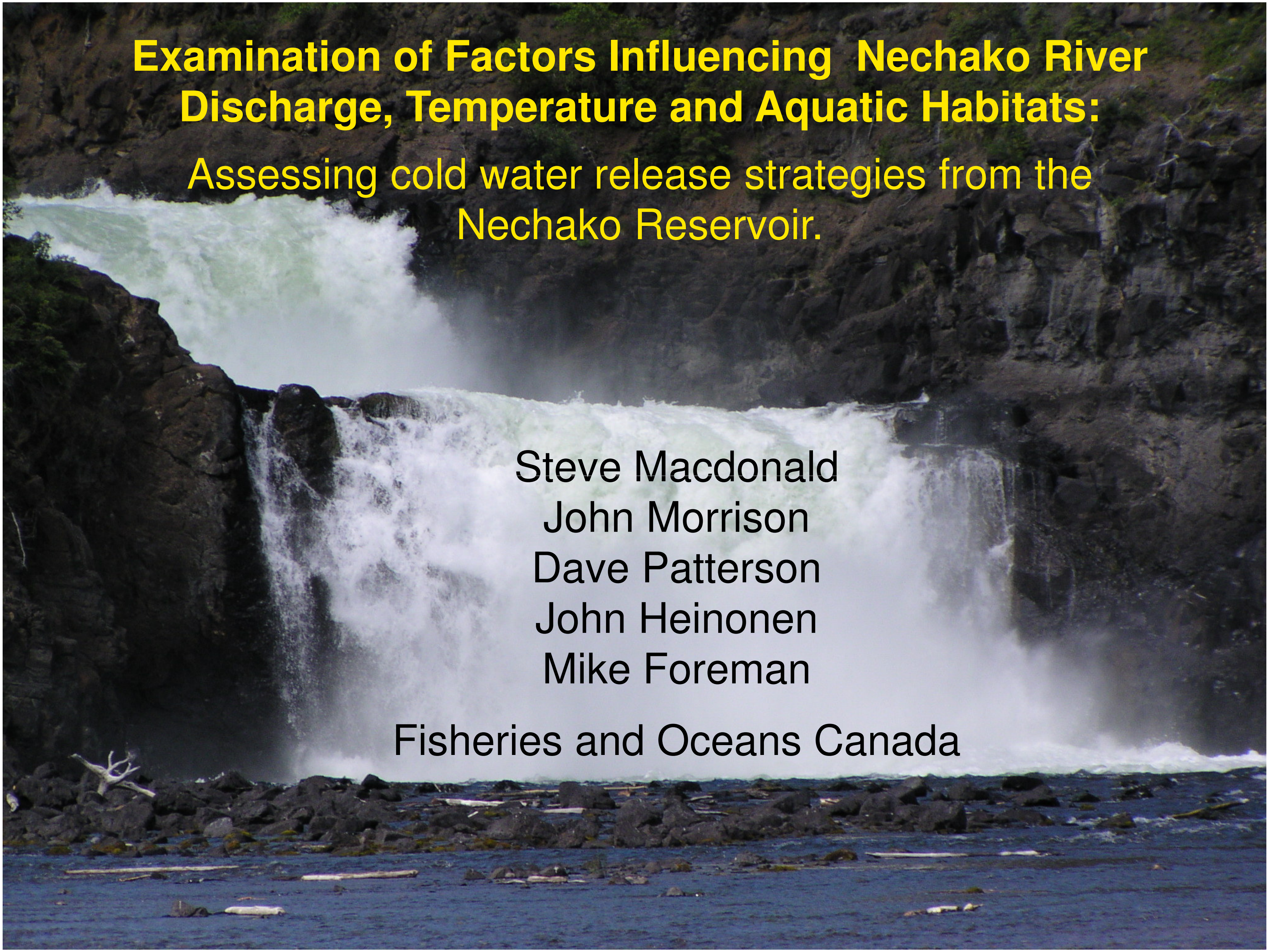


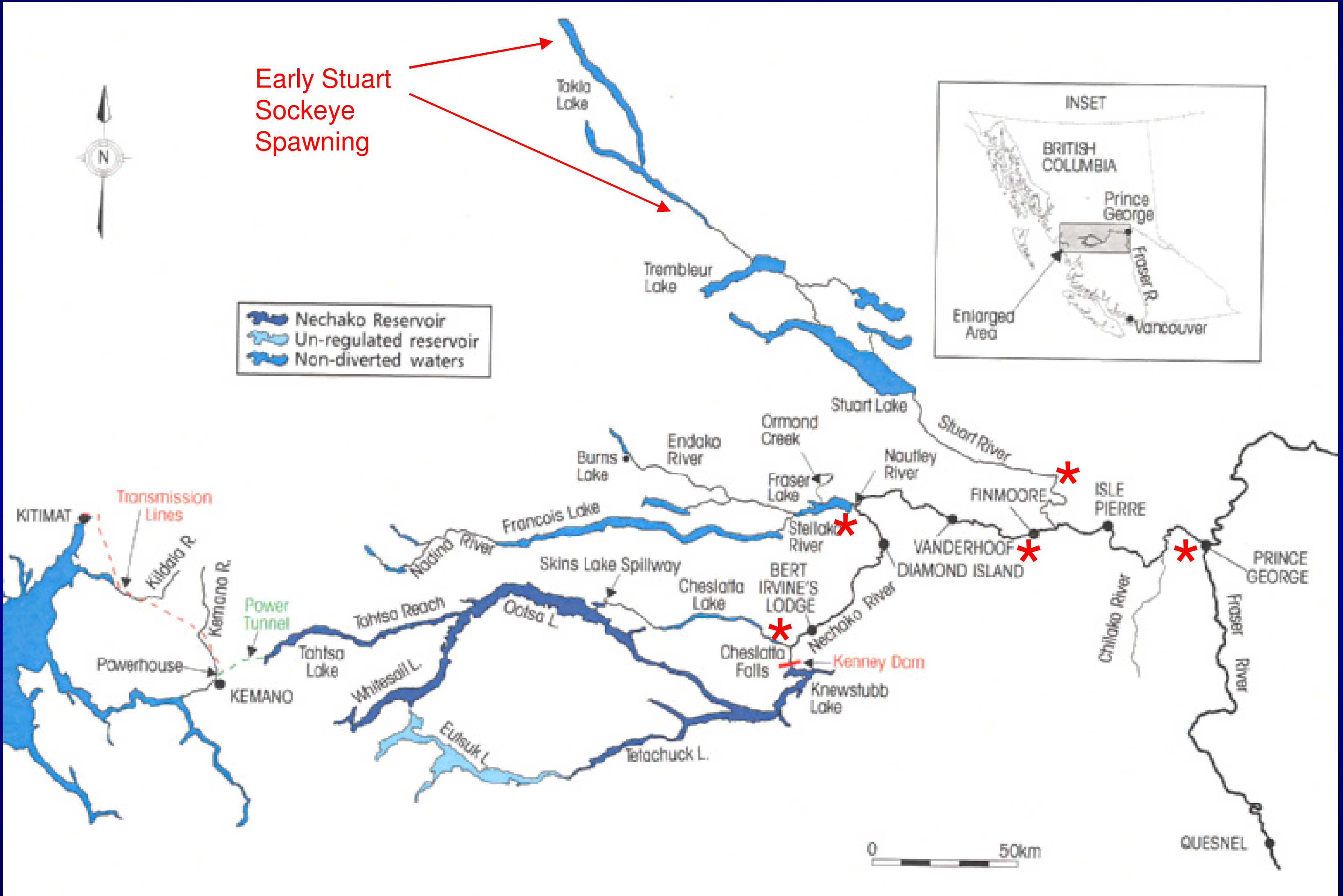
Examination of Factors Influencing Nechako River Discharge, Temperature and Aquatic Habitats:

Assessing cold water release strategies from the Nechako Reservoir.

Steve Macdonald
John Morrison
Dave Patterson
John Heinonen
Mike Foreman

Fisheries and Oceans Canada

The Nechako Watershed and the Migration Path of the Early Stuart Sockeye Salmon



* - Important reaches for temperature and flow measurements

This Presentation will Address Three Questions….

A. Are Summer Temperature Management Plan (STMP) flows effective ?

B. Do proposed Kenney Dam water release scenarios influence downstream temps/flows ?

C. What influence do water management schemes (e.g. cold water releases, STMP) have on migration and spawning of Sockeye Salmon ?

A) Are Summer Temperature Management Plan (STMP) flows effective:

- Variables* Available to Predict Water Temperature at Vanderhoof
  - Lagged (4D) Skins Lake Discharge (Q)
  - Air Temperature
  - Dew Point
  - Solar Radiation

* - all significant predictors from regression analysis of Vander T°C vs PC scores.

Methods: PC Analysis followed by a multiple regression using the PC scores

Variable	PC1	PC2	PC3	PC4
Skins4.0	0.225	-0.191	**0.954**	0.051
PG Air T	**0.735**	-0.001	-0.138	-0.664
PG Dew	0.401	**-0.721**	-0.265	0.500
PG Solar	0.498	**0.667**	-0.014	0.554
Proportion	0.402	0.294	0.240	0.064

$$\text{Vander}_{\text{water } T^{o}C} = 18.0 + 0.792\ \text{PCI} + 0.0923\ \text{PCII} - 0.193\ \text{PCIII}$$

Predictor	T	Prob	R^2	N
Constant	368.78	0.000	40.5%	629
PCI (PG Air Temps)	20.19	0.000		
PCII (Humidity)	2.11	0.035		
PCIII Q (independent of STMP releases)	-3.96	0.000		

Data range used: STMP period (July 20^{th} to August 20^{th}), 1981 to 2002

Predicting Vanderhoof Summer Water Temperatures from Prince George Air Temperatures and Discharge

Vanderhoof T°C = 13.2 - 0.00331 Vanderhoof Q + 0.346 PG AirT°C

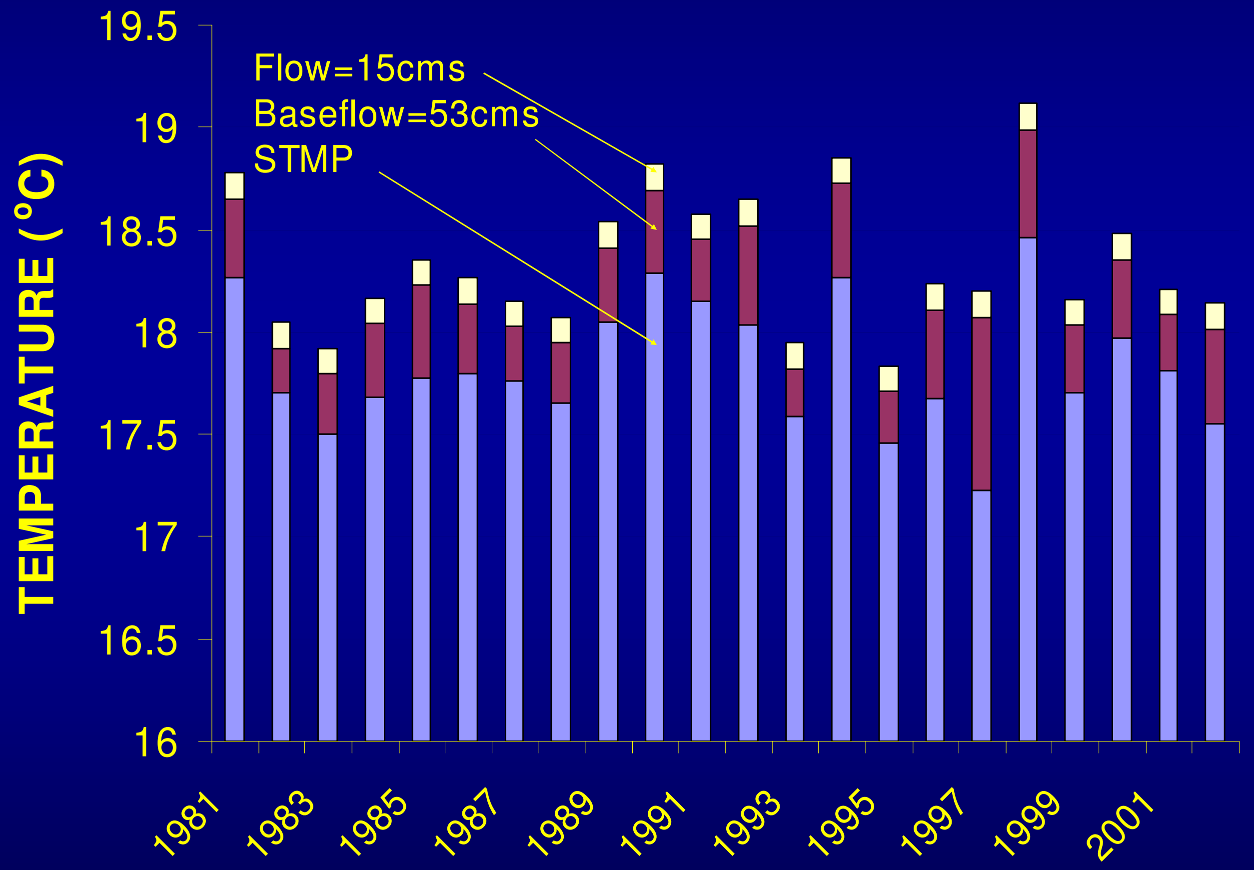
Predictor	T-value	Probability	N
Constant	59.57	0.000	1097 (1981-2002)
Vanderhoof Q	-7.15	0.000	
PG Air T °C	25.36	0.000	

R-Sq = 37.2%   R-Sq(adj) = 37.1%

Note: - Vanderhoof Q was modified for various Skins Lake releases assuming a 4 day lag time.
- Database range used July 7th to August 20th or 31st 1981-2002.

