Dilution Gauging: An Alternative Discharge Measurement

Joe Famularo
Division of Mitigation Services
North Carolina Department of Environmental Quality

Agenda

I. History

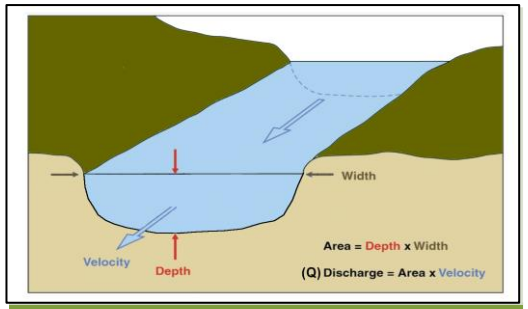
II. Application

III. Methodology

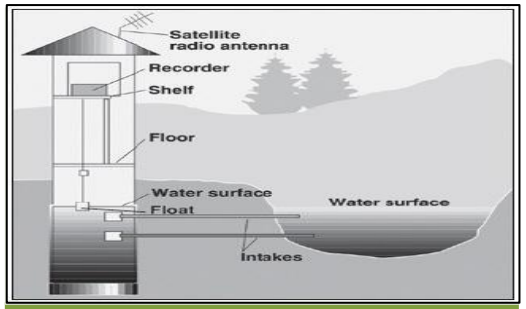
IV. Limitations

A Brief History of Measuring Stream Discharge

Hydrologic Cycle



Discharge Measured



Early Continuous Monitoring

3000 B.C.

1500's

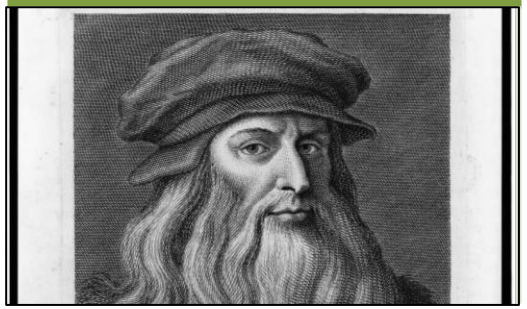
1600's

1700's

1900's

2000's

Velocity Measurements



Velocity Gauges

Digital and Remote

History of Dilution Gauging in Publications

- Dilution Gauging – Well Adapted to Mountain Torrents (Schloesing, **1863**)
- Chemical methods of gauging streams (Dumas et al., **1952**)
- Gauging Water Flow By the Salt Dilution Method (Hutton & Spencer, **1960**)
- The Gauging of Mountain Streams with Particular Reference to The Salt Dilution Method (Carter, **1963**)
- Discharge Measurement in Lower Order Streams (John, **1978**)
- Measurement of Discharge using Tracers (Kilpatrick & Cobb, **1985**)

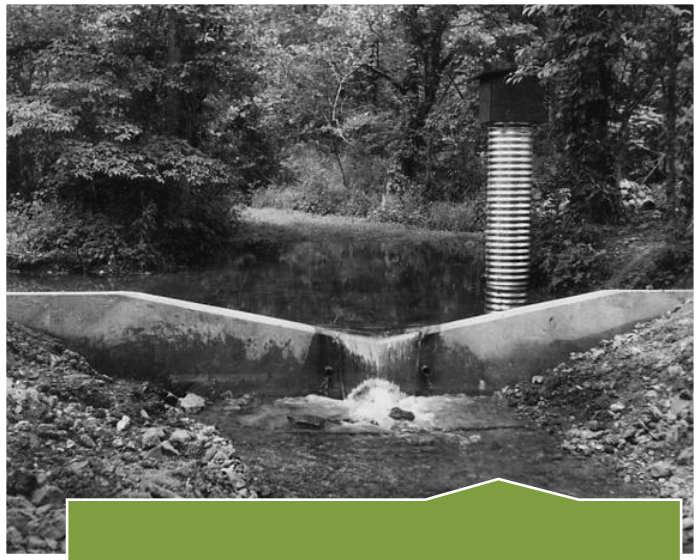
Dilution Gauging – What is it?

I. Method of discharge measurement where a conservative tracer (NaCl, rhodamine dye) in dissolved water is added to a stream and the response is monitored downstream of addition site.

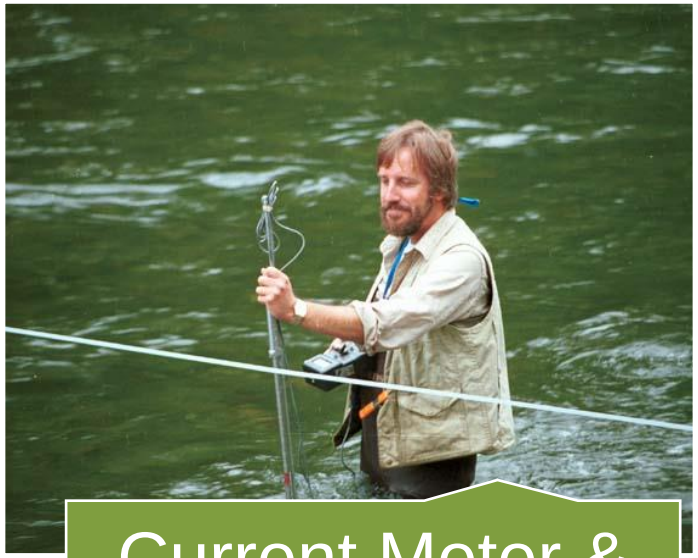
I. Multiple approaches:
   I. Constant rate (AKA plateau method)
   II. Slug addition

II. Fundamentally, the approach uses a known value of added tracer upstream relative to the observed downstream tracer to determine discharge.

