Design Flow Analysis Project

Phase One: Low-Flow Analysis
Case Study

This analysis was done by EPA summer intern Graham Jonaitis in 2002.

Overview/Agenda

- Project background and purpose
- Present status of DFLOW 3.0 as tool for States
- Present case study
- Lay out plan for next steps of project

Background / Purpose

- Why low flow?
  - Wastewater effluent-dominated pollution typically violates chemical criteria during low streamflow
  - EPA designates the biological design flow 4B3 for use in establishing discharge permits to protect aquatic life for chronic exposure
  - 1986 EPA analysis determined that hydrological flow statistic 7Q10 was equivalent to 4B3

Background / Purpose

- Why revisit this analysis?
  - Since 1986, 7Q10 statistic criticized as either over- or under-protective in various areas of US
  - States frequently set their own hydrological low flow standards to replace 7Q10, or use flow percentiles (percent of flows in a given stream's daily record that are less than the design flow) to impose pollution limits
  - EPA desires to evaluate such limits in relation to 4B3

Background / Purpose

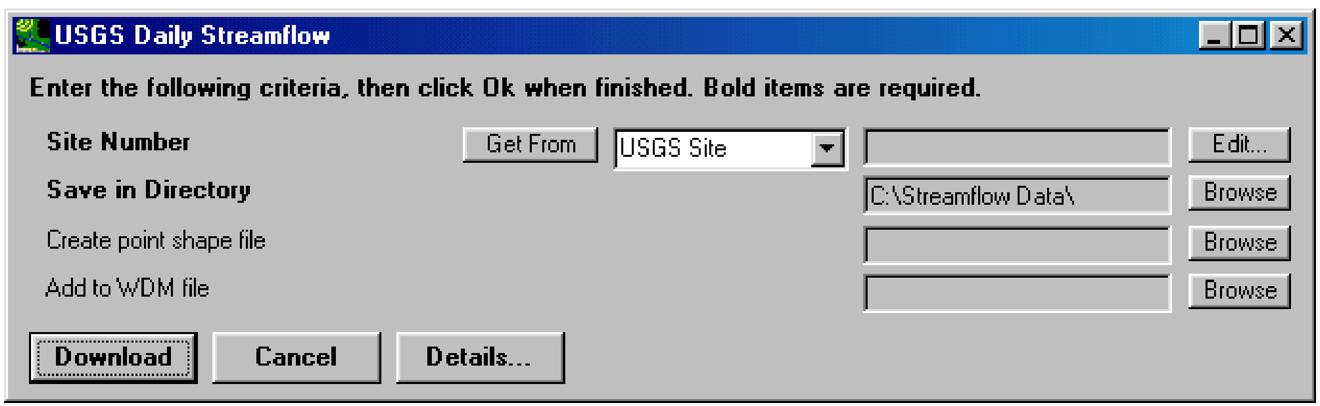
- Design Flow Analysis project scope
  - Phase One: Single-State Case Study
    - Download and filter streamflow data from USGS
    - Using the DFLOW 3.0 program, determine 4B3, 3Q2, and 7Q10 for each (valid) gage station
    - Analyze relative protectiveness of 3Q2 and 7Q10
    - Determine relationship between 4B3 and percentile flows
  - Phase Two: Case Study Delivery
    - Provide web access to DFLOW 3.0
    - Provide web access to case study
      - Demonstrate use of DFLOW in analyzing xQy statistics
      - Demonstrate use of these analyses

Background / Purpose

- Design Flow Analysis project scope
  - Phase Three: National Study
    - Download and filter national streamflow data
    - Determine relationship between 4B3 and 7Q10 or other state-specific statistics
    - Evaluate relationship between 4B3 and flow percentiles
    - Evaluate this relationship with respect to ecoregion, stream order, previous EPA study
    - Report on the above analysis

Data Acquisition

- Beta-version utility designed for use with BASINS allows streamgage data to be downloaded from USGS subject to various geographic criteria
- Quick – downloaded two hundred datasets in ~ 20 minutes
- Data downloaded in individualized datasets, one per streamgage – format used by DFLOW

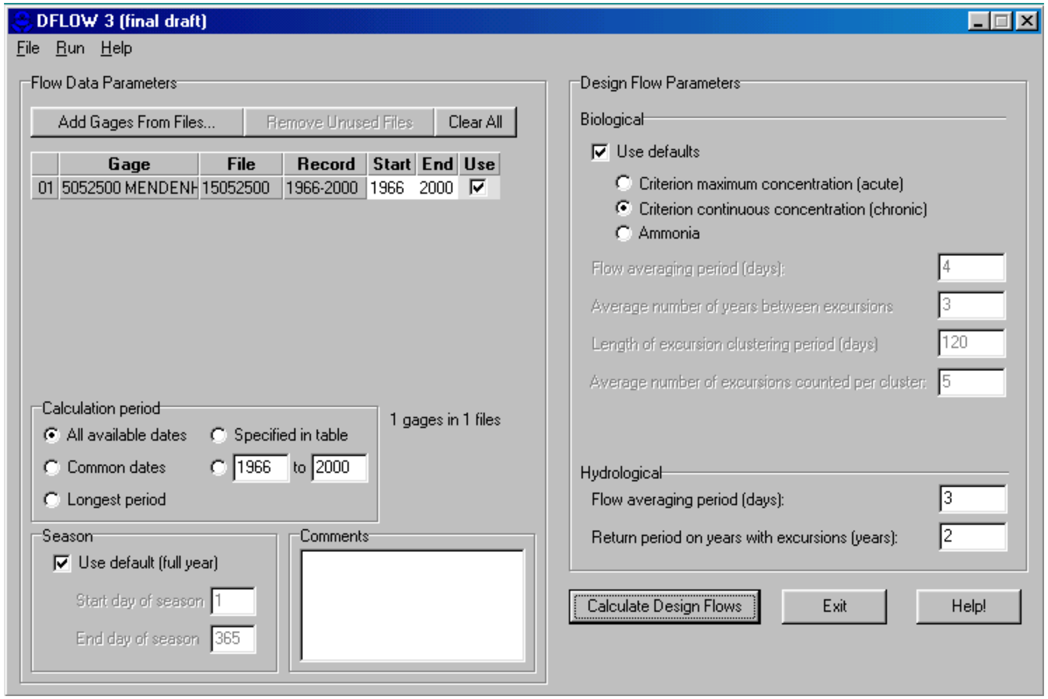


Data Filtering

- ASCE (1980) used stations with at least 15-20 years of record for calculating hydrological design flows
- All records with less than 20 years (7300 days) of observations were removed
- Removal of inconsistent data
  - Contacted state's USGS district office, received spreadsheet of information about stream exceptions (regulation, urbanization, etc.)
  - Removed all stations without 20 years of consistent data from statistical consideration (e.g. station with10 years unregulated, 15 years regulated would be removed)
  - Kept urbanized and consistently regulated streams
- 74 streamgage stations remained for analysis

