



Memorandum

Date:	April 25, 2013
To:	John Arterburn, Colville Confederated Tribes
Cc:	Greer Maier, Upper Columbia Salmon Recovery Board
From:	Eric Doyle EDT Project Manager - ICF International
Subject:	OBMEP/EDT Life History Model Parameters for Okanogan/Okanagan Steelhead

Introduction

ICF International is working with the Confederated Tribes of the Colville Indian Reservation (CCT) to integrate the existing Ecosystem Diagnosis and Treatment (EDT) model for the Okanogan subbasin with long-term habitat status and trend monitoring conducted by the Okanogan Basin Monitoring and Evaluation Plan (OBMEP). The purpose of OBMEP/EDT integration is to provide a tool that translates multiple metrics of habitat condition and change into direct measures of habitat potential for Okanogan Chinook salmon and steelhead. The results of this effort will support fisheries management decision making, the identification and prioritization of habitat protection and restoration opportunities, and evaluation of the effectiveness of ongoing habitat restoration efforts.

A core component of OBMEP/EDT integration is the definition of a revised life history model for Okanogan summer steelhead. ICF, working in collaboration with CCT and regional fisheries professionals, assembled and interpreted available data, knowledge, and professional opinion about steelhead population structure and life history diversity. This information was used to develop a set of behavioral forms and EDT input parameters for each of these forms, which are collectively referred to as an EDT life history model. The EDT life history model characterizes the spatial and temporal distribution of steelhead pathways within the EDT model environment, and the conditions those pathways experience.

EDT life history model development requires information about the timing, duration, habitat selection and movement speed associated with each of these life history stages for each behavioral form. This information is used in EDT to generate life history trajectories. Trajectories are spatial and temporal pathways through the EDT model habitat environment that are created by differential

selection of life stage duration and movement patterns from the range of possibilities defined by the life history model. Each EDT model run generates thousands of trajectories each having a unique combination of habitat selection, timing, duration and movement patterns. Each trajectory travels a different spatial and temporal pathway through the model environment, experiences different survival conditions, and succeeds or fails based on the conditions experienced. The combined success of the trajectory set results in a model population that is representative of the range of potential life history expression that the model habitat environment can support.

This memorandum presents a summary of the behavioral forms of Okanogan steelhead identified by the CCT, and the EDT life history model parameters for each of these forms that are used to build the model population. The source information used to define these components and the life history model parameters are detailed below. When interpreting these parameters it is important to recognize that they are intended to represent the current and historical range of life history expression. Also, the range of timing and movement speeds has been designed to provide a realistic dispersal of trajectories within the model environment and may not directly correlate with observed movement speeds.

Environmental Setting

The Okanogan River subbasin is located in the northern part of central Washington and southern British Columbia, Canada. Anadromous species returning to the Okanogan River they must navigate a series of nine major dams on the Columbia River. More than 70% of the Okanogan subbasin lies in British Columbia, however the majority of anadromous habitat, approximately 66%, lies on the U.S. side of the border. The Okanogan River mainstem is characterized by two divergent habitat types roughly separated by the international border. Conditions in the U.S. portion of the Okanogan mainstem are dominated by runoff from the Similkameen River, a turbid, snowmelt-fed basin that drains the northern portion of the Cascade Mountain Range in southern British Columbia. The upper Okanogan River above the Similkameen is fed by a series of large lakes which moderate hydrographic fluctuations and contribute to water clarity. Both segments of the Okanogan mainstem have been hydromodified modified for urban and agricultural development purposes. The U.S. portion of the mainstem has retained a semblance of historic sinuosity and habitat complexity, while the Canadian portion has been extensively channelized and straightened. Stream flows in both segments are affected by agricultural withdrawals. Zosel Dam, located approximately 1.5 miles downstream from the outlet of Lake Osoyoos, forms the primary mainstem obstruction on the U.S. side of the border. On the Canadian side, no less than 20 channel-spanning diversion structures occur on the mainstem between Lake Osoyoos and Vaseux Lake.

The Okanogan River has long been considered suboptimal habitat for salmon and steelhead due to its regionally unique characteristics, most notably its low gradient, high summer temperatures, turbid water (downstream of the Similkameen River confluence), and small, flashy tributary streams (Fish and Hanavan 1948). Despite these limitations the subbasin still supports relatively healthy populations of sockeye salmon (*Onchorhynchus nerka*) and summer/fall-run Chinook salmon (*O. tshawytscha*), as well as a smaller population of summer steelhead (*Onchorhynchus mykiss*)

(Arterburn et al. 2005). The Okanogan River currently provides the northernmost accessible spawning habitat for these species in the Columbia Basin.

Okanogan Steelhead Management History

Okanogan River summer steelhead is one of four populations that make up the Upper Columbia River Evolutionary Significant Unit that is currently listed as “threatened” under the federal Endangered Species Act (ICBTRT 2003). This population is considered distinct primarily on the basis of reproductive isolation from other populations within the Upper Columbia River distinct population segment (UCR DPS). The state of Washington considers steelhead from the Methow and Okanogan Rivers to be a single population based on the general proximity of these two river systems (WDFW 2002).

