# Methods

## Stryke

Kleinschmidt assessed whole project passage survival with the open source software package stryke[[1]](#footnote-1). Stryke is an individual based model (IBM), which follows the fate of a population of fish as they migrate past a hydroelectric project. Movement and survival are simulated with Monte Carlo methods. The software is written in Python 3.7.x and utilizes SQLite[[2]](#footnote-2) for data management, Networkx[[3]](#footnote-3) to simulate routes of passage, and Numpy[[4]](#footnote-4) for pseudo-random probability distribution draws. Kleinschmidt has validated stryke with the USFWS blade strike simulation tool[[5]](#footnote-5)

Fish move through a hydroelectric project where migratory routes are described with a directed acyclic graph. Fish are obligated downstream migrants. If fish survive their current node, they can move to the next one in the graph. If there is more than one node available at their current location, then a Monte-Carlo role of the dice and *a priori* determined transition probabilities control their movement. The simulation ends for a fish when it arrives at the last node in the migratory network or dies.

For fish passing via entrainment, individuals are exposed to turbine strike, which is modeled with the Franke et. al. 1997 equations. For fish that pass via passage structures or spill, mortality is assessed with a roll of the dice using survival metrics determined *a priori*, sourced from similar studies, or via expert opinion. The Franke et al. equations calculate the probability a fish of a given length will get struck by a turbine runner blade. Essentially, if we know how long a given fish is, the velocity of the water as it travels through the turbine, the type of turbine, how many blades and how fast it is rotating, we can calculate, with certainty, the probability of being struck. For simplicity, we assume that all blade strikes result in death.

## Turbine Parameters

The blade strike models derived by Franke et al. (1997) require accurate measurements of a suite of turbine parameters. The generating units at the Project are reversable Francis turbines of similar design. Required inputs for the blade strike model include: rated turbine head (ft), estimated maximum discharge (cfs), discharge at maximum efficiency (cfs), percent discharge at maximum efficiency, runner speed (rotations per minute, rpm), runner diameter (in), runner diameter at the inlet/centerline/discharge (in), runner inlet height (in), number of blades, turbine efficiency (nameplate). These parameters (Table 1) were used to develop an initial blade strike model for a suite of species at Banks Lake.

Table 1 Banks Lake Unit Parameters

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Symbol** | **Value** |
| Rated Turbine Head (ft) |  | 360 |
| Max. Discharge (cfs) |  | 7,513 |
| Efficient Discharge (cfs) |  | 7,062 |
| Percent Discharge at Max. Efficiency |  | 94% |
| Runner Speed (rpm) |  | 150 |
| Runner Diameter at Inlet/Centerline (in) |  | 228 |
| Runner Diameter at Discharge (in) |  | 181 |
| Runner Inlet Height (in) |  | 44 |
| Number of Blades |  | 9 |
| Turbine Efficiency |  | 93.5% |

## Migratory Routes and Movement

The Banks Lake Pumped Storage project is not a traditional hydroelectric generating station. The simulated fish are not downstream obligated migrants, they do not have to migrate past the intake facility, thus the overall probability of entrainment is low, and the overall effect on the population will be low as well. However, stryke is still an effective tool to assess the survival of organisms who are entrained, which is of interest to stakeholders. The migratory network at Banks Lake is described with the following graph (Figure XX). Fish start in the lower impoundment (Lake Roosevelt, i.e. Columbia River) where they can either be entrained or they can remain in the lower impoundment. If a fish survives entrainment, it can remain in the upper impoundment or become entrained again and be exposed to turbine mortality stressors again. Since the overall rates of entrainment during pump and discharge modes is unknown, Kleinschmidt constructed a sensitivity analysis on population impacts if rates of entrainment were allowed to vary (Table XX).

Figure XX

## Node Survival

Stryke assesses survival for individual fish is at each node within the migratory network. For the lower and upper impoundment nodes, the survival probability is the nominal baseline natural survival probability, which was assumed to be XX. When a fish is entrained, survival at a turbine is assessed with the Franke et al. (1997) equations. Fish can be entrained during pumping and discharge modes of operation. For fish entrained during discharge model, the traditional Franke et al. 1997 equations were applied. The first step calculated the angle tangential of absolute flow upstream of the runner () with Equation 3:

|  |  |
| --- | --- |
|  | 1 |

where is the energy coefficient, is the turbine efficiency and is the discharge coefficient. The energy coefficient is given with Equation 4:

|  |  |
| --- | --- |
|  | 2 |

where is the acceleration due to gravity (), is the turbine net head (ft, is the rotational speed of the runner (, and is the diameter of the runner (ft). The turbine efficiency ( is given with Equation 5:

|  |  |
| --- | --- |
|  | 3 |

where is the diameter (ft) of the runner cubed. The relative flow angle () is given with Equation 6:

|  |  |
| --- | --- |
|  | 4 |

where is the turbine discharge at best efficiency () and is the ratio between discharge (Q) with no exit swirl and . A value of 1.1 for was used as suggested by Franke et al. (1997). Finally, the probability of mortality from blade strike during discharge model is given with Equation 7:

|  |  |
| --- | --- |
|  | 5 |

Where is a strike mortality correlation factor, is the number of buckets, and is the length of the fish (ft). A correlation factor (λ) was utilized in the Advanced Hydro Turbine (Franke et al. 1997) model to adjust the predictive model results to correspond with documented empirical results. This correlation factor was originally introduced by Von Raben (cited by Bell 1981) because the contact of a fish with a turbine component does not always result in injury or mortality (Bell 1981; Cada 1998). Therefore, Von Raben introduced the correlation factor to adjust the predicted turbine strike results to more closely match empirical results. This factor also extends the applicability of these predictive equations to all injury mechanisms related to the variable NL/D (see above for definition of parameters). As stated in Franke et al. (1997) "*such mechanisms could include mechanical mechanisms leading edge strike and gap grinding as well as fluid induced mechanisms related to flow through gaps or other flow phenomena associated with blades.*" Based on a substantial number of test results obtained from studies conducted with salmonids on the west coast, Franke et al. (1997) recommends that the correlation factor be set between 0.1 to 0.2, and we used 0.2 as a conservative estimate.

For those fish entrained during pumping mode, the following formula were used to calculate the probability of blade strike. This reformulation reapplies the basics of Franke et al. equations and is expected to have a reasonably high level of accuracy. We first calculate a new pump discharge coefficient ( with:

|  |  |
| --- | --- |
|  | 6 |

where is the pump discharge. Then, we substitute equation 7 for equation 4 to calculate the relative flow angle at turbine discharge (pump inlet) is given with:

|  |  |
| --- | --- |
|  | 7 |

Where is the relative flow angle at turbine discharge. Then, we can calculate the probability of turbine strike mortality () during pump operation with:

|  |  |
| --- | --- |
|  | 8 |

Where is the mean diameter of the runner at turbine discharge.

## Simulation

Isha – please describe simulation

# Results

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1. <https://github.com/knebiolo/stryke> [↑](#footnote-ref-1)
2. <https://www.sqlite.org/index.html> [↑](#footnote-ref-2)
3. <https://networkx.github.io/> [↑](#footnote-ref-3)
4. <https://numpy.org/> [↑](#footnote-ref-4)
5. <https://www.fws.gov/northeast/fisheries/fishpassageengineering.html> [↑](#footnote-ref-5)