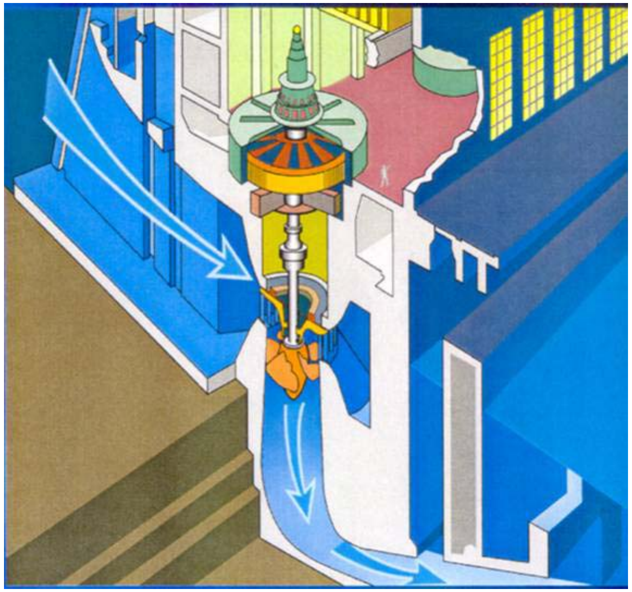
Effects of Turbine Operating Efficiency on Smolt Passage Survival

John R. Skalski
University of Washington
and
Dilip Mathur
Normandeau Associates



History of Presentation

- Turbine Passage Survival Workshop, Portland, Oregon, 14-15 June 2000
- Skalski, Mathur, and Heisey, 2002, *North American Journal of Fisheries Management* 22:1193-2000
- New input from 2002 McNary Dam studies, US Army Corps of Engineers

Purpose of Talk

Review of existing data on relationships between smolt survival and turbine operating efficiency using:

1. Bell (1981) report
2. Analyses of planned experiments
   - Lower Granite Dam 1995
   - Wanapum Dam 1996
   - Rocky Reach Dam 1997
   - Bonneville Dam 2000
   - McNary Dam 2002
3. Meta-analysis across multiple projects

Background

1994 Columbia River Basin Fish and Wildlife Program

5.6D.1 "Operate turbine units within 1 percent of peak operating efficiency from April through August of each year, and especially during peak migration periods."

Background (con't)

1995 FCRPS Biological Opinion (IV)

- "Improvement in the operational control of turbine units, allowing operation within one percent of peak efficiency at all eight mainstem federal dams on the Snake and Columbia Rivers."
- "Turbine survival is directly related to turbine efficiency."
- " . . . But the precise benefits of increased turbine efficiency . . . are unknown."

Background (con't)

2000 FCRPS Final Biological Opinion

Action 58:

"The Corps and BPA . . . shall operate all turbine units at FCRPS dams for optimum fish passage survival. The Corps and BPA will operate turbines within 1% of peak efficiency during juvenile and adult migration seasons . . . ."

10.5.1.8 Monitor Turbine Efficiency

"The BPA and the Corps shall provide an annual summary report detailing compliance with the 1% peak efficiency turbine operation guideline . . . ."

Historical Information
Bell (1981) Report

Big Cliff Dam Study (1964, 1966)

Evaluated Kaplan turbine unit

- 6 blades
- 164 rpm
- Head at 90 ft

Study design

- Release at 1 location

Fish

- Chinook salmon (mean length 101 mm)