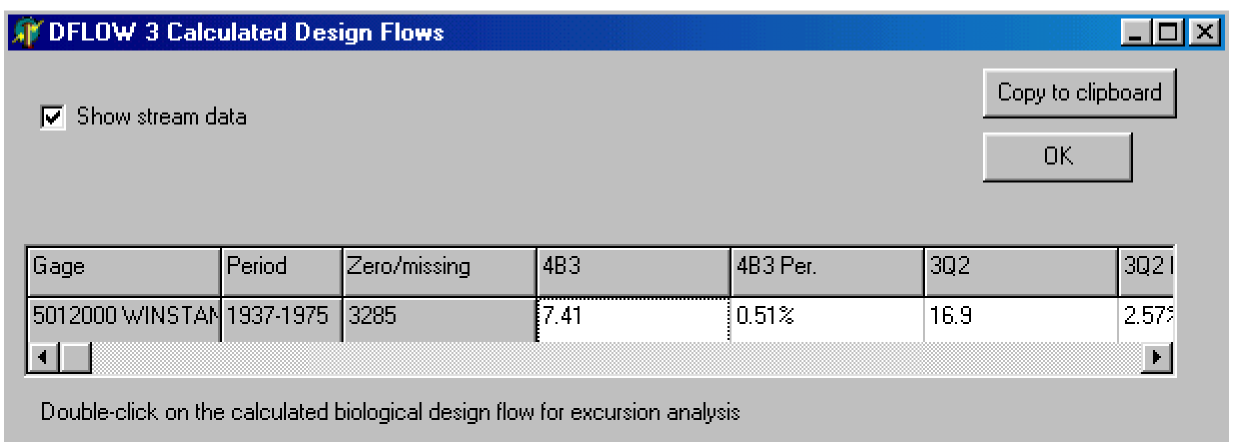
Determining Design Flow

- What is DFLOW?
  - Calculates xBy and xQy design flows, given historical streamflow data
  - Easy to use



Determining Design Flow

- How does DFLOW output flow statistics?
  - DFLOW outputs calculations in tabular form – can be copied and pasted into spreadsheet
  - For each flow value DFLOW calculates, it also outputs corresponding percentile



Determining Design Flow

- Previous Constraints
  - DFLOW Program
    - Problem: Output format contains both 4B3 and 4B3 percentile in the same column
    - Solution: DFLOW code altered to use separate columns
    - Problem: Program bugs cause compromised output when multiple datasets run within one session of DFLOW
    - Solution: Code altered to allow simultaneous runs

Determining Design Flow

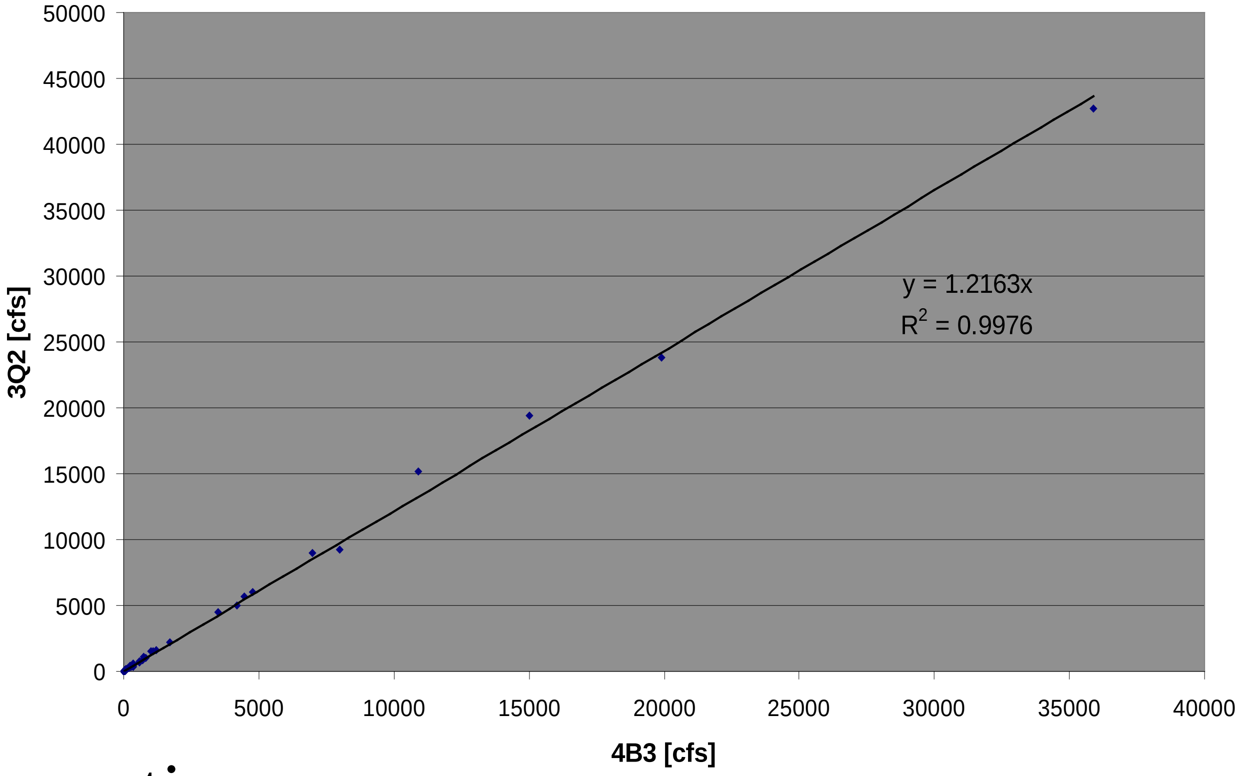
- Current Constraints
  - Data acquisition
    - Problem: BASINS download tool lacks filter for dataset size (i.e. number of observations)
    - Temporary Solution: After download, sort dataset text files by file size, giving estimate of number of observations

Project Analysis

- Analysis
  - Examine relationship between 4B3 and 3Q2, compare to relationship between 4B3 and 7Q10
  - Examine relationship between $^{3Q2}/_{4B3}$ and 4B3, compare to relationship between $^{7Q10}/_{4B3}$ and 4B3
  - Explore probability distribution of 4B3 percentiles
    - Attempt to fit to a standard distribution (e.g. lognormal)
    - Using cumulative distribution, identify reasonable percentile to capture “most” 4B3 flow values

Design Flow Analysis:

