# Glen Canyon Down-Ramp Rates and Automatic Generation Control

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# Background

- Exceedances in 1500 cfs/hr down-ramp rate noted and attributed to effect of automatic generation control

- Definitions
  - *Area Control Error:* instantaneous difference between scheduled generation and actual load
  - *Automatic generation control (AGC):* automatic adjustments of releases to compensate for ACE

# Background (Cont'd)

- Normally 80/20% split between Hoover and Glen Canyon Dams
- July 1998, target down-ramp rate reduced to 1450 cfs/hr and AGC switched entirely to Hoover during down-ramp periods to eliminate exceedances
- Concern regarding resource effects led to proposal to further evaluate issue

# Analysis Questions

- What are the sources and causes of down-ramp exceedances?
- What are the frequency and magnitude of down-ramp exceedances?
- Are there temporal patterns in exceedance frequency?
- Do the measurements of releases correlate to flow data?
- To what level of accuracy can AGC comply with down-ramp rate targets?

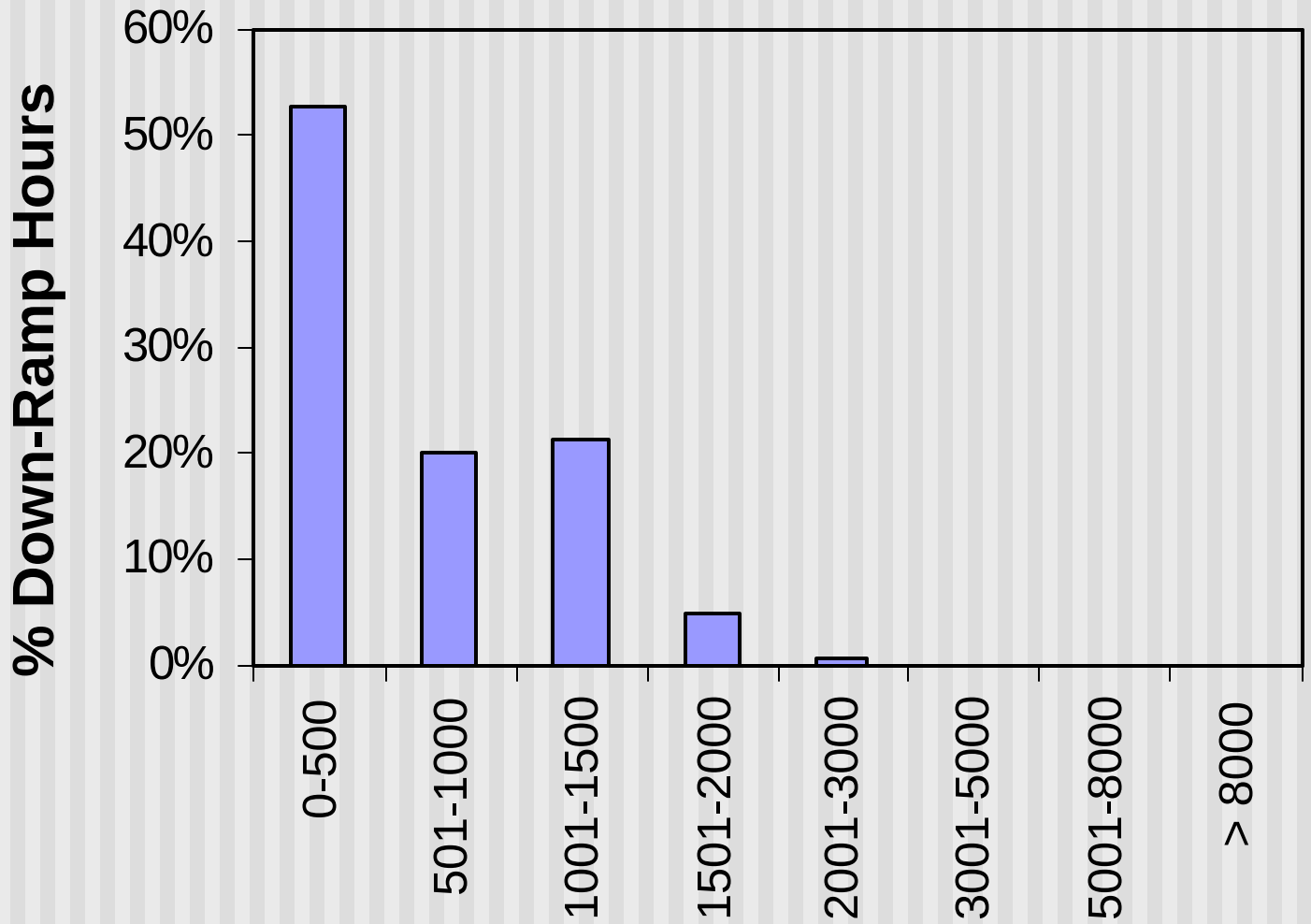
# Two Phases of Study

- Evaluation of existing SCADA data
  - January 1993 to April 2000
- AGC experiments
  - Glen Canyon gage re-established
  - Accusonic data gathered
  - September 2000 to July 2001

