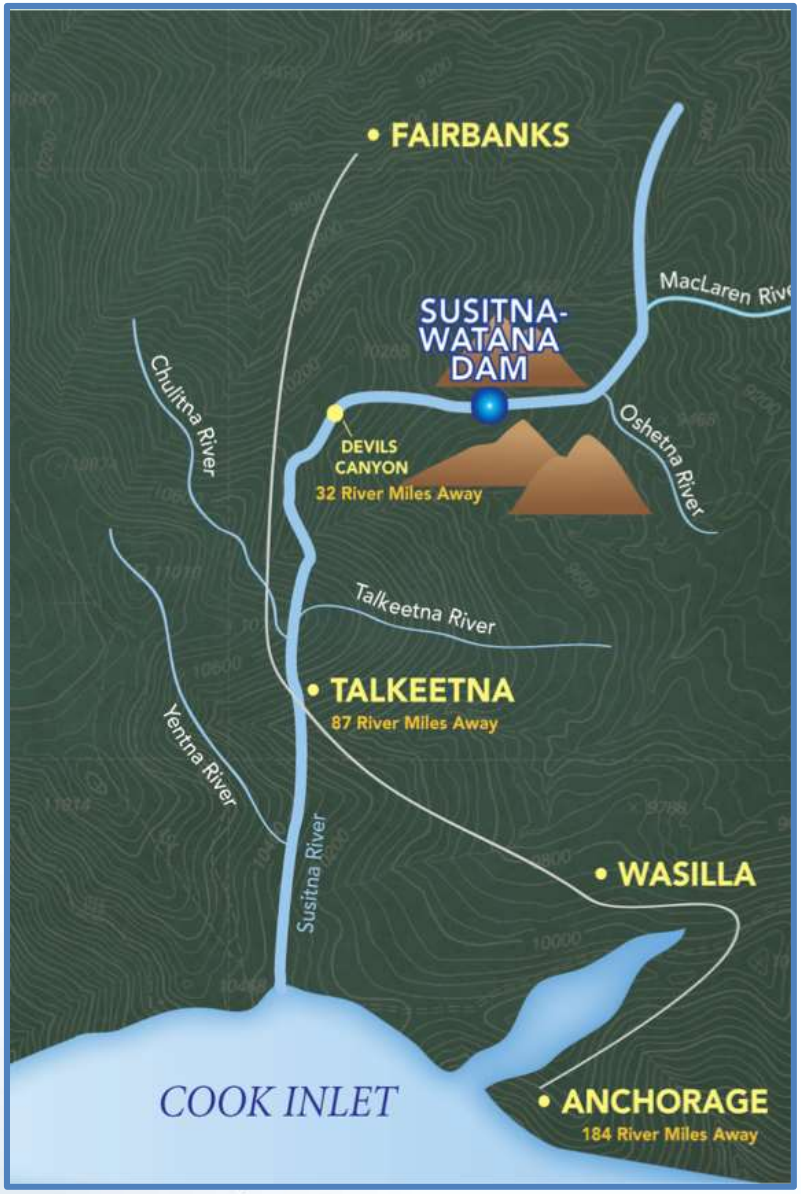

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Fisheries Technical Meeting

Study 9.12 Fish Passage Barriers

December 2, 2014

Prepared by
R2 Resource Consultants

Fish Passage Barrier Assessment Topics

- Target/priority fish species selection (ISR Part A, Section 4.1; 4)
- Species-specific passage criteria (depth, velocity and leaping ability) for individual fish species (ISR Part A, Section 4.2; 6)
- Application of passage criteria in Focus Areas to evaluate current limits of fish habitat access and potential changes with Project conditions (ISR Part A, Section 4.4; 8)

9.12 Fish Passage Barriers – Objectives

- Locate and categorize all existing fish passage barriers located in selected tributaries in the Middle and Upper Susitna River
- Locate, identify the type (permanent, temporary, seasonal, partial), and characterize the physical nature of existing fish barriers within the Project's Zone of Hydrologic Influence (ZHI)
- Evaluate potential changes to existing fish barriers within the Project's ZHI
- Evaluate the potential creation of fish passage barriers within existing habitats (tributaries, sloughs, side channels, off-channel habitats) related to future flow conditions, water surface elevations, and sediment transport

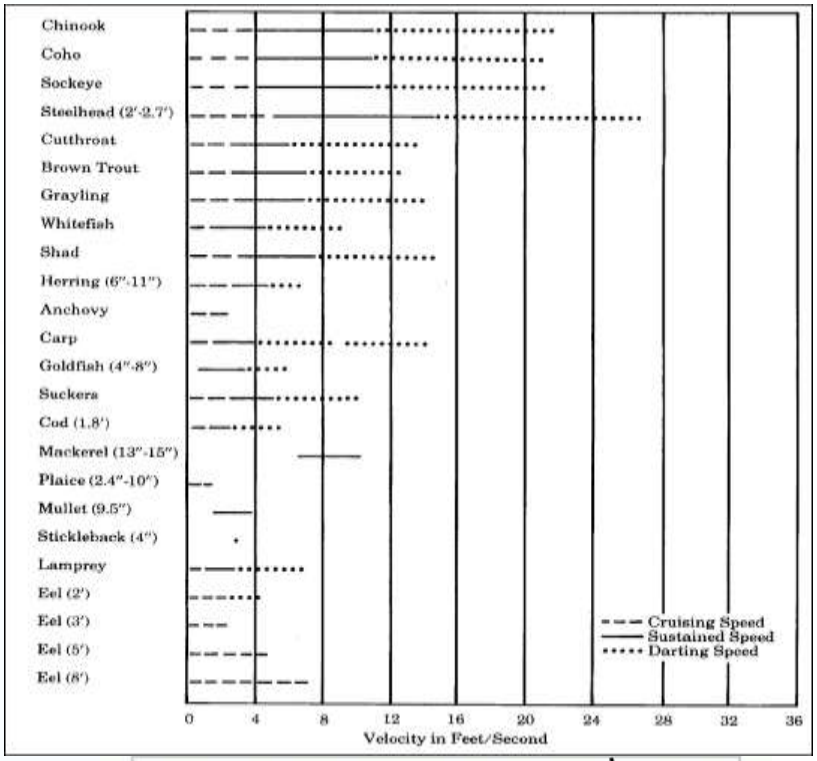
Susitna Fish Species
Arctic grayling
Dolly Varden
Humpback whitefish
Round whitefish
Burbot
Longnose sucker
Sculpin
Eulachon
Bering cisco
Threespine stickleback
Arctic lamprey
Chinook salmon
Coho salmon
Chum salmon
Pink salmon
Sockeye salmon
Rainbow trout
Northern pike
Lake trout

