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Lessons from Loads

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Over some 50 years of research experiences relating to watershed hydrology in Ontario, including the International Hydrologic Decade, PLUARG, SWEEP etc. – and involving the measurement and analysis of many hydrologic variables such as precipitation, streamflow, sediment and nutrient loads – many lessons have been learned. This presentation offers some reflections on lessons learned relating to the estimation of stream loadings.

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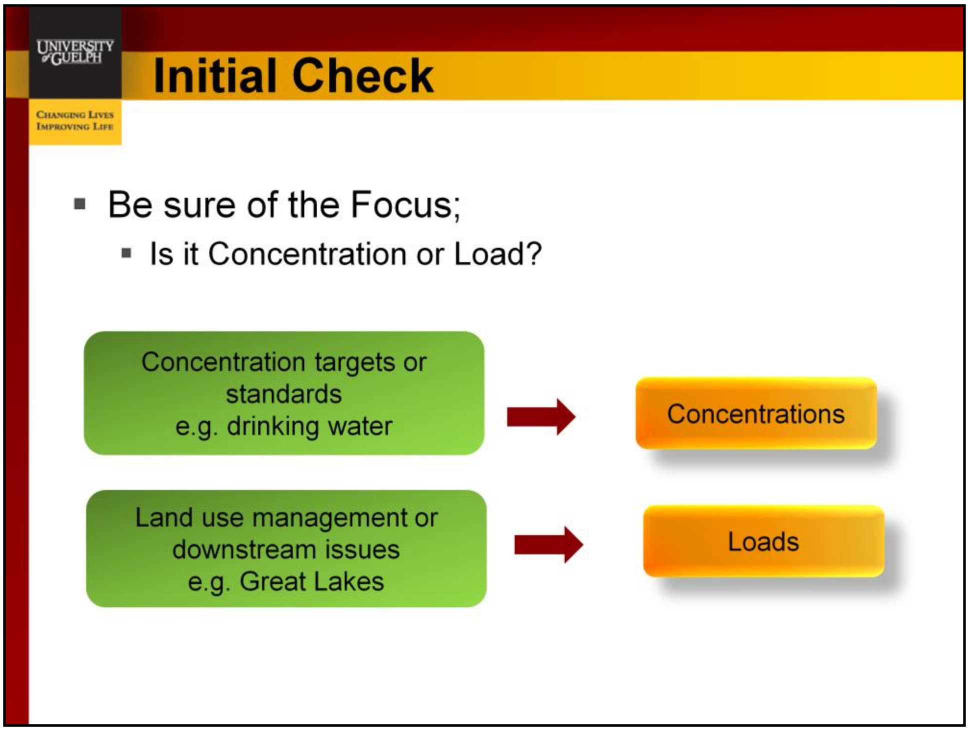
Themes

- The relationship between Concentration and Flow
- The Accuracy of Load Estimates

The lessons learned are discussed in relation to 2 main themes:

- the relationship between concentration (of a variable of interest) and streamflow, and

- the accuracy of load estimates in relation to the method of their determination.

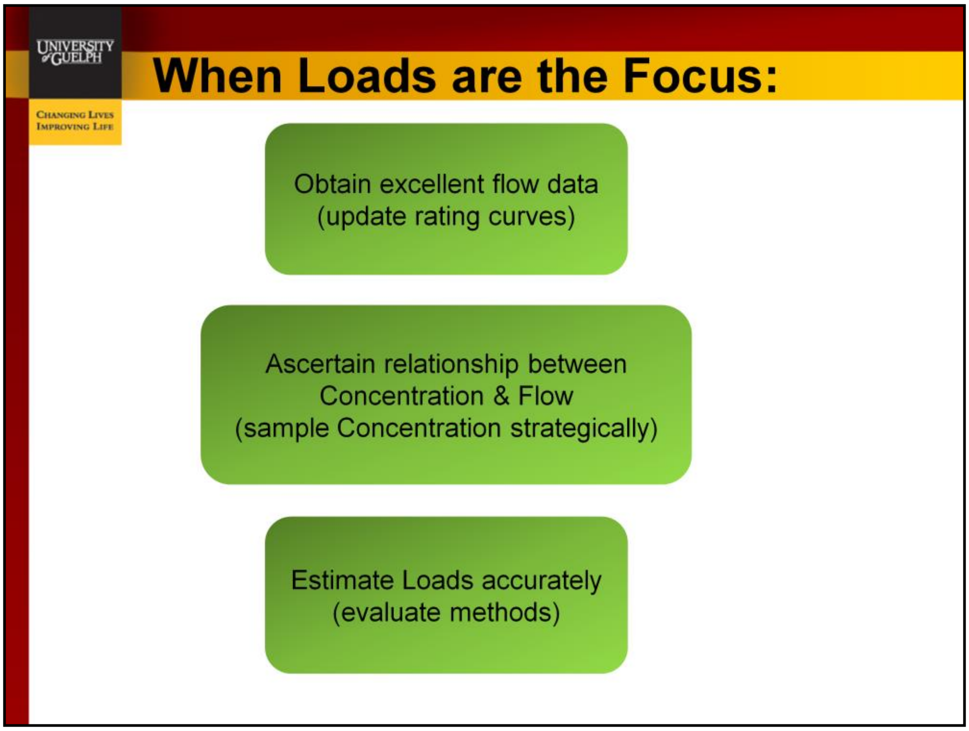


Before addressing the main themes, it is well to ask the question:

