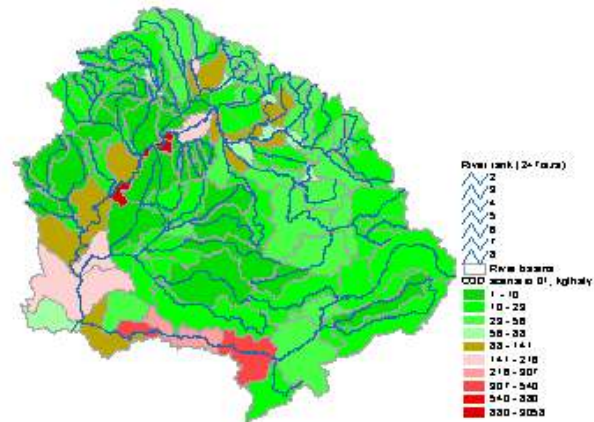
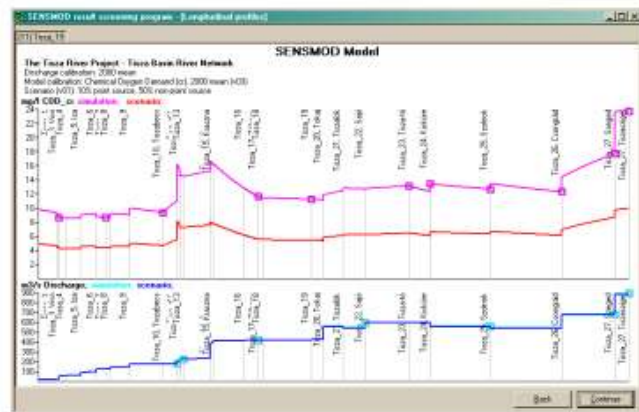


# Monitoring and Pollutant Load Estimation



*The possible most optimistic clean-up scenario for COD removal (90% removal of all point source loads and 50% removal of the load of diffuse sources) by model SENSMOD of VITUKI, COD concentration profile for the main course of the River Tisza and the map of remaining diffuse (unidentified!) pollution loads*

