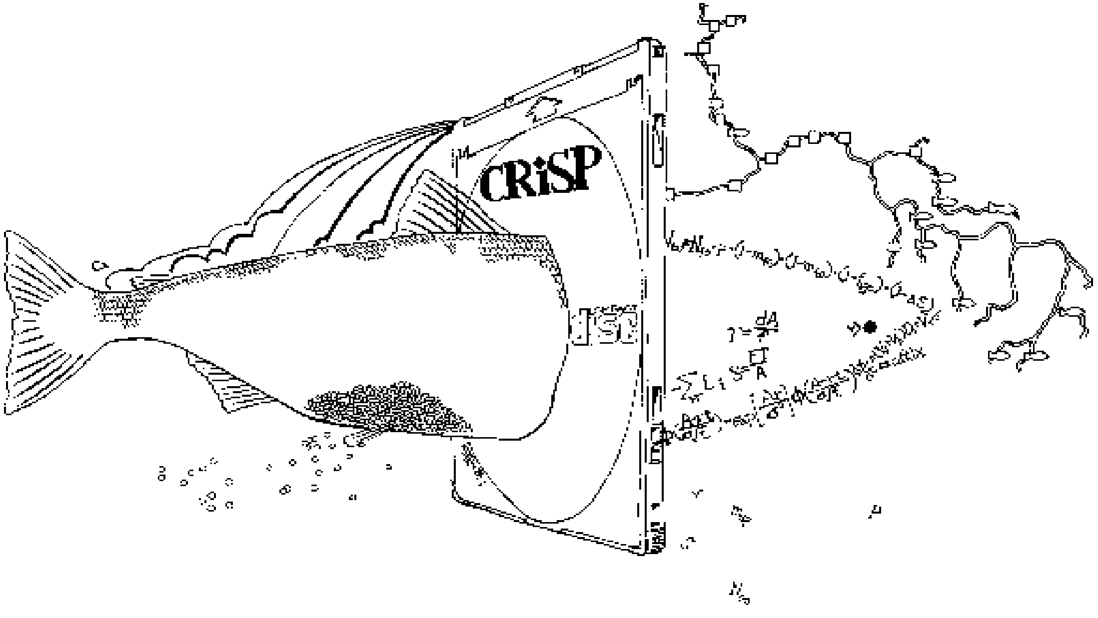
University of Washington's
Columbia River Salmon Passage Model



Chris Van Holmes
Dr. James Anderson

CRiSP Basics

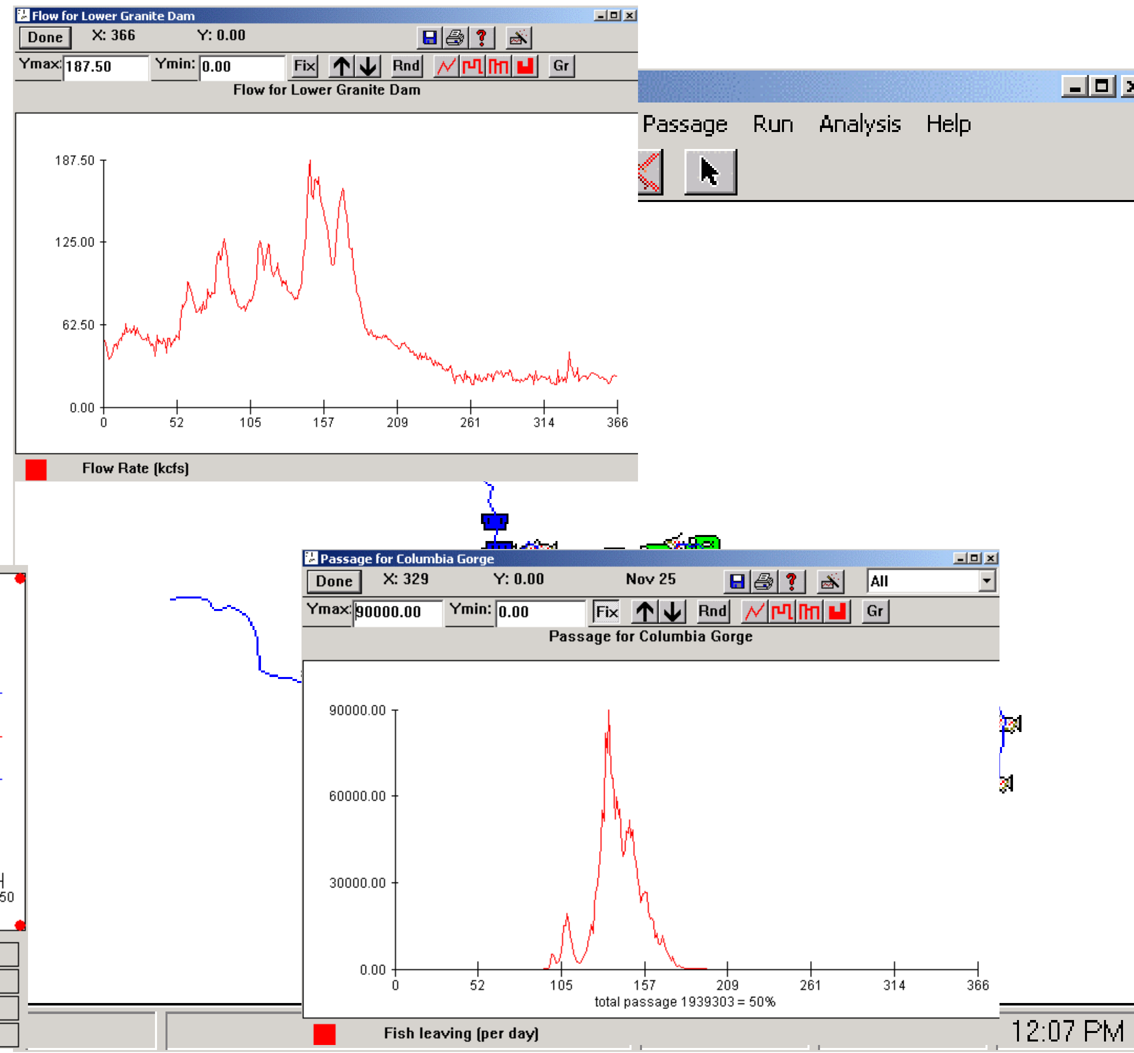
- Models smolt downstream migration and survival through tributaries, dams and estuary
- Uses daily and hourly time-step inputs to model river parameters
- Describes detailed fish movement, survival and river conditions
- Migration and survival models are calibrated to PIT-tag data.
- Dam passage parameters from NOAA estimates

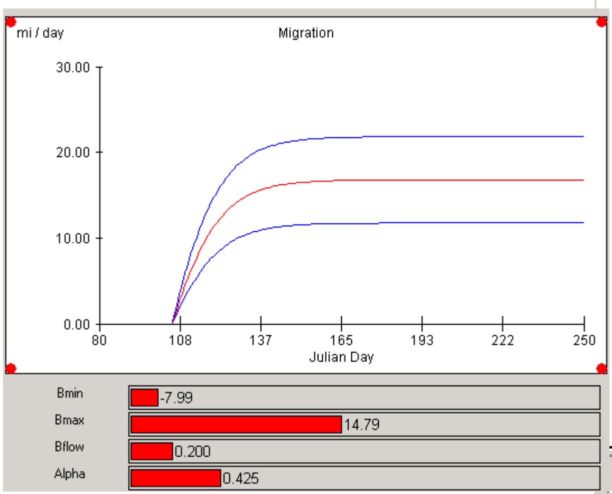
CRiSP Components

- GIS Based River Model
- Component Submodels
  - submodels are changed as science advances.
- River conditions
  - Provide detailed hydroregulation descriptions on hourly and daily basis for each year.
- Input Parameters from NOAA studies
  - FGEs, Separation Probability, Spill Efficiency
- Calibrated Parameters PIT tag studies
  - Migration and survival calibrated for specific cohorts.

CRiSP Smolt Passage Model

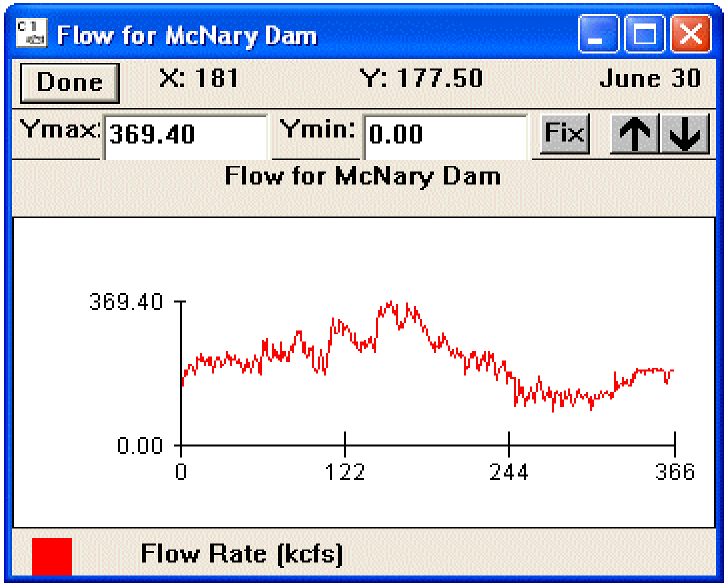
- Shows data
- Shows results
- Shows functions