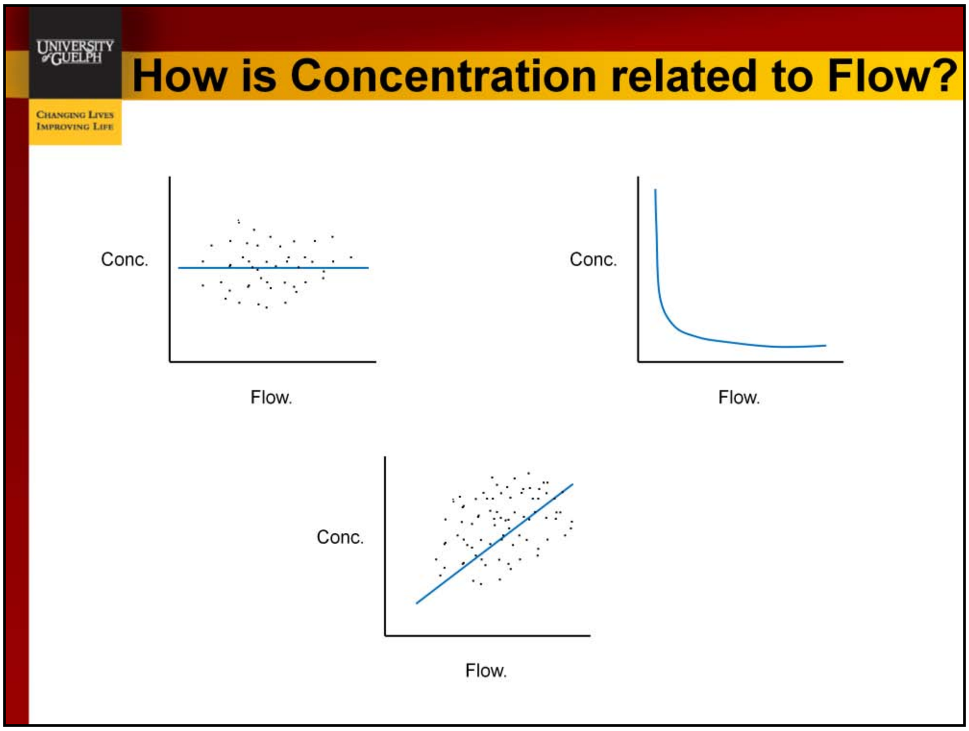
Are concentrations or loads the main concern?

Where concentration targets or standards are of importance e.g. drinking water standards or limiting ecological conditions, then concentrations themselves become vitally important.

Where downstream volumes of material are of concern, because of the subsequent release of concentrations of undesirable variables e.g. suspended sediment, particulate P, it is loads that are important.

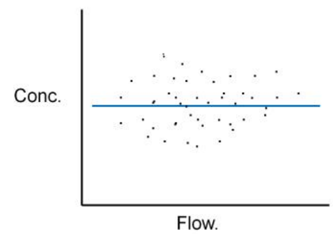


When it has been determined that loads are the prime focus, it is absolutely vital to obtain excellent flow data, including an ongoing program for checking and updating stage;flow rating curves. It is also very important to ascertain the nature of the concentration versus flow relationships, including again a program for checking how such relationships vary with time. Given excellent flow data and reliable relationships between concentration and flow, then one must select a method which can be trusted to provide accurate load estimates.



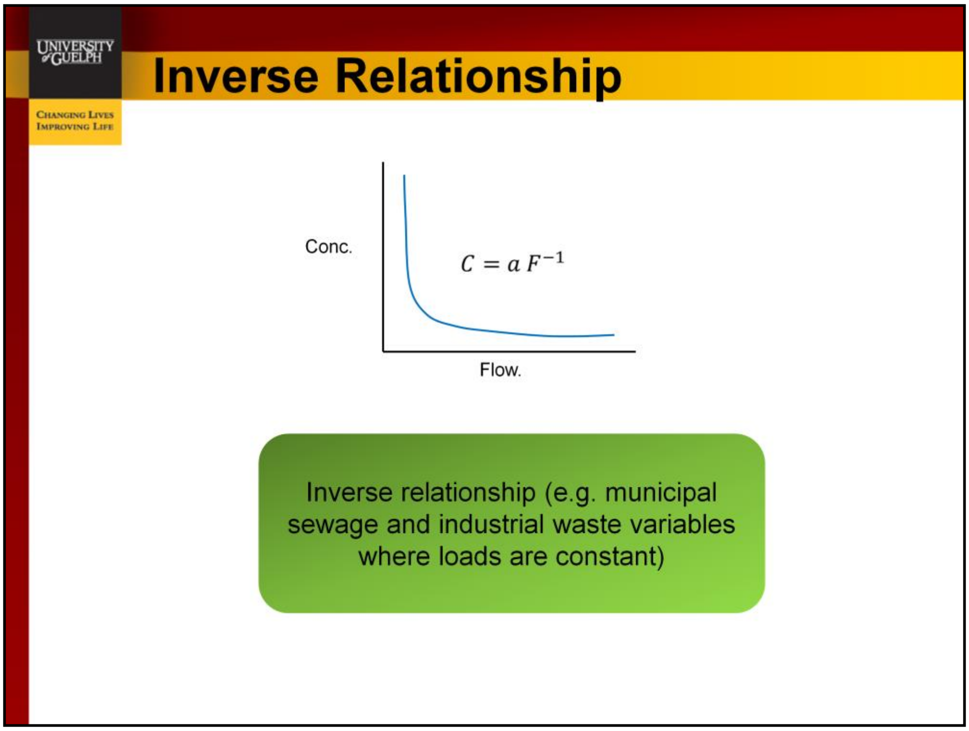
The reason it is important to ascertain how concentration varies with flow is that this relationship can take very different forms for different variables, as shown above.