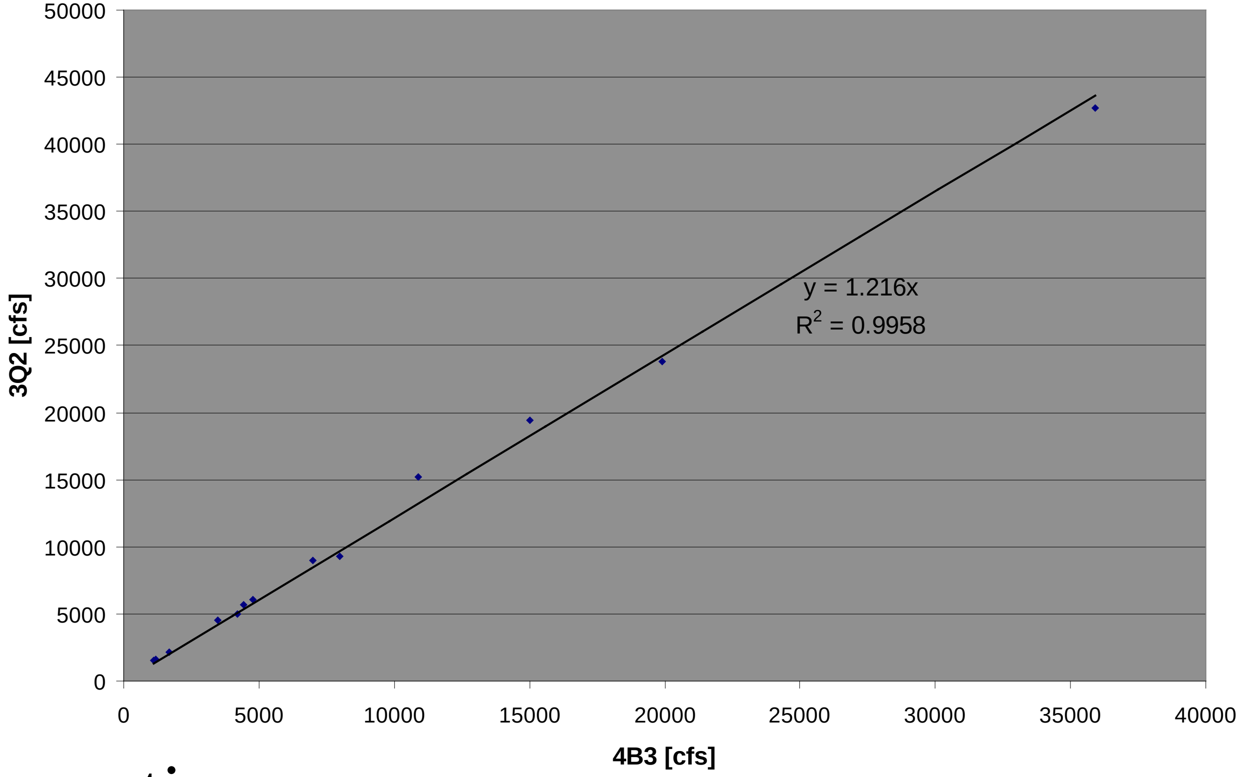
3Q2 vs. 4B3 for All Streams



- Observations:
  - 3Q2 strongly correlated with 4B3 ($R^2 = 0.9976$)
  - 3Q2 flow 22% greater than 4B3 ($y = 1.2163x$)

Design Flow Analysis:

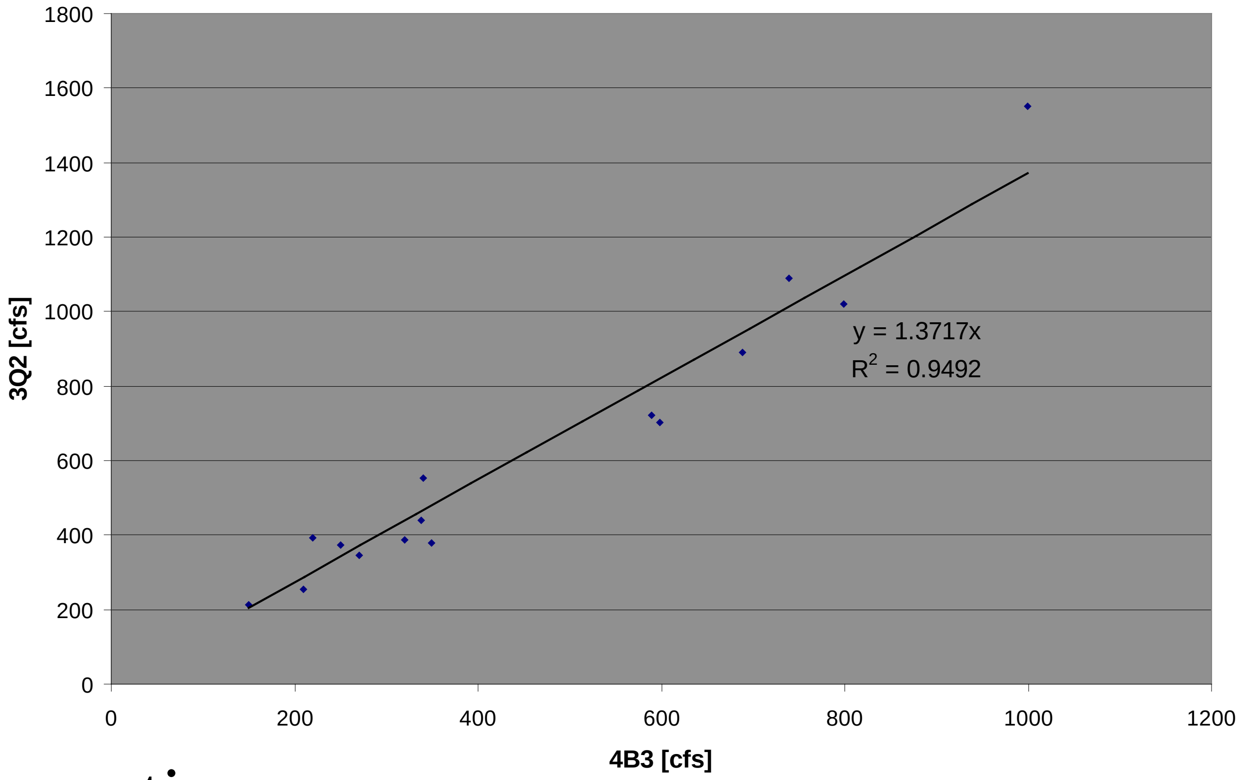
3Q2 vs. 4B3 for Large-Flow Streams (1000 cfs < 4B3)



- Observations:
  - 3Q2 strongly correlated with 4B3 ($R^2 = 0.9958$)
  - 3Q2 flow 22% greater than 4B3 (y = 1.216x)

Design Flow Analysis:

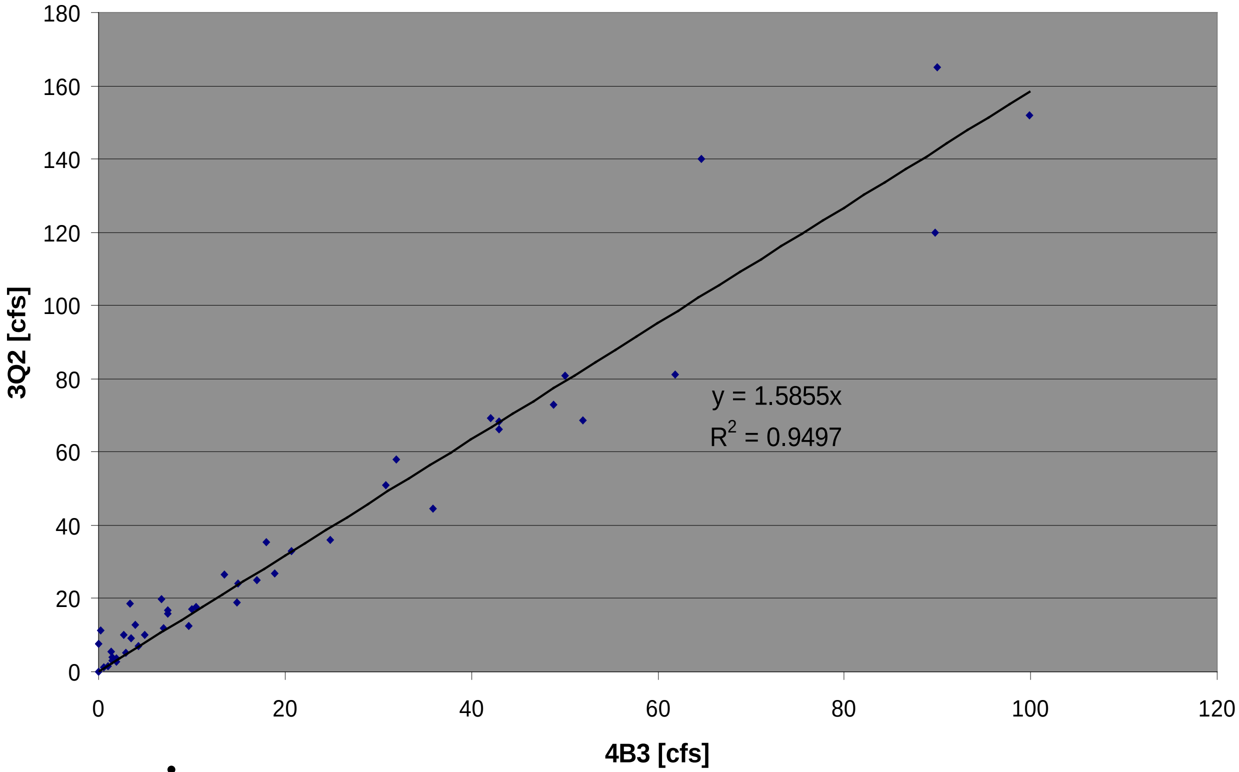
3Q2 vs. 4B3 for Medium-Flow Streams (100 cfs < 4B3 < 1000 cfs)