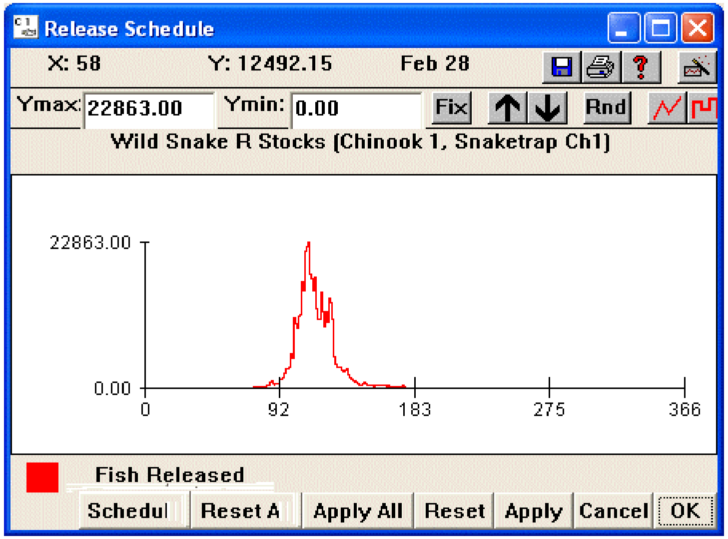




Model Inputs

- Daily flows
- Hourly spill
- Water temperatures
- Pool elevations
- Headwater dissolved gas
- Transport operations
- Fish release profiles
- Fish Guidance Efficiency
- Spill Efficiency
- Dam passage mortalities
- Pool-specific predator density

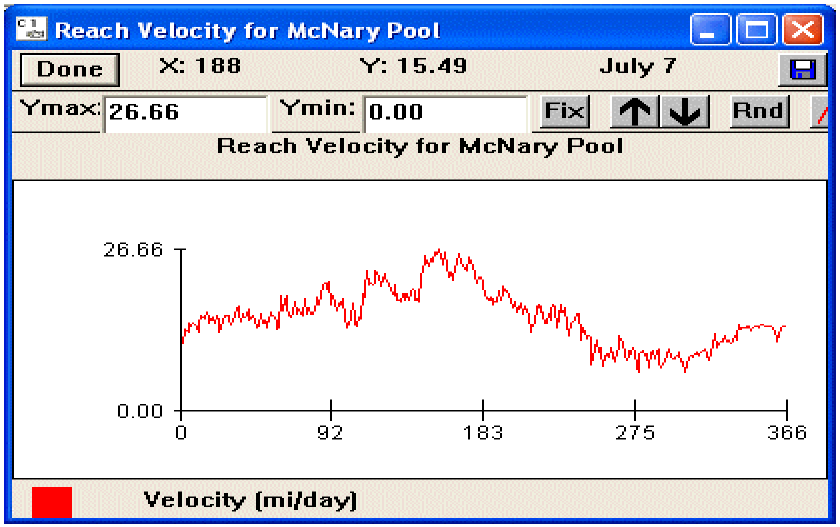


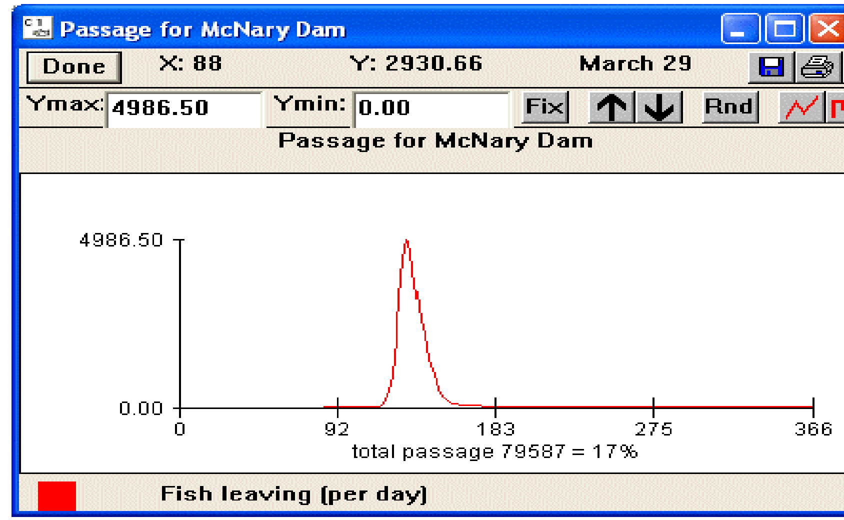


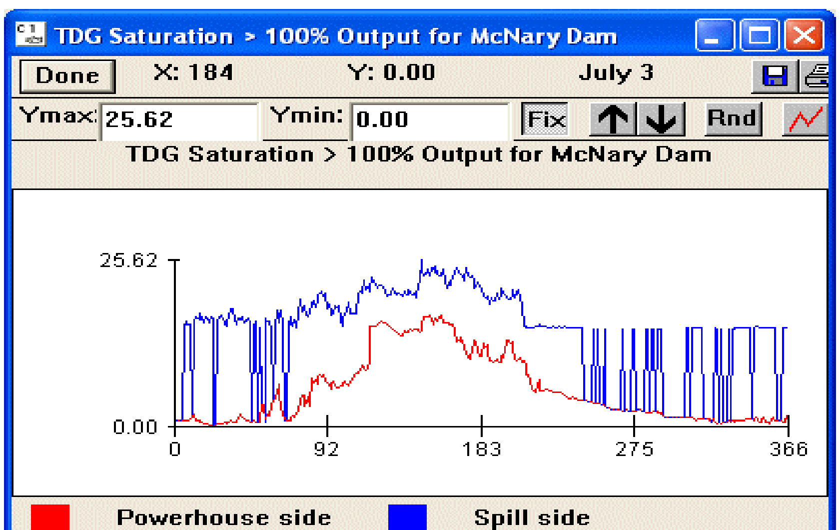
Submodels

- Water velocity
- Dissolved gas generation from spill
- Mixing: flow, temperature, TDG
- Fish transport and dam passage routing
- Migration timing
- Mortality from predation and Gas Bubble Disease