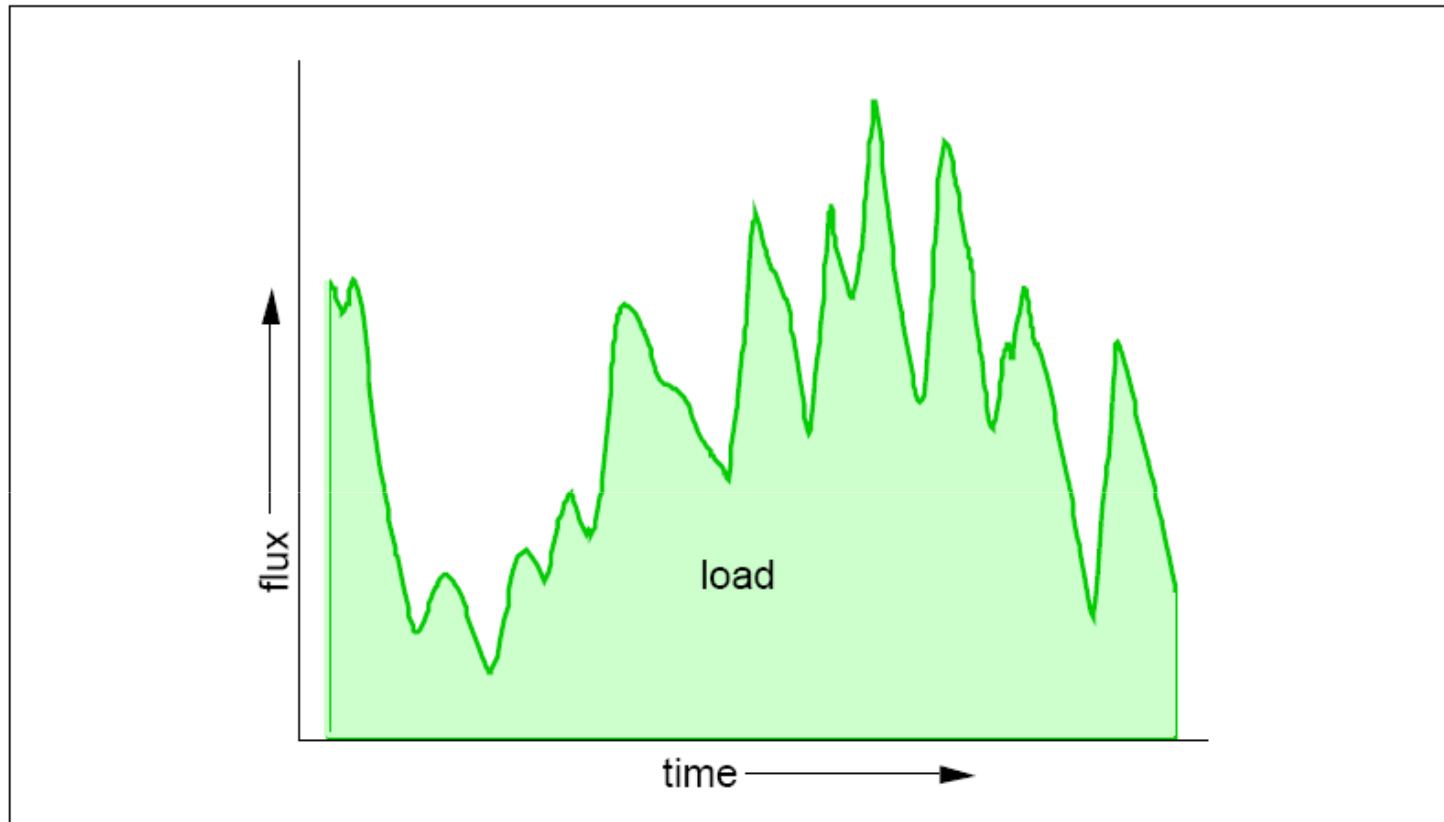
# Definitions

Load = the mass or weight of pollutant that passes a cross-section of the river in a specific amount of time

Flux = the instantaneous rate at which the load is passing a point of reference on a river, e.g., a sampling station

Discharge = the volume of water that passes a cross-section of the river in a specific amount of time

Flow = the instantaneous rate at which water is passing the reference point



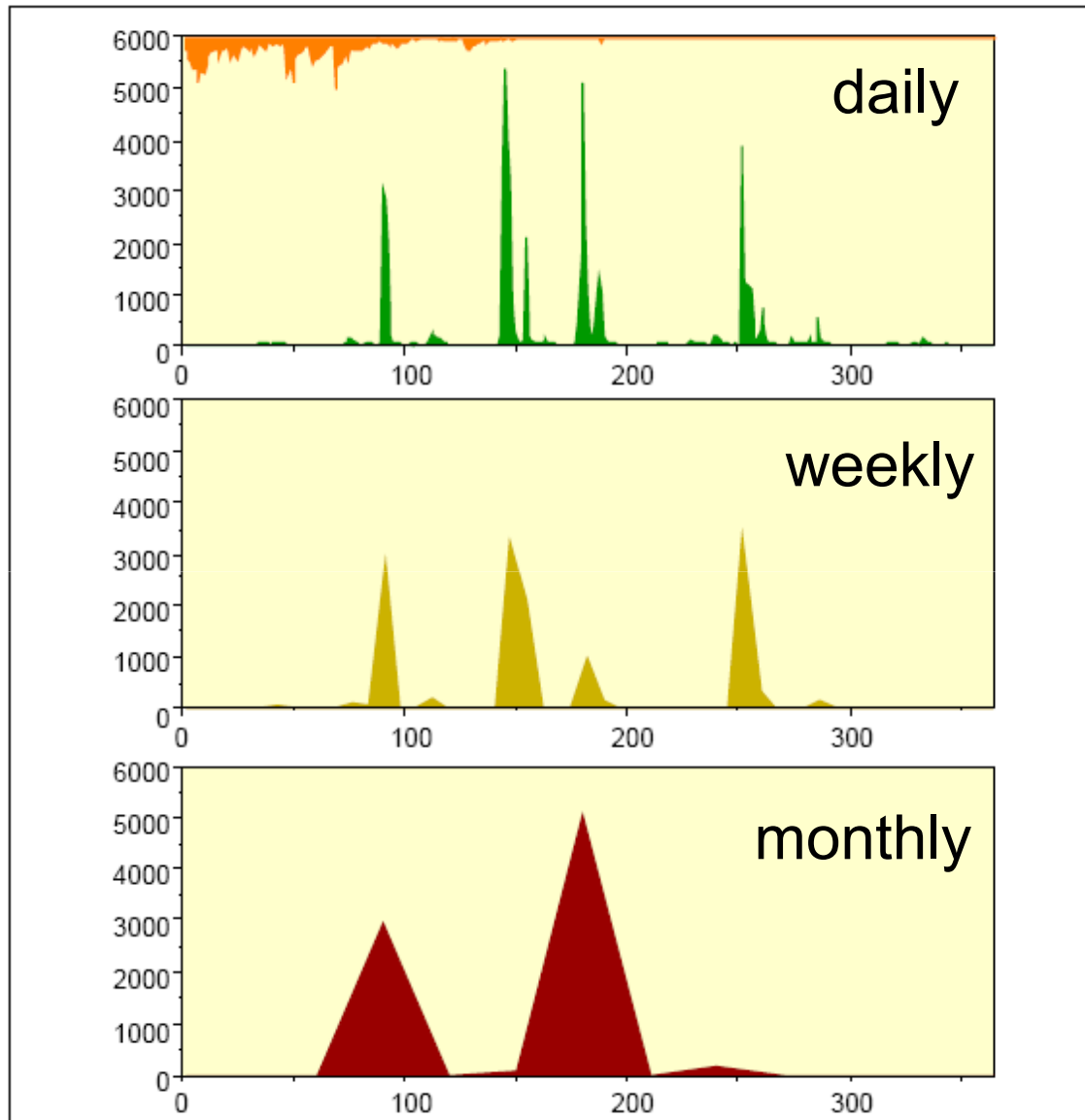
$$\text{Load} = \int_t \text{flux}(t) dt$$

However, cannot measure flux directly, so calculate load as product of concentration and flow:

$$\text{Load} = k \int_t c(t)q(t)dt$$

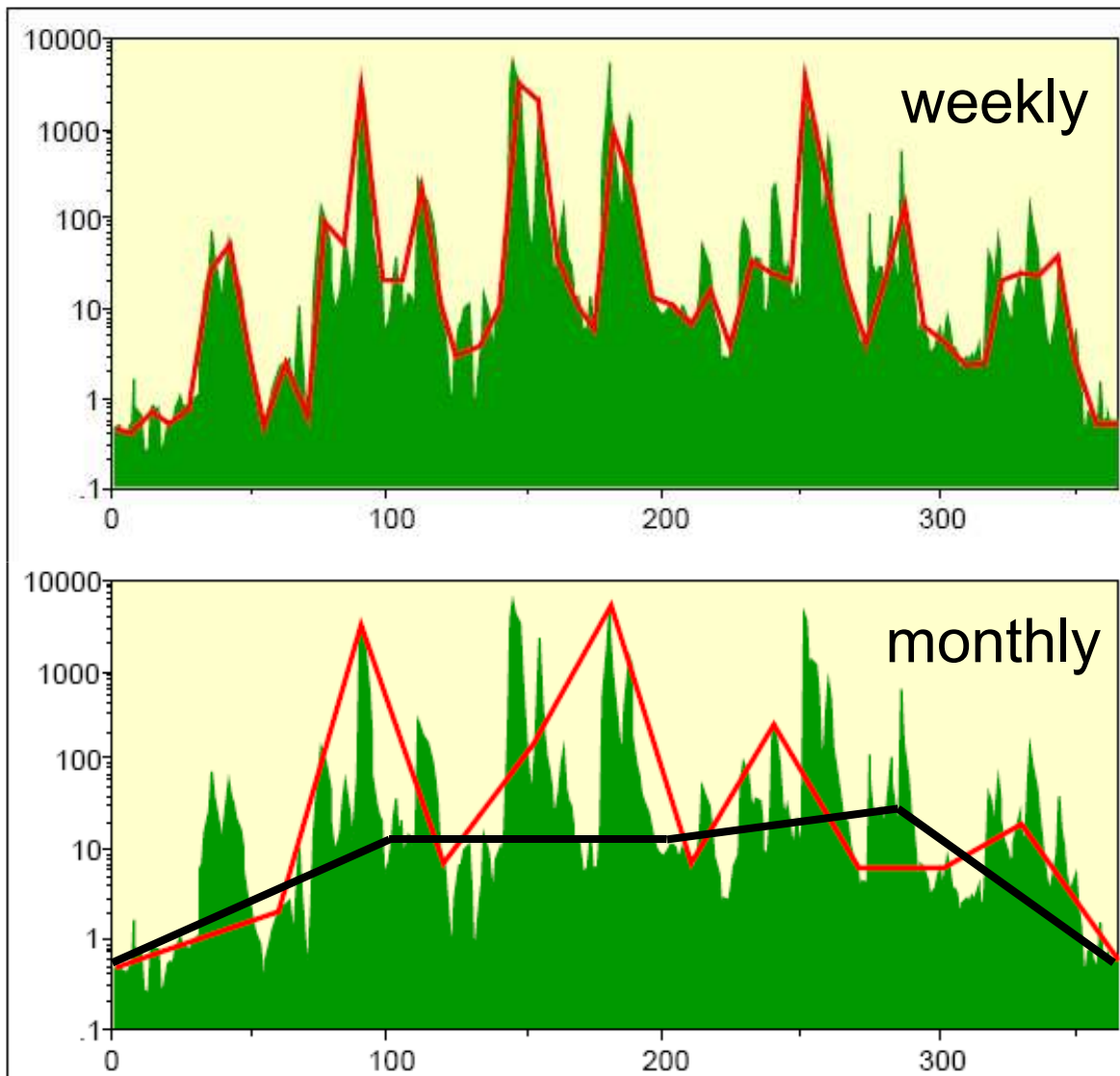
Because we must almost always measure concentration in a series of discrete samples, estimation of load becomes sum of a set of products of flow and concentration:

$$\text{Load} = k \sum_{i=1}^n c_i q_i Dt$$



The central problem becomes how best to set up the discrete samples to give the most accurate estimate of load.

how many samples  
and  
when to take them



Because in nps, most flux occurs during periods of high discharge (~80 – 90% of annual load in ~10 – 20% of time), when to sample is especially important.

Quarterly ~~X~~

Monthly ~~X~~

Weekly ?

- **Total load** is the load over the main period of interest, e.g., one year  
is represented as the sum of
- **Unit loads**, i.e., individual calculations of load as product of concentration and flow over a smaller, more homogeneous time span.

The central problem is to accurately characterize  
all the unit loads;  
adding them up to the total load is simple.

# Practical load estimation

Ideally, most accurate approach to load estimation is to sample very frequently and capture all the variability.

Flow is relatively straightforward to measure continuously

Concentration is expensive to measure and in most cases impossible to measure continuously.

**Must choose a sampling interval to give an appropriate characterization of concentration component.**

# Practical load estimation

**Grab samples** – represent concentration at a single point in time

**Fixed-interval** (time-proportional) samples – poorly suited for load estimation because they ignore changes in flow that occur between samples and are usually biased toward low flows

**Flow-proportional** samples - ideally suited for load estimation, can provide a precise and accurate load estimate if the entire time interval is properly sampled.

# Practical load estimation

In general, the accuracy and precision of a load estimate increases as sampling frequency increases.

- Sample frequency determines the number of unit load estimates that go into our total load estimate → more unit loads mean we are more likely to capture variability across the year and not miss an important event
- Because of autocorrelation, at some point, greater sample frequency will not improve load estimate

# Practical load estimation

Timing of samples more complex than frequency

Selecting when to collect samples for concentration determination = selecting when the unit loads that go into an annual load estimation are determined

Consider sources of variability, e.g., season, flow, agricultural activities

# Practical load estimation

1. Find a way to estimate "missing" concentrations to go with the flows observed at times when chemical samples were not taken.

- ~~2~~ Abandon most of the flow data and calculate the load using the concentration data and just those flows observed at the same time the samples were taken.

3. Do something in between - find some way to use the more detailed knowledge of flow to adjust the load estimated from matched pairs of concentration and flow.

# Practical load estimation

When decision to calculate loads is made after monitoring program is in place or data collected, little can be done to compensate for a data set that contains too few observations collected using an inappropriate sampling design

**The sampling needed for load estimation must be established in the initial monitoring design, based on quantitative statements of the precision required for the load estimate to meet project goals.**

# Practical load estimation

- Is load estimation necessary or can project goals be met using concentration data?
- Determine precision needed in load estimates – don't try to document a 25% load reduction from a BMP program with a monitoring program that may give load estimates  $\pm 50\%$  of the true load.
- Decide what approach will be used to calculate the loads, based on known or expected attributes of the data.
- Use the precision goals to calculate the sampling frequency and timing requirements for the monitoring program.
- Compare ongoing load estimates with program goals of the and adjust the sampling program if necessary.