July/August Mean Nechako Temperatures (Vanderhoof): Three Skins Lake Release Scenarios

Vanderhoof T°C = 13.2 - 0.00331 Vanderhoof Q + 0.346 PG AirT°C



- $\text{Mean}_{81\text{-}02}$ STMP-Baseflow_{53} = **0.38°C** (range 0.22 – 0.85°C)
- $\text{Mean}_{81\text{-}02}$ STMP-Flow_{15} = **0.51°C** (range 0.34 – 0.97°C)

Rules for Mixing Water

Volume

Easy

$$V_1 + V_2 = V_3$$

Temperature

Not so easy $T_1 + T_2 = ?$

Need to include the effect of the volume

$$V_1T_1 + V_2T_2 = V_3T_3$$

Can be re-arranged to find temperature of combined volume

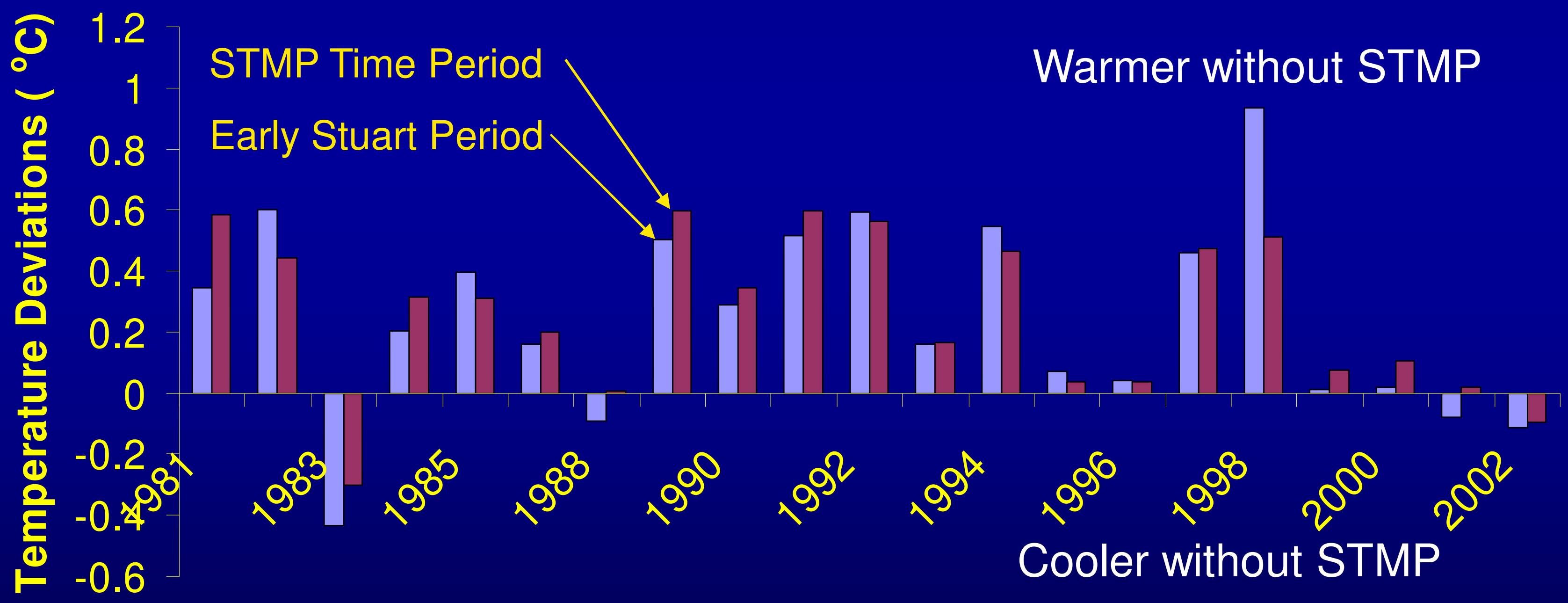
$$T_3 = \frac{V_1T_1 + V_2T_2}{V_3}$$

What is the effect of reduced flows (53 cms) on temperatures below the confluence with the Stuart ?

Mixing model:

Nechako$_{low}$ T^{o}C = (Stuart Q/Total Q) X Stuart ^{o}C) + (Vander Q/Total Q) X Vander ^{o}C)

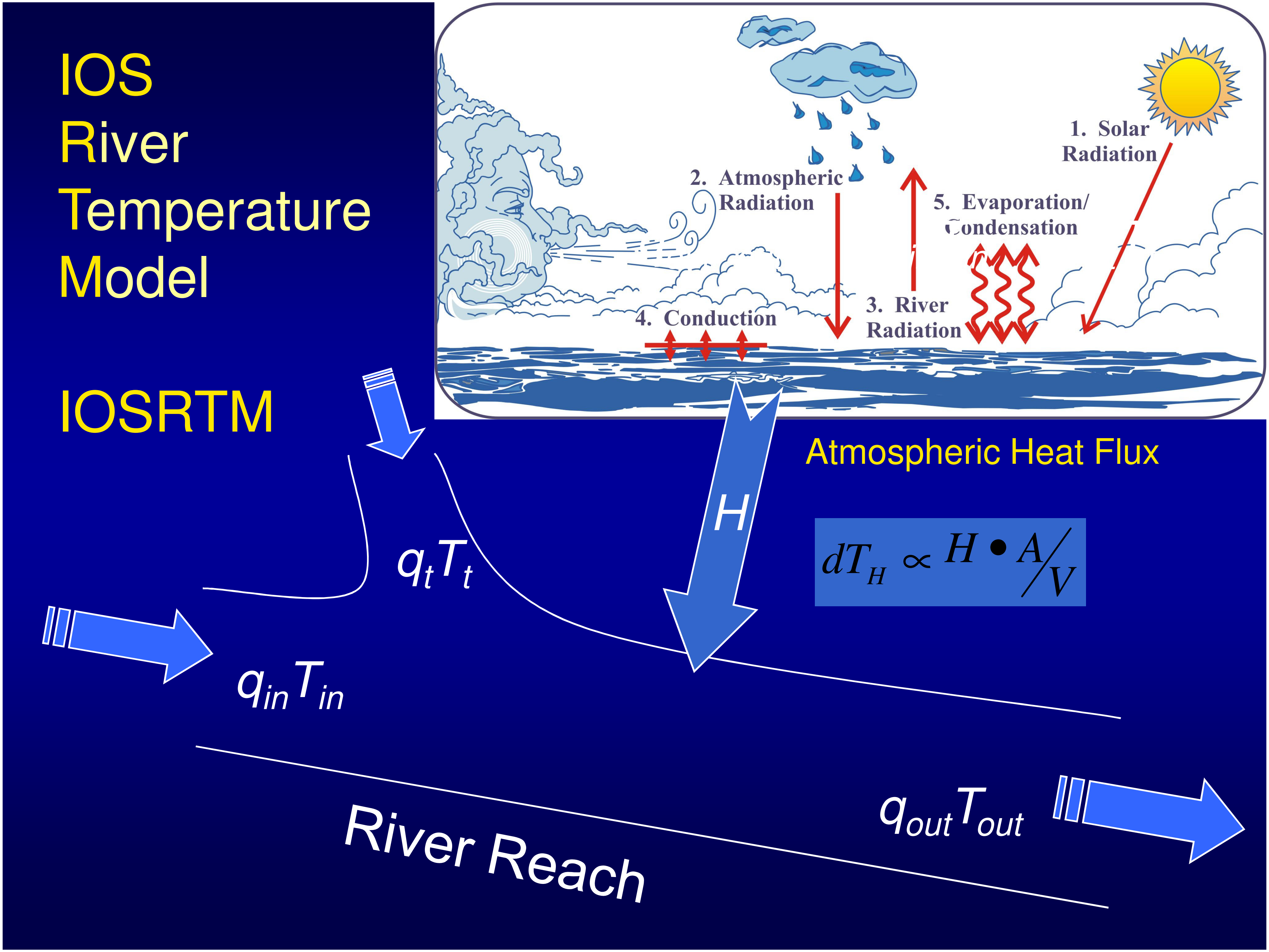
where: Total Q = Stuart Q + Vander Q



- during many years Stuart temperatures are moderated by the Nechako at the confluence

B) Modeling Kenney Dam Water Releases:

The influence on downstream temperatures and flows

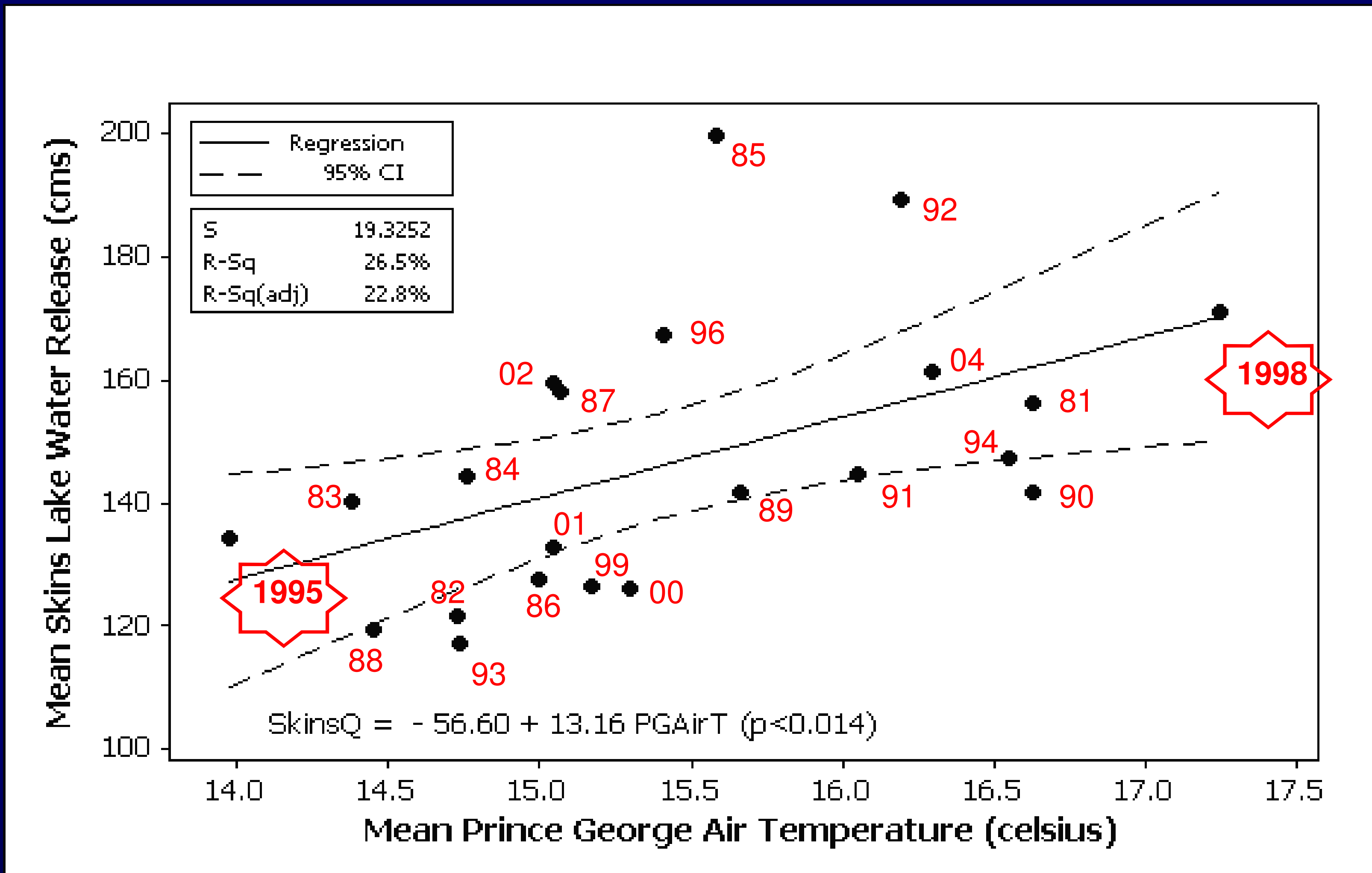

IOS
River
Temperature
Model
IOSRTM
1. Solar Radiation
2. Atmospheric Radiation
3. River Radiation
4. Conduction
5. Evaporation/ Condensation
Atmospheric Heat Flux
H
$dT_H \propto H \bullet A/V$
$q_t T_t$
$q_{in} T_{in}$
$q_{out} T_{out}$
River Reach

Model Schematic

Model Run Series Assumptions

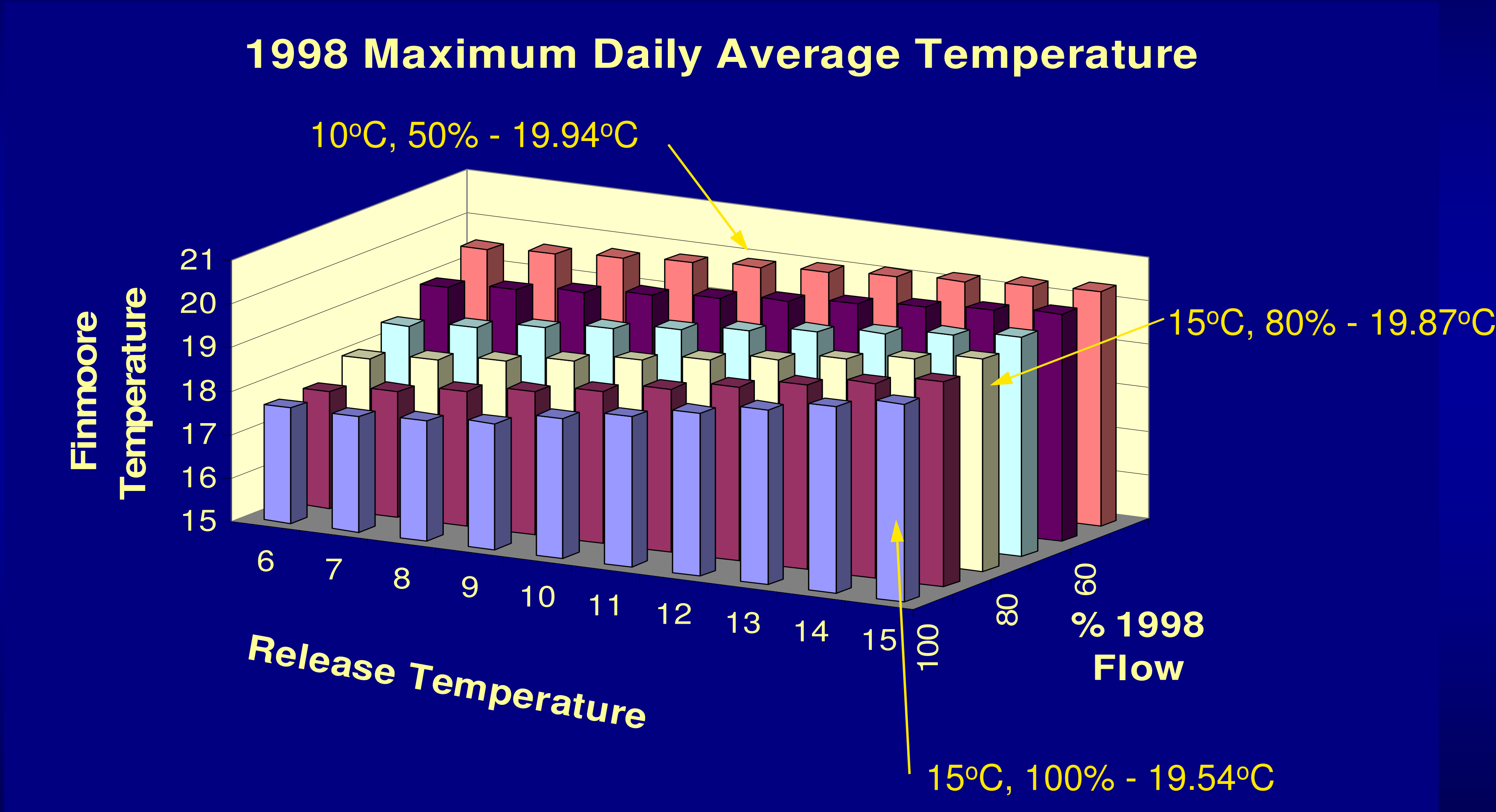
- During July and August, Cheslatta flows through Skins spillway will be maintained at a base flow of 7cms.
- Base flows from Kenney Dam will be composed of surface water and released in sufficient volume to ensure 50cms at Irvine's.
- Cooling flow releases will be simulated to mimic previous patterns from representative years, and will occur between July 7th and August 20th.
- Cooling flow releases will assume the availability of a deep water intake allowing the delivery of water temperatures as low as 7^{o}C at Irvine's.

Choosing "Representative Years": Annual Skins Releases in Response to Summer Temperatures



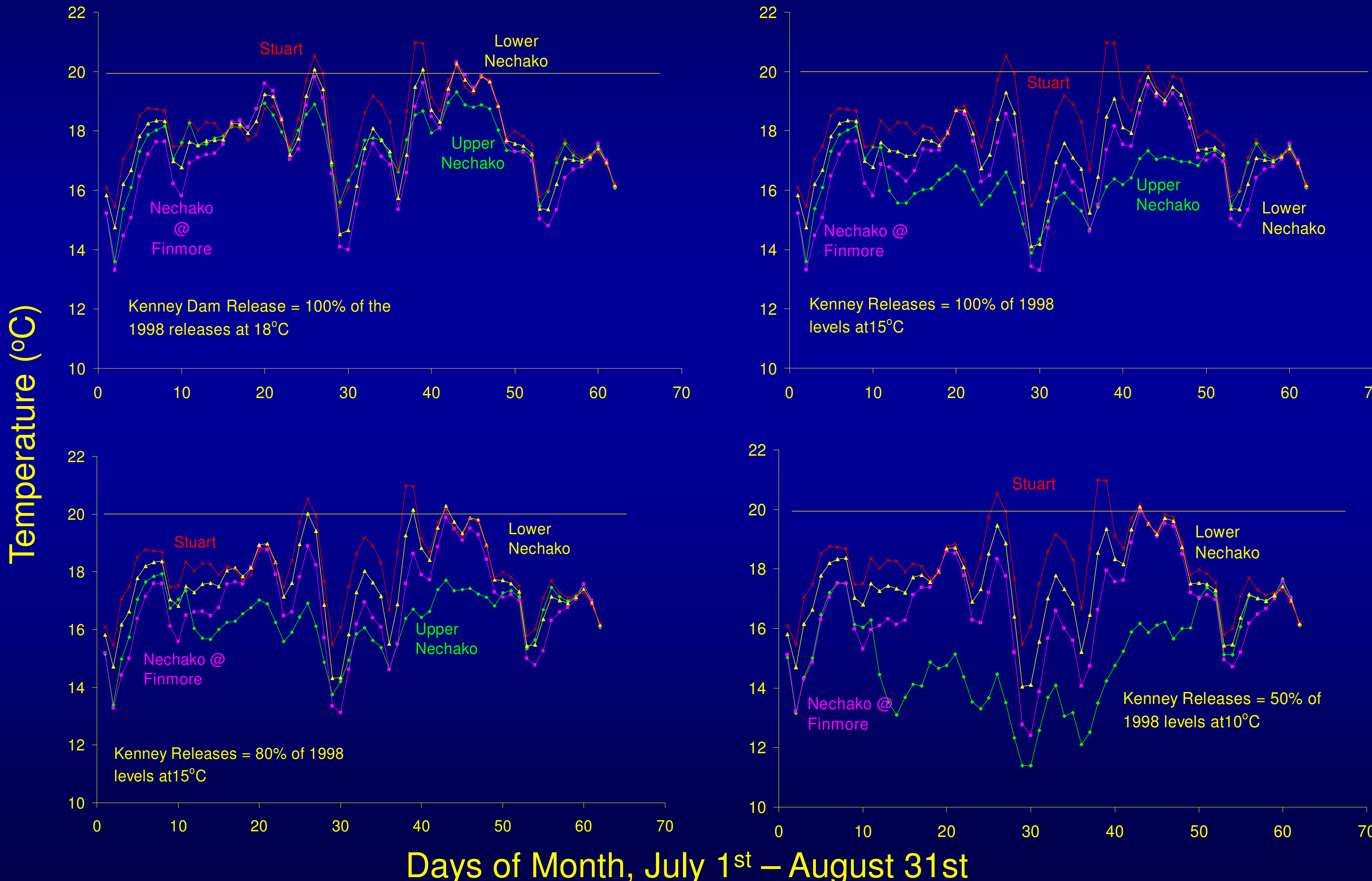
Note: 1997 removed from analysis (15.7°C X 284.2 cms)

Effect of Release Temperature and Volume: choosing release scenarios



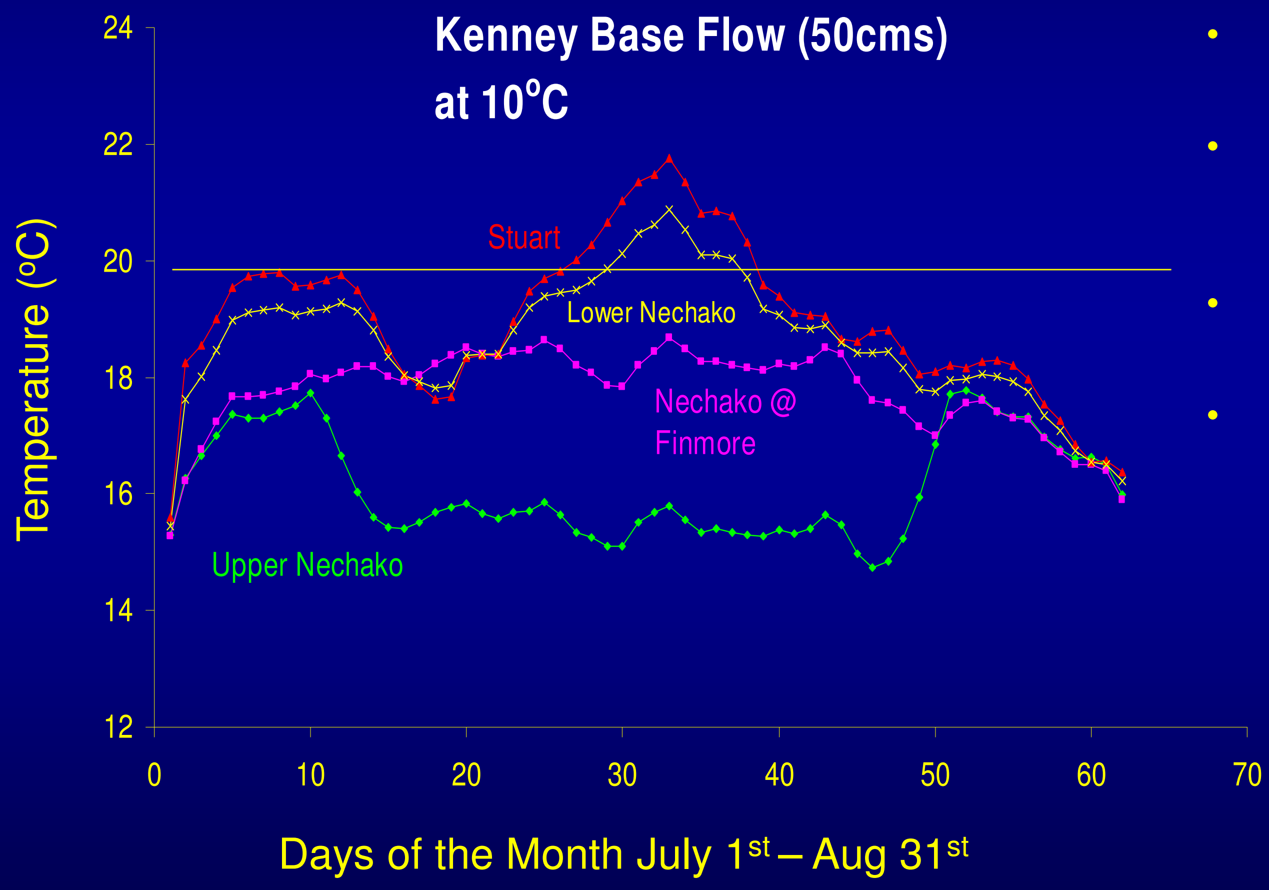
• a 4th scenario was run, 100% at 18°C, to represent a surface water release

Modeled Nechako Temperatures @ 4 Locations Using 4 Kenney Release Scenarios, 1998



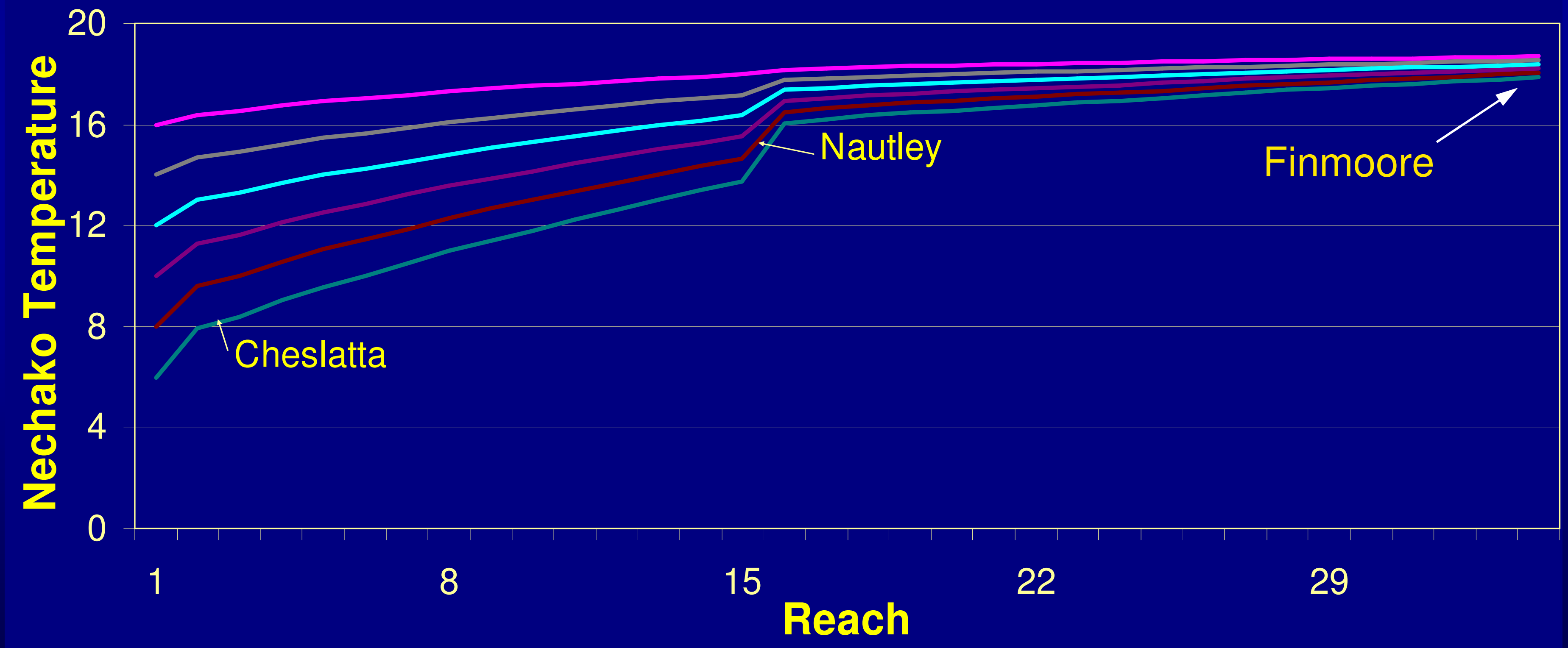
Consequences of low flows on conditions downstream

(30yr normal atmospheric and tributary data and low release temperatures)