Submodel Results

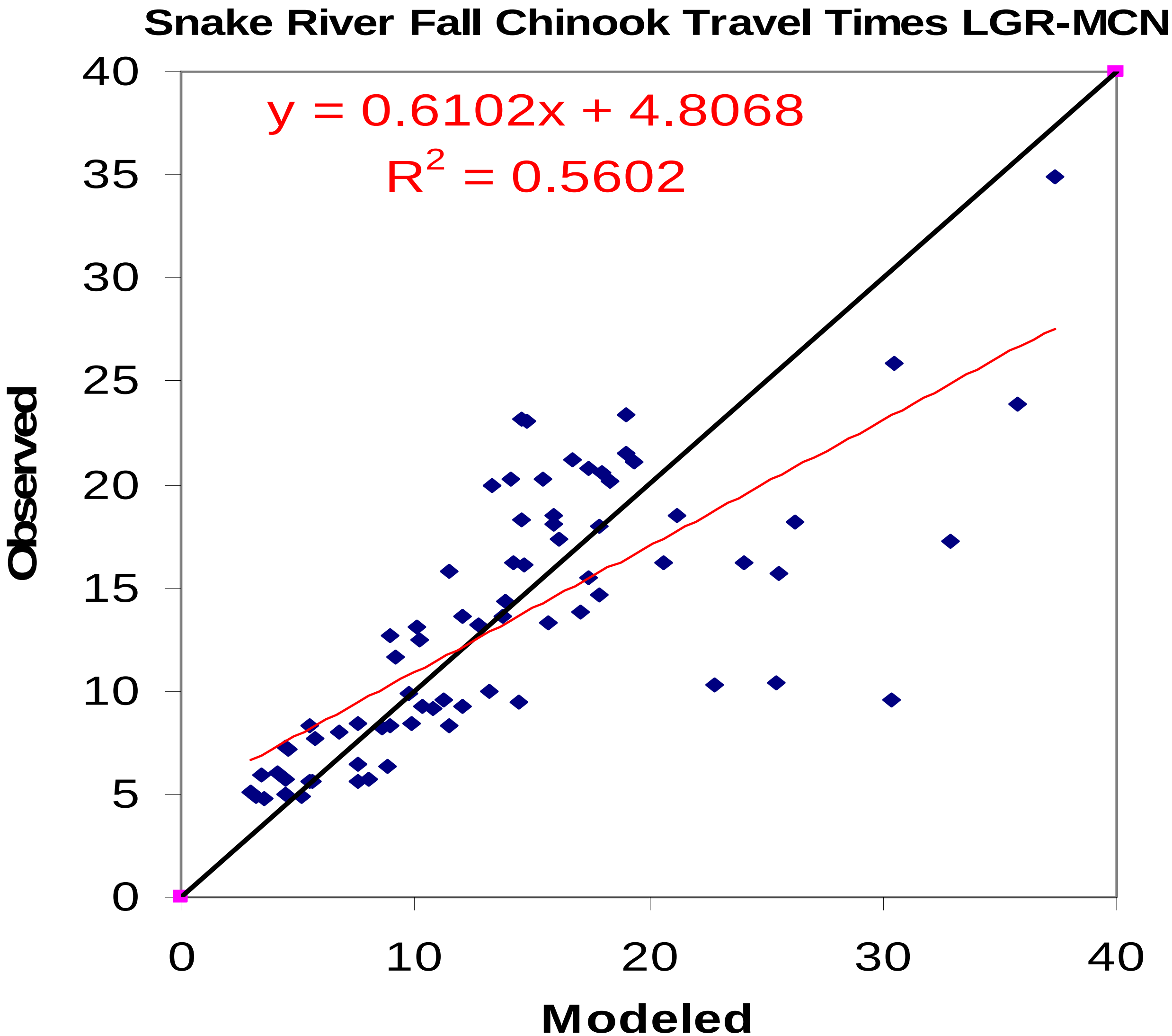




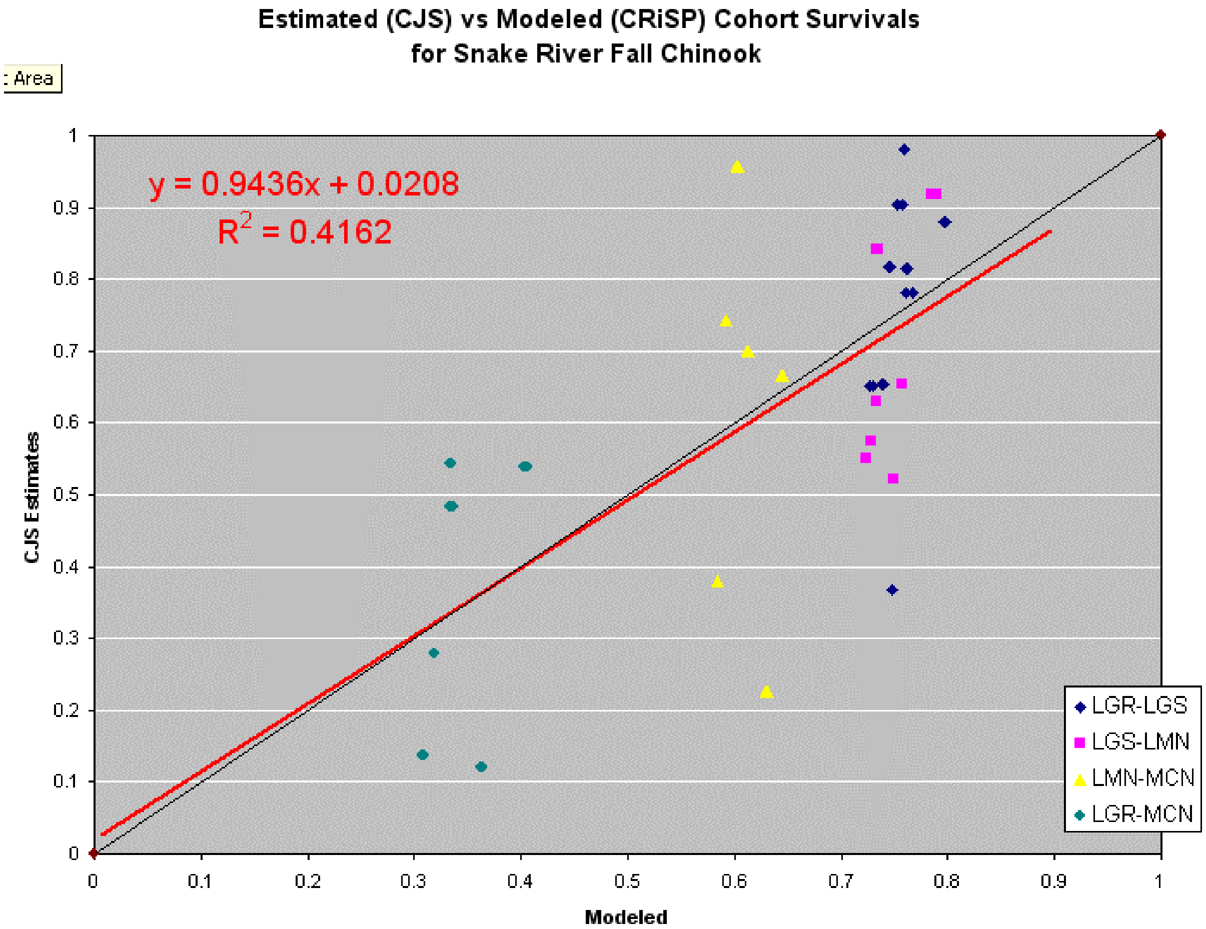


Survival fractions from after Lower Snake River through McNary Pool :
Main Reach survival fraction = 0.95321
Inriver survival fraction from release thru Main Reach = 0.64157
Median passage day: 134.31
Forebay survival fraction = 0.99400
Total Pool survival fraction = 0.94749
Inriver survival fraction from release thru entire McNary Pool = 0.63384
Median passage day: 134.35
Survival fractions through McNary Dam :
Total Project survival fraction = 0.94995
Turbine survival fraction = 0.90000 Percent of survivors this route: 10.06
Spillway survival fraction = 0.98000 Percent of survivors this route: 36.49
Transported Fraction = 0.99269 Percent of survivors this route: 54.15
Bypass survival fraction = 0.98004 Percent of survivors this route: 0.39
Tailrace survival fraction = 0.993
Inriver survival fraction from release thru entire McNary Dam = 0. 60157