Methods of Direct Discharge Measurement



Weir & Volumetric



Current Meter & Doppler

Dilution Gauging

Weir

- Stable and effective at long term monitoring.
- Requires construction and maintenance, restricts passage.

Velocity - Area

- Relatively quick and commonly applied method.
- Seasonal limitations depending on discharge.

Dilution Gauging

- Relatively cheap and the least field-intensive.
- Can take a long time to record data during low-discharge conditions.

Weir

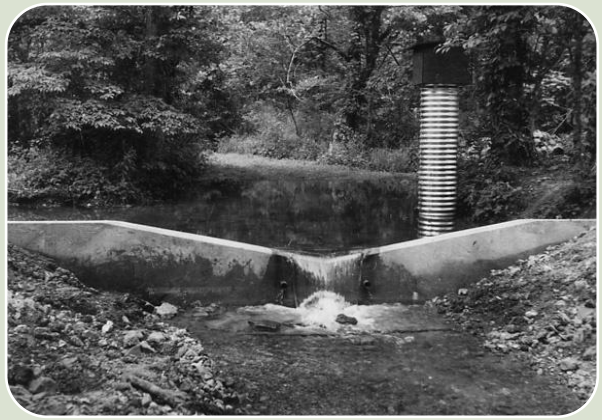
- Construction supplies – varies depending on site

Velocity - Area

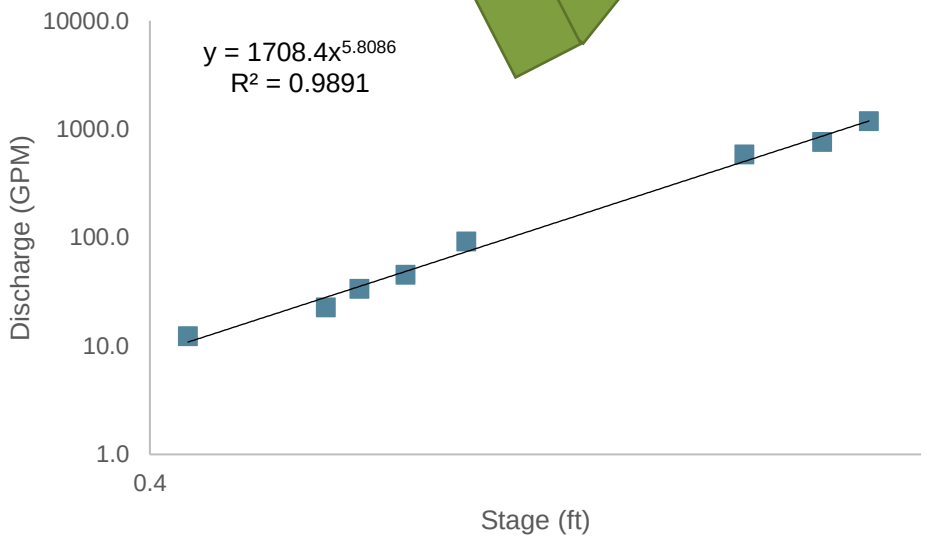
- Measuring tape
- Velocity meter
- Top setting wading rod

Dilution Gauging

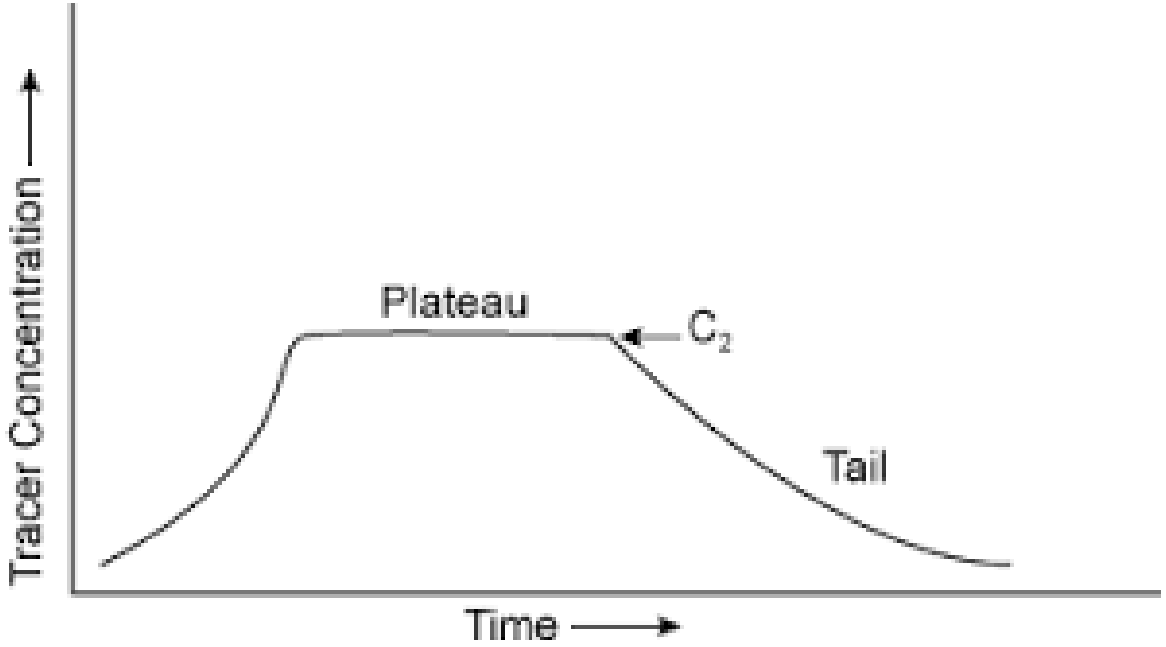
- Bucket
- Conservative tracer
- Conductivity meter or fluorometer