- Observations:
  - 3Q2 well correlated with 4B3 (R^2 = 0.9492)
  - 3Q2 flow 37% greater than 4B3 (y = 1.3717x)

Design Flow Analysis:

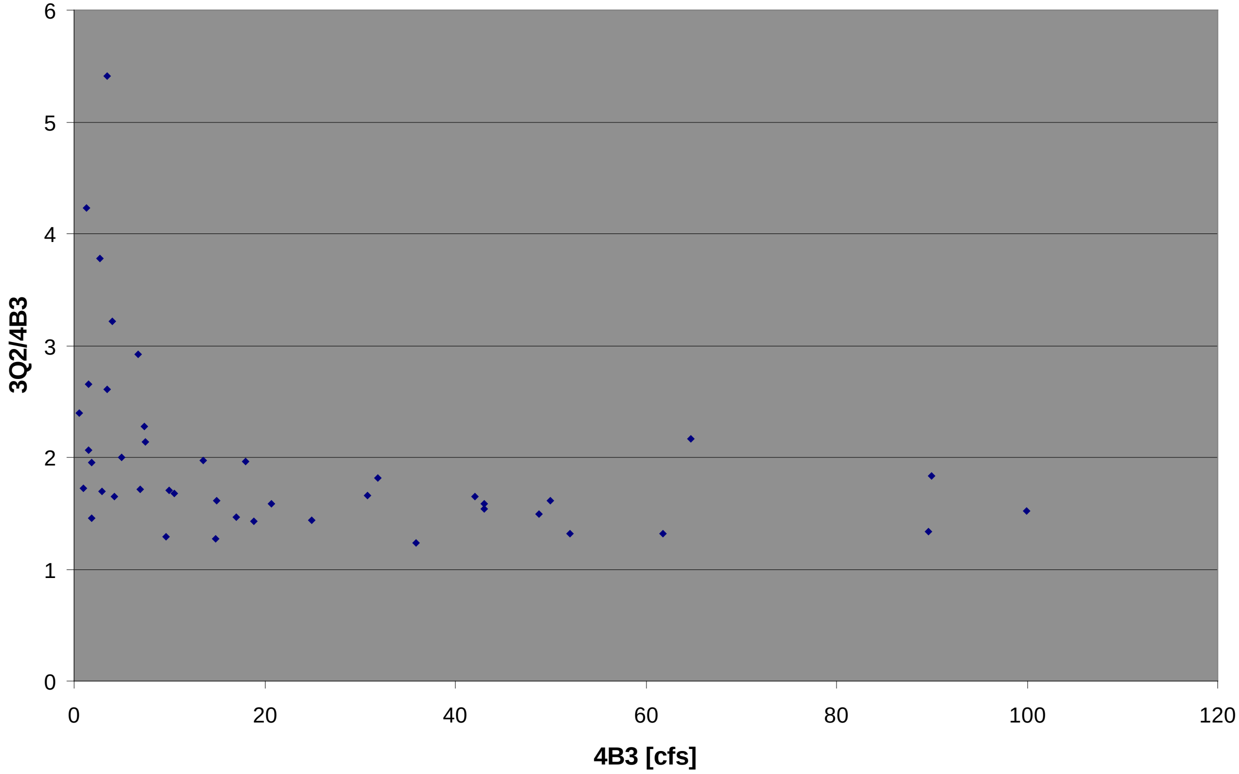
3Q2 vs. 4B3 for Small-Flow Streams (4B3 < 100 cfs)



- Observations:
  - 3Q2 well correlated with 4B3 (R^2 = 0.9497)
  - 3Q2 greatest: 59% greater than 4B3 (y = 1.5855x)

Design Flow Analysis:

