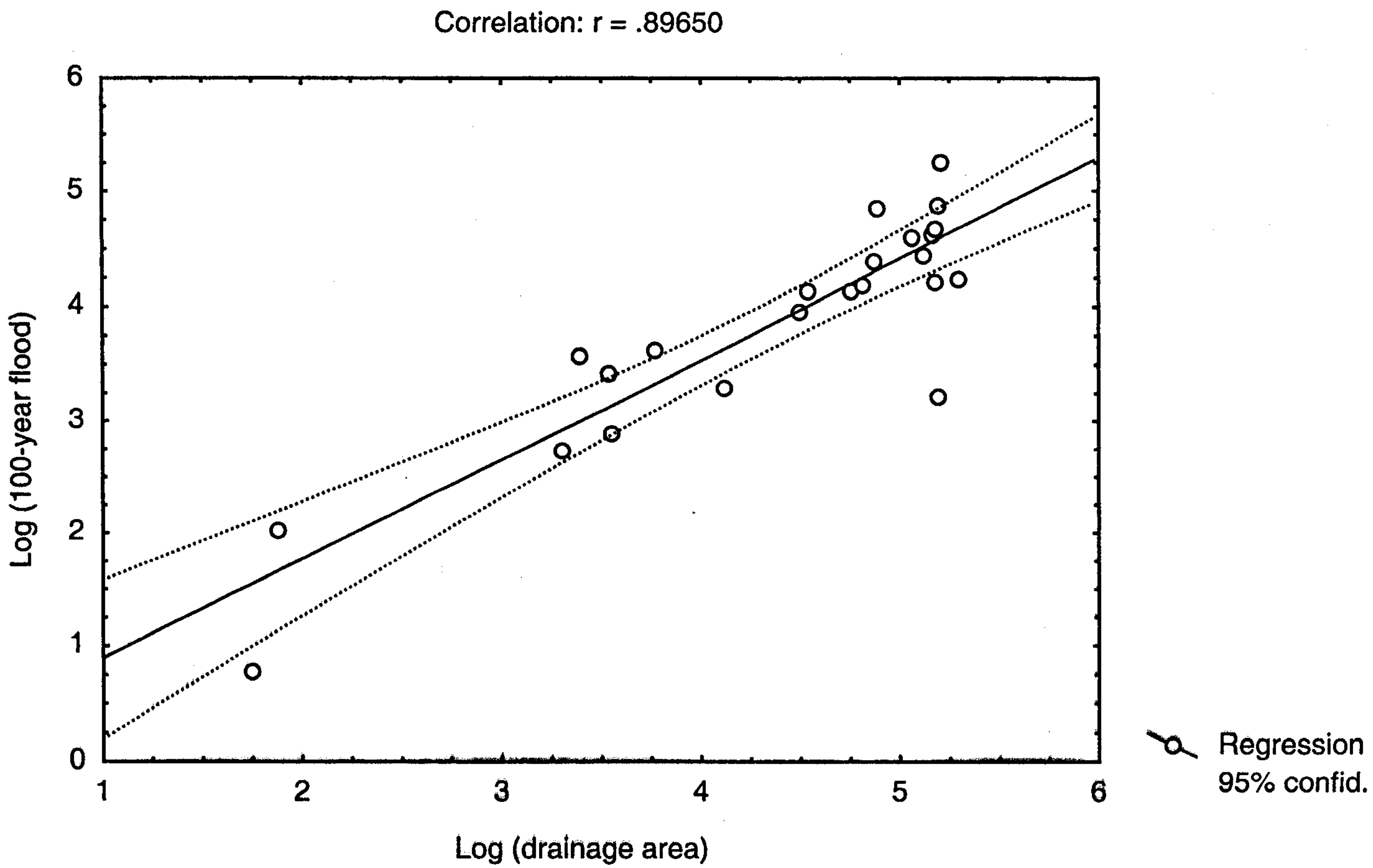

Figure 6. Regression between 100 year flood discharge (F100) and drainage area (from El Jabi et al. 1994)

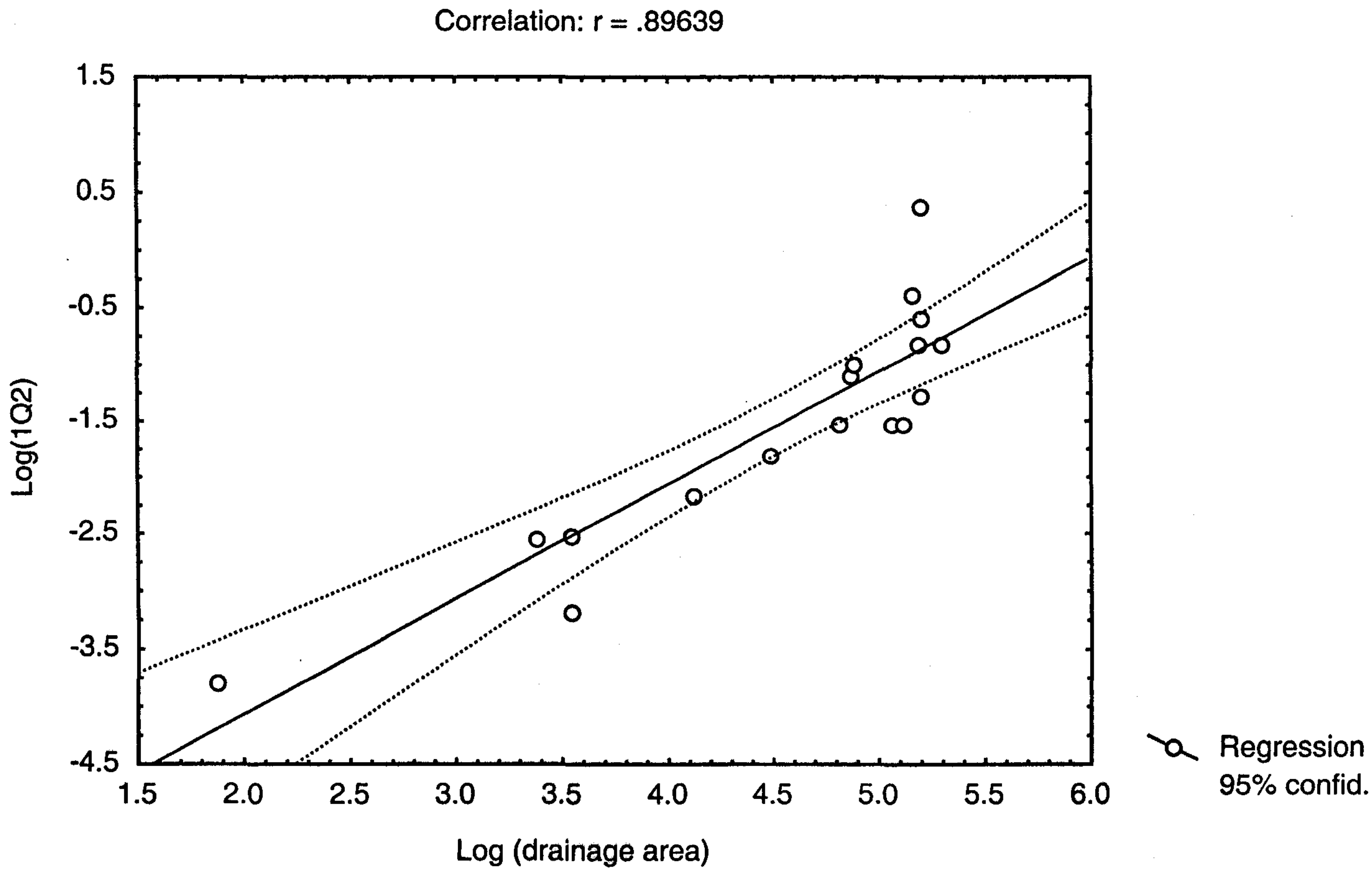

Figure 7. Regression between two year low flow with a one-day duration (1Q2) and drainage area (from El Jabi et al. 1994)

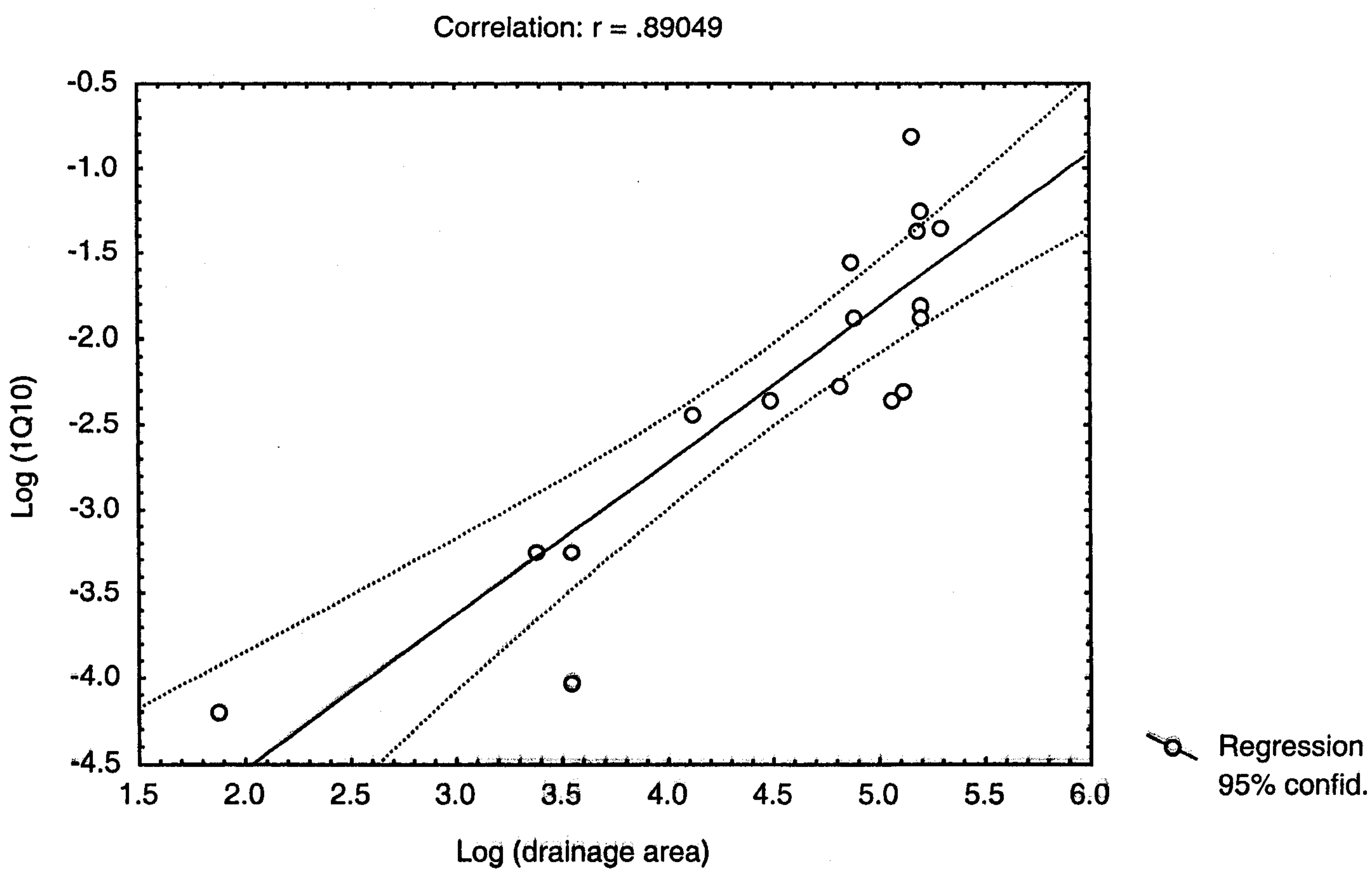

Figure 8. Regression between 10 year low flows with a one-day duration (1Q10) and drainage areas (from El Jabi et al. 1994)

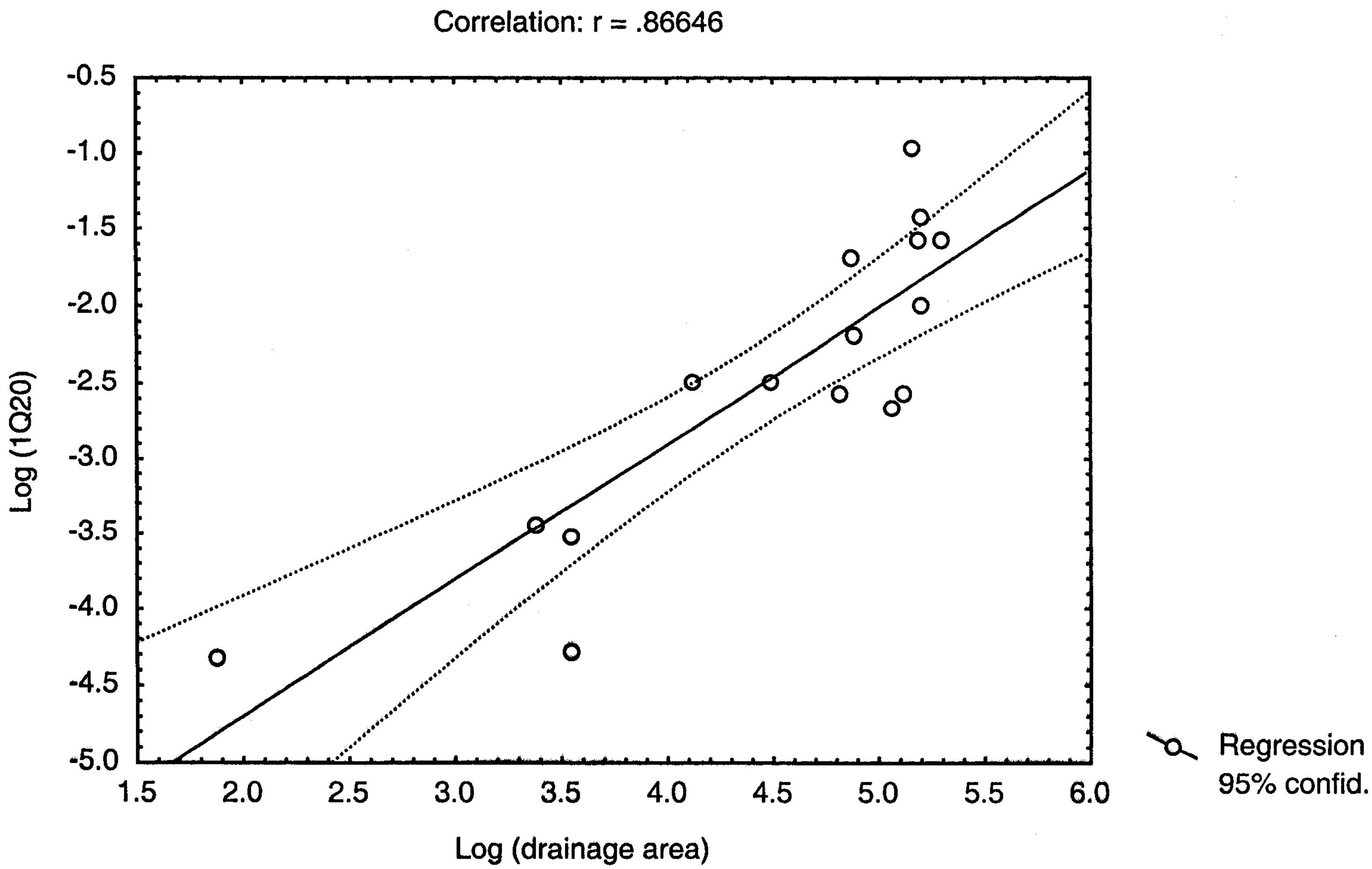

Figure 9. Regression between 20 year low flows with a one-day duration (1Q20) and drainage areas (from El Jabi et al. 1994)

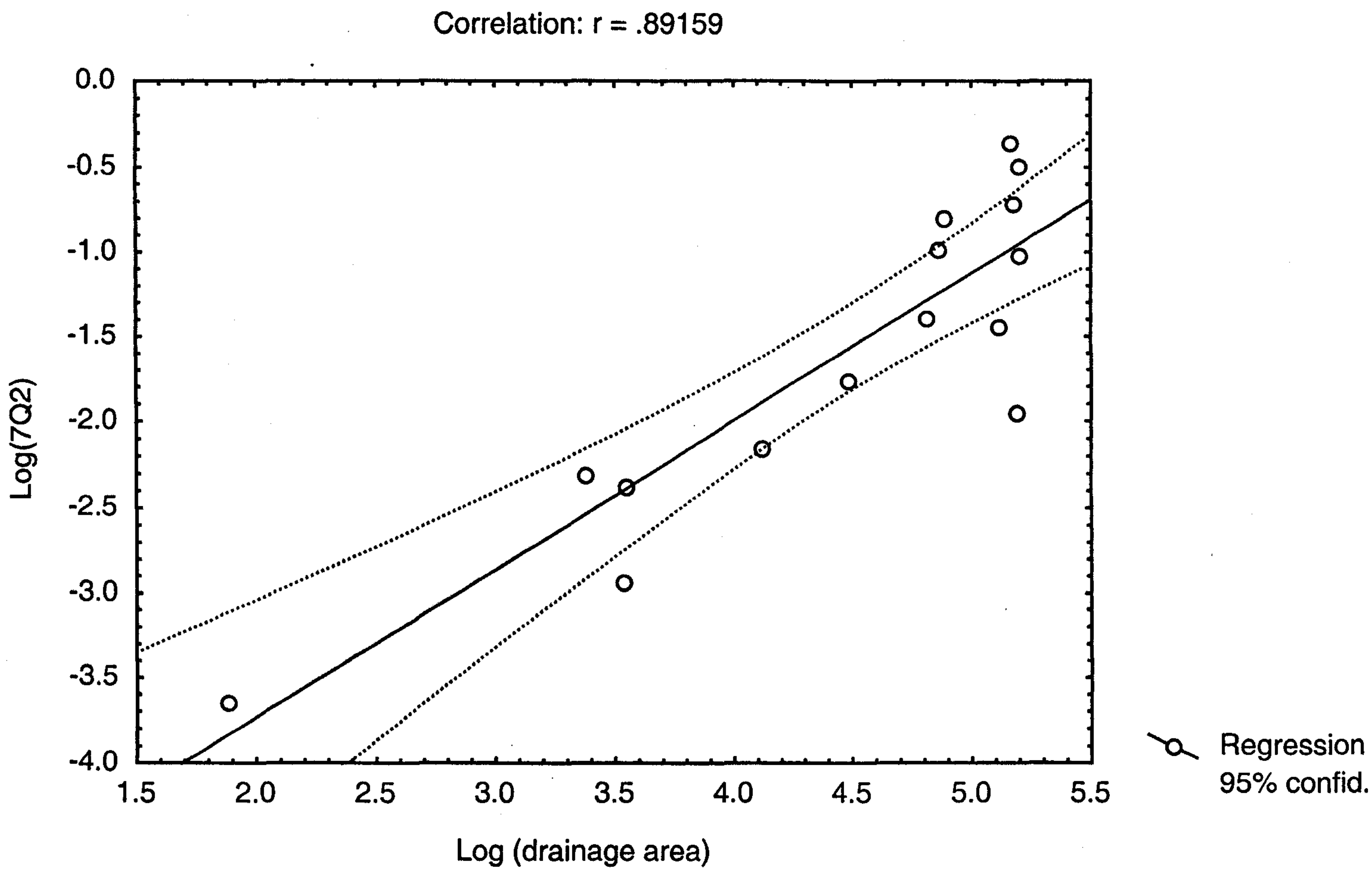

Figure 10. Regression between two year low flows with a seven-day duration (7Q2) and drainage areas (from El Jabi et al. 1994)

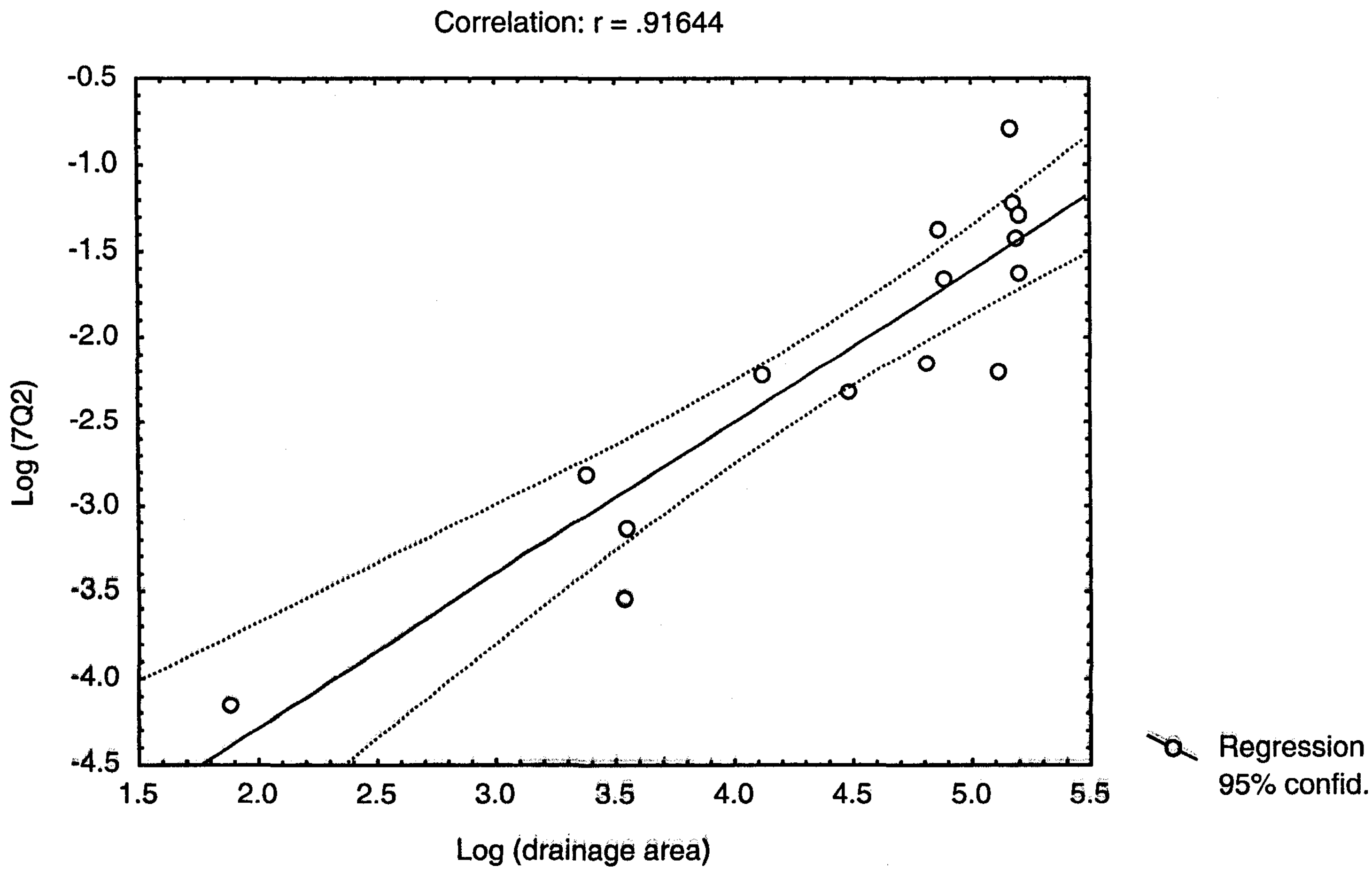

Figure 11. Regression between 10 year low flows with a seven-day duration (7Q10) and drainage areas (from El Jabi et al. 1994)

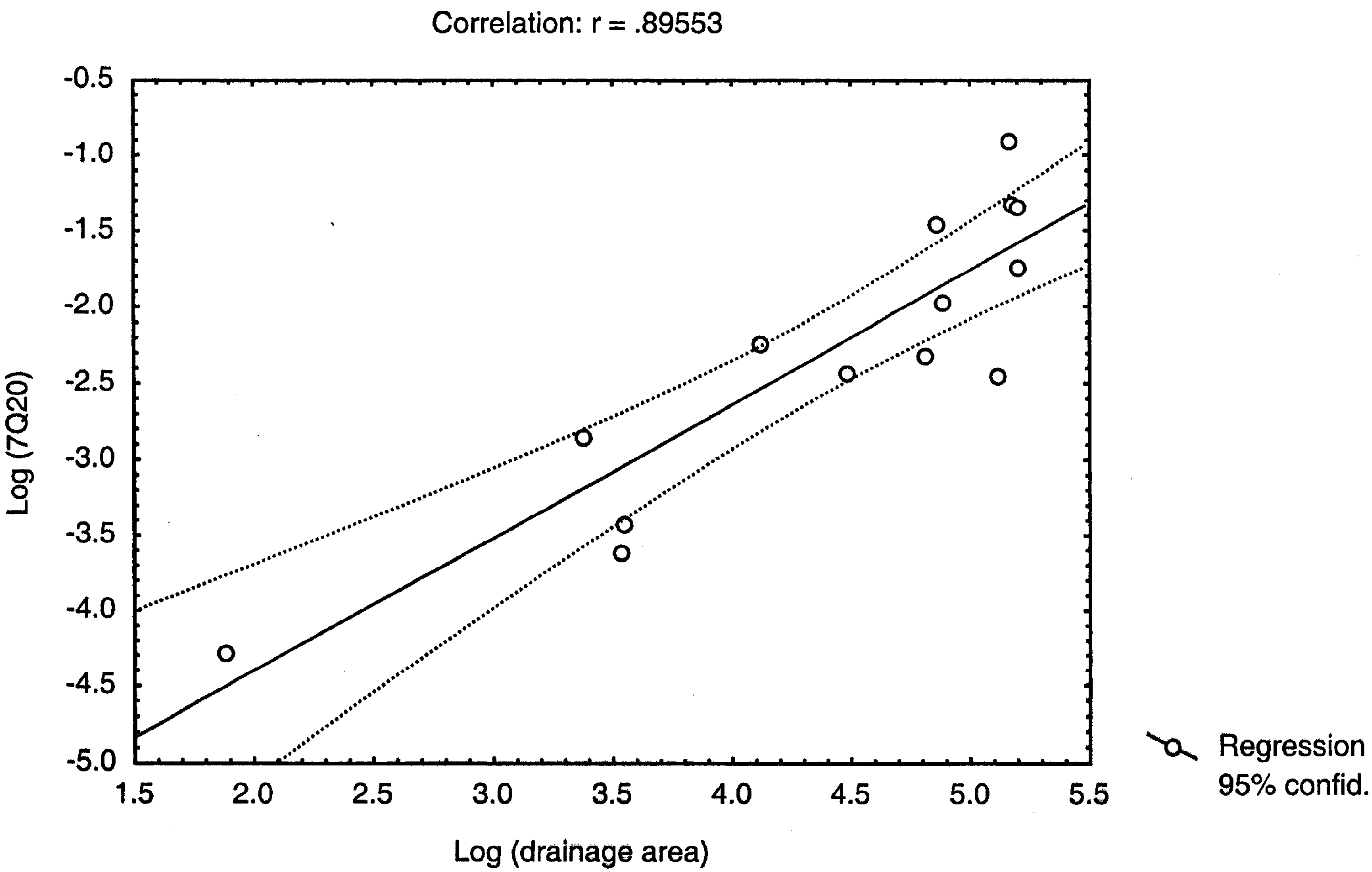

Figure 12. Regression between 20 year low flows with a seven-day duration (7Q20) and drainage areas (from El Jabi et al. 1994)

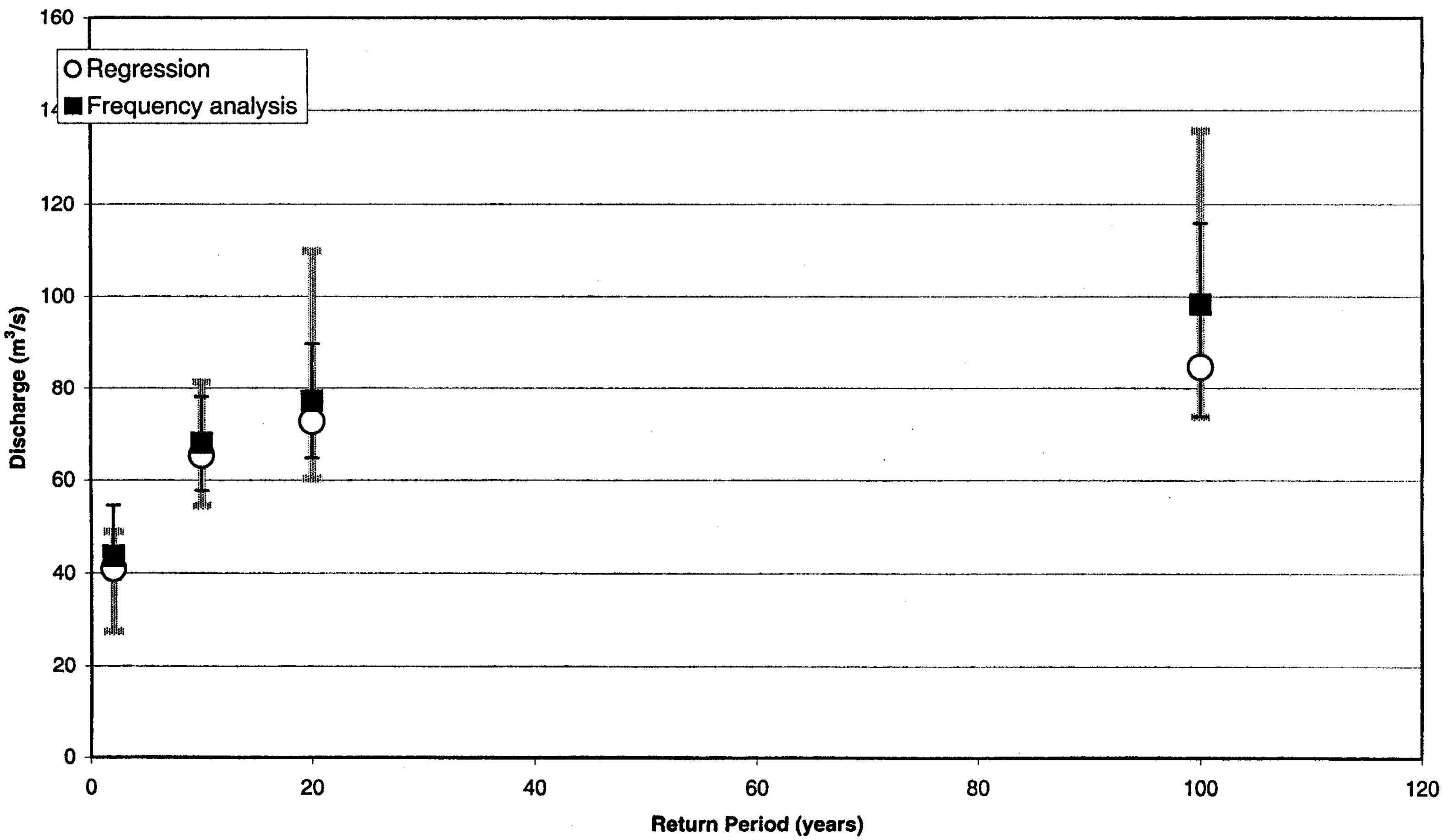

Figure 13. Comparison between flood quantiles evaluated by frequency analysis and by regression at station 01BS001 (Coal Branch at Beersveille). Lower and upper confidence intervals are represented by a dashed line for the regression results and by a full line for the frequency analysis.