The history of the Okanogan summer steelhead population is complicated by actions taken under the Grand Coulee Fish Maintenance Program (GCFMP). The GCFMP was implemented to address the anticipated loss of spawning habitat available to salmon and steelhead resulting from the construction of Grand Coulee Dam during the 1930s. Under this program, Chinook and sockeye salmon and steelhead attempting to pass Rock Island Dam were captured and used as broodstock for natural and artificial propagation between 1939 and 1943. No salmonids were passed naturally above Rock Island until passage was restored in 1944 (Fish and Hanavan 1948).

Prior to the completion of the Leavenworth Fish Hatchery in 1940, all steelhead reaching Rock Island were transported to selected tributaries in the Wenatchee and Entiat River watersheds for natural spawning. Barriers were erected to hold the fish in place until spawning was completed. Once the hatchery became operational, steelhead captured at Rock Island were spawned together to create hatchery broodstock. This undoubtedly resulted in genetic mixing of Okanogan steelhead with populations from the Methow, Entiat and Wenatchee River systems. In the latter years of the GCFMP Leavenworth production was also supplemented by steelhead eggs imported from the Carson National Fish Hatchery (located on the Wind River in the Columbia River Gorge) (Fish and Hanavan 1948). Eyed eggs from the Leavenworth hatchery were transported to satellite stations on the Entiat and Methow Rivers for outplanting as fingerlings. Interestingly, a third satellite station planned for the Okanogan River was never built and, according to the project record, none of the steelhead produced at Leavenworth or its satellite stations between 1940 and 1947 were released in the Okanogan River (Fish and Hanavan 1948).

This suggests that Okanogan steelhead may have escaped the worst of interbreeding and hatchery propagation effects imposed on the other steelhead populations in the UCR. Moreover, a small but measurable portion of this population is composed of 5-year and older fish. This implies that some individuals could have avoided the barrier imposed at Rock Island and returned to spawn successfully with other anadromous steelhead or with residualized redband trout. Despite this relative advantage, hatchery supplementation has accounted for the majority of spawning fish in recent years, ranging from 80% to 93% of adult escapement (Busby et al. 1996; Miller et al. 2012). Estimated annual steelhead escapement in the Okanogan River subbasin is summarized in Table 1. The wild origin counts should be viewed with caution because of the known but unquantified presence of unmarked hatchery fish and large adfluvial rainbow trout on the spawning grounds.

Table 1. Estimated adult steelhead escapement in the Okanogan Subbasin, 2005 to 2011.

Escapement		2005	2006	2007	2008	2009	2010	2011
U.S. Mainstem (Okanogan & Similkameen)	Total	832-1072	450-514	684	1061	1441	1841	849
	Marked	--	--	621	929	1319	1674	734
	Unmarked	--	--	63	132	122	167	115
U.S. Tributaries	Total	316-411	76-136	461	209	258	1278	651
	Marked	--	--	401	154	218	829	475
	Unmarked	--	--	60	55	40	449	176
Canada	Total	--	253-278	121	116	334	377	174
	Marked	--	--	92	78	284	265	136
	Unmarked	--	--	29	38	50	112	38

Population Structure and Behavioral Forms

The Okanogan steelhead population is considered to be composed of two subpopulations for the purpose of EDT modeling: a U.S. subpopulation, spawning in the mainstem Okanogan and Similkameen Rivers and tributary watersheds; and a Canadian subpopulation. Spawning in the mainstem Okanogan River and its tributaries north of the border. The ecological basis for this distinction is the fact that the Canadian portion of the subbasin is dominated by large mainstem lakes that are lacking in the U.S. portion of the subbasin. These lakes provide extensive and productive rearing habitat that may favor an adfluvial life history form over anadromy. This distinction is also convenient for modeling purposes, because the extent and quality of empirical habitat data differs between these two portions of the subbasin.

Each of these subpopulations is characterized by four potential behavioral patterns, identified by the CCT on the basis of long-term monitoring of habitat use in the subbasin. These include:

- Tributary spawning, local rearing – adult spawning in tributary watersheds to the Okanogan/Okanagan with juvenile rearing within the same natal tributary (i.e. limited juvenile movement)
- Tributary spawning, transient rearing – tributary spawning with extensive juvenile movement between summer and winter rearing habitats in the mainstem and other tributary streams
- Mainstem spawning, local rearing – mainstem spawning with juvenile rearing in mainstem habitats in relatively close proximity to spawning reaches

- Mainstem spawning, transient rearing – mainstem spawning with extensive juvenile migration between summer and winter rearing habitats in tributaries and the mainstem

These four behavioral forms are aggregated into two life history strategies, resident rearing and transient rearing, with distribution determined by the selection of spawning reaches for each subpopulation in the EDT model.

The life history model input parameters used to characterize these behavioral forms include:

- Spawn timing and spawning distribution
- Incubation duration and subsequent fry dispersal
- Juvenile rearing behavior, including localized and transient rearing patterns
- Juvenile age structure
- Smolting behavior, including outmigration timing and migration speed
- Adult age structure
- Adult migration behavior
- Adult overwintering behavior

The two life history strategies are differentiated primarily by the timing of spawning, and the speed and direction of juvenile movement during active summer rearing and the transitions to and from inactive winter rearing habitats. Adult migratory and holding behavior are assumed to be similar between the two life history strategies because no information is available that would support further differentiation.

Information Used to Construct the Life History Model

Spawning

The historical spawning distribution of Okanogan steelhead is not well documented or understood and identified as an information gap in restoration planning (ICBTRT 2003). The general consensus of regional fisheries experts is that the majority of Okanogan steelhead spawning historically occurred in tributary streams. The mainstem has and historically had a relatively low gradient, conditions conducive to high summer water temperatures, and elevated turbidity associated with snowmelt driven runoff from the Similkameen River in the U.S. portion of the subbasin.

The CCT has conducted annual surveys of steelhead spawning distribution in the U.S. portion of the Okanogan River watershed since 2005. A combination of reaches are surveyed in each year, including a set of fixed reaches that are surveyed annually, and a rotating panel of reaches that are surveyed at 4 to 5 year intervals consistent with the spatially-balanced survey design developed for the OBMEP monitoring effort (Arterburn et al. 2007a, 2007b). In addition, the CCT has directly enumerated steelhead in portions of the Okanogan River and its tributaries using video monitoring and weir trapping methods (Arterburn and Miller 2009). These surveys have improved

understanding of both the timing and distribution of steelhead spawning within the Okanogan River watershed. In combination with abundance, age, and sex ratio information collected at mainstem Columbia River dams further, these data efforts have expanded the collective knowledge of Okanogan steelhead spawning behavior. These spawning surveys have confirmed that steelhead spawning occurs in the tributary streams as expected. However, a significant number of steelhead also spawn in the mainstem at locations with suitable gradient, substrate conditions, and downwelling (Arterburn et al. 2005; Arterburn and Kistler 2006; Arterburn et al. 2007; Arterburn et al. 2010; Miller et al. 2011).

Spawning Distribution

Steelhead spawning on the Okanogan mainstem occurs most commonly in areas with relatively steep gradient and high water velocity, with moderately sized substrate and localized downwelling. These types of habitats are most prevalent near the confluence of the mainstem with Similkameen River, Omak Creek, and Bonaparte Creek, as well as higher gradient areas near Janis and McAllister Rapids. The primary spawning tributaries in the United States include Loup Loup, Salmon, Omak, Tunk, Bonaparte, and Ninemile Creeks (Miller et al. 2012). Known spawning tributaries in Canada include Inkaneep and Vaseux Creeks, with spawning potential in Haynes, Shuttleworth, Ellis, and Shingle Creeks.

Total spawning escapement has been estimated based on a combination of redd counts and sex ratios observed at Wells Dam and at the weir trap on Omak Creek, and video monitoring/enumeration of steelhead passing Zosel Dam. The steelhead sex ratio observed at Wells Dam has averaged 0.55 males per female in recent years, which translates to a sex ratio of 1.55 fish per redd (FPR). This value was used to expand redd counts into an escapement estimate for steelhead spawning in the Okanogan River mainstem downstream of Zosel Dam (Miller et al. 2011). A sex ratio of 0.8 males per female was observed at the Omak Creek weir trap, which translates to 1.8 FPR. This value was used to extrapolate a spawning escapement estimate in tributary streams (Miller et al. 2011).

The spawning component of the EDT life history model includes all reaches currently and historically likely to be used as spawning habitat by steelhead, with the understanding that this distribution includes habitats that are currently unused. The success or failure of steelhead trajectories originating from each of these reaches is determined by the survival conditions experienced in the EDT model landscape. The intent of this approach is to allow the model to characterize historical as well as current habitat potential, therefore the spawning reaches selected should be viewed in this context. Spawning reaches for the U.S. and Canadian subpopulations are identified in Tables 2 and 3, respectively.

Table 2. OBMEP/EDT modeled spawning reaches and diagnostic units for the Okanogan (U.S.) steelhead subpopulation

OBMEP/EDT Diagnostic Unit	OBMEP/EDT Spawning Reaches
Chilliwist Creek	Chilliwist 1, Chilliwist 3
Okanogan River 01	Okanogan 4a, Okanogan 4b, Okanogan 5, Okanogan 6, Okanogan 7, Okanogan 8
Loup Loup Creek	Loup Loup 1, Loup Loup 3, Loup Loup 5, Loup Loup 7, Loup Loup 9
Salmon Creek	Salmon 1, Salmon 2, Salmon 3, Salmon 4, Salmon 5a, Salmon 6, Salmon 7, Salmon 8, Salmon 9, Salmon 11, Salmon 11h, Salmon 12
Okanogan 02: Salmon to Omak	Okanogan 9, Okanogan 10a, Okanogan 10c, Okanogan 11, Okanogan 12
Omak Creek Lower	Omak 1, Omak 3, Omak 4, Omak 6, Omak 7a, Omak 7b, Omak 9,
Okanogan 03: Omak to Riverside	Okanogan 12a, Okanogan 13h, Okanogan 13, Okanogan 14a, Okanogan 14h, Okanogan 14b
Wanacut Creek	Wanacut 1, Wanacut 3, Wanacut 4
Johnson Creek	Johnson 1, Johnson 3, Johnson 5, Johnson 7, Johnson 9, Johnson 10a (irrigation diversion), Johnson 11
Okanogan 04: Riverside to Janis	Okanogan 14c, Okanogan 15, Okanogan 16, Okanogan 17, Okanogan 19, Okanogan 20, Okanogan 21a
Tunk Creek	Tunk 1, Tunk 3, Tunk 4
Okanogan 05: Janis to Siwash	Okanogan 21b, Okanogan 21c, Okanogan 21d, Okanogan 22a, Okanogan 22c, Okanogan 22g, Okanogan 22i, Okanogan 22j, Okanogan 22k, Okanogan 22n, Okanogan 22o, Okanogan 22p, Okanogan 22m, Okanogan 22u, Okanogan 22v
Bonaparte Creek	Bonaparte 1, Bonaparte 3, Bonaparte 2 (trap), Bonaparte 5a
Siwash Creek	Siwash 1, Siwash 3
Okanogan 06: Siwash to Confluence	Okanogan 24a, Okanogan 24b (hatchery release), Okanogan 24c, Okanogan 25, Okanogan 26, Okanogan 27a, Okanogan 27c, Okanogan 27d, Okanogan 27e, Okanogan 27f
Antoine Creek	Antoine 2, Antoine 2h (hatchery release), Antoine 3a, Antoine 4, Antoine 5 (multiple barriers), Antoine 6, Antoine 8, Antoine 10, Antoine 12
Wildhorse Spring Creek	Wildhorse 1, Wildhorse 3, Wildhorse 4, Wildhorse 6, Wildhorse 7, Wildhorse 8, Wildhorse 11
Similkameen Lower, Middle, and Upper	Similkameen 1a, Similkameen 1b, Similkameen 9, Similkameen 2a, Similkameen 2c, Similkameen 2e, Similkameen 2f (hatchery release), Similkameen 2g, Similkameen 3, Similkameen 4, Similkameen 5, Similkameen 6, Similkameen 7, Similkameen 8a (falls), Similkameen 8b (falls)
Okanogan 07: Confluence to Zosel	Okanogan 28a, Okanogan 28b, Okanogan 28c, Okanogan 28d, Okanogan 28e, Okanogan 28h
Tonasket Creek	Tonasket 1, Tonasket 2a, Tonasket 2b, Ninemile 2, Ninemile 2h
Ninemile Creek	Ninemile 3, Ninemile 4 (irrigation), Ninemile 5

Table 3. OBMEP/EDT modeled spawning reaches and diagnostic units for the Okanogan (Canada) steelhead subpopulation

OBMEP/EDT Diagnostic Unit	OBMEP/EDT Spawning Reaches
Haynes Creek	Haynes Creek 2, Haynes Creek 3, Haynes Creek 5
Inkaneep Creek	Inkaneep Creek 2a, Inkaneep Creek 2c, Inkaneep Creek 4, Inkaneep Creek 4a
Okanagan River 08: Channelized V	Okanagan River 35a, Okanagan River 36, Okanagan River 37, Okanagan River 38a, Okanagan River 39, Okanagan River 40, Okanagan River 41, Okanagan River 42a, Okanagan River 43a, Okanagan River 44a, Okanagan River 45b, Okanagan River 44b, Okanagan River 46, Okanagan River 47a, Okanagan River 48, Okanagan River 49b, Okanagan River 50, Okanagan River 52a, Okanagan River 53, Okanagan River 55b, Okanagan River 57a, Okanagan River 59c, Okanagan River 60
Testalinden Creek	Testalinden 2, Testalinden 3, Testalinden 4, Testalinden 6, Testalinden 8, Testalinden 10, Testalinden 12, Testalinden 14, Testalinden 16, Testalinden 18, Testalinden 20
Okanagan River 09: Semi Natural Section	Okanagan River 61, Okanagan River 64, Okanagan River 65b
Okanagan River 010: Natural Section	Okanagan River 65c, Okanagan River 65d, Okanagan River 67, Okanagan River 66
Vaseux Creek	Vaseux 1, Vaseux 2, Vaseux 4, Vaseux 6, Vaseux 7, Vaseux 8
Okanagan River 011/Vaseux Lake	Okanagan River 68b, Okanagan River 72a, Okanagan River 73, Okanagan River 74, Okanagan River 75b, Okanagan River 76a (naturalized), Okanagan River 77
Shuttleworth Creek Lower/Upper	Shuttleworth Creek 1, Shuttleworth Creek 2 (sediment trap), Shuttleworth Creek 3, Shuttleworth Creek 5, Shuttleworth Creek 7, Shuttleworth Creek 8, Shuttleworth Creek 10, Maurice Creek 1, Maurice Creek 3, Maurice Creek 5, Shuttleworth Creek 11
McLean Creek	McLean Creek 2, McLean Creek 4, McLean Creek 6, McLean Creek 8, McLean Creek 10
Skaha Lake	Okanagan River 80, Okanagan River 81, Okanagan River 82, Okanagan River 83, Okanagan River 86,
Ellis Creek	Ellis Creek 1, Ellis Creek 2, Ellis Creek 4a, Ellis Creek 5, Ellis Creek 7, Ellis Creek 8, Ellis Creek 9, Ellis Creek 11, Ellis Creek 13, South Ellis Creek 1, South Ellis Creek 3, Ellis Creek 14
Shingle Creek Lower/Upper	Shingle Creek 1, Shingle Creek Dam, Shingle Creek 7, Shingle Creek 11, Shingle Creek 13, Shatford Creek 3, Shatford Creek 7, Shatford Creek 9, Shingle Creek 16, Shingle Creek 18, Shingle Creek 20
Okanagan River 012: Channelized III	Okanagan River 87, Okanagan River 88, Okanagan River 89, Okanagan River 90a

Spawn Timing and Incubation

Okanogan steelhead spawn timing was derived from several sources, including spawner surveys on the mainstem Okanogan River and its tributaries, video monitoring counts at Zosel Dam, and anecdotal observations by CCT and Okanogan Nation Alliance Staff (ONA) (Benson and Squakin 2008; Miller et al. 2012; Wiens et al. 2012). There are observed differences in spawn timing between mainstem and tributary habitats, with spawning initiating slightly earlier in the mainstem. The differences in spawn timing are attributed to differences in water temperature, with the mainstem habitats warming more quickly than the tributaries. There is some uncertainty as to the end of the typical spawning period because it occurs during the spring freshet when visibility and weir trap efficiency is low. Spawn timing ranges used in the EDT model are listed below, with spawn timing recommended by OBMEP in parentheses.

- Mainstem spawning:
 - First week: March 5 to 11 (March 20)
 - Last week: May 21 to 27 (May 15)
- Tributary spawning:
 - First week: March 11 to 15 (April 1)
 - Last week: May 21 to 27 (June 1)

The duration of incubation was estimated at 24 to 40 days for mainstem spawning and 26 to 53 days based on 320 degree days of thermal unit accumulation and habitat specific temperature ranges of 8 to 13°C and 6 to 12°C, respectively (J. Arterburn, personal communication, 2012). The modeled range of spawn timing is slightly different from the observed range. As stated previously, this was necessary to create a representative distribution of life history trajectories in the model environment.

Juvenile Age Structure and Rearing Behavior

The regional fisheries experts surveyed for this effort generally concurred that the majority of steelhead rearing habitat in the U.S. portion of the Okanogan subbasin is likely concentrated in tributary habitats. This perception is driven by a long history of summer mainstem water temperatures above the optimal thermal range for rearing. Rearing habitat selection by the Canadian subpopulation is likely to be similar, with the significant caveat that the large stratified lakes in this portion of the subbasin are likely to provide productive foraging and overwintering habitat with depth strata offering optimal temperatures year-round. However, this habitat type is likely to favor the adoption of an adfluvial life history form, as evidenced by the observation of large adfluvial trout during redd surveys (Benson and Squakin 2008; Wiens et al. 2012), a factor which complicates modeling of habitat potential for steelhead.

While tributary watersheds are likely to provide the bulk of juvenile rearing habitat, there is some evidence that that mainstem habitats were historically used extensively and are still used to a more limited extent. Photographic and narrative evidence exists for the presence of a robust trout

population in the mainstem Okanogan River near Omak, possibly steelhead, targeted by tribal and recreational fisheries in the early 20th century (Mintzer 1910) (see Figure 1). This suggests that temperature conditions at least would likely have supported spawning and rearing. In addition, CCT has observed juvenile trout rearing in the Similkameen River during snorkel surveys. These individuals are typically associated with thermal refugia provided by groundwater inputs and upwelling zones.

Collectively this information indicates that the Okanogan mainstem historically provided summer rearing habitat and may still do so at selected locations. The mainstem may also provide suitable temperatures for winter rearing, on the basis that cold temperatures and occasional icing in tributary streams may prompt juvenile steelhead to seek out more stable conditions. However, the mainstem generally lacks cobble substrate with the interstitial spaces used extensively by juvenile steelhead during winter inactivity, so the capacity of the mainstem to support inactive rearing is likely limited.



Figure 1. Trout catch from the mainstem Okanogan River near Omak, circa 1910 (Mintzer 1910).

Movement Patterns

Juvenile movement patterns are parameterized in the EDT model by assigning a range of potential movement speeds to each life history type. The EDT trajectory generator selects a unique movement speed (and thereby direction) for each trajectory during each life history stage, ensuring a uniform distribution of potential movement patterns. Movement speeds are expressed in kilometers per day (km/day) with negative numbers denoting upstream movement and positive numbers downstream

movement. The range of juvenile movement speeds selected for the Okanogan steelhead life history model are:

- Fry colonization (downstream movement after swim up)
 - Local form: 0 to 0.5 km/day
 - Transient form: 0 to 1 km/day
- Age-0 active rearing
 - Local form: -0.05 to 0.1 km/day
 - Transient form: -0.25 to 0.5
- Age-0/1 inactive rearing
 - Local form: 0 km/day
 - Transient form: -0.01 to 0.01 km/day
- Age-1 active rearing
 - Local form: -0.1 to 0.1 km/day
 - Transient form: -0.5 to 1.0 km/day
- Age-1/2 inactive rearing
 - Local form: 0 to 0.01 km/day
 - Transient form: 0 to 0.1 km/day
- Age-2+ active rearing
 - Local form: -0.1 to 0.1 km/day
 - Transient form: -1.0 to 1.0 km/day
- Age-2+ inactive rearing
 - Local form: 0 to 0.01 km/day
 - Transient form: 0 to 0.1 km/day

These movement patterns have been selected to provide a broad distribution of steelhead trajectories, in order to ensure that potentially suitable habitats in the model environment are adequately sampled. When considering these numbers it is important to focus on the range of possible outcomes rather than the bounds, recognizing that the intent is to create a broad distribution of EDT trajectories representative of the range of potential life history expression.

Age Structure

Juvenile age structure information for Okanogan steelhead is derived from study of smolt age distribution at Upper Columbia dam sites (Peven et al. 1994), and rotary screw trap surveys of smolting behavior in the Okanogan subbasin (Miller et al. 2011b). Peven et al. (1994) observed that

the average age structure of smolts captured at Rocky Reach Dam in 1988 and 1989 was 2.0% age 1, 45.4% age 2, 41.4% age 3, and 10.4% age 4, with the remainder distributed across older age classes. CCT fisheries staff believe that this distribution is not representative of Okanogan steelhead however, on the basis that the population is composed primarily of hatchery steelhead that smolt at age 1, and the relatively warm and productive conditions in this system promote faster growth and earlier age at smolting (John Arterburn, personal communication 2012). Steelhead smolts passing Rocky Reach Dam originate from three areas, the Entiat River, the Methow River, and the Okanogan River and associated hatchery programs. The Entiat and Methow Rivers drain the east slopes of the Cascade Mountains and are characterized by relatively cool temperatures and low productivity conditions in comparison to the Okanogan. These systems also produce more steelhead than the Okanogan River, and are therefore likely to dominate the range of observed age classes at Rocky Reach Dam.

The age at smolting distribution used the EDT steelhead life history model is based on the professional judgment of CCT fisheries staff, informed by rotary screw trapping studies of smolting behavior. The selected range used for the EDT life history model is 30% age 1, 50% age 2, and 20% age 3.

Smolt Migration Behavior

Smolt migration timing and migration speed in the Okanogan River is based on rotary screw trap observations (Rayton and Arterburn 2007; Jahns and Nass 2009), migration speed and timing in the Columbia River mainstem is based on COMPASS model predictions described by Zabel and Anderson (1997) and Zabel et al. (2008), performance monitoring and evaluation of Program RealTime predictions (Townsend et al. 2010), and tagging studies of steelhead estuarine residence time (Melnychuck et al. 2007; Welch et al. 2004). Rotary screw trap observations indicate that wild steelhead smolting begins in the second week of April and extends through mid-June. Hatchery smolt migration is more compressed, occurring between the third week of April and the end of May. There is no well-defined peak migration period for wild steelhead. This is likely due to the relative low abundance of wild steelhead in the subbasin as a whole and variable efficiency (Rayton and Arterburn 2007).

A smolt timing distribution of April 8 to June 20 was used in the EDT life history model in order to evaluate the entire range of observed emigration timing. The range of migration speeds used in the model is 10 to 50 km/day, which provides a range of travel speeds through the mainstem Columbia. Migration rates are slowed in the Columbia River Estuary to a range of 5.6 to 15.8 km/day, based on tagging studies of estuarine residence (Melnychuck et al. 2007; Welch et al. 2004). Ocean entry in the EDT life history model occurs between June 30 and July 20 based on these migration speeds.

Ocean Rearing and Adult Age Structure

Ocean rearing is treated generally in the EDT model by assigning different survival characteristics to major ocean habitat units. Steelhead distribution in these habitat units is informed by Myers et al. (1996) and Percy et al. (1990). Adult age structure is derived from sampling of returning spawners at the Wells Dam (Chapman et al. 1994; Snow et al. 2008) and the observed size distribution of adult

spawners within the Okanogan subbasin (Arterburn et al. 2007). Adult age class is dominated by one ocean year (1-salt) and 2 ocean year (2-salt) spawners, with 3 ocean year adults exceedingly rare. The average age structure observed at Wells Dam has varied over the past three decades with no particular age class dominant, averaging 32.7% 1-salt and 67.4% 2-salt from 1987 to 1993 (Chapman et al. 1994), and 57.2% 1-salt and 42.7% 2-salt from 1997 to 2006 (Snow et al. 2008). Given this variability, an even age class distribution of 49% 1-salt and 51% 2-salt was selected for the EDT life history model for this population.

Adult Migration

River Entry and Upstream Migration

Adult Columbia River entry parameters for Okanogan steelhead were derived from the 10-year (2003 to 2012) average distribution of steelhead passage recorded at Bonneville Dam by the Fish Passage Center (FPC 2013). The summer steelhead migration begins in mid-June and continues through the end of October, peaking between late-July and late-August. A migration window of June 15 through October 20 is used in the EDT model consistent with this information. An upstream migration speed of -17 to -23 km/day was selected based on radio telemetry studies of migration rates through the Upper Columbia River (English et al. 2003; English et al. 2006),

Overwintering

The overwintering behavior of Okanogan steelhead is not fully understood, but the available information for the Okanogan subbasin suggests that a significant percentage of adult steelhead overwinter upstream of the Wells Pool. The 10-year average migration timing of steelhead past the Wells Dam (FPC 2013) shows migration past the dam from the beginning of July through mid-November, which is generally consistent with the timing of Columbia River entry allowing for upstream travel time. Notably however, these monitoring data do not include the months of December through April, so there remains some potential for steelhead past Wells Dam in late-winter and early-spring before regular monitoring begins each year. This would be consistent with historical observations of steelhead run timing in the Columbia prior to hydrosystem completion, which showed a distinct bimodal peak in run timing past Rock Island Dam (Fish and Hanavan 1948). The majority of migrating steelhead passed the dam between mid-July and late-November, but a significant minority was observed passing the dam from early-April through late-June. The behavior of the latter group is explained only by overwintering in the Columbia mainstem or perhaps other tributary streams.