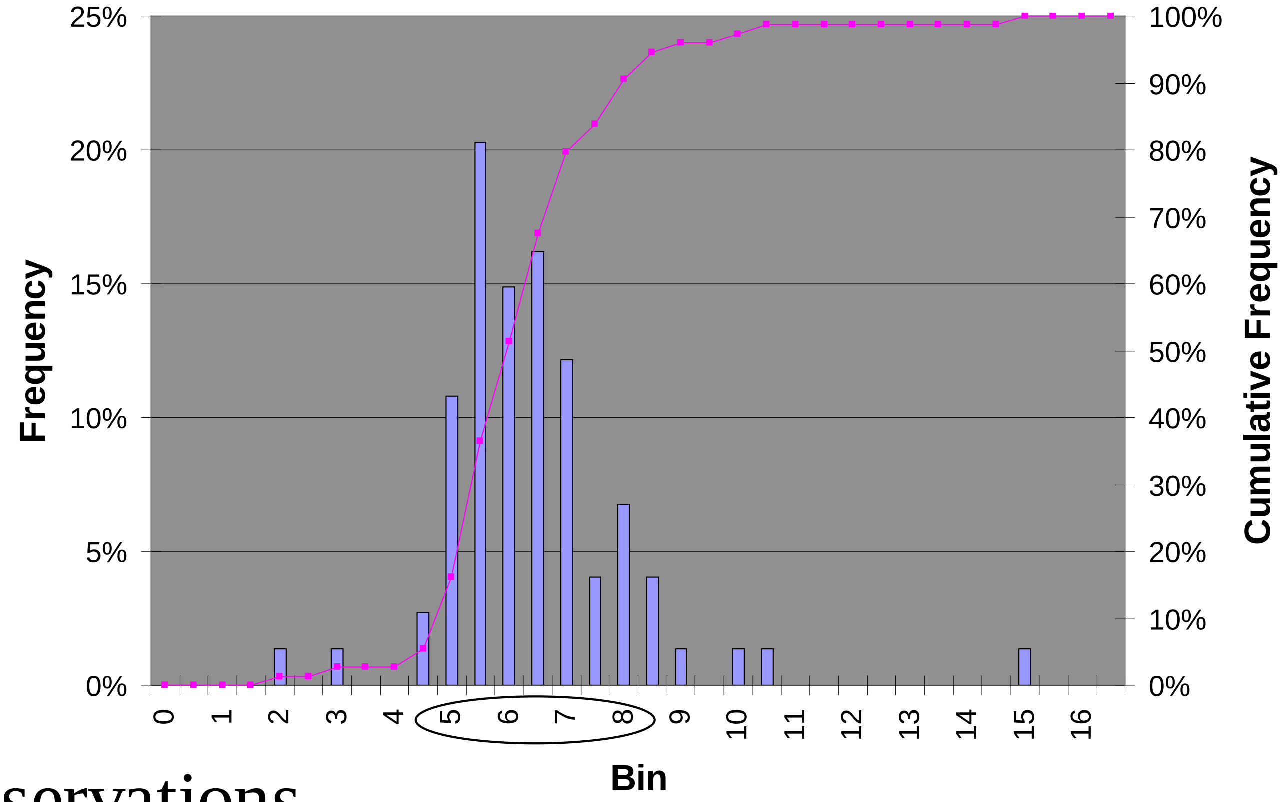
$^{3Q2}/_{4B3}$ vs. 4B3



- Observation: 3Q2 dramatically higher for small streams (factor of two to five for 4B3 < 20 cfs)

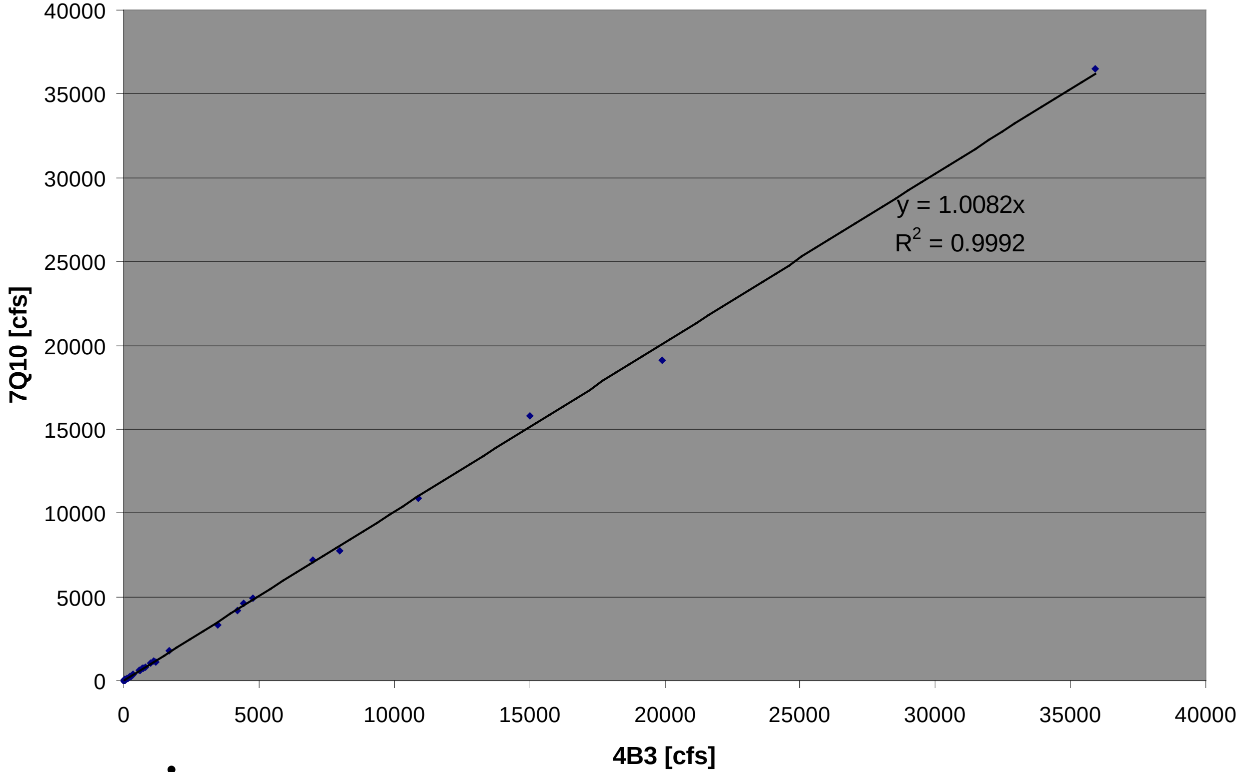
Design Flow Analysis:

Excursions Per Three Years for 3Q2



- Observations
  - Excursions per three years centered around six
  - All stations show at least two excursions per three years

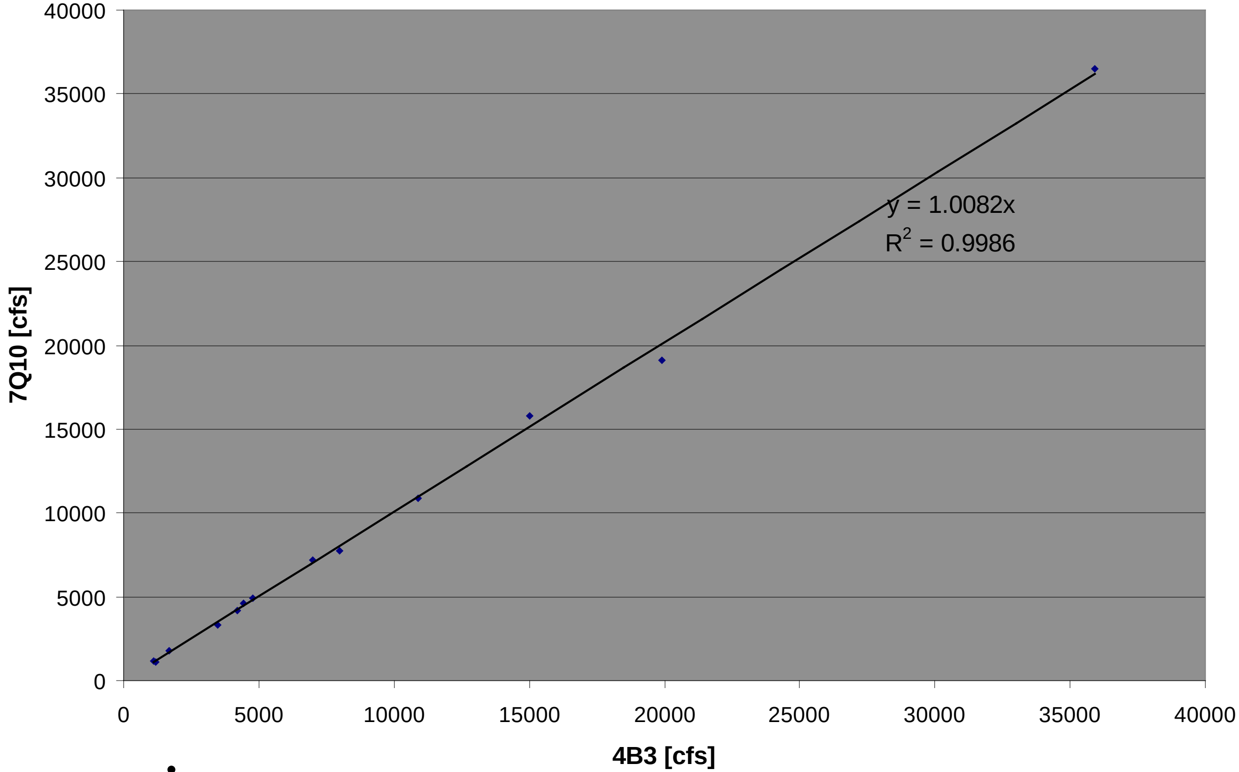
Design Flow Analysis:
7Q10 vs. 4B3 for All Streams