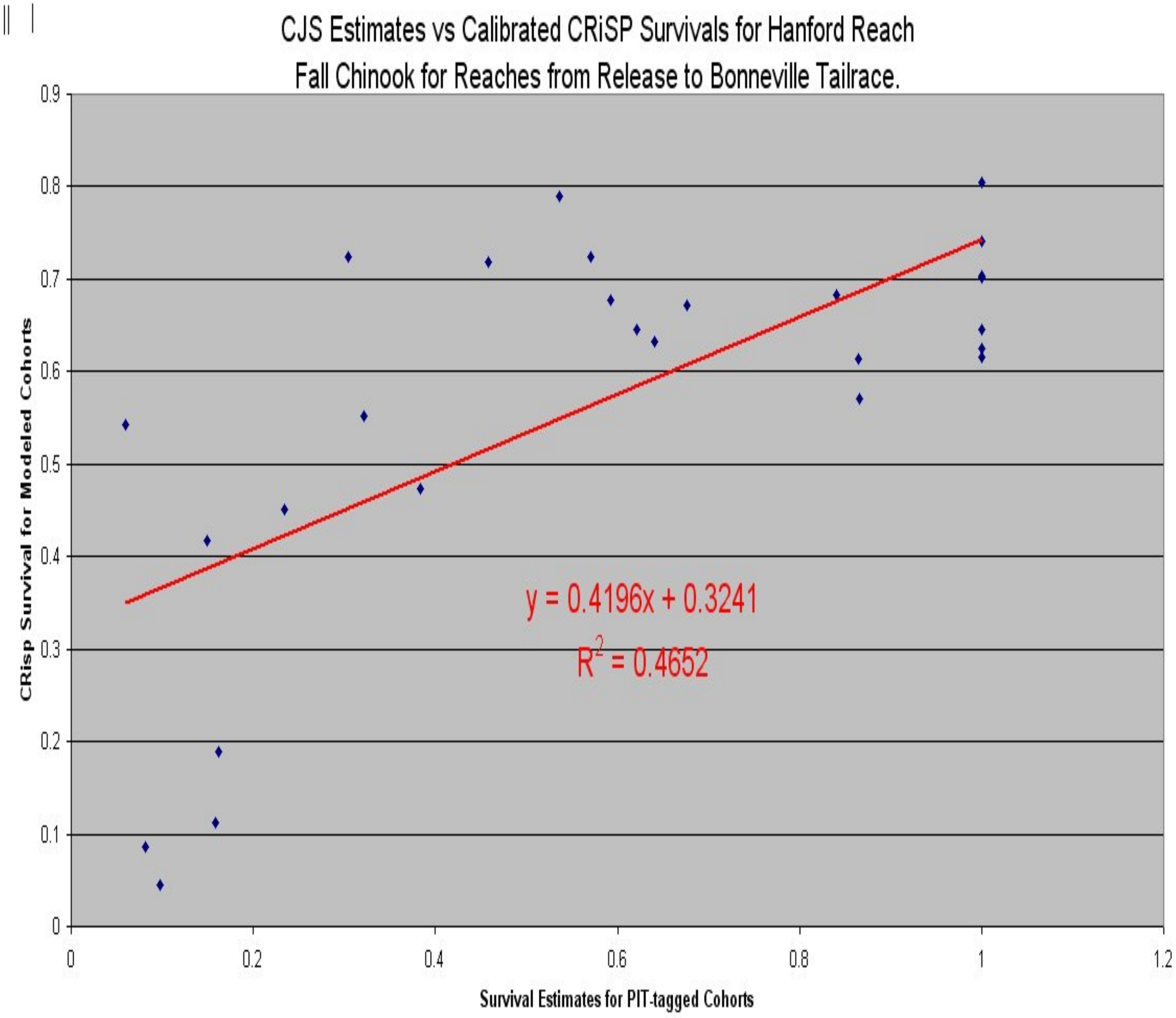
Travel-Time Calibrations



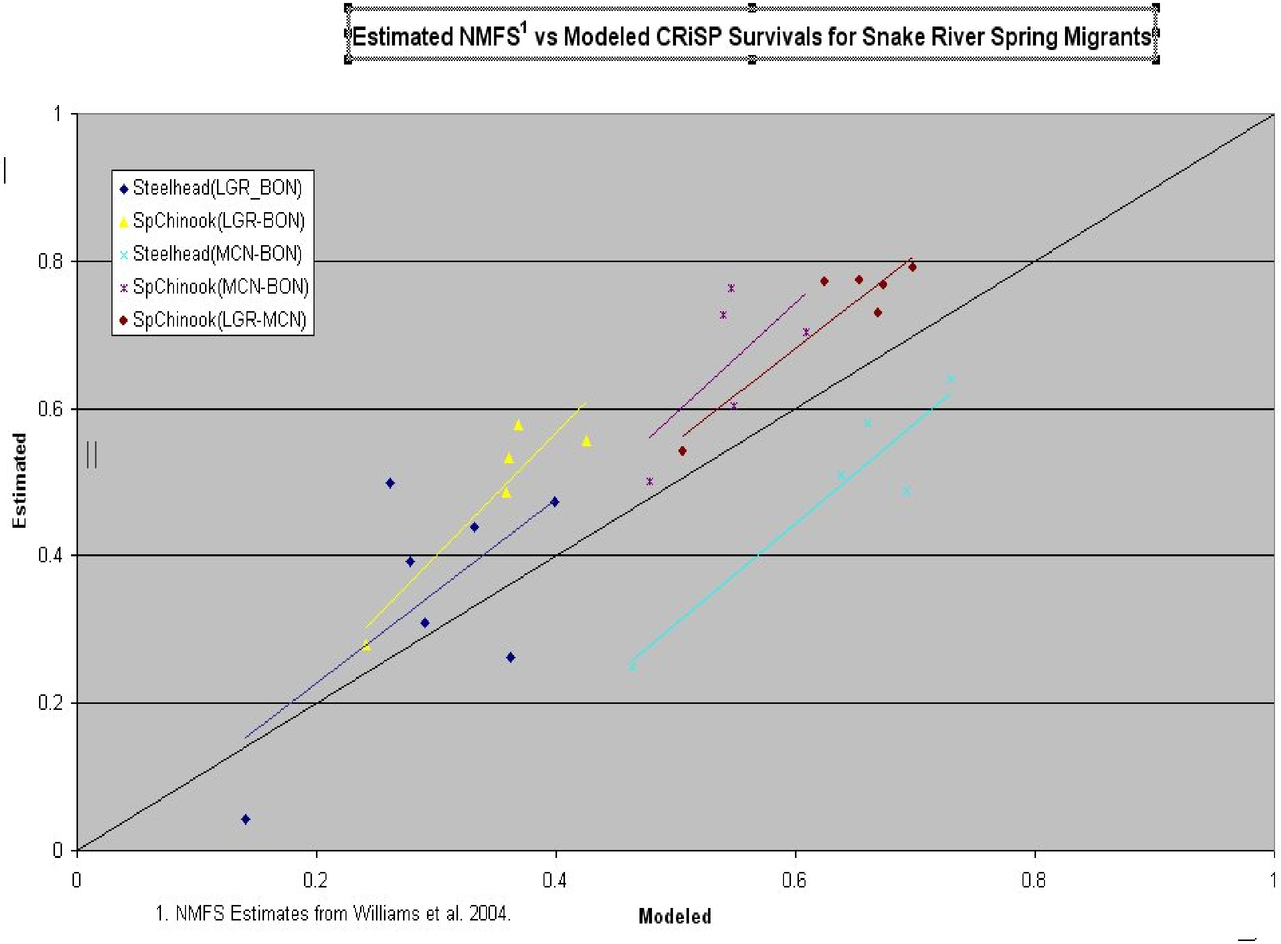
Snake River Fall Chinook Survival Calibration



Hanford Reach Fall Chinook Survival Calibrations

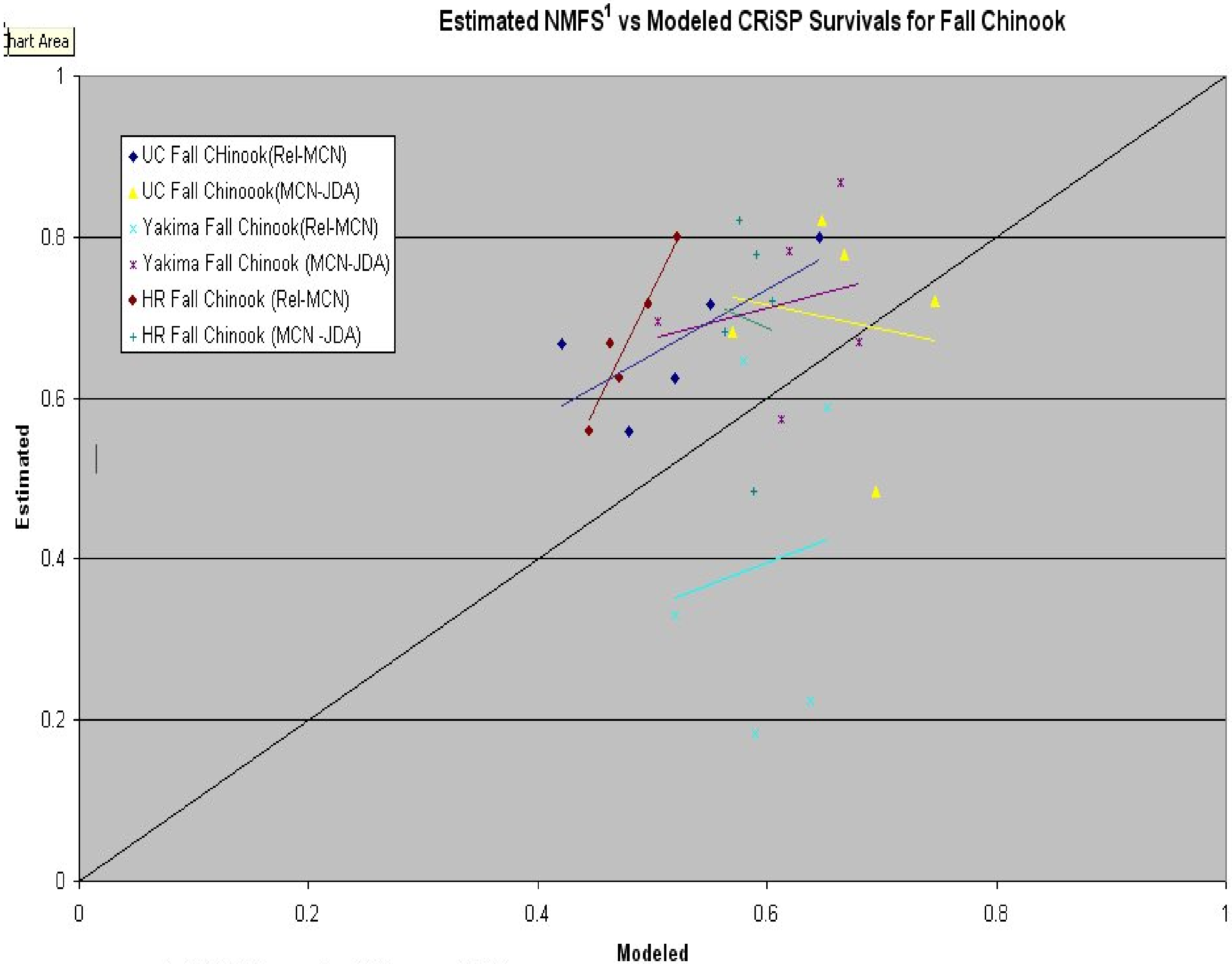


NMFS vs CRiSP: Spring Migrants



1. NMFS Estimates from Williams et al. 2004.

NMFS vs CRiSP: Fall Chinook



1. NMFS Estimates from Williams et al. 2004.

Current CRiSP Development

- Continued migration and survival calibration
  - Improved river descriptions of Upper Columbia and Yakima basins
  - Improve fall chinook calibrations
  - Expansion of calibrated stocks for alternate model comparisons.
  - Use identical migration cohorts for both travel time and survival.
- Reach-specific migration and survival equations.
  - Calibration to specific reach's observed survivals and travel times allows for model adjustments to tributaries, upper impoundments and the lower river.
- Development of temperature modeling for examining temperature mitigation effects.
- Add turbidity to river descriptions for potential incorporation in survival models

Recent CRiSP modeling includes:

- Evaluating spill scenarios
  - Hourly spill time step allows for fine grade manipulation
- Predicting effects of flow regulation changes
- Predicting impact of temperature mitigation efforts
- Determining flow impacts on water velocities
- Categorizing irrigation impacts on flows and survivals

Evaluating and choosing reservoir survival submodels for CRiSP

based on

Anderson, Gurarie, Zabel

Ecological Modeling (*2005*)

Anderson and Van Holmes

Canadian Journal of Fisheries and Aquatic Sciences (In Review)

How does one choose a survival submodel for CRiSP from among all the models put forth in the past two decades?

Criteria for judging models

- Examine r^2 across all years:

  Look for the best fit.
- Compare r^2 of modeled odd year data using parameter fit from even year data:

  Illustrates predictive value.
- Does it fit broken stick Flow-Survival pattern?

  Adheres to between year flow survival pattern.
- Does mathematical form allow a fit to 2001 data?