More recent studies are equivocal. Keefer et al. (2008) used radiotelemetry to study the overwintering behavior of Columbia and Snake River Basin steelhead and determined that an estimated 12.4% of fish that successfully reached spawning habitats overwintered at least partially in the hydrosystem. However, steelhead from the Okanogan and Methow Rivers generally migrated past Wells Dam without overwintering in the mainstem. Their behavior after passing Wells was not well established by this study.

The CCT have not observed significant numbers of steelhead overwintering in the Okanogan River or its tributaries. Adult steelhead are seen in the Okanogan River and the Similkameen River in the fall but are rarely present in winter (J. Arterburn, personal communication, 2012). Observations of steelhead movements into spawning tributaries and past the video monitoring station at Zosel Dam (Miller and Arterburn 2009; Miller et al. 2010; Miller et al. 2011) suggest that the majority of steelhead are migrating directly to spawning habitats from overwintering habitats, most likely in the Wells Pool based on the observations of Keefer et al. (2008). However, Zosel video monitoring indicates that small numbers of steelhead are moving upstream into Canada between November and January in some years (Miller and Arterburn 2009; Miller et al. 2010; Miller et al. 2011). This indicates that at least a percentage of individuals periodically overwinter in the Canadian portion of the subbasin, and suggests that the same behavior is possible south of the border.

Steelhead overwintering is usually characterized in EDT by selecting a known or probable overwintering reach and parameterizing the model population to stop and remain in that reach for a variable overwintering period. Because the overwintering behavior of Okanogan steelhead is somewhat unclear, the life history model was parameterized to allow for overwintering distribution throughout the Okanogan mainstem from the Wells Pool upstream to the Canadian lakes. Movement speed during overwintering was reduced to 0 to 0.5 km/day.

Smolt to Adult Return Rates (SAR)

Smolt-to-adult return rates (SARs) for Okanogan steelhead were derived from PIT-tag studies of wild and hatchery steelhead from various systems throughout the Columbia and Snake River Basins (Faulkner et al. 2010; Tuomikoski et al. 2012), extrapolated to estimate appropriate subbasin exit to subbasin entry SAR values. SAR values are parameterized in EDT by adjusting early marine rearing and migrant survival rates in the Columbia River. The subpopulation-level SAR is an aggregate of combined performance of steelhead life history trajectories, which is variable from model run to model run.

A set of test EDT model runs were used to calibrate the SAR for each Okanogan steelhead subpopulation for consistency with observed rates, and three model runs were used to test the stability of the final calibration for each subpopulation. These model runs returned SAR values of 1.88%, 1.92%, and 1.93% for the U.S. subpopulation, and 1.99%, 2.00%, and 2.01% for the Canadian subpopulation.

Life History Model Parameters by Steelhead Behavioral Type

OMBEP/EDT steelhead life history model parameters for the local and transient behavioral forms are detailed below in Tables 4 and 5, respectively. The composition of the U.S. and Canadian subpopulations were each assumed to be 20% local rearing form and 80% transient rearing form, on the basis that suitable summer and winter rearing habitats are fragmented and infrequent within the subbasin. Therefore the ability and propensity to move between habitats provides a greater

likelihood of survival. Increasing the proportion of the transient form also ensures that the EDT trajectories generated for each subpopulation will broadly sample the model habitat environment, allowing for more reliable identification of capacity and productivity bottlenecks within the system.

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Table 4. EDT Life History Model Parameters for Okanogan/Okanogan Steelhead: Local Rearing Behavioral Form

Life History Stage	Period	Duration (days)*	Age Structure	Travel Speed (km/day)		Description
				Stage	Transition	
Spawning	First wk: April 1 Last wk: June 1	EDT2 BM: 7 Min: 4 Max: 10	n/a	n/a	n/a	Based on Okanogan tributary redd and weir counts
Incubation to Emergence	n/a	EDT2 BM: 49 Min: 26 Max: 53	n/a	n/a	n/a	Duration of incubation compared to the stereotypical duration for this LH stage in EDT (reflects influence of warm water temperatures on incubation rate).
Fry Colonization	First wk: May 28 Last wk: Jul 7	EDT2 BM: 14 Min: 10 Max: 17	n/a	Min: 0 Max: +1	Min: -0.01 Max: +0.01	Slow dispersal, remain near natal habitats.
Age-0 Active Rearing (summer)	First wk: June 7 Last wk: July 24	EDT2 BM: 112 Min: 153 Max: 244	n/a	Min: -0.5 Max: +0.1	Min: 0 Max: 0	Remain in proximity to natal habitats, exploiting available thermal refugia.
Age-0/1 Inactive Rearing (winter)	First wk: Nov 1 Last wk: Dec 1	EDT2 BM: 140 Min: 105 Max: 165	n/a	Min: 0 Max: +0.1	Min: 0 Max: 0	Inactive juvenile overwintering (first winter).
Age-1 Active Rearing (summer)	First wk: Mar 15 Last wk: Apr 15	EDT2 BM: 196 Min: 153 Max: 244	n/a	Min: -0.1 Max: +0.1	Min: 0 Max: 0	Remain in proximity to natal habitats, exploiting available thermal refugia.
Age-1/2 Inactive Rearing (winter)	First wk: Nov 1 Last wk: Dec 1	EDT2 BM: 140 Min: 151 Max: 182	n/a	Min: 0 Max: +0.1	Min: 0 Max: 0	Inactive juvenile overwintering (second winter).
Age-2+ Active Rearing (summer)	First wk: Mar 15 Last wk: Apr 15	EDT2 BM: 196 Min: 153 Max: 244	n/a	Min: -0.1 Max: +0.1	Min: 0 Max: 0	Remain in proximity to natal habitats, exploiting available thermal refugia.

