PACIFIC LAMPREY ARTIFICIAL PROPAGATION AND REARING INVESTIGATIONS: ROCKY REACH PACIFIC LAMPREY MANAGEMENT PLAN

Chelan County PUD

Rocky Reach Hydroelectric Project

FERC Project No. 2145

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ROCKY REACH FISH FORUM

Pacific Lamprey Artificial Propagation Project Detailed Report Information

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1.0 INTRODUCTION AND BACKGROUND

1.1. Introduction and Background

The impetus for developing this document is through implementing the Rocky Reach Pacific Lamprey Management Plan (PLMP), a component of the Rocky Reach Comprehensive Settlement Agreement, both of which are discussed more thoroughly in Section 1.2. The ultimate goal of the PLMP is to achieve No Net Impact (NNI) to Pacific lamprey of ongoing operations of the Rocky Reach Hydroelectric Project. Conducting artificial propagation of Pacific lamprey was considered by the state and federal fishery agencies and Tribes that are parties to the Settlement Agreement as a potential Protection, Mitigation, and Enhancement measure (PME) for achieving NNI during the term of the current Rocky Reach license. This document is intended to provide guidance as to the feasibility of culturing Pacific lamprey, the associated facilities necessary for culture practices, and identifying uncertainties for monitoring culture efficacy and rationale for implementing Pacific lamprey artificial propagation

Pacific lamprey (*Lampetra tridentata*) are an anadromous species of fish native to the Columbia River Basin, including tributary watersheds in the Middle and Upper-Columbia (USFWS 2010). Recently, fisheries resource managers have acknowledged that less is known about this species than most other native and non-native fish species within the Columbia Basin. However, it is generally understood and accepted by resource managers and fishery scientists that this species plays a significant ecological role in Columbia riverine system. Juvenile lamprey filter feed and remove suspended sediment and organic material from the water and are potential prey to larger fish and other predatory animals while adult lamprey transport ocean-derived nutrients upstream into tributary watersheds. To the Native Americans of the region, this species has a long history of cultural and economic importance (Close et al. 1995, Nez Perce/Umatilla/Yakama/Warm Springs Tribes 2008).

Pacific lamprey populations throughout the Columbia River Basin have declined significantly in recent years (Close et al. 1995, Close et al. 2003, Palacios 2007, Nez Perce/Umatilla/Yakama/Warm Springs Tribes 2008). It s believed that dams along the Columbia River could potentially add to the decline in adult returns. Other factors contributing to declines potentially include ocean conditions, ocean harvests of other species, habitat loss, reduction of in-stream flows, water diversions, dredging, scour and channelization processes, pollution and degradation of riparian habitat (USFWS 2008, Gunckel et al. 2009).

A greater emphasis towards understanding this species is underway. Recent data collected at dams has revealed clear evidence that the species has declined significantly from historical population levels and has been extirpated from various sub-basins and many watersheds. Observations that this trend is occurring has been reported repeatedly over the last decade by essentially every resource management agency within the Columbia Basin. However, only recently have regional decision-makers responded to the fact that something must be done to prevent the demise of the species.

Recent interest in Pacific lamprey has sparked research projects scattered throughout the entire Columbia River Basin and many coastal streams. Findings from these research projects have revealed that this species is a fundamental component to the natural ecology of the Upper Columbia River Basin and there is hope that it can be saved. Although limited, data has revealed that the current state of this species throughout much of its historic (pre-Columbia River dams) distribution is "functionally" or truly extinct with regards to its ecological contribution and contribution to Indian livelihood and cultural values. Reversing the declining population trends and establishing self-sustaining populations will take continued and diligent efforts over the long-term.

1.2. Mitigation Responsibilities of Chelan County PUD

The Chelan County Public Utility District (PUD) entered into a Comprehensive Settlement Agreement on February 3, 2006 with the U.S. Fish and Wildlife Service (USFWS), the U.S. Bureau of Land Management (BLM), U.S. National Park Service (USNPS), the Washington State Department of Fish and Wildlife (WDFW), the Washington State Department of Ecology (Ecology), the Washington State Parks and Recreation Commission (WSPRC), the Confederated Tribes of the Colville Reservation (CCT), the City of Entiat, the Confederated Tribes and Bands of the Yakama Nation (YN) and Alcoa Power Generating Inc. (APG) and the following entities were encouraged to sign this Agreement: the Columbia River Inter-Tribal Fish Commission (CRITFC) and the Confederated Tribes of the Umatilla Indian Reservation (CTUIR).

The goal of the Pacific Lamprey Management Plan (PLMP) is to provide safe, timely, and effective passage for adult and juvenile Pacific lamprey; and where unavoidable Project impacts are measured, then provide appropriate and reasonable Protection, Mitigation, and Enhancement measures (PMEs) that achieve an overall No Net Impact (NNI) on this population. Objectives to achieve this goal include addressing:

- Potential ongoing Project impacts on upstream passage of adult Pacific lamprey;
- Potential ongoing Project impacts on downstream passage of juvenile Pacific lamprey;
- Potential ongoing Project impacts on the existing reservoir habitat used currently by juvenile Pacific lamprey; and
- Unavoidable impacts by identifying and implementing measures to achieve No Net Impact (NNI).

The PLMP uses Adaptive Management to resolve critical uncertainties and to achieve the goal and objectives. Accordingly, the PLMP will be reviewed on a periodic basis by the Rocky Reach Fish Forum (RRFF) to allow for planning and future adjustments over the term of the New License. In addition, the PLMP is intended to be consistent with other Pacific lamprey management plans in the mid-Columbia region.

The PLMP calls for Chelan PUD to implement the following protection, mitigation and enhancement (PME) measures:

- Continue to provide upstream and downstream passage for Pacific lamprey through the Project's upstream fishway and downstream bypass, in accordance with the operation criteria for anadromous salmonids and compatible bull trout migration guidelines;
- Conduct upstream fishway passage counts of adult Pacific lamprey;

- As part of the monitoring program, complete and update a literature review for the effectiveness of lamprey passage measures implemented at other hydroelectric projects in the Columbia and Snake rivers;
- Investigate and implement appropriate and reasonable upstream fishway modifications to provide safe, timely and effective volitional Pacific lamprey passage;
- Implement a monitoring program, such as through the use of radio telemetry or other appropriate methods, to evaluate fishway modifications;
- Develop a plan and implement appropriate and reasonable measures to address ongoing Project effects on downstream adult passage if any effects are identified through the monitoring program;
- Once adult passage success has been achieved, conduct monitoring every 10 years to confirm the success of any modifications, using radio telemetry;
- Monitor juvenile Pacific lamprey impingement and implement appropriate and reasonable measures to address ongoing Project effects, if any;
- Measure the type and magnitude of any ongoing Project impacts on the downstream passage of juvenile lamprey, using appropriate and reasonable methodologies.
- Determine juvenile Pacific lamprey presence/absence and relative abundance in the Reservoir; and
- Identify and implement appropriate and reasonable measures to address unavoidable impacts to achieve NNI.

Therefore based on the information summarized above, the artificial propagation project is a measure that falls under the duties and responsibilities that the Chelan County PUD agreed to in an effort to mitigate ongoing operations and projects.

1.3. Purpose

In accordance with the PLMP goals mentioned above, the purpose of this document is to investigate reliable and technically feasible techniques for culturing Pacific lampreys in support of mitigation responsibilities, identify potential facilities associated with culture techniques, and to provide specimens for research activities. In order to provide research stock, this document was developed to initiate the artificial propagation of Pacific Lamprey.

1.4. General Approach

According to Section 4.2.3, Measurement Impacts on Juvenile Downstream Passage, of the 2006 Rocky Reach PLMP, "Chelan PUD shall continue to measure the type and magnitude of any ongoing Project impacts on the downstream passage of juvenile lamprey, using appropriate and reasonable methodologies. Specifically, these methodologies will address juvenile lamprey downstream migration timing and passage survival through the Project. Associated with these methods, Chelan PUD shall, in consultation with the Rocky Reach Fish Forum (RRFF), develop the means to provide sufficient numbers of juvenile lamprey for these evaluations. Chelan PUD, in consultation with the RRFF, may choose to contribute to other local or regional lamprey investigation programs in order to gain efficiencies in the development of methods for lamprey investigations at the Project."

In accordance with this statement and the overall PLMP goals and objectives, the Chelan PUD has coordinated with the RRFF to identify potential rearing and spawning sites within the regional watershed. This report represents the initial effort to meet the overall goals of the PLMP.

1.5. Terminology / Life History

1.5.1. Phylogenetics

Pacific lampreys are in the Class Petromyzontida, Order Petrmyzoniformes, Family Petromyzontidae, and Genus Lampetra and were first described in 1836 by Gairdner (Richardson 1836). Pacific lamprey (*Lampetra tridentata*), is one of at least 21 species within this genus. Pacific lampreys are considered part of an ancient assemblage (Agnatha) dating back to the Ordovician Period. Agnathans are jawless fishes that include filter feeders, scavengers, and ecto-parasites. All northern hemisphere lampreys belong to the family Petromyzontidae (Moyle et al. 1989).

1.5.2. Genetic Structure

To date, there have been four genetic studies that have evaluated the broad scale population structure of the Pacific lampreys. Close et al. (2001) used protein electrophoresis and examined Pacific lamprey within the Columbia River Basin and found no significant intra-population variation. Likewise, Goodman et al. (2008) investigated population structure of Pacific lampreys from central British Columbia to southern California. In this study, no significant population structure was identified among populations or regions. Lin et al. (2008) investigated population structure from northern California to Alaska and Japan. This data also suggests significant levels of historic gene flow among populations. Finally, a report by Docker (2010) that examined populations from California up to British Columbia also suggests that genetic differentiation among locations was low. The results of the these genetic studies on Pacific lampreys indicate high levels of historic gene flow among collection localities, even those separated by large geographic distances (Northern California to Japan). However, refinement in genetic differentiation techniques in the future may alter this paradigm.

1.5.3. Morphology

Adult life history stages of Pacific lampreys differ quite dramatically. Both life history stages exhibit scaleless, elongated bodies that are cylindrical toward the head becoming slightly compressed toward the tail. Larval stages have fins that are substantially reduced in size, consisting of a low dorsal fold that is notched to form the caudal fin. Eyes of larval lampreys are small and barely functional; with the ammocoete life history stage distinguished by larval fish lacking visible eyes (organs are located beneath the skin). Conversely, the macrophthamia life history stage can be determined by the appearance of eyes as well as changes to the mouth structure. The mouth structure in ammocoetes is protected by a small thin hood that encloses sieve-like oral cirrhi (Richards and Beamish 1981). This structure changes during metamorphosis to a large sucking disc armed with horny teeth and a rasping tongue (Manion and Stauffer 1970; Youson and Potter 1979). Adults have two anteriorly positioned dorsal fins. The caudal oedema is dimorphic during sexual maturity where the female develops a ventral fold that resembles an anal fin (Wydosky and

Whitney 2003). Both sexes swell at the anterior edge of the second dorsal fin as they become sexually mature (Wydosky and Whitney 2003). Adults are equipped with a round mouth (oral disc) with three large teeth (cusps) on the supraoral bar and three points on each of the central four lateral tooth plates used for parasitic feeding. Unlike teleosts, Pacific lampreys respire through multiple gill openings instead of an operculum. They lack swim bladders and must swim constantly or hold fast to objects to maintain their position in the water column (Mesa et al. 2003).

1.5.4. Spawning

Pacific lampreys spawn from April to July (Wydoski and Whitney 2003) in low gradient stream reaches in sand and silt substrates (Mattson 1949; Pletcher 1963; Kan 1975). Pacific lampreys may reside in freshwater for a few months up to two years prior to reproduction (Chase 2001; Whyte et al. 1993; Fox and Graham 2008). Redds have been observed in water velocities that range from 0.5 to 1.0 meter per second ($m{\cdot}s^{-1}$) and at depths between 30 centimeters (cm) to 4 meters (m) (Pletcher 1963; Kan 1975; Gunckel et al. 2006). Redds can range between 20 to 73 cm in diameter at a depth of 4 to 8 cm (Kan 1975; Russell et al. 1987; Howard et al. 2005). Fecundity ranges from 30,000 to 238,400 eggs (Kan 1975; Close et al. 2002; Wydoski and Whitney 2003). Eggs hatch within 2 to 3 weeks depending upon water temperature (Meeuwig et al. 2005; Brumo 2006). Survival to hatching ranges from 50 percent to 60 percent (Close et al. 2002). Adults die 3 to 36 days after spawning (Pletcher 1963; Kan 1975; Beamish 1980).

1.5.5. Ammocoete

After Pacific lampreys eggs hatch, larval fish drift downstream and burrow into the substrate within low gradient areas characterized by slow water velocities and fine substrates (Pletcher 1963; Lee et al. 1980; Richards 1980; Potter 1980; Roni 2002; Pirtle et al. 2003; Torgerson and Close 2004; Graham and Brun 2005; Stone and Barndt 2005; Cochnauer et al. 2006; Sutphin and Hueth 2010). Ammocoetes remain within the stream substrate and metamorphose in four to seven years (Beamish 1987; Wydoski and Whitney 2003).