  Model applies to within year flow and temperature data
- Number of model parameters and covariates

  Occam's Razor
- Biological realism

  Gives confidence in new situations

F = Flow

θ = Temperature

T = Time

X = Distance

D = Day

B = spill

Z = transparency

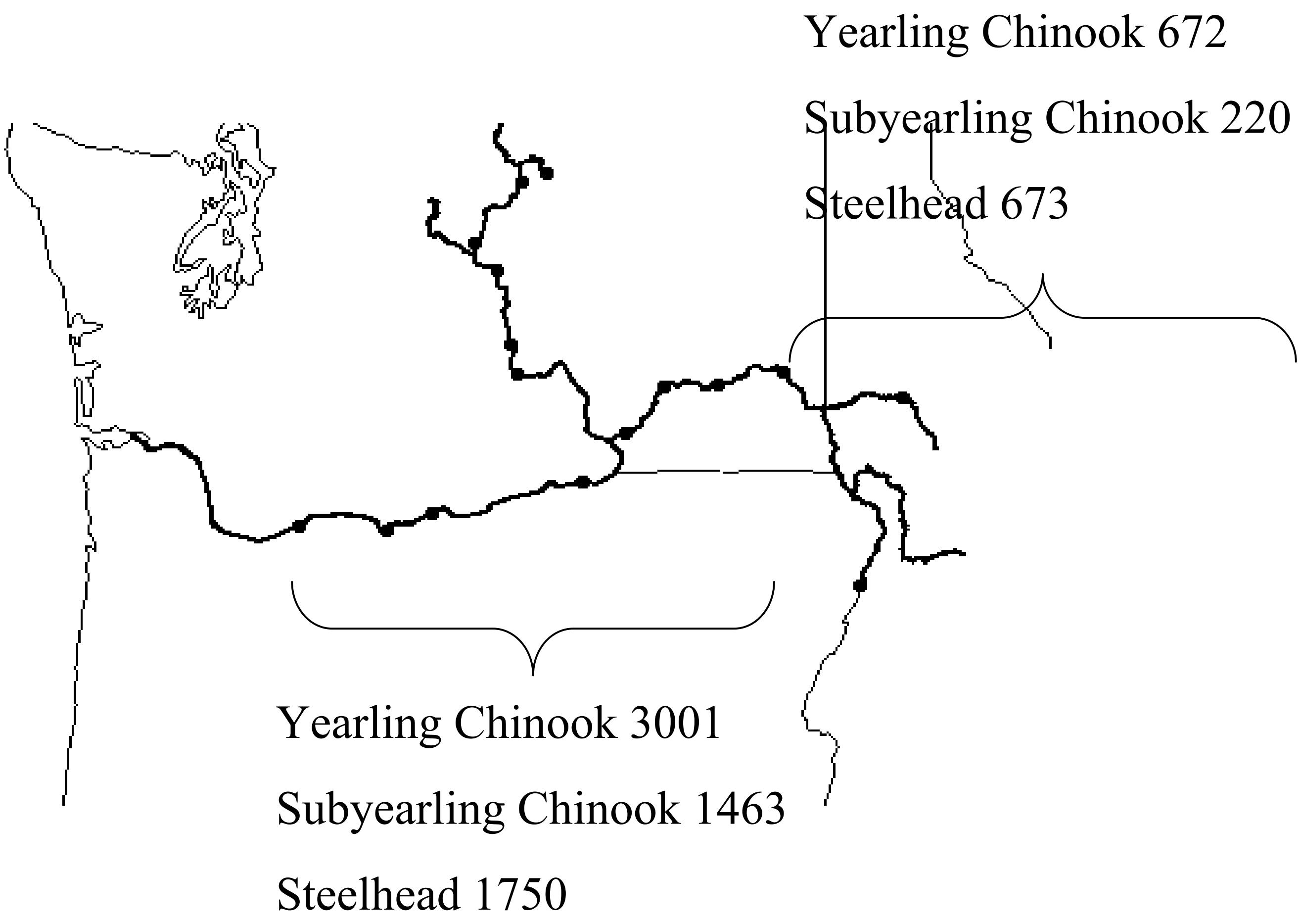
ω = random vel.

V = migration vel.

S_{dam} = Dam Surv.

1	$S=\left(a+bF+cF^2\right)^N$		Sims and Ossiander (1981)
2	$S=\begin{cases} a+bF & F<F^* \\ bF^* & F\geq F^* \end{cases}$	Broken Stick	Chapman et al. (1991), Williams et al. (2004)
3	$S=S_{dam}\exp\left(-ae^{b\theta}T\right)$	CRiSP 1.6	CBR (2003)
4	$S=S_{dam}(1+a)\exp(-bT)/\left(1+a\exp(-bT)\right)$		Marmorek et al. (1996)
5	$S=S_{dam}\exp(-aX)$	SimPass	NMFS (2000)
6	$S=a+bD+cF+d\theta$		Smith et al. (2002)
7	$S=a+bT_w+cB+d\theta$		Petrosky et al. (2003)
8	$S=a+bT_w$		Petrosky et al. (2003)
9	$S=\exp(a-b/F)$		ISAB (2003)
10	$S=S_{dam}\exp\left(-aX\theta^m\right)$		Anderson (2003)
11	$S=a/\left(1+\exp(b-cF)\right)$	Sigmoidal	Smith et al. (2003)
12	$S=a+bF+c\theta$		Connor et al. (2003)
13	$S=a+bF+cF^2$		Smith et al. (2003)
14	$S=a+b\theta+c\theta^2$		Smith et al. (2003)
15	$S=a+bZ+cZ^2$		Smith et al. (2003)
16	$S=S_{dam}\exp\left(-ae^{m\theta+n_1Z+n_2Z^2+c\log X}\sqrt{1+\omega^2/V^2}\right)$		Anderson et al (In press) Mean Free Path Models
17	$S=\exp\left(-ae^{m\theta+n_1Z+n_2Z^2+c\log X+bB}\sqrt{1+\omega^2/V^2}\right)$		Anderson et al (In press))