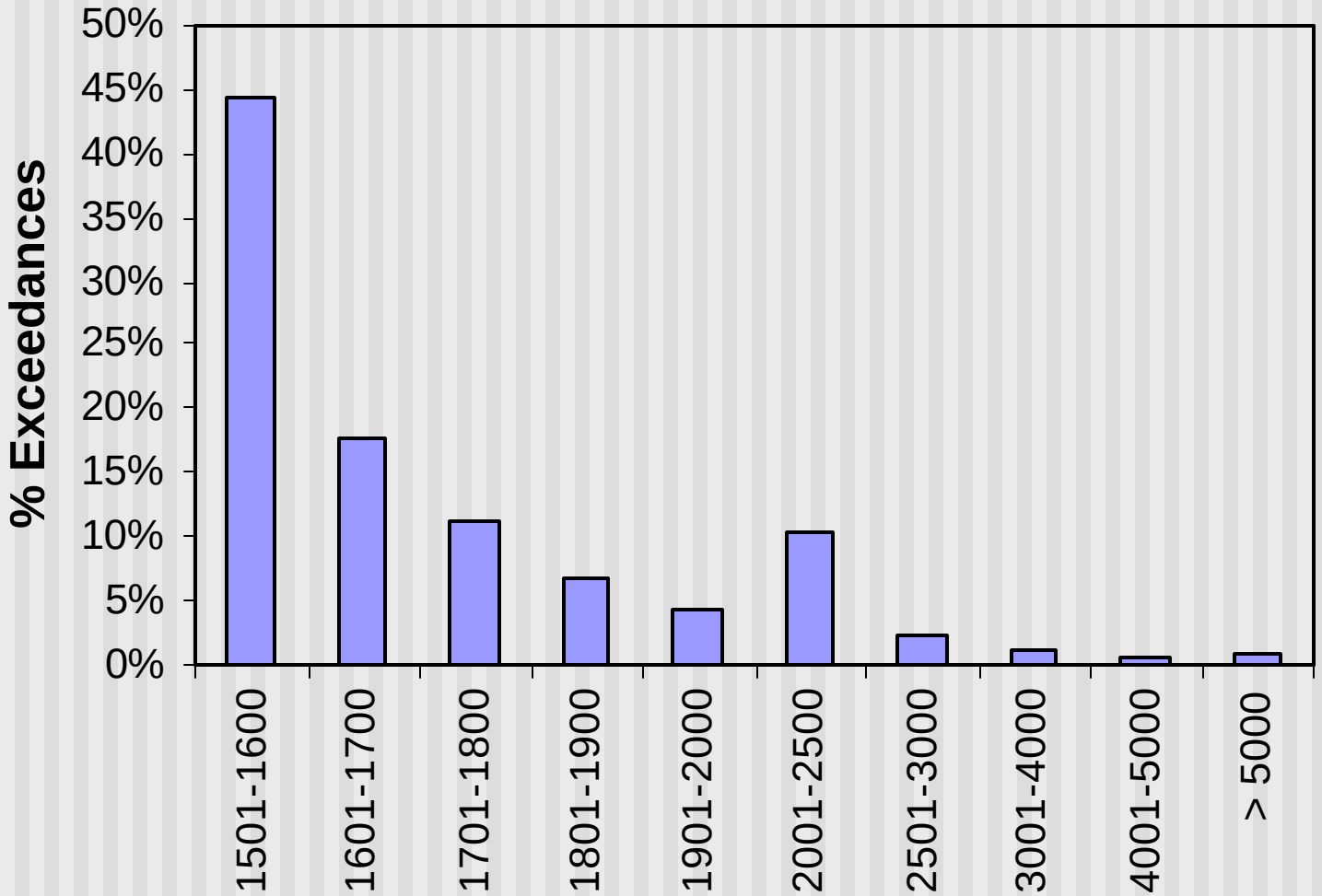
# Phase I: Analysis of SCADA Data

- Only source of “historical” release data
- Analysis examined data from 1-93 to 4-00
- Statistical analyses to determine:
  - Frequency and magnitude of exceedance
  - Temporal patterns (are exceedances more common during periods of high demand?)

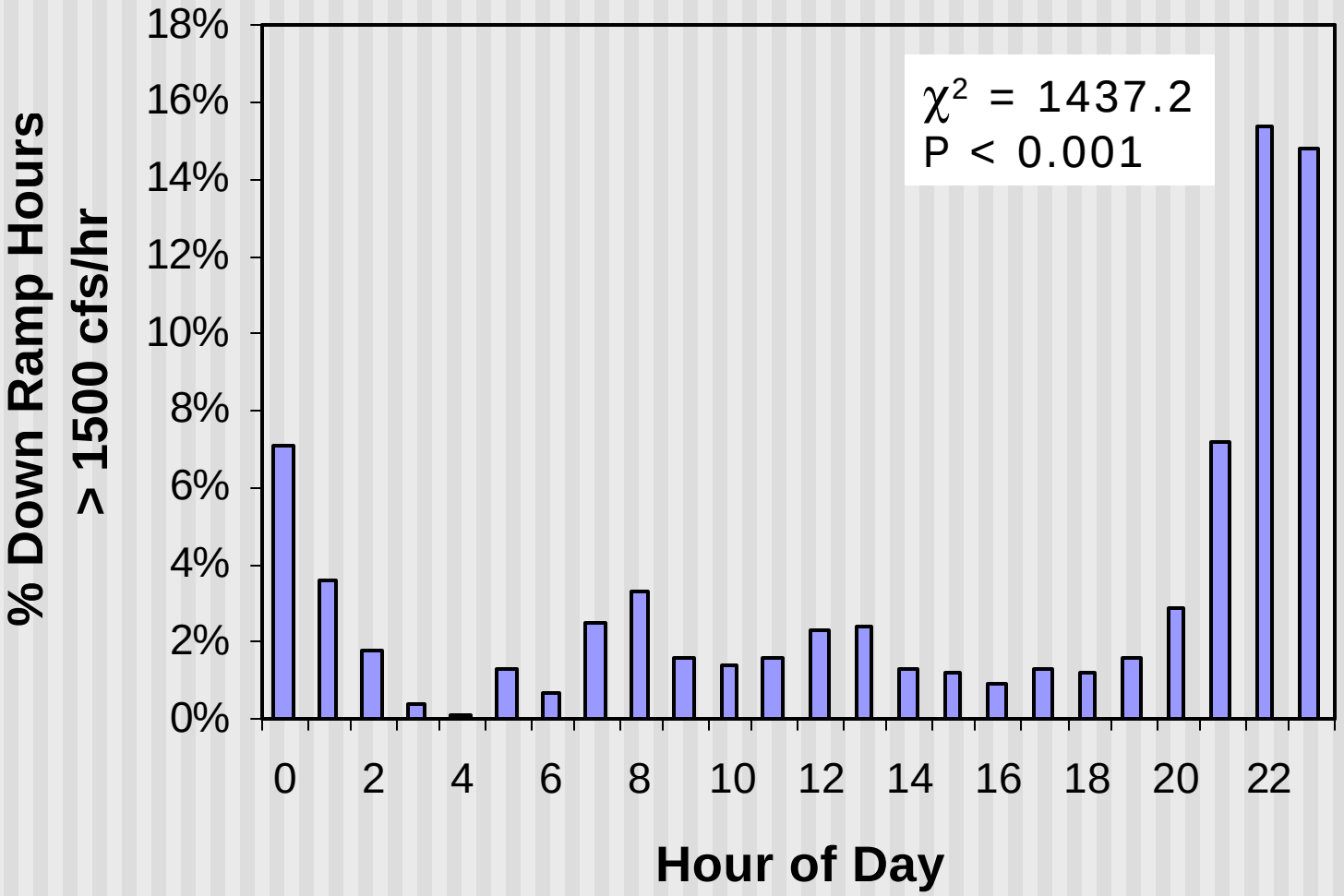
# Frequency of Down-Ramp Magnitudes: 1993 to 2000



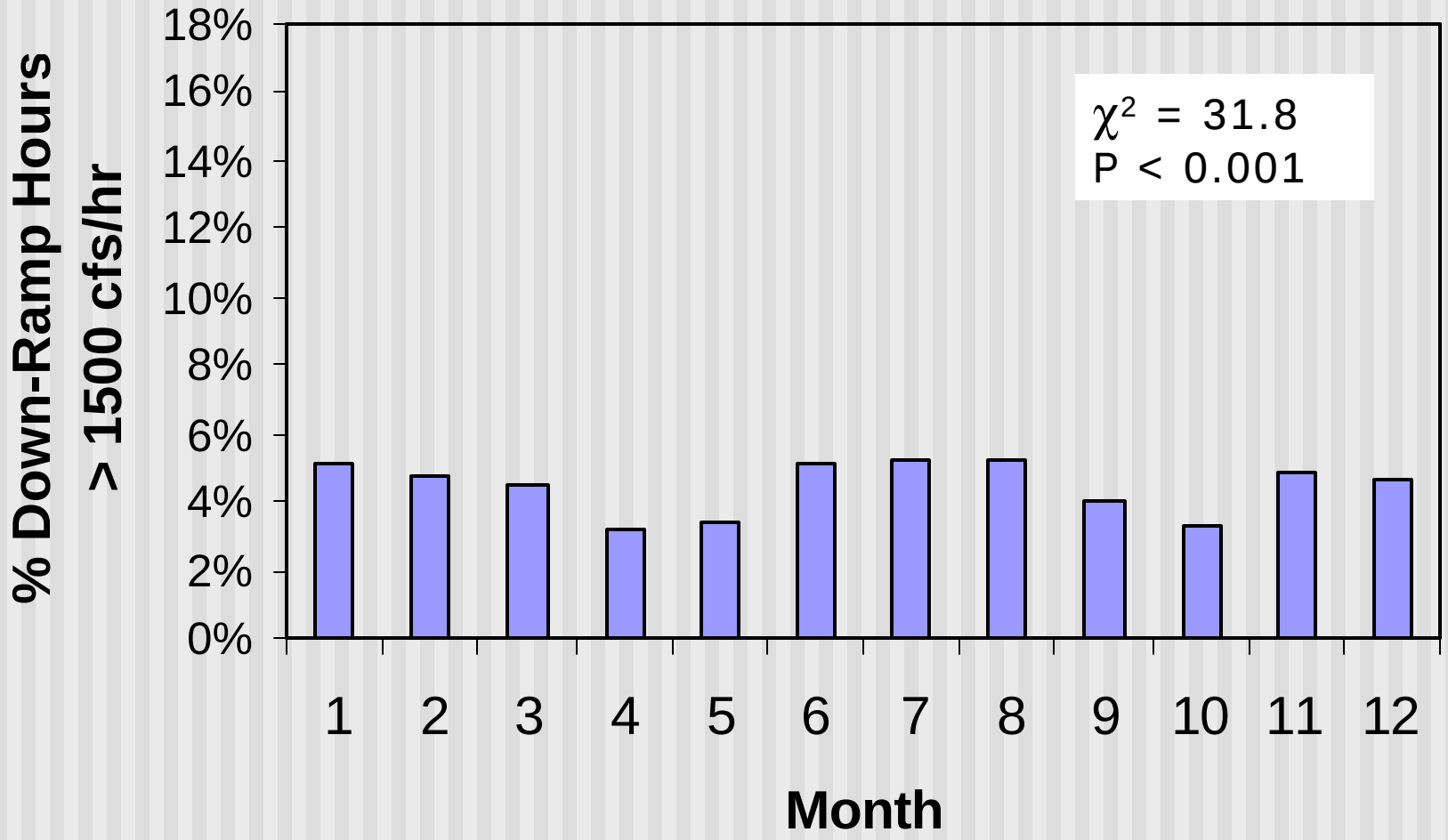
# Percent of Exceedances of Different Magnitudes