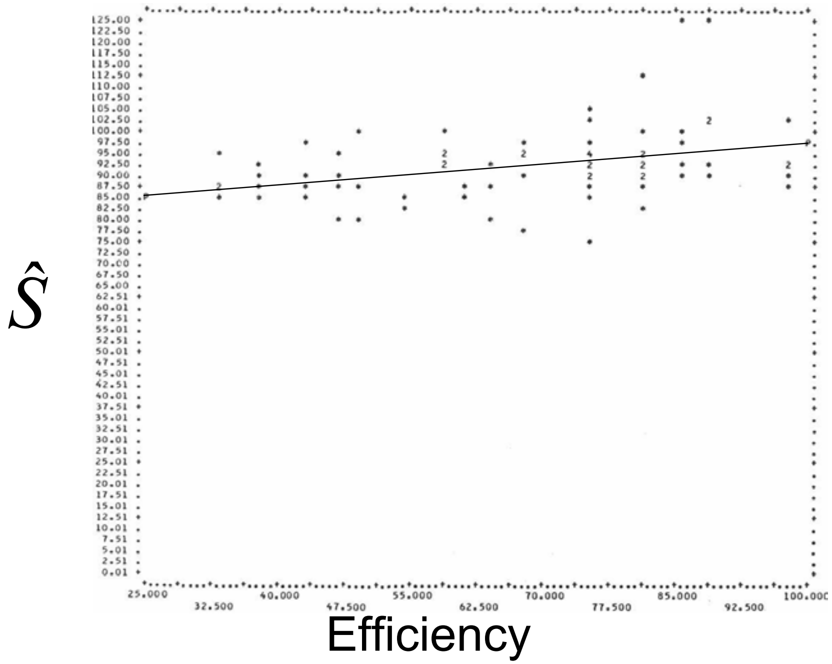
Bell (1981)

Kaplan Turbine at Big Cliff Dam

Year	Efficiency Range	Regression	
		r^2	P-value
1964	32.5% - 96%	0.254	0.017*
1966	32.5% - 96%	0.020	0.258
Combined	32.5% - 96%	0.112	0.003*

Survival vs. Efficiency Plot

Big Cliff (1964 and 1966)



Bell (1981)

"There does not seem to be a smooth ascending and descending curve following the efficiency line of the turbines as might have been expected."

"The data offer some support, however, . . . the best points of machine efficiency should give the best points of fish passage survival."

Bell (1981)

- Did <u>not</u> actually measure turbine efficiency
  - Instead used % wicket-gate opening as surrogate
- Hence, no actual data on efficiency-survival relationship

Site-Specific Studies Columbia Basin

- Lower Granite, 1995
- Wanapum, 1996
- Rocky Reach, 1997
- Bonneville, 2000
- McNary, 2002

Lower Granite Dam Study (1995)