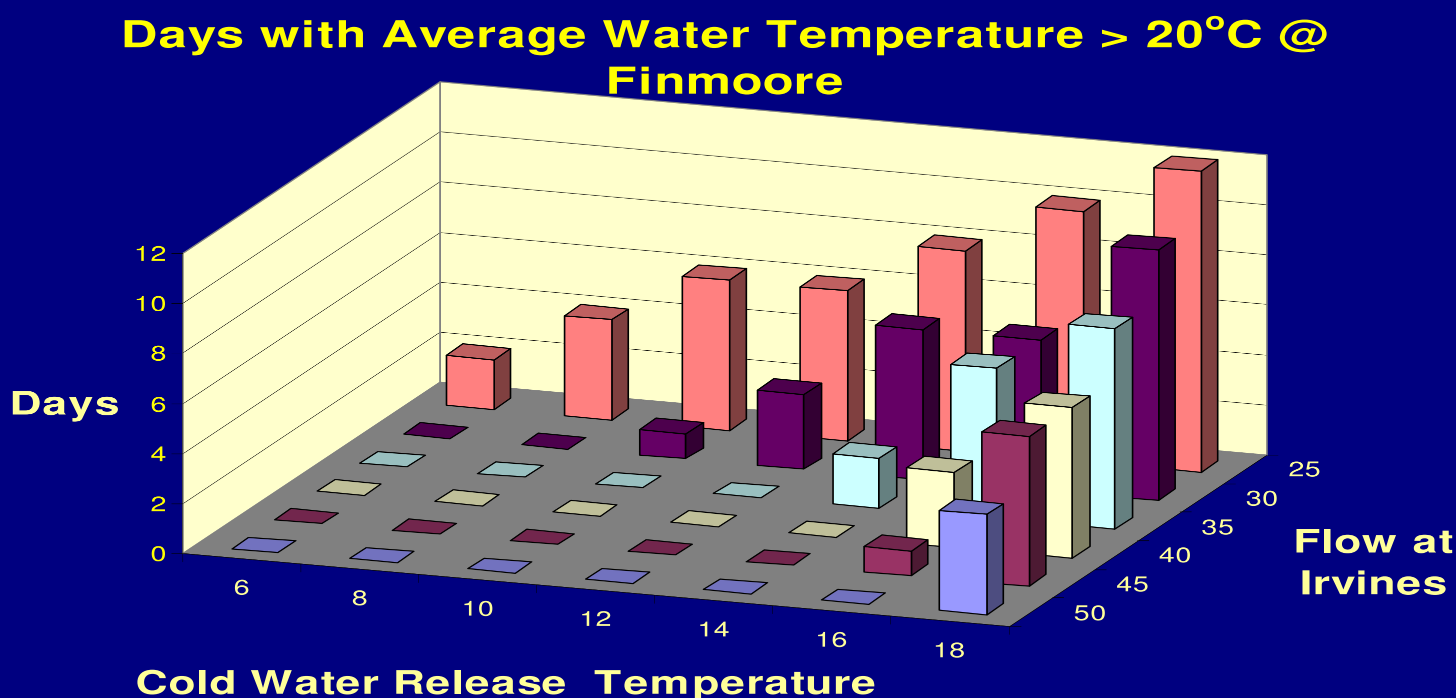
- Despite release at 10 and 12°C, upper Nechako temp's are 16°C.
- Both have a diminishing influence on downstream temperatures (Finmoore)
- Finmoore compliance despite low flow
- However, the Stuart which is generally warmer than the Nechako, causes downstream temps's to exceed 20°C.

Nechako Downstream Temperature Progression at Low Flow (25 cms)



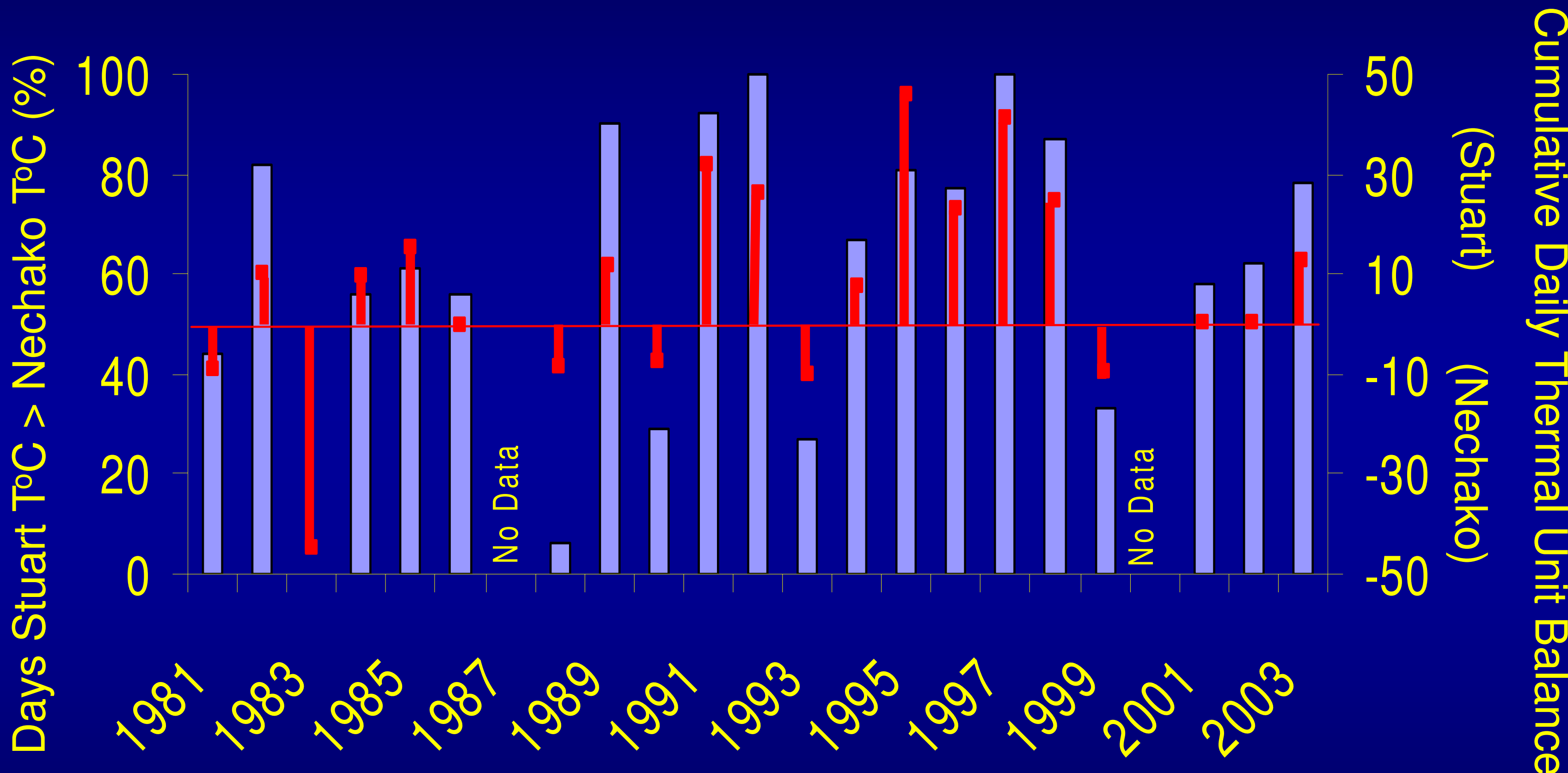
Influence of Climate Change @ Finmoore

1.25° C added to Normal Air Temperature



NOTE: Daily average of 20° C not exceeded with Normal Air Temperature

Annual Influence of the Stuart River on the Nechako River



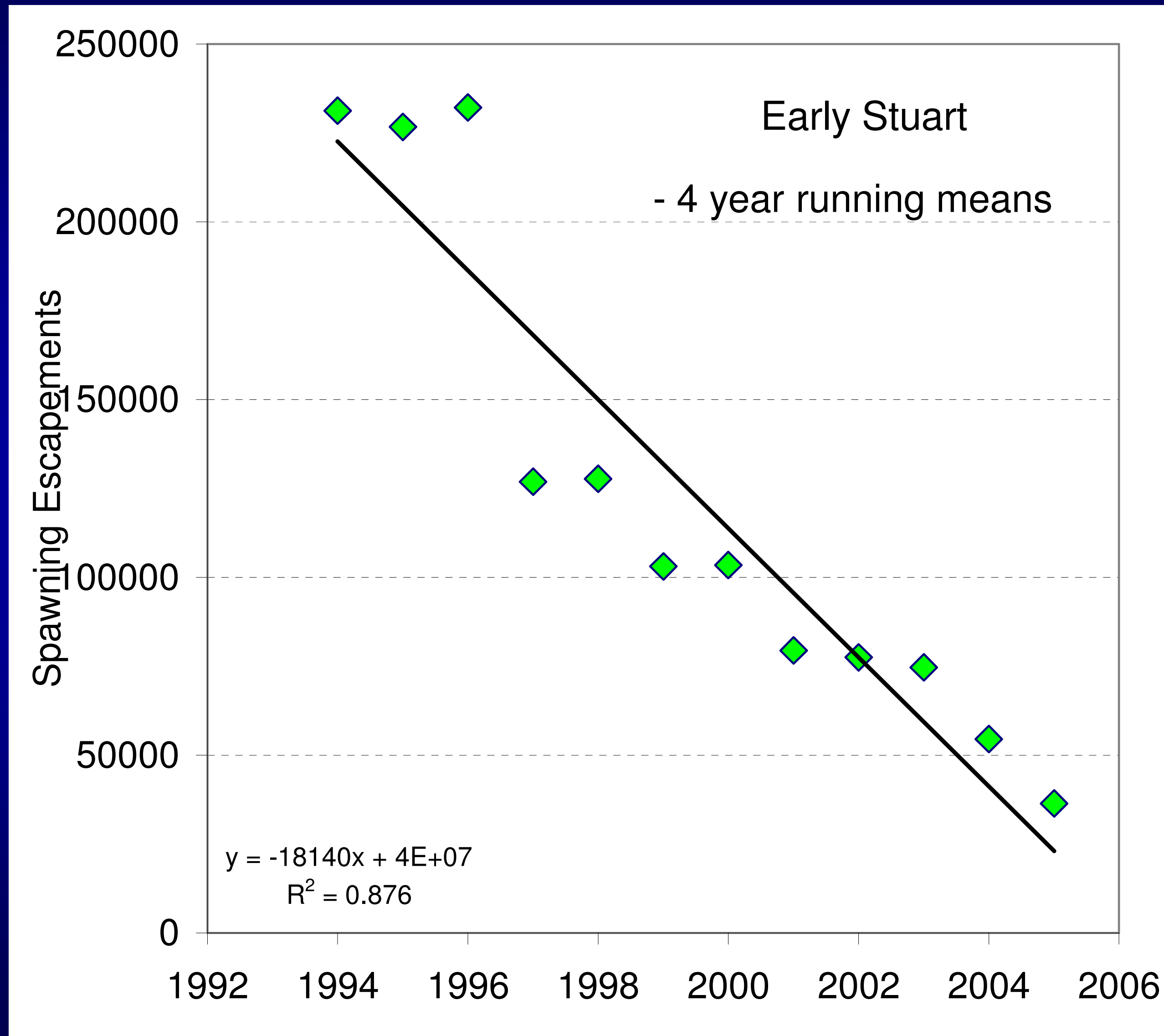
- Calculated during a 31 day period centred on peak Early Stuart abundance
- Doesn't consider the influence of discharge

C) The influence of cold water release scenarios on the migration and spawning of Sockeye Salmon

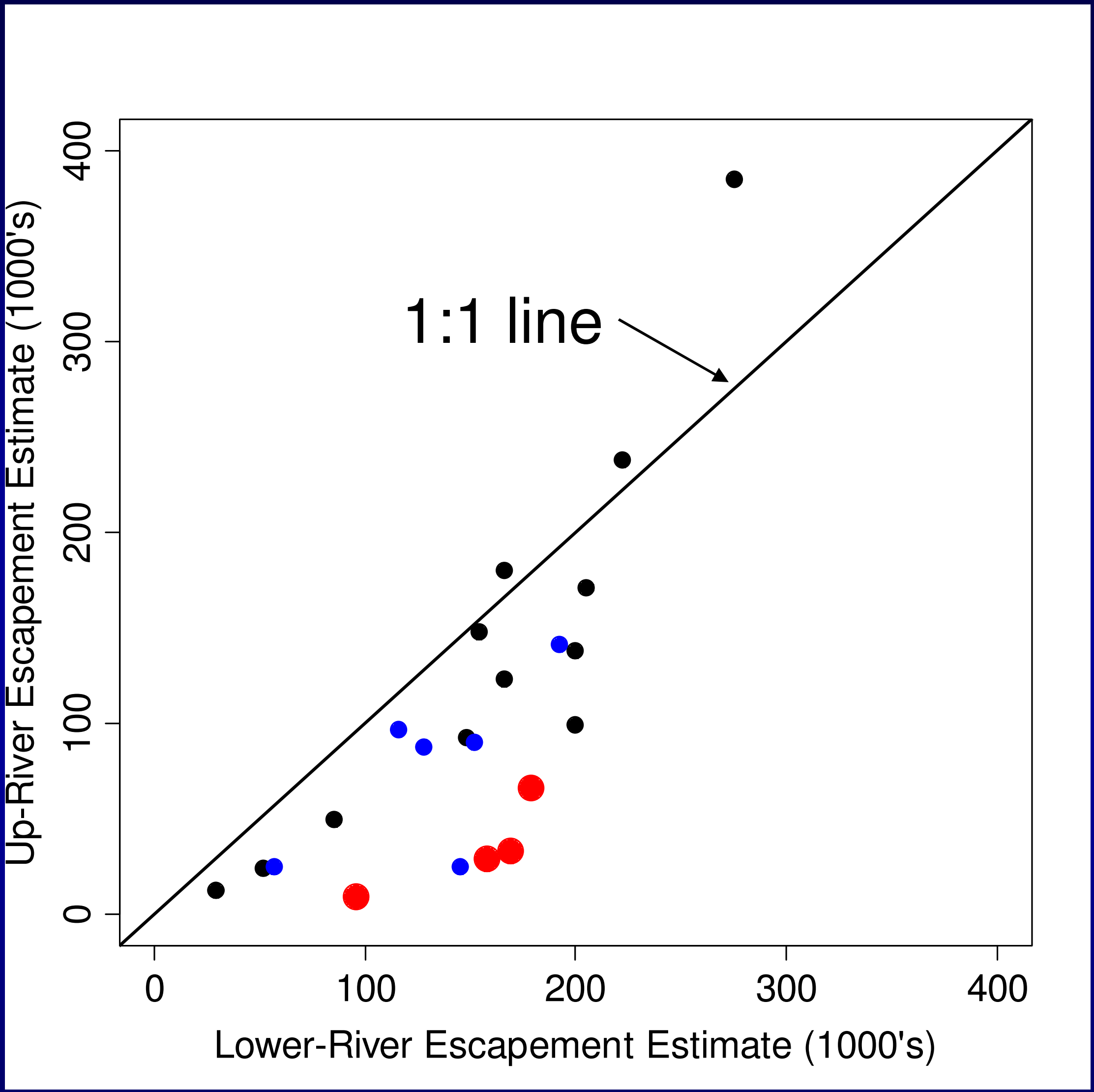
- Search for causes for the current state of the Stuart stock
- Can sockeye salmon migration or spawning success be attributed to Nechako River conditions?
  - Enroute mortality
  - Pre-spawn mortality
- Can we measure the efficacy of temperature control strategies (e.g. STMP, cold water release scenarios) in terms of fish survival?
  - Cooling power of the Nechako at Finmoore
- Do river temperatures approach sockeye physiological thresholds?

Early Stuart Sockeye Salmon Spawning Escapement Trends

- 84% decline in 3 generations
- not a result of increased harvest
- Wild Salmon Policy identifies 3 conservation units within this stock
- risk of listing, there's an effort to account for the decline

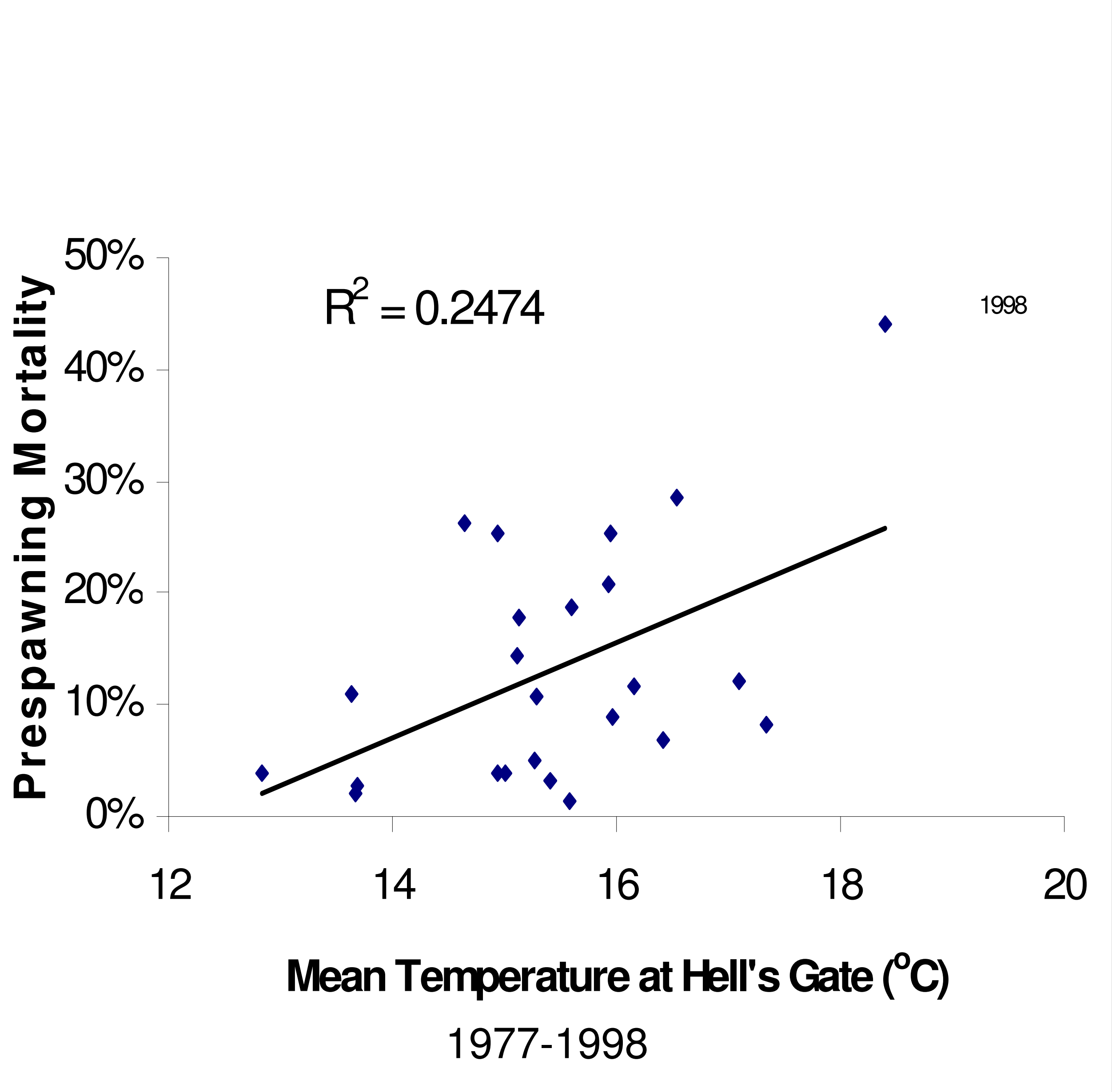


EARLY STUART SOCKEYE ENROUTE LOSSES 1977-2004



- discrepancy between Mission and spawning ground estimates
- migration route temperature is a predictor of migration loss
- basis for environmental management adjustment models
- Nechako temperatures do not explain enroute losses, but data not available pre-1981.

High temperature (1992,1994,1998,2004)
High discharge (1990,91,96,97,99,2000,02)
Moderate environmental condition years



EARLY STUART PRE-SPAWN MORTALITY EXPLAINED

- fish that arrive on the spawning grounds but fail to spawn
- detected by egg retention surveys
- data from the Early Stuarts since 1948

Do Nechako conditions predict pre-spawn loss?

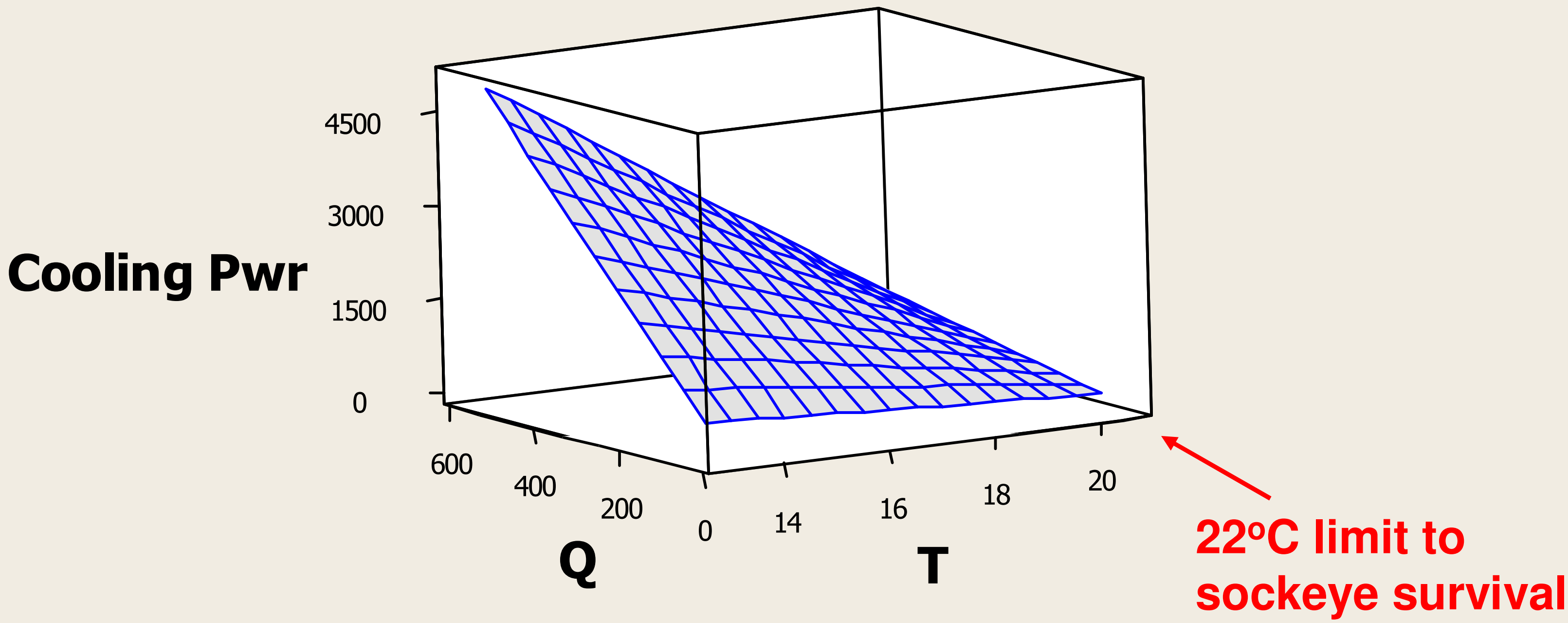
Cooling Power:

The ability of the Nechako to moderate temperatures in downstream reaches of the migration corridor….

$$\text{CoolPwr} = Q(22^{o} - \text{Temp.}^{o}\text{C})$$

- *where*:
  - Q = Nechako Discharge (cms) at Vanderhoof
  - Temp = Nechako Temperature (celsius)
  - 22^{o} – critical temperature for sockeye migration.
- *why*:
  - with the exception of the Nechako at Vanderhoof, pre-1981 water temperature data is scarce in the upper Fraser Basin.

Cooling Power increases with increasing flow and decreasing temperature at Vanderhoof



Cooling Power Measurements at Representative Q's (cms) and T's (°C)

Mean Summer Temperature (°C)

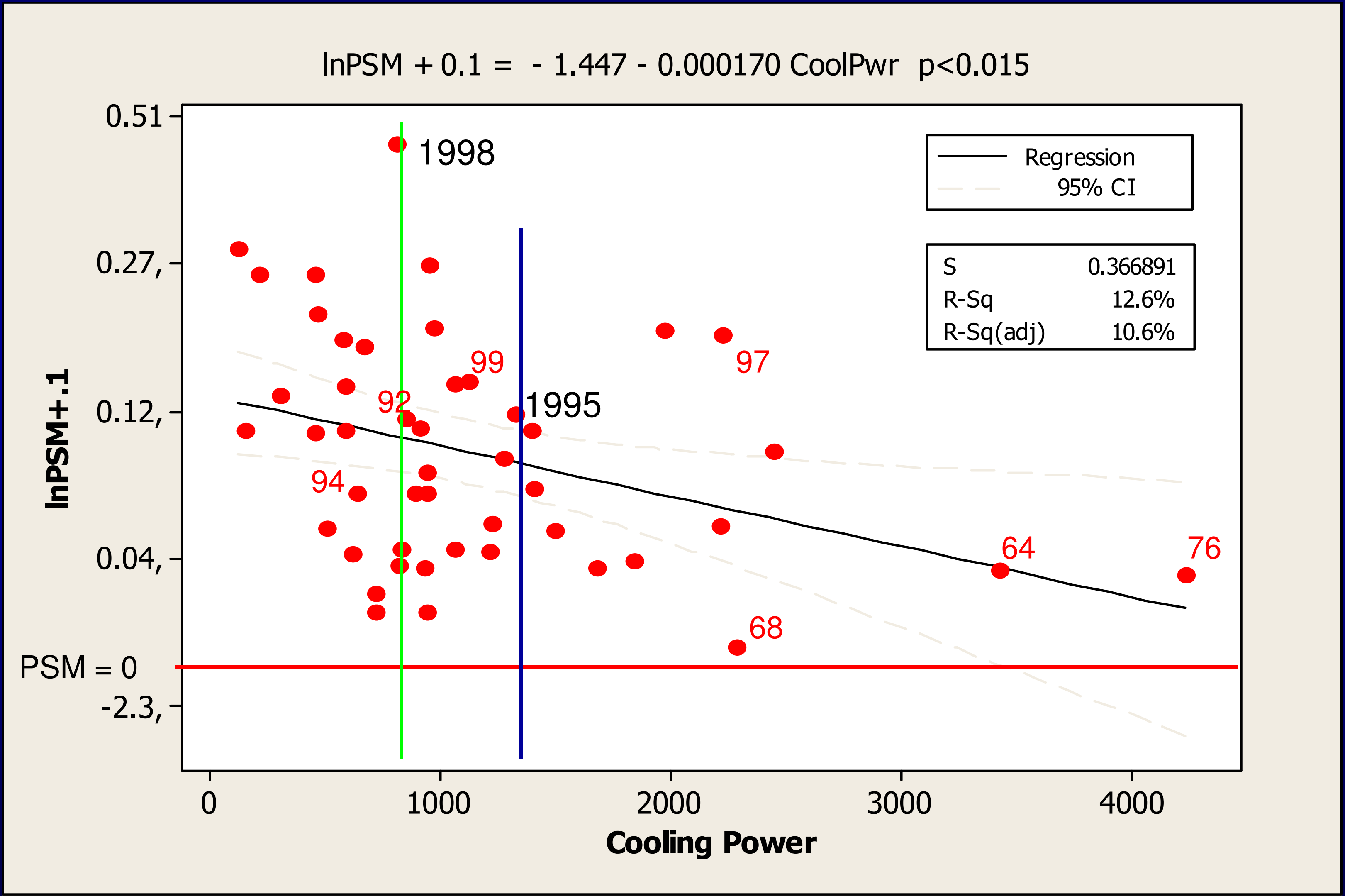
Q	13	13.5	14	14.5	15	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	20.5
50	450	425	400	375	350	325	300	275	250	225	200	175	150	125	100	75
100	900	850	800	750	700	650	600	550	500	450	400	350	300	250	200	150
150	1350	1275	1200	1125	1050	975	900	825	750	675	600	525	450	375	300	225
200	1800	1700	1600	1500	1400	**1300**	1200	1100	1000	900	800	700	600	500	400	300
250	2250	2125	2000	1875	1750	1625	1500	1375	1250	1125	1000	875	750	625	500	375
300	2700	2550	2400	2250	2100	1950	1800	1650	1500	1350	1200	1050	**900**	750	600	450
350	3150	2975	2800	2625	2450	2275	2100	1925	1750	1575	1400	1225	1050	875	700	525
400	3600	3400	3200	3000	2800	2600	2400	2200	2000	1800	1600	1400	1200	1000	800	600
450	4050	3825	3600	3375	3150	2925	2700	2475	2250	2025	1800	1575	1350	1125	900	675
500	4500	4250	4000	3750	3500	3250	3000	2750	2500	2250	2000	1750	1500	1250	1000	750
550	4950	4675	4400	4125	3850	3575	3300	3025	2750	2475	2200	1925	1650	1375	1100	825

1995

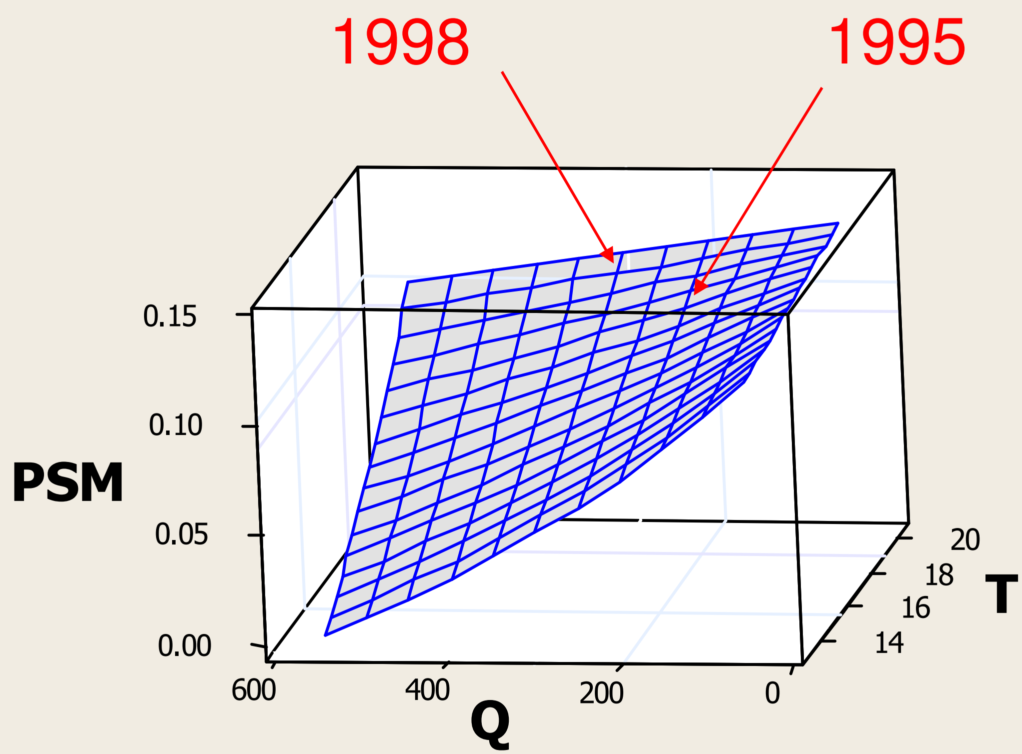
1998

Early Stuart Sockeye Pre-Spawning Losses in Response to Nechako R. Temperature and Flow (1952-2003)

Note: 1997 removed from analysis (15.7°C X 284.2 cms)



Early Stuart Sockeye PSM Observations Associated with Nechako Q's (cms) and Temp's (°C) @ Vanderhoof



Ten Kenney Dam Water Release Scenarios

DATE	Q/T°C	Mean T°C Finmore	SD T°C Finmore	Mean Flow Finmore	SD Flow	CoolPwr	PSM
1995	100/15	16.88	1.58	217.85	84.22	772.20	0.106
1995	80/15	17.12	1.57	179.39	66.71	614.62	0.112
1995	50/12	16.96	1.67	122.17	40.56	440.51	0.118
1995	actual	17.17	1.20	231.66		1329.28	0.088
1998	100/18	17.95	1.45	266.38	56.96	1280.08	0.089
1998	100/15	17.13	1.34	266.38	56.96	1492.88	0.083
1998	80/15	17.31	1.44	218.62	44.70	1212.36	0.091
1998	50/10	16.99	1.54	147.24	26.44	894.29	0.102
1998	actual	19.24	1.05	274.94		813.68	0.105
81-99	Base/10	18.17	0.26	93.45	8.19	396.85	0.120
81-99	Base/12	18.28	0.30	93.45	8.19	384.18	0.120
81-99	Base/15	18.04	0.26	93.45	8.19	362.64	0.121
81-99	actual	18.10		247.68		978.60	0.099

Is Cooling Power a Surrogate for (or correlate with) other migration route variables ?

	Cooling Power	Stuart Temperature	Spawn Temperature	Entrance Island	Nechako @ Isle Pierre
Stuart Temperature	**-0.472** **0.048**				
Spawn Temperature	-0.345 0.175	**0.732** **0.001**			
Entrance Island ToC	0.156 0.537	0.053 0.840	0.005 0.986		
Nechako ToC @ Isle Pierre	**-0.706** **0.001**	**0.893** **0.000**	**0.759** **0.001**	-0.036 0.891	
Hells Gate Temperature	-0.160 0.512	**0.493** **0.038**	0.397 0.114	**0.560** **0.016**	0.426 0.078

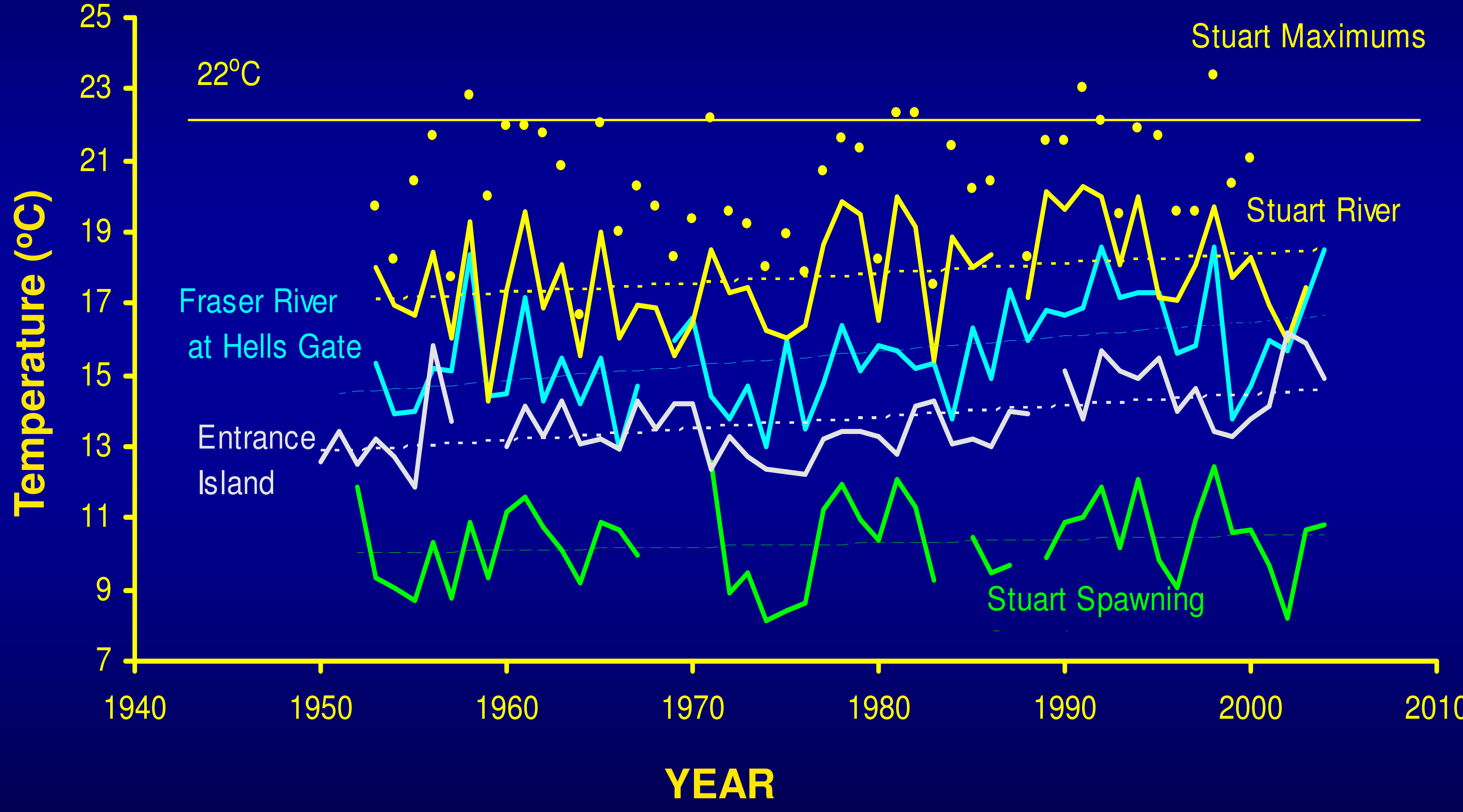
Pearson coefficients

Probability

- analysis restricted to data from 1981-1999.

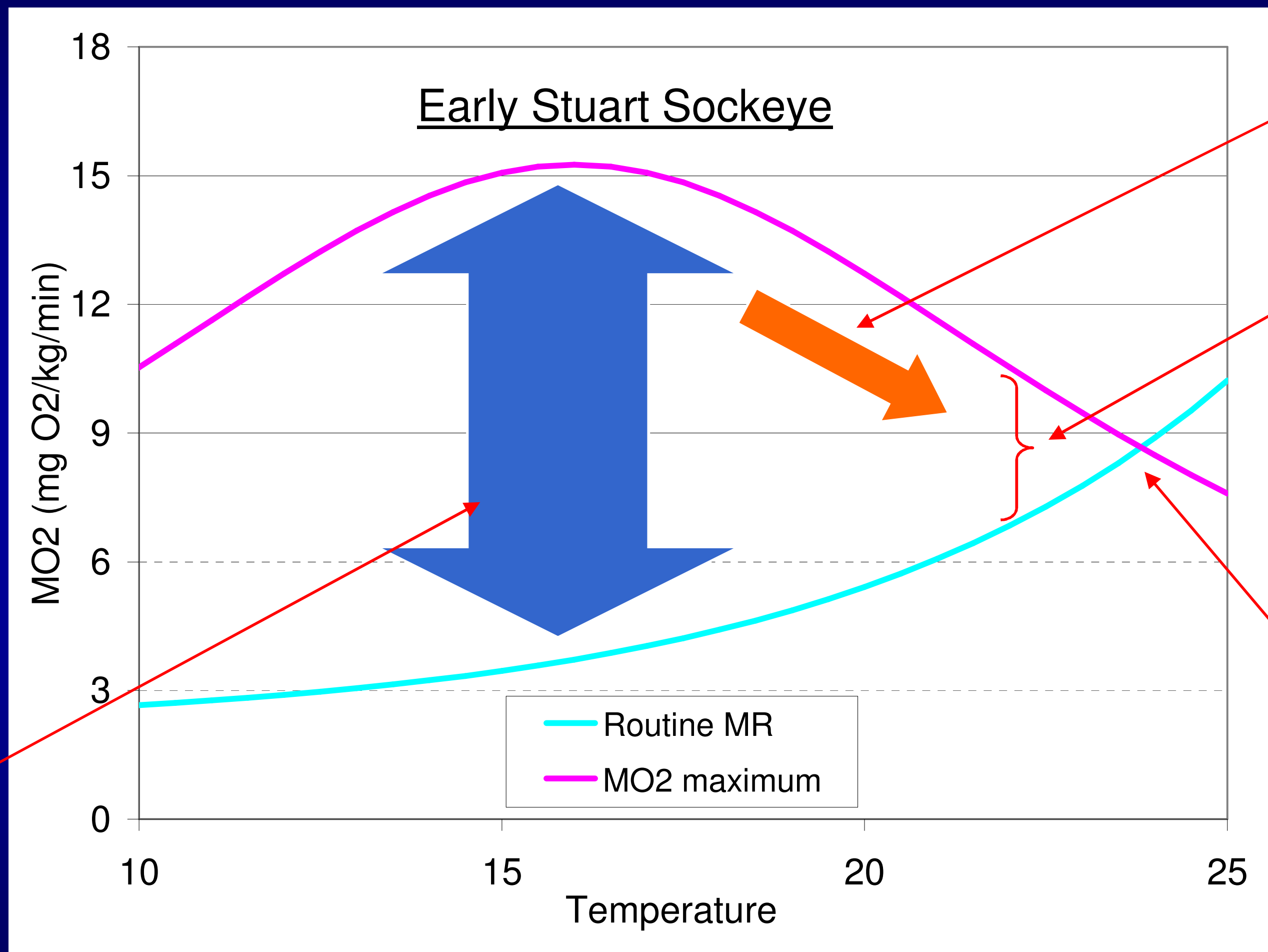
- Nechako @ Isle Pierre data generated from model using climatic/hydrologic data.

Water Temperatures During Early Stuart Migration (1952-2004)



- temperatures from Prince George to Stuart Lake are the warmest the sockeye will experience in their entire life history.

3) What effect does temperature have on routine metabolism and aerobic swimming ability ?



Reduced swimming ability

>T°C Lower Scope for activity

Death

Optimum Aerobic Scope Range

- Increase temperature exponential increase in energy costs
- Approx. >21 °C reduce optimum swim speed – stop migration

Cold Shock

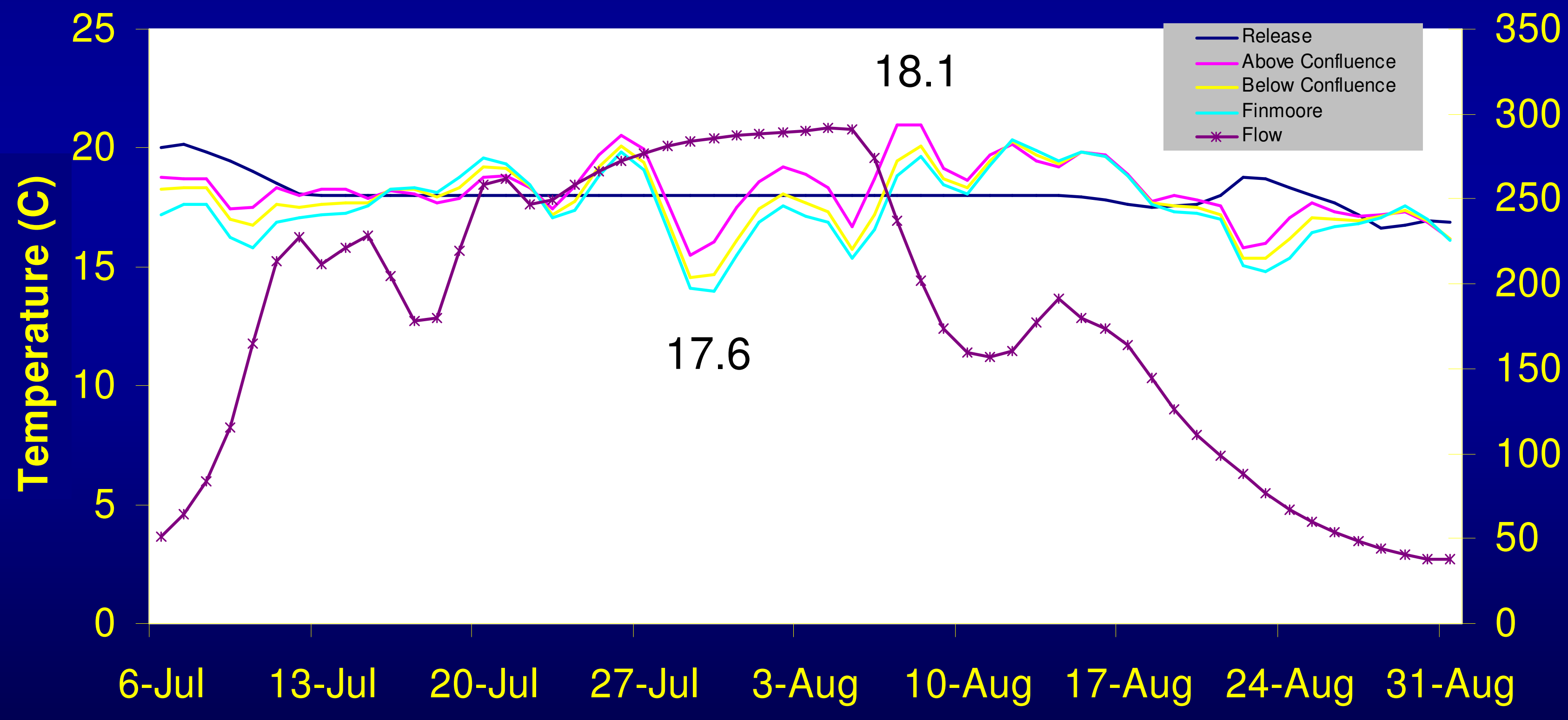
In Relation to the Kenney Dam Cold Water Release

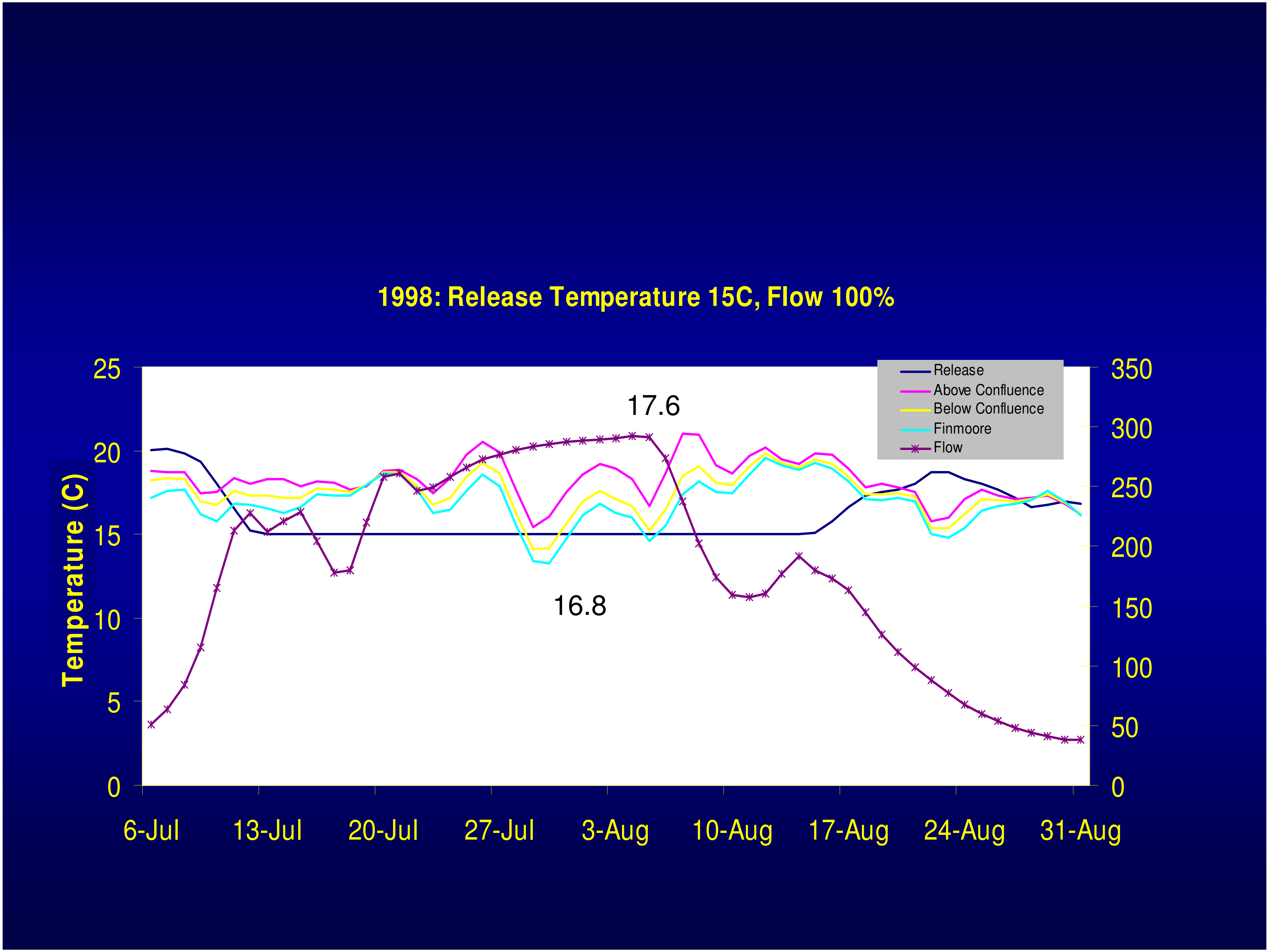
- **Promote gradual volume and temperature changes**
- **ΔT between discharge and ambient waters should be adjusted on a seasonal basis to compensate for variable water temperatures**
- **Promote heterogeneous mixing between cold discharge and ambient waters**
- **Cold-water release facility should have a tempering system or "fine control" structure**
- **Develop a small-scale experimental laboratory to determine/test/refine operational strategies prior to formal implementation**
- **Initially operate the CWRF in a conservative manner and use the experimental testing facility to assess alternative thermal regimes prior to making them operational**
- ***In situ* monitoring should be conducted to characterize optimal flow rates, discharge temperatures, mixing, and fish biology**

CONCLUSIONS/ RECOMMENDATIONS (from the fishes perspective)

- Maintain the STMP – it works.
- More water above the confluence is generally good - it moderates temperatures below the confluence most years.
- Improved watershed forecasting to anticipate years when tributary flow (Nautley, Stuart) will compensate for reduction in flow from the reservoir.
- Beware of climate change.
- Fish population fitness measures can be linked to Nechako variables – fisheries management models based on these relations will be woefully imprecise.
- A Kenney coldwater release facilities provides many opportunities:
  - a modest reduction of water at cooler temperature can meet targets above and below the confluence (see below).
  - restrict release temperature reduction to 2-3^{o}C below ambient.
  - with Kenney releases, the Cheslatta will no longer need to be surcharged on July 10-19th thus saving water.
  - cooling flow releases from Kenney may be more efficient creating more water savings during the STMP period.
  - Cheslatta flows will be normalized allowing for habitat restoration activities.

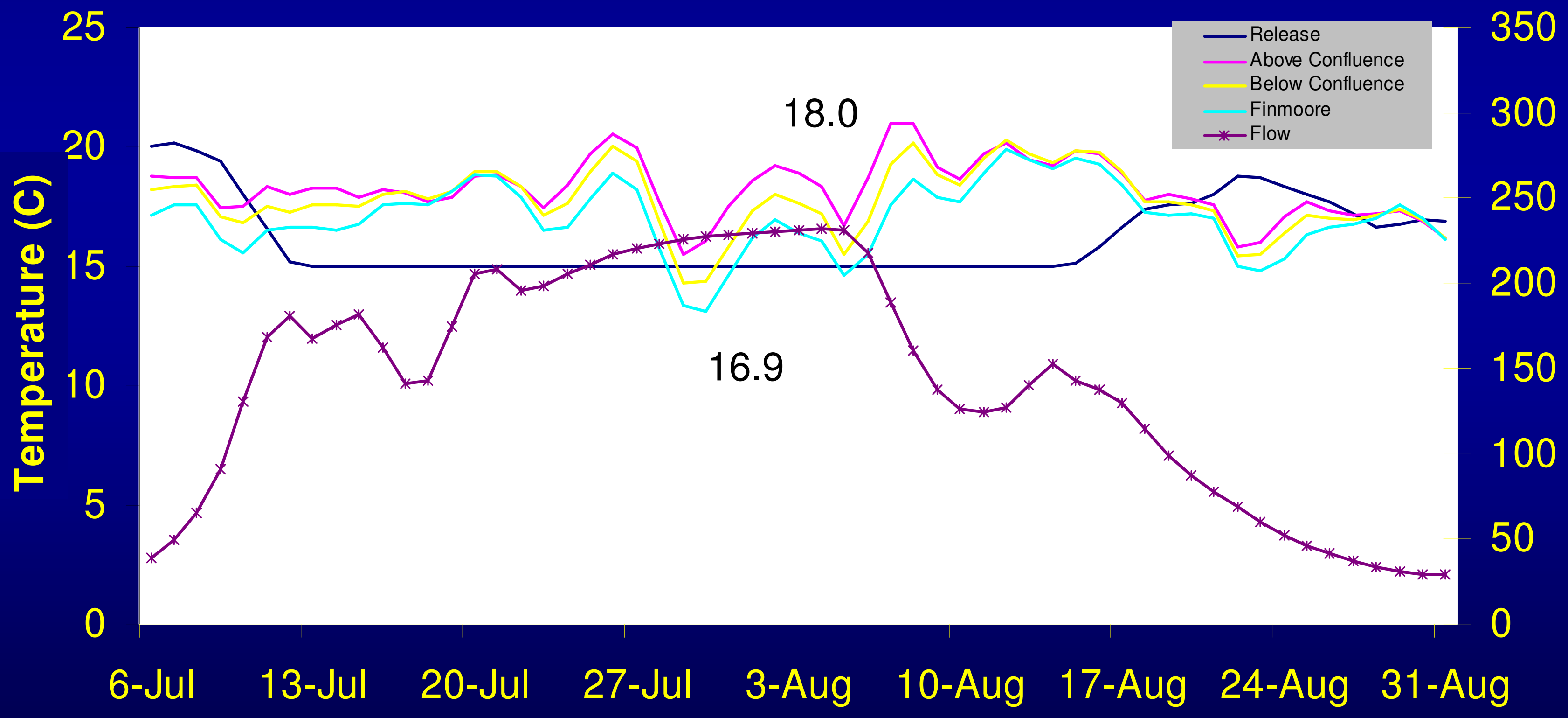
1998: Release Temperature 18C, Flow 100%



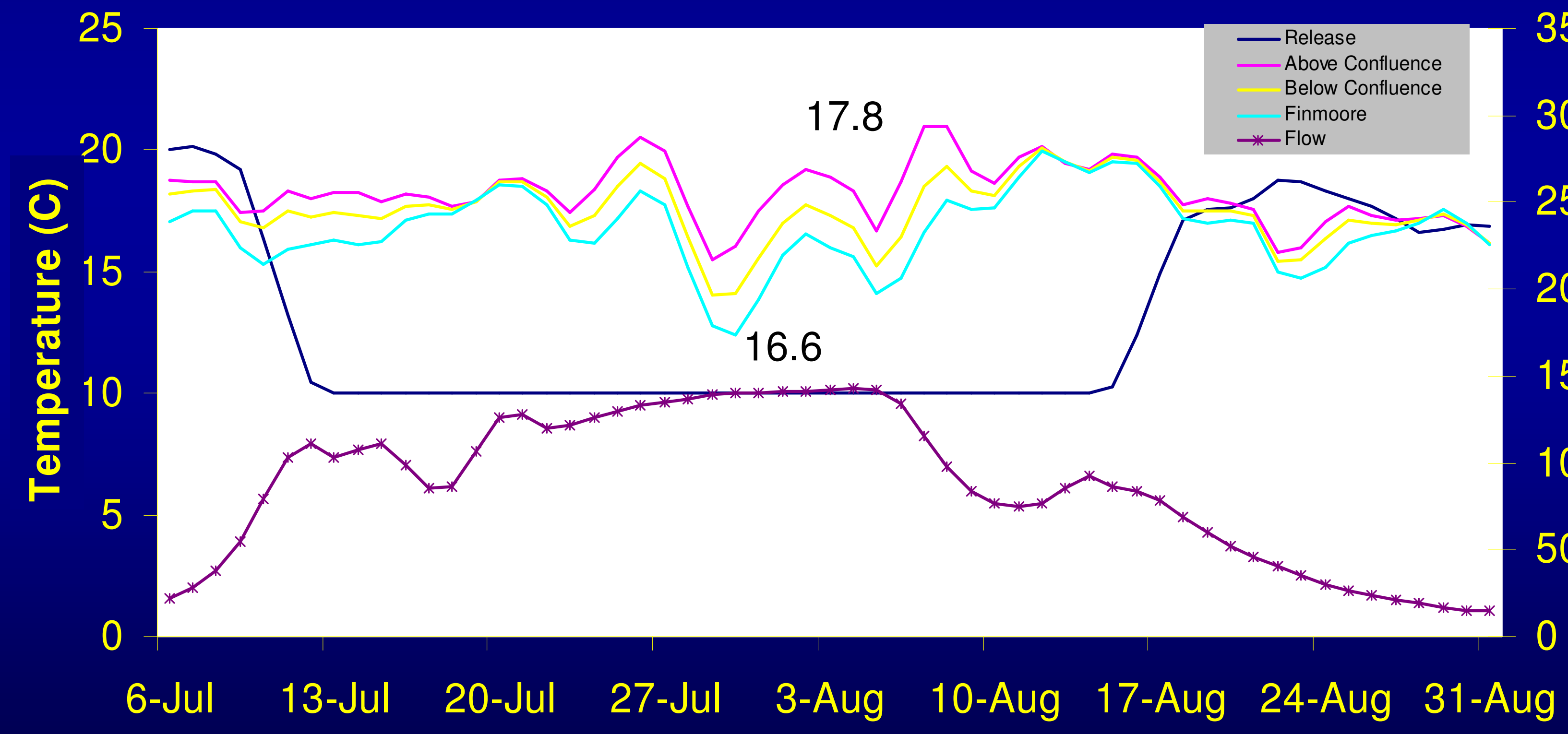


1998: Release Temperature 15C, Flow 100%
Temperature (C)
25
20
15
10
5
0
350
300
250
200
150
100
50
0
6-Jul
13-Jul
20-Jul
27-Jul
3-Aug
10-Aug
17-Aug
24-Aug
31-Aug
Release
Above Confluence
Below Confluence
Finmoore
Flow
17.6
16.8

1998: Release Temperature 15C, Flow 80%



1998: Release Temperature 10C, Flow 50%




Questions ?

A) Conclusions

- Do Water Releases from Skins Lake Moderate Nechako River Temperatures?
  - *Yes.*
- Which meteorological/hydrometric variables are predictors of Nechako River temperatures?
  - *Discharge.*
  - *Prince George Air Temperatures.*
- What would the Nechako temperatures be at Vanderhoof without STMP?
  - *Range 0.22 – 0.97.^{o}C warmer from 1981-2002 at Vanderhoof.*
- What influence does the STMP flow have on the Nechako below the Stuart?
  - *Generally has a cooling influence on the lower Nechako as the Stuart is warmer than the Nechako.*

B) Conclusions

- Can models be developed to measure the efficacy of controlled Kenney Dam water releases (temperature and discharge) on hydrologic conditions in the Nechako watershed?
  - *Yes*
- Can cool water releases from Kenney Dam in July and August meet a 19.8^{o}C maximum W/T limit at Vanderhoof/Finmoore while releasing less water than required within the STMP?
  - *Generally yes, but not in all years.*
- What influence will lower flows at Vanderhoof/Finmoore have on Nechako temperatures below the Stuart confluence?
  - *Reduced Finmoore flow significantly impedes the moderating influence of the Nechako on the Stuart (which is generally warmer than the Nechako in the summer).*
- What influence will climate change have on our conclusions?
  - *A 1.25 ^{o}C increase in air temperature will result in temperatures at Finmoore exceeding 20^{o}C at some release scenarios.*

C) Conclusions

- Can we link ecological conditions to long-term sockeye survival?
  - *Yes, but insufficient pre-1981 data from Isle Pierre*
- Can sockeye salmon migration or spawning success be attributed to Nechako River conditions?
  - *Yes, using a balance of probability approach*
- Does the provision of STMP flows to comply with Finmoore temperature targets, improve sockeye migration corridors in the Nechako, below the Stuart confluence?
  - *Yes – the Nechako is generally cooler than the Stuart*
- Can we develop management tools to estimate fish survival associated with temperature control strategies (e.g. STMP, cold water release scenarios)?
  - *No , not yet*

Model Root Mean Square Error

	Vanderhoof		Finmoore	
	RMSE	Mean°C	RMSE	Mean°C
1981	0.71	-0.55	0.55	-0.34
1982	0.92	-0.77	0.66	-0.02
1983	0.52	-0.34	2.59	2.53
1984	0.61	-0.41	0.82	0.60
1985	0.60	-0.44	1.61	-0.75
1986	0.85	-0.62	0.80	-0.36
1988	0.81	-0.61	0.66	-0.28
1989	1.20	-1.01	1.07	-0.71
1990	1.37	-1.04	1.13	-0.46
1991	0.68	-0.43	0.73	0.20
1992	0.75	-0.57	0.73	-0.09
1993	0.58	-0.12	1.06	0.42
1994	1.37	-1.05	1.21	-0.74
1995	1.98	1.84	0.60	0.03
1996			0.66	0.17
1997	0.53	-0.46	0.70	0.10
1998	0.71	-0.59	0.73	-0.44
1999	0.60	-0.49	0.76	-0.31
Mean	0.80	-0.59	0.83	-0.16
Stdev	0.28	0.26	0.21	0.41

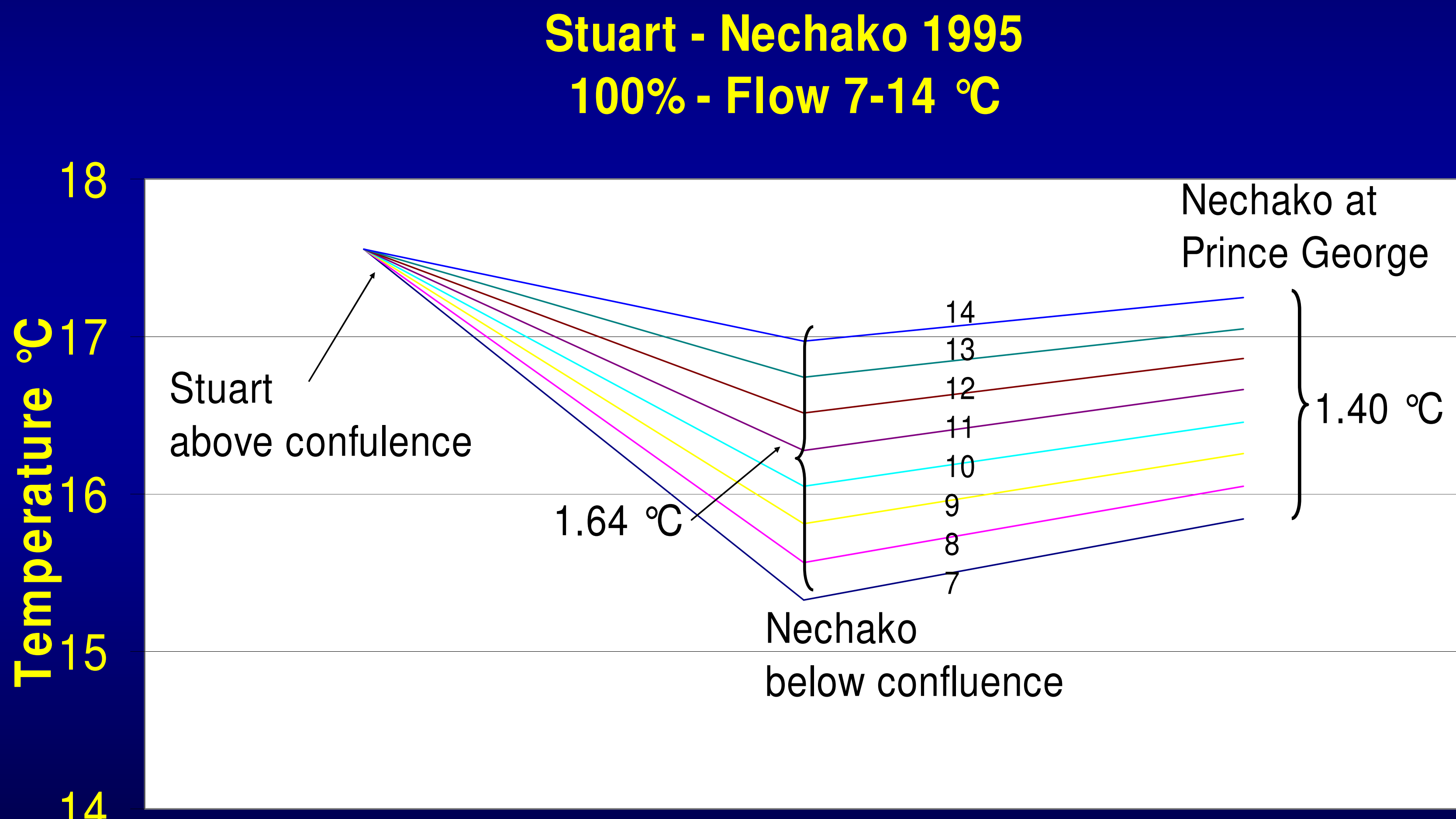
RMSE is higher than expected
- May be possible to adjust model to reduce error

Model has –ve bias at Vanderhoof
- Results reported in this report are conservative

Difference in Mean error is unexpected
- Finmoore/Vanderhoof comparative analysis required

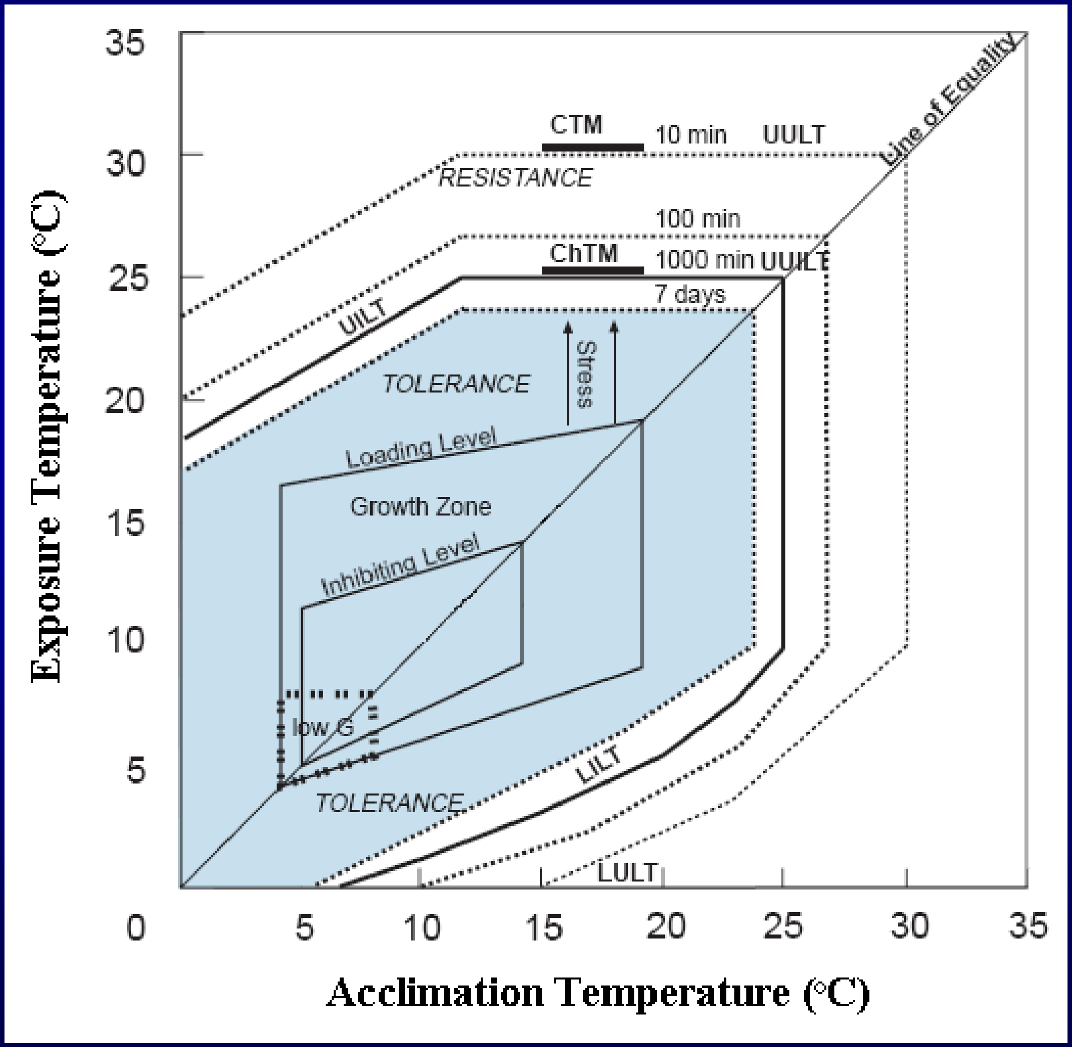
Note. Highlighted values in black not used in error evaluation due to outstanding issues about the observed data files.

Temperature Scenarios following Mixing at the Confluence



Thermal Tolerance Polygon

Example: Spring chinook salmon (*Oncorhyncus tshawytscha*)



McCullough 1999