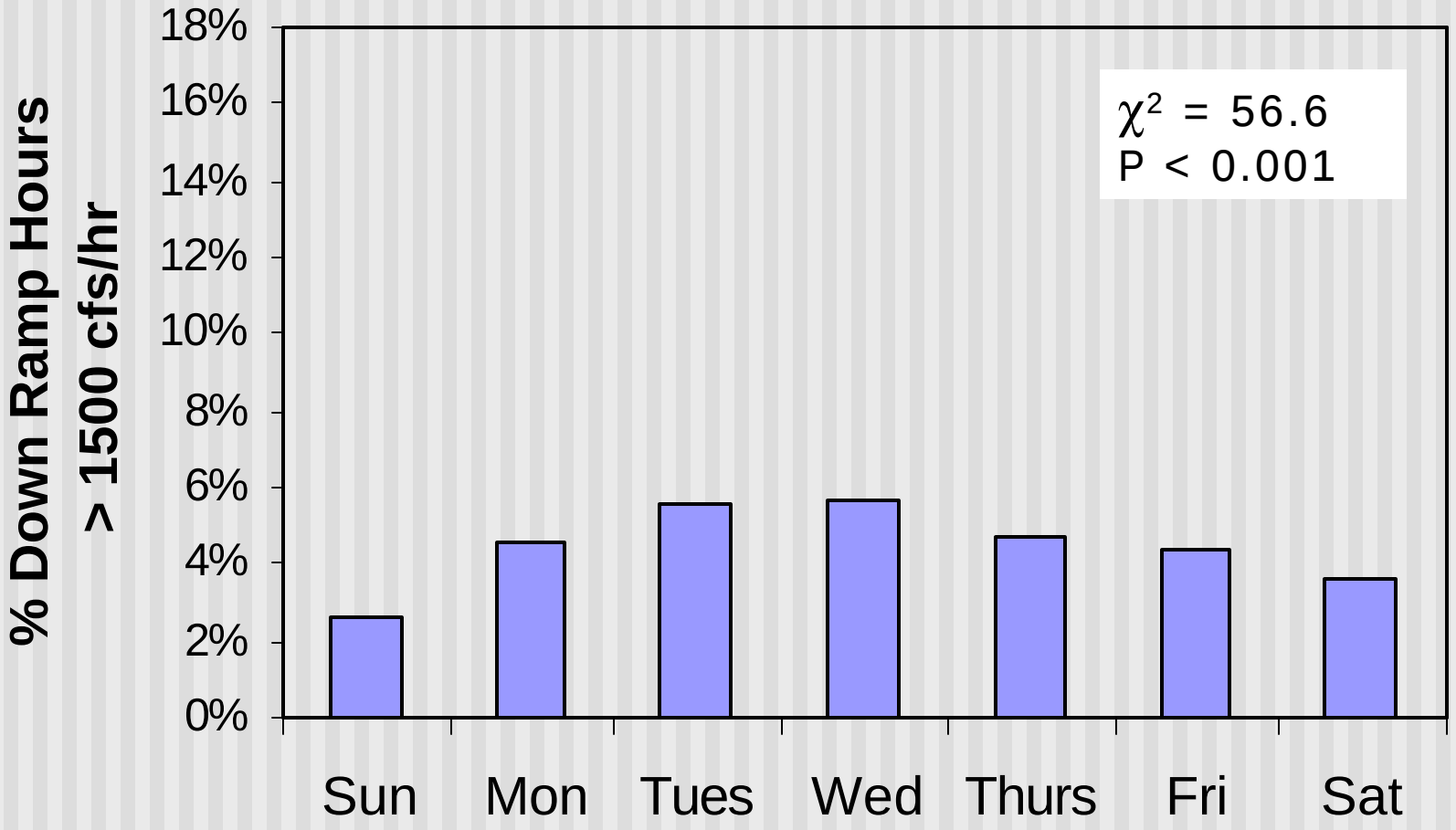
# Hour of Day Effect



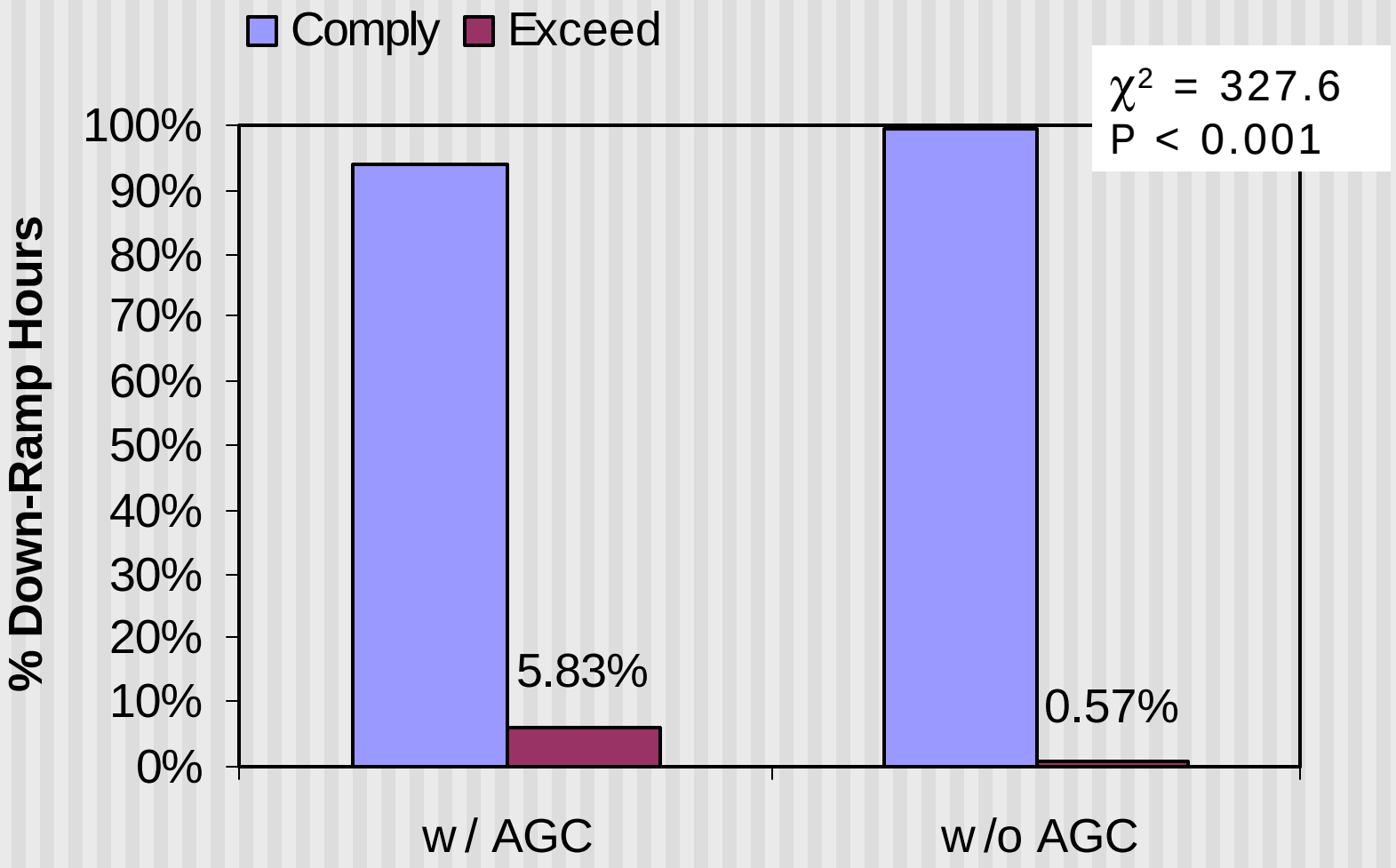
# Month Effect



# Day Effect


% Down Ramp Hours
> 1500 cfs/hr
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
$\chi^2$ = 56.6
P < 0.001
Sun
Mon
Tues
Wed
Thurs
Fri
Sat

# “AGC” Effect


Comply
Exceed
$\chi^2$ = 327.6
P < 0.001
% Down-Ramp Hours
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
5.83%
0.57%
w/ AGC
w/o AGC

# Conclusions: Phase I

- About 5% of down-ramp hours had ramp rates > 1500 cfs/hr
- Down-ramp exceedances most frequent during late evening down-ramp period and periods of high power demand

# Conclusions: Phase I (Cont'd)

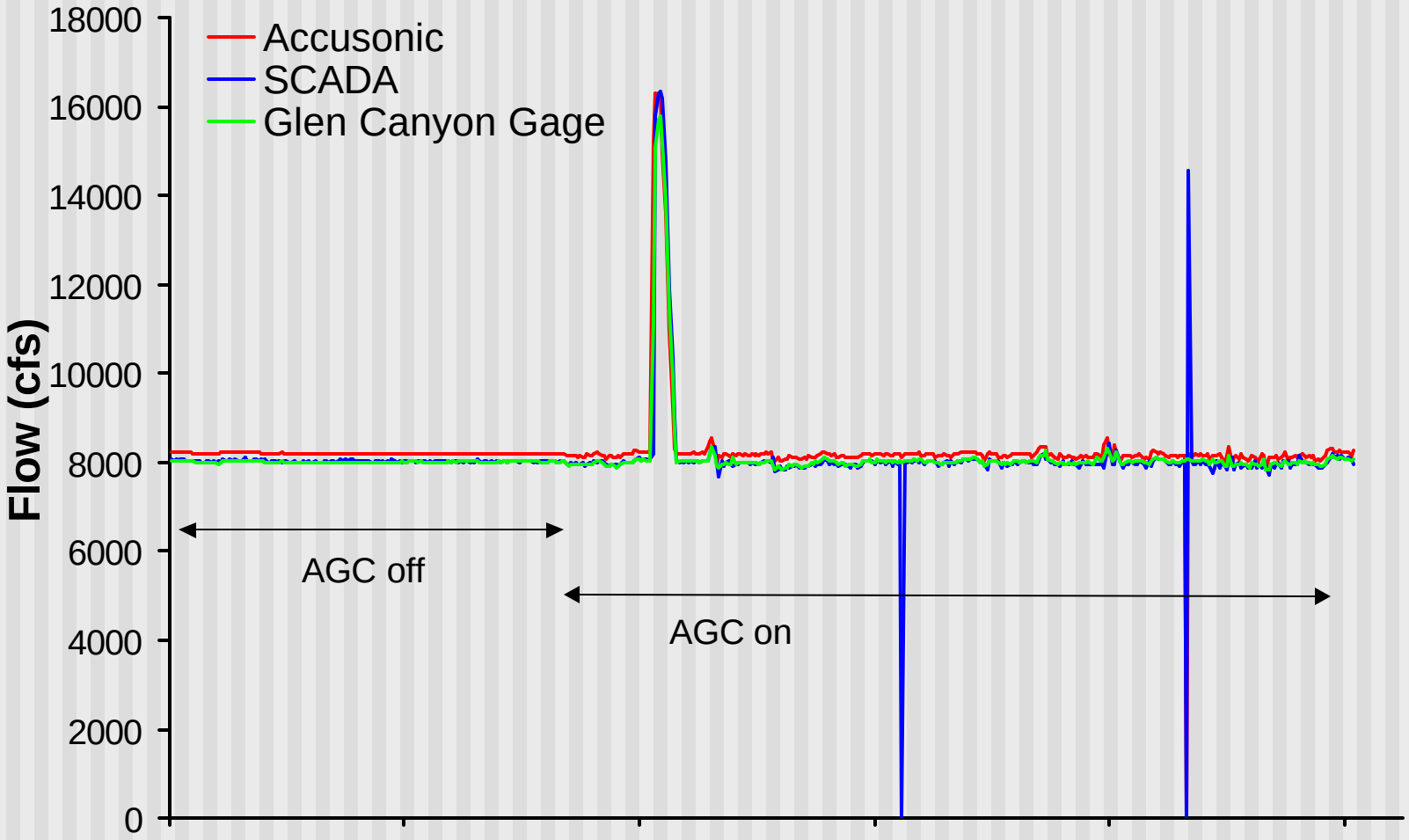
- Fewer than 1% of down-ramp hours had ramp rates > 1500 cfs/hr during the period when AGC was off Glen

- Effect of AGC not clear because it was confounded with reduction in target ramp rate during test period

# Phase II: AGC Experiments

- Reduce the measurement period to get better understanding of AGC effect on flow variability