Evaluated turbine unit 4

- Kaplan
- 6 blades
- 90 rpm
- Head at 98 ft

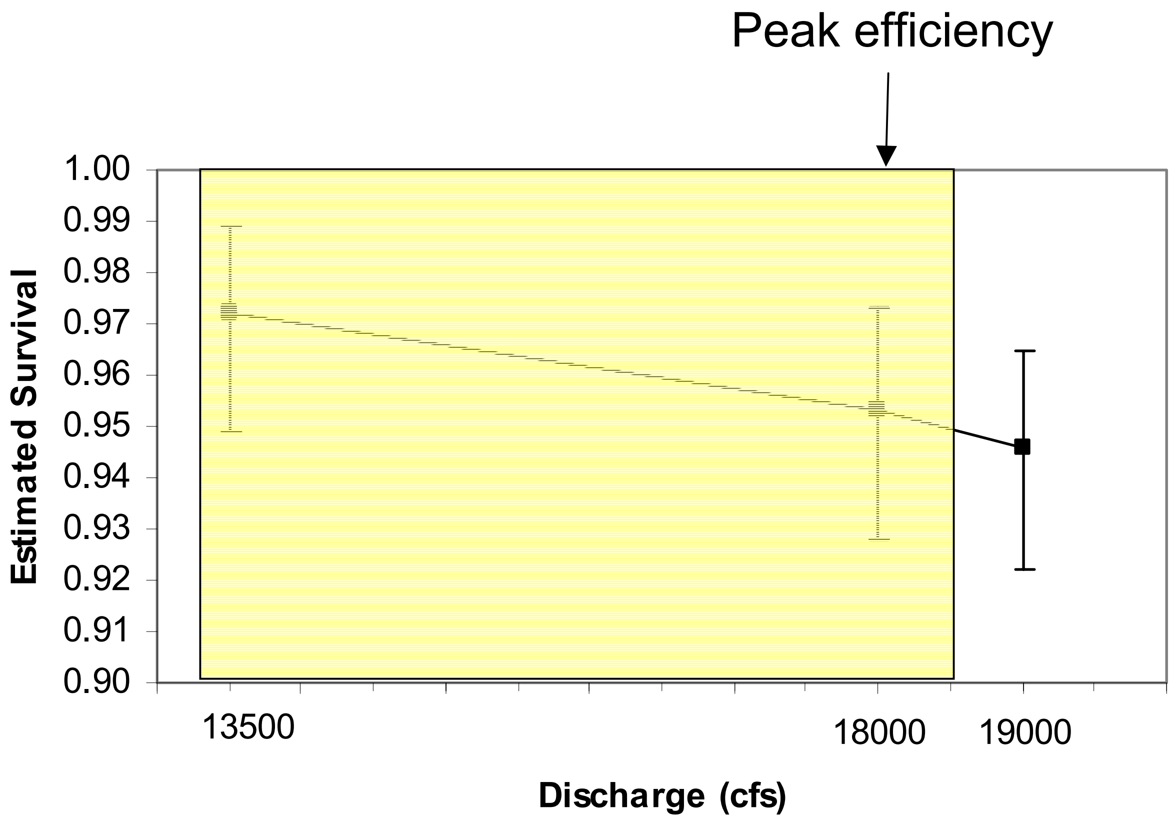
Study design

- 3 turbine operating levels
  - Low end of ±1%
  - Normal ±1%
  - Cavitation mode
- 1 mid-release location

Fish

- Spring chinook salmon (mean length 150 mm)

Survival Plot: Lower Granite Dam (1995)



Wanapum Dam Study (1996)