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Life History Stage	Period	Duration (days)*	Age Structure	Travel Speed (km/day)		Description
				Stage	Transition	
Age-2+ Inactive Rearing (winter)	First wk: Nov 1 Last wk: Dec 1	EDT2 BM: 140 Min: 151 Max: 182	n/a	Min: 0 Max: +0.1	Min: 0 Max: 0	Inactive juvenile overwintering (third winter).
Juvenile Migrant (smolt)	First wk: Apr 8 Last wk: June 20	EDT2 BM: 14 Min: 10 Max: 20	Age 1: 30% Age 2: 50% Age 3: 20%	Min: +10 Max: +50	n/a	Timing of smolt initiation, duration of smolting period, and downstream migration speed. Age at smolting intended to be representative of historical potential
Estuarine	Based smolt migration speed for trajectory.	Min: 5 Max: 14	n/a	Min: +5.6 Max: +15.8	n/a	Travel speed derived from estimated estuarine residence.
Marine	First wk: June 30 Last wk: July 20	Based on adult age structure	1-salt: 49% 2-salt: 51%	n/a	n/a	Marine age structure.
Pre-Spawn Migrant	First wk: Jun 15 Last wk: Oct 20	Based on initiation of holding	n/a	Min: -17 Max: -23	n/a	Upstream migration speed.
Pre-Spawn Holding	First wk: Aug 15 Last wk: Nov 15	Min: 126 Max: 217	n/a	Min: 0 Max: +0.5	Min: -18 Max: -21	Overwintering duration based on observed migration timing in UCR initiation of spawning in Okanogan R.

Note: EDT2 BM = EDT benchmark duration for this steelhead life history stage for comparison to the selected parameter range. See Tables 2 and 3 for EDT spawning reaches selected for the U.S. and Canadian subpopulations.

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Table 5. EDT Life History Model Parameters for Okanogan/Okanogan Steelhead: Transient Rearing Behavioral Form

Life History Stage	Period	Duration (days)*	Age Structure	Travel Speed (km/day)		Description and Information Sources
				Stage	Transition	
Spawning	First wk: Mar 20 Last wk: May 15	EDT2 BM: 7 Min: 4 Max: 10	n/a	n/a	n/a	Based on Okanogan mainstem redd counts.
Incubation to Emergence	n/a	EDT2 BM: 49 Min: 24 Max: 40	n/a	n/a	n/a	Duration of incubation compared to the stereotypical duration for this LH stage in EDT (reflects influence of warm water temperatures on incubation rate).
Fry Colonization	First wk: May 3 Last wk: June 18	EDT2 BM: 14 Min: 10 Max: 17	n/a	Min: 0 Max: +0.5	Min: -0.01 Max: +2	Estimated duration based on stereotypical 14-days for this LH stage in EDT.
Age-0 Active Rearing (summer)	First wk: May 13 Last wk: July 5	EDT2 BM: 112 Min: 172 Max: 202	n/a	Min: -0.25 Max: +0.5	Min: -1 Max: +0.5	Move to rearing areas w/thermal refugia in Okanogan mainstem or Columbia R.
Age-0/1 Inactive Rearing (winter)	First wk: Nov 1 Last wk: Dec 1	EDT2 BM: 140 Min: 134 Max: 165	n/a	Min: 0 Max: +0.01	Min: -1 Max: +3	Inactive juvenile overwintering (first winter).
Age-1 Active Rearing (summer)	First wk: Mar 15 Last wk: April 15	EDT2 BM: 196 Min: 200 Max: 261	n/a	Min: -0.5 Max: +1	Min: -2 Max: +0.5	Move to rearing areas w/thermal refugia in Okanogan mainstem or Columbia R.
Age-1/2 Inactive Rearing (winter)	First wk: Nov 1 Last wk: Dec 1	EDT2 BM: 140 Min: 134 Max: 165	n/a	Min: 0 Max: +0.01	Min: -3 Max: +3	Inactive juvenile overwintering (second winter).
Age-2+ Active Rearing (summer)	First wk: Mar 15 Last wk: April 15	EDT2 BM: 196 Min: 200 Max: 261	n/a	Min: -1 Max: +1	Min: -4 Max: +0.5	Return to rearing areas w/thermal refugia in Okanogan mainstem or Columbia R.
Age-2+ Inactive Rearing (winter)	First wk: Nov 1 Last wk: Dec 1	EDT2 BM: 140 Min: 134 Max: 165	n/a	Min: 0 Max: +0.01	Min: -3 Max: +3	Inactive juvenile overwintering (third winter).

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Note: EDT2 BM = EDT benchmark duration for this steelhead life history stage for comparison to the selected parameter range. See Tables 2 and 3 for EDT spawning reaches selected for the U.S. and Canadian subpopulations.

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