- Compare steady flow and fluctuating flow periods with AGC on and off
- Compare Glen Canyon gage, Accusonic, and SCADA data

# Steady Flow Test Period: 9/10 to 9/30/00



# Variation in 5-minute Data: Steady Flows with AGC Off

- Accusonic
  - Range:  8032 to 8279 cfs (247 cfs)
  - CV: 0.23%
  - Max difference between consecutive readings: 150 cfs
- Gage
  - Range:  7971 to 8061 cfs (90 cfs)
  - CV: 0.20%
  - Max difference between consecutive readings: 45 cfs
- Stage
  - Range:  31.42 to 31.46 ft (0.5 in)
  - CV:  0.02%
  - Max difference between consecutive readings: 0.02 ft (0.25 in)

# Variation in 5-minute Data: Steady Flows with AGC On

- Accusonic
  - Range:  6944 to 9497 cfs (2553 cfs)
  - CV: 1.51%
  - Max difference between consecutive readings: 1352 cfs
- Gage
  - Range:  7704 to 8472 cfs (768 cfs)
  - CV: 0.94%
  - Max difference between consecutive readings: 158 cfs
- Stage
  - Range:  31.30 to 31.64 ft (4 in)
  - CV:  0.11%
  - Max difference between consecutive readings: 0.07 ft (0.8 in)