Target Species Selection

- 9.12 Study Plan - select same species or a sub-set of those selected for IFS Study 8.5
- Apply same 3 criteria for target fish species selection from Study 9.11 (Fish Passage Feasibility Study):
  - ***Exhibits migratory and/or anadromous behavior*** most significant for species for which migration is necessary to complete its life cycle.
  - ***High relative abundance***
  - ***Important to commercial, sport, or subsistence fisheries***

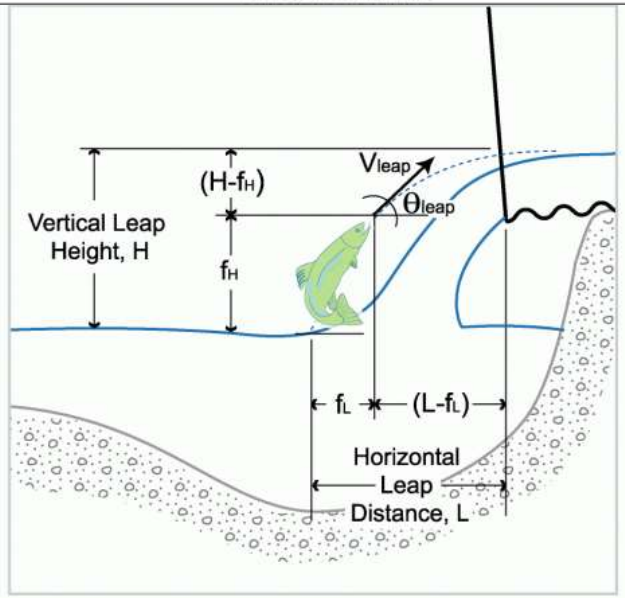
Final Species List

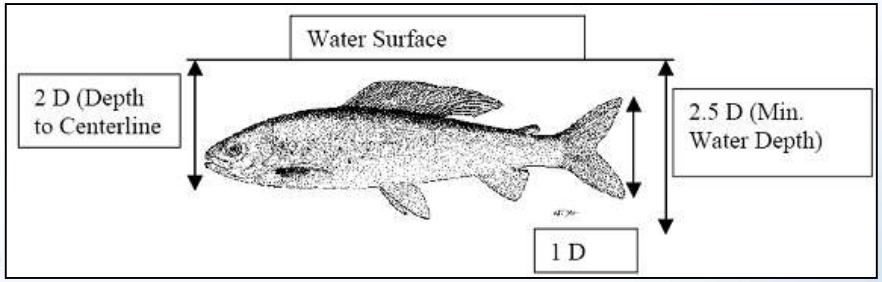
AEA Proposed Species List	Additional Species Suggested by Licensing Participants	Species List Following Consultation
Chinook salmon	Arctic lamprey	Chinook salmon
Chum salmon	Bering cisco[1]	Chum salmon
Coho salmon	Eulachon[1]	Coho salmon
Pink salmon	Northern pike[1]	Pink salmon
Sockeye salmon	Humpback whitefish	Sockeye salmon
Arctic grayling		Arctic grayling
Burbot		Arctic lamprey
Dolly Varden		Burbot
Rainbow trout		Dolly Varden
		Humpback whitefish
		Rainbow trout
[1] Species not added due to absence from study area		



Passage Criteria for Identified Fish Species

- Upstream ***Velocity*** Criteria
- ***Leaping*** Criteria for Adult Upstream Migration
- ***Depth*** Criteria for *Upstream* Adult Migration and *Downstream* juvenile and resident seasonal movement





Velocity Criteria

Category	Period	Definitions
Sustained speed	> 200min	Maintained indefinitely w/o fatigue, purely aerobic
Prolonged speed	20s to 200min	Short periods of travel at high speeds, aerobic to anaerobic
Burst speed	< 20s	Max swimming speed or jumping, inducing fatigue, anaerobic

U_{crit} (critical swimming speed) max swimming speed a fish can maintain for a period of time (e.g. 10min, 20min, …) under laboratory conditions. Top end of prolonged speed/aerobic range. Useful for understanding fish passage through culverts

- **Prolonged** swimming and **U_{crit}** indicative of fish ability to travel long distances upstream and how fish condition may change in upper reaches of Susitna
- **Burst** swimming speed useful to understand fish movement across discrete rapids/riffles or high velocity areas

Fish Swimming Performance

SPECIES	LIFE STAGE	PROLONGED SPEED		BURST SPEED	
		ft/s	References	ft/s	References
Arctic Grayling	Adult	1.4 - 4.1	Katapodis (1992)	6.9 - 13.9	Bell (1991)
	Juvenile	0.5 - 0.8	Deegan et al. (2005)	NR	NR
Arctic Lamprey	Adult	0.2 - 0.8	*Robinson/Bayer (2005), *Clemens (2012)	2.5 to 10	*Mesa et al. (2003), *Keefer (2010)
	Juvenile	0.3 - 0.6	*Sutphin and Hueth (2010)	1.0 to 2.5	*Sutphin and Hueth (2010)
Burbot	Adult	1.3 - 2.6	Jones et al. (1974), Schwalme et al. (1985)	1.1 to 4.0	Bell (1991)
	Juvenile	1.1 - 1.3	Jones et al. (1974)	NR	NR
Dolly Varden	Adult	2.0 - 3.3	**Beamish (1980)	4.2 to 7.5	+Mesa (2004)
	Juvenile	0.5-1.6	+Mesa (2004)	NR	NR
Humpback Whitefish	Adult	1.0 - 2.3	Jones et al. (1974), Beamish (1980)	3.0 - 4.0	Bell (1991)
	Juvenile	0.2 to 1.3	Jones et al. (1974)	NR	NR
Chinook salmon	Adult	2.9 - 11.0	Bell (1991)	11.0 - 22.1	Bell (1991)
	Juvenile	0.5 - 0.9	Furniss et al. (2008)	2.0 - 2.3	Randall et al. (1987)
Coho salmon	Adult	3.1 - 10.9	Lee et al. (2003)	11.7 - 21.0	Bell (1991)
	Juvenile	0.4 - 2.1	Bell (1991)	NR	NR
Chum salmon	Adult	1.7 - 5.1	Aaserude and Orsborn (1985)	6.0 - 12.6	Powers and Orsborn (1985)
	Juvenile	0.4 - 0.6	Smith and Carpenter (1987)	NR	NR
Pink salmon	Adult	2.9 - 11.0	Lee et al. (2003), Bell (1991)	11.0 – 21.0	Bell (1991)
	Juvenile	0.4 - 0.5	Smith & Carpenter 1987	7.7 – 11.0	Powers & Orsborn (1985)
Sockeye salmon	Adult	4.0 – 8.8	Bell (1991)	10.0 - 21.9	Bell (1991), Bainbridge (1960)
	Juvenile	1.4 - 2.1	Bell (1991)	NR	NR
Rainbow trout	Adult	2.1 - 2.6	Furniss (2008)	14.0 - 20.3	Bell (1991)
	Juvenile	1.0 - 2.0	Bainbridge (1960)	2.4 - 7.2	Bainbridge (1960)

*for Pacific Lamprey , **for Arctic Char, +for Bull Trout, *NR = no reference available*

Velocity Criteria (cont)

- Swimming speed proportional to fish length

  Adult speed > Juvenile speed
- Gradients or channel constrictions at entrances to sloughs and side channels not sufficient to create velocity barriers for adult or juvenile fish
- Velocity barriers most likely a factor in tributaries where steep gradients create uniform, high velocity flows in chutes and waterfalls and at tributary mouths before entering the main channel
- Which swimming speed category best represents limitations for fish passage in Susitna River and its tributaries?

Criteria Suggestion - high-end prolonged speed and burst speed represent the fish speeds required to attain chutes and waterfalls in major tributaries

Hunter and Mayor (1998)
Swim Speed Equation

$$V = aL^{b}t^{-c}$$

V = swim speed of fish relative to the water
L = length of the fish
t = time to exhaustion
a,b,c = regression constants

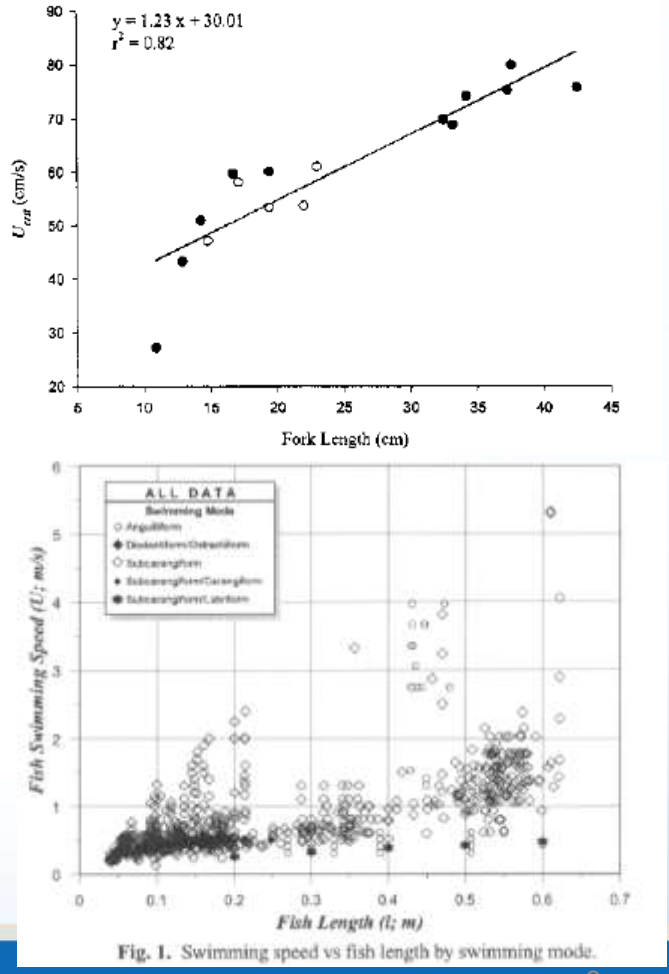


Fig. 1. Swimming speed vs fish length by swimming mode.

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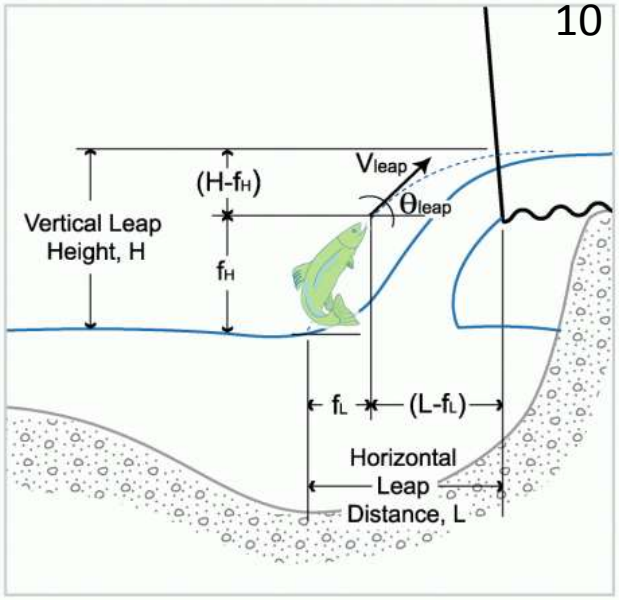
Leaping Criteria

- Ability of fish to pass a vertical barrier is determined by:
  - species- and life stage-specific factors such as burst speed, swimming form, and leaping capability.
  - water depth, stream flow, and barrier geometry
- Leaping curves and jumping equations assume pool depth below barrier is adequate
  - 1:1.25 barrier height/leaping pool depth (Powers Orsborn 1985)
  - Pool depth at least 2.5m (Reiser and Peacock 1985)
- Other barrier considerations – stream gradient
  - See Forest Service Handbook (FSH) 2090.21 Adult Salmonid Migration Blockage Table.