Evaluated turbine unit 9

- Kaplan with adjustable blades
- 5 blades
- 87.5 rpm
- Head at 74.5 ft

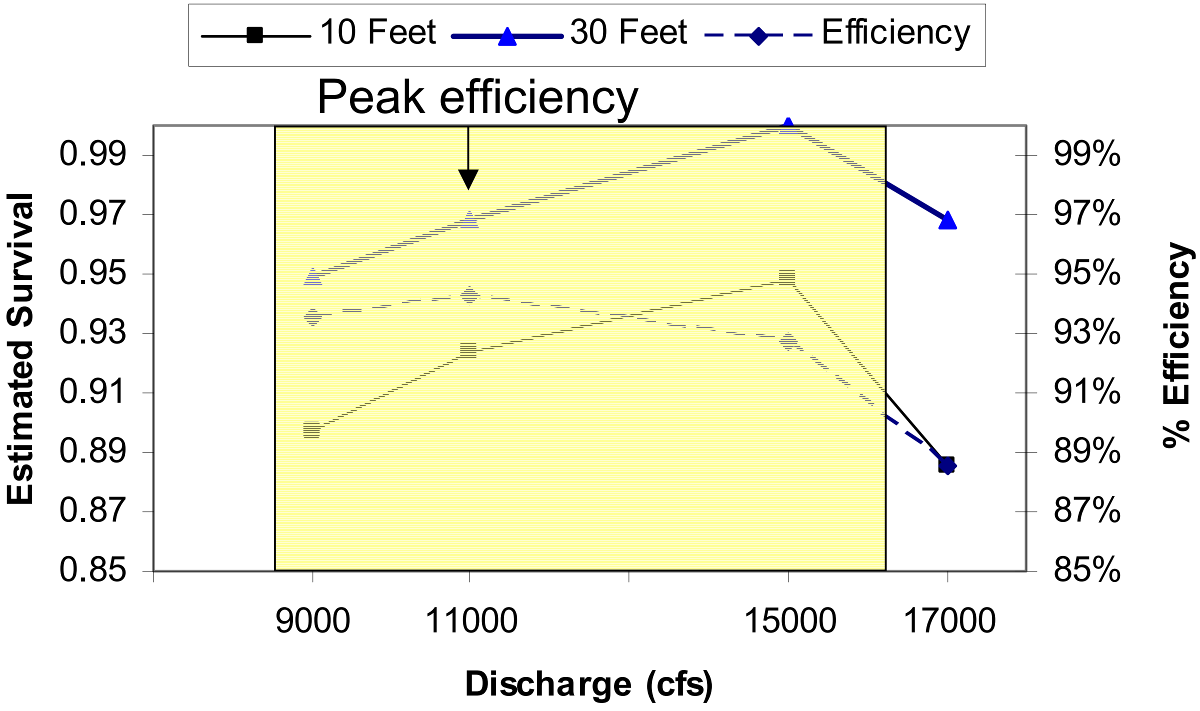
Study design

- 4 turbine operating levels
- 2 release locations
  - 10 ft and 30 ft below intake ceiling

Fish

- Coho salmon (mean length 154 mm)