# Hourly Flow Statistics during Steady Flow Test Period

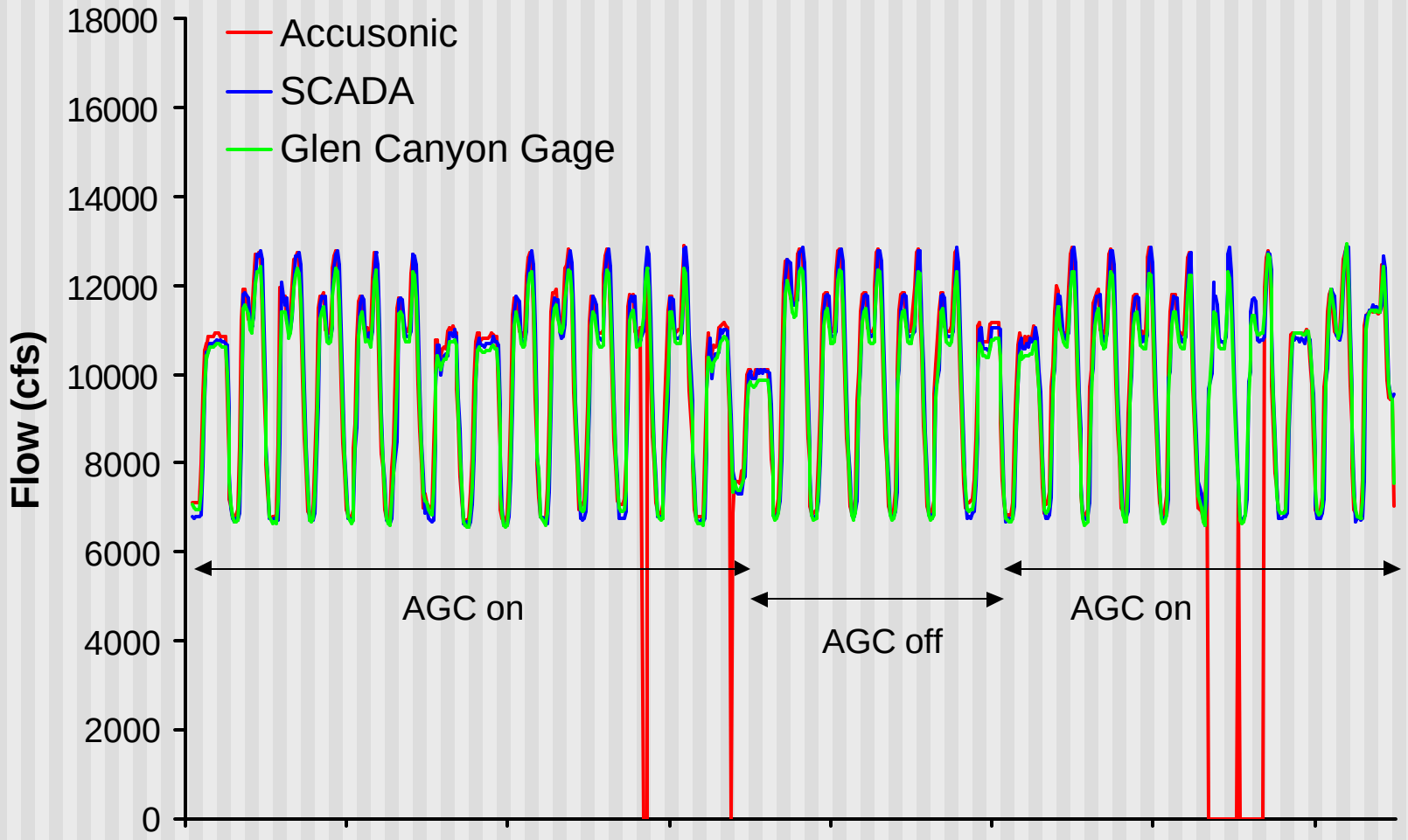
**AGC Off**

| | Mean | Min | Max | CV |
|---|---|---|---|---|
| **Accusonic** | 8210 | 8179 | 8246 | 0.17 |
| **SCADA** | 8035 | 7980 | 8110 | 0.32 |
| **Gage** | 8008 | 7973 | 8053 | 0.17 |
| **Stage** | 31.44 | 31.42 | 31.46 | 0.02 |

**AGC On**

| | Mean | Min | Max | CV |
|---|---|---|---|---|
| **Accusonic** | 8169 | 7861 | 8576 | 0.93 |
| **SCADA** | 7959 | 0 | 14580 | 9.75 |
| **Gage** | 8012 | 7817 | 8340 | 0.87 |
| **Stage** | 31.44 | 31.35 | 31.58 | 0.10 |

# Fluctuating Flow Test Period: 10/1/00 to 10/31/00



# Hourly Flow Statistics during Fluctuating Flow Test Period

## AGC Off

| | Mean | Min | Max | CV |
|---|---|---|---|---|
| **Accusonic** | 9992 | 6870 | 12815 | 19.39 |
| **SCADA** | 9894 | 6770 | 12850 | 20.06 |
| **Gage** | 9717 | 6712 | 12395 | 18.62 |
| **Stage** | 32.15 | 30.84 | 33.26 | 2.41 |

## AGC On

| | Mean | Min | Max | CV |
|---|---|---|---|---|
| **Accusonic** | 9884 | 6681 | 12908 | 20.15 |
| **SCADA** | 9834 | 6560 | 12900 | 20.66 |
| **Gage** | 9715 | 6553 | 12925 | 19.34 |
| **Stage** | 32.13 | 30.75 | 33.28 | 2.50 |