1.5.6. Macropthalmia

The stages of metamorphosis have been described for Pacific lampreys (see Richards and Beamish 1981 and McGree et al. 2008). Proximate and ultimate cues for Pacific lamprey metamorphosis and thus the ability to predict it remain unknown. Migrating macrophthamiahave been collected year round and correlated with rain or snow melt, distance from ocean, and elevation (Beamish 1980; Potter 1980; Richards and Beamish 1981; Close et al. 1995; Kostow 2002).

1.5.7. Adult

Time spent in the marine habitat for adults is thought to be six months to three and a half years (Kan 1975; Beamish 1980; Richards 1980). They have been caught at depths ranging from 90 to 800 m and at distances greater than 100 kilometers (km) offshore in ocean haul nets (Close et al. 2002; USFWS 2004; Orlov et al. 2008). Pacific lampreys most commonly occupy the upper 100 m pelagic zone and at bottom depths as deep as 500 m (Beamish 1980; Orlov et al. 2008). Pacific lampreys apparently make daily vertical migrations from the ocean bottom into the pelagic zone, presumably to feed (Orlov et al. 2008). Adults are parasitic on fishes and marine mammals (Scott and Crossman 1973; Beamish 1980). Adults migrate back to freshwater streams to reproduce.

2.0 LITERATURE REVIEW

2.1. Introduction

Conservation of Pacific lamprey is an increasingly important priority given their ecological and cultural importance. Development of the methodology for the culture of this species is desired for a number of reasons including creating surplus stock for mitigation, research, translocation efforts and to serve as a means to establish and maintain refugia populations. However, very few fisheries researchers, managers, or culturists have documented techniques and practices for the successful spawning, rearing, and release of Pacific lamprey progeny. Development and documentation of aquaculture practices for Pacific lampreys has been limited to a handful of researchers that have used wild caught specimens maintained in laboratory settings. More often these limited culture activities have only included spawning and rearing of fish for brief periods of time. Successful culture of all life stages should benefit the species by reducing collection pressures on wild populations.

2.2. Lamprey Culture/Propagation

Pacific lampreys have been propagated, although it has not been done intensively (where all life-stages are reared under controlled culture conditions) on a production scale or from gametes to reproductively mature adults (Table 1). In most cases, lamprey culture has been carried out on small scales for individual research studies or classroom aquarium observations (Table 1). Production scale or culture endeavors through one or more life stages are reared in hatchery jars and trays, tanks, raceways, ponds, or natural water systems. This typically begins with collection of wild fish, gamete stripping and artificial insemination. The embryos and newly hatched larvae are then placed into natural watersheds, raceways, ponds, or tanks for grow-out on either processed feed or supplemented and naturally occurring food resources. Although, the release of cultured fishes into natural bodies of water is usually delayed until fish are well past the fragile life history stages (e.g. embryonic, larval, and early ammocoete stages) this may not be the best approach for lampreys. Lamprey in general present significant difficulties for intensive culture because of the long duration of the juvenile period that requires a supply of food for anywhere from four to seven years while they are ammocoetes (Beamish 1987; Wydoski and Whitney 2003) and the maintenance of food sources for the parasitic life history form. Developing a methodology for the culture of Pacific lampreys through all life history stages will take several years to achieve, and challenges will be encountered with each life stage until they are successfully raised to adults. Nevertheless, production scale or culture endeavors through one or more life stages may be of significant conservation value, given the current demographic trends observed with this species. This manual describes Pacific lamprey life stages and major bottlenecks to successful culture.

TABLE 1. PREVIOUSLY REPORTED ATTEMPTS SPECIFIC TO CULTURE AND/OR REARING VARIOUS LIFE HISTORY STAGES OF LAMPREY WITHIN A LABORATORY OR HATCHERY SETTING. THE NUMBER OF DAYS THAT INDIVIDUALS WERE MAINTAINED IN CAPTIVITY ARE REPORTED AS DAYS (D).

Author (Year)	Lamprey Species	Purpose (Life Stage Reared)	Time in Captivity (Number of days)
Beamish (1980)	Pacific & River	Life history parasitic feeding (ammocoetes, macopthalmia, adults)	N/A
Close et al. (2001)	Pacific	Culture techniques (gametes to ammocoetes)	92
Mallatt (1983)	Pacific	Larval growth (larvae to ammocoetes)	180
McGree et al. (2008)	Pacific	Laval metamorphosis (ammocoetes to macropthalmia)	150
Meeuwig et al. (2005)	Pacific & W. Brook	Temperature on survival and development (gametes to larvae)	294*
Meeuwig et al. (2006)	Pacific & W. Brook	Morphometric description (embryos)	30+
Richards and Beamish (1981)	Pacific	Initial feeding and salt tolerance (ammocoetes & macropthalmia)	75
Yamazaki et al. (2003)	Pacific	Embryonic development (embryos)	32
Fredricks and Seelye (1995)	Sea	Recirculation system to induce spawning (gametes to larvae)	42
Hanson et al. (1974)	Sea	Culture methods (gametes to ammocoetes)	730
Holmes and Lin (1994)	Sea	Thermal niche (ammocoetes)	40
Holmes and Youson (1994)	Sea	Metamorphosis (ammocoetes to macropthalmia)	270
Holmes and Youson (1997)	Sea	Larval density and metamorphosis (ammocoetes to macropthalmia)	321
Holmes and Youson (1998)	Sea	Temperature for metamorphosis (ammocoetes to macropthalmia)	300
Langille and Hall (1988)	Sea	Artificial fertilization embryo development (gametes to ammocoetes)	60d
Lennon (1955)	Sea	Propagation (gametes to ammocoetes)	147
Mallat (1982)	Sea	Feeding (ammocoetes)	60
Murdoch et al. (1992)	Sea	Growth rates (ammocoetes)	273
Paivis (1961)	Sea	Embrological stages (gametes to embryos)	37
Paivis and Howell (1969)	Sea	Rearing embryos in distilled water (gametes to ammocoetes)	22

Author (Year)	Lamprey Species	Purpose (Life Stage Reared)	Time in Captivity (Number of days)
Rodríguez-Muňoz et al. (2001)	Sea	Temperature on survival and growth (gametes to ammocoetes)	100+
Rodríguez-Muňoz et al. (2003)	Sea	Density dependent growth of larvae (ammocoetes)	10d
Rodríguez-Muňoz and Ojanguren (2002)	Sea	Gamete preservation (gametes to ammocoetes)	N/A
Sawyer (1957)	Sea	Laboratory care and feeding (ammocoetes)	180
Youson et al. (1993)	Sea	Metamorphosis (ammocoetes to macropthalmia)	153
Holmes et al. (1999)	Brook	Metamophosis (ammocoetes to macropthalmia)	117
Malmqvist and Brönmark (1981)	Brook	Filter feeding rates (ammocoetes)	7
Moore and Potter (1976)	Brook	Feeding (ammocoetes)	60d
Murdoch et al. (1991)	Sea and Brook	Interspecific competition (ammocoetes)	365
Resse (1900)	Sea and Brook	Maintain in captivity (gametes, ammocoetes, & adults)	180
Lee (1989)	Sea and Brook	Substrate selection (ammocoetes)	6
Cochran (1989)	Sea & Chestnut	Behavioral observations (ammocoetes & adult)	365
Hardisty and Potter (1977)	Sea & Silver	Diets and culture of lampreys (gametes to adults)	N/A
Smith et al. (1968)	Sea, Brook, Chestnut, N. Brook, & Silver	Comparative embryology (gametes to embryos)	22
HARA (2008)	Arctic	Develop hatching techniques (gametes to larvae)	14
Hagelin (1959)	River	Spawning observations (gametes to embryos)	N/A

Notes: N/A = Not Available; * = Degree Days

2.3. Propagation Methodologies

2.3.1. Adult Broodstock Collection

Adult Pacific lampreys can be collected for brood stock from the Columbia River and its tributaries. Pacific lampreys tend to congregate at manmade fishways and barriers and where the river geology causes flowing water to drop abruptly or is nearly vertical. Capture and handling survival is most likely improved by waiting to collect fish when the ambient water temperature is low (e.g. <15 ºC). Regardless of what active and passive capture techniques are employed to capture individuals, all attempts should be made to minimize injury and sub-lethal stress. All fish should be quickly retrieved and placed into well oxygenated transport containers. Ice can be used as necessary to prevent a large rise in temperature. There is a greater risk of mortality with increased stress levels, so fish should be handled and transported expeditiously and with care.

Adult Pacific lamprey collection in the Pacific Northwest can take place once individuals return from saltwater to freshwater (April to June; Beamish 1980; Close et al. 2002). Pacific lamprey may reside in freshwater for a few months up to 2 years prior to reproduction (Beamish 1980; Whyte et al. 1993; Chase 2001; Fox and Graham 2008), so holding fish in a captive environment may be required until gonadal recrudescence is complete. Although stocking densities of wild caught fish are unknown, fishes should be kept at relatively low density to minimize the risk of disease. Conversely, it is presumed that cultured fishes can be successfully maintained at much higher stocking densities. Adults held prior to spawning do not feed and rely on stored carbohydrates, lipids, and proteins for energy (Read 1968), often losing body weight and decreasing in size (Beamish 1980). Adults have been held for extended periods of time in relatively large circular tanks (e.g., 1400 L tanks) provided with continuous inflow of water (e.g., 0.3 $L \cdot min^{-1}$) with or without gravel and rock substrate (Close et al. 2001; Meeuwig et al. 2005). Although circular tanks are generally self-cleaning when sufficient water flow is used, they should be cleaned at regular intervals to remove unwanted debris and growth. Broodfish should be visually inspected at regular intervals for morphological changes associated with reproductive readiness.

2.3.2. Morphological Indicators of Spawning Readiness

Although both sexes swell at the anterior edge of the second dorsal fin as they become sexually mature, the caudal oedema is dimorphic once fish become sexually mature (Wydosky and Whitney 2003). Females develop a ventral fold that resembles an anal fin (Wydosky and Whitney 2003). This is initially visible in females as a ridge starting immediately posterior to the cloaca that eventually becomes filled with blood and swollen at sexual maturity (Photo 1; Close et al. 2001). Conversely, males develop urogenital papillae (Close et al. 2001).

Photo 1. Pacific Lamprey Oedema and Cloaca of a mature female prior to manually stripping. Credit: Close et al., 2001.

2.3.3. Gamete Collection and Fertilization

Although lampreys acclimated to laboratory conditions may spawn naturally when held between 10 and 16 °C under a natural photoperiod (Close et al. 2001), intensive culture may require manual spawning. Eggs and sperm can be obtained from lampreys after being anesthetized with a 60 mg/L concentration of tricaine methanesulfonate (MS-222; 3-aminobenzoic acid ethyl ester, Sigma Chemical Co., St. Louis MO; Close et al. 2001) buffered with a equal concentration of sodium bicarbonate to pH 7 (Langille and Hall 1988; Close et al. 2001;

Meeuwig et al. 2005). Stripping Stripping captive lamprey is carried out by grasping the head and exerting gentle pressure posteriorly from the branchial region anteriorly to the caudal fin given that males and females are "ripe". Male lampreys are considered ripe when milt can be obtained with gentle pressure. Examination of the milt, via a compound microscope, should reveal motile sperm. Females are considered ripe when eggs can be readily voided with gentle stripping (Photo 2). Females not sexually mature will have eggs still bound to the ovarian tissue and eggs will not be readily voided. Forcibly stripped gametes should be discarded since cell division will not typically occur after fertilization is attempted (Lennon 1955). Eggs may be removed surgically following the methods of Piavis (1961), although no viable Pacific lampreys have been produced from this method (Langille and Hall 1988).

Photo 2. Female Pacific Lamprey being manually stripped of eggs into a clear glass bowl. Credit; Close et al., 2001

Viable mature eggs and milt can then be placed into the same container, filled with either dechlorinated water or 10 percent Holtfreter's solution (35 mg NaCl, 0.5 mg KCl, 1mg $CaCl_2$, 2 mg $NaHCO_3$ in 100 ml H_2O), gently mixed, and left for 1 to 3 hours at 16 to 21 ºC (Langille and Hall 1988; Close et al. 2001; Meeuwig et al. 2005). Fertilization rates range from 65 percent to 98 percent with hatching rates of 85 percent to 90 percent (Close et al. 2001). Pacific lampreys produce small negatively buoyant eggs, which are approximately 1.7 ± 0.1 millimeter (mm) in diameter (Close et al. 2001). Healthy zygotes are a pale yellow-green color with a large perivitelline space (Close et al. 2001). Activation of the egg occurs within 10 to 30 seconds following fertilization providing the zygotes with a slightly adhesive property (Close et al. 2001).

2.3.4. Fecundity and Hatching

Embryos can be transferred to hatching trays or other containers, such as prefabricated "McDonald" type jars (Close et al. 2001, Meeuwig et al. 2005; Photo 3).