# Practical load estimation

Someone may say that it's too expensive or complex to conduct a monitoring program sufficient to obtain good load estimates.

***Is a biased, highly uncertain load estimate preferable to no load estimate at all?***

# Approaches to load estimation

## Numeric integration

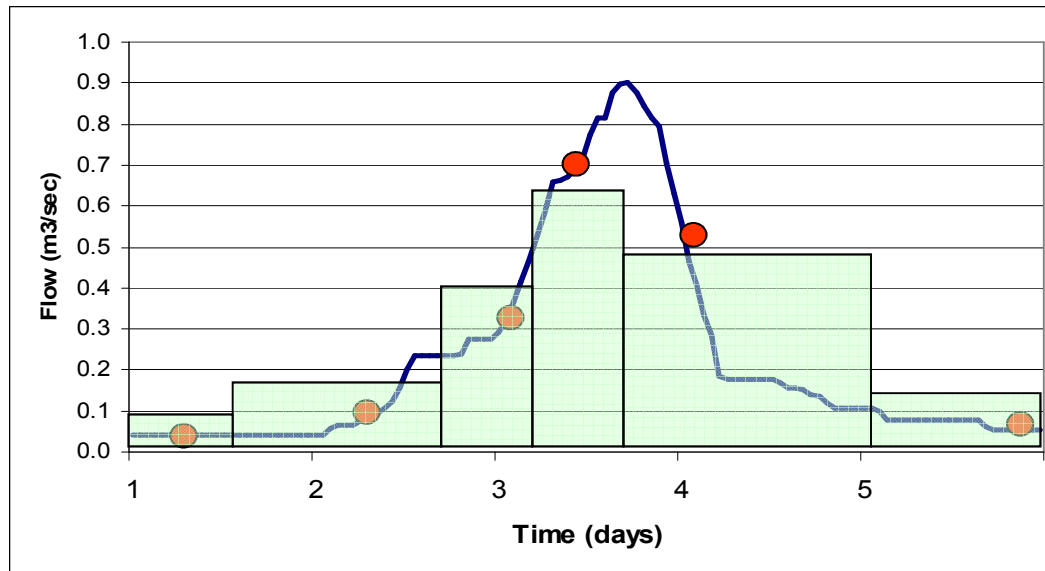
$$\text{Load} = \sum_{i=1}^n c_i q_i t_i$$

$c_i$  = concentration of  $i^{\text{th}}$  sample

$q_i$  = corresponding flow

$t_i$  = time interval represented by  $i^{\text{th}}$  sample

$$\frac{1}{2}(t_{i+1} - t_{i-1})$$



# Approaches to load estimation

## Numeric integration

Question becomes how fine to slice the pie – few slices will miss much variability, many slices will capture variability but at a higher cost/effort.

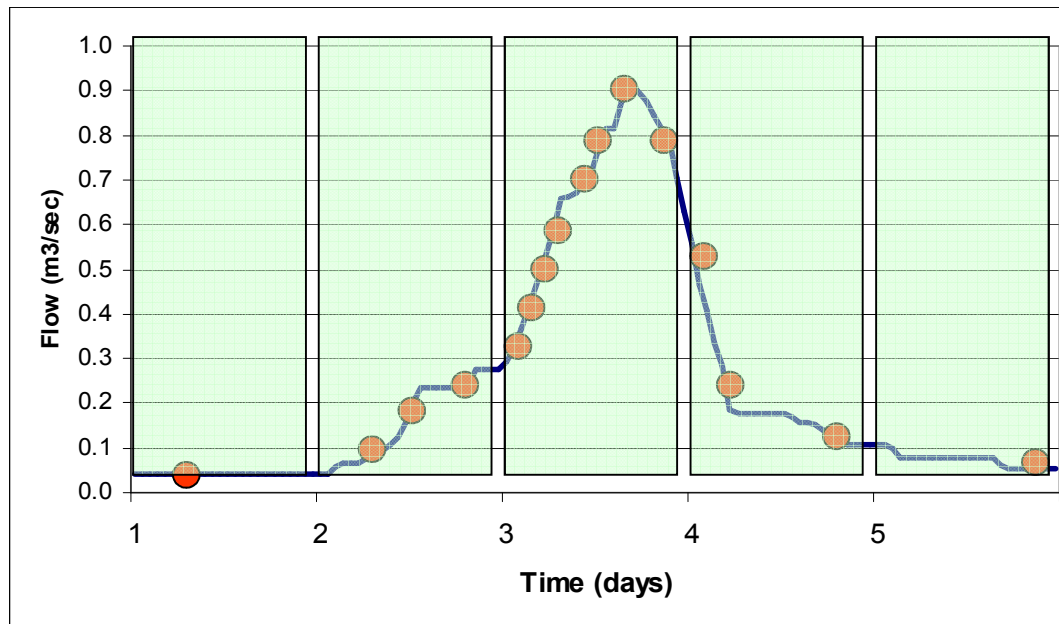
Numeric integration is only satisfactory if the sampling frequency is high - often on the order of 100 samples per year or more, and sufficiently frequent that all major runoff events are well sampled.