Survival Plot: Wanapum Dam



Rocky Reach Dam Study (1997)

Evaluated turbine unit

- Kaplan
- 6 blades
- 90 rpm
- Head at 92 ft

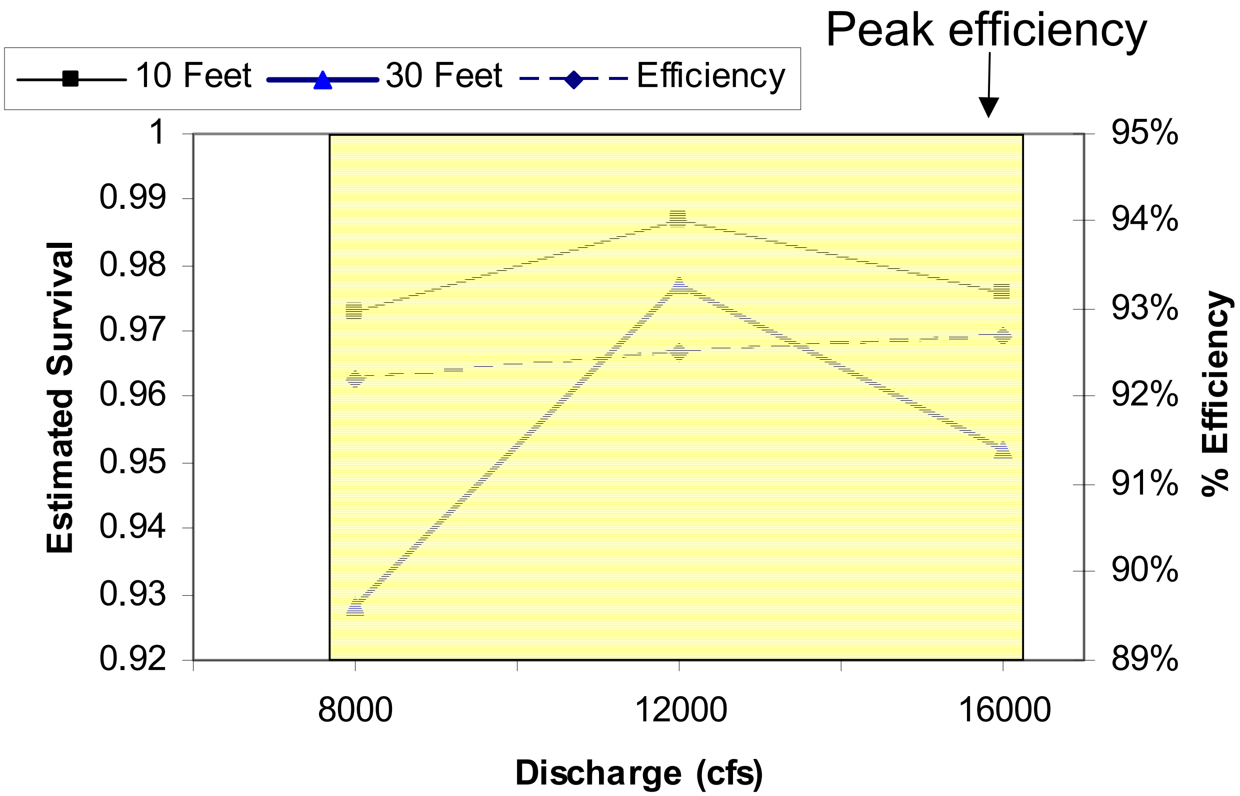
Study design

- 3 turbine operating levels
- 2 release locations
  - 10 ft and 30 ft below intake ceiling

Fish

- Spring chinook salmon (mean length 184 mm)

Survival Plot: Rocky Reach Dam



Bonneville Dam Study (2000)

Evaluated turbine unit 5

- Kaplan with adjustable blades
- 5 blades
- 75 rpm
- Head at 57 ft

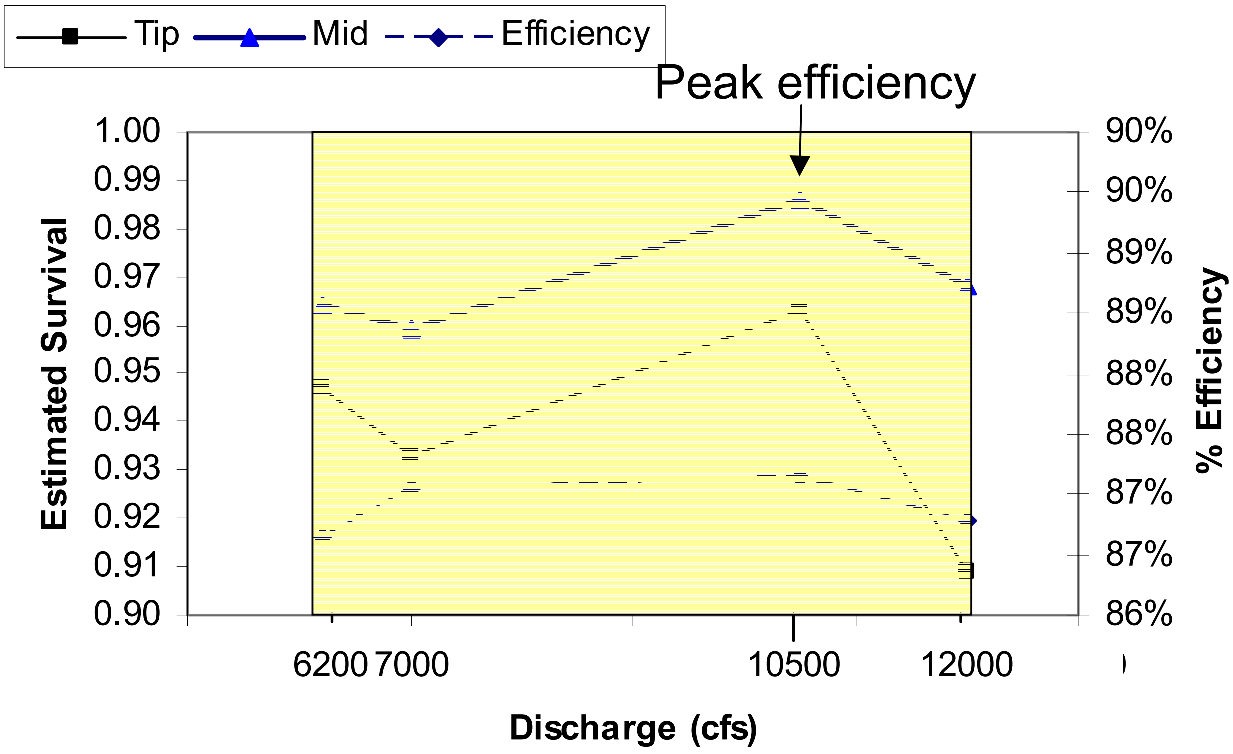
Study design

- 4 turbine operating levels
- 3 release locations
  - Hub, Tip, and Mid-blade

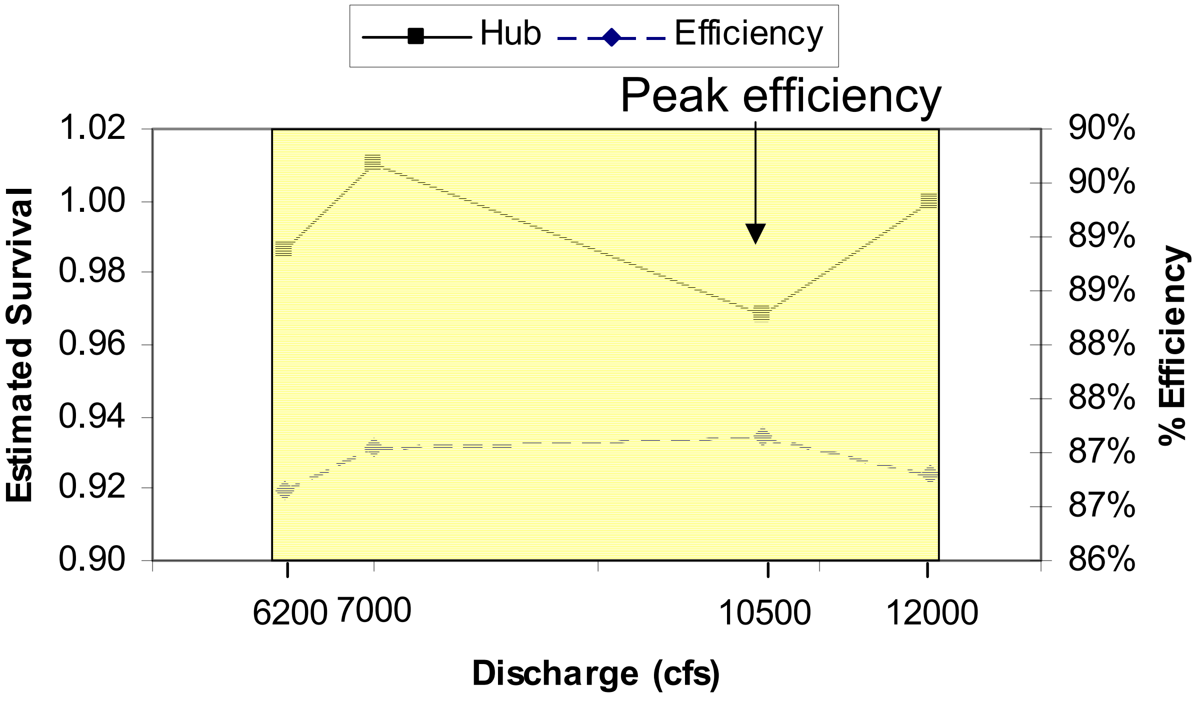
Fish

- Spring chinook salmon (mean length 155 mm)

Survival Plot: Bonneville Dam (2000)



Survival Plot: Bonneville Dam (2000)



McNary Dam Study (2002)

Evaluated turbine unit 9

- Kaplan with adjustable blades
- Six blades
- 85.7 rpm
- Head at 75 ft

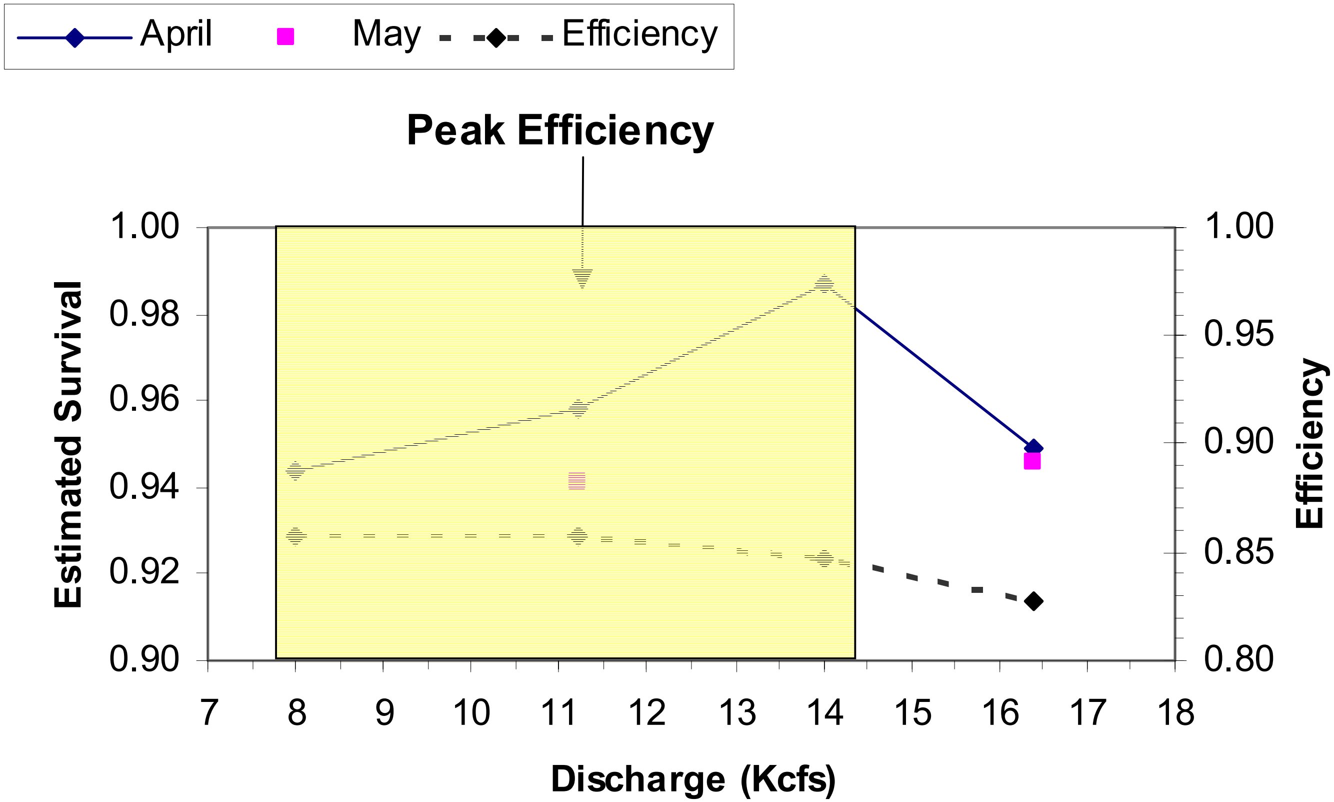
Study design

- 4 turbine operating levels in April
- 2 levels repeated in May
- 1 release location below screen

Fish

- Spring chinook salmon (mean length 155 mm April, 140 mm May)

Survival Plot: McNary Dam (2000)



Multi-Project Analysis Across Country

- Meta-analysis across:
  - 51 trials
  - 17 turbine units
  - 13 projects
- All Kaplan turbines

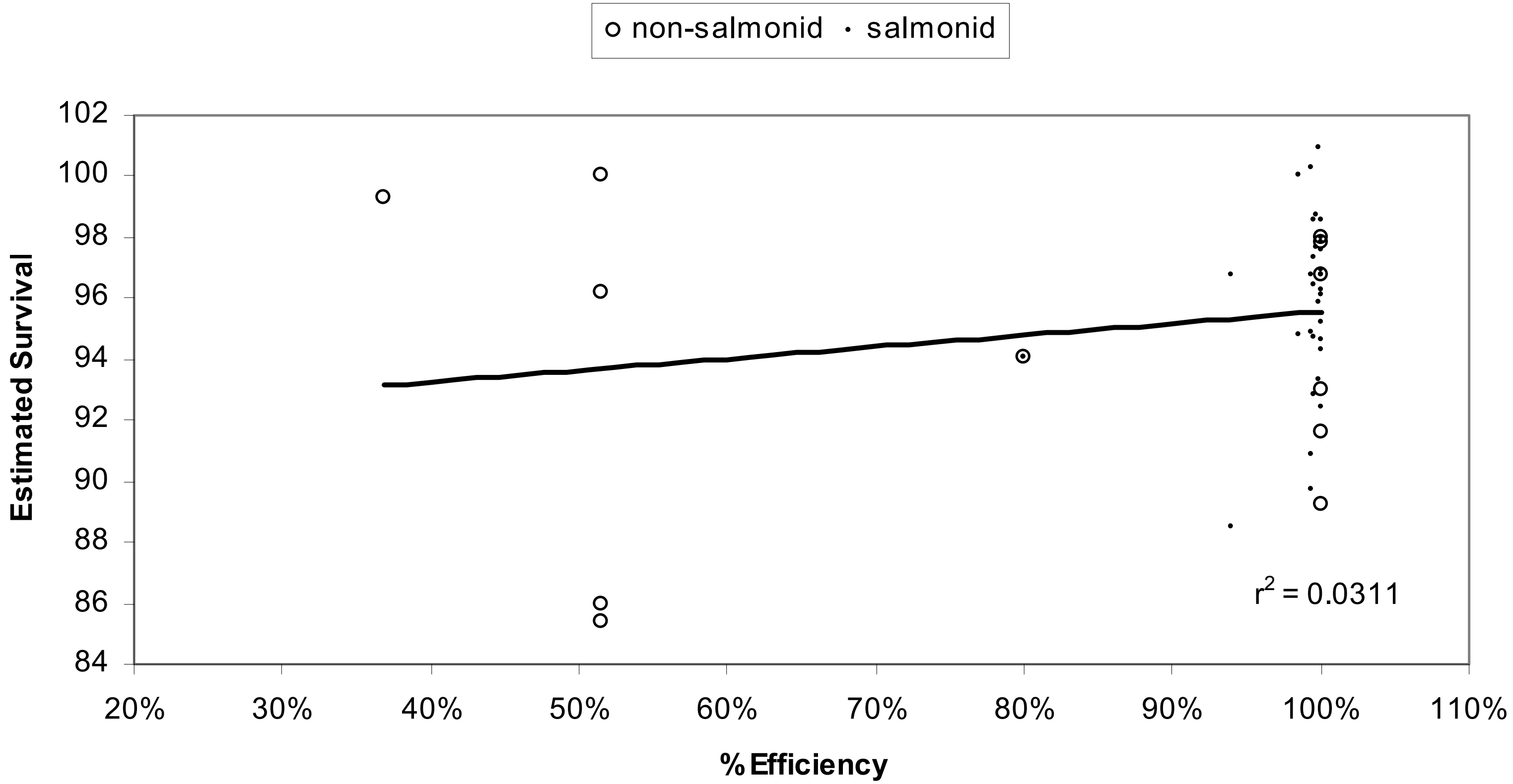
Multi-Project Analysis

- Assess correlation between turbine passage survival and
  - Efficiency
  - Mean length
  - Number of blades
  - Speed (rpm)
  - Head
  - Strike probability

Results of Regression Analysis

Factor	P-Value	r^2
Efficiency	0.2933	0.0298
Mean Length	0.0149*	0.1173
No. of Blades	0.2498	0.0275
Speed	0.1021	0.0547
Head	0.2412	0.0285
Strike Probability	0.0157*	0.1157

Scatterplot: Survival vs. Efficiency



Conclusions

- Bell (1981): Did not measure turbine efficiency despite wide-spread interpretation

- Lower Granite (1995): Peak survival $\neq$ peak efficiency
- Wanapum (1996): Peak survival $\neq$ peak efficiency
- Rocky Reach (1997): Peak survival $\neq$ peak efficiency
- Bonneville (2000): Possible peak efficiency relationship
- McNary (2002): Peak survival $\neq$ peak efficiency

  – In 8 of 10 curves, peak survival not at peak efficiency

- Meta-analysis: No efficiency relationship, $r^2 = 0.030$

Conclusions (cont'd)

- Turbine efficiency curves for Kaplans have broad shallow shapes
  - $\pm$1% rule encompasses wide range of discharges
  - Range generally includes maximum survival
- Peak survival usually not at peak efficiency
- Difference between:

Peak Survival
and
Survival at Peak Efficiency } Up to 3.2%

Conclusions (cont'd)

- Potential benefits from operating turbines at peak survival
- Rule needs to be examined for new generation of turbines