- Observations:
  - 7Q10 strongly correlated with 4B3 ($R^2 = 0.9992$)
  - 7Q10 flow 1% greater than 4B3 ($y = 1.0082x$)

Design Flow Analysis:

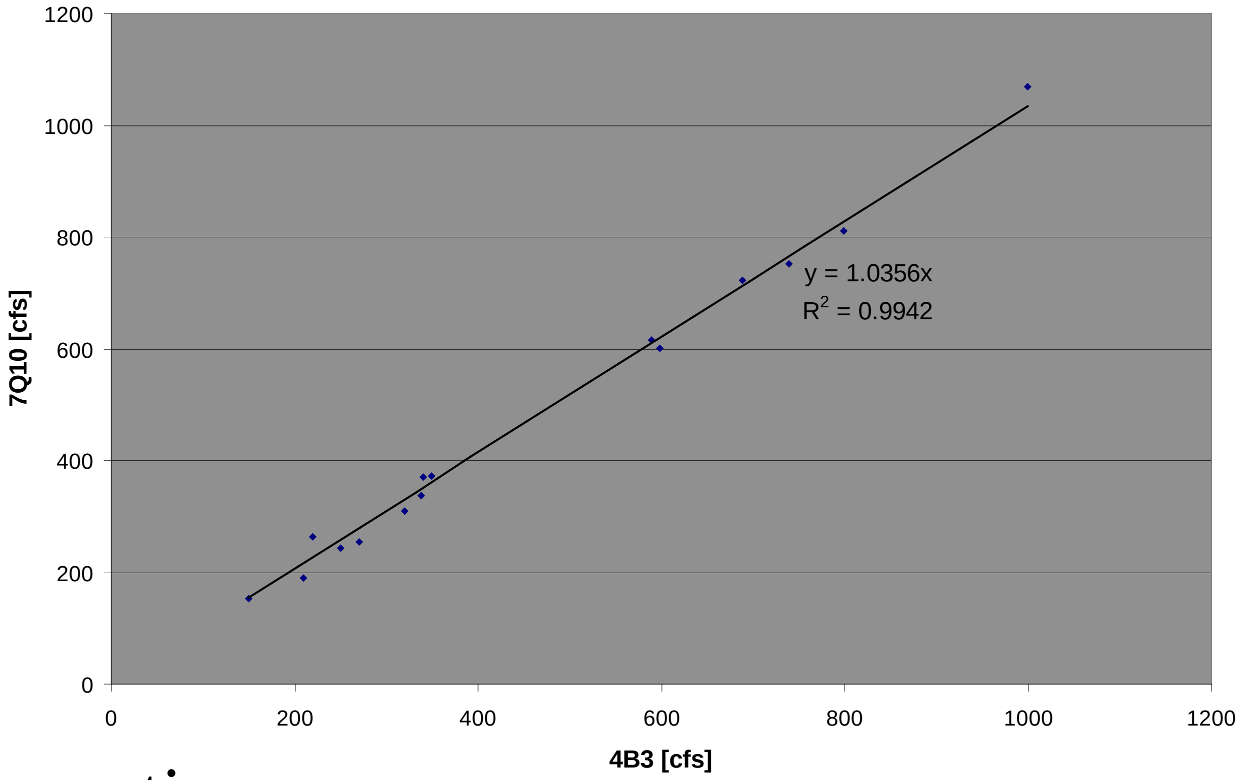
7Q10 vs. 4B3 for Large-Flow Streams (1000 cfs < 4B3)



- Observations:
  - 7Q10 strongly correlated with 4B3 (R^2 = 0.9986)
  - 7Q10 flow 1% greater than 4B3 (y=1.0082x)

Design Flow Analysis:

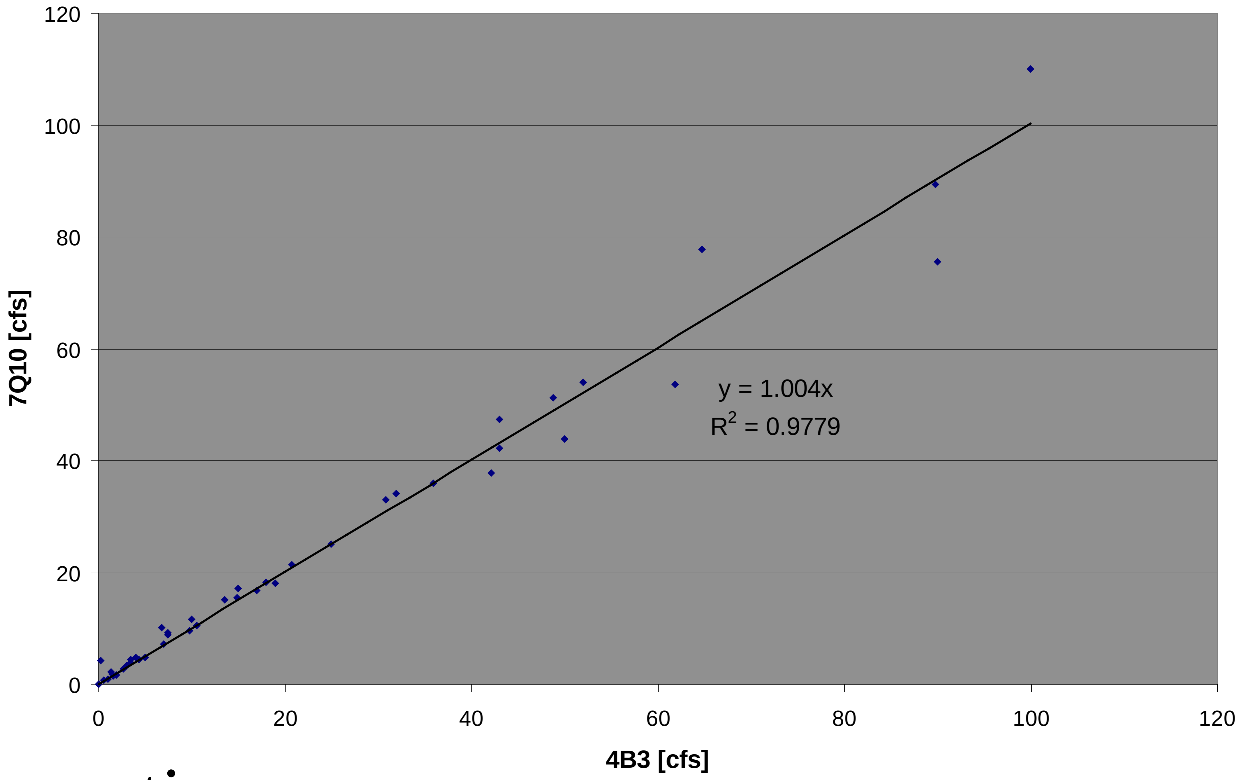
7Q10 vs. 4B3 for Medium-Flow Streams (100 cfs < 4B3 < 1000 cfs)