Close et al. (2001) reported that prefabricated jars 42 cm tall, 11.5 cm in diameter; volume = 6 liters (L) could hold 600,000 to 700,000 eggs and require a minimum inflow of 1 to 3 liters per minute ($L \cdot min^{-1}$) to keep a good flow of water passing the eggs and to maintain their suspension and movement within the jar. Nevertheless, once transferred, it is important that the eggs remain free of debris and disease during incubation. Removal of dead eggs from the incubators is critical to prevent fungus and bacterial outbreaks. Eggs that are not fertilized or that experience abnormal cell division will decompose and turn white, and a light table may be useful to identify and remove dead eggs. A piece of black plastic can be used in conjunction with the light table to help identify live eggs. The eggs can be maintained at various temperatures depending upon desired hatch timing (11 to 30 days; Table 2); however, temperatures of 22 ºC or greater appear to significantly increase mortality rates and the incidence of developmental abnormalities (see Meeuwig et al. 2005).

Photo 3. McDonald hatching jar containing Pacific Lamprey eggs and larvae. Credit: Close et al., 2001.

TABLE 2. TEMPERATURE AND DAYS REQUIRED TO OBTAIN 50 PERCENT AND 90 PERCENT HATCH AND FOR PACIFIC LAMPREYS TO REACH THE LARVAL STAGE. DAYS ARE SHOWN AS THE MEAN ± 1 SE CREDIT: MEEUWIG ET AL. (2005).

Temperature (°C)	Days to Hatch (50 percent)	Days to Hatch (95 percent)	Days to Larval Stage
10	26 ± 0.57	29 ± 0.50	56
14	17 ± 0.20	19 ± 0.36	35
18	11 ± 0.03	12 ± 0.10	23
22	8 ± 0.05	9 ± 0.08	17

2.3.5. Embryo Development

Embryonic development of the Pacific lamprey requires approximately 11 to 30 days (Close et al. 2001; Yamazaki et al. 2003; Meeuwig et al. 2005; Meeuwig et al. 2006) and has been fully described by Meeuwig et al. (2006). The stages of embryonic development occur at a similar rate as other lampreys (Photo 4; Yamazaki et al. 2003). The internal organs, circulatory system, and yolk are readily visible in Pacific lamprey as they develop (Close et al. 2001).

After larvae fully absorb their yolk sac, approximately 28 days, the ammocoetes begin feeding (Close et al. 2001) and can be transferred to aquaria or tanks that have substrate (e.g. sand) and a continuous flow of water.

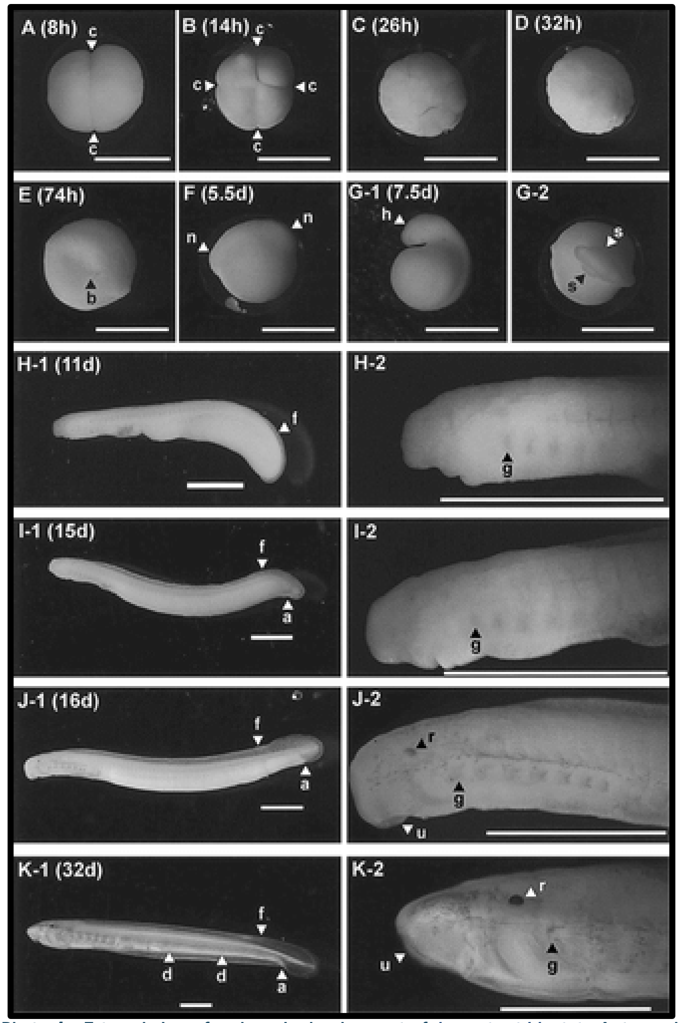


Photo 4. External view of embryonic development of *lampetra tridentata*. A: two-cell stage, b: eight-cell, c: morula, d: early blastula, e: early gastula, f: early neurula, g-1: lateral view of head protrusion, g-2: dorsal view of g-1, h-1: hatching, h-2: enlargement of h-1, i-1: melanophore, i-2: enlargement of i-1, j-1: eye spots, j-2: enlargement of j-1, k-1: completion of digestive tract, k-2: enlargement of k-1. Numerals in parenthesis indicate time (day) after fertilization. A, anus; b, blastopore groove; c, cleavage furrow; d, digestive tract; f, dorsal fin; g, 1st gill pore; h, head protrude; n, neural fold; r, pigmented retinae; s, cheek-like swellings; u, upper lip. Scale bars indicate 1 mm. Credit: yamazaki et al. (2003).

2.4. Ammocoete Rearing

2.4.1. Required Substrate

Rearing of ammocoetes may require that facilities be equipped with raceways or tanks that contain a natural or artificial substrate [e.g. glass bead or silica sand substrates (range = 0.5 to 1.0 mm); Moore and Potter 1976a,b]. Sea lamprey substrate preference tests indicate that both the mean grain diameter and permeability set limits to burrowing substrate suitability (Lee 1989). The substrate used in ammocoete rearing tanks should be equipped with sediments that have a mean diameter of less than 1.0 to 2.0 millimeters (mm) and a porosity that ranges between 1 to 7 cm·min^{-1} (Lee et al. 1989). There is no evidence that mean grain diameter per se set a lower limit to substrate suitability (Mallatt 1982; Lee 1989).

Stock rearing tanks equipped with appropriate substrate are needed to maximize food assimilation rates. Ammocoetes that are active pass food items through the gut faster than if at rest or when minimally active (Moore and Potter 1976a). For example, sea lamprey held at 16 °C in tanks with substrate take about 54 hours to evacuate the gut (Moore and Beamish 1973) as opposed to individuals maintained in glass aquaria with no substrate that take approximately 1 hour to evacuate the gut (Moore and Potter 1976a). This occurs presumably due to an increased metabolic rate from increased swimming activity and branchial pumping in containment vessels without substrate (Potter and Rogers 1971; Moore and Potter 1976a; Sutton and Bowen 1994) coupled with an apparent lack of morphological adaptations for detritus digestion. In short, low metabolism is linked to slow growth and an extended length of detritivorous larval phase.

2.4.2. Ammocoete Feeding and Assimilation

Ammocoetes feed very slowly and are inefficient at utilizing their food, a characteristic of many organisms that feed mainly on detritus and/or algae (Moore and Potter 1976a,b). Glandular goblet cells that reside in the lateral portion of each gill filament and lateral walls of the pharynx produce feeding mucus that is secreted liberally and occupies almost all available space within the pharynx. Mucus moves inward via lateral braches found within each gill pouch toward the central part of the pharynx where it is collected into a lateral band (also referred to as the food cord) by ciliary movement. Thus the mucus acts to trap, aggregate, and transport food particles up to 300 micrometers (µm) in diameter (Moore and Mallatt 1979). This characterization of feeding mechanism appears to be common to ammocoetes of all sizes and genera.

Even though ammocoetes are considered to be filter feeders where a large proportion of their food is drawn in from the water, the constant shifting of sediments and movement of larvae suggest that benthic organisms may also be consumed in varying degrees. Furthermore, given that burrows are often closed off it follows that food may be drawn in by a combination of water and sediments depending upon the activity and environmental conditions.

Although both algae and detritus have been shown to support growth in ammocoetes, organic detritus is most likely the principal resource supporting metabolism and growth in Pacific lampreys even though detritus is relatively energy poor given that it is composed (90 to 95 percent) of cellulose, lignin, and ash (Calow 1973; Monk 1976). Detritus makes up the largest proportion (>95 percent) of the diet, followed by algae, diatoms, and bacteria in congeneric lamprey species (Moore and Potter 1976a; Sutton and Bowen 1994). Gut fullness of ammocoetes (4.2 to 5.5 mg diet ash-free-dry-mass AFDM·g^{-1} ammocoete·d^{-1}), that is positively related to water temperature as opposed to diet digestibility, is far below typical values for juvenile fishes (60 mg AFDM·g^{-1} fish·d^{-1}; Sutton and Bowen 1994). Though food items (e.g. detritus) have been added to aquaria at rates of 30 mg·L^{-1} (Sutton and Bowen 1994), feeding rates appear to be less dependent upon food density and more so on water temperature (Moore and Mallatt 1979). Ammocoetes assimilate only 30 percent to 40 percent of the protein, lipid, and carbohydrate and 6 percent to 7 percent of the cellulose in their food (Moore and Mallatt 1979). As a result, ammocoetes pass large quantities of undigested food and algae through their guts, especially at low water temperatures.

Although both algae and detritus have been shown to support the growth of ammocoetes, yeast appears to be a reasonable alternative food source for intensively cultured lampreys given its low cost. Mallatt (1983) found that Pacific lampreys fed yeast had weight increases (>6 percent $month^{-1}$) similar to wild fish for up to 6 months. In this study growth (+41 percent $month^{-1}$) was most rapid at 14ºC with an animal density kept at <0.5 g of animal (wet weight) L^{-1} and an average daily yeast concentration of 4 to 13 mg·L^{-1}. Growth was slower at cooler (4ºC) and warmer (20ºC) water temperatures and at higher animal densities. Growth may be enhanced if yeast concentrations are increased; however, means to keep tanks clean and appropriate rearing densities will need to be investigated.

2.5. Macrophthamia Rearing/Maintenance/Release

2.5.1. Size at Metamorphosis

How long the ammocoete stage lasts before metamorphosis is not known; however, the literature suggests that within cohort variability may be high (Purvis 1979; McGree et al. 2008). As a general "rule of thumb", lampreys tend to metamorphose once they reach 3 to 5 grams and mean length of about 150 mm (Hardisty 1961) in 4 to 7 years *in situ* (Beamish 1987; Wydoski and Whitney 2003). Data suggests that lampreys begin metamorphosis during the summer (i.e. July; McGree et al. 2008). Pacific lampreys require a minimum of 105 to 150 days once metamorphosis begins until fish are considered macrophthamia(McGree et al. 2008) and presumably ready to emigrate (Richards and Beamish 1981). Condition factor, a surrogate used to determine individuals that are going to metamorphose in other species (Potter et al. 1978), is not related to morphological characteristics in Pacific lampreys (McGree et al. 2008). Presumably, Pacific lampreys feed during metamorphosis given that fish continue to increase in length and weight during this period. Therefore, it is encouraged that feeding regimes, whether supplemental or providing unfiltered stream water, continue until metamorphosis is complete even though it has been reported that other lamprey species do not feed during this period (Purvis 1980; Morman 1987; Youson et al. 1993; Holmes and Youson 1994).