USFS Fish Xing
Leaping equations

$$H = V_{leap}(\sin\theta_{leap})\ t + \frac{1}{2} g\, t^2$$

$$L = V_{leap}(\cos\theta_{leap})\ t$$

Where:
H = Vertical leap distance
L = Horizontal leap distance
Vleap = Leap velocity
θleap = Leap angle
g = Gravitational acceleration
t = Time

Leaping Criteria – literature values

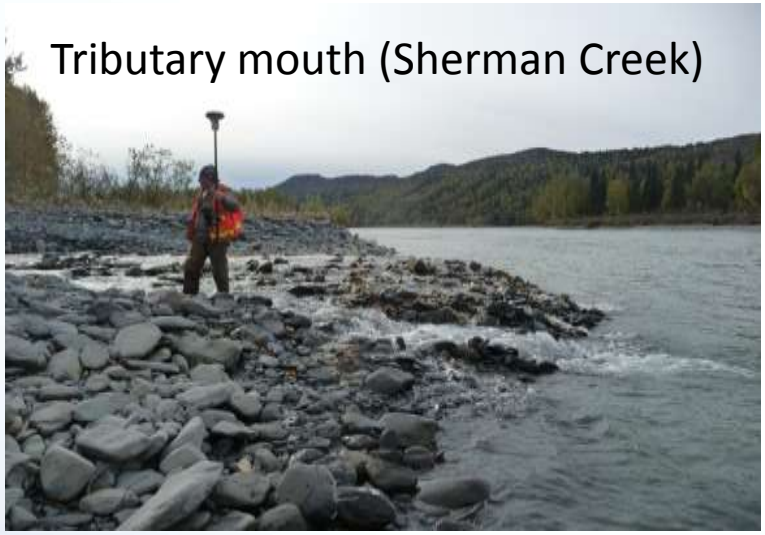
Species	Leaping Height (in feet)		
	Powers and Orsborn (1985)[1]	Reiser and Peacock (1985)	USFS (2001)
Dolly Varden	-	-	6.0
Chinook	7.5	7.9	11.0
Chum	3.5	4.0	4.0
Coho	7.5	7.3	11.0
Pink	3.5	4.0	4.0
Sockeye	7.5	6.9	10.0

Pool depth and gradient criteria

*adapted from the Forest Service Handbook (FSH) 2090.21 Adult Salmonid Migration Blockage Table.

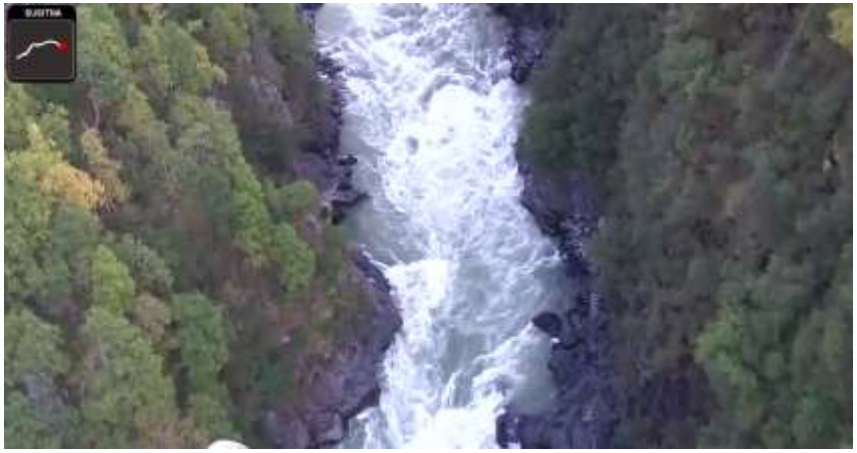
	Species				
Criterion	**Chinook**	**Coho**	**Sockeye**	**Pink/Chum**	**Dolly Varden**
Pool depth A blockage may be presumed if pool depth is less than the following, and the pool is unobstructed by boulders or be bedrock:	1.25 x jump height, except that there is no minimum pool depth for falls: (a)<4 feet (1.2,) in the case of coho and steelhead; and (b)<2 feet (0.6m) in the case of other anadromous fish species.				
Steep channel A blockage may be presumed if channel steepness is greater than the following without resting places for fish:	>225 feet (68.6m) @ 12% gradient >100 feet (30.5m) @ 16% gradient >50 feet (15.2m) @ 20% gradient			>100 feet (30.5m) @ 9% gradient	>50 feet (15.2m) @ 30% gradient

Dynamic Barriers



Velocity Barriers – Devils Canyon

passage of adult salmon addressed by Study 9.7 (Salmon Escapement)



Impediment 1 (PRM 154.8) – Sept 11, 2012
11,600 cfs at Gold Creek
8,840 cfs at Tsusena

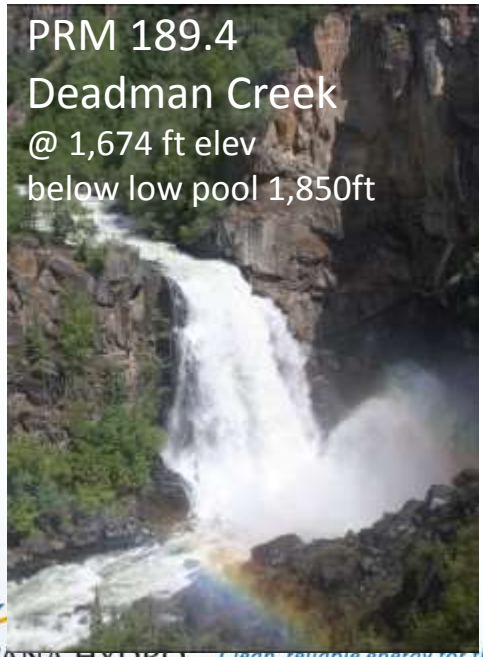
Impediment 3 (PRM 164.5) - Sept 7, 2012
16,500 cfs at Gold Creek
11,800 cfs at Tsusena

- Movement of radio tagged fish will be compared to discharge during spawning period by the Salmon Escapement Study 9.7
- *2012 results - 12 Chinook passed through impediment 3*
- *2013 results - 3 Chinook passed through impediment 3*
- *2014 results – 2 Chinook passed through impediment 3*

Study 9.12 Summary of Results in ISR (ISR Study 9.12, Part A – Section 5)

Middle and Upper River Vertical Barriers surveyed in 2012

- 72 potential barriers surveyed in 2012
- 38 confirmed as barriers to fish passage due to height, greater than 12 ft
- 3 tributaries with barriers that will be inundated, below max pool elevation 2,050 ft



Depth Criteria

- A minimum depth may be chosen that a fish species can successfully swim through (Furniss 2008),
- or a minimum depth may be considered that is required to fully submerge the species (Powers and Orsborn 1985).
- In other studies, a body depth plus an additional depth to account fish behavior, injury prevention or substrate composition is suggested (e.g. 2.5 times the caudal fin depth; ADFG (2001)).
- Overall, minimum depth varies with fish size and life stage. A range of minimum depth criteria from the literature for selected fish species and life stages are presented in depth criteria table (table 5-2 in TM)

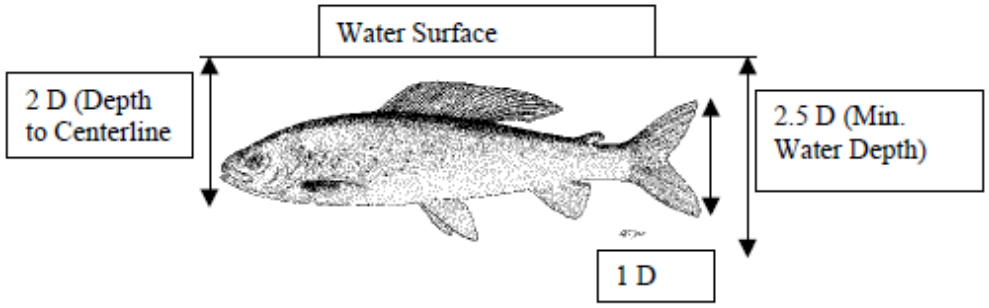


Figure A-2. Minimum water depths for fish passage (D = height of caudal fin).

Depth Criteria – literature values

SPECIES	LIFE STAGE	DEPTH CRITERIA	
		Ft	References
Arctic grayling	Adult	0.6	ADFG (2001)
	Juvenile	0.4	ADFG (2001)
Dolly Varden	Adult	0.2 - 1.0	ADFG (2001)
	Juvenile	0.2	Bugert et al. (1991)
Chinook salmon	Adult	0.8 - 0.9	CDFG (2013), Thompson (1972)
	Juvenile	0.3	CDFG (2013)
Coho salmon	Adult	0.6 - 0.7	CDFG (2013), Thompson (1972)
	Juvenile	0.3	CDFG (2013)
Chum salmon	Adult	0.6 - 0.8	CDFG (2013), Thompson (1972),
	Juvenile	0.3	CDFG (2013)
Pink salmon	Adult	0.6 - 0.8	CDFG (2013), Thompson (1972),
	Juvenile	0.3	CDFG (2013)
Sockeye salmon	Adult	0.6 – 0.7	Bates et al. (2003)
	Juvenile	0.3	CDFG (2013)
Rainbow trout	Adult	0.5 - 0.7	Snider (1985), CDFG (2013)
	Juvenile	0.3	CDFG (2013)

Example of Potential Depth Barrier

Whisker Slough Mouth
at FA-104 (Whiskers Slough)

upstream view

downstream view

July 18 2013, Susitna R at Gold Creek 16,000-20,000 cfs

Passage Criteria and Fish Abundance/Habitat Use

- Fish **abundance** and **habitat** use considerations
  - Upper River
    - Arctic Grayling (all habitats; MC,SC,BW, CWP, SS)
    - Chinook and Dolly Varden - less abundant
  - Middle River
    - Tributaries – Chinook, Coho, Chum, Pink
    - Sloughs – Chum, Sockeye, some Pink
    - Side Channel/Mainstem - limited use by Chum, Coho, Sockeye

- **Periodicity** – adult anadromous migration, and resident/juvenile migrations

- ***Leaping*** and ***Velocity*** criteria –tributary vertical barriers and mouths

- ***Depth*** Criteria – Focus Areas and Tributary Mouths
  - Upstream – adult anadromous migration
  - Downstream – anadromous juvenile and migratory resident movement between summer rearing and overwintering habitats

Study 9.5/9.6 FDA Adult and Juvenile Resident Fish Counts by Macrohabitat 2013

Macrohabitat	Dolly Varden	Burbot	Arctic grayling	Rainbow trout
	Upper River			
Black River		11	108	
Clearwater Plume		18	17	
Goose Creek			1502	
Jay Creek	137	3	42	
Kosina Creek			180	
Main Channel		58	270	
Oshetna River		16	227	
Side Channel		3	17	
Side Slough	15		29	
Tsisi Creek			198	
Unnamed Tributary 194.8	71		16	
Upland Slough		1	19	
Watana Creek	520		1008	
	Middle River Above Devils Canyon			
Backwater	1	5	110	
Chinook Creek	63			
Clearwater Plume	2	3	299	
Fog Creek	256			
Main Channel	3	13	141	
Side Channel		6	150	
Side Slough	11	13	727	
Tributary Mouth	2	4	42	
Tsusena Creek	4		74	

Macrohabitat	Dolly Varden	Burbot	Arctic grayling	Rainbow trout
	Middle River Below Devils Canyon			
Backwater	4	38	21	4
Clearwater Plume		4	33	13
Main Channel	4	52	41	24
Side Channel	7	35	16	6
Side Slough	3	39	49	22
Side Slough Beaver Complex		19	2	6
Tributary	16	37	101	141
Tributary Mouth	27	4	49	17
Upland Slough		39	1	12
Upland Slough Beaver Complex	8	82	2	26

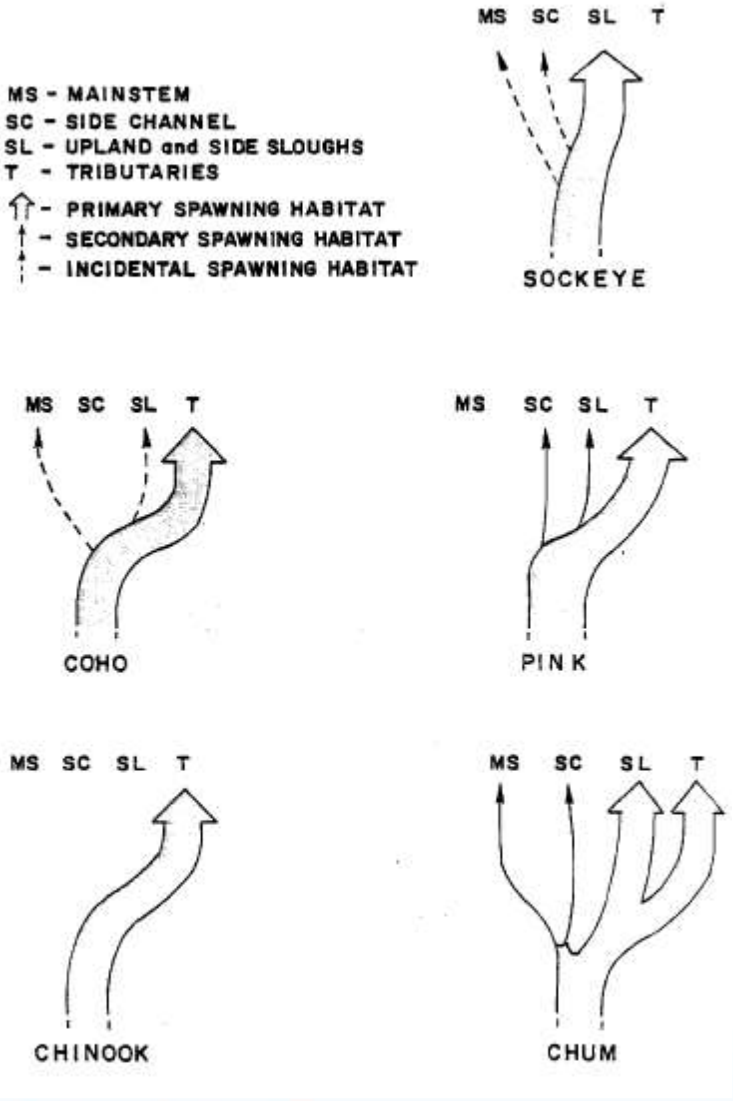
Preliminary data, may not contain all data sources, subject to QC

Study 9.5/9.6 FDA Juvenile Anadromous Fish Counts by Macrohabitat 2013

Macrohabitat	Chinook	Chum	Coho	Pink	Sockeye
	Upper River				
Black River	69				
Clearwater Plume					
Goose Creek					
Jay Creek					
Kosina Creek	116				
Main Channel					
Oshetna River	2				
Side Channel					
Side Slough					
Tsisi Creek					
Unnamed Tributary 194.8					
Upland Slough					
Watana Creek					
	Middle River Above Devils Canyon				
Backwater	1				
Chinook Creek					
Clearwater Plume					
Fog Creek					
Main Channel					
Side Channel					
Side Slough					
Tributary Mouth					
Tsusena Creek					

Macrohabitat	Chinook	Chum	Coho	Pink	Sockeye
	Middle River Below Devils Canyon				
Backwater	30		104	4	98
Clearwater Plume	5		49		8
Main Channel	6		5		1
Side Channel	121	17	321		174
Side Slough	77		412	1	235
Side Slough Beaver Complex	62	4	217		992
Tributary	170	1	880		40
Tributary Mouth	12	6	309		17
Upland Slough	22		205		10
Upland Slough Beaver Complex	543	1	2947		29

Adult Anadromous Spawning by Macrohabitat 1980s



1980s periodicity and habitat observations

Common Name	Presence (p 101, Table 8.1-1)					Peak Use Period (All River) (p 83, Table S-1)					Spawning Habitat (Primary and/or Secondary) (p 105, Fig. S-1)			
	Lower River	Lower Middle	Upper Middle	Upper River	Tribs	June	July	Aug.	Sept	Oct.	Main-stem	Side Channel	Side Slough	Trib
Arctic grayling	X	X	X	X	X									
Dolly Varden	X	X	X		X									
Chinook salmon	X	X	X	X	X									1
Chinook salmon, Spawning														
Coho salmon	X	X			X									1
Coho salmon, Spawning														
Chum salmon	X	X			X						2	2	1	1
Chum salmon, Spawning														
Pink salmon	X	X			X							2	2	1
Pink salmon, Spawning														
Sockeye salmon	X	X			X	A	A B			B			1	
Sockeye salmon, Spawning						A		A B		B				
Rainbow trout	X	X			X									

Key
Off-Peak Use, Adult
Peak Use, Adult Migration
Off-Peak Use, Spawning
Peak Use, Spawning

Notes: 1st (A) and 2nd (B) run Sockeye exhibit distinct timing of adult migration and spawning, and use separate areas for spawning.

Depth Criteria Application

ADF&G (1984)

- depth x distance curves for uniform and non-uniform substrate with Chum as surrogate for salmonids 0.41 ft uniform, 0.54 ft non-uniform

Thompson (1972)

- The critical passage section of the reach is identified with a transect that follows the shallowest course from bank to bank.
- A flow is considered adequate for passage when minimum depth and maximum velocity criteria are met for at least 25 per cent of the total transect width and for a continuous portion for at least 10 percent of the total width

Passage Criteria Application

- **Integration with modeling - Focus Area**
  - Fluvial Geomorphology Study 6.5 - depth threshold magnitude and frequency with 2-D model runs including upstream/downstream velocity, hydraulic dynamics and sediment aggradation/degradation, channelization and tributary mouth barriers, formation and removal of barriers under project conditions
  - Ice Processes Study 7.6 - address juvenile fish passage during ice-cover periods with 1-D and 2-D models including ice formation and breakup; ice thickness, elevation, and blockage of off-channels and tributary deltas; passageways beneath ice and changes in ice-free areas at slough entrances

Passage Criteria Application

- **Integration with modeling – tributary barriers**
  - The 2-D model results from the Evaluating passage into tributaries will include the potential for fan growth, changes in slope and length of the tributary channel within the fan, and the location and elevation of the intersection of topset and foreset slopes.
  - This information would be combined with hydraulic and hydrologic information for the mainstem and tributary to evaluate potential with-Project changes to tributary access.

Application of Depth Criteria – 1980s depth/distance

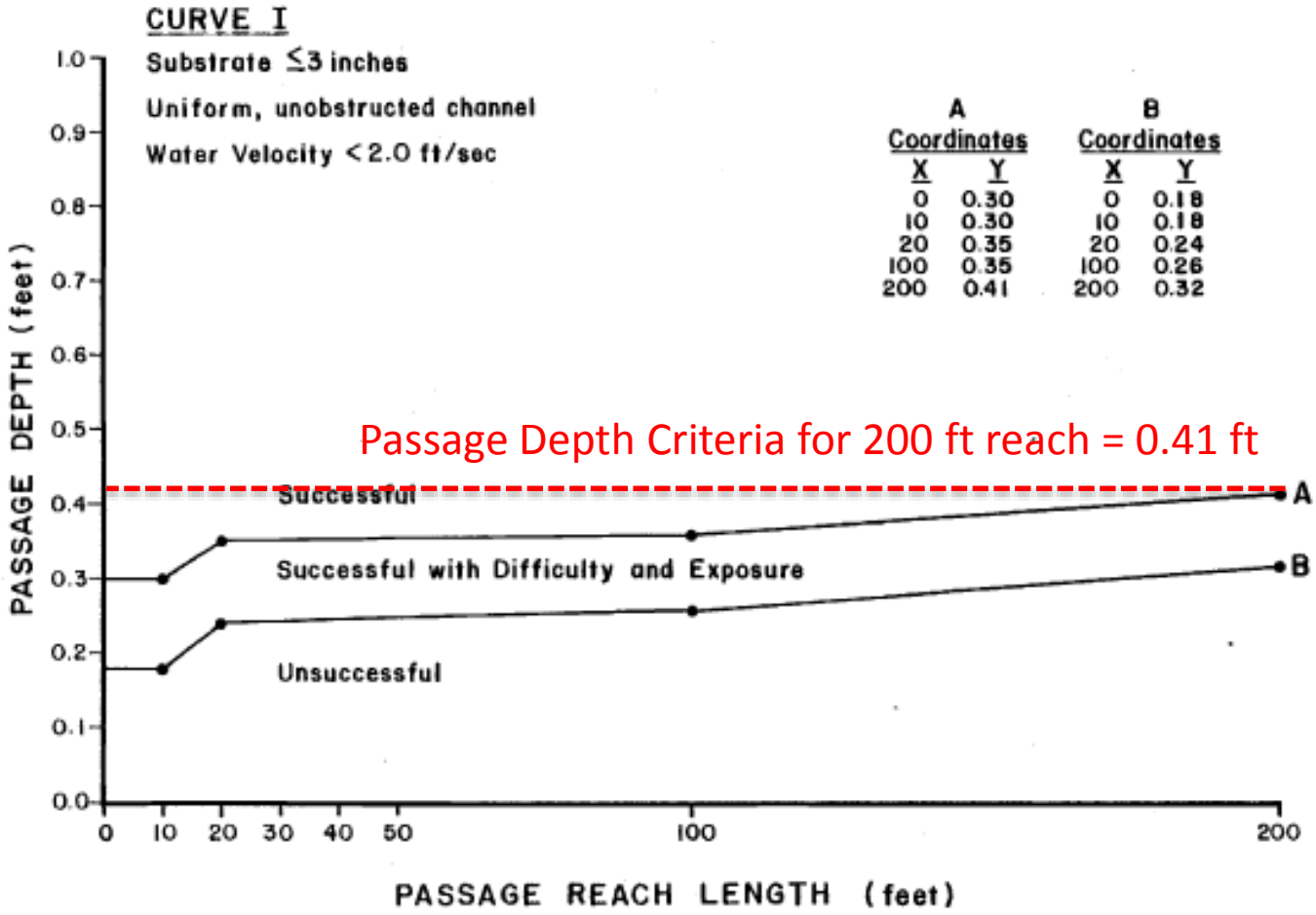


Figure 6-4. Passage depth requirements for chum salmon as a function of passage reach length within sloughs and side channels having substrates less than 3.0 inches in diameter, uniform morphology and water velocities less than 2.0 ft/sec.

Application of Depth Criteria – 1980s depth/distance

Chum as surrogate for salmonids

CURVE II

Substrate >3 inches

Non-uniform, braided and obstructed channels

Velocities <2.0 ft/sec

A Coordinates		B Coordinates	
X	Y	X	Y
0	0.41	0	0.30
10	0.41	10	0.30
20	0.48	20	0.35
100	0.48	100	0.35
200	0.54	200	0.41

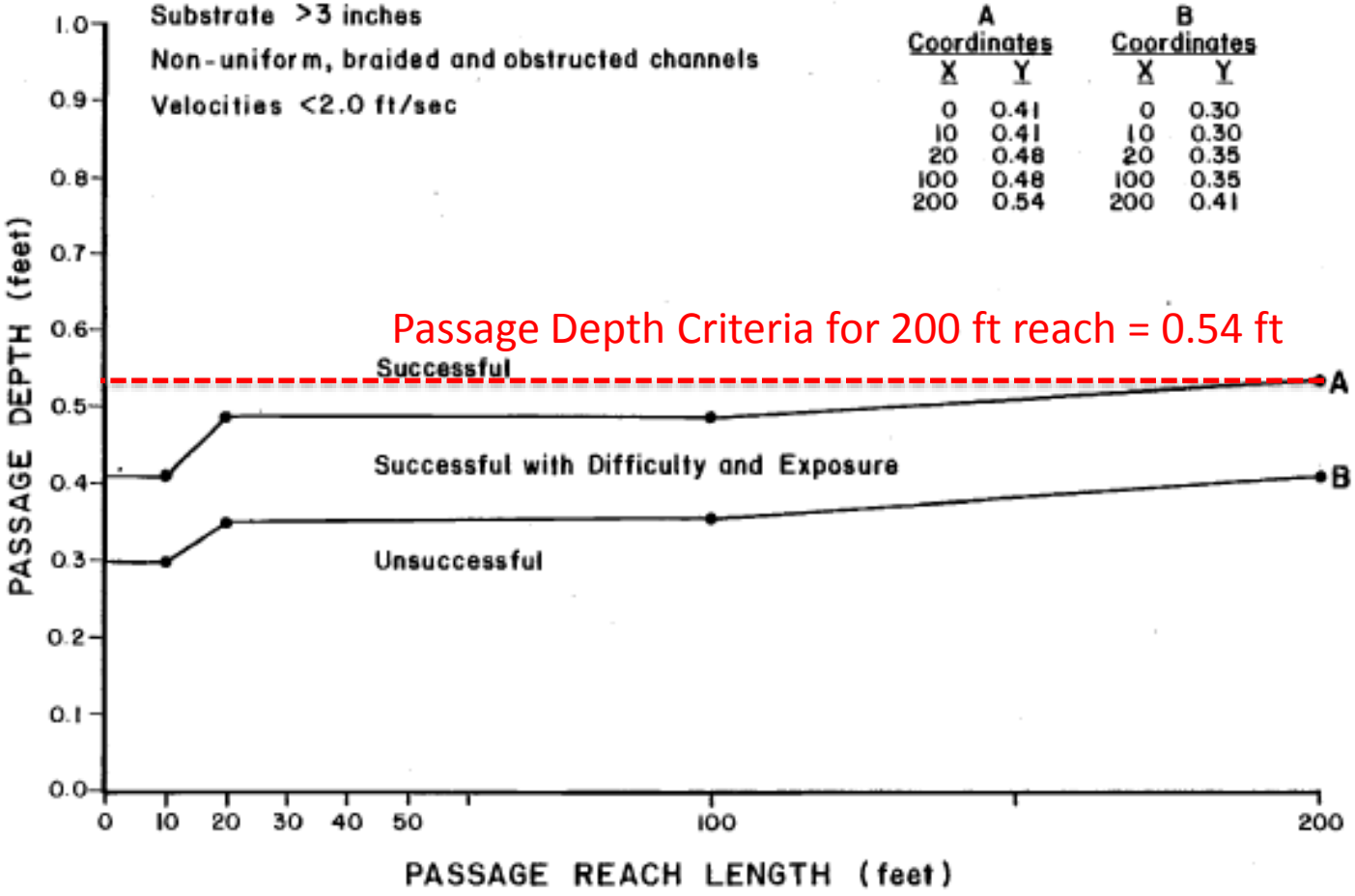


Figure 6-5. Passage depth requirements for chum salmon as a function of passage reach length within sloughs and side channels having substrates greater than 3.0 inches in diameter, non-uniform, braided and obstructed channels and velocities less than 2.0 ft/sec.

Application Depth Criteria – slough and SC habitats

Breaching, backwater, local flows

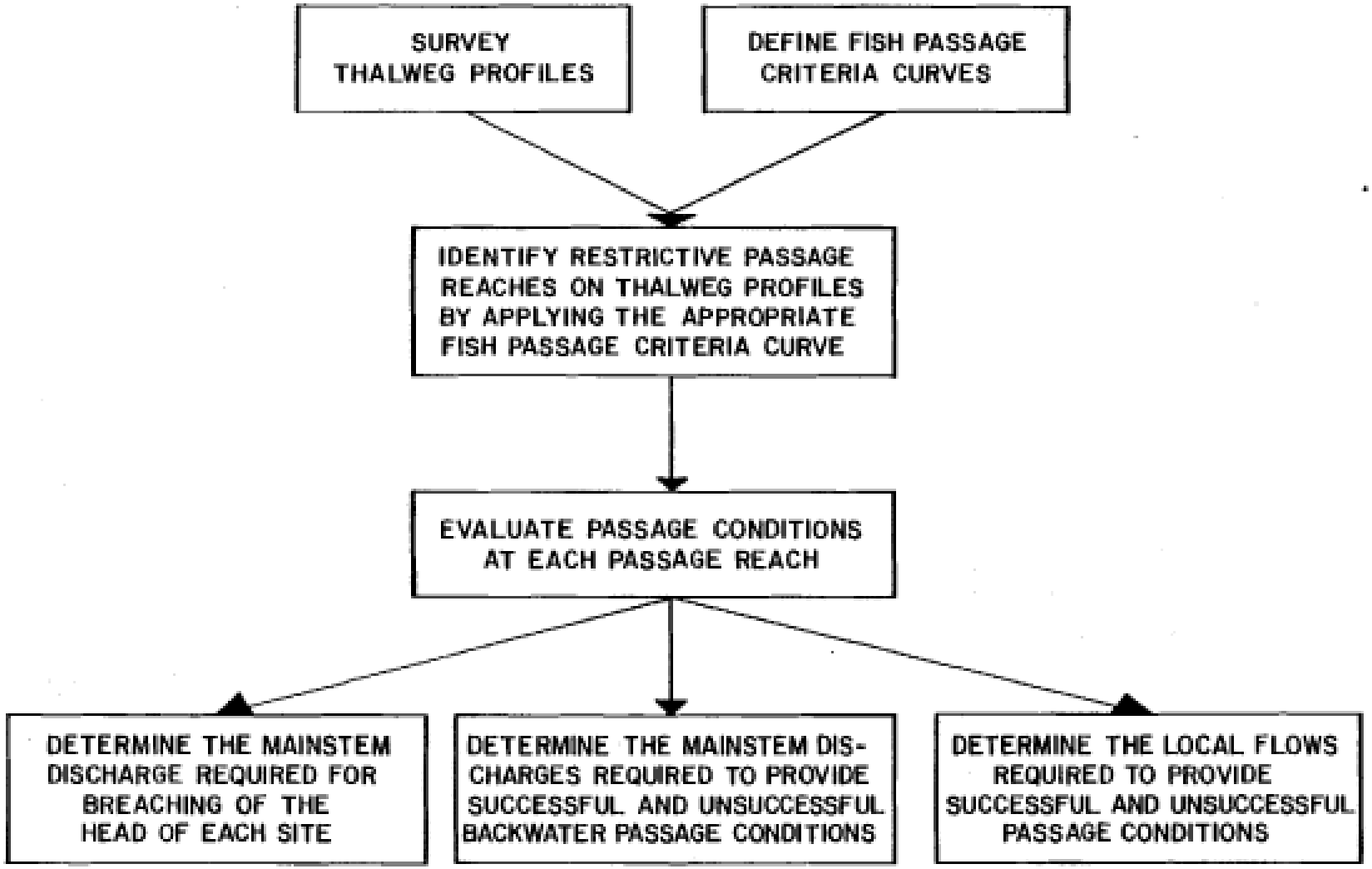


Figure 6-3. Flow chart displaying the methods employed to evaluate passage reach conditions.

DISCUSSION