- Observations:
  - 7Q10 strongly correlated with 4B3 (R^2 = 0.9942)
  - 7Q10 flow 4% greater than 4B3 (y = 1.0356x)

Design Flow Analysis:

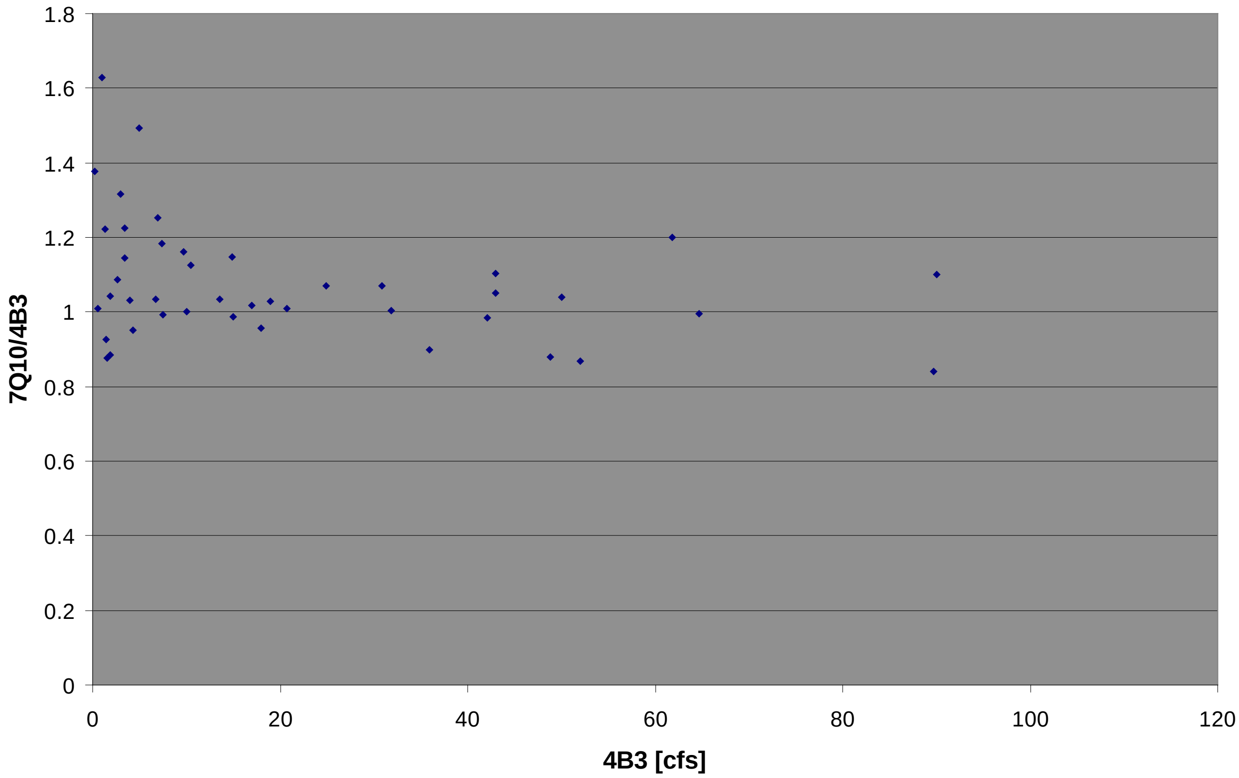
7Q10 vs. 4B3 for Small-Flow Streams (4B3 < 100 cfs)



- Observations:
  - 7Q10 slightly less correlated with 4B3 ($R^2 = 0.9779$)
  - 7Q10 flow 0.4% greater than 4B3 (y = 1.004x)

Design Flow Analysis:

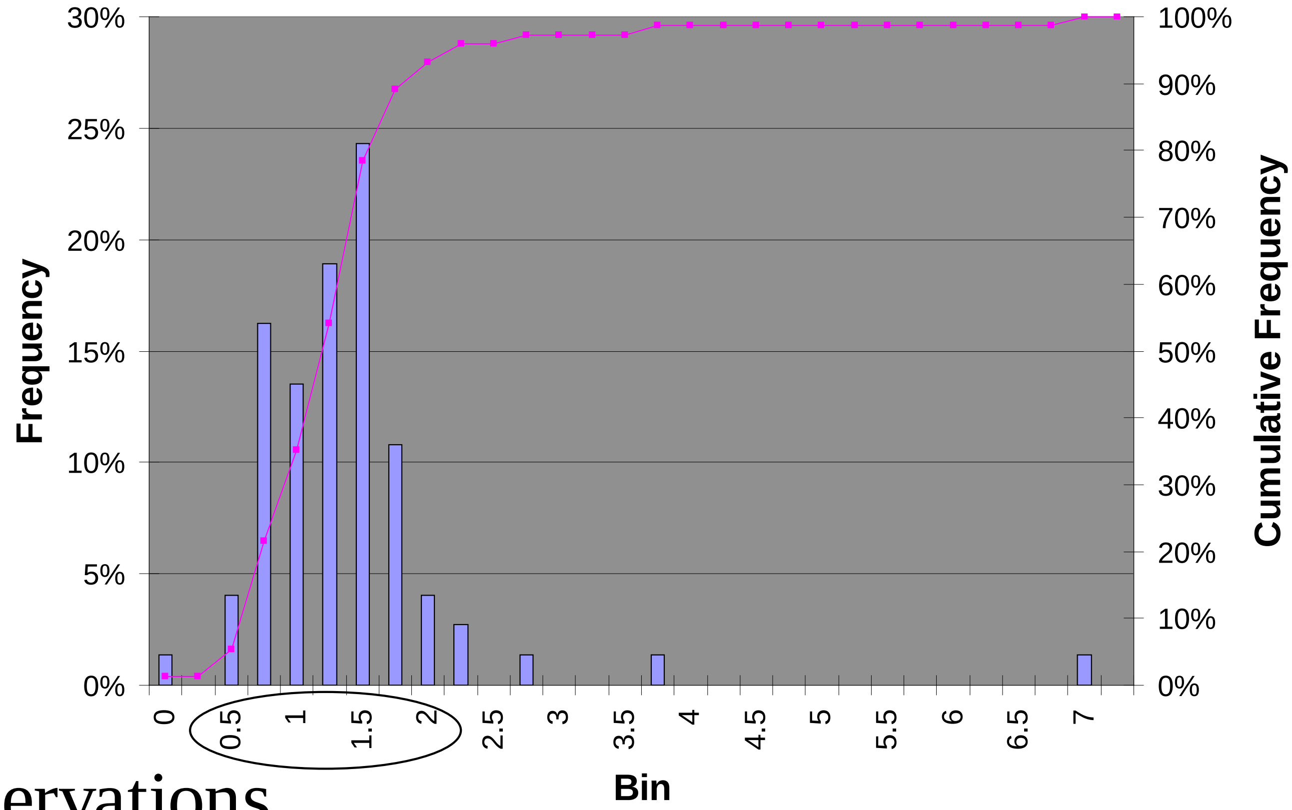
$^{7Q10}/_{4B3}$ vs. 4B3



- Observation: 7Q10 clustered around 4B3 equivalence, but ratio for very small streams is as high as 1.6