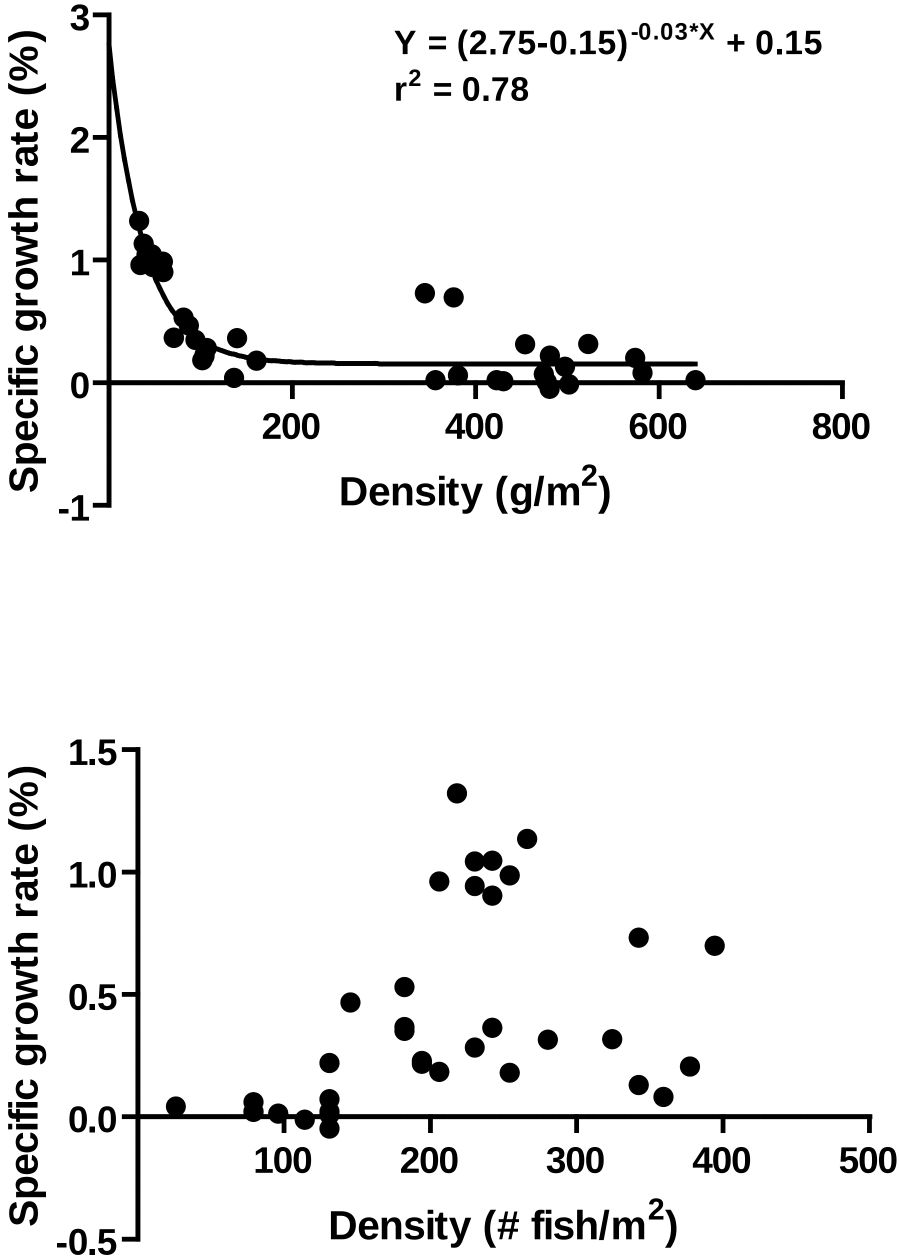
2.5.2. Volitional Release

Given that ammocoete growth rates are variable and the onset of metamorphosis is relatively unpredictable, or as of yet undetermined, for a cohort, volitional release may be an option that ensures juvenile lampreys are released in concert with optimal morphological and physiological development. The primary assumptions underlying volitional release strategies are that 1) hatchery fish will not choose to initiate downstream migration until physiologically and morphologically prepared; and 2) since these volitional release migrants are physiologically primed for downstream migration, they will have a survival advantage as compared to force-released fish (Gale et al. 2009). However differences in lamprey physiology have yet to be related to differences in migratory behavior (e.g. travel time) or enhanced survival (Richards and Beamish 1981) relative to traditional force released fish. Although the downstream migration of lampreys appears to be positively related to increased stream discharge (Hardisty and Potter 1971; Richards and Beamish 1981), there is a complete lack of information concerning the migratory behavior and post-release survival of volitionally released lampreys as they travel to the ocean (assumption based on salmonid data). Volitional release strategies will therefore involve designing release facilities so that fish can choose between leaving the hatchery or release site and entering their natal stream or remaining.

2.6. Structural Characteristics and Equipment

Little is known about the artificial propagation of lampreys, particularly when compared to the extensive knowledge available on the culture of other fishes, such as salmonids or catfish (see Piper et al. 1983). The few studies describing lamprey aquaculture conditions suggest that they require specialized, low density rearing conditions (Hanson et al. 1974; Mallatt 1983; Swink 1995; Murdoch et al. 1991; Rodriguez-Muñoz et al. 2003; Meeuwig et al. 2005, 2007; Stone et al. 2006; McGree et al. 2008; Silver et al. 2009). Pacific lamprey aquaculture requires handling, holding, and rearing of the following life stages: adult, egg, embryonic, and larval. Adult lampreys must be collected from the wild during their upstream migration-probably during the late spring through summer months-and held until sexually mature (up to 1 year) in large circular tanks (e.g., 5-foot-diameter, 3 foot water depth) or raceways with flow-through water at temperatures consistent with those found in the natural environment (5°C to 22°C). It would also be advisable to hold lampreys under a simulated or natural photoperiod because of the influence of changing environmental conditions (i.e., water temperature and day length) on reproductive development in fishes (Munro et al. 1990). It is not know whether or not lampreys will sexually mature if reared under uniform environmental conditions—the influence of changing water temperatures and photoperiod on the sexual maturation of Pacific lampreys requires further study. Once sexually mature, they can be manually spawned and the eggs fertilized *in vitro* using fairly standardized procedures developed for teleost fishes (Piper et al. 1983). Methods specific for spawning Pacific lampreys have been presented in Close et al. (2001) and Meeuwig et al. (2005). Pacific lamprey eggs have been successfully incubated during early embryonic development in flow-through hatching jars (McDonald jars) followed by transfer to small rearing vessels for hatching (Meeuwig et al. 2005). Appropriate temperatures for rearing eggs range from 10°C to 18°C, with the best survival at 18°C (Meeuwig et al. 2005). It is not know as to whether or not other types of egg incubators, such as hatching trays, various troughs, and hatching baskets (see Piper et al. 1983 for a discussion), have been evaluated for lamprey culture. When the lampreys have hatched and reached the larval stage, they are usually transferred to aquaria or shallow tanks containing a layer of burrowing substrate (3 to 40 cm in depth, depending on size of tank).

Many studies (see previous paragraph) indicate that larval lampreys (ammocoetes) grow best at low densities, but variation in species, experimental design, size at stocking, feeding, and perhaps other factors make it difficult to draw definite conclusions. For Pacific lampreys, optimal growth was reported at about 10 fish per meter squared (fish/m^2) (12.5 to 25 g/m^2) due to growth inhibition at higher densities (Mallatt 1983). Other studies showed good survival and growth at densities of 48 fish/m^2 for ammocoetes of unknown age collected from the wild (Stone et al. 2006; McGree et al. 2008; Silver et al. 2009). This equates to 10 to 12 fish per 50 L tank (McGree et al. 2008, Silver et al. 2009). Ammocoetes (89 to 122 mm TL) caught from the wild showed negative growth when held at densities of 242 fish/m^2 (Meeuwig et al. 2007). In contrast, recent work by the USGS showed that ammocoetes ranging from 45 to 78 mm TL and reared at a slightly lower density of 201 fish/m^2 increased in mass by 31 percent in about three months. The discrepancy between these two studies is probably related to the initial size of fish at stocking-the actual density (by mass) of the fish used by Meeuwig et al. (2007) was 536 g/m^2, whereas the USGS data was only 105 g/m^2. Thus, the USGS success with a high numerical density was likely due to the smaller initial size of the ammocoetes and emphasizes the need to determine fish density based on mass rather than numerical metrics. It is recommended that rearing density for young ammocoetes be expressed as g/m^2 of substrate, which shows a strong relation to growth rate (Graph 1). For comparison, studies on larval sea lampreys (*Petromyzon marinus*) indicate good growth and high survival at numerical densities ranging from 26 to 600 animals/m^2 of substrate (Hanson et al. 1974; Swink 1995; Murdoch et al. 1991; Rodriguez-Muñoz et al. 2003).



Graph 1. Specific growth rate (percent change per day) of pacific lamprey ammocoetes relative to biomass (top panel) and numerical (bottom panel) rearing densities. The line of best fit is shown as an exponential decay model.

Collectively, the information presented above suggests that substantial space will be required to rear larval lampreys under intensive culture conditions and produce sufficient numbers of fish. For an extreme example, rearing 100,000 ammocoetes at the densities suggested by Mallatt (1983; 12.5 to 25 g/m^2) would require a massive array of tanks since a single 50 L tank would hold only one or two ammocoetes with a mass of 2.5 g. While this is an extreme example, it does illustrate the need for more research on the influence of density, and other factors, on the growth of larval lamprey. Based on recent USGS experience, it may be possible to rear young ammocoetes at a density of about 135 g/m^2 of substrate. For rearing in the laboratory, the USGS use rectangular fiberglass tanks that are 51×43×27 cm (L×W×D) and had a bottom surface area of 0.15 m^2. If a starting average mass of 0.1 g per lamprey is assumed, then conceivably a tank could be stocked with approximately 203 ammocoetes. To raise 100,000 lampreys would therefore require almost 500 tanks. To house this number of tanks would require a room of about 1,200 ft^2 (111 m^2), assuming tanks were stacked two high and space was allotted for working. These examples are for illustrative purposes only and indicate a need for a complete understanding of the impacts of density on ammocoete growth, health, and condition prior to implementing any intensive culture efforts.

While it is inferred that adult lampreys could be held in or outdoors, indoor facilities will probably be required for egg, embryonic, and larval culture so that temperature and light regimens can be controlled. For now, facilities should focus only on spawning, incubating eggs, and rearing ammocoetes for a year or two. Culturing lampreys through the macrophthamiastage is not recommended because of the long maturation time of larval lampreys (4 to 6 years, Scott and Crossman 1973) and the sensitivity of metamorphosed lampreys to aquatic disease in captivity (Schreck et al. 1999; Meuller et al. 2006). This endeavor should be approached on a small-scale, research basis only.

To summarize, aquaculture of Pacific lampreys will, at a minimum, require the following:

- Several large rearing tanks or raceways for adult rearing
- Photoperiod control
- Water temperature control
- Egg incubators
- Aquaria, shallow tanks, or troughs for ammocoete rearing
- Burrowing substrate
- Food and preparation area
- Indoor and outdoor rearing areas

2.7. Heath, Disease and Treatment

In Pacific lamprey, the primary pathogen of concern is a bacterium (*Aeromonas salmonicida)* the causative agent of furunculosis (S. Gutenberger, USFWS pers. comm.). U.S. Fish and Wildlife Service and Oregon Department of Fish and Wildlife data suggest that approximately 8 percent to 10 percent of adult lamprey have infections of *A. salmonicida.* Infections of this type ultimately result in mortality of the fish. Therefore, it is advisable to inject oxytetracycline (10 to 20 $mg{\cdot}kg^{-1}$ per fish) intraperitoneally before or after transport of adults to a culture facility. The injection also controls *A. hydrophila*, an opportunistic bacterium that causes disease and mortality in ammocoetes and adults subjected to stressful environments. Both pathogens may result in ammocoete mortality. *Vibrio vulnificus*, a bacterium that causes epizootics in European Eel, has also been detected in juvenile Pacific lamprey. Given that the integument of Pacific lamprey is sensitive to mechanical trauma during handling, careful handling practices are advised. Rough handling may lead to lesions that become secondarily infected with opportunistic bacteria and fungus. It is recommended that fish be transported in a salt bath (0.1 percent) to reduce stress.

Upon arrival at a site, formalin (167 parts per million (ppm)) for 1 hour, static bath, every 3 days until cleared) may be needed to control fungus.

Good fish health is imperative for a stable and reliable culture program, and protocols for accurate monitoring of the fish and their rearing systems must be implemented. If efforts are taken to ensure that water quality is appropriate, stress is minimized, and care is taken to prevent introduction of pathogens, then disease should not be prevalent. Good biosecurity ensures that risk of pathogens from an outside source is minimal, especially when personnel or visitors from other labs are entering the premises.

The most effective measure against disease is preventative maintenance. Careful daily monitoring of the tanks can prevent poor water quality, overfeeding (or underfeeding), and decrease stress causing agents, thereby reducing the chance of a disease outbreak. Each individual stressor may not result in direct harm, but their effect is additive and can lower the fish immune response, resulting in disease. Careful monitoring is also required to enable an early diagnosis for disease. Preventative maintenance may appear to be labor intensive in that additional steps must be taken, however it is considerably easier and more cost effective to perform good management practices than to treat sick fish and risk exposure of other systems on site.

Each fish system should be kept separate with safeguards to avoid contamination within and among systems. Sampling devices, such as pipettes, beakers, nets etc. should be disinfected between uses (e.g., iodine). Designated scrub pads, nets, and siphons should also be identified and ideally stored in a bucket of dilute iodine solution by each tank (flow-through system) or for each separate system (recirculation systems). This will help reduce transmission of pathogens among tanks and systems. Disinfection footbaths and hand baths are also an effective measure to reduce the risk of contamination. If a disease outbreak does occur, its early diagnosis and treatment is the best option. Any sick or moribund fish should be quickly removed as these individuals pose a risk of transferring pathogens to other fish, tanks or systems at the facility.

3.0 STRUCTURED REARING FACILITIES

3.1. Introduction

For lamprey aquaculture to be successful there will need to be facilities available to conduct this work and standard protocols developed to ensure the production of healthy fish in sufficient numbers to achieve restoration and research goals. As stated, little is known about the intensive culture of lampreys. Most work has been completed on an experimental basis and the development of effective and efficient techniques will likely involve the collective efforts of fisheries researchers, fish culturists, and nutritionists.

3.2. Regional Facilities Inventory/Evaluation

To evaluate the potential of various existing hatchery and research facilities in Oregon and Washington for lamprey aquaculture, a questionnaire was developed (Appendix B) specific to the needs of a basic lamprey aquaculture facility. The questionnaire was then sent to the managers or leaders of each site (Table 3) and summarized their responses. The focus was on facilities that were near the Wenatchee, Entiat, and Methow drainages but also included some others because of their previous experience with lampreys or other unique attributes. Details of the facilities are shown in Table 4, and the following are summaries of the responses received from each facility.