# Down-Ramp Rate Values During Fluctuating Flow Test Period

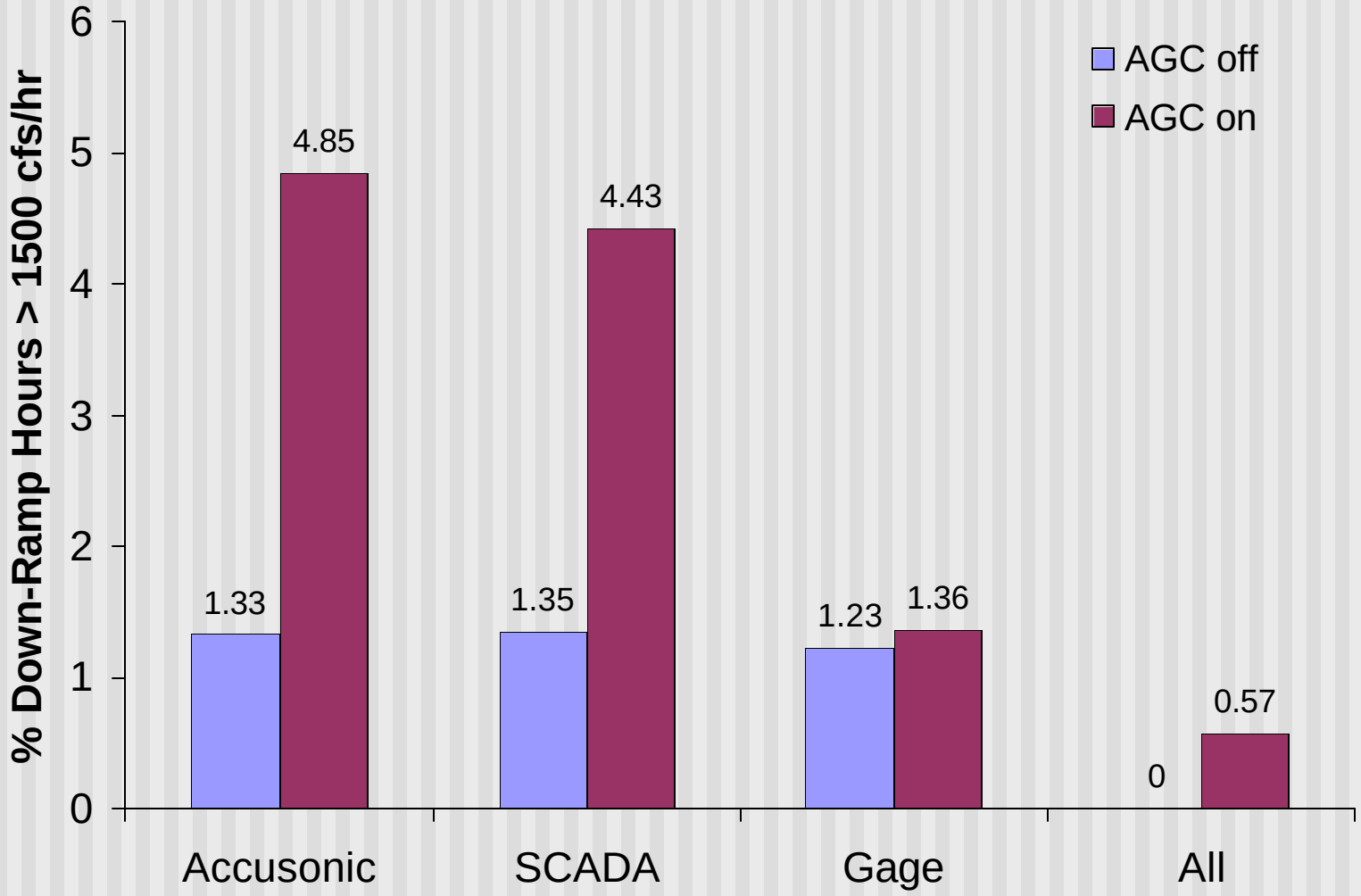
## AGC Off

| | Mean | Min | Max | CV |
|---|---|---|---|---|
| **Accusonic** | 558 | 0.1 | 1666 | 96 |
| **SCADA** | 588 | 10 | 1520 | 94 |
| **Gage** | 485 | 2.1 | 1559 | 91 |
| **Stage** | 0.2 | 0 | 0.7 | 91 |

## AGC On

| | Mean | Min | Max | CV |
|---|---|---|---|---|
| **Accusonic** | 526 | 0.2 | 2413 | 102 |
| **SCADA** | 565 | 10 | 1990 | 96 |
| **Gage** | 477 | 0 | 1886 | 96 |
| **Stage** | 0.2 | 0 | 0.8 | 95 |

# Exceedance as Measured by Different Methods During Fluctuating Flow Test Period



# Statistical Tests of AGC Effect on Down-Ramp Rate During Fluctuating Flow Test Period

***Frequency of Exceedance (?$^2$)***

| | |
|---|---|
| Accusonic | P = 0.17 |
| SCADA | P = 0.22 |
| Gage | P = 0.93 |

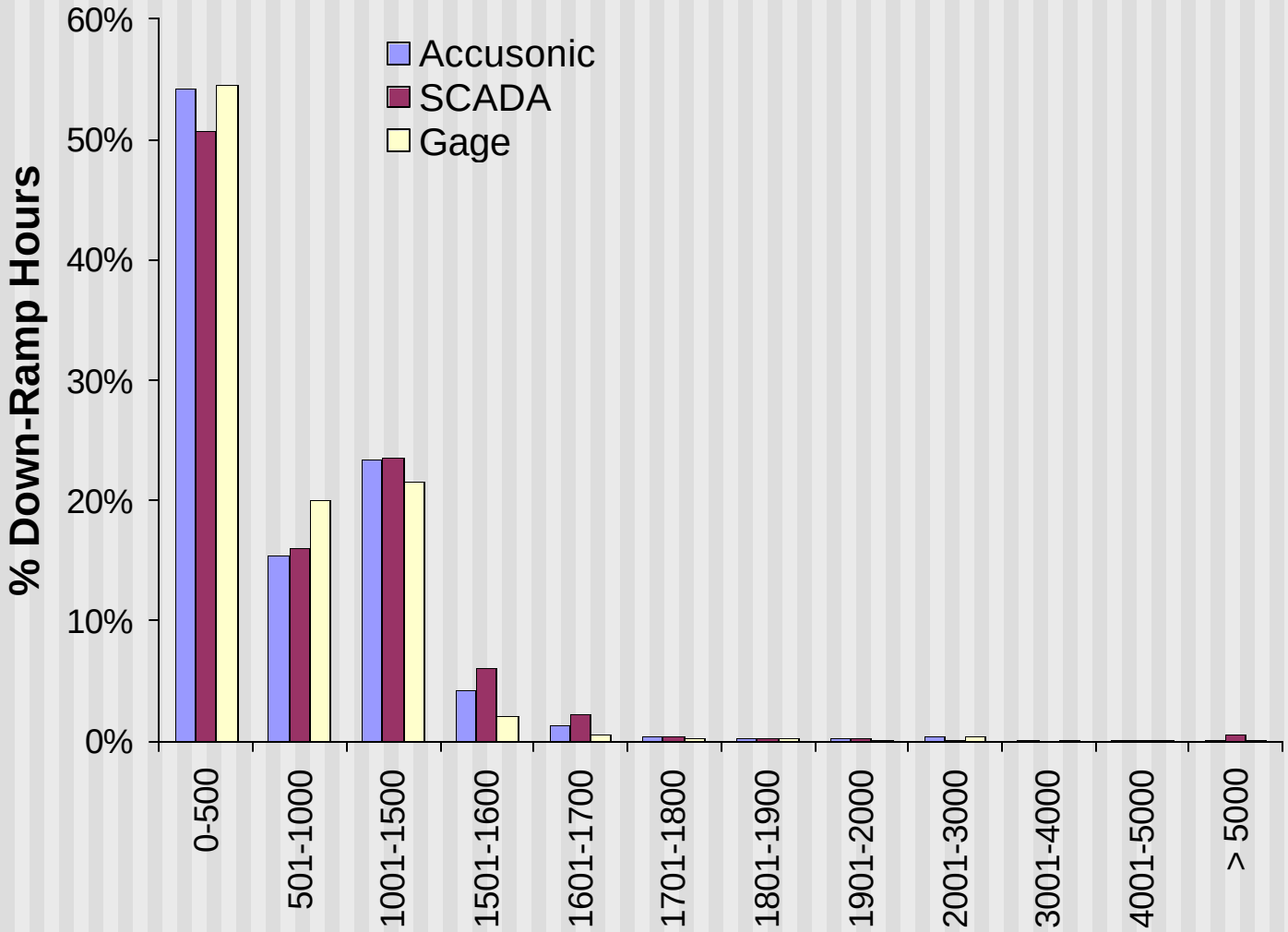
***Magnitude of Ramp Rate (t-Test)***

| | |
|---|---|
| Accusonic | P = 0.65 |
| SCADA | P = 0.75 |
| Gage | P = 0.88 |