Selection of sample frequency and distribution over the year is critical – must focus on times when highest fluxes occur, i.e., periods of high discharge

# Approaches to load estimation

## Numeric integration

### Flow-proportional sampling



**Very efficient and cost-effective method of obtaining total load.**

Requires reliable equipment and careful attention

No information available at resolution less than chosen period

Not compatible with other goals, such as monitoring for ambient concentrations that are highest at low flow

# Approaches to load estimation

## Regression

Regression relationship developed between concentration and flow, based on the days on which samples are obtained.

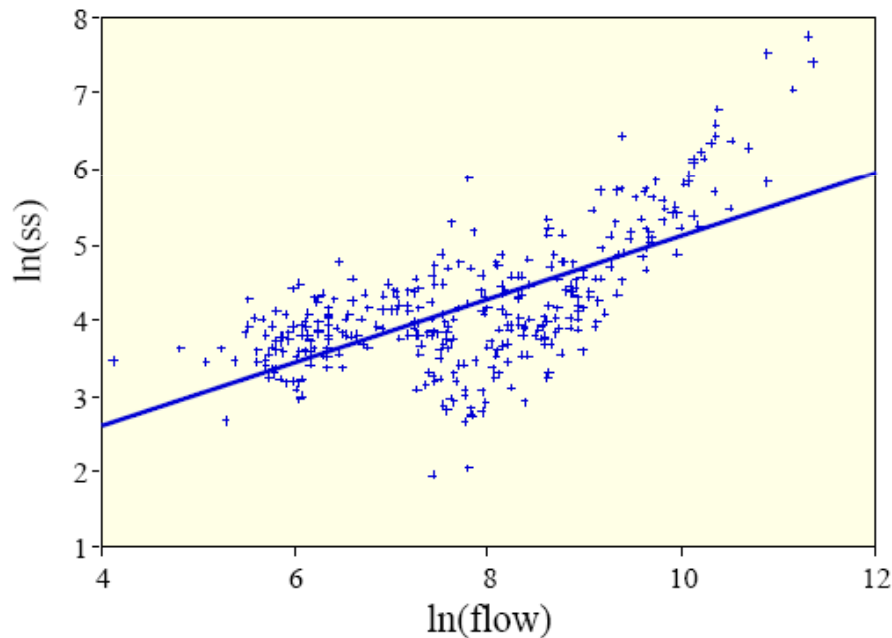
Regression relationship used to estimate concentrations for each day on which a sample was not taken, based on the flow (usually the mean daily flow) for the day.

The total load is calculated as the sum of the daily loads, obtained by multiplying the measured or estimated concentration by the flow

Goal of chemical sampling becomes one to thoroughly characterize the relationship between flow and concentration. May be able to do this with ~20 samples a year, focusing on high-flow or critical season events

# Approaches to load estimation

## Regression



Must pay attention to potential changes or trends in conc-flow relationships – especially where BMPs may influence

Must manage sampling program to effectively capture range of flows/conditions – using data from fixed-interval time-based sampling is not appropriate

# Approaches to load estimation

## Ratio Estimators

On days on which samples are taken, the daily load is calculated as the product of concentration and flow, and the mean of these loads is also calculated.

The mean daily load is then adjusted by multiplying it by a flow ratio, which is derived by dividing the average flow for the year as a whole by the average flow for the days on which chemical samples were taken.

A bias correction factor is included in the calculation, to compensate for the effects of correlation between discharge and load.