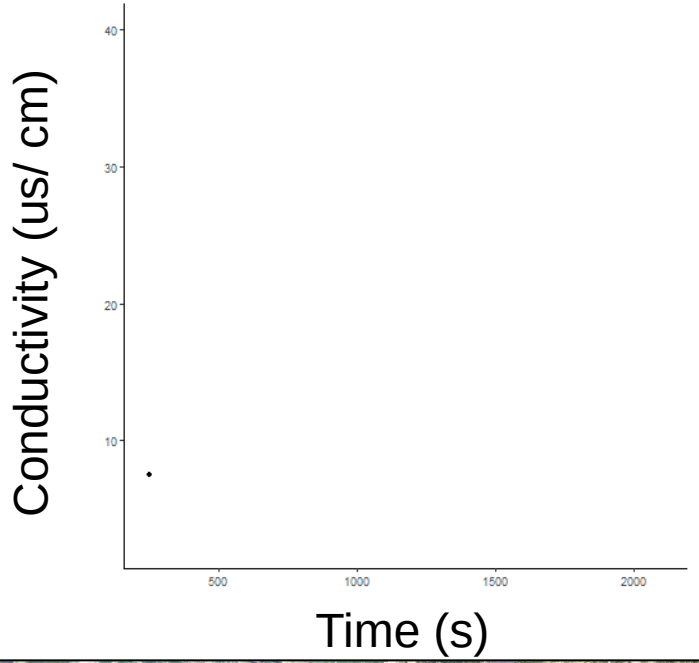
$$Q = 4.28C \tan\frac{\theta}{2}(h+k)^{\frac{5}{2}}$$

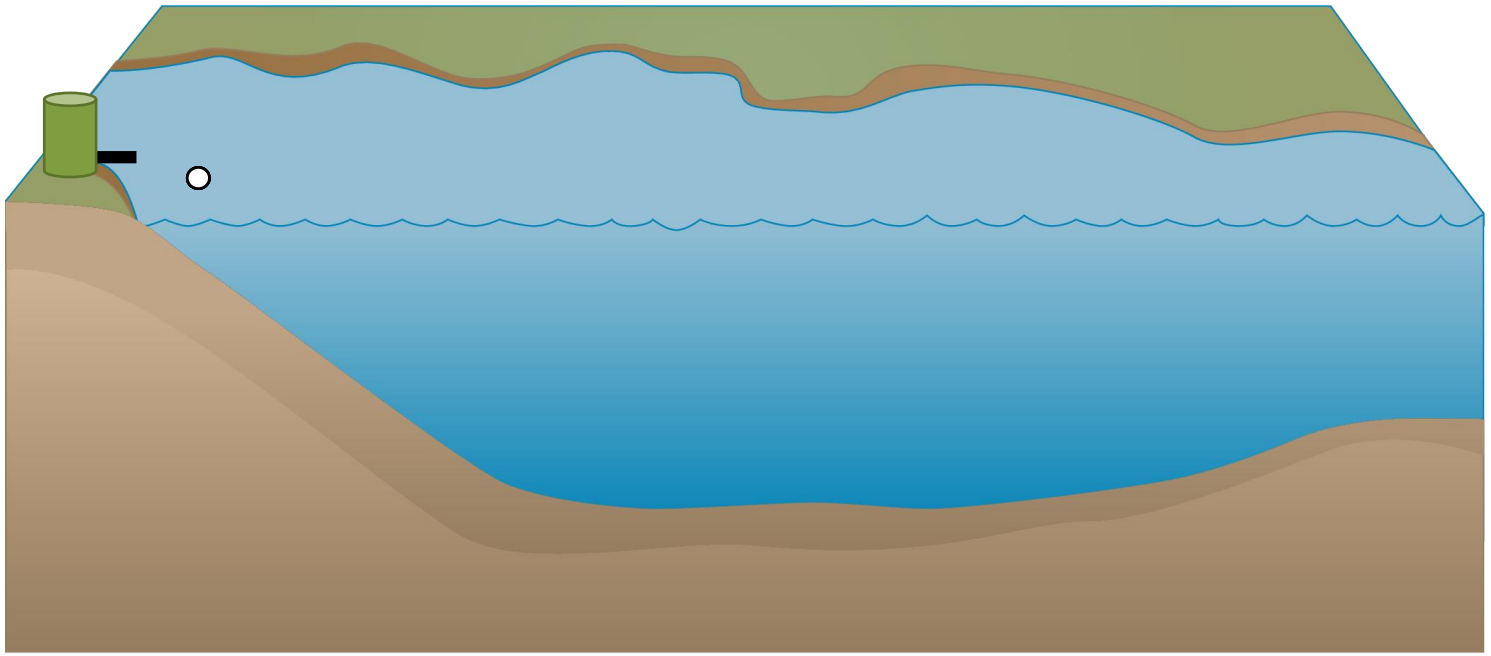


Methods of Discharge Measurement: Dilution Gauging (Constant Rate Injection)

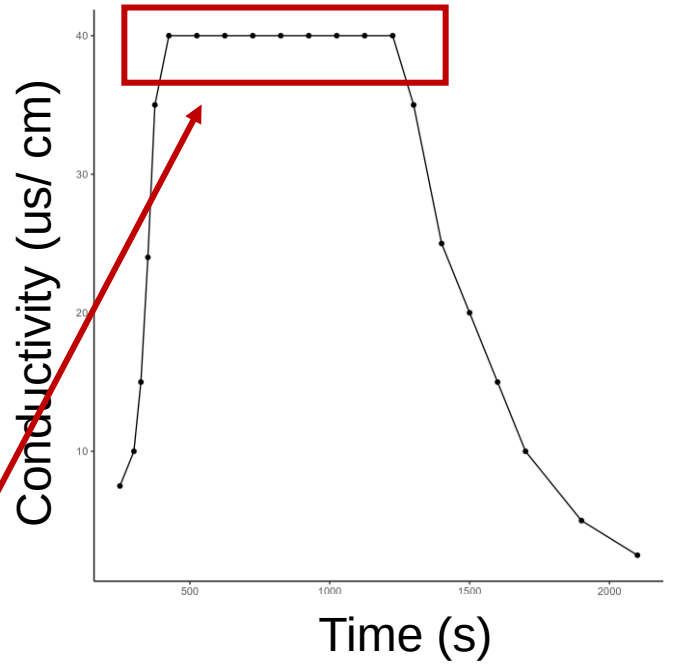


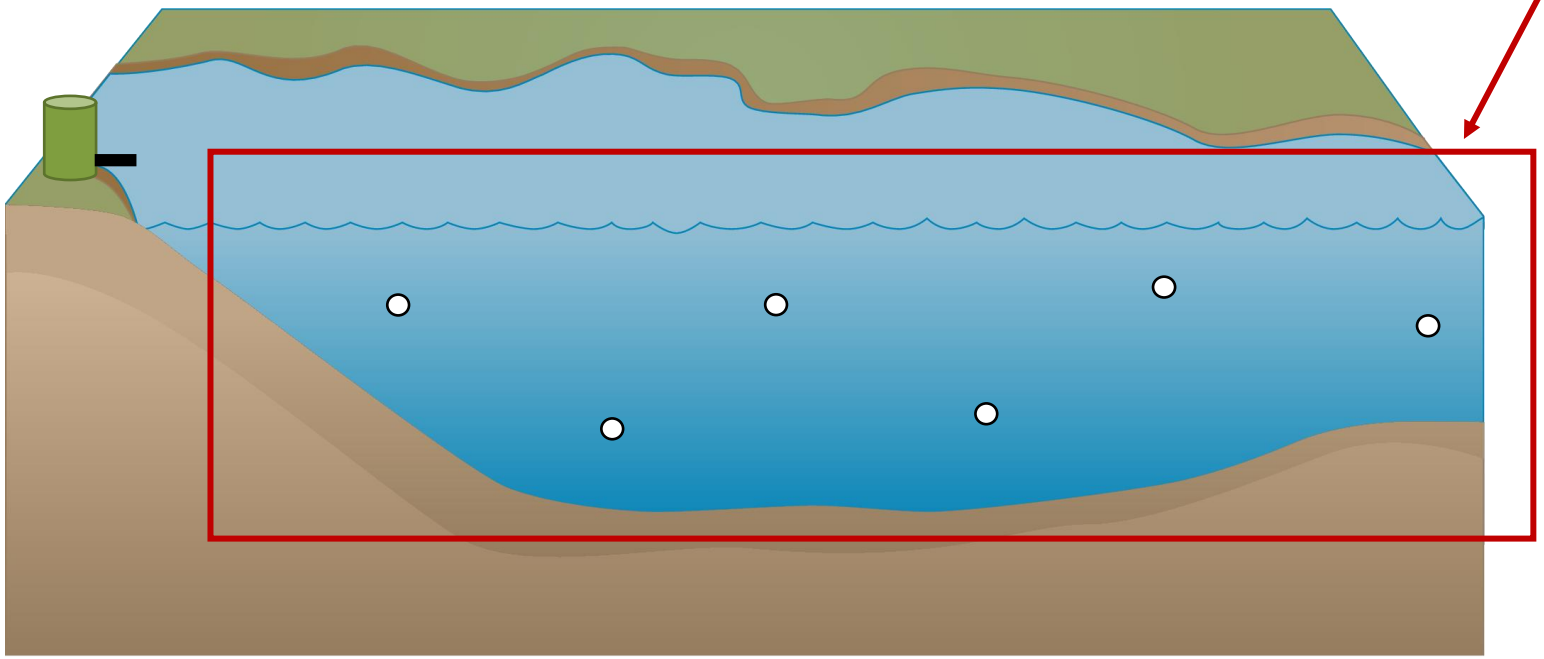
Dilution Gauging (Constant Rate Injection) Visualized





Dilution Gauging (Constant Rate Injection) Visualized

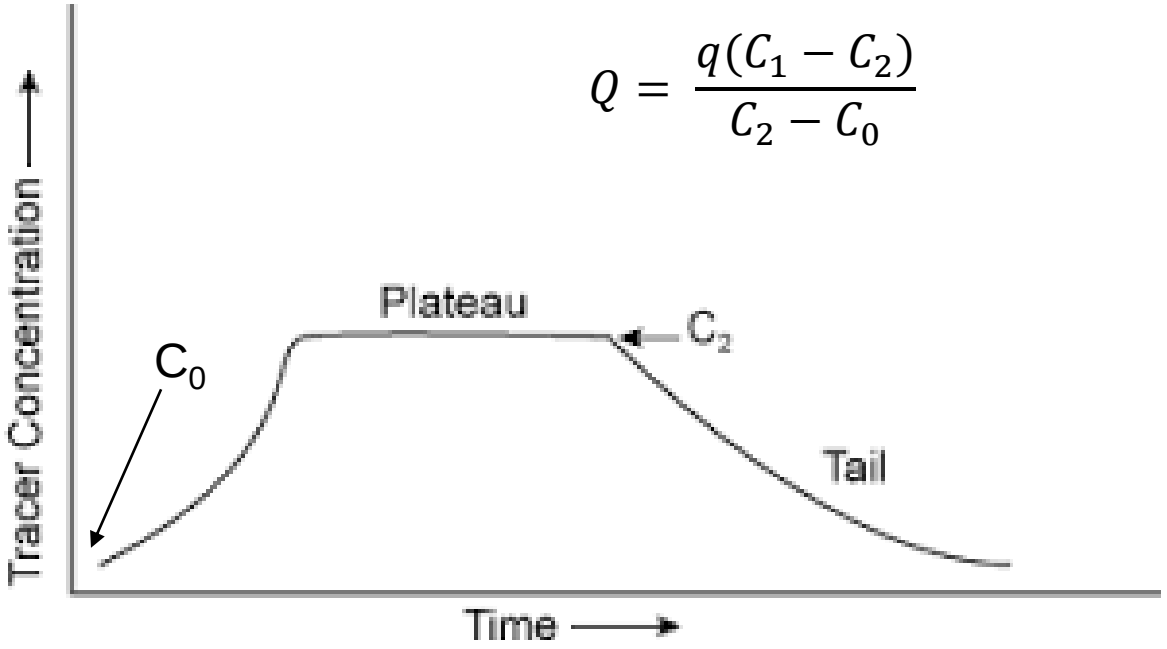




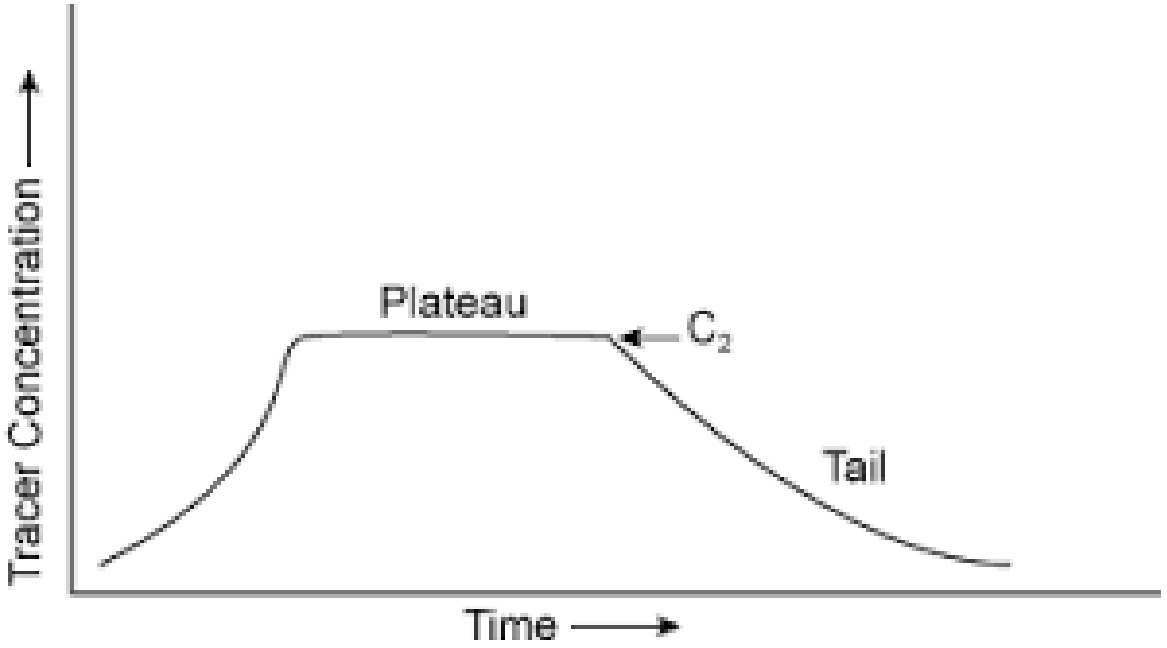
Methods of Discharge Measurement: Dilution Gauging (Constant Rate Injection)

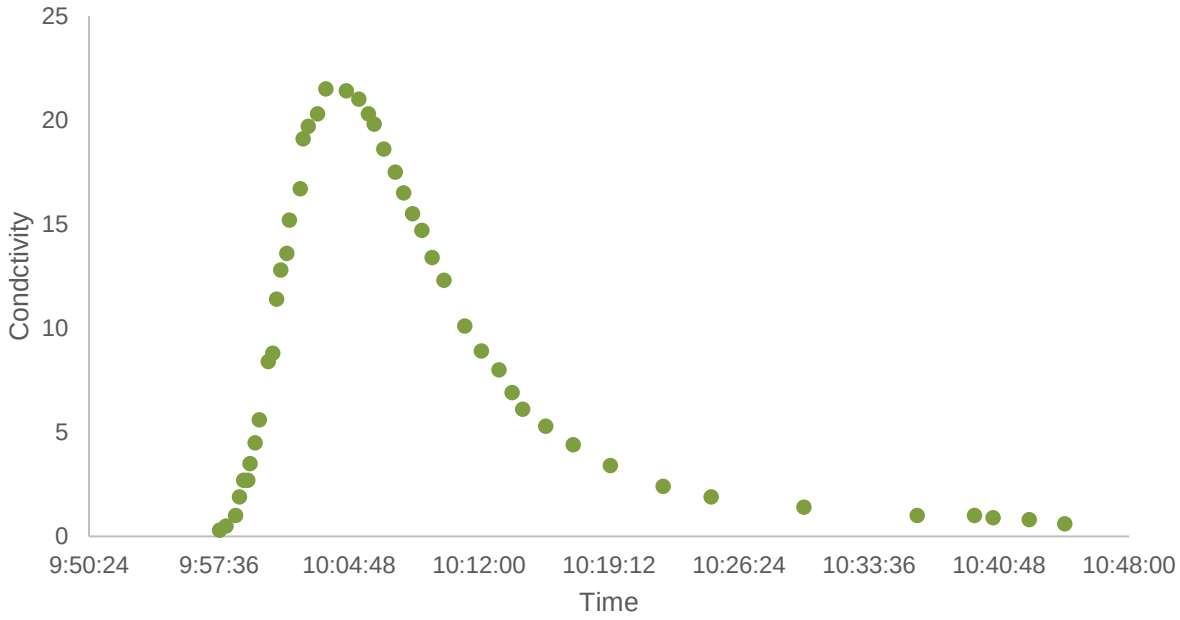
- Discharge is determined using:
  - Injection rate (q)
  - Injection concentration (C_1)
  - Plateau concentration (C_2)
  - Background concentration (C_0)

$$Q = \frac{q(C_1 - C_2)}{C_2 - C_0}$$

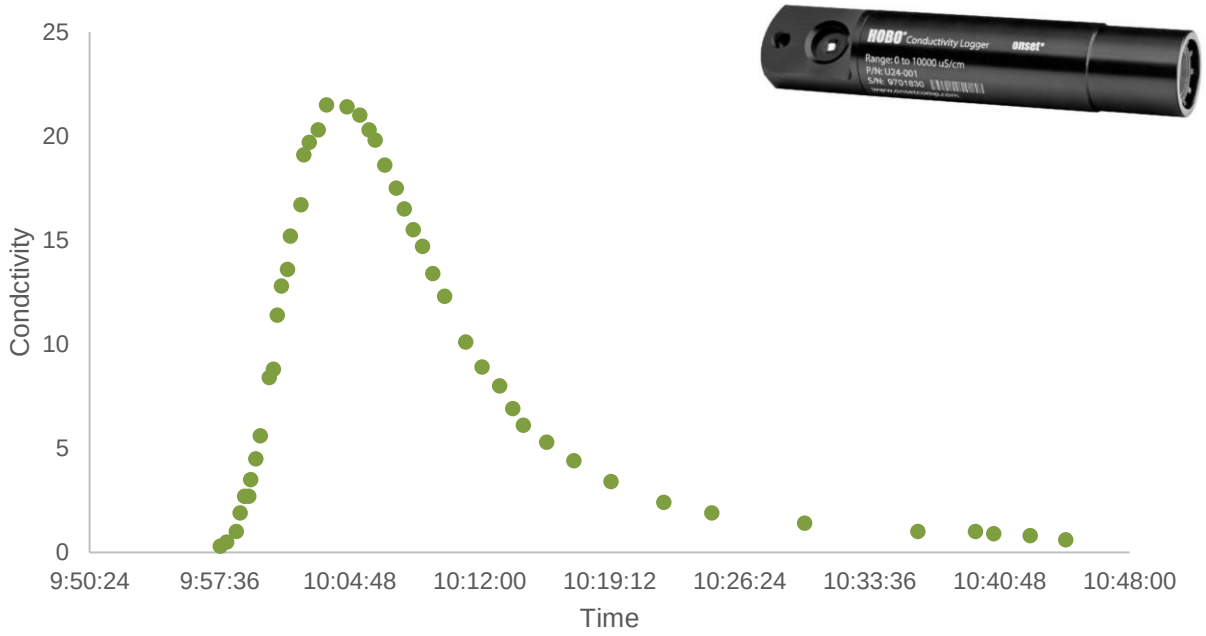


Constant Rate vs. Slug Addition

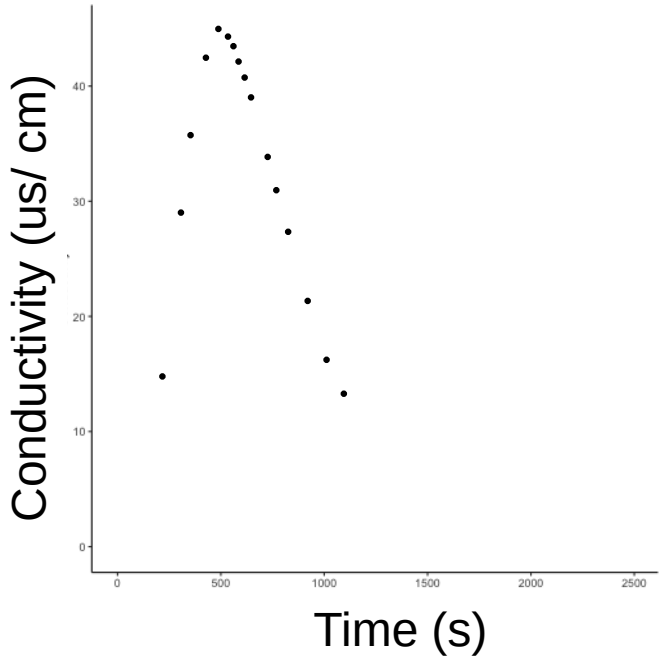


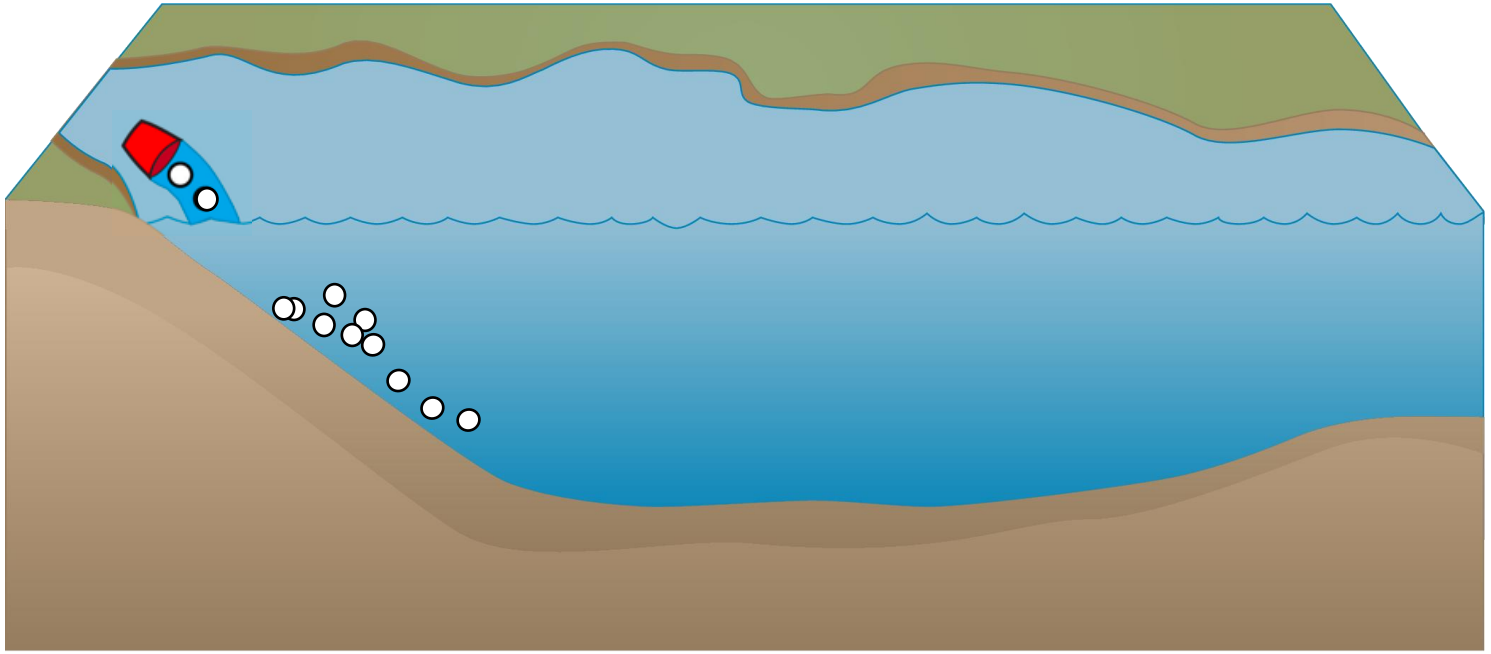


Methods of Discharge Measurement: Dilution Gauging (Slug Injection)



Dilution Gauging (Slug Injection) Visualized



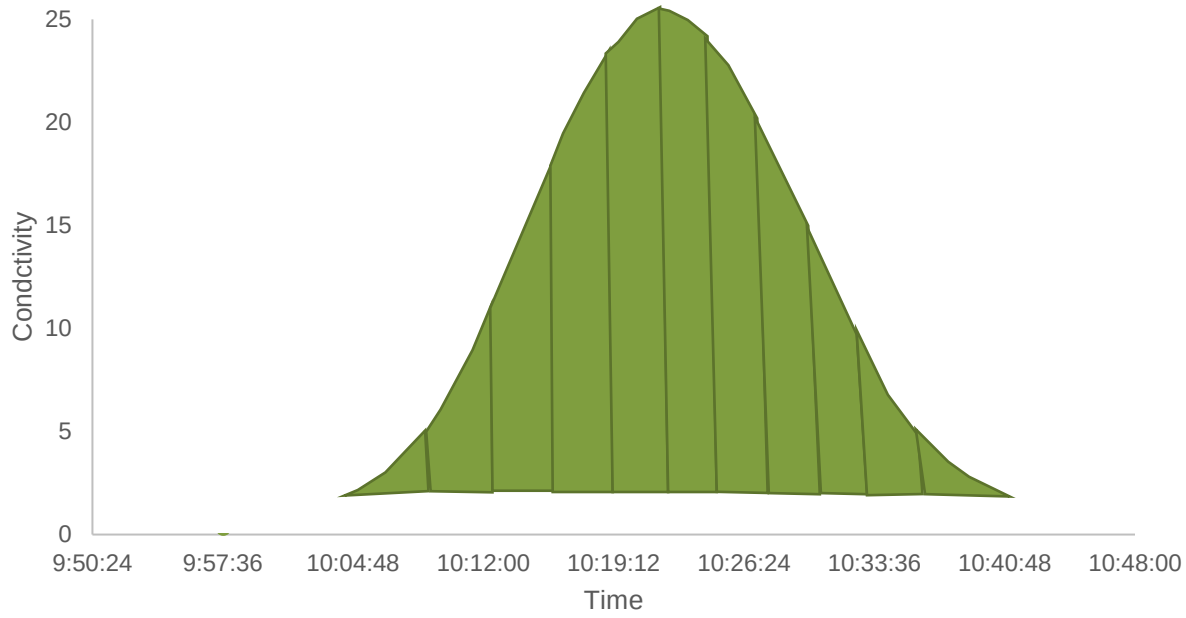


Methods of Discharge Measurement: Dilution Gauging (Slug Injection)