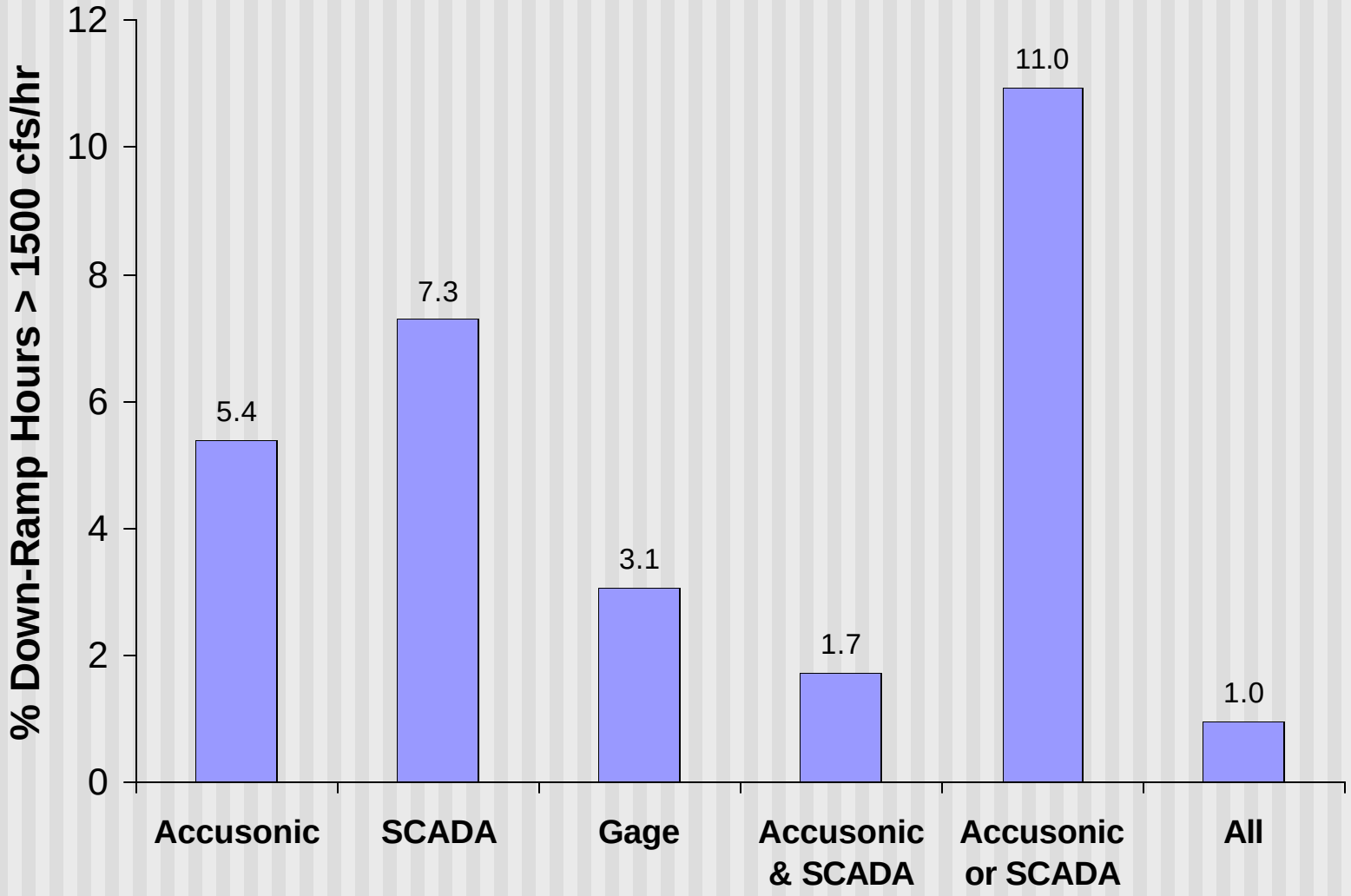
***Equality of Variances (F-test)***

| | |
|---|---|
| Accusonic | P = 1.00 |
| SCADA | P = 0.80 |
| Gage | P = 0.77 |

# Frequency of Down-Ramp Magnitudes as Measured by Different Methods: 10/00 to 7/01



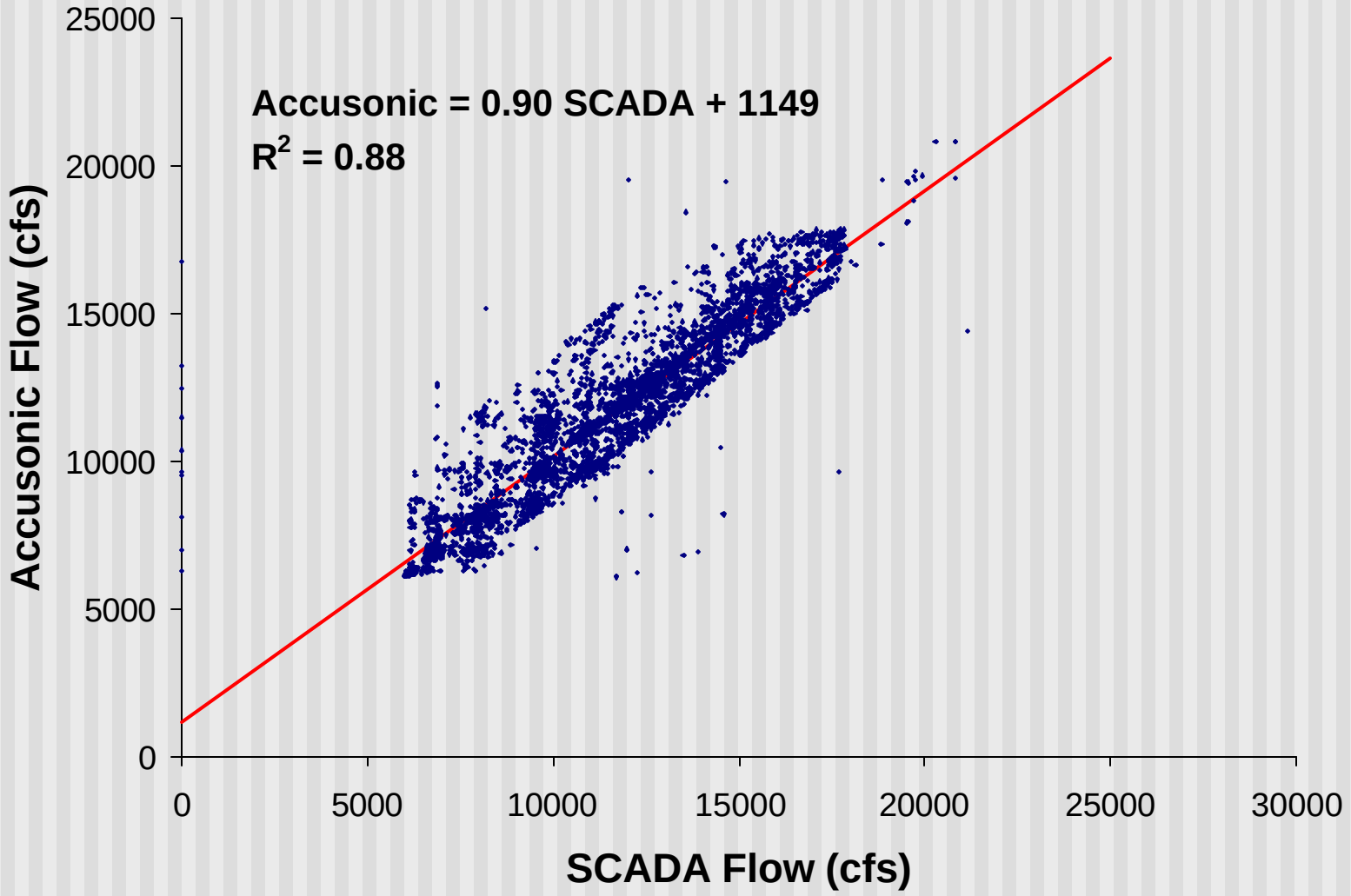
# Exceedance Frequency as Measured by Different Methods: 10/00 to 7/01



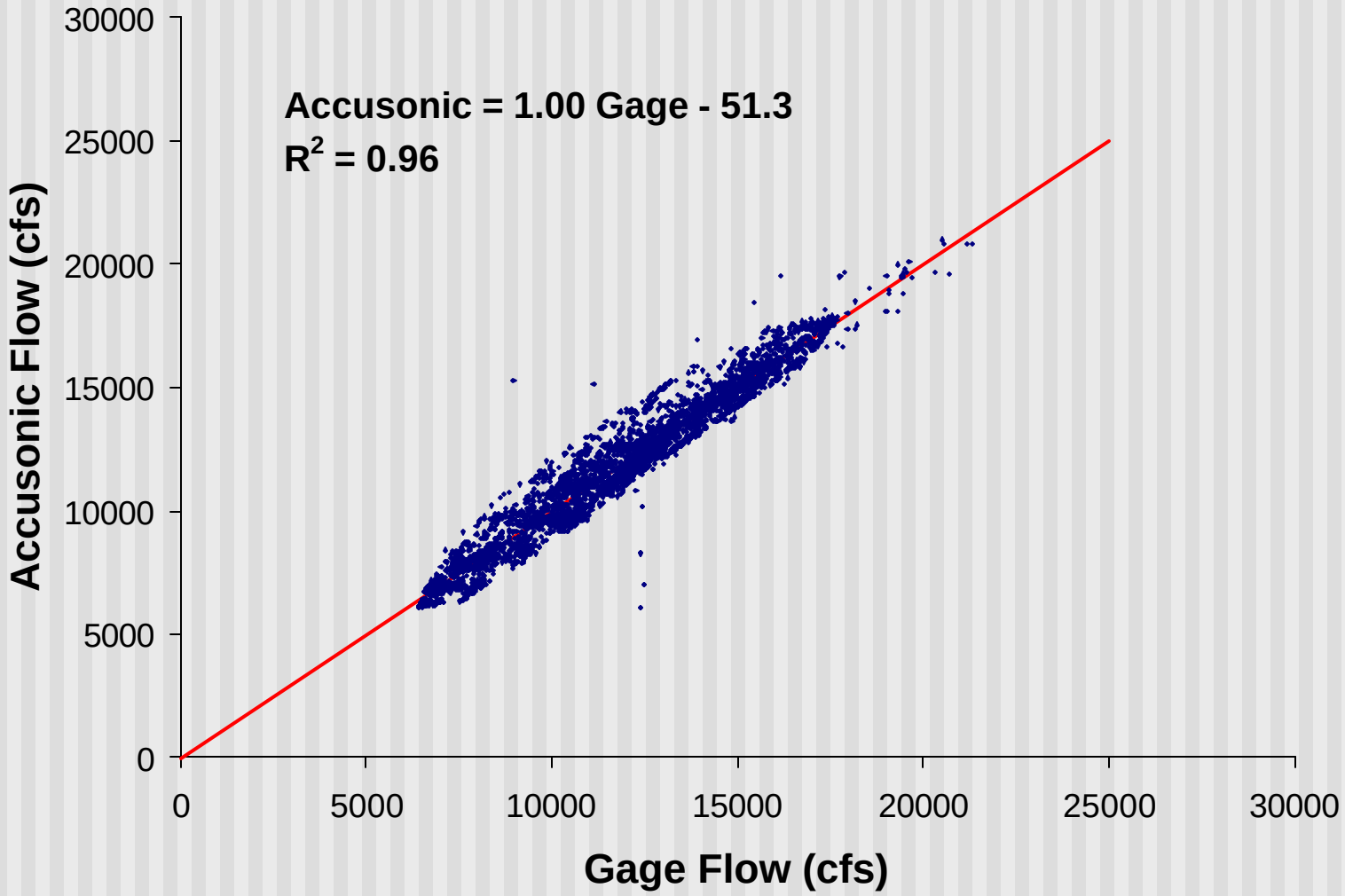
# Example Down-Ramp Data

| Accusonic | SCADA | Gage |
|---|---|---|
| 1606 | 1590 | 1363 |
| 1059 | 1540 | 1204 |
| 1534 | 1300 | 1202 |
| 1520 | 1370 | 1208 |
| 1833 | 1360 | 1247 |

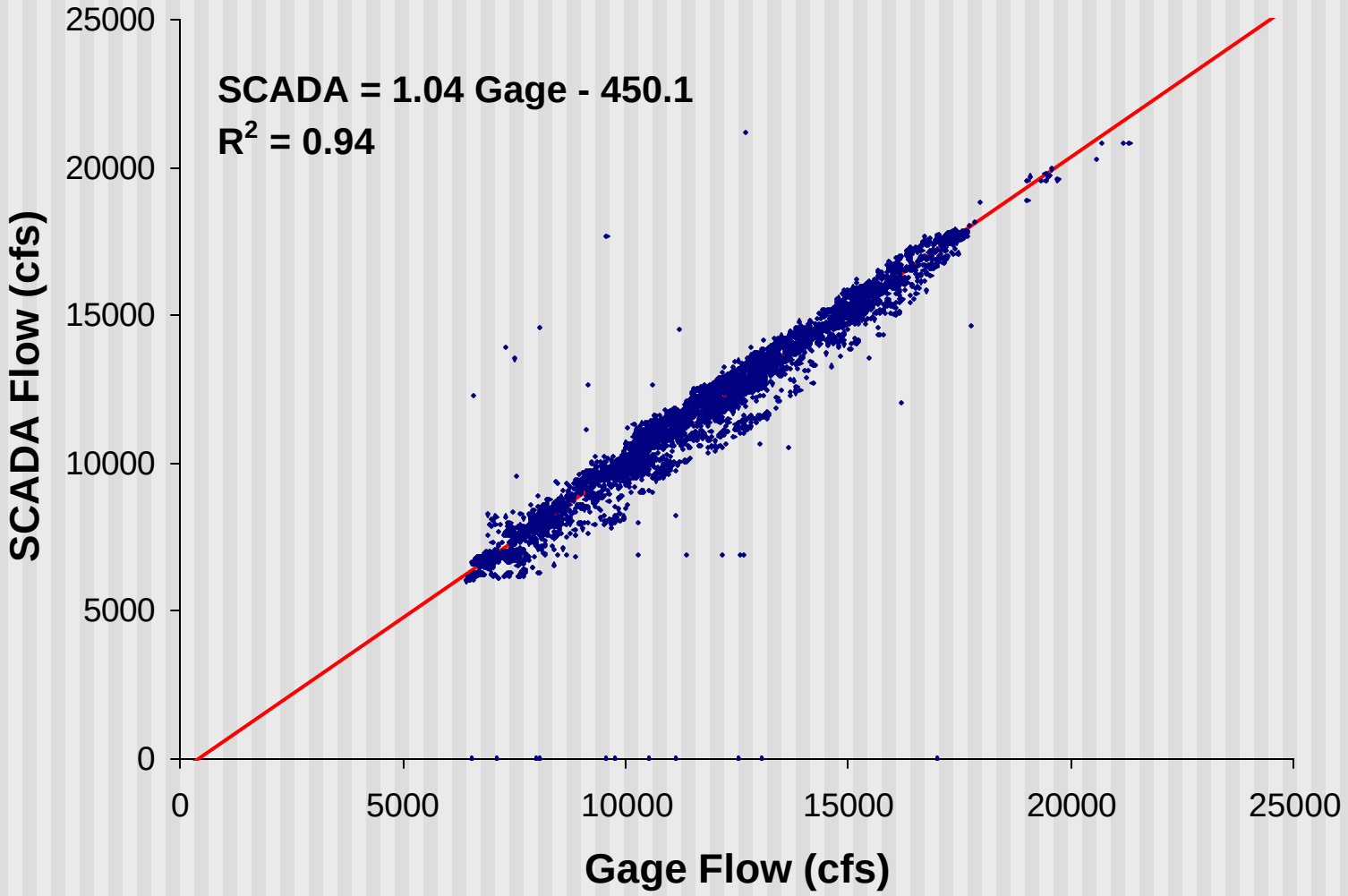
# Comparison of Accusonic and SCADA Flow Data



# Comparison of Accusonic and Gage Flow Data



# Comparison of SCADA and Gage Flow Data



# Conclusions: Phase II

- Flow variation was greater with AGC on
  - More apparent in short (5-min) time frame
  - More apparent in Accusonic and SCADA data than in gage data (sensitivity? attenuation?)
- Accusonic and SCADA: frequency of exceedance higher with AGC on than off, but not significantly
- Gage: frequency of exceedance same with AGC on and off
- Down-ramp rate magnitude did not differ significantly between AGC periods

# Conclusions: Phase II (Cont'd)

- Measurements using different methods strongly correlated, but variable
- Variability leads to difference in detected frequency of exceedance
  - SCADA > Accusonic > Gage
- All 3 techniques seldom measured down-ramp rates > 1500 cfs/hr simultaneously (1% of the time)

# Bottomline

- AGC increased variability in releases, but did not increase the frequency of down-ramps > 1500 cfs/hr at the Glen Canyon gage