TABLE 3. CANDIDATE FACILITIES FOR LAMPREY AQUACULTURE AND IDENTIFICATION OF FACILITIES THAT ARE INTERESTED IN PARTICIPATING IN A LAMPREY AQUACULTURE PROGRAM

Name of Facility	Location	Affiliation	Interest in Lamprey Aquaculture
State Fish Hatcheries			
Chelan Hatchery	Chelan, WA	WDFW	Unknown
Chiwawa Ponds Hatchery	Leavenworth, WA	WDFW	Unknown
Lake Wenatchee Hatchery	Leavenworth, WA	WDFW	Unknown
Eastbank Hatchery	Wenatchee, WA	WDFW	Unknown
Turtle Rock Hatchery	Wenatchee, WA	WDFW	Unknown
Columbia Basin Hatchery	Moses Lake, WA	WDFW	Yes
Priest Rapids Hatchery	Mattawa, WA	WDFW	No
Methow Hatchery	Winthrop, WA	WDFW	Unknown
Omak Hatchery	Omak, WA	WDFW	Unknown
Similkameen Pond	Oroville, WA	WDFW	Unknown
Wells Hatchery	Pateros, WA	WDFW	Unknown
Naches Hatchery	Naches, WA	WDFW	No
Ringold/Meseberg Hatchery	Mesa, WA	WDFW	Yes
Federal Fish Hatcheries			
Entiat National Fish Hatchery	Entiat, WA	USFWS	Yes
Leavenworth National Fish Hatchery	Leavenworth, WA	USFWS	Yes
Winthrop National Fish Hatchery	Winthrop, WA	USFWS	No
Tribal Fish Hatcheries			
Colville Tribal Hatchery	Bridgeport, WA	Colville Tribe	No
Cle Elum Fish Hatchery	Cle Elum, WA	Yakama Nation	Unknown
Prosser Facility	Prosser, WA	Yakama Nation	Unknown
Marion Drain	Near Granger, WA	Yakama Nation	Unknown
Klickitat Fish Hatchery	Near Glenwood, WA	Yakama Nation	Unknown
Research Laboratories			
Columbia River Research Laboratory	Cook, WA	USGS	Yes
Cle Elum Supplementation and Research Facility	Cle Elum, WA	Yakama Tribe	No response
Abernathy Fish Technology Center	Longview, WA	USFWS	Yes
Oregon Hatchery Research Center	Alsea, OR	ODFW	Yes

ODFW—Oregon Department of Fish and Wildlife, WDFW—Washington Department of Fish and Wildlife, USGS—U.S. Geological Survey, USWFS—U.S. Fish and Wildlife Service

TABLE 4. SUMMARY OF FACILITY DETAILS FOR HATCHERIES AND RESEARCH CENTERS INTERESTED IN LAMPREY AQUACULTURE.

Facility Name	Experience Raising Eggs	Egg Facilities Available	Indoor Space Available	Tanks/Raceways for holding adults	Water Source	Water Temperature	Contaminants	Water Heaters
Entiat NFH	Yes	Yes	2,500 ft^2 for egg facilities 280 - 1,000 ft^2 concrete pad.	Tanks: 150, 360 or 800 gallons	Spring or Well	Spring: 0.5°C to 23.8°C Well: 8.8°C to 10°C	None	No
Leavenworth NFH	Yes	Yes	300 ft^2	15 small Foster Lucas ponds	River or Well	River: 0.5°C to 20°C Well: 5.5°C to 11.1°C	None	No
Columbia Basin State Hatchery	Yes	No	600 ft^2	25 ft x 4 ft x 2.5 ft 15 ft x 3 ft x 2ft Various Round Tanks	Spring	14.4°C	None	No
Ringold/Meseberg State Hatchery	Yes	Yes	Very limited	Raceways: 15 ft x 3 ft x 2 ft	Spring	14.4°C	None	No
Columbia River Research Laboratory	Yes	Yes	2,000 ft^2 Contingent	Tanks: 5 ft diameter x 3 ft deep (423 gallons)	River	4.4°C to 7.2°C	None	7 flow-through heaters (7kW to 75kW), two 300k boiler system
Oregon Hatchery Research Center	Yes	Yes	538 ft^2	Tanks: 3 - 13 ft diameter 4 - Raceways: 10 ft x 79 ft	River	4°C to 12°C	None	Yes, can heat water up to 12.7°C above ambient
Abernathy Fish Technology Center	Yes	Yes	See Text	Tanks: 10 ft circular Raceways: 8 ft x 80 ft	River or Well	River: max of 20°C Well: 11.7°C to 12.1°C	None	Yes

3.3. Facility Details - Strengths and Weaknesses of Viable Facilities

3.3.1. Entiat National Fish Hatchery

The Entiat National Fish Hatchery currently has an experienced aquaculture staff, and there are incubator and hatching facilities available in May and June, during lamprey spawning season. The hatchery manager was quite interested in the prospect of lamprey aquaculture. The indoor incubation and early-rearing facility has about 2,500 ft^2 of space available. There is also an existing 28 foot by 10 foot concrete pad with power and water hook ups that could be used to construct an isolation unit dedicated to lamprey rearing, and the pad could be increased to approximately 50 foot by 20 foot if desired. Options for holding adult lampreys include sixteen indoor early-rearing tanks (16 foot by 4 foot, 800 gallons), six early-rearing troughs (16 foot by 16 inch, 150 gallons), and a few circular tanks (5-foot-diameter, 360 gallons). The water for the facility comes from six wells and one spring capable of producing a combined 1,500 to 2,000 gallons per minute (gpm). Less than 100 gpm of first pass well water could be dedicated toward lamprey production, but effluent well water from salmon production raceways could also be used to supplement. The seasonal variation in water temperature is 48°C to 10°C for well water and 0.5°C to 23.8°C for spring water. There are no known contaminants in either water source. The hatchery does not have the capability to heat water, but well water can be tempered with spring water during winter months and vice versa during summer months to control water temperature. The hatchery has some capability to chill water, if necessary.

3.3.2. Leavenworth National Fish Hatchery

The National Fish Hatchery in Leavenworth, WA, also has an experienced crew that was very interested, and their egg incubation and hatching facilities are available in May and June. About 300 ft^2 of indoor space could be allocated to lamprey aquaculture, and there are 15 small Foster Lucus ponds that could be used to hold adult lampreys prior to spawning. The hatchery has access to river water (42 cubic feet per second (cfs)) and 7 wells. The seasonal range of water temperature is 0.5°C to 20.0°C for river water and 5.5°C to 11.1°C for well water. There are no known water contaminant issues, and dissolved oxygen is greater than 9 ppm year round. There are currently no water heating capabilities at this facility.

3.3.3. Washington State Fish Hatcheries

The State Fish Hatcheries overseen by the Washington Department of Fish and Wildlife (WDFW) are available for lamprey aquaculture, but completed questionnaires were only received from four of them. Two hatcheries expressed an interest in lamprey aquaculture (facility details summarized below), and two did not. The remainder declined to fill out the questionnaire at present. Once the facility requirements for lamprey aquaculture are established and an aquaculture program is ready to be funded, Heather Bartlett, the State Hatcheries Division Manager, will assess available hatcheries for adequacy as lamprey aquaculture sites (personal communication).

3.3.3.1. COLUMBIA BASIN STATE HATCHERY

The Columbia Basin Hatchery, overseen by the WDFW, is interested in lamprey aquaculture. They have staff experienced with egg rearing protocols, and egg incubation and hatching facilities are available during lamprey spawning season. They have about 600 ft^2 of indoor space available for lamprey aquaculture and indoor (15 foot by 3 foot by 2 foot) or outdoor (25 foot by 4 foot by 2.5 foot) raceways for holding adult lampreys. Various round tanks are also available. The facility uses spring water that does not contain known contaminants. The water temperature is 14.4°C year round, and no heating sources are available.

3.3.3.2. RINGOLD/MESEBERG STATE HATCHERY

The Ringold/Meseberg Hatchery, also overseen by the WDFW, is interested in lamprey aquaculture but has very limited space. They have staff with egg rearing experience, but their egg incubation and hatching facilities are not available during lamprey spawning season. Although an estimate of available indoor space was not provided, it was indicated that space was very limited. There are outdoor raceways (15 foot by 3 foot by 2 foot) available for holding adult lampreys. The water for the facility comes from a spring that is thought to be contaminant-free. The water temperature is 14.4°C year round, and no heating sources are available.

3.3.4. Columbia River Research Laboratory

The Columbia River Research Laboratory (CRRL) has previous experience rearing all life stages of Pacific lamprey for research purposes (e.g., Meeuwig et al. 2005; Meeuwig et al. 2007; Mesa et al. 2003; Mesa et al. 2010; Robinson et al. 2009) and would be interested in conducting lamprey aquaculture research. They have staff familiar with lamprey spawning and egg rearing techniques, and egg incubation and hatching facilities are available year round. The wet lab facility at the CRRL has approximately 2,000 ft^2 of indoor wet lab space, but available space is contingent upon other research activities. For example, in 2011 there would be two rooms available - 324 ft^2 and 494 ft^2 each. For holding adult lampreys, there are tanks available both indoors and out. Most tanks are 5 feet in diameter and 3 feet deep with a volume of 423 gallons. The water source currently used for lamprey aquaculture at the CRRL is river water from the Little White Salmon River, and the seasonal water temperatures range from 4.4°C to 7.2°C. There are no known water contaminants, and Pacific lampreys have survived well on this water source. With heavy rain, there is increased turbidity, and water visibility can decrease to zero during flood events in the winter or during spring runoff. These events typically last only days or a couple of weeks at most. The increase in turbidity has had no effect on lamprey survival in previous work. The river water system has two sand filters for partial sediment reduction. For heating water, there are seven flow-thru water heaters, ranging in power from 7 kW to 75kW. The lab is also equipped with two 300k BTU boiler systems that are fueled with liquid propane. Heating capacity is dependent upon flow rates, but river water has been heated as high as 18°C at 5 to 6 gpm.

3.3.5. Oregon Hatchery Research Center

The Oregon Hatchery Research Center has experience spawning fish and incubating and hatching eggs, and their egg incubation and hatching facilities are available year round. They would be interested in conducting lamprey aquaculture. There are about 538 ft^2 of indoor wet lab space that could be allocated to lamprey aquaculture. For holding adult lampreys, tanks ranging from 3 to 13 feet in diameter are available as are 4 raceways (10 feet by 79 feet) with a flow rate of 20 ft^3/min. Fall Creek and Carnes Creek provide water to the facility, and the seasonal range in water temperature is 4°C to 12°C. There are no known water contaminants though there is a heavy silt load in winter months after high water flow due to rain events. There are heaters available for use by a new project, and water can be heated up to 12.7°C above the ambient water temperature.

3.3.6. Abernathy Fish Technology Center

The Abernathy Fish Technology Center has previous experience with Pacific lamprey aquaculture and would be interested in conducting further research on this topic. They currently have experienced staff and facilities for egg incubation and hatching that are available during lamprey spawning season. Indoor facilities include an 8 foot by 10 foot enclosed wet laboratory and a hatchery building with 109, 4 foot circular tanks, 24, 2½ foot circular tanks, 8 troughs, 40 incubator stacks, and 2 moist air incubators. About one quarter to one half of the space in the hatchery building could be used for new culture activities. For holding adult lampreys there are 12, 8 foot by 80 foot concrete raceways and 10 above ground 10 foot circular tanks. The use and allocation of these facilities would be dependent on project details and needs. The Center has access to water from Abernathy Creek (average flow 7 cfs) and well water (3,000 gpm). The seasonal water temperature variation for the well water is 11.7°C to 12.1°C, and the river water has a maximum temperature of 20°C. There are no known contaminants in either water source. To control water temperature, river and well water may be combined to achieve the desired temperature, or the Center also has the capability of heating water for individual tanks or aquaria but cannot manipulate large quantities of water (1000+ gallons) for raceways or outdoor tanks.

3.3.7. Yakama Nation Facilities

The Yakama Nation has four facilities within the Yakama River Basin, all of which may be suitable for artificial propagation of lampreys with regards to space, water quality and level of interest in lamprey aquaculture. All facilities have experienced staffs, incubation rooms, potential for expansion of existing structures, and a variety of water sources (either existing or being planned, including water temperature control). These facilities include the Cle Elum Fish Hatchery, Prosser Fish Facility, Marion Drain Salmon Facility and Marion Drain Sturgeon Facility. In the Klickitat River basin, the Yakama Nation also owns and operates the Klickitat Fish Hatchery, near Glenwood WA., which may also provide suitable conditions for lamprey aquaculture. Several of these facilities are currently undergoing a Master Planning process in which major expansions and improvements will be implemented within the next few years, including the Klickitat, Prosser, and both Marion Drain facilities. The Yakama Nation is currently discussing options for incorporating Pacific lamprey propagation in Master Planning design and construction in each of these facilities.

3.3.7.1. CLE ELUM FISH HATCHERY

This modern facility has ample space and water and is ideally situated in the upper Yakama Basin near abundant, high quality habitat that is currently devoid of Pacific lamprey due to passage and other issues. This area is high priority for the Yakama Nations future research into the propagation, growth, productivity, and re-introduction of lampreys.

3.3.7.2. PROSSER FACILITY

The Prosser Facility is being redesigned and can incorporate lamprey aquaculture. Advantages of this facility are direct access to adults (at Prosser Fish Ladder) that enter the Yakama River and access to adults (at Prosser Fish Ladder) that enter into the Yakama River and access to a wide range of water temperatures. Sufficient water and space is available for a wide range of aquaculture objectives.