7779 survival estimates between 1995-2003



r-sqr of observed vs. model survival

Criteria

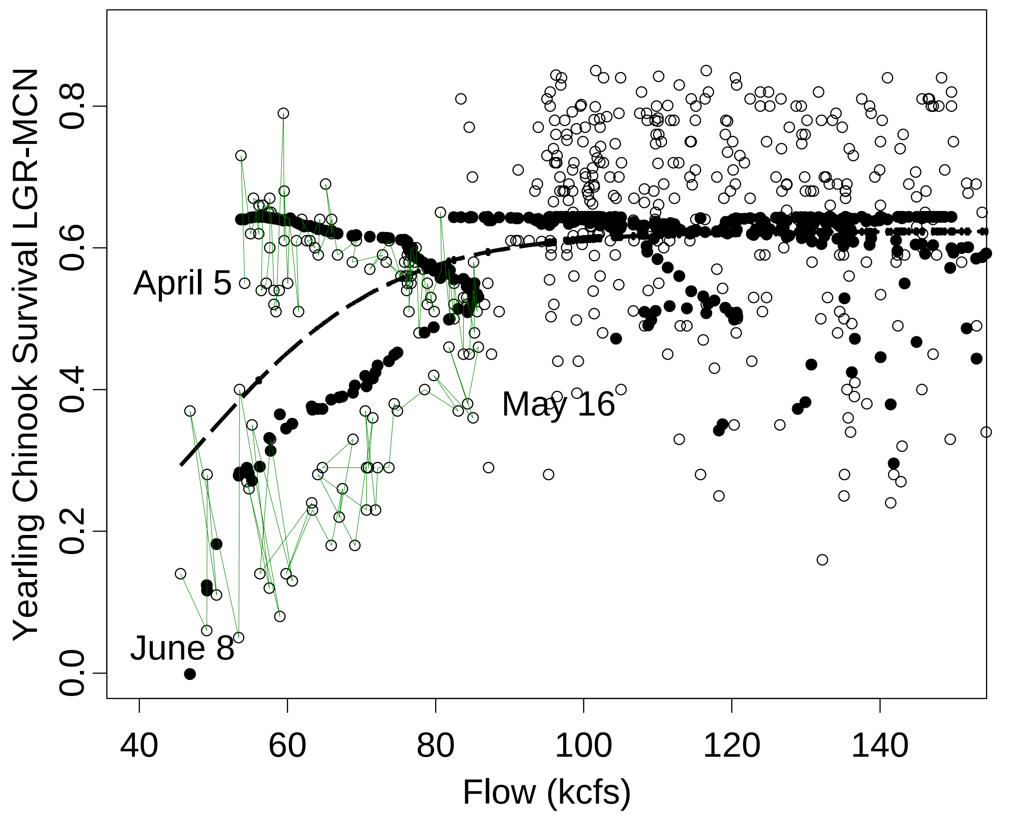
I= 1995-2003

V = 2001

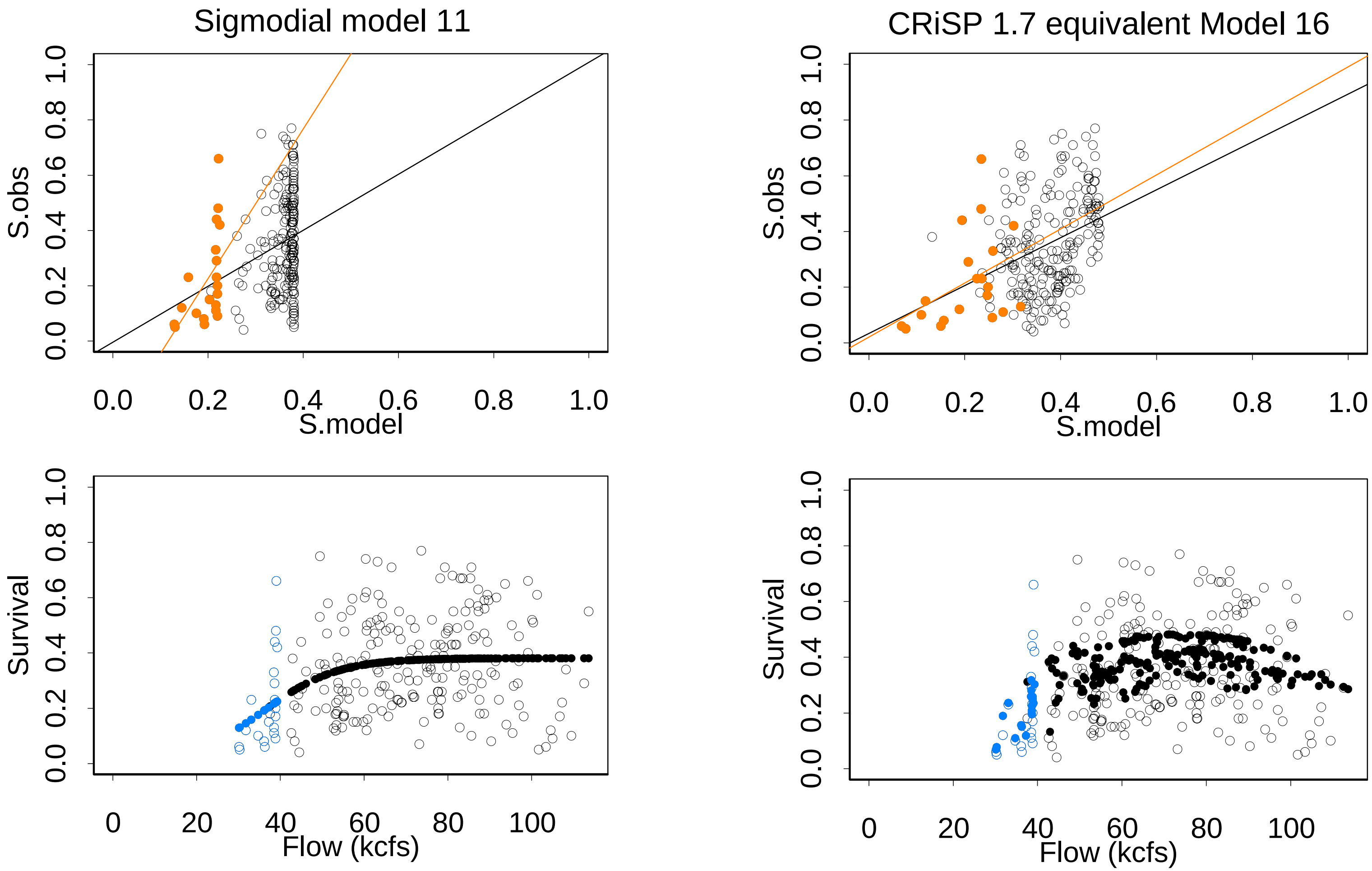
II = even years predicted with models calibrated to odd year data

Model No.	Reach	Yearling Chinook			Steelhead			Subyearling Chinook		
	Reach	LGR-BON	LGR-MCN	LGR-BON	LGR-BON	LGR-MCN	LGR-BON	LGR-BON	LGR-MCN	LGR-BON
	Criteria	I	V	II	I	V	II	I	V	II
	Number	3001	576	1222	1750	443	369	1463	218	662
1	F, N	0.24	0.15	0.18	0.31	0.23	0.30	0.18	0.12	0.15
2	F	0.07	0.14	0.08	0.01	0.27	0.01	0.02	0.08	0.06
3	T, θ, S_{dam}	0.18	0.24	0.09	0.29	0.20	0.18	0.14	0.16	0.10
4	T, S_{dam}	0.17	0.09	0.07	0.20	0.09	NA	0.13	0.16	NA
5	X, S_{dam}	0.26	0.13	0.17	0.32	0.28	0.32	0.21[3]	0.08	0.22[2]
6	D, F, θ	0.16	0.22	0.12	0.12	0.21	0.14	0.08	0.16	0.10
7	T_w, B, θ	0.15	0.24	0.17	0.19	0.31	0.20	0.07	0.18[2]	0.06
8	T_w	0.04	0.06	0.12	0.00	0.21	0.10	0.02	0.07	0.06
9	F	0.04	0.04	0.13	0.00	0.14	0.14	0.01	0.07	0.05
10	X, θ, S_{dam}	0.29	0.23	0.20	0.37	0.15	0.33	0.21[3]	0.04	0.22[2]
11	F	NA	0.12	NA	NA	0.28	NA	NA	0.10	NA
12	F, θ	0.11	0.19	0.14	0.06	0.21	0.18	0.02	0.14	0.06
13	F	0.07	0.15	0.14	0.02	0.25	0.23	0.02	0.12	0.07
14	θ	0.08	0.26	0.07	0.06	0.13	0.04	0.00	0.05	0.00
15	Z	0.00	0.10	0.00	0.07	0.13	0.14	0.01	0.05	0.01
16	θ, Z, V, X, S_{dam}	0.34	0.39	0.23	0.39	0.27	0.33	0.25[2]	0.17[3]	0.22[2]
17	θ, Z, V, X, B	0.33	0.40	0.22	0.40	0.34	0.33	0.27[1]	0.20[1]	0.24[1]

Can models fit Seasonal and year-to-year flow-survival patterns?