The adjusted mean daily load is multiplied by 365 to obtain the annual load.

# Approaches to load estimation

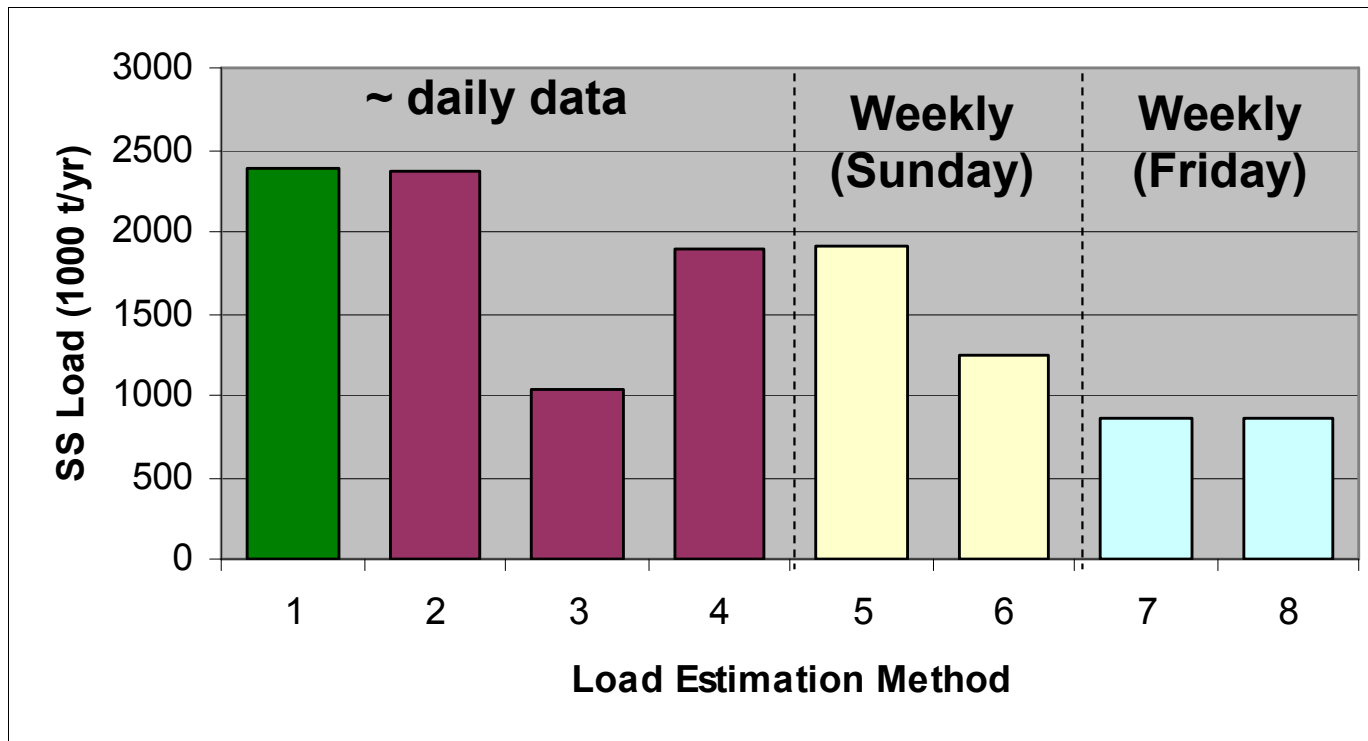
## Ratio Estimators

Stratification - division of the sampling effort or the sample set into two or more parts which are different from each other but relatively homogeneous within, e.g., growing season vs. winter vs. spring

May improve precision and accuracy of load estimate by allocating more of the sampling effort to the aspects which are of greatest interest or which are most difficult to characterize because of great variability such as high flow seasons

*Beale Ratio Estimator* is one common technique; computer programs available to implement.

# Approaches to load estimation



1 – True load (numeric integration)

2 – Beale

3 – Regression

4 – Seasonal regression

5 – Beale

6 – Regression

7 – Beale

8 – Regression

# Load estimation

- Load estimation is not a trivial task that can be done as an afterthought
- Quarterly or even monthly concentration data are unlikely to be adequate for good load estimates
- Emphasize high-flow events, seasons
- Estimating load based on cookie-cutter approach or feeding data into a computer program is dangerous
- If load data are necessary, design monitoring program with load estimation in mind