3.3.7.3. MARION DRAIN

The Marion Drain consists of two adjacent facilities, each situated on Yakama Nation owned lands. Several wells are currently in operation or are being developed and evaluations to use Marion Drain water are ongoing. Marion Drain contains constant and even flows and, with some development, could provide sufficient space and water for future production of lampreys.

3.3.7.4. KLICKITAT FISH HATCHERY

The Hatchery is relatively high in the river system and has abundant clear, cool water year-round. The hatchery is currently undergoing significant modifications and will continue to be in transition for several years. Considerable space is available at this site for future developments.

3.4. Worldwide Facilities

This report did not review potential worldwide hatchery facilities outside of the local region of Chelan County, Washington. If the data collected for the regional facilities proves to be insufficient for artificial propagation needs, further research should be conducted to locate hatchery facilities within a larger radius from the project area. This may included other parts of the Unites States or international locations if needed.

4.0 RIVERINE REARING FACILITIES

4.1. Introduction

This section of the report discusses riverine rearing facilities that may be appropriate for propagation of juvenile lamprey in the study area. The purpose of this inventory is to identify natural riverine sites within the study area watersheds (Methow, Chelan, Entiat and Wenatchee) that have high potential value to support the goals of the Pacific lamprey Artificial Propagation Project by providing rearing sites for artificially propagated juvenile Pacific lamprey. These sites include natural land forms that could be employed for propagation in place of, or as supplementation to, artificial sites being developed for similar purposes.

The following sub-sections of this report discuss selected riverine facilities that have been identified in each watershed in the context of suitability for rearing juvenile lamprey. Monitoring recommendations that should be implemented in order to evaluate the effectiveness of these sites in achieving program goals are also discussed.

4.2. Juvenile Lamprey Habitat Needs

As noted previously, few details are known about the specific biological requirements and mechanisms leading to successful rearing of juvenile lamprey (ODFW 2005, Columbia River Basin Lamprey Technical Workgroup 2005). Most of the current knowledge is based on observations of juvenile rearing in specific locations within a river system.

Juvenile lamprey may rear in tributary watersheds for up to seven years following hatching (Close et al. 1995). Lamprey generally emerge from the gravel approximately two weeks following hatching and then drift downstream to appropriate rearing habitat (Close et al. 2002). Rearing typically occurs in slow backwater areas near the channel margin where habitat is suitable for burrowing (Close et al. 1995). Juvenile lamprey burrow into the substrate and then filter-feed on suspended organic matter (plankton, algae, et cetera) in the water (Close et al. 1995, Nelson and Nelle 2007).

One of the most comprehensive studies on habitat preference of juvenile Pacific lamprey was conducted by Close et al. (2002). This study demonstrated that larvae typically prefer soft sediments such as silt, sand or organic detritus over courser mineral substrates such as gravel, cobbles and boulders. However, some juveniles do use cobble-dominated areas, particularly larger larvae that are able to withstand higher velocity currents. In general, larvae prefer slow currents less than 0.1 meters per second (m/s) and strongly avoid currents above 0.19 m/s. Consequently, they are commonly found near the margins of the channel in pools and riffles rather than mid-channel, in other words, lamprey do not like stagnant water. Close et al. (2002) noted that the size of the larvae plays a significant role in habitat selection.

Other factors potentially important to successful rearing of lamprey include proximity to spawning areas and water temperature. Rearing areas should be located downstream of spawning habitat (except in supplementation situations) so that juveniles may access them after emergence during downstream drifting (Close et al. 1995, 2002). Suitable spawning habitat includes primarily gravel-rich habitats at pool tailouts and low-gradient riffles with water temperature ranging from 10ºC to 15ºC (Close et al. 1995, Gunckel et al. 2009). Appropriate water temperatures for juvenile rearing may range from as low as approximately 5ºC to as high as 22ºC, with an optimum around 18ºC (USFWS 2009).

Little is known about the homing mechanisms, if any, that adult lamprey use to find appropriate spawning sites. Although it has not been demonstrated in documented research, it is believed that adult lamprey may be chemically attracted to bile acids secreted by rearing larvae that act as pheromones (Nez Perce/Umatilla/Yakama/Warm Springs Tribes 2008). This potential mechanism for population maintenance should be considered when selecting rearing sites in the natural environment.

4.3. Riverine Facilities Evaluation

Potential riverine facilities were evaluated throughout the Methow, Chelan, Entiat and Wenatchee watersheds. The Okanogan watershed was originally considered but subsequently eliminated due to budgetary and time constraints and the desire of the Rocky Reach Fish Forum to have one "untreated" watershed for potential future comparison to "treated" watersheds. Within the subject watersheds, potential sites were identified through discussions and coordination meetings with a variety of local biologists and fisheries experts from organizations and agencies such as the WDFW, USFWS, Yakama Nation, private consultants and PUDs.

Preliminary screening of potential sites was conducted using a criteria form developed specifically for this project and agreed to by the primary stakeholders for the project, which is the Rocky Reach Fish Forum. This form is included as Appendix A to this report with field data following. A list of potential sites was submitted to attendees at a workshop put on by the Rocky Reach Fish Forum, which was held in Wenatchee, Washington, on August 24, 2010. During this workshop, a comprehensive list of the top potential riverine facility sites was identified and agreed to by the participants. This included some new sites that had not been previously identified.

Once the top sites were identified, GeoEngineers biologists conducted site visits to document site conditions with particular reference to suitability as a rearing facility, based on RRFF criteria. Specifically, site hydrology, substrate composition, water temperature and quality, and spatial layout with regard to accessibility and associated habitat in the mainstem water body were documented. The sites evaluated by GeoEngineers were photographed and are included as Appendix C Plates C-1 through C-49.

4.3.1. Methow River Basin

A panel of local experts was assembled to develop a list of potential natural, riverine lamprey facility sites, and to prioritize among the sites to develop a list of four site for further investigation. Local experts used to assess potential facility locations in the Methow included: Jeff Osborn (Chelan PUD), Bob Rose (Yakama Nation), John Jorgenson (Yakama Nation), Charlie Snow (WDFW) and Debby Bitterman (Chelan PUD).

The potential sites identified within the Methow River Basin, included:

- Chewuch River – multiple locations
- Chewuch Ditch
- Beaver Creek – multiple locations
- Black Canyon Ponds
- Biddle Pond
- Fulton Ditch
- Hancock Springs (Big Valley Ranch)
- Winthrop National fish Hatchery (NFH) Abatement Pond
- Wolf Creek

Utilizing site selection criteria developed by the RRFF, and summarized in a site criteria sheet, the four sites were selected:

- Black Canyon Ponds
- Biddle Pond
- Chewuch River – WDFW Methow State Wildlife Areas (MSWA)
- Hancock Springs

Of these sites, the WDFW Methow State Wildlife Area and Biddle Pond sites appear the most promising and warrant further investigation and evaluation. Upon further investigation, the Black Canyon Ponds and Hancock Springs sites did not appear to meet criteria for suitability as lamprey rearing sites; however, further evaluation of these sites could reveal information that was not considered or insufficiently covered at the time of this report. Observations, evaluations and site suitability within the Methow River Basin are discussed in the following sections.

4.3.1.1. BLACK CANYON PONDS

A string of small ponds is reportedly located approximately ½- to ¾-mile up the Black Canyon Road from the Methow Valley Highway (State Route [SR] 153). Land ownership adjacent to the Black Canyon Road is private; therefore a full evaluation of the site could not be conducted.

Limited access from the road allowed visual confirmation of a single pond located immediately adjacent to SR 153. This pond has a relatively high amount of wetland vegetation growing within it and at its margins. A distinct inlet and/or outlet were not observed, though hydrology appears to generally enter from the southwest and flow out to the north. Substrate conditions appeared to be comprised of silt and sand with large amounts of organic detritus as well as living vegetation (algae as well as emergent vascular plants) on the bottom.

Positive attributes of the site include:

- Accessibility via vehicle,
- Year-round flow,
- Low water velocities,
- Substrate suitability,
- Stable hydraulics and
- Productive, nutrient-rich water

There appeared to be no obvious signs of compromised water quality, although Black Canyon Creek does parallel a dirt road in the lower watershed and there is some human activity, including residences, nearby.

Limitations of the site include:

- Likely inaccessibility by adult lamprey due to an indistinct outlet not clearly connected to the mainstem stream,
- Limited suitable downstream habitat for lamprey in the small and relatively high-gradient Black Canyon Creek and
- Land ownership, which may be private (there were "No Trespassing" signs on an adjacent private driveway).

Furthermore, although vehicle access is readily available along the road, staging areas adjacent to the road from which to conduct activities at the site without blocking it may be limiting and aquatic vegetation within the pond may confound efforts to recover lamprey from the pond without prior modification.

4.3.1.2. WDFW METHOW STATE WILDLIFE AREA

This site, locally referred to as the "WDFW-MSWA site," is located in a natural off-channel oxbow associated with the Chewuch River, approximately 10 miles upstream from the town of Winthrop and just upstream of Eightmile Creek.

The oxbow, which is on the west side of the mainstem Chewuch River, contains two existing large ponds that are divided by an earthen and log berm that may have been constructed by beavers. The northern pond is smaller, deeper and more open (un-vegetated) whereas the southern pond is lengthier, shallow and contains a significant amount of low-growing emergent and algal vegetation.

There was no surface inlet to the ponds from the mainstem river at water levels observed during the site visit. Hydrology at low water levels appears to originate from high groundwater seeping in from the adjacent river through wetland habitats. There is, however, evidence of surface overbank flow from the mainstem into the ponds at higher water elevations. The outlet from the southern pond is also controlled by a beaver dam and was not flowing at the time of the site visit. It appears that slightly higher flow elevations would result in a surface connection between the oxbow and the mainstem. During higher mainstem flows, there may also be backwater flow into the oxbow.

The site has many positive attributes that may contribute to its suitability as a riverine rearing facility. They include:

- Adequate vehicle access to the site via the existing MSWA access road and trucks would likely be able to get within 50 to 100 feet of the northern pond without further modification.
- The structure and arrangement of the ponds appears to be conducive to retention and recovery of macropthalmia.
- Addition of a small structure at the outlet could enable regulation of ingress/egress of juvenile and adult lamprey to the site at a variety of water levels.
- Pond substrate, which consisted of silts, sands and some organic material, is highly suitable to juvenile lamprey rearing, though therefore less so for adult spawning.
- The availability of suitable habitat for both adult spawning and juvenile rearing in the adjacent mainstem river was also very high.
- The Chewuch River has riffle and glide habitats dominated by gravels and cobbles, as well as pools, side pockets and backwater eddies with finer substrates (including a backwater eddy right at the outlet of the oxbow).

Flow within the ponds was very low during the site visit (almost stagnant) and likely remains so during most of the year. However, there was evidence of overbank flooding into the oxbow during high water levels, which would likely be the primary concern at this site if it were to result in flushing rearing juveniles out of the ponds.

4.3.1.3. BIDDLE PONDS

The Biddle Ponds site is located adjacent to Wolf Creek approximately one mile upstream from its confluence with the Methow River. The site is accessed by vehicle from Wolf Creek Road and is approximately four miles from the town of Winthrop.

There are two ponds at the site (the “upper” and “lower” ponds). Hydrologic flow from Wolf Creek enters the upper pond from the west through a constructed intake structure and excavated channel. From the upper pond, flow is conveyed through another structure, dropping the water elevation a few feet, to the lower pond. The structure between the two ponds is fish impassible in the upstream direction. The outlet of the lower pond is a constricted channel that appears to be of artificial origin but resembles a natural channel.

Although land ownership is private, the owner is very agreeable to conducting fish restoration activities on the land and the lower pond is currently in use by the Yakama Nation Fisheries program for acclimation of hatchery Chinook and Coho salmon. Vehicle access is available right to the edge of the lower pond via an unmaintained primitive dirt road on the same property.

Yakama Nation personnel have used nets to contain and recover hatchery salmon within the lower pond. Feasibility of doing so with juvenile lamprey is questionable because of the fine mesh netting material that would be required. Otherwise, retention and recovery of macrophalmia may require construction of a structure at the pond outlet.

Water velocity (very low) and substrate (fine sediments with some aquatic vegetation) within the lower pond are well-suited to juvenile lamprey rearing. Limitations at the site may include water temperature and seasonality of flow. The Yakama Nation indicated that they had to install heating elements during the winter to keep the intake structure from icing up and cutting off flow into the ponds. Water temperatures may drop considerably during winter at this site due to its location in a shaded area and association with a smaller tributary stream. Limited water quality data obtained from Fred Alfred, Fish Biologist with the Yakama Nation, that was gathered from the Biddle Ponds from March 26, 2010 through April 18, 2010 documented the following averages.

- Averaged water temperature was 4.1°C during the 25 day period.
- Averaged dissolved oxygen was 10.3 ppm to 10.6 ppm during the 25 day period.

Adult lamprey have unimpeded access to the site via the Methow River, Wolf Creek and the pond outlet channel. Wolf Creek may have limited lamprey rearing and spawning habitat, but the site is only one mile upstream from the Methow River, which has abundant suitable habitat.