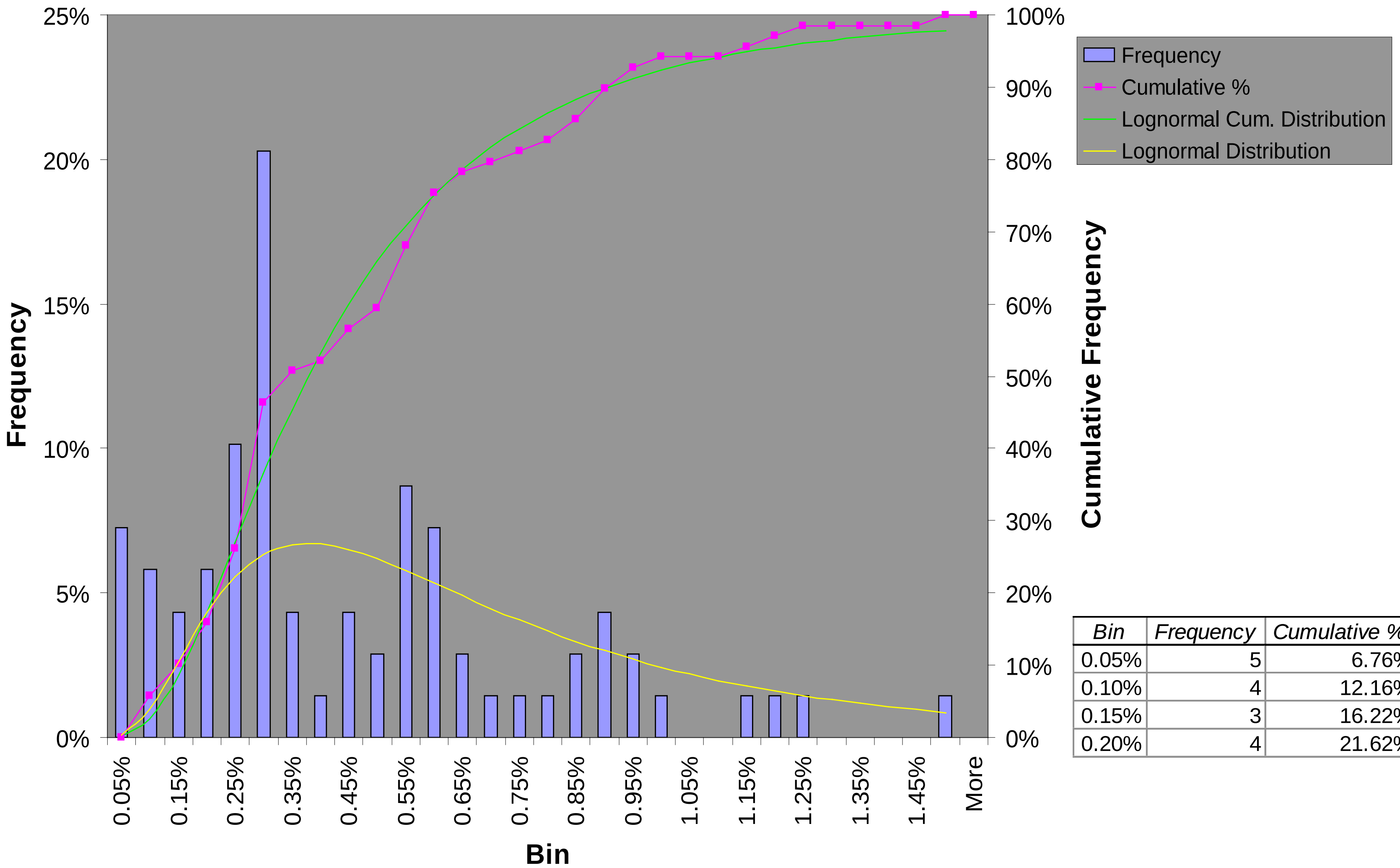
Design Flow Analysis:

Excursions Per Three Years for 7Q10



- Observations
  - Excursions per three years centered near one and one half
  - 65% of the rivers exceed criteria more than once per year

Design Flow Analysis:
Distribution of 4B3 Percentiles



Bin	*Frequency*	*Cumulative %*
0.05%	5	6.76%
0.10%	4	12.16%
0.15%	3	16.22%
0.20%	4	21.62%

Design Flow Analysis:
Distribution of 4B3 Percentiles

- Delta-Lognormal Distribution
  - Five data points (4B3% = 0%) assumed to be nondetect values, based on sensitivity of 4B3 method
    - Data presumed to fit lognormal distribution, but values too low
    - Retained in cumulative distribution to determine number of low-end streams protected by percentile limits
  - Poor fit: p-correlation of 0.0826
  - National data may show better fit
- Observations
  - Distribution mean = 0.48% ; mode = 0.40%
  - High end of distribution = 1.40% for empirical data, 2.96% for distribution

Conclusions

- DFLOW and download tool should make analysis easy for states to perform
- 3Q2 vs. 4B3
  - 22% greater than 4B3 across the board
  - 59% greater than 4B3 for small streams
  - Shows 4-8 excursions per 3 years vs. 1 for 4B3
- 7Q10 vs. 4B3
  - Generally equivalent to 4B3 (1% greater overall)
  - 4% less than 4B3 for medium- and small-flow streams
  - Shows 0-2 excursions per 3 years

Conclusions

- Percentile Flow
  - 4B3 percentiles show no clear statistical distribution
  - 4B3 percentiles range from 0% to 1.40% for flow data, hence any percentile limit above 1.40% will under-protect streams

Next Steps

- Phase Two: Case Study Delivery
  - Number of biological excursions per three years will be added to DFLOW output
  - Make data download tool and DFLOW known and available to State water quality programs
  - Web publication of case study
- Phase Three: National Study
  - $^{7Q10}/_{4B3}$ Analysis
    - Separate into large, medium, and small-flow streams
    - Regional variability (e.g. with states, ecoregions)

Appendix

- How does DFLOW determine xQy?
  - DFLOW uses the following formula:

$$xQy = \exp(u + \sigma K(g, y))$$

where u = mean of logarithms of annual low flows

σ = standard deviation of above

g = skewness coefficient of above

  - K is calculated using:

$$K = \tfrac{2}{g}\left[\left(1 + \tfrac{gz}{6} - \tfrac{g^2}{36}\right)^3 - 1\right] \quad ; \quad z = 4.91\left[\left(\tfrac{1}{y}\right)^{.14} - \left(1 - \tfrac{1}{y}\right)^{.14}\right]$$

Appendix

- How does DFLOW determine xBy?
  - Calculate total allowed excursions over flow record using number of years in record divided by y
  - Use xQy design flow as an initial guess for xBy
  - Identify excursion periods based on xBy
  - Calculate number of excursions in each excursion period using period length divided by y
  - Sum total number of excursions over record; maximum excursions in a low-flow period (120 days) is five
  - True 4B3 is the greatest flow that keeps excursion sum below total allowed excursions – iterative process

References

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