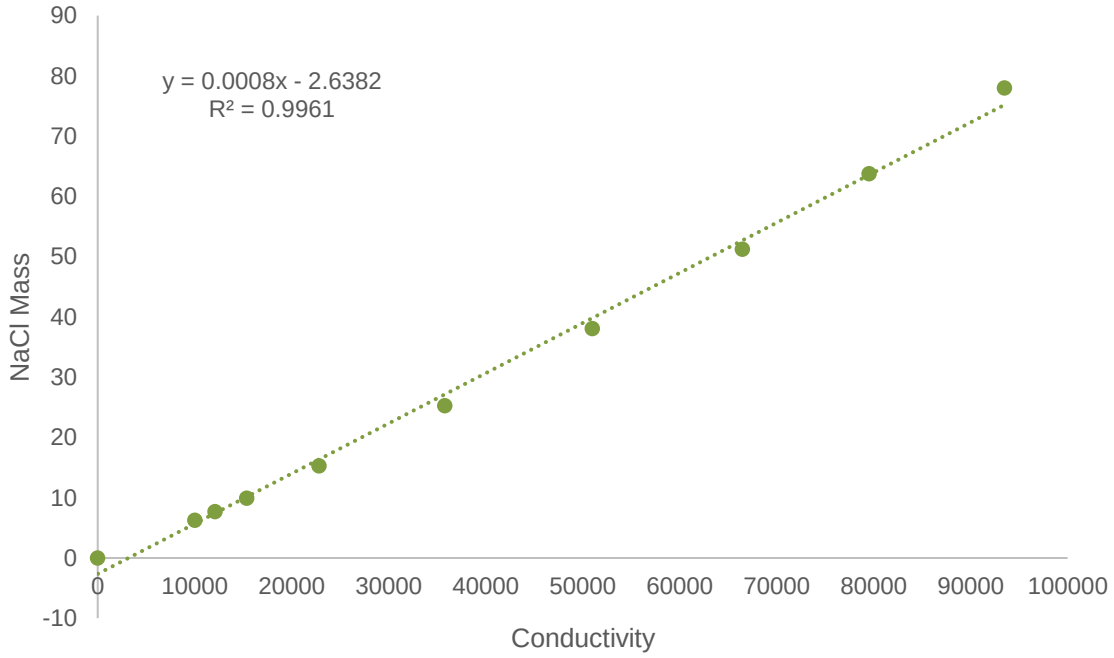
- Discharge is determined using:

$$Q = \frac{m_{added}}{m_{recovered}} = \frac{m_{tr-added}}{\sum_{i=1}^{D}(C_{T(t)} - C_0)dt}$$

  - Injection mass added ($m_{tr-added}$)
  - Observed concentration ($C_{T(t)}$)
  - Background concentration (C_0)



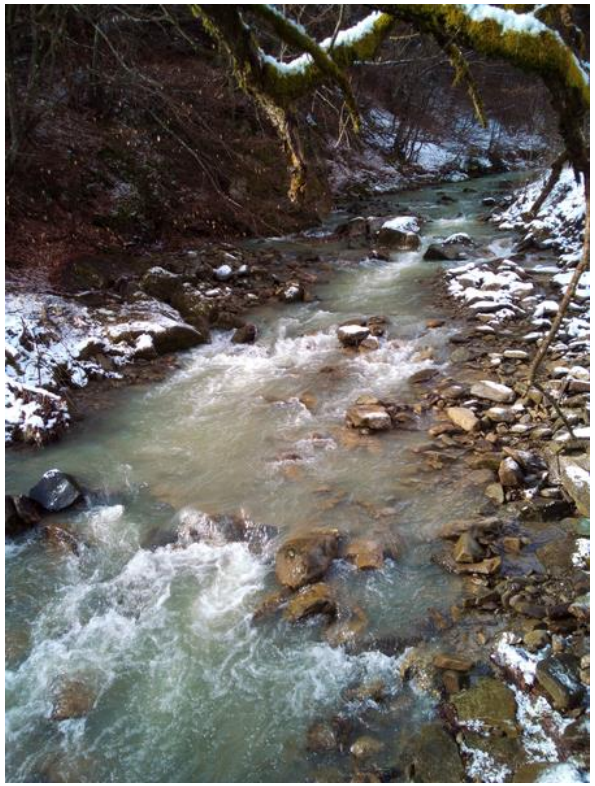
Converting Electrical Conductivity to Concentration



$$Q = \frac{m_{added}}{m_{recovered}} = \frac{m_{tr}}{\sum_{i=1}^{D}(C_{T(t)} - C_0)dt}$$

Additional Considerations

- Mixing length (10-20 times channel width; *Hudson and Fraser 2002)*
  - Reduce number of pools for quicker outcomes
- Addition location
- Addition quantity
  - Enough to create a downstream signal with sufficient resolution
  - Corresponds with mixing length, discharge
- Solute additions can also be used to determine:
  - Velocity
  - Transit times
  - Transient storage



Limitations

- Need sufficient length of reach to promote complete mixing of solute.
- Can take a long time to return to background concentrations during low discharge conditions.
- If done incorrectly, could introduce NaCl pulse that is outside of tolerable range. However, if done correctly, the addition represents minimal risk of affecting aquatic life (Butterworth et al., 2007).

Questions?