4.3.1.4. HANCOCK SPRINGS

The Hancock Springs site contains habitat stretching over the length of a spring-fed creek nearly one mile long before it flows into the Methow River. The source of the creek at the uppermost spring can be accessed from Kumm Road and Wolf Creek Road crosses the creek, which is culverted under it, near the confluence with the Methow River. Both of these roads extend to the south from SR 20 approximately 40 miles northwest of the town of Winthrop. The creek can be divided into three segments:

- Segment One - The uppermost segment extends from the source through cattle fields where riparian vegetation has been completely removed to approximately half-way to Wolf Creek Road;
- Segment Two - The second segment starts where the creek enters an area with intact riparian vegetation that was not historically as severely degraded by cattle and extends to the culvert under Wolf Creek Road; and
- Segment Three - From Wolf Creek Road to the mouth at the Methow River.

The Hancock Springs creek is entirely spring-fed and therefore has very stable water temperatures and flow regime. Land ownership is private, but there is a conservation easement in place for an active restoration work project. Vehicle access to Segment 1, as identified above, is available across private property. The only access point in Segments 2 and 3 are at Wolf Creek Road.

The site is currently the site of a habitat restoration effort on the part of Yakama Nation Fisheries. Restoration efforts are concentrated in Segment 1, the uppermost part of the stream that has been subject to severe cattle grazing impacts. The effects of cattle grazing resulted in bank erosion, a widened channel, slow flow and silt deposition. Restoration efforts have included fencing most of the creek off to restrict cattle access and installation of in-stream structures and bank improvements. This has resulted in significant improvements to channel dynamics resulting in increased sinuosity and habitat heterogeny. However, there are still cattle crossings that are actively used and current water quality conditions may be suspect. Yakama Nation Fisheries has collected some water quality data that may be available.

Segment 2 of the creek has intact riparian vegetation, higher sinuosity and a lower degree of cattle grazing and subsequent degradation. Restoration efforts in this area are present but limited in scope. Segment 3 has not been the subject of restoration and is currently dominated by invasive reed canarygrass.

The site contains a variety of stream habitat types and is low gradient with low volume. There are faster-moving areas with gravel and sand substrate as well as many small pockets of backwater eddy habitat with sand and silt substrates. Many of the habitats would be acceptable for juvenile lamprey rearing. However, there is no single larger area where lamprey would be likely to congregate. Therefore, retaining and recovering macrophthamiamay prove problematic. Downstream habitat within the Mainstem Methow River likely contains adequate adult spawning habitat as well as additional juvenile lamprey habitat; it would be unlikely that adult lamprey would come up the creek to spawn.

4.3.2. Chelan Basin

A panel of local experts was assembled to develop a list of potential natural, riverine lamprey facility sites, and to prioritize among the sites to develop a list of sites for further investigation. Local experts used to assess potential facility locations in the Chelan Basin included: Jeff Osborn (Chelan PUD), Bob Rose (Yakama Nation), Kate Terrell (USFWS), RD Nelle (USFWS) and Phil Archibald (retired USFS Biologist).

Two potential sites were identified within the Chelan Basin, including:

- Beebe Springs and
- Chelan River.

Because so few sites were identified within the Chelan Basin, both were selected for further evaluation through site visits. Upon further investigation, neither the Beebe Springs nor the Chelan River sites appeared particularly well suited for lamprey rearing sites, based on criteria. However, further evaluation of these sites could reveal information that was not considered or insufficiently covered at the time of this report. Observations, evaluations and site suitability within the Chelan Basin are discussed in the following sections.

4.3.2.1. BEEBE SPRINGS

This site is located just upstream from Beebe Bridge on the right (west) bank of the Columbia River, just north of the Chelan River and Columbia River confluence. The Beebe Springs site was assumed to be the entirety of the newly constructed stream channel, approximately 800 feet in length, located between the Beebe Spring Hatchery and the Columbia River.

After the channel crosses under HW 97 through a culvert, the created channels diverge, forming two channels that flow across the Columbia River floodplain, and converge a short distance upstream from the confluence with the Columbia River. Both channels were designed and constructed to have a step-pool conformation with hard substrate varying between small and large grave with boulder complexity. The northern channel appears to be the smaller of the two and is less confined. The south channel flows directly from the culvert outlet to the Columbia River.

Surfacewater flow is relatively stable, both in temperature and quantity of flow, regulated by operations of the Chelan Hatchery located at the upstream most location, at the toe of the Columbia River glacial outwash terrace slope.

Riparian vegetation was limited along the margin of both channels. Such a condition should be expected when new stream channels and alignments are constructed in arid eastern Washington where little vegetation previously existed. With the construction of stream channel and planning of riparian vegetation, one can assume that riparian vegetation conditions will significantly improve and planting grow and the stream channels continue to provide water to the floodplain area.

The site has many positive attributes that may contribute to its suitability as a riverine rearing facility. They include:

- Adequate vehicle access to the site via highway 150 and access roads used to construct the channel, enabling trucks to approach the channel to within approximately 50 feet utilizing asphalt highway, and closer if gravel access roads were used.
- With a hatchery system located at its upstream-most end, existing structures could be used to retain and recover macrophthamia returning to the Beebe Springs channel and Chelan Hatchery.
- Construction of small structures within the channels and near the confluence of Beebe Spring and the Columbia River enable regulation of ingress/egress of juvenile and adult lamprey to the site at a variety of water levels, and potentially create experimental enclosures.
- Substrates did not appear particularly favorable for lamprey within the existing channels in their existing condition. However, one of the two channels could be modified, or backwater areas could be constructed that connect to the existing channels to provide habitat suitable for early life history habitat needs of lamprey. Existing substrates and flows may be suitable for spawning purposes.
- The Beebe Springs area is located upstream from additional potential lamprey rearing areas along the margins of the Columbia River, including constructed slough areas along the right bank of the Columbia River at the eastern edge of the Beebe Springs Natural Area.
- Availability of suitable habitat for adult spawning and potential for construction of juvenile rearing habitat might favor selection of such a site.

- The potential to couple hatchery production at the Chelan Facility, together with potential natural production and natural rearing (if such habitat were created), might offer fishery managers the opportunity to focus artificial and natural production in a single location.
- The fact that Beebe Spring is an isolated surface water body connected only to the Columbia River could offer fishery managers the opportunity to manage Pacific lamprey within a closed system. Such a design might help fishery managers evaluate the efficacy of management actions, eliminating from analysis confounding influences that occur in large, complex basins like the Methow and Wenatchee.
- Flow within the channels is moderate and relatively stable. Such conditions are favorable for the engineered design and construction of habitats to meet specific life-history requirements.

4.3.2.2. CHELAN RIVER

This site is located just upstream from the confluence of the Chelan River with the Columbia River. The Chelan River "Arm" site was assumed to be the backwater areas of the Chelan River, adjacent to Powerhouse Park, located on the right (south) bank of the Chelan River, just upstream from the Chelan Falls Road and the railroad bridge crossings.

The backwater area is approximately 125 feet wide by 250 feet long, and is presently managed for recreational uses such as swimming. Depths and velocities are variable, influenced by Chelan River flows down the Chelan Falls channel, flows through the Lake Chelan Hydroelectric Power facility, and backwater effects of the Columbia River. Thus, depths, velocities and hydraulic patters are variable. Substrate that was observed from shore was silt, sand, and gravel. The area was observed to be surrounded by sparse riparian vegetation. The backwater area of the Chelan River "Arm" is connected at the north with the main flow of the Chelan River, which then flows under Chelan Falls Road and the railroad bridges into the Columbia River.

Surfacewater flow is relatively stable, with continuous inundation across a broad range of flows, although variable with seasonal and operational changes in flow.

The site has few positive attributes, suggesting that the Chelan River site may not be the most suitable riverine rearing facility. Positive attributes include:

- Adequate vehicle access to the site via highway 150 and the Powerhouse Park access road.
- Substrates may be suitable for rearing lamprey ammocoetes.
- The Chelan Arm area is located upstream from additional potential lamprey rearing areas along the margins of the Columbia River.
- The fact that the Chelan River is an isolated surface water body connected only to the Columbia River could offer fishery managers the opportunity to manage Pacific lamprey within a closed system. Such a design might help fishery managers evaluate the efficacy of management actions, eliminating from analysis confounding influences that occur in large, complex basins like the Methow and Wenatchee.
- Flow within the rearing area is moderated by backwater effects of the Columbia River and out of the main flow through the Chelan River.

4.3.3. Entiat River Basin

A panel of local experts was assembled to develop a list of potential natural, riverine lamprey facility sites, and to prioritize among the sites to develop a list of sites for further investigation. Local experts used to assess potential facility locations in the Entiat River Basin included: Jeff Osborn (Chelan PUD), Bob Rose (Yakama Nation), Kate Terrell (USFWS), RD Nelle (USFWS) and Phil Archibald (retired USFS Biologist).

A number of potential sites were identified within the Entiat River Basin, including:

- Chelan PUD Irrigation Channel
- City of Entiat – Entiat River/Columbia River Confluence
- Cottonwood
- Dillwater
- Entiat National Fish Hatchery Abatement Pond
- Hanan-Detwiler Side Channel
- Keystone
- Shamel Creek
- Stormy Gage
- Wilson Side Channel

Of these sites, four were selected for further investigation and evaluation through site visits. These sites were:

- Dillwater
- Shamel Creek
- Stormy Gage, and
- Cottonwood

The following provides summary findings for each of the priority sites, based on evaluation through site visits.

4.3.3.1. DILLWATER

The Dillwater site is located between approximately RM 21.2 and 21.4 of the Entiat River, along the left (north) bank, just upstream from the Dill Creek bridge, and just downstream from the Sego Yurt site. The Dillwater site is a relict side channel of the Entiat River, and location of a salmonid habitat enhancement project proposed by the USFWS.

The Dillwater was assumed to be the entirety of the relict side channel, although attributes of the site primarily describe the area of the side channel at its downstream-most location, prior to its confluence with the Entiat River.

After the relict side channel diverges from the Entiat River, just below the Sego Yurt site, the channel traverses the Entiat River floodplain through immature riparian vegetation. Evidence of scour, racking of small woody debris and beaver activity was prevalent in the upper portions of the side channel. No flow was observed in the channel during the October base-flow condition.

Surfacewater flow would need to be modified to provide water to the potential rearing site.

The site has several positive attributes, conducive to suitability as a riverine rearing facility. However, relatively significant hydraulic modifications would be required to provide through flow. Such actions should be approached cautiously, however, as hydraulic modification in a dynamic river like the Entiat River may not lead to predictable low-velocity rearing areas necessary for lamprey rearing. Assuming such modification could be made, positive attributes of the site include:

- Potential vehicle access to the site off the Entiat River road and to the river through the south end of the Sego Yurt site would enable vehicular access to within approximately 200 to 300 feet of the side channel.
- The site ownership/management by the Chelan-Douglas Land Trust (CDLT) would enable fishery managers to work with a single landowner, and one known to be committed to aquatic resource protection and restoration.
- Substrates in the downstream-most portion of the relict side channel appeared to be well suited to Pacific lamprey rearing through the early life-history stages.
- The Dillwater area is located upstream from additional potential lamprey rearing areas along the Entiat River, including the Shamel Creek, Stormy Gage, Cottonwood areas described below all of which are in a low-gradient section of the Entiat River known as the Stillwaters.
- It is likely that there is the availability of suitable habitat for adult spawning upstream from the Dillwater Site, potentially serving as a natural production and seeding area, if such natural production objectives were the primary objective of using an area like the Dillwater site.

4.3.3.2. SHAMEL CREEK

The Shamel Creek site is located at approximately RM 18.3 of the Entiat River, along the right (south) bank, approximately 0.3 RM upstream from the Stormy Gage and bridge. The site is a relict meander scroll of the Entiat River, formed as the Entiat River has migrated away from the right bank and toward the left bank. The property is owned and managed by the CDLT.

The Shamel Creek site was assumed to be the entirety of the backwater area presently inundated by the Entiat River in the baseflow condition, including the channel connecting the backwater with Shamel Creek and the Entiat River.

The backwater area is approximately 250 feet long and approximately 40 feet wide. A narrow channel (approximately 2 to 4 feet wide in the baseflow condition) connects the backwater to the Entiat River. Shamel Creek flows into the connecting channel, conveying water to both the backwater area and the Entiat River. Surfacewater flow may be adequate in the existing condition to provide suitable water quantity and quality to the potential rearing site.

The site has several positive attributes, conducive to suitability as a riverine rearing facility. Hydraulic modifications may or may not be required to provide through flow. Further investigations would be required to determine hydrologic and hydraulic suitability. One significant concern is the potential for continued channel migration to move away from the backwater area, disconnecting the habitat from the river, and eventually drying up.