No Relationship

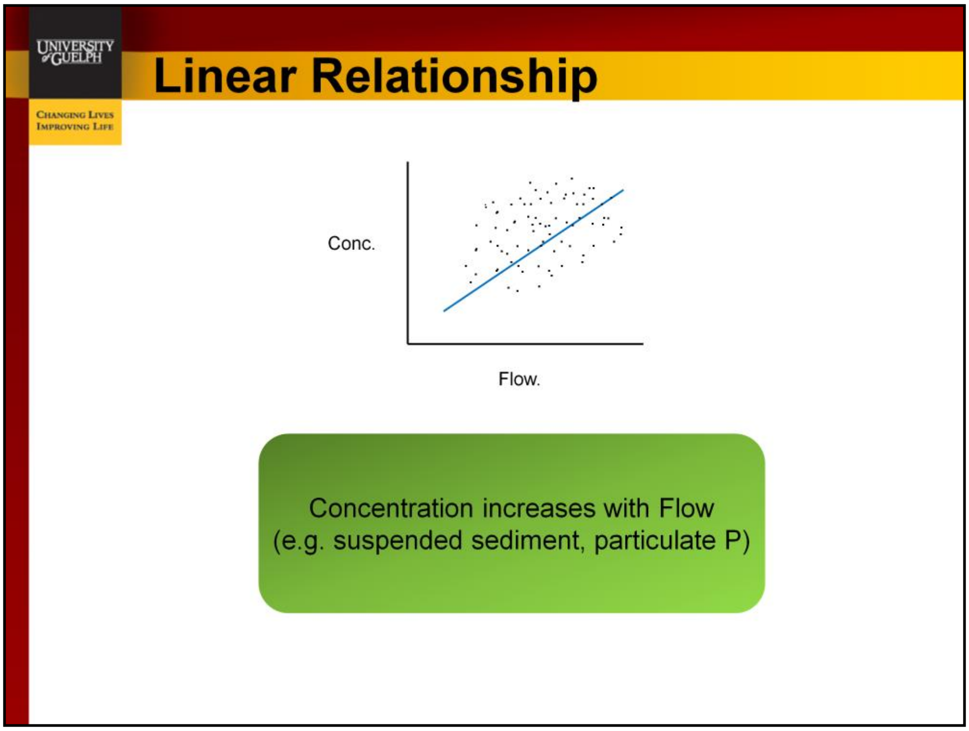


No relationship (e.g. Nitrates)
- Best estimate of Concentration is Mean
- Best estimate of Load is: Mean Concentration × Total Flow

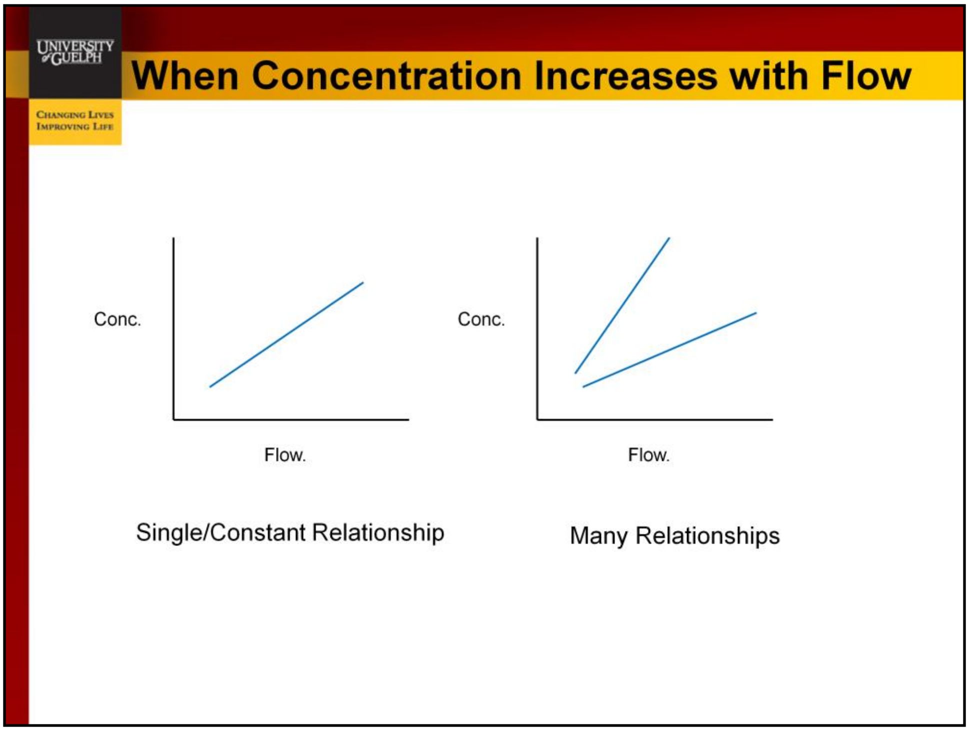
Concentration may appear to be just a random variable, with no obvious relationship to flow e.g. nitrate concentrations in many rivers. In this case, the best estimate of concentration over time is the mean, and the best estimate of load values is the mean concentration times the total flow.