Fall chinook survival LGR-MCN 1995-2003

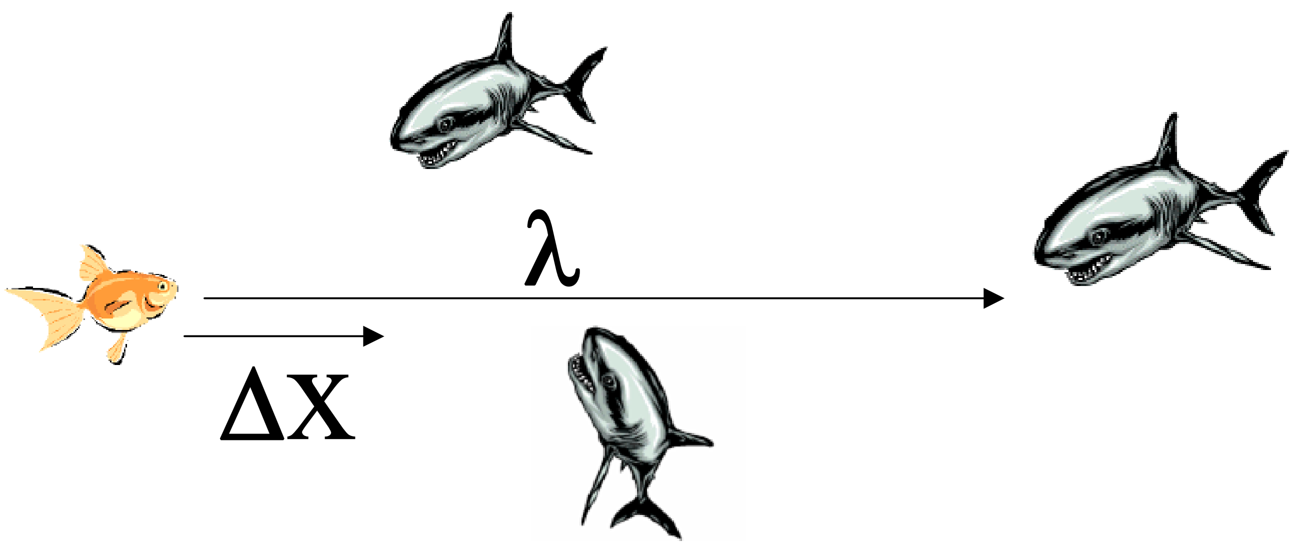


Development of the mean free-path length theory of predator-prey interactions

Survival based on the mean free-path length to a predator encounter

1. Probability of encounter in Δx

$$Prob = \Delta x / \lambda$$

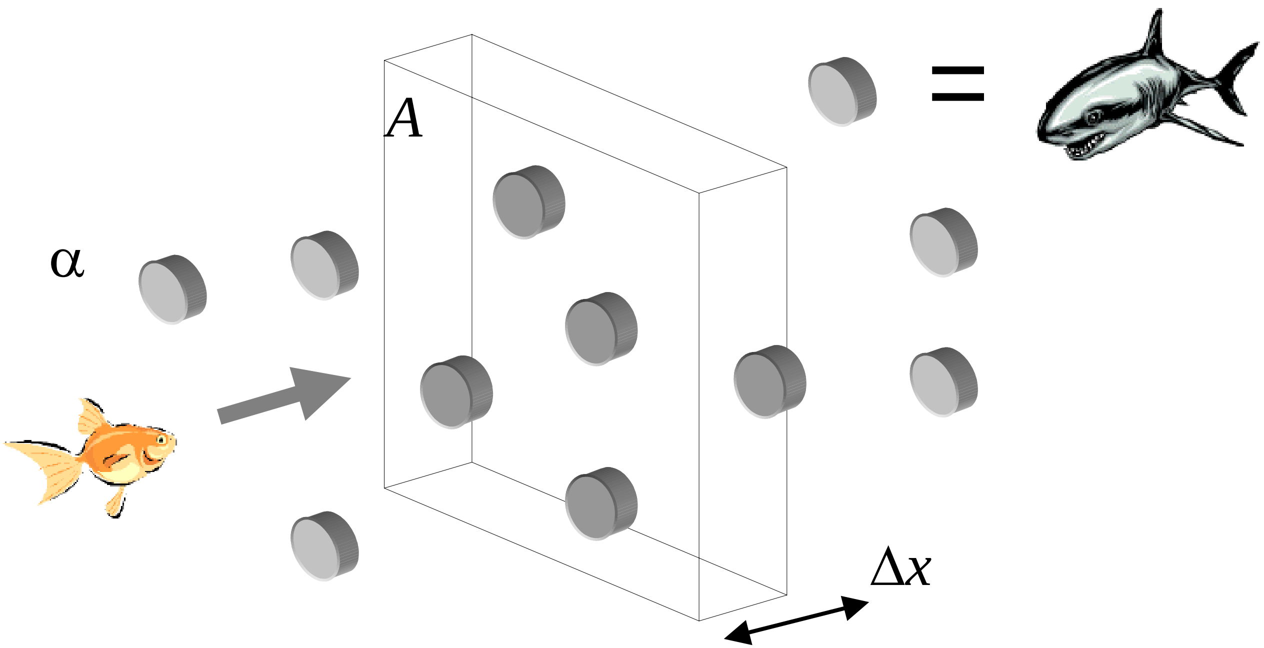


Model ranking

	Rank	Eq. No.	Covariates	No. para.	Flow -surv break point	2001 pattern?	Biol. Mech ?	r-sqr
Full model ⟶	**1**	**17**	***Q, Z, V, X, B***	**7**	**Y**	**Y**	**Y**	**0.30**
	2	16	Q, Z, V, X, S_{dam}	6	Y	Y	Y	0.29
CRiSP 1.7 ⟶	**3**	**10**	**Q, X, S_{dam}**	**2**	**Y**	**Y**	**Y**	**0.23**
CRiSP 1.6 ⟶	4	3	T, Q, S_{dam}	2	Y	Y	Y	0.18
	5	7	T_w, B, Q	4	Y	Y	N	0.17
	6	6	D, F, Q	4	Y	Y	N	0.15
	7	12	$F\ Q$	3	Y	Y	N	0.12
	8	14	Q	3	Y	Y	N	0.08
	9	15	Z	3	Y	Y	N	0.06
	10	11	F	3	Y	N	N	0.15
Sigmodial ⟶	**11**	**2**	***F***	**3**	**Y**	**N**	**N**	**0.08**
	12	8	T_w	2	Y	N	N	0.08
	13	9	F	2	Y	N	Y	0.07
SIMPAS ⟶	14	5	X, S_{dam}	1	N	N	Y	0.22
	15	1	F, N	3	N	N	N	0.21
	16	4	T, S_{dam}	2	N	N	N	0.14
	17	13	F	3	N	N	N	0.12

2. Probability of encounter in Δx

Prob = predators' area/unit area



Equating the two probabilities defines path length λ

$$prob = \frac{\text{small distance}}{\text{path length}} = \frac{\Delta X}{\lambda}$$

$$prob = \frac{\text{area with predators}}{\text{unit area}} = \frac{\alpha\rho\Delta X A_{unit}}{A_{unit}}$$

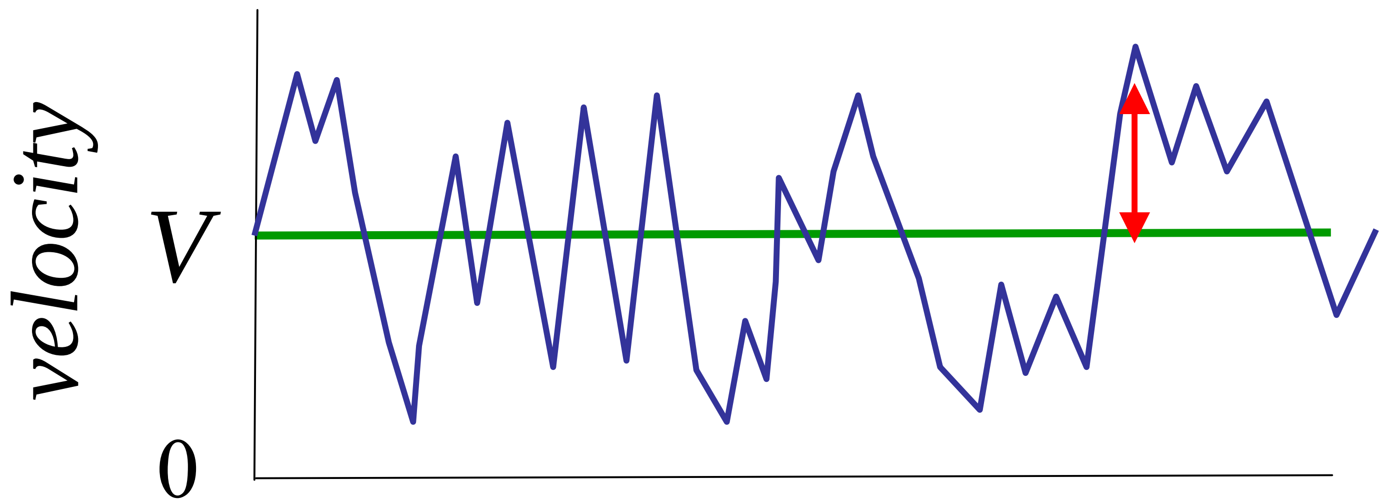
$$\lambda = \frac{1}{\rho\alpha}$$

The travel time, τ, at which encounter probability = $prob$

$$\tau = \frac{\lambda}{w} = \frac{1}{w\rho\alpha}$$

w is the speed between predator and smolt

Describe encounter speed w with mean V and random parts v^*



Velocity: $w = V + v^*$

Decompose predators and prey velocities into components

then do some math

$$u_i = v_i - w_i$$

$$u = E\left[\sqrt{u_x^2 + u_y^2 + u_z^2}\right]$$

$$w_i = W_i + w_i^* \quad \text{and} \quad v_i = V_i + v_i^*$$

$$u_i^2 = V_i^2 - 2V_i v_i^* + v_i^{*2} - 2V_i W_i - 2W_i v_i^* + W_i^2 + 2V_i w_i^* - 2v_i^* w_i^* + 2W_i w_i^* + w_i^{*2}$$

$$E(v_i^* w_i^*) = 0 \quad E(V_j w_i^*) = 0$$

$$E\left[u_i^2\right] = V_i^2 + E\left[v_i^{*2}\right] + E\left[w_i^{*2}\right]$$

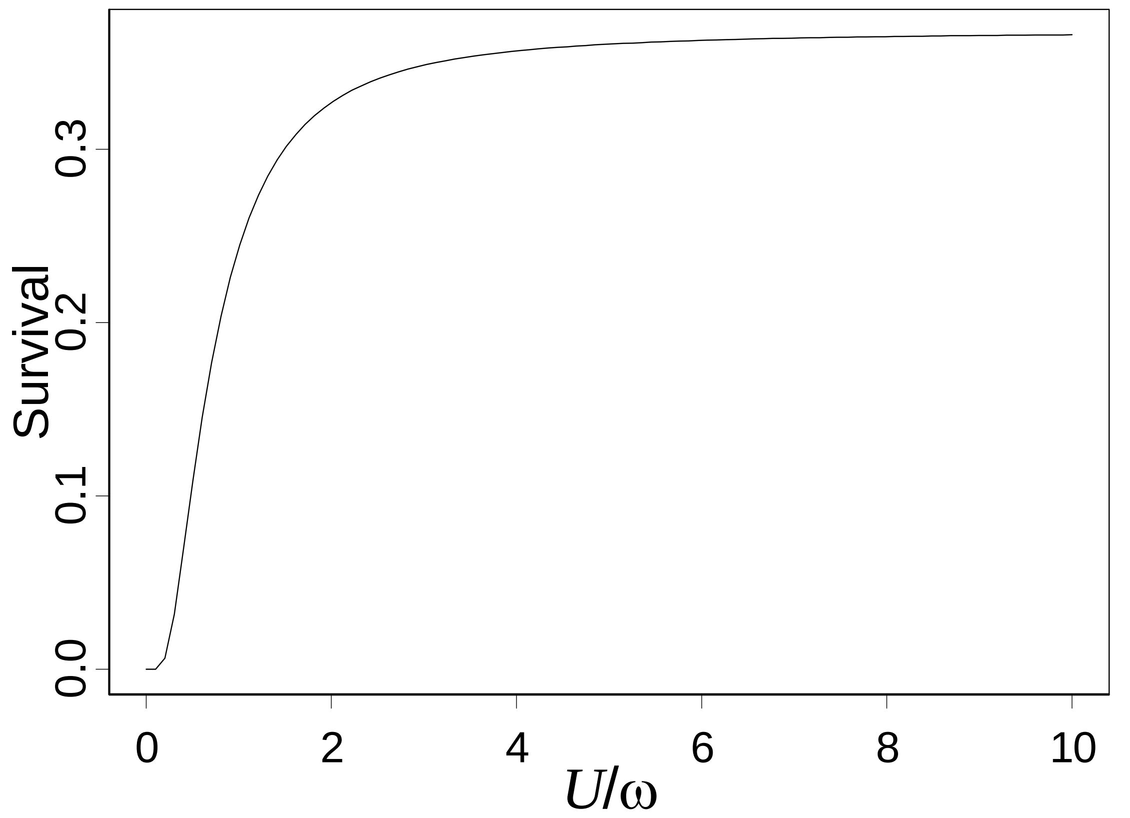
$$\omega^2 = v^{*2} + w^{*2} = \overline{v_x^{*2}} + \overline{v_y^{*2}} + \overline{v_z^{*2}} + \overline{w_x^{*2}} + \overline{w_y^{*2}} + \overline{w_z^{*2}}$$

Reach migration survival

$$S = \exp\left(-\alpha\rho X\sqrt{1+\omega^2/U^2}\right)$$

- Smolt migration velocity: *U*
- Migration distance X
- Random predator-prey velocity: ω
- Reaction area: α
- Predator density: ρ

Effect of travel time on survival depends on the ratio of migration velocity to random encounter velocity



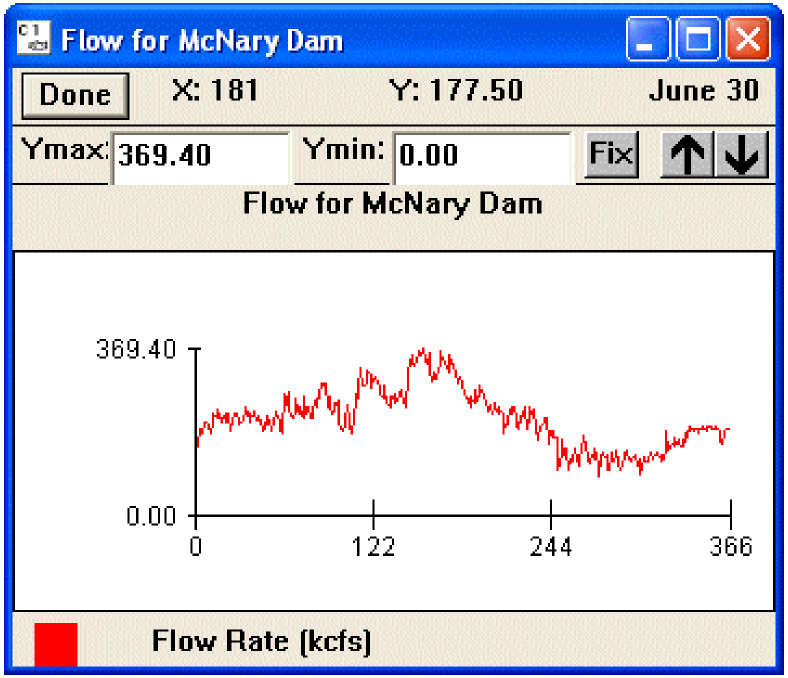
Environmental effects expressed on model terms

reaction area depends on turbidity Z

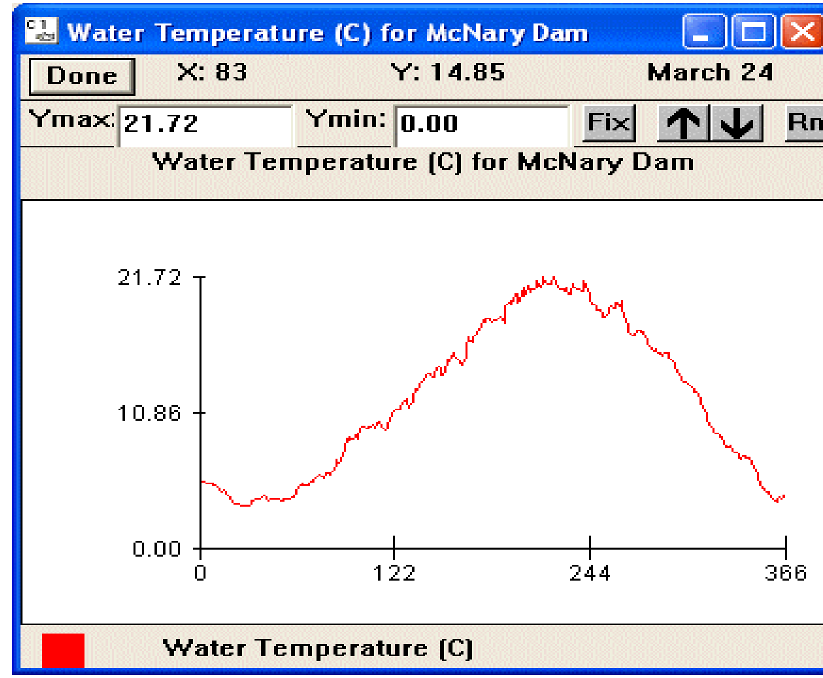
$$\alpha \sim f(Z) = \exp\left(aZ + bZ^2\right)$$

active predator density depends on temperature Q

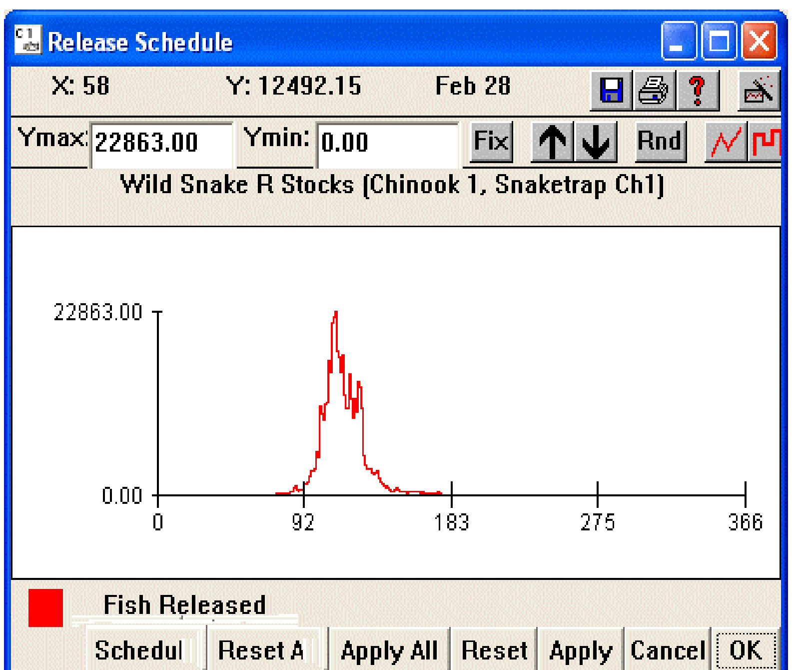
$$\rho \sim \rho_0 f(Q) = \rho_0 \exp\left(aQ\right)$$



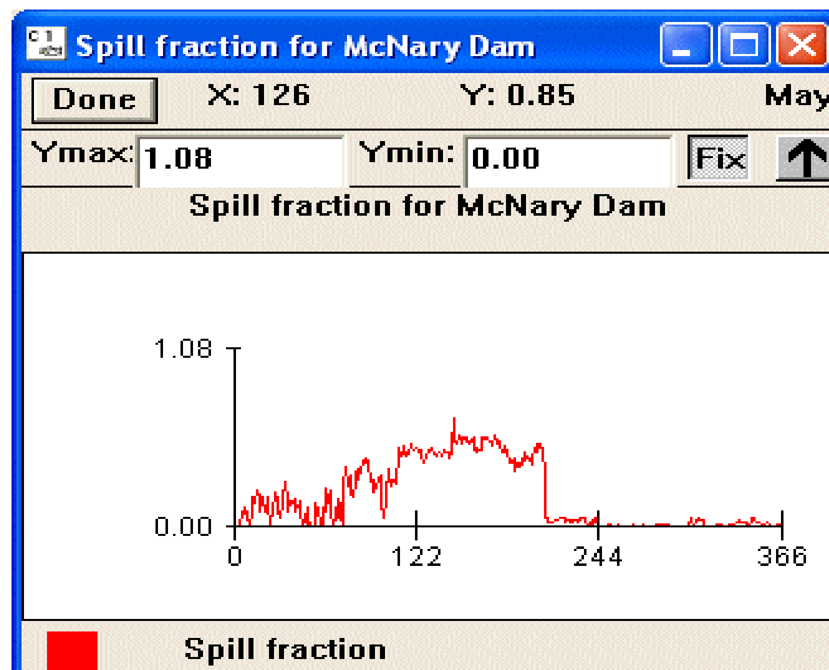
Flow for McNary Dam
Done
X: 181
Y: 177.50
June 30
Ymax: 369.40
Ymin: 0.00
Fix
Flow for McNary Dam
369.40
0.00
0
122
244
366
Flow Rate (kcfs)



Water Temperature (C) for McNary Dam
Done
X: 83
Y: 14.85
March 24
Ymax: 21.72
Ymin: 0.00
Fix
Water Temperature (C) for McNary Dam
21.72
10.86
0.00
0
122
244
366
Water Temperature (C)



Release Schedule
X: 58
Y: 12492.15
Feb 28
Ymax: 22863.00
Ymin: 0.00
Fix
Rnd
Wild Snake R Stocks (Chinook 1, Snaketrap Ch1)
22863.00
0.00
0
92
183
275
366
Fish Released
Schedul
Reset A
Apply All
Reset
Apply
Cancel
OK



Spill fraction for McNary Dam
Done
X: 126
Y: 0.85
May
Ymax: 1.08
Ymin: 0.00
Fix
Spill fraction for McNary Dam
1.08
0.00
0
122
244
366
Spill fraction