Manipulation of an active channel and floodplain to meet fishery management objectives should be approached cautiously. Assuming fishery managers are willing to utilize the habitat in its existing condition, or make limited modifications to make the site suitable, positive attributes of the site include:

- Potential vehicle access to the site utilizing CDLT right-of-way, directly to the Shamel Creek and backwater confluence area. During the site visit, vehicle parking was available at a point approximately 150 feet from the confluence area.
- The site ownership/management by the Chelan-Douglas Land Trust (CDLT) would enable fishery managers to work with a single landowner, and one known to be committed to aquatic resource protection and restoration.
- Substrates in the backwater area, in the Entiat River adjacent the site, and in the Entiat River downstream of the site all appear well suited to Pacific lamprey rearing through the early life-history stages.
- The Shamel Creek area is located upstream from additional potential lamprey rearing areas along the Entiat River, including the Stormy Gage and Cottonwood areas described below
- It is likely that there is the availability of suitable habitat for adult spawning upstream from the Shamel Creek site, potentially serving as a natural production and seeding area, if such natural production objectives were the primary objective of using the site.
- The potential to couple hatchery production at the Entiat National Fish Hatchery, located downstream, with potential natural production and natural rearing (if such habitat were created), might offer fishery managers the opportunity to focus artificial and natural production within the Entiat River watershed.

4.3.3.3. STORMY GAGE

The Stormy Gage site is located at approximately RM 18.1 of the Entiat River, along the left (north) bank, approximately 0.1 RM upstream from the Stormy Gage and bridge. The site is a relict meander scroll of the Entiat River, formed as the Entiat River has migrated away from the left bank and toward the right bank, forming an ever enlarging point bar in the Entiat River downstream from the Stormy Creek and Entiat River confluence. This site is also owned and managed by the CDLT.

The Stormy Gage site was assumed to be the entirety of the backwater area presently inundated by the Entiat River in the baseflow condition, including the channel connecting the backwater with the Entiat River. An additional site was investigate just up-gradient from the backwater, appearing to be another meander scroll backwater that has been partially disconnected from the Entiat River, although holding water. It is assumed that this secondary wet area is inundated during high flows and sustained through groundwater upwelling. Additional investigations of hydrogeologic and hydraulic conditions would be required to determine suitability of each of these habitats.

The backwater area connected directly with the Entiat River is approximately 100 feet long and approximately 50 feet wide. A narrow channel (approximately 4 to 6 feet wide in the baseflow condition) connects the backwater to the Entiat River. The secondary backwater area was separated from the Entiat River by a dry, narrow channel being approximately 50 feet in length and approximately 5 feet wide. The secondary backwater area was approximately 50 feet long and 20 feet wide at the time of the site visit.

The site has several positive attributes, conducive to suitability as a riverine rearing facility. Hydraulic modifications may or may not be required to provide through flow. Certainly modification would be required to restore connectivity of the secondary backwater area with the Entiat River, is this area were to be used. Further investigations would be required to determine hydrologic and hydraulic suitability. One significant concern is the potential for continued channel migration to move away from the backwater area, disconnecting the habitat from the river, and eventually drying up.

Manipulation of an active channel and floodplain to meet fishery management objectives should be approached cautiously. Assuming fishery managers are willing to utilize the habitat in its existing condition, or make limited modifications to make the site suitable, positive attributes of the site include:

- Potential vehicle access to the site utilizing CDLT right-of-way, enabled reasonable access to the Stormy Creek site. During the site visit, vehicle parking was available at a point approximately 500 feet from the backwater area. If right-of-way permissions were made available, it would be possible to drive to within 100 feet or less of the backwater area.
- The site ownership/management by the Chelan-Douglas Land Trust (CDLT) would enable fishery managers to work with a single landowner, and one known to be committed to aquatic resource protection and restoration. Access to the site, however, would likely require involvement of a private landowner.
- Substrates in the backwater area, in the Entiat River adjacent the site, and in the Entiat River downstream of the site all appear well suited to Pacific lamprey rearing through the early life-history stages. Photographs (Appendix C) and video footage of groundwater upwelling at the site, together with anecdotal evidence of previous use of the site by lamprey provides further evidence of suitability of the site for natural, riverine rearing.
- The Stormy Gage site is located upstream from additional potential lamprey rearing areas along the Entiat River, including the Cottonwood areas described below. It is located within a long, low-gradient section of the Entiat River, known as the "Stillwaters" reach, providing miles of low velocity and fine sediment substrate.
- It is likely that there is the availability of suitable habitat for adult spawning upstream from the Stormy Gage site, potentially serving as a natural production and seeding area, if such natural production objectives were the primary objective of using the site.
- The potential to couple hatchery production at the Entiat National Fish Hatchery, located downstream, with potential natural production and natural rearing (if such habitat were created), might offer fishery managers the opportunity to focus artificial and natural production within the Entiat River watershed.

4.3.3.4. COTTONWOOD

The Cottonwood site is located between approximately RM 17.5 and 17.7 of the Entiat River, along the right (south) bank, at the location of an unfinished bridge, referred to locally as the "bridge to nowhere". The site is an active floodplain of the Entiat River, with multiple high flow channels and backwater areas. This site is also owned and managed by the CDLT.

The Cottonwood site was inspected throughout the floodplain area owned and managed by the CDLT, being over 100 feet in length and 600 feet wide. Site inspections focused on the wetted backwater areas presently connected to the Entiat River. However, recognizing that considerable space is available at the site, several high-flow channels were inspected as well. Additional investigations of hydrogeologic and hydraulic conditions would be required to determine suitability of each of these habitats.

The first area inspected was located approximately 150 feet downstream from the bridge, at a point where flows of the Entiat River impact a large boulder and produce a scour hole. The scour hole was area was approximately 20 feet in length and 10 feet wide. Although the scour hole had suitable substrate and was well inundated even at baseflow, such a small site was also assumed inadequate for use as part of a large-scale lamprey protection and restoration program.

A second backwater area inspected is located approximately 500 feet downstream from the bridge, at a point where flows of the Entiat River are backed up by a low gradient riffle, located a short distance downstream. The backwater area was approximately 30 feet in length and 20 feet wide. Although the backwater had suitable substrate and was well inundated even at baseflow, such a small site was also assumed inadequate for use as part of a large-scale lamprey protection and restoration program.

Inspection of the remainder of the site revealed the presence of multiple channels, most of which were disconnected from the Entiat River. Significant hydraulic modifications would be required to provide through flow, and provide suitable, long-term rearing area. Further investigations would be required to determine hydrologic and hydraulic suitability. Manipulation of an active channel and floodplain to meet fishery management objectives should be approached cautiously. Assuming fishery managers are willing to utilize the habitat in its existing condition, or make limited modifications to make the site suitable, positive attributes of the site include:

- Very large land area within which to develop a customized site design.
- Potential vehicle access to the site utilizing CDLT right-of-way, enabled reasonable access to the Cottonwood site at the bridge. Completion of construction of the bridge could enable vehicular access onto the site, if desired by fishery managers and approved by CDLT.
- The site ownership/management by the CDLT would enable fishery managers to work with a single landowner, and one known to be committed to aquatic resource protection and restoration. Access to the site, however, would likely require involvement of a private landowner.
- The Cottonwood site is located upstream from additional potential lamprey rearing areas along the Entiat River, within the long, low-gradient section of the Entiat River known as the "Stillwaters" reach, providing miles of low velocity and fine sediment substrate.

- It is likely that there is the availability of suitable habitat for adult spawning upstream from the Cottonwood site, potentially serving as a natural production and seeding area, if such natural production objectives were the primary objective of using the site.
- The potential to couple hatchery production at the Entiat National Fish Hatchery, located downstream, with potential natural production and natural rearing (if such habitat were created), might offer fishery managers the opportunity to focus artificial and natural production within the Entiat River watershed.

4.3.4. Wenatchee River Basin

A panel of local experts was assembled to develop a list of potential natural, riverine lamprey facility sites, and to prioritize among the sites to develop a list of sites for further investigation. Local experts used to assess potential facility locations in the Chelan Basin included: Jeff Osborn (Chelan PUD), Bob Rose (Yakama Nation), Kate Terrell (USFWS), and RD Nelle (USFWS).

Potential sites identified within the Wenatchee River Basin and discussed by the panel included:

- Blackbird Island
- Cashmere Pond
- Chelan PUD – Dryden Ditch
- Chumstick Ponds
- Icicle Creek Historic Channel Adjacent Leavenworth NFH
- Lake Jolanda (mainstem Wenatchee River above Tumwater dam)
- Lower Icicle Creek – Leavenworth National Fish Hatchery (NFH) Abatement Pond
- Nason Creek Oxbow

Of these sites, the Cashmere Ponds, Blackbird Island and Nason Creek Oxbow sites were identified as the most promising and warranted further investigation and evaluation. Upon further investigation, the Chumstick Ponds and Lake Jolanda sites did not appear to meet criteria for suitability as lamprey rearing sites; however, further evaluation of these sites could reveal information that was not considered or insufficiently covered at the time of this report. Observations, evaluations and site suitability within the Wenatchee River Basin are discussed in the following sections.

4.3.4.1. CASHMERE POND

The Cashmere Pond is located adjacent to the Wenatchee River and within its floodplain near the town of Cashmere, Washington. The site is located on the north bank of the river, between the river and Highway 2/97. The pond has been recently modified and is the site of ongoing restoration activities. It is understood that restoration work currently underway was planned for salmon enhancement activities.

The site is separated from the Wenatchee River to its south by a high berm that may be of artificial origin, although sandbar vegetation, estimated at a couple years old, was observed growing on it. There is also evidence of beaver activity, including what appears to be an active beaver lodge, within the pond that may in part explain its origin. The source of hydrology within the pond appears to be subsurface seepage from the adjacent river and a permanently (year-round) high groundwater table. There is evidence at the site of overbank flooding during very high water levels within the river. Evidence included some erosional rilling and one apparent overbank flow path. However, during normal flow levels, there is no surface connection into the pond from the river. There is also an adjacent wetland to the northwest of the pond and a surface connection between the wetland and pond habitats.

The pond outlet was recently modified as part of the restoration activities. The former outlet, which was short and connected to the river on its southeast side, appears to have been filled and blocked. In its place, a lengthy artificially channel has been installed from the northeast corner of the pond, flowing downstream parallel to the river (east) for approximately 1,000 feet before joining the mainstem. Channel features include a number of engineered log jam and other LWD structures contributing to habitat complexity.

Pond substrate is dominated by sand with some finer (silt) particles and moderate amounts of organic detritus. Pond conditions are likely to be very favorable for lamprey rearing as long as levels of suspended organic matter are high enough to support them. This is likely to be the case due to the adjacent wetland and intact riparian vegetation at the site which contribute to primary productivity in this location. Water temperature is likely to be moderated seasonally by the low position of the site within the watershed and the source of hydrology from groundwater and seepage from the adjacent river. However, temperature monitoring is recommended to confirm suitability. There appears to be adequate downstream rearing habitat both within the constructed outlet and the mainstem Wenatchee River. Spawning habitat is also available within the mainstem.

Retention and recovery of lamprey at the site would be relatively straightforward due to the constricted pond outlet and rare overbank flooding; however, rare flood events could result in loss of stock when they do occur. Additional hydrologic modeling may be necessary to determine flood elevation and risk at this site.

One of the primary site concerns that we noted includes difficult vehicle access. The site is adjacent to the highway, but there is no existing parking or pullout area and it is separated from the highway by a steep embankment. An adjacent landowner does have a private drive from the highway down onto the floodplain near the site. Recent restoration work on the site indicates that there is some existing access, but it is unclear how access for that work was obtained.

4.3.4.2. CHUMSTICK PONDS - SHEIBLER

Potential riverine rearing sites were noted at several ponds within the Chumstick Creek drainage. These sites were located on private property owned by two different landowners. The Scheibler property is located approximately eight miles from the town of Leavenworth up Chumstick Road, on the west side of the road.

The Scheibler property (Chumstick 1) is currently the site of a USFWS and Chelan County Department of Natural Resources (CCDNR) joint project to remove passage barriers on Chumstick Creek. There are three barriers on the property, all of which have been or will be removed by the time of project completion. Because of the active project taking place on the site and information obtained from CCDNR regarding site access and landowner concerns, we did not conduct a field visit to this site. The following summary was obtained from conversations with Kate Terrell (USFWS) and Mike Kane (CCDNR). Chumstick Creek flows through the center of the property, which has been cleared for agricultural purposes. The creek is generally channelized and there is an irrigation pond along it formed by one of the barriers. The landowners are hesitant to allow projects on their property. Furthermore, the passage barrier removal design is complete and the finished project will not likely be suitable for lamprey rearing.

4.3.4.3. CHUMSTICK PONDS - SHEILDS

The Shields property is located approximately three and a half miles up the Chumstick Road from Leavenworth, on the east side of the road.

The Shields property (Chumstick 2) includes a small pond, approximately 30 feet in diameter, located adjacent to Chumstick Creek. The pond is of artificial origin, excavated by the current owner to provide a fish pond on the residential property. The owner states that he has struggled to maintain hydrology in the pond, which is fed by a buried pipe connecting it to Chumstick Creek. He is very receptive to restoration of the pond and would consider allowing a propagation program in it.

At the time of the site visit, the pond was virtually dry with no open water. Instead, it is dominated by cattails and other wetland vegetation. The pond does not contain a surface water connection to Chumstick Creek. For this reason, retention and recovery of juveniles would be straightforward. Pond substrate is fine with excess organic matter due to the depressional topography and wetland characteristics. Because of the lack of hydrology and very small size of the pond, it is not recommended that this site be pursued for propagation of lamprey.

4.3.4.4. BLