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ENGLISH RIVER NEAR SIOUX LOOKOUT BACKWATER STUDY

Ian McLaurin

August 1981

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ENGLISH RIVER NEAR SIOUX LOOKOUT BACKWATER STUDY

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Purpose: To produce and test an improved computational technique for English River near Sioux Lookout 050A001.

The Problem: This station is on the English River just above Lac Seul in a section that resembles a chain of lakes. The control consists of a series of rapids between the gauging and metering site and Lac Seul. High stages on Lac Seul produces backwater of the site, expecially at low flows. There is no backwater due to ice during the winter.

> A variety of computational methods have been used, The latest, a Normal Fall technique, was devised in 1967 with subsequent revisions. An analysis in 1977 by myself indicated that although the method was not entirely correct it was the best of the standard text book methods.

A plot of the correction curve used in the method was done on March of 1980 to enable the curve to be extended. The data from approx. 200 measurements was plotted and the scatter was found to be very large e.g. for a given condition correction factors ranged from 1.0 (no correction necessary) to 0.65.

- Proposed: To attempt an improved fit with a new computational method it is proposed that the problem be approached using multivariate analysis e.g. components analysis and multivariate regression. Elements of this might include:
 - 1) Check on stability of the control from 1921 to present by plotting all measurements H vs Q year by year.
 - 2) Place measurement data on computer file including generated data such as fall to Lac Seul.
 - 3) Produce the envelop curve for H vs Q in equation form.
 - 4) Use Cybershare's SPSS sub programs FACTOR and REGRESSION to locate the significant variables and produce the regression equation relating them to discharge or a correction factor.
 - 5) Test the method(s) found in (4) against i) the measurements ii) the range of conditions iii) the published record, looking for in i) a high R².
 - ii) reasonable answers in all ranges of stage and discharge that might be expected.
 - iii) periods with significant (> 5%) difference.
 - 6) Prepare a detail Procedures Mannual for Surveys to compute the data operationally and revise past record where necessary.

Ian McLaurin April 1980

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SYNOPSIS

The purpose of this study, as indicated in the proposal on the previous page, was to produce, and test, an improved computational method or technique for the English River near Sioux Lookout hydrometric station 05QA001. However as the study progressed it became apparent that the problems at the station were quite complex and an improved method could not be produced. Being unable to develop an improved computational technique the study shifted away from the proposal's outline to investigate the alternatives to the present operation of the station. Through these investigations the following recommendation was arrived at.

It is recommended that, with the concurence of the Canadian Lake of the Woods Control Board, the station <u>English River near Sioux Lookout</u>, 05QA001 be discontinued.

This recommendation was made considering the following points:

- i The quality of the discharge record for this station is well below the quality typical for the Shield area of N.W. Ontario.
- ii It is unlikely that any improvement in quality can be made through a computational procedure that uses the stage at the station and the stage of Lac Seul.
- iii The installation and maintenance of additional equipment to continuously measure velocity, slope, or flow is not justifiable.
- iv The relocation of the station would not be effective.
 - v A requirement for real time data from this particular station has not been identified.
- vi A reasonable relationship exists between the flows computed at English River at Umfreville and Marchington River at McDougall Mills and the flow at this station.

ENGLISH RIVER NEAR SIOUX LOOKOUT - BACKWATER STUDY

1.0 STATION BACKGROUND

English River near Sioux Lookout O5QA001 was established in August of 1921 at the CNR bridge west of Sioux Lookout Ontario over the Pelican Lake section of the English River several miles above Lac Seul. During the late 1920's and early 1930's the Ear Falls Dam at the outlet of Lac Seul was constructed and the reservoir filled. By 1936, the high lake levels were causing significant amounts of backwater at the station and the stage discharge relationship, which had been stable to that time, became unstable. In 1956 the station was moved to the #72 highway bridge at the upstream end of Pelican Lake just below Abram Lake. The gauge was placed on the Pelican Lake side and upgraded to a recorder. The move of the station was only to improve accessibility and the backwater problem has persisted to the present time.

The backwater occurs when Lac Seul is high and the English River is low. With the lake being regulated this is a regular occurrence, especially in the late summer and fall when river flows have receded but the lake levels are maintained high to store water for winter releases. In 1967 Mr.O.Fjeldsted and Mr.D. Kinley of WSC, Winnipeg adopted the normal fall computational method for the station. This method was documented and used by Mr. J. Long in his "Frequency of Discharge Measurement Study - English River near Sioux Lookout, Ontario -O5QA001" of 1973 (revised 1976). In 1977 Mr. I. McLaurin discussed the normal fall method in his report "English River near Sioux Lookout - Analysis of Computation Method". The report includes discussion on the applicability of the normal fall technique to the English River near Sioux Lookout situation and presents the



idea that the method was not entirely correct but more appropriate than the constant fall method or the stage ratio method. (These methods of computing discharge under variable slope conditions are described in "Applied Hydrology" by Linsley, Kohler and Paulhus in the McGraw-Hill Civil Engineering Series and in the United States Geological Survey's "Water Supply Paper #888".)

The normal fall computational method uses three curves -

- 1) the base or backwater free stage-discharge curve
- 2) the river stage vs. normal fall to Lac Seul curve
- the correction curve of the ratio of actual fall to normal fall vs. the ratio of the actual (true) discharge to normal (backwater free) discharge

These above three curves can be found on Figure 4. The daily mean values for the stage of the English River near Sioux Lookout and the fall, or stage difference, from the river site to the Lac Seul at Hudson station are applied to these curves, either manually or using the NRMFALL computer program written in 1979 by Mr. I. McLaurin and Mr. B. Spencer, to produce daily mean discharges for the English River at Sioux Lookout.

In 1979 on September 28 a discharge measurement was taken which fell outside of the range of the normal fall method's curves. In April of 1980 during the course of developing the required extension to the correction curve the inadequacy of the normal fall method became more apparent necessitating this major check of the method.

2.0 STUDY APPROACH

This study was approached by considering that the measurements taken at English River near Sioux Lookout were samples out of the population of all the daily values for the period of 1921 to 1980 and the curves used in the normal fall computation method were models of the population. These models could be checked using statistical methods on the available samples.

As almost all the data were in Imperial units this report is in the Imperial units of; feet for stage or water level; cfs for river discharge or flow rate and similar units for the other variables.

There were three stages to the study. The first stage was carried out by Mr. P. Saka, an engineering student from the University of Manitoba working with Water Survey for the summer. By using graphical techniques on selected measurements the stability of the base curve of the stage discharge relationship was examined. Several possible relationships between the river stage, the downstream lake stage (Lac Seul) and the river discharge were investigated. The first stage provided the groundwork for the second stage.

The second stage was carried out by Mr. Saka and Mr. McLaurin using statistical computer techniques. Data for the 570 measurements taken at Sioux Lookout from Feb. 13, 1921 to July 28, 1980 were placed in a computer file. For each measurement the data included; year, month, day, cross-sectional area, mean velocity, river stage, metered discharge, equivalent gauge height, equivalent discharge and stage at Lac Seul at Hudson. This information was obtained from the R56 forms with confirmation from the meter notes when required. To obtain equivalent gauge height and equivalent discharge correction factor, stage discharge table #12 dated March 13, 1978 was used. The file was broken into

three sub-files; 1921 - 1933 when Lac Seul was low, 1934 - 1956 when Lac Seul was high and the measurements were made from the railway bridge, and 1956 - 1980 when the measurements were from the highway bridge.

The computer programs used in the second stage were those in the SPSS (Statistical Package for the Social Sciences) library at the Cybershare computer in Winnipeg. CONDESCRIPTIVE was used to calculate the derived variables such as normal fall, actual fall, backwater, etc. and produce the SPSS data file. CONDESCRIPTIVE also calculated the simple statistics such as the mean, range, and standard deviation of each variable. FACTOR, with its output of the correlation matrix and the factor matrix with a plot, was used to obtain an understanding of the interrelationships of the various variables. The bulk of second stage of the study was an attempt to find relationships between these variables using REGRESSION and SCATTERGRAM. SCATTERGRAM plots any two variables in a printer plot and develops the best fit linear equation. In total there were approximately a dozen multiple regression runs made and nearly 40 SCATTERGRAM plots produced during this stage of the study. The plotting feature of SCATTERGRAM was also used to check the input data for errors by plotting, for example, metered discharge vs. the product of mean velocity and cross sectional area. Outliers were then checked for possible coding errors.

The third stage of the study was initiated after results of the second stage indicated that the accurate computation of discharge using data gathered at English River near Sioux Lookout and Lac Seul at Hudson was not possible. A double mass curve of the annual discharges from 1921 to 1979 for English River at Umfreville and English River near Sioux Lookout was produced and the linear

relationships observed. REGRESSION and SCATTERGRAM were then used to determine if a relationship existed between the measured discharges at Sioux Lookout and the flows computed for the same day at Umfreville and the Marchington River at McDougall Mills station. Both stations are upstream of Sioux Lookout. For the period 1956 to 1980 there were 267 data points available for analysis of the relationship between the Umfreville and Sioux Lookout station. As the Marchington River station was established in 1961 there were only 197 data points available for the analyses that included that station.

3.0 DISCUSSION OF RESULTS

3.1 The Base Curve

Throughout the years from 1921 to 1980 the base or backwater free stage discharge curve has remained essentially unchanged. Figures 5, 6 and 7 are the plots of all the measurements taken at the station with the present stage discharge curve #12 superimposed on them. Figure 5 shows the 66 discharge measurements taken from 1921 to 1933 in a narrow band just to the right of curve #12. In Figure 6, the effect of the high water levels is shown as the 237 measurements to 1956 range from just right of curve #12 to well left of it. In the cases with the most backwater the metered discharge was less than half what curve #12 would indicate. Figure 7 is a plot of the measurements for the period 1956 to 1980 with the station at its present location. These 267 measurements range from just right of curve #12 to the left of it. The left envelope corresponds to an approximately 25% reduction in discharge. Due to the very significant amount of backwater being investigated and with the allowance for some measurement error the fact that the base curve doesn't pass directly through the extreme right of the scatter is of little concern to this study.

A measure of the quality of the actual measurements was assessed by plotting stage vs. area for all the measurements. This produced two straight lines, one for each site, and each with a band width of \pm 3%. This indicates precise measurements of stage and area.

The scatter of the measurements taken on the English River is then determined to be due to backwater, and not a shifting control or large measurement errors.

3.2 The Normal Fall Method's Curves

The curves used in the normal fall computational method - The Normal Fall Curve and the Correction Curve of Figure 4 - were assessed by plotting the points from the measurement data. The plot of river stage vs. the actual fall to Lac Seul produced a uniform scatter of points, with no line being apparent ($\mathbb{R}^2 = .03$). When only the fall of backwater free measurements was considered no line was evident either. However, by considering a number of plots, each produced with increasing backwater, it <u>appeared</u> that the Normal Fall Curve would be better approximated by the equation:

NFLL = (82.00 - RIVH) where NFLL = Normal (Backwater Free) Fall to Lac Seul

RIVH = English River Stage (-1100 feet)

as opposed to the existing curve:

NFLL = (RIVH - 67.93)

Figure 8, the plot of the correction factor vs. the fall ratio, shows the wide $(\pm 20\%)$ point scatter along with the correction curve in current use. By using other normal fall curves and/or by entering additional variables the relationship between the fall ratio and discharge correction factor was improved only slightly.

The present Normal Fall curves have no statistical significance and produce little improvement in accuracy except that the curves qualitatively indicate that at a very low fall the discharge drops. It also appears that a more accurate Normal Fall method can not be produced.

3.3 Regressions

The bulk of this study was an attempt to find through regression

an equation or relationship which related the two continuously measured variables to the actual discharge as sampled by the meterings. The two continuously measured independant variables are the river stage (RIVH) and the lake stage (LAKH). These variables make up other variables used in the analyses including base curve discharge and actual fall. The dependant variable of measured discharge (QMEAS) is also found in such variables as velocity and amount of backwater. Therefore, although the analyses involved a dozen or more variables there are in reality only 3 variables, RIVH, LAKH and QMEAS. The interdependence between the variables is shown through the zero determinant of the correlation matrices of Table 1.

The two significant areas in the three correlation matrices are 1) the high interdependence of the variables associated with the river station with each other and 2) the correlation of lake stage with the river's variables. For example for 1934 - 1956 the measured discharge correlates highly with velocity $(R^2=.98)$, river stage (R^2 =.86), and the base curve discharge (R^2 =.93) and also with lake stage $(R^2=.18)$ but to a much lesser extent. Also significant is that the correlation of the measures of backwater (BCKW and CORF: see Table 2 for definitions of these and other variable names) are poorly correlated with the other variables (typical R^2 =.12 or less). The highest correlations of the primary variables are of measured discharge with velocity for each of the three sub-files $(R^2=.99)$.98 and .97). However, these correlations could be considered spurious as velocity is computed from measured discharge and measured area and may be more an indication of the accuracy of the measurement of area. All these values of R^2 should be compared to the coefficient of determination of a typical transformed stage discharge curve - R^2 =.999 - and of the value we wish to improve on for this station - R^2 =.95.

The factor analysis grouped the variables into three factors. The first factor strongly involved the variables associated with the discharge measurement with a weak involvement of lake stage. The second factor had weak involvements of the variables associated with backwater and also included the lake stage. The third factor was quite weak and insignificant for these purposes. However, because of the near zero determinate of the correlation matrix (1.0×10^{-20}) the factor analysis may be unreliable and was not persuaded further.

A number of multiple regressions on the primary variables were attempted and a few examples are included in Table 2. The best fit was with new normal fall (NFLL= 82-RIVH) and correction curves and additional variables to produce an \mathbb{R}^2 of only .97. This represents an increase in accuracy but still leaves 3% of the variation in discharge unexplained.

This does not imply that the regression equation produces discharges that are accurate to 3% but in fact, as shown in Section 3.5, the regression equation produces discharges that are within 20% of the measured value only half the time. <u>Therefore the use of equations obtained through regression</u> <u>analysis on the data presently collected will not give a sufficient improvement</u> in accuracy.

3.4 The Use of Upstream Stations

When the regression analyses of the second stage of this study failed to produce an accurate method of computing the flows for the English River near Sioux Lookout a third stage was initiated. This third stage of the study looked at the two upstream stations, English River at Umfreville and Marchington River at McDougall Mills. They are shown on the Location Map and Figures 3A, 3B

and together they drain 4300 sq. mi. or 82% of the drainage area at the Sioux Lookout Station. The discharge data from both these stations is good. They have stable stage-discharge relationships and are unaffected by backwater.

A double mass plot of the annual discharges at Umfreville and Sioux Lookout identified a three segmented linear relationship. From 1921 to 1929 the Sioux Lookout discharges were 2.38 of the Umfreville discharges. From 1929 to 1956 the ratio was 2.23 and from 1956 to 1980 it was 1.98. These changes in the slope of the plot are distinct and can be related to the regulation of Lac Seul beginning in 1929 and the move of the English River near Sioux Lookout station in 1956. The only change that has occured at English River at Umfreville was the construction of a bridge on the control in 1949 and the subsequent decay of the bridge during the 1970's. Thus the Umfreville station was essentially unchanged during the entire period 1921 to 1980 and the slope changes in the double mass curve must be attributed to changes at the Sioux Lookout station.

With the relationship between the flows at Sioux Lookout and the flows at Umfreville changing in 1929 and 1956 there are two important consequences. The first is that the flows at Sioux Lookout are of three separate populations and, as was done using the sub-file structure in the previous statistical analyses, should be considered separately. The second consequence is that these changes in the relationship reveal the magnitude of the relative errors in the discharge data. For instance, from 1929 to 1956 the computed annual yield at Sioux Lookout was 2.23 times the computed annual yield at Umfreville, but from 1956 to 1980 the yield was only 1.98 times the yield at Umfreville. This is a change of 11% and represents the magnitude of the error.

For the period 1956 to 1980 SCATTERGRAM was used to produce a linear equation relating the measured discharge at English River near Sioux Lookout to the computed flow for the same day at Umfreville. A plot is shown in Figure 12 and the equation produced from the 267 values is:

QSLO = $1.666 \times \text{QUMF} + 677$ (R² = .91)

where QSLO = discharge metered at English River near Sioux Lookout

QUMF = daily discharge at English River at Umfreville

when the plotted points of Figure 12 are considered the equation,

 $QSLO = 2.0 \times QUMF$

appears to include the most data points of any linear relationship. It is also closer to what would be expected with a drainage area ratio of 2.125 : 1.

The station on the Marchington River was established in 1961 and when its data for 1961 - 1979 is included in this analysis the resultant regression equation from the 197 data points is:

QSLO = QUMF x 1.42 + QMAR x .38 + 717 (R^2 = .93)

where QMAR = daily discharge at Marchington River at McDougall Mills A flow model based solely on drainage area:

 $QSLO = (QUMF + QMAR) \times 1.2208$

resulted in a coefficient of determination (R^2) of .915

The only other possible upstream site to gauge the English River inflow into Lac Seul would be to establish a new station at the outlet of Minnitaki Lake. However maps indicate that there are no roads to this location and a station here would be above the confluence with the Marchington River and only 1000 square miles below Umfreville on the English River. Therefore, a station at that location would gauge approximately 66% of the drainage area at Sioux Lookout. A downstream

site would be affected by Lac Seul.

The use of these simple equations and the computed daily discharges from English River at Umfreville and Marchington River at McDougall Mills produces computed discharges of less accuracy, in the terms of R², than presently computed for the Sioux Lookout station using the normal fall curves. In Section 3.5 and 4.0 the accuracy of these equations is explored further, and a tentative conclusion reached that it may be possible to use the data from upstream stations to compute discharges for English River near Sioux Lookout.

3.5 Accuracy of Computed Discharges

So far in this report the results of the analyses have been expressed in terms of the coefficient of determination, or \mathbb{R}^2 . A value of 1.0 (or .9999) is understood to be an excellent fit of the data points to a straight line and an \mathbb{R}^2 of 0.0 indicates that there is no fit whatsoever. However, an understanding of the accuracy involved with an \mathbb{R}^2 of .97, for example, has not been clear. In Figure 9, 10 and 11 the accuracy of these computation techniques becomes clear. In each graph the vertical axis is the metered discharge and the horizontal axis is the discharge that would have been computed using; in Figure 9, the river stage applied to the base curve; in Figure 10, the present normal fall computational technique; and in Figure 11, one of the better multiple regression equations. In Figure 12 only the measurements taken from the highway bridge are considered. Figure 12 shows the discharges that would be computed if the daily mean discharge at English River near Umfreville were multiplied by the ratio of the drainage areas for these two English River stations.

These figures are summarized in Table 3 which shows that from 1921 -1980 when the discharge was metered at 5000 cfs the discharges that would

have been computed by the various methods fell in bands of 2600 cfs wide (52% of 5000) or wider. For the period from 1956 when the river was relatively free from major backwater (see Figure 7), the normal fall method offers no real improvement over the use of a mean curve without any adjustments and although the total range of computed discharges using Umfreville discharges is much larger, the range of centre half of the scatter is the same for all three methods - approx. 13%. This means that for half the measurements during the period 1956 - 1980 the computed discharge, by any of the three methods, was within 7% of the true, i.e. metered, value.

4.0 SUMMARY AND ALTERNATIVES

4.1 The Base Curve

After allowing for slight shifting of the stage discharge curve when the station moved from the railway bridge to the highway bridge and small measurement errors it has been concluded that the base, or backwater free, curve has not shifted significally since 1921. This was also borne out in the first stage of the study in that in almost every year a discharge measurement was found that was quite close to the base curve, arbitrarily chosen to be curve #12. However, many curves have been drawn. Since 1956 there has been almost one a year. If these curves are considered as backwater curves and have been shifted from during the backwater free period they have not been used incorrectly. There may be a problem with the upper end of the base curve. As Figures 5, 6 and 7 show there is a wide scatter above 17000 cfs and if all these measurements are good the base curve should be then redrawn to the right of them.

4.2 The Normal Fall Method's Curves

The Normal Fall Curve of river stage vs. fall has been demonstrated to not correctly represent the fall from the river site to the lake site when the river is free of backwater, but the more correct representation of normal fall derived in Section 3.2 of this report does not result in a better Correction Factor curve or improved accuracy in the computed discharges.

4.3 Least Squares Regression

The use of linear regression on the primary or derived and transformed variables failed to obtain a significant improvement over the Normal Fall method

of computation. It did, however, lead to some interesting analyses of the data.

The regression and factor analyses demonstrated that lake stage in some form, has a significant effect upon discharge but there was also something else affecting discharge. It is suggested that this other variable(s) operates independently of river stage or lake stage. This independence is suspected because most SCATTERGRAM plots produced, be they; YEAR vs FALL, LAKH vs BCKW, CORF vs FAFN, etc. produced a uniform scattering of points within a reasonably well defined area. Figures 8 and 11 are examples of this. If there is another independent variable it is then impossible to obtain accurate discharges without measuring it. This other variable may be the fall through the metering section. As the source of the scatter is unknown its time base is also unknown. In other words it is not known if the error in the computational method as indicated by a measurement, persists for a month, a day, or an hour.

As the plot of the measured stages vs areas for the highway bridge metering site is very tight and straight and correlation between velocity and metered discharge is also very good. If the velocity profiles in the measurement section are stable, an accurate velocity meter with recorder could give accuracies more in line with those of typical WSC stations. Such an installation would require significant capital, (at least \$10K) plus set up and calibration time.

4.4 The Use of Upstream Stations

The inaccuracy at the station is halved when a Normal Fall method or a multiple regression equation is used but is still high with computed discharges being within + 10% of the true value only half the time. When the daily discharges

at Umfreville are used to compute discharges at Sioux Lookout the computed discharges are within \pm 7% of the discharges metered half the time.

Figure 12 is the plot of the 267 measurements taken at English River near Sioux Lookout vs the same day's discharge at English River at Umfreville multiplied by the ratio of the drainage areas. It shows a very wide scatter, up to \pm 35%, about the centre line but the data points have a normal distribution about the centre line such that half the points are within \pm 7% of the line. This normal distribution, as opposed to the more random distributions seen previously in this study, means that the mean line can be determined quite accurately. Also by examining the flow conditions for the time period surrounding the discharges that produce an outlier, the variables that creates these outliers can be identified.

Figure 13 is a comparison hydrograph plot for 1976 for these and 2 other stations in N.W. Ontario. It shows that during times of steady flow the ratio of metered discharge at Soux Lookout to the computed daily discharge at Umfreville is very close to the drainage area ratio. This ratio falls (and produces the outliers on Figure 12) when the hydrographs rise, and rises when the hydrographs fall. This effect is likely due to the large lake, Lake Minnitaki, between the two river stations, moderating the flow at Sioux Lookout. It is also likely that the effect of this lake can be modelled as a linear reservoir. It then appears, that, unlike the scatter involved with the Normal Fall or regression equation computations, the scatter in the Umfreville computational method can be modelled, or at least explained.

4.5 Alternative Courses of Action

There are then three clear alternatives:

1) Carry on as before and accept large errors which may, or

may not, cancel out in the long or short term.

- Install and maintain a velocity meter at the English River near Sioux Lookout metering site to obtain accuracies more typical of WSC.
- 3) Discontinue the English River near Sioux Lookout station because upstream station(s) can provide a reasonable indication of the English River inflow to Lac Seul.

5.0 RECOMMENDATIONS

In view of the present poor accuracy, high worklaod, and the existance of alternatives, this station should not continue to operate in its present state. The installation of a velocity meter, e.g. an electromagnetic point velocity meter, or an acoustic flow meter, is prefered if the equipment installation and maintenance costs can be justified. The remaining alternative of discontinuing the station can not be ruled out. The station is a long term station and is a major inflow into the Lac Seul reservoir, BUT the English River at Umfreville station was also started in 1921 and the inclusion of the Sioux Lookout station raises the proportion of Lac Seul inflow that is gauged from 46% to only 57%. The two stations upstream of English River near Sioux Lookout, Marchington River at McDougall Mills and English River at Umfreville both have good quality record with stable stage discharge curves and no ice effect. These 2 stations gauge 82% of Sioux Lookout's drainage area and the analysis of the data has indicated the addition and routing of their flows can be used by those interested in the flows at Sioux Lookout to produce discharges that may be more accurate than WSC can produce by continuing to operate the station in the present manner. It is therefore recommended that the station be discontinued with the concurence of the Canadian Lake of the Woods Control Board.

During the course of this study two items that could require further study were noted. They were beyond the scope or capabilities of this study but it is recommended that they be pursued further.

The first item was not mentioned in this report but it can be seen on Figures 5, 6 and 7 that there are 5 discharge measurements greater than

17500 cfs. Three of these five fall well to the right of the existing base curve. It is recommended that the higher measurements and the upper end of the stage discharge curves used be investigated to confirm that the published discharges above 17500 cfs do not require revision.

The second item was brought up in the discussion of the double mass curve of the Umfreville and Sioux Lookout data. When the station, i.e. the metering site, was moved in 1956 the computed discharge changed by 11% when compared to the Umfreville discharges. It may be that the metered discharge at one or both of the two metering sites (the railway bridge and the highway bridge) is not the true discharge. This could be due to irregular river channels producing non-typical velocity profiles. In a non-typical velocity profile the average of the velocities measured at 0.2 and 0.8 of the depth is not the true mean velocity for the vertical. It is recommended that the velocity profiles be measured at the old railway bridge metering site and the present highway bridge metering site. Initially this would involve velocity measurements in 5 representative verticals with velocity measurements at the surface and 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 of the total depth and just off the bottom. This could lead to a series of such measurements to develop, revisions to the published record.



FIGURE 2







1) apply elevation of Eng. R. to Normal Fall Curve to obtain Fn elevation from Eng. R. elevation to obtain actual fall, Fa 4) apply Eng. R. elevation to HQ curve to obtain Qn 3) apply Fa/Fn ratio to Correction Curve to obtain Qa/Qn 2) subtract Lac Seul 5) multiply Qn by Qa/Qn to obtain actual discharge COMPUTATION NORMAL FALL PROCEDURE 1971 To Date Rating with no back water from Use From 1976 On tac Seul ļį FIGURE 2 19.71 To Date CURVES FOR NORMAL FALL METHOD OF COMPUTATION OF DISCHARGE MONG ł NOIT Dec B ; *** ÷ BATTER ACTIVITIES - ANTER ACTIVES CANES d 6 • 11111 2 a-actual 1-normal DISCHARGE 1 CURVE il Cre ł 111 SASE CURVE 2 NORMAL 4 : 1 1. UTAQ - 0P C NI --

FIGURE 4

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CNGLISH RIJER AT	FILE MDSLORS SUBFTLE 02133 SCATTERGAM OF	78.00 + I	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 26.00	1 75.00 + 75.00	74.00 H		72.00 + I	71.00 +	70.00 1	H + 00 69.00	4 H4 H4 -

FIGURE 5

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FIGURE 6



		ACTUAL FALL		00.	1.80	1.60	1.40	1.20	1.00	. 80	. 60	.40	0	0 0.0
	80/10/22. FAGE 9	S 1921-80 IN 3 SAFILES GROSS) FAFN - KATIO OF NOKHAL FALL TO	1.30 1.50 1.70 1.90	+ == == == =				нн+нн *						I I
FIGURE 8		NGLISH RIVER SIOUX LOOMOUT 0' Or of omeas over he <mark>o</mark>	.70 .90 1.10	-				*		I 2 * 3 * * * * * * * * * * * * * * * * *	- ★★*-**			I I I
	SIOUX LOOKOUT BACKWATER STUD	CREATION LATE = 80/08/18.) E1 03456 05680 (JIOUN) CORF CORRECTION FACT(.10 .30 .50	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1				*		203724-472 *** * 742 2532**2 * * * * 742 2532**2 * * * * 742 * 1 * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2 * * 2		A A A NORMAL FALL METHOD'S	CORRECTION CURVE	00
	ENGLISH RIVER AT	FJLE MESLOOS (SUBFILE 02133 SECATERGEOM DE		• • • • • • • • • • • • • • • • • • •		1.60 H	1 1 1 1 1 1	1.20 +		н н + н + 08		4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	-20	1 = + + • 0 • • • • • • • • • • • • • • • • • •

	HUIA		1.4664 +00	00.00	2000 0-00	12500.00	15000.00	12500.00	10000.00	1 1 1 1	1 1 1 1 1 1 1	2500.00	•••••
F-AGE 4	S CUEVE DISCHARGE OF	.60 23750.90	+ =, =				- H + H P			.96856 837.29368 570	-328.74066 -328.74066 00001 -94572	5	0 22500.00 25000
-20×10×03	s21-80 IN 3 SKFILE .5) HCO BASE	0 13750.00 21250	-		*		I I I			TISTICS OKRELATION (R)- TD EKR OF ESL - HOTTED VALUES -	SQUARED - NTERCEFT (A) - XCLUDED VALUES- NIGNIFICANCE - SLOPE (B) -	IISSING VALUES II II	I 17+++++++++-
	100% LOOMOUT 0'S 1'	14750.00 1:750.0	2				* 6) *	* * *	₩ **		. <u>κ</u> . Ξ Ψ Ο Ο	Σ	500.00 15000.00
UPY	ENGLISH KIVER SI	НАКСЕ <u>IN UFS</u> 50.00 11250.00	· · · · · · · · · · · · · · · · · · ·	пенени	1			И					I I 00 10000.00 125
FACRUATER ST	: = 8070S718.) Ģ5680	- <u>measuken Misu</u> Do leso.00 87)) 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1					64002446464 K 7400544 4 9400544 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	-++++++++++
AT SIGUY LOOPOUT	S (CREATION DATE 33556 3356	F (1000) (756) (1921-1980					• H H H + M			I I I I I I I I I I I I I I	I 26**
AND THE BUDGE	FILE RUSLOO FILE RUSLOO	SCATTERSRAM 0			00.0000C	17500.00	15000.00	12500.00	10000.00	7500.00	2000.00	2500.00	00.0

FIGURE 9

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. 30

F NISLARGE	25,006.00	00,0050	00.0000	17500.00	00.00021	12500.00	10000.00	7500.00	2000.00	2500.00	0.00
FAGE 2 FALL <u>COMFUTATION O</u>	00 [3756.00	• • • • • • • • • •	+					I 			-++++ -22500.00_25000.00
80/10/22. *5 1921-80 IN 3 SEFILES Actiss) valasa *25MAL	50.00 16750.00 21250. 	*	* * ~	a pas pas pas set			ының	STATISTICS CORRELATION (R)- STD ERR OF EST -	FLUTEL VALUES R SQUARED INTERCEFT (A) - EXCLUDED VALUES- SIGNIFICANCE -	SLOFE (B) MISSING VALUES - I I I	I I 00 17500.00 20000.00
RIVER SIOUX DOMOUT 0			·	*	* * *	* * * * * * * * * * * * *	**************************************	 			
EACRWATER STUDY Borobyle,) English Borobyle,) English	HEASURED 11500AAFUE 18 -250,00 8750,00 11			ныны			*** ** **		*222 # 2 I * 3452323* # I 22 3 3 3* # I 224242** # I		1 000.00 7500.00 1000
at SIDUX LOOKOUT (CKEATION IMTE = 3 (3456 G	(1.54N) RMEAS	1921-1980							*	I #56997453 = #5699797453 = #5699953 = #5999953 = #5999653 = #5999653 = #5999653 = #5999653 = #5999652 = #5999652 = #5999652 = #5999652 = #5999652 = #5999552 = #59995552 = #59995552 = #5999552 = #5999555 = #5995555 = #599555 = #5995555 = #59955555 = #59955555 = #59955555 = #59955555 = #59955555 = #59955555 = #599555555 = #599555555 = #5995555555 = #599555555555 = #5995555555555555555555555555555555555	I 8672* I 26** +++++ 0.00 2500.00 50
ENGLISH RIVER (File Mislors Subfile Oci33	SCATTER SKAN OF		1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 17500.00 +	I 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1000001	7500.00	£000 • 00	2500.00	0.0

i 7

FIGURE 10

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	scottart. And faile		500 .00	2500.00	00.0000	7560.00	00 0005	.2500.00	000001	7500.00	5000.0 0	00.005	00.0	•
10/22. FAGE 6	SBFILES DISCHARGE AS A FUNCTION OF	21250.00 23750.00 	+ = = = + *	د، • • • • • •						R)		о о		000.00 22500.00 25000.00
1/08	SIDUX LODADUT 0'S 1921-80 N 3 (ACK02S) G#EASE	13750.00 16250.00 18750.00			*		H & H H H * * * * *	******		STATISTICS. STATISTICS. CORRELATION (F STD ERR OF ER FI DITFI VALUES	R SQUARED INTERCEFT (A) EXCLUDED VALU SIGNIFICANCE SLOFE (B)	MISSING UALUES I I I	- - - - - - - - -	500.00 15000.00 17500.00 200
RACKWATER STUDY	80/03/18.) ENGLISH FIVER S 35,590 Measurer fischarge in CFS	6250.00 6750.00 11250.00	- 		ы ы ы ы ы	bed bed ped bed	минии	11111	I I X X X X X X X X X X X X X X X X X X	1400 1400 1400 1400 1400 1400 1400 1400	₩ 5×5×2 ₩ 1 4324534×22 I 2224222 ₩ I 132×3 ₩ I 13 ¥ ₩ I	1 		
AT SIDUX LOONDUT	S (CREATION DATE = 13 03456 0 1 (POWN) OMEAS 1	1250.00 3750.00	• • • • • •	1921-1980		/	1	¥	1		* 200 * 200 * * * * * * * * * * * * * * * * * *	22999944#	I 6952 I 262 +	.++++++
ENGLISH RIVER	FILE MUSLOOS SURFILE 0213 Scattergram OF	- - -		1 22500.00 +	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 1200.00	1 15000.00	12500.00 +	1100000	7500.00	C C C C C C C C C C C C C C C C C C C	52 2200.00	00.0	

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80/10/22.



FIGURE 13 HYDROGRAPH COMPARISON - SIOUX LOOKOUT AND UMFREVILLE NUMBER SHOWN = <u>CFS METERED AT ENGLISH RIVER NEAR SIOUX LOOKOUT</u> MEAN DAILY FOR ENGLISH RIVER AT UMFREVILLE



TABLE 1 TABLE 1	JURGELAU WALKLE
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CORRELATION COEFFICIENTS.. FOR THE PERIOD 1921-1933

	YEAR	AREA	VELO	RIVH	QMEAS	EQGH	BCG	LANH	BCNU	CORF	AFLL	FAFN
YEAR	1.00000	06531	09425	11429	07765	12855	07611	.45276	.11270	<u> </u>	70586	02989
AREA	06631	1.00000	195191	• 77023	24043	¥95677	495817	.71541	12547	13170	24294	-+81677
VELO	09425	*95191	1.00000	97918	01964	.98591	199351	.70336	25141	05757	21954	27440
RIVH	11429	.97023	97918	1.00000	.96180	06986	308255	.70189	13406	20069	20162	
OMEAS	07756	24043	.99610	96180	1.00000	\$7224	-20144	.20264	27048	04024	23182	73049
EDGH	12865	95677	19292	06984.	.97224	1.00000	• 97830	.68792	29220	09501	14261.1	₹.82 835
BCG	07511	95817	2.99351	+ 98255	.99144	.97830	1.00000	.71235	15472	15095	+.0000	76543
I AKH	45274	7154	70335	. 70163	.702 - 4	•68792	-71235	1.00000	06477	20295	215 E8	75934
	02611	C 7 5 C 7 -		13405	27049	29220	13472	04477	1.00000	061651-	15-:0	.03460
		18170		- 2000 -	040.1	09501	15005	いっこう。ー	59990	1.00000	.12570	.27073
AF1		19745	21954	20102	23187	19241	+2925	839:7	01331	.12590	1.00030	.39406
FAFN	02989		77440	- 85250	73045	8283ó	76543	-,75994	.03450	.27073	·39406	1.00000

CORRELATION COEFFICIENTS.. FOR THE PERIOD 1934-1936

	YEAR	AREA	VELO	RIUH	QMEAS	EGGH	P C/0	LAKH	BCNU	C 0K7	AFLL	FAF~
Ŀ.	1.00000	•08¢33	,09 ⁻⁵ 4	.16164	.09146	.11843	:135ē;	.14245	.12313	2175:) -ÉLQ*-	14200
	N9990.	1.00000	.85749	.90684	.88335	.89857	.908.3	•25413	07720	10-42.	- 145	- * 35 * 1
c	FE.250	85749	1.00-00	94199	.98877	.98168	.96516	-43612	-*536*5	.4187.	1.380.	
Ξ	.14144	POAR 4	.94199	1.00/00	.92944	.95295	.98952	:56283	13020.	.1599.	-1201.	45801
	09145	0.88839	98877	.92944	1.00000	.97816	.96445	.42977	26774	.44632	.28510	26437
Ĩ	.11863	. A9857	98168	.95295	# 7816	1.00000	.96541	.46113	26494	- 40121	26705	32326
	18511	90B13	.94514	.98852	96445	.96541	1.00000	024430	03779	.23552.	.17107	0925E -
1	14242	52418	43612	59589	42977	+46113	.56430	1.00000	.37536	27916	71017	88589
. 3	12313	07726	- 23942	.03931	26774	25494	037.9	.37555	1.00000	0101 8 1	1.1304 -	39204
1	21751	24781	43827	.15994	.44607	40122		27815	813-0	000001	.49307	.34970
-	03383	14892	.2882.	.14219	.285.10	,26705	.17107	- 1012 -	- 1000	40307	1.07733	- 69 000
z	- 14255	39412	28500	45821	26437	32376	39240	8858	39264	•24020	CC069.	1.00000
:)]											

CORKELATION COFFICIENTS.. FOR THE PERIOD 1956-1980

	YEAR	AREA	VE, D	RIUH	DMEDS	HUUB	BCN	LANH	Biot co	COH:	AFLL	F af
YEAR	1.00000	06304	.05387	14530	.04045	.02481	02806	0481:)	r~t 62 *-	. 60 30 3	.02473	.16530
35 F 3	40140 -	1.00000	07215	C1989.	.97475	.97515	.98362	.55405	.30925	11040	20.0	5353-9
VELD	05.787	97215	1.00000	.98098	.98529	.98565	.97644	. 20. 1	24812.	5t+20.	51210°-	41090
HOLA	05571	.98932	. 98098	1.00000	.97435	.97994	00066.	.57359	19925.	13094	08712	55752
	.04045	.97475	.98529	97435	1.00000	.97728	.98945	.48671	.22518	•0560.	Sec 00 *	44331
F004	02401	97515	.98565	97994	.97728	1.00000	.97374	.52180	.14575	.00317	07677	51744
2 4	20800	.98362	97644	99000	.98945	47374	1.00000	53993	.315.0	21030	05229	48245
T T	04840	55455	50242	03225	.48674	52180	26622.	1.0000^	.33513		85600	- 83236
	30454	30956	21862	33997	22:18	.14575	.31959	:1385.	1.00000		26084	
Sherf Sherf	50203 ·	08922	.03449	13094	.07994	.00317	08917	35977	66503	1.00000	.35:41	.33269
0F: 1	ELV.C.	07047	01218	08712	.00285	03637	05229	86600	26054	. 37.761	1.00000	.67193
FALM	.1~389	53548	49590	55752	44441	51744	48245	83236	374,89	09112 2 '	.67193	1.00000

TABLE 2

RESULTS OF MULTIPLE REGRESSION

Dependent Variable- LQMEAS - Log 10 of metered discharge Independant Variables- LGHT - Log 10 of river stage above zero flow point AFLL - Actual fall to Lac Seul LAKH - Lac Seul stage	Increase in R ² .925 .028 .010
Equation- LQMEAS = .975 LGHT + .086 AFLL + .073 LAKH - 2.18	Total R ² . 95
Dependant Variable - QMEAS - metered discharge Independant Varibles - RIVH - river stage	Increase in R ² .886
FAFN - ratio of actual fall to normal fall AFLL - actual fall to Lac Seul	. 029 . 001
Equation - QMEAS = 2410 RIVH + 257 FAFN & 47.7 AFLL - 167970	Total R ² . 92
Dependant Variable - BCKW - amount of backwater	Increase in R^2
Independant Variables - LAKH - Lac Seul stage	. 284
BCQ - base curve discharge for RIVH (river stage	e) .010
AFLL - actual fall to Lac Seul 🥠	. 052
LGHT - Log 10 of river stage above zero flow poir	nt .012
Fruchian	Total R ²
BCKW = 1.74 LAKH00053 BCQ + 1.68 AFLL - 3.48 LGHT - 118.7	. 36
Demondent Veriable - CORE - discharge correction factor	Increase in R ²
Jedenendent Variables JAKH - Las Seul stage	.348
BCO - base curve discharge for RIVH	.074
AFLL - actual fall to Lac Seul	. 050
LGHT- Log 10 of river stage above zero flow point	. 002
	Total P2
Equation - CORF =364 LAKH + .00013 BCQ338 AFLL + .500 LGHT + 25.8	. 47
Dependant Variable - QMEAS - metered discharge	Increase in R ²
normal fall = 78 -RIVH + 4 and the new correction curve that it derives.	. 968
BCO - base curve discharge	. 002
RIVH - river stage	. 002
IAKH - stage of Lac Seul	. 0002
AFLL - actual fall to Lac Seul	. 0000
	Total R ²
QMEAS = .656 QCOM + .624 BCQ - 684 RIVH - 19.8 LAKH + 48521	. 97

TABLE 3

SUMMARY - ACCURACY OF THE COMPUTATIONAL METHODS

DISCHARGES COMPUTED WHEN ACTUAL DISCHARGE METERED AT 5000 CFS

		RANGE OF	CENTRE HALF	RANGE OF ALL	COMPUTED DISCHARGES
AND YEARS USED	R ²	IN CFS	AS % OF 5000	IN CFS	AS % OF 5000
1921 - 1980					
BASE CURVE	ħ6.	5300-7200	38%	4700-8300	72%
NORMAL FALL METHOD	.96	5100-6250	24%	4500-7200	548
MULTIPLE REGRESSION EQN.	.97	4900-5900	20%	4000-6500	528
1956 - 1980	·····				
BASE CURVE	. 98	5400-6000	12%	4750-6700	40%
UMFREVILLE DISCHARGES	.91	4900-5600	148	3500-7000	708
NORMAL FALL METHOD	.98	5100-5750	13%	4500-6750	458

R² = COEFFICIENT OF DETERMINATION