Comparing Potential Total Dissolved Gas (TDG) Mortality in Chinook Salmon Juveniles Below Big Cliff and Foster Dams

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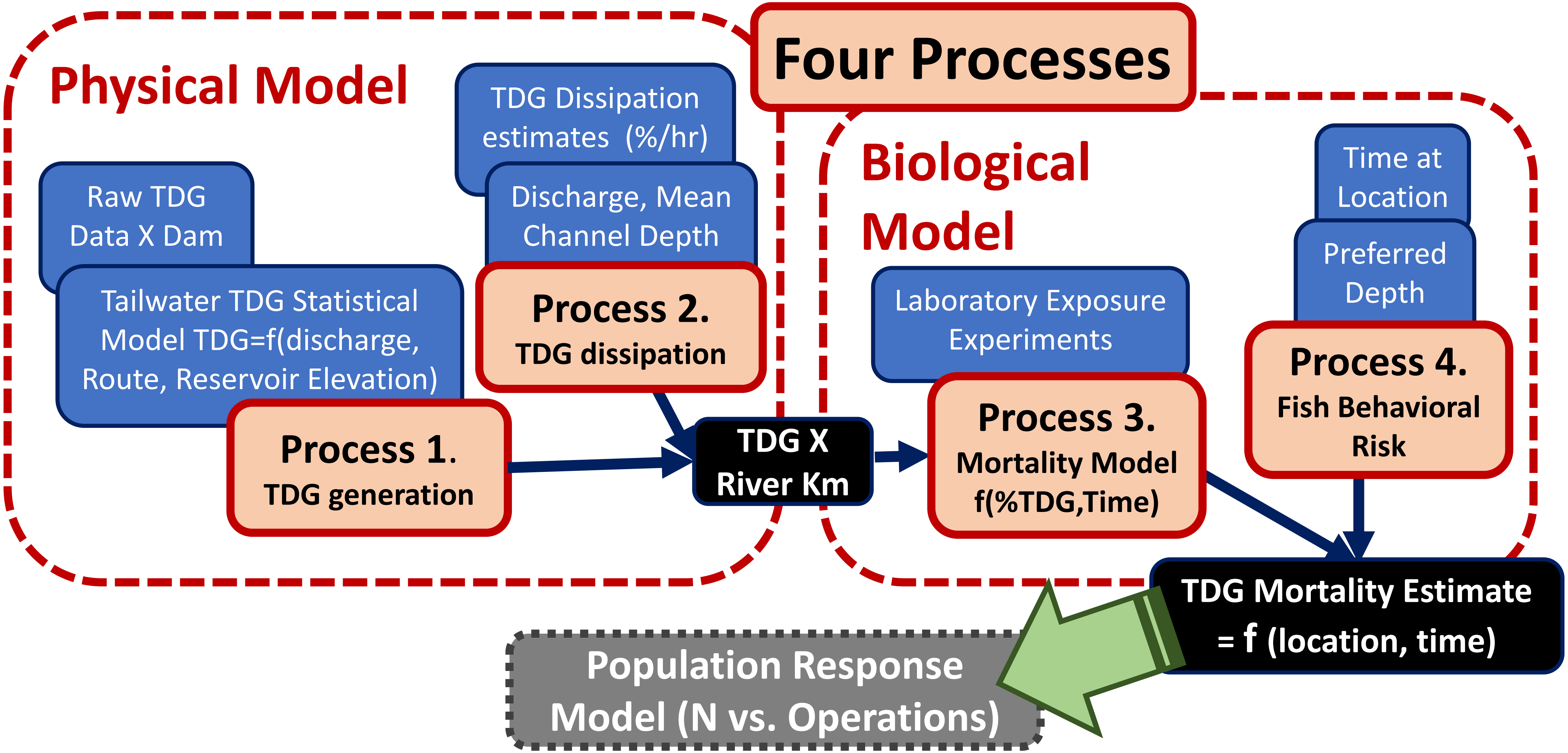
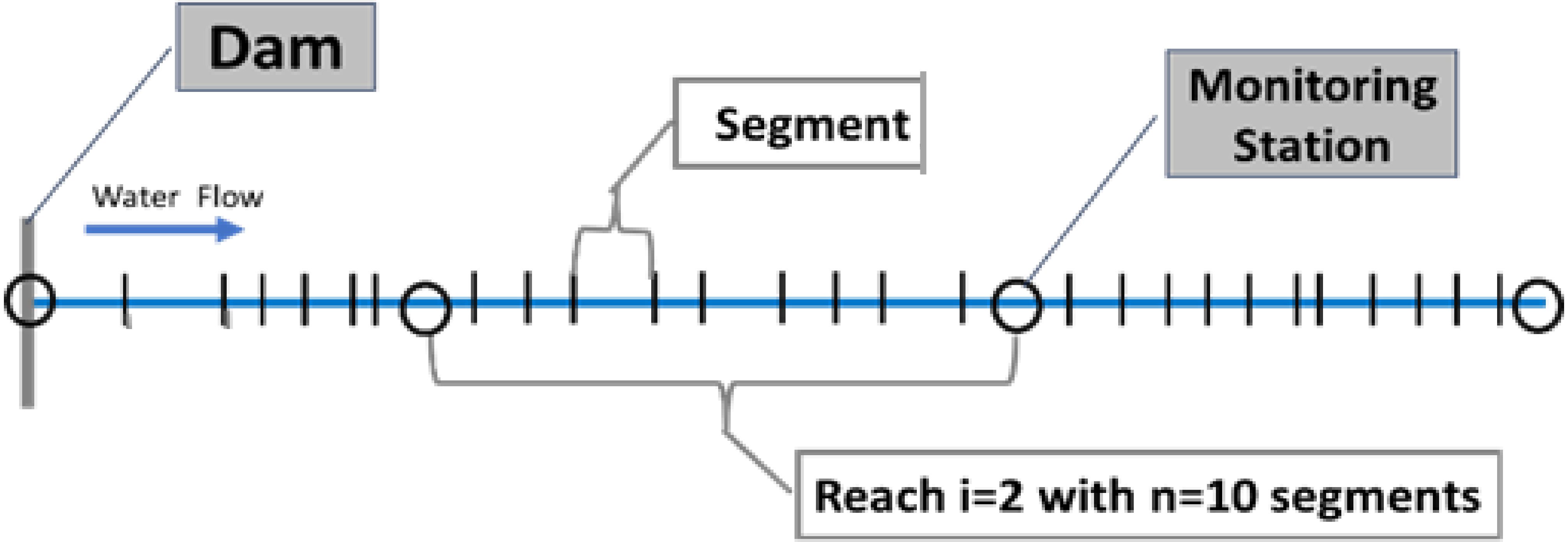
Estimating TDG Mortality: Review from 2023

We want to quantify the population response to TDG patterns



The Structure of the Dataset*

- Tailwater is divided into Reaches and Segments
- Depth and Velocity is modeled for each segment over a range of discharge
- TDG is predicted for each segment X discharge, validated by field data from monitoring stations at the end of each Reach



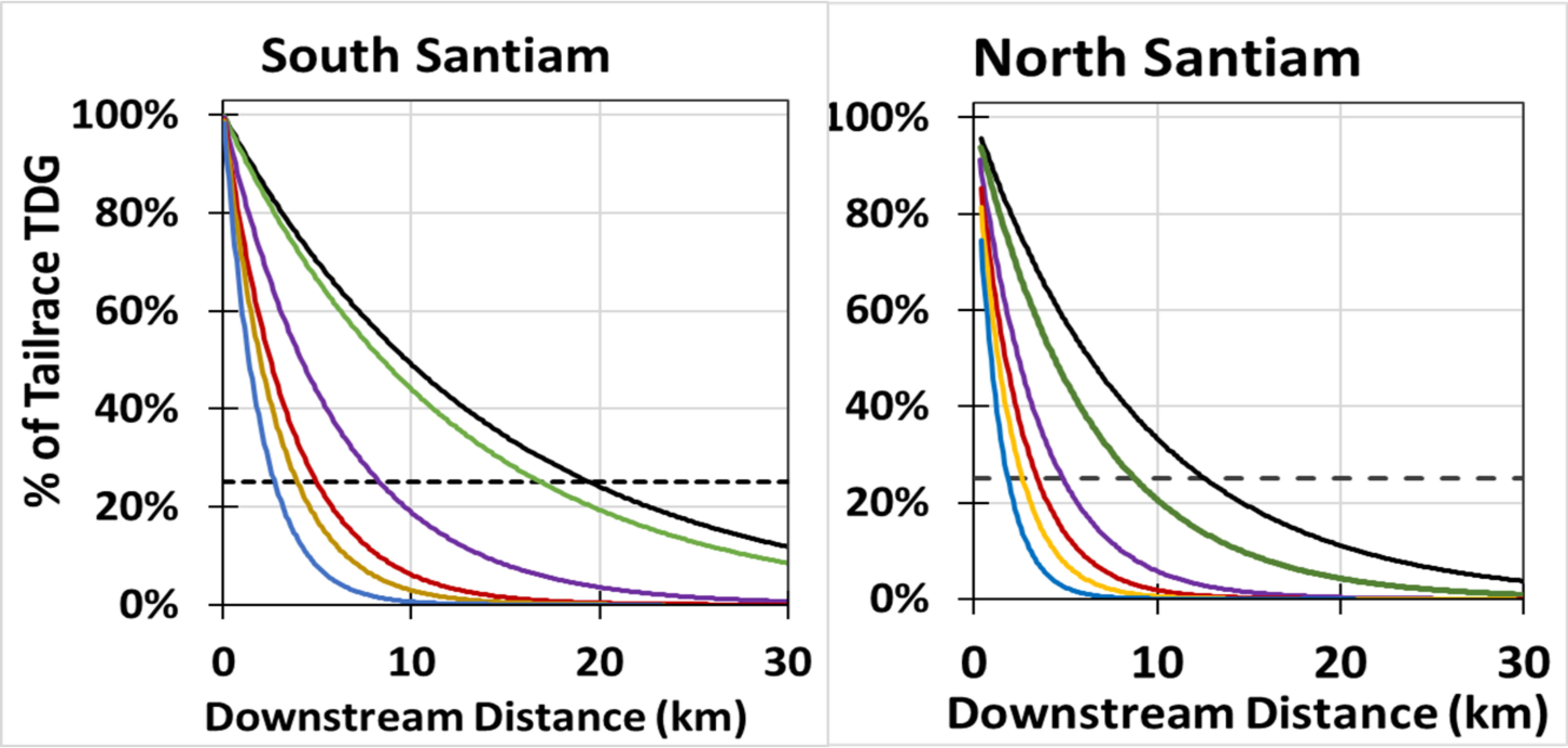
* From USACE, Norm Buccola

Empirical Estimates of TDG Dissipation

- TDG dissipates exponentially with distance from source* $C=C_0e^x$

$$C = C_0 e^{-3.43L\left(q+5.6\right)^{-0.63}}$$

$$C = C_0 e^{-6.37L(q-11.0)^{-0.65}}$$



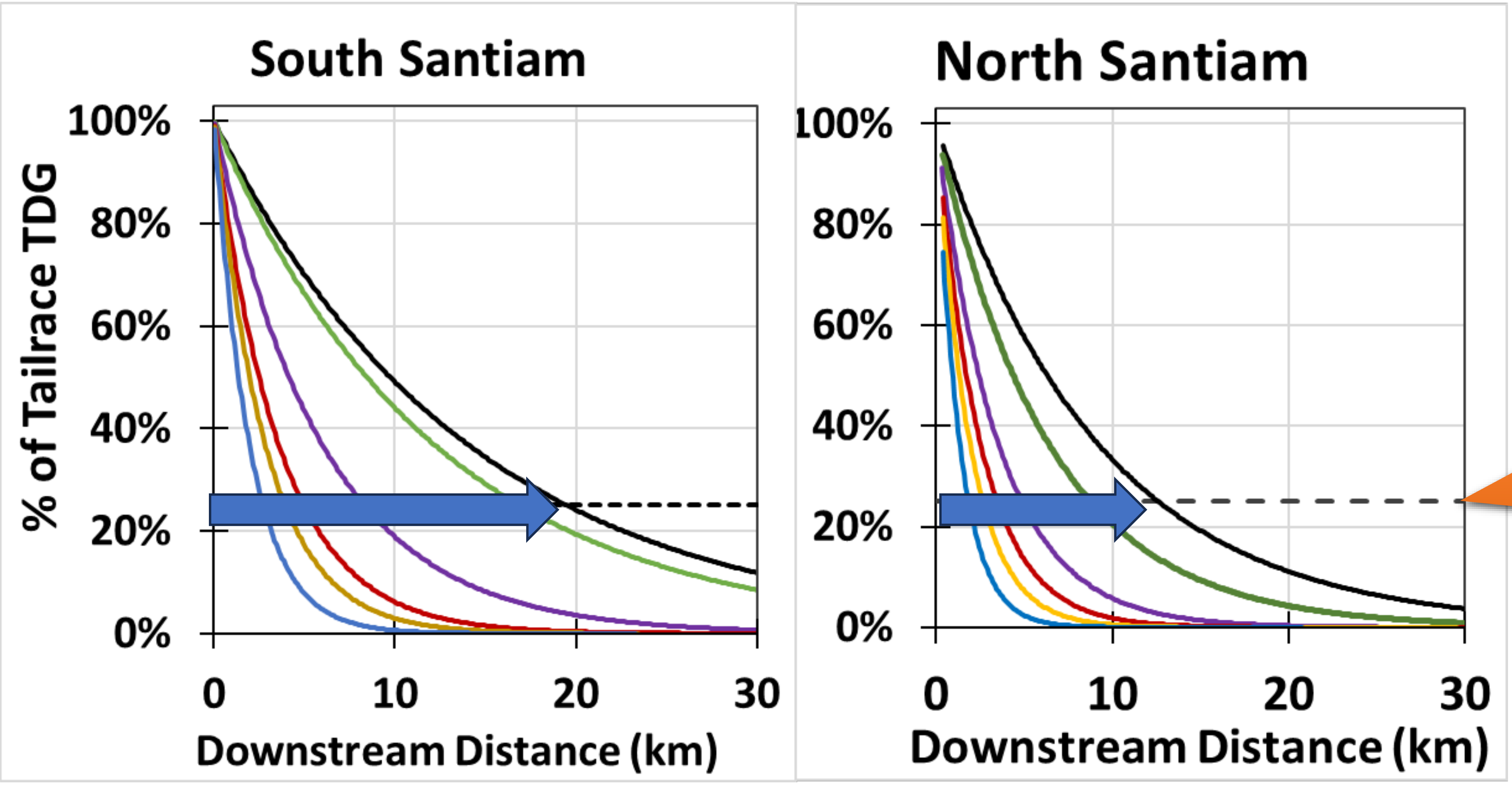
*L = distance downstream. q = discharge in m^3/se

TDG Dissipation

- Dissipation takes longer in the South Santiam (low turbulence)

$$C = C_0 e^{-3.43L(q+5.6)^{-0.63}}$$

$$C = C_0 e^{-6.37L(q-11.0)^{-0.65}}$$



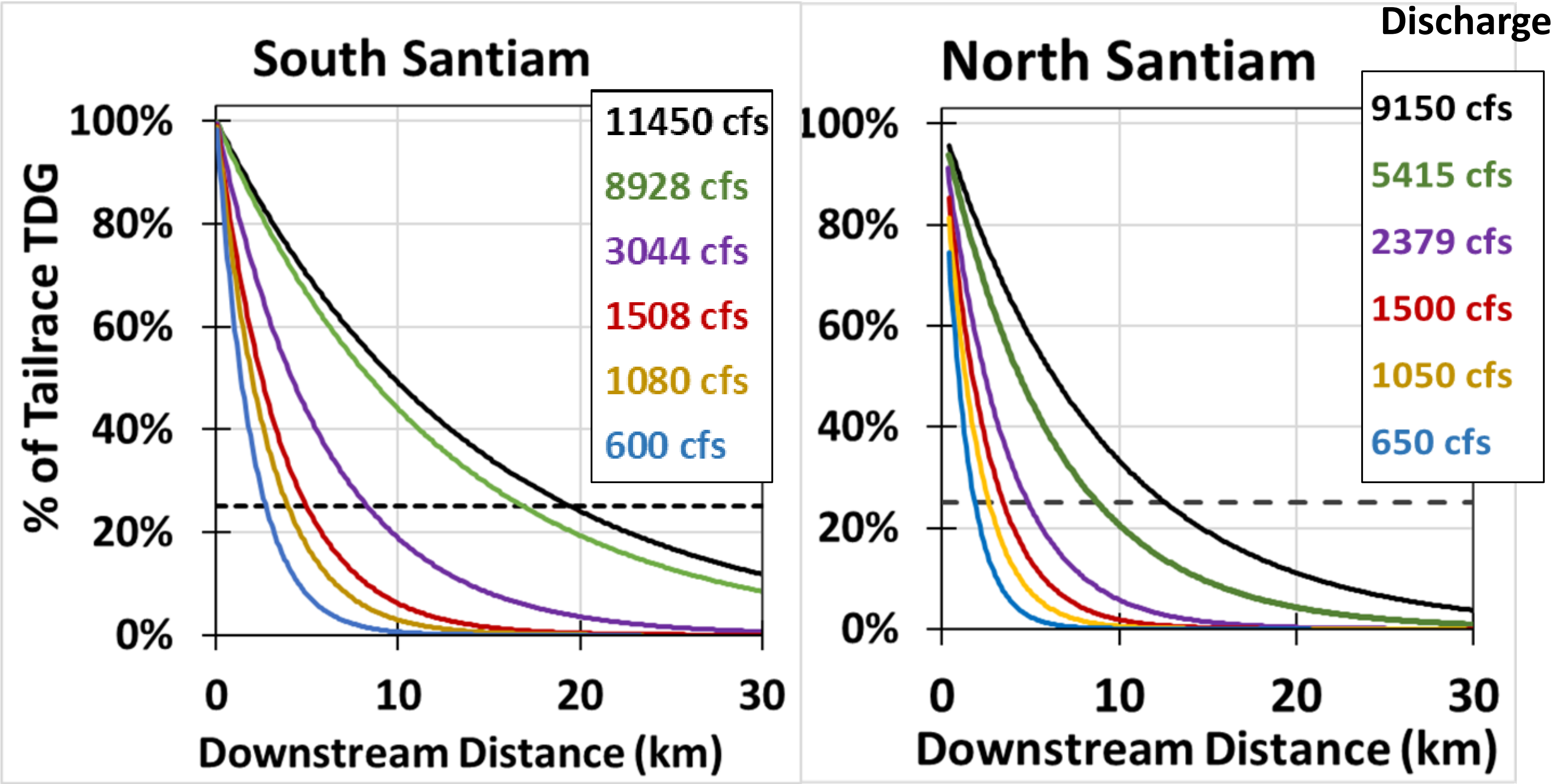
"Safe" TDG"*

TDG is <110% with C_0=140%

* 1/5th of excess TDG is generally oxygen, which can be metabolized

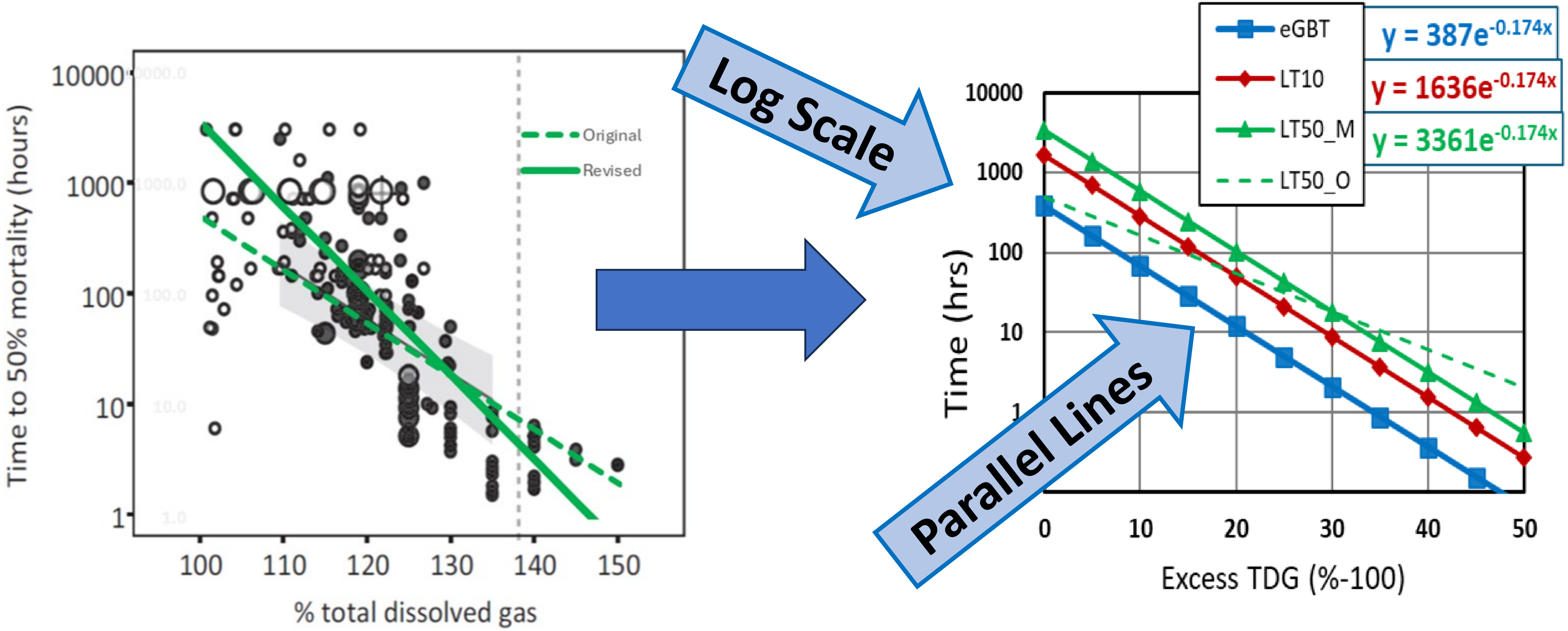
TDG Dissipation

- Decline is slower at high discharge and in the South Santiam R
  - Water covers distances in shorter times
  - and Deeper water reduces the surface to volume ratio



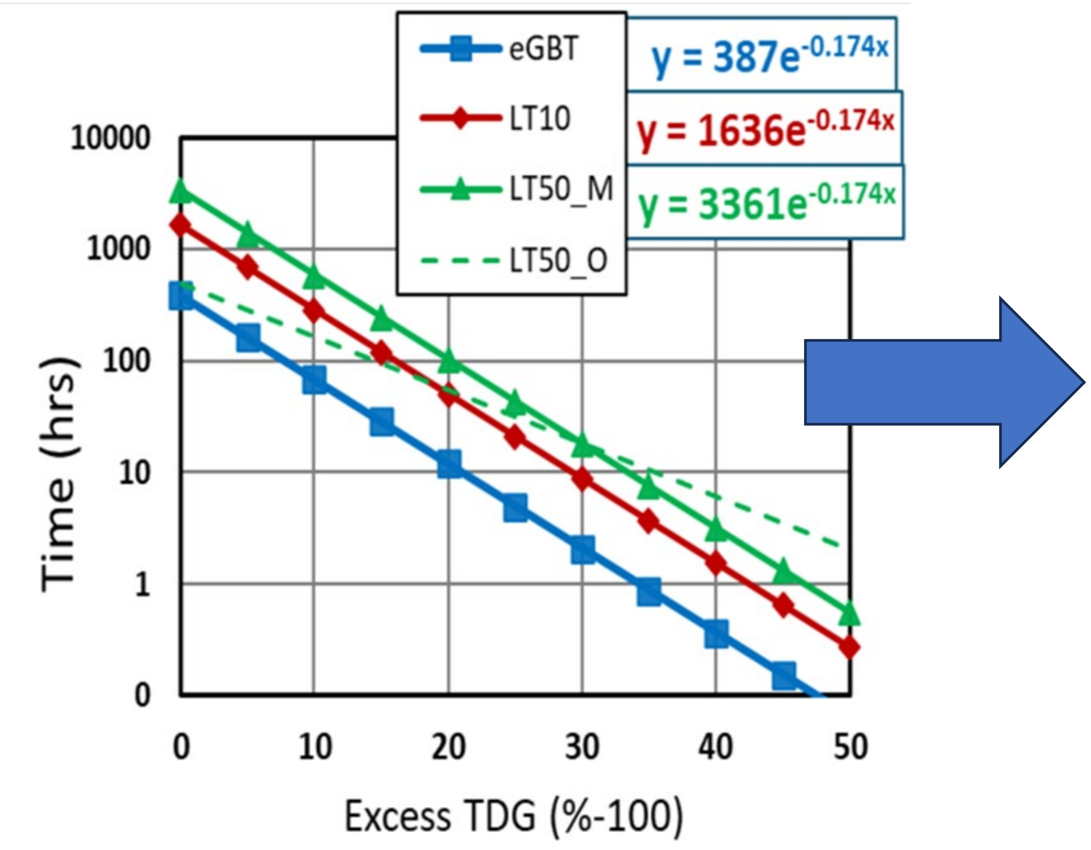
Modeling Survival

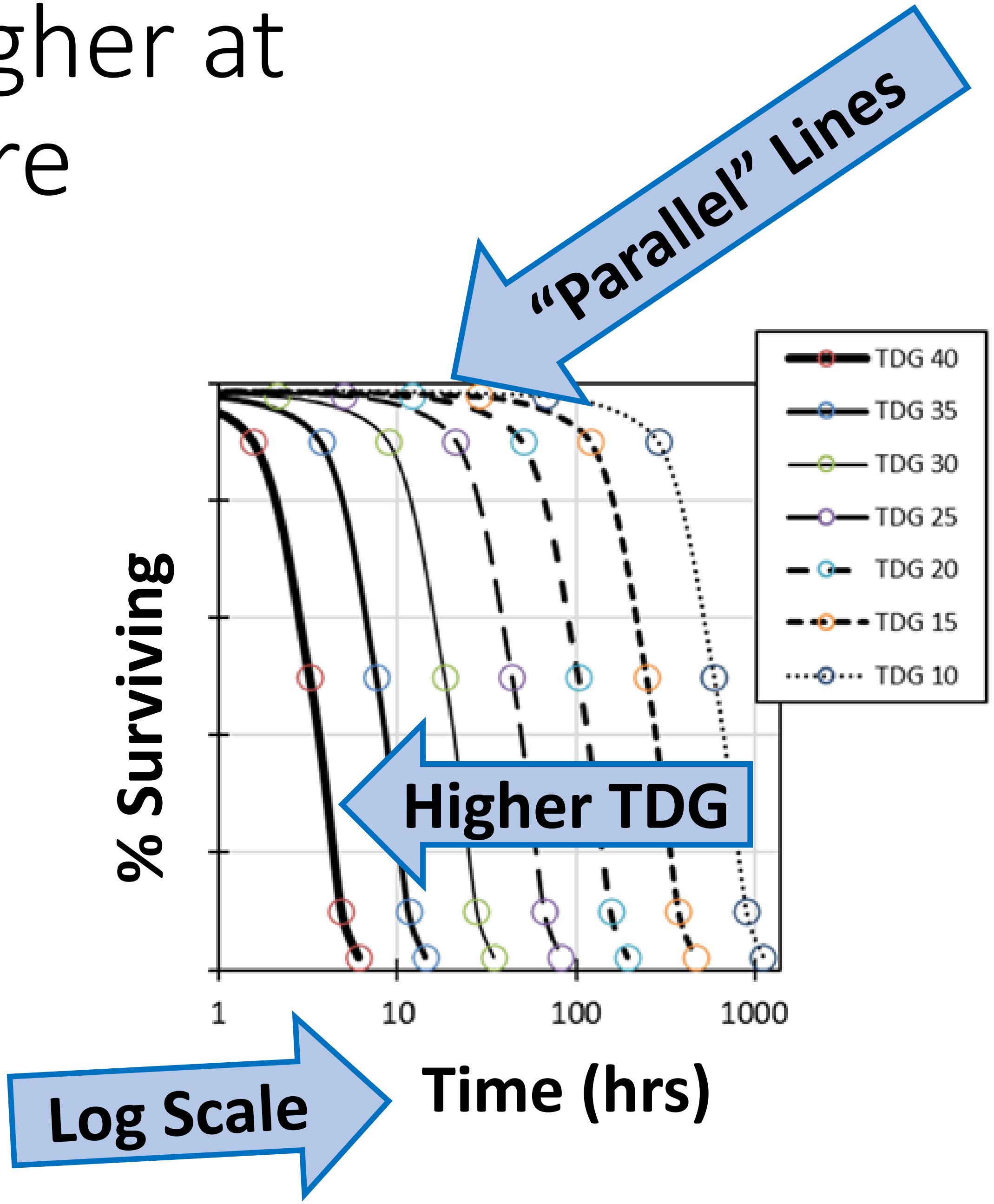
- Start with predictions from lab studies*
- Time to Gas bubbles, 10% mortality, 50% Mortality*



*Pleizier et al. 2020

Predicted Survival is higher at low TDG, short exposure



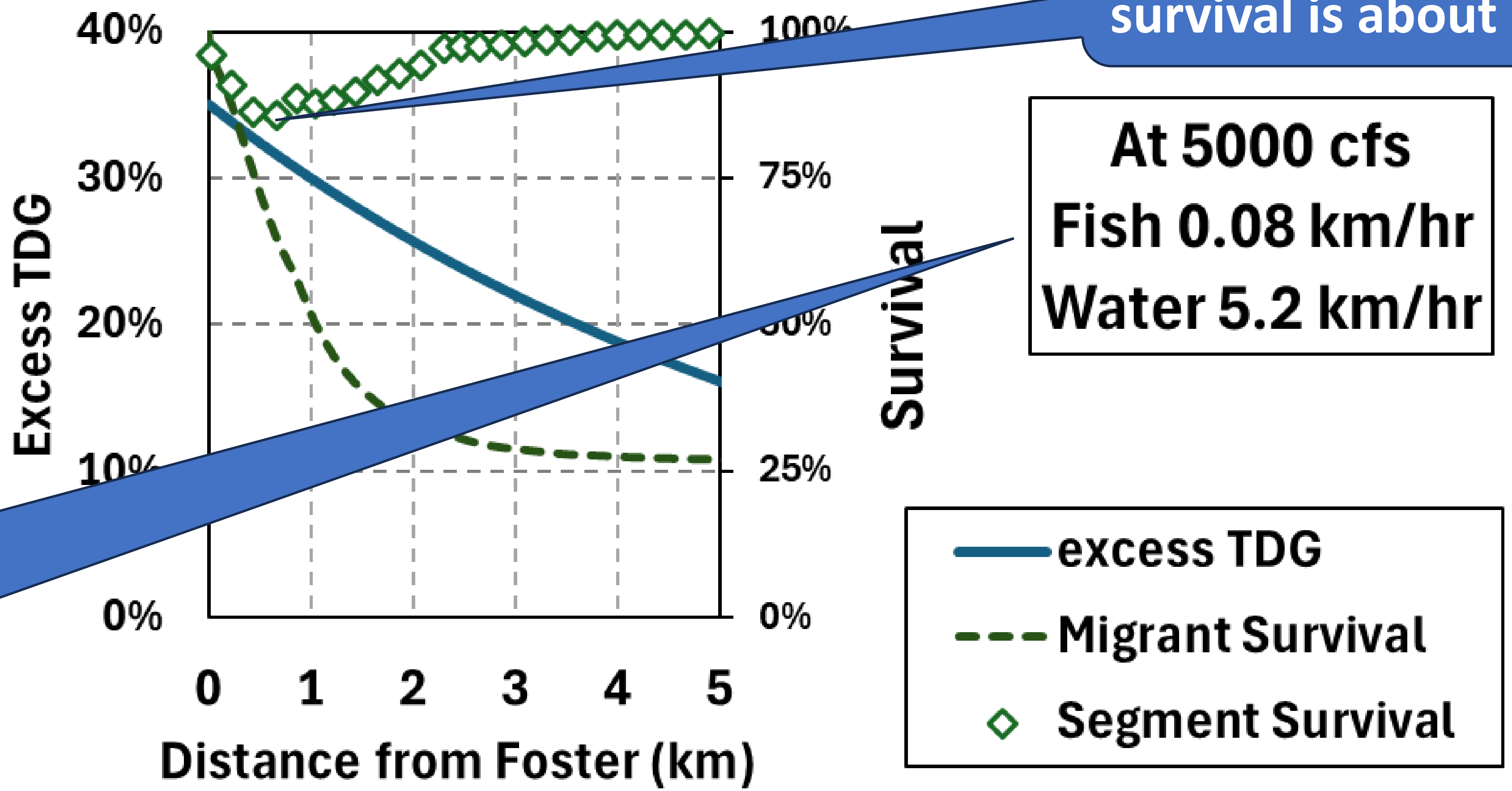


South Santiam: Survival under a single set of conditions

- **Segment Survival** is estimated from TDG and the time that it takes the fish to pass through the segment (i.e. exposure time)

Minimum Segment survival is about 80%

Migrant survival is the product of the segment survivals



If the fish are not moving slowly, exposure times are not long enough to lower survival

Survival across a range of conditions

- Survival is low only when:

Fish migration rate is very slow; Water velocity is high; Excess TDG is >20%

Survival (Foster to Waterloo, 23 km)

South Santiam Foster to Waterloo

Discharge (cfs)	Water Velocity (m/s)	Slow (Fish Velocity 0.007 m/s), Excess TDG (%) 20	25	30	35	Med (Fish Velocity 0.014 m/s), Excess TDG (%) 20	25	30	35	Faster (Fish Velocity 0.028 m/s), Excess TDG (%) 20	25	30	35
400	0.61	96%	95%	90%	63%	98%	98%	97%	91%	99%	99%	99%	97%
600	0.69	95%	93%	85%	40%	98%	97%	95%	85%	99%	[illegible]	8%	95%
900	0.81	95%	91%	76%	13%	98%	97%	93%	75%	99%	[illegible]	7%	93%
1,400	0.94	93%	87%	58%	1%	97%	95%	89%	57%	99%	[illegible]	6%	89%
2,200	1.11	91%	79%	30%	0%	97%	93%	82%	29%	99%	97%	94%	82%
3,500	1.28	87%	64%	5%	0%	95%	90%	68%	5%	98%	96%	91%	68%
5,500	1.47	79%	39%	0%	0%	94%	84%	44%	0%	98%	95%	86%	44%
8,700	1.72	65%	10%	[illegible]	[illegible]	91%	73%	14%	0%	97%	92%	76%	14%
13,700	1.97	41%	0%	[illegible]	[illegible]	85%	53%	1%	0%	95%	88%	57%	1%

High Survival

Low Survival

Survival across a range of conditions

- Survival is higher in the North Santiam because TDG dissipates more rapidly, which shrinks the danger zone

South Santiam

Water Velocity (m/s)	Survival (Foster to Waterloo, 23 km)				
		Excess TDG (%)		**Fish** Velocity	**0.015 m/s**
	Discharge (cfs)	**20**	**25**	**30**	**35**
0.53	**500**	98%	98%	96%	88%
0.61	**800**	98%	97%	94%	82%
0.75	**1,100**	98%	96%	92%	72%
0.89	**1,700**	97%	95%	88%	55%
1.06	**2,400**	97%	94%	82%	32%
1.25	**3,600**	96%	91%	72%	9%
1.50	**5,300**	95%	87%	55%	1%
1.81	**7,700**	93%	80%	31%	0%
2.14	**11,300**	90%	69%	8%	0%

North Santiam

	Survival (Big Cliff to 23 km)				
water velocity		Excess TDG (%)		**Fish** Velocity	**0.015 m/s**
1.86	Discharge (cfs)	**20**	**25**	**30**	**35**
0.86	**500**	99%	98%	98%	98%
0.97	**800**	98%	98%	98%	96%
1.14	**1,100**	98%	98%	97%	94%
1.31	**1,500**	98%	97%	96%	91%
1.47	**2,200**	98%	97%	94%	85%
1.69	**3,200**	97%	96%	92%	75%
1.94	**4,500**	97%	95%	88%	58%
2.22	**6,500**	96%	93%	82%	33%
2.56	**9,300**	95%	90%	71%	9%

Survival is High at realistic smolt migration rates

- Smolts moving at 10km/day do not stay in the high TDG zone for long
  - Migration rates are faster at high discharge in the Columbia (Berggren & Filardo 1993)
  - High TDS zones are much longer in larger rivers and in reservoirs

Survival (Foster to Waterloo, 23 km) — **Fish Velocity 0.015 m/s**

Water Velocity (m/s)	Discharge (cfs)	Excess TDG (%) 20	25	30	35
0.53	500	98%	98%	96%	88%
0.61	800	98%	97%	94%	82%
0.75	1,100	98%	96%	92%	72%
0.89	1,700	97%	95%	88%	55%
1.06	2,400	97%	94%	82%	32%
1.25	3,600	96%	91%	72%	9%
1.50	5,300	95%	87%	55%	1%
1.81	7,700	93%	80%	31%	0%
2.14	11,300	90%	69%	8%	0%

10 km/day

Survival (Foster to Waterloo, 23 km) — **Fish Velocity 0.116 m/s**

Discharge (cfs)	Excess TDG (%) 20	25	30	35
500	100%	100%	100%	99%
800	100%	100%	99%	99%
1,100	100%	100%	99%	99%
1,700	100%	100%	99%	98%
2,400	100%	99%	99%	98%
3,600	100%	99%	99%	97%
5,300	100%	99%	98%	96%
7,700	99%	99%	98%	94%
11,300	99%	99%	97%	92%

Other Considerations in TDG Survival Modeling

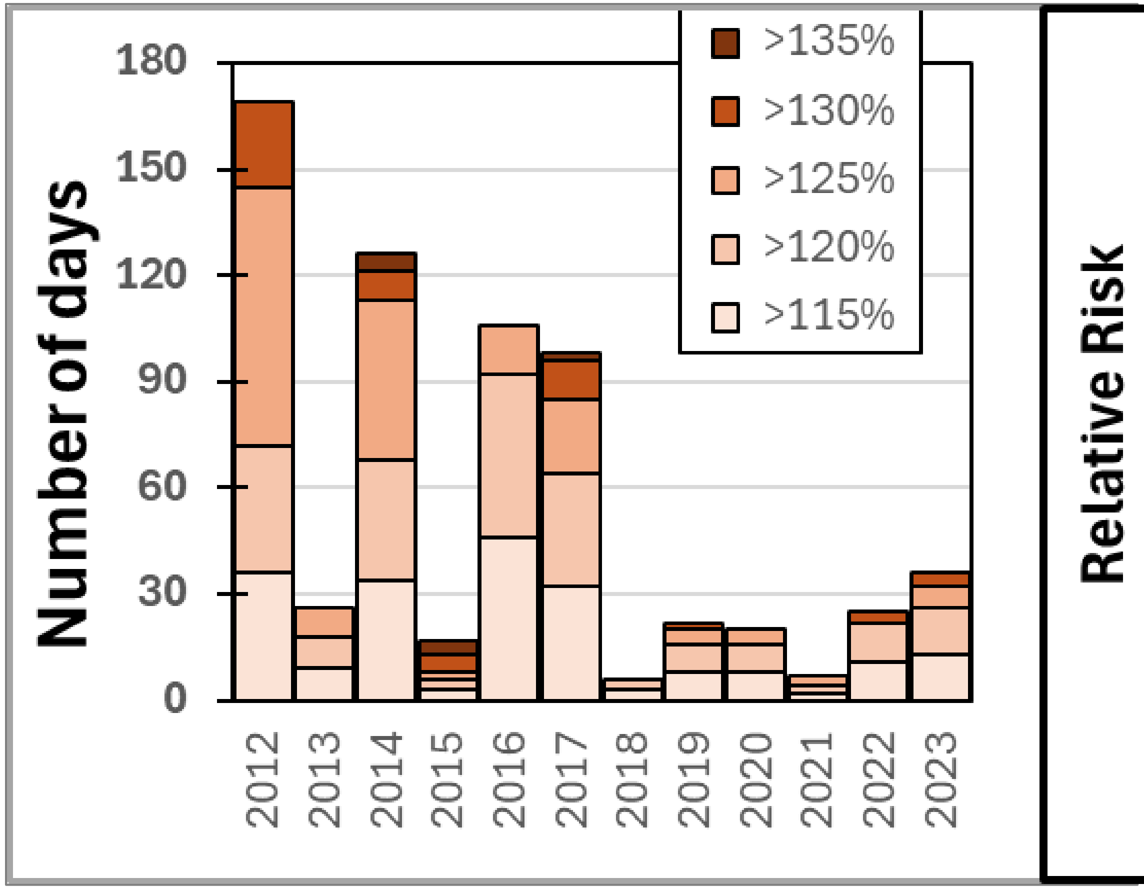
- Mitigating factors
  - Depth compensation: relatively shallow depths (2-3m) give full protection
  - Seasonal timing of high TDG events vs Smolt migration
- Prior Exposure
  - Fish moving through high TDG reservoirs accumulate TDG asymptomatically
  - Bubbles can start forming as shortly after entering the tailwater
  - Mitigating factors become an important consideration
- Fish rearing in tailwaters
  - Given enough time, even low levels of TDG (110-120%) produce high mortality
  - The danger zone is areas <2-3m deep at the tailrace, sloping to zero at 5-10 km
  - Buried eggs are at the least risk (depth compensation, eggshell pressure)
  - The duration of high TDG events becomes an important consideration

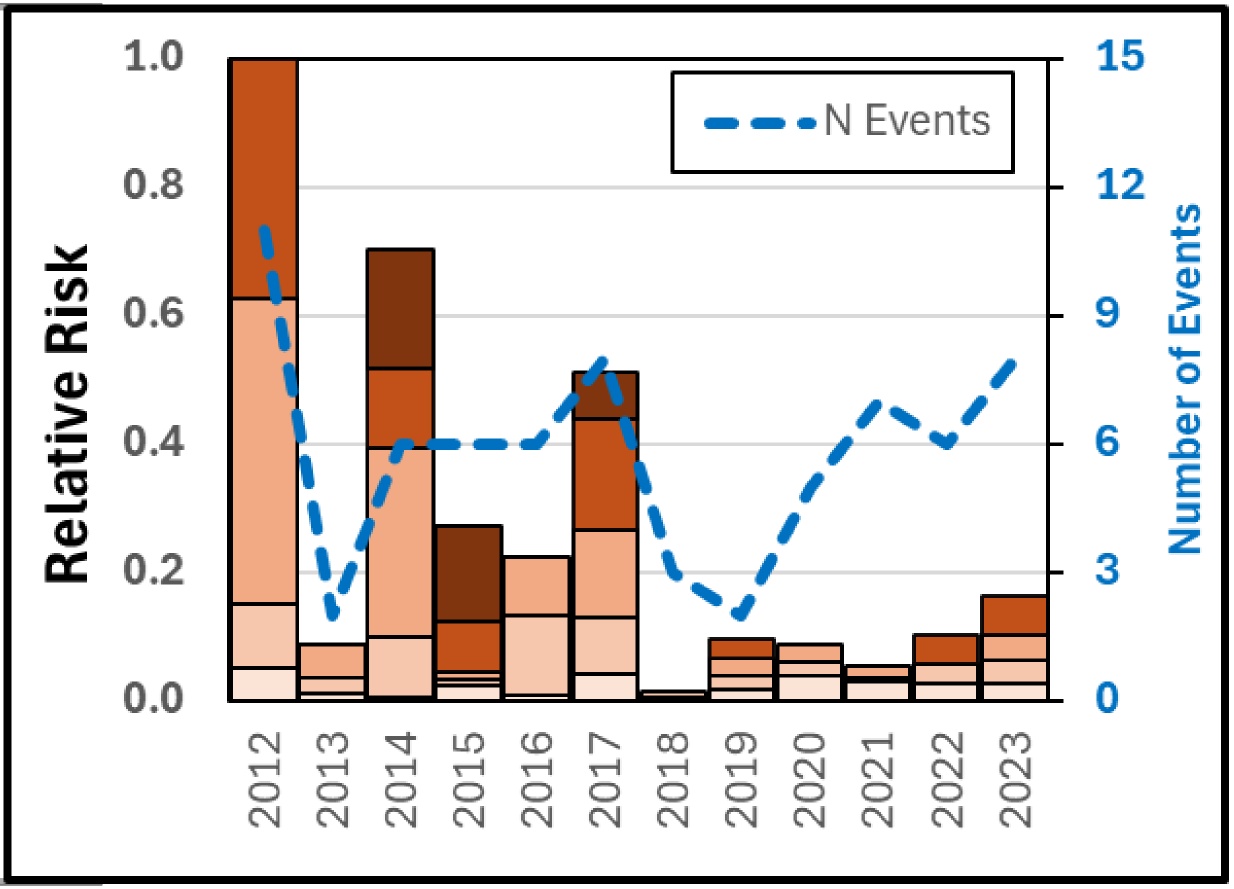
TDG and Relative Risk

- The mortality functions can be used to convert TDG to “Relative Risk”

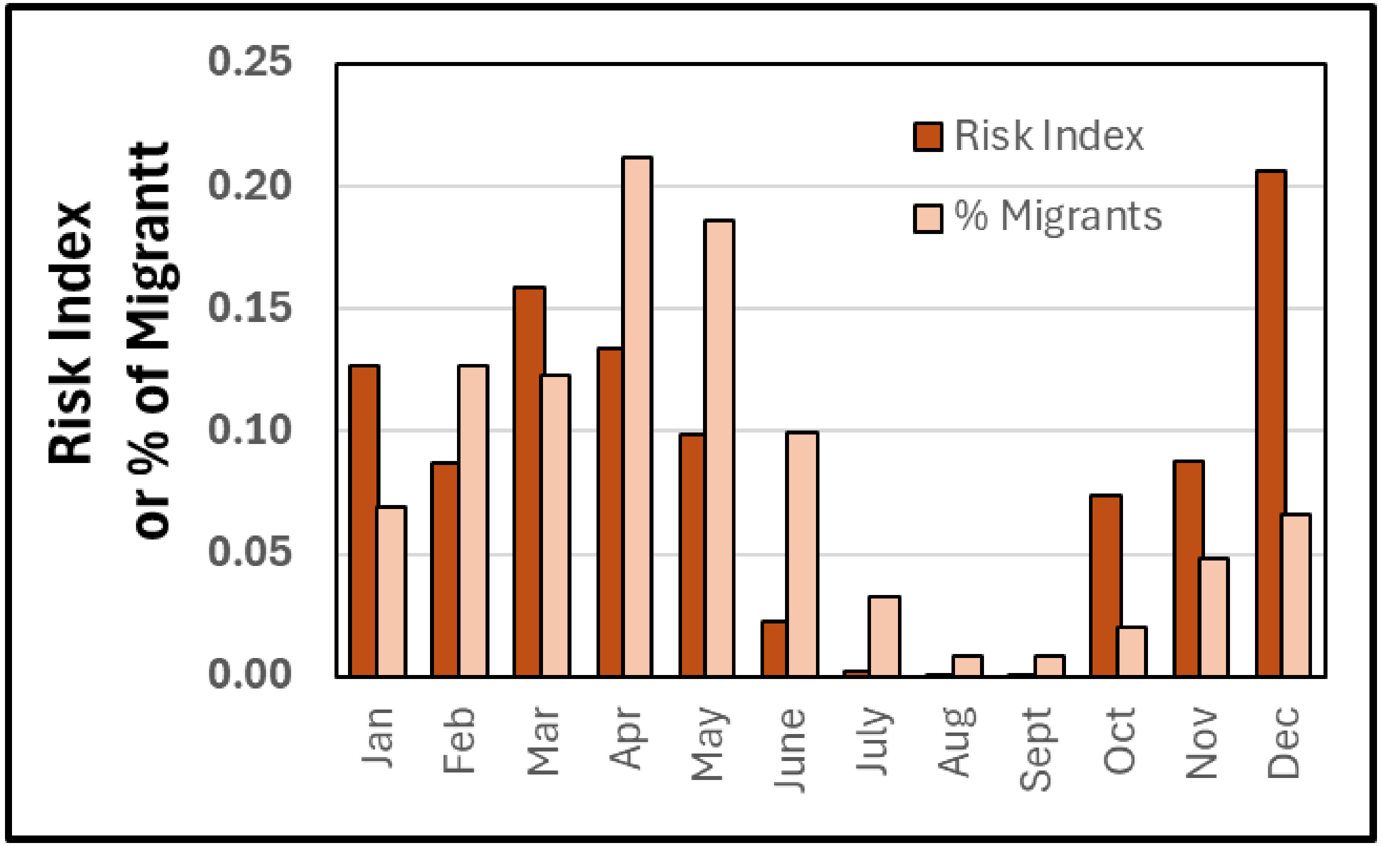
A mortality estimate requires more details on discharge, fish behavior, etc.

Similar number of Multi day Events, but shorter, with lower mortality risk





e.g. Mitigating Factor:
Seasonal Migration vs Seasonal TDG Timing



Observed Migrant Abundance*

- Migrant abundance is lower in some high risk months
- Seasonal abundance weighted by risk is 29% higher than Average abundance weighted by Risk

* At Willamette Falls Friesen et al. 2007, Schroeder et al. 2016

Conclusions

- TDG does not appear to be an issue for Chinook or Steelhead migrants in either the N or S Santiam.
  - Migrating fish must keep moving but the required movement rates are well within estimated movement rates of both Chinook and Steelhead smolts
  - High TDG loads acquired in reservoirs prior to dam passage may be an issue
    - Reabsorption of bubbles is relatively rapid (hours, Hans et al 1999, Elston et al. 1997)
    - Bubble formation is slower
    - It is not clear if the amount of dissolved gas stored in a fish at the time of passage is sufficient to generate significant volume of bubbles
- The potential for TDG mortality in rearing/developing fish depends on mitigating factors (seasonal timing, depth compensation)
  - The overlap between the high TDG zone and the quality and quantity of freshwater habitat can be mapped and quantified

Next steps

- Integrate TDG mortality into the life cycle model as a component of juvenile mortality
  - Includes integrating the TDG mortality model from the RST data analysis
  - Resolve the unexpected negative relation of mortality vs TDG in the RST data
- Expected %TDG X Discharge X Season for each operational scenario is the key data input requirement
- Mitigating factors will need to be quantified if significant mortality is predicted for rearing fish
- The "Prior Exposure" methodology requires additional validation*

* Velázquez-Wallraf et al. 2022