For some variables, for which the load to the river remains near constant e.g. municipal and some industrial waste products, concentration has a strong inverse relationship with flow. From such a relationship, it becomes clear what flow must be maintained (e.g. with flow augmentation from upstream reservoirs etc.) in order to maintain acceptable downstream concentrations (i.e. where such concentrations are the prime concern).

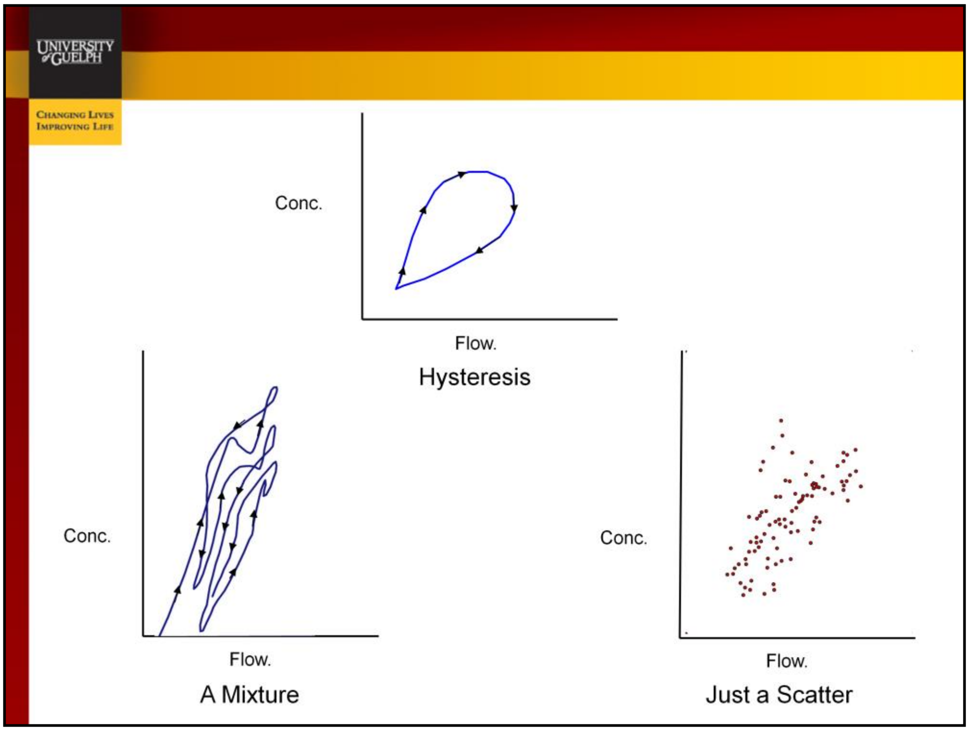


For variables such as suspended sediment and particulate P, concentrations increase with flow – linearly or otherwise.



In some reasonably stable regimes, there may be a single or constant concentration versus flow relationship.

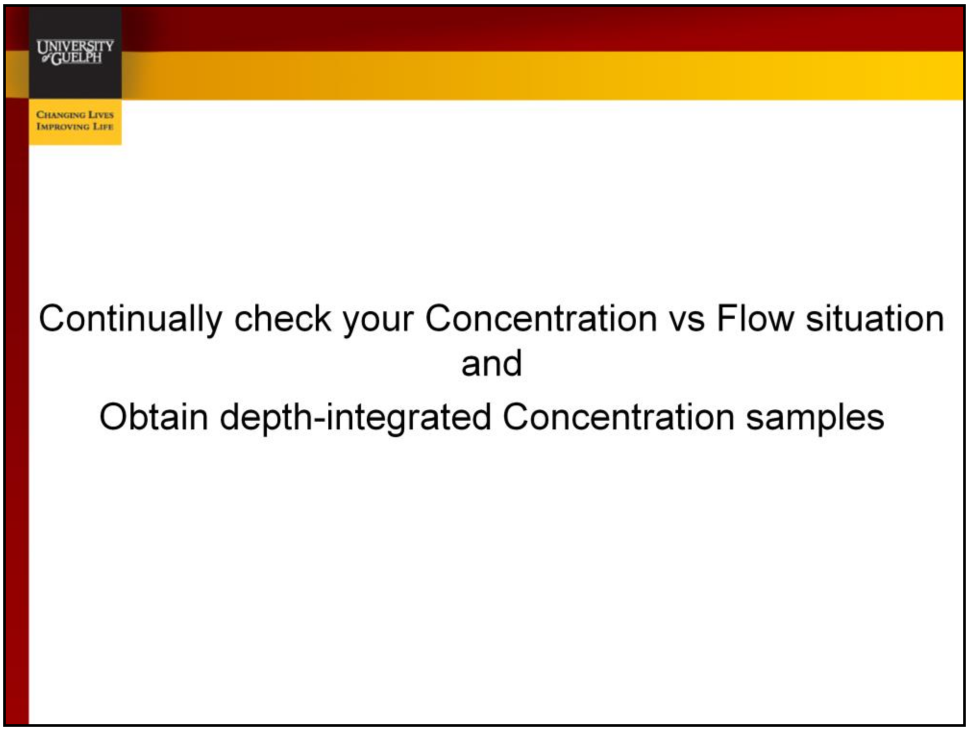
Other times, the relationship may change with time - systematically or somewhat irregularly.



It is not unusual for there to be a hysteresis effect – with concentration values increasing and decreasing in a looped fashion during a runoff event i.e. as the stream hydrograph rises and falls.

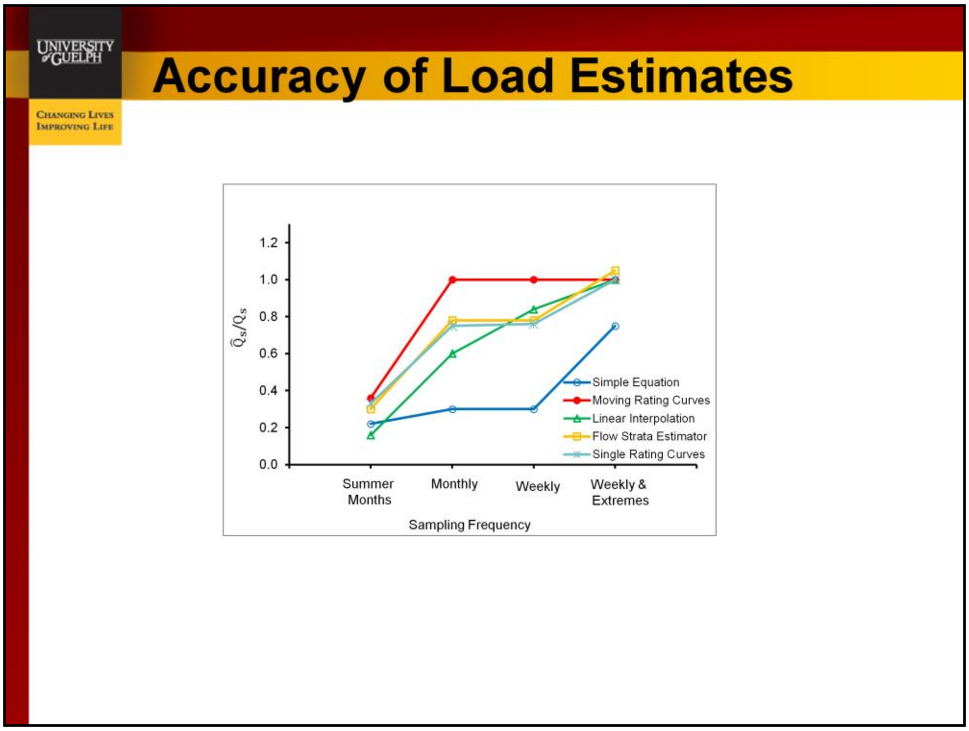
During a sequence of runoff events, there may be a combination of hysteresis effects and a moving relationship.

Or indeed, concentration versus flow may appear to be a scatter diagram; although in such cases it is well to explore the possibilities of hysteresis and/or a moving relationship.



So remember:

- continually check whether and how the concentration versus flow relationship is varying, and
- where possible, obtain depth-integrated concentration values – at least as a check on grab or other samples.



The accuracy of load estimates can vary dramatically, depending on the method of estimation and the frequency of concentration sampling, as shown above for suspended sediment data from the Big Creek Watershed. The index of accuracy used here is the ratio of the annual load estimated by a particular estimation method and sampling frequency to an annual load deemed to be near true.

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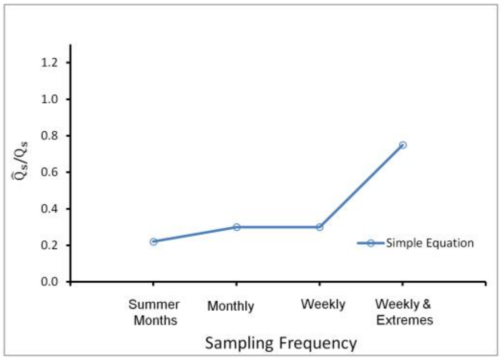
Simple Equation

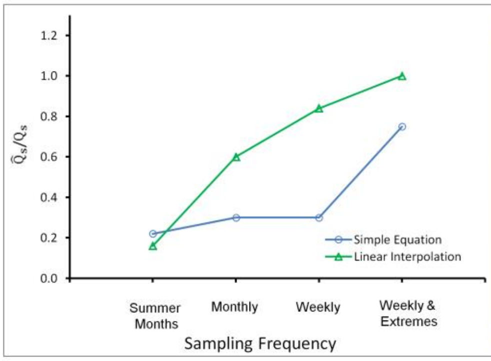


$\hat{Q}_s = C.Q$

Where;
$\hat{Q}_s$= estimated annual suspended sediment load
C = mean suspended sediment concentration for year
Q = total annual streamflow

A very simple method used for estimating annual suspended sediment loads from rivers into the Great Lakes back in the ‘70s involved multiplying the mean suspended sediment concentration for each year (from whatever number of concentration samples had been collected during the year) times the corresponding annual flow. It can be seen that this method is extremely inaccurate, and significantly underestimates the loads – the estimated annual loads being only about 20% of the true loads, until concentrations occurring during significant flow events were included. Even then, the estimated loads were only about 70% of the true loads.

Linear Interpolation



$$\hat{Q}_s = \sum_{i=1}^{365} C_i Q_i$$

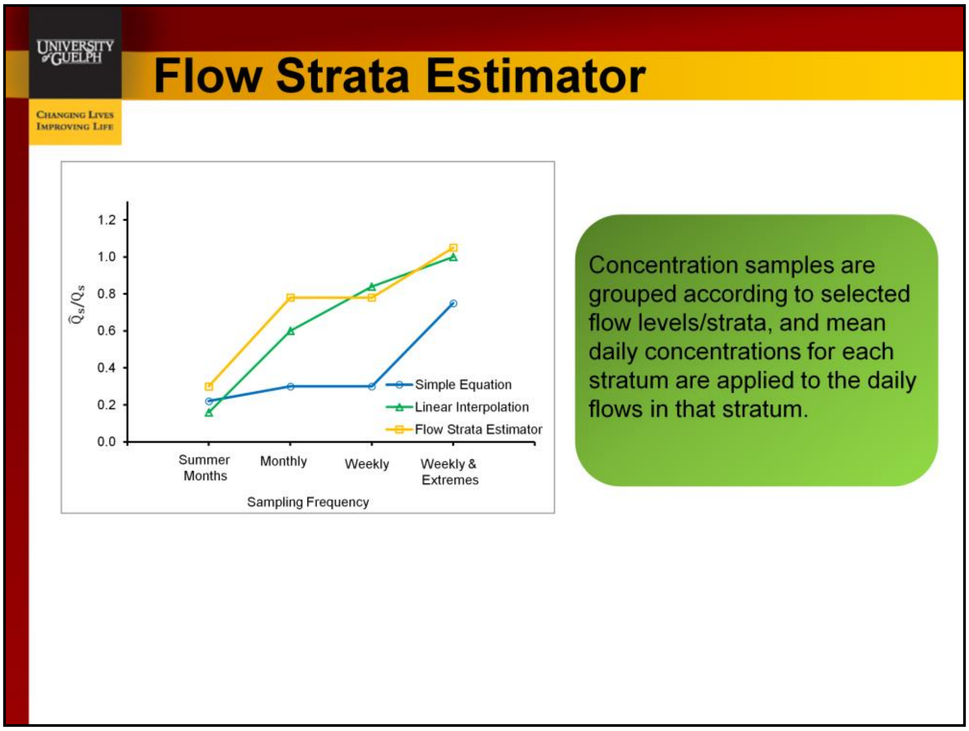
Where;

$\hat{Q}_s$=estimated annual suspended sediment load

C_i = estimated mean daily sediment concentration including sampled values on sample days and linearly interpolated values for non-sampled days

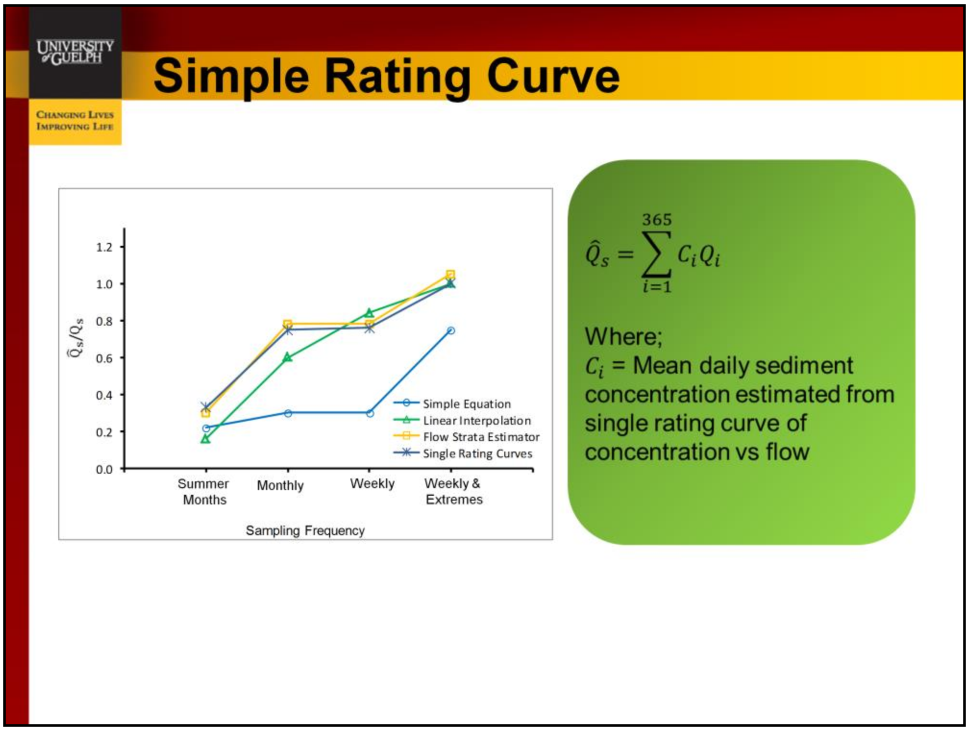
Q_i = mean daily streamflow

For the method involving linear interpolation, sampled concentrations were used to estimate daily concentrations for those days when samples were taken, and otherwise daily concentrations were estimated by linear interpolation between the sampled concentrations, to estimate daily loads. The estimated annual load was then determined by the sum of the daily loads. Again, this method underestimates annual loads, until the sampling frequency increases to include significant flow events.

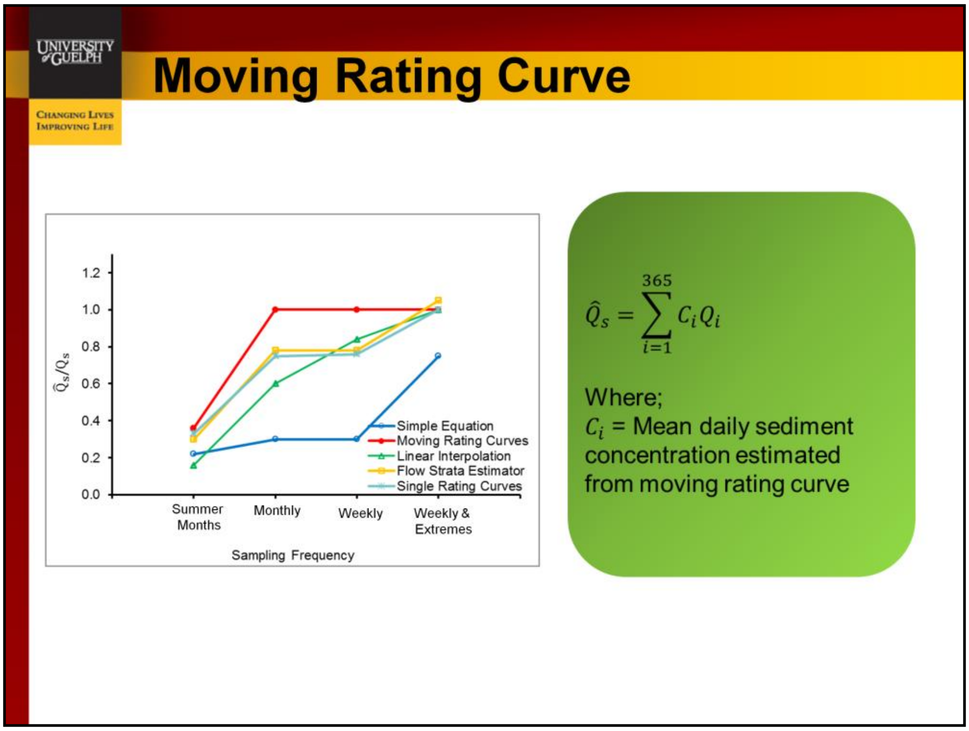


For an estimate based on a consideration of flow strata, the range of flows experienced on the river can be broken or subdivided into a number of flow categories e.g. high, medium and low flows. The suspended sediment concentration values can then also be subdivided into those obtained during flows falling into each category i.e. concentrations obtained during low flows, concentrations obtained during medium flows, and so on. Then mean concentrations obtained during each flow category can be applied to those days with flows in that category.

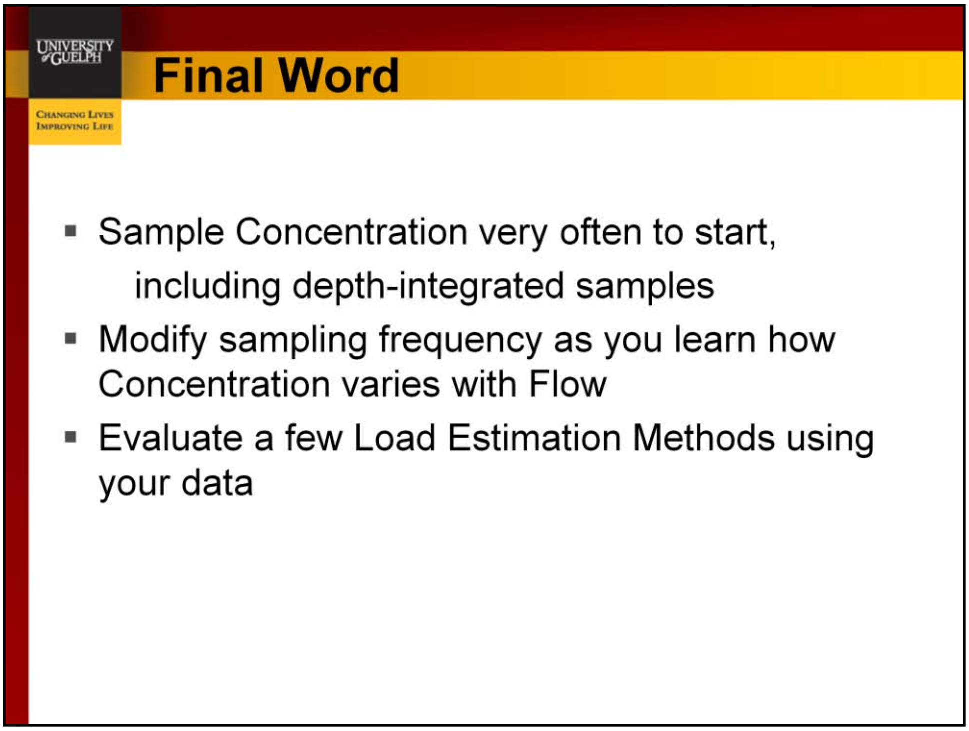
The results shown above were determined on the basis of 3 flow categories. Once again the annual loads are underestimated, in a manner not very different from that seen for the linear interpolation method.



For the single rating curve method, as the name implies, daily concentrations were estimated from a single regression equation fitted to a plot of concentration versus flow data, no attention having been paid to hysteresis or any movement of the relationship with time. Yet again, this method underestimates the annual suspended sediment load until extreme flow events are sampled, and the pattern of accuracy is similar to that seen for the 2 previous methods.

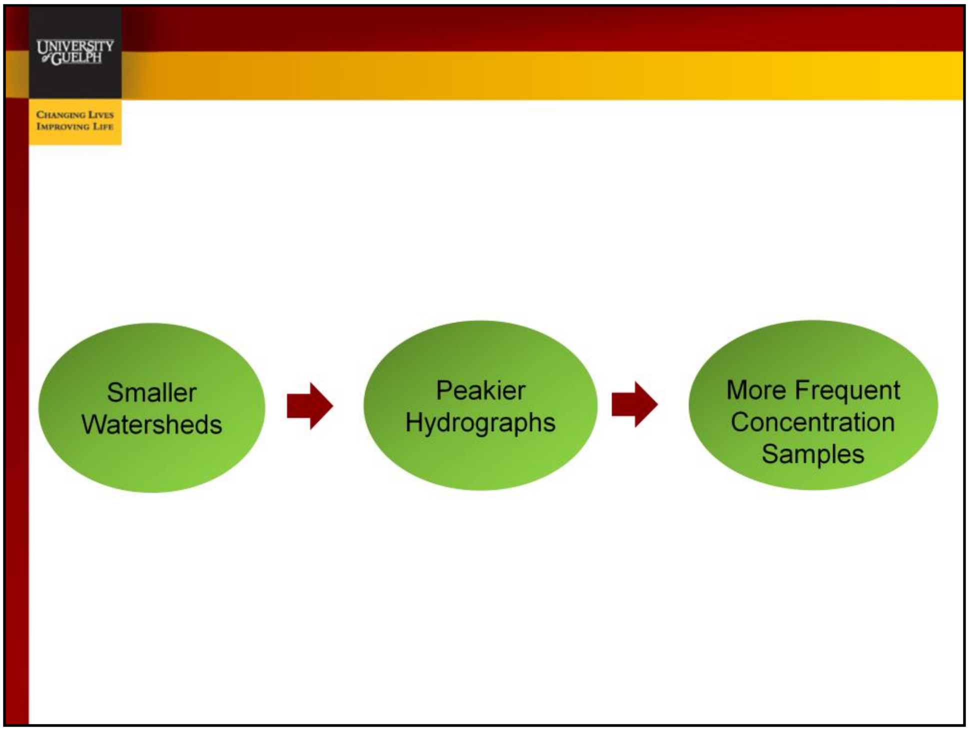


For the moving rating curve method, attention was paid to how the relationship between concentration and flow changed with time, and a series of regression equations were determined to capture this movement. It is clear that, at least for the river under consideration, this method can yield very accurate results for all sampling frequencies except that involving only the summer months. In that case, the concentration data are able to reflect only low flows, and the load estimates are very inaccurate and very low.



In light of lessons learned, I would now begin by sampling concentrations very frequently, over as wide a range of flow as possible and using depth-integrated samples as much as possible.

I would explore the data collected in this fashion in great detail to determine how concentration seemed to be varying with flow. I would then select a load estimation method consistent with the manner in which the concentration versus flow relationship seemed to be varying; and I would play around with reducing the sampling frequency to the extent that I could still be confident that I was obtaining an accurate load estimate.



It is well to keep in mind that, as the watershed study area gets smaller, runoff hydrographs get flashier i.e. peak more suddenly and last a shorter time, and there is therefore a need to sample concentrations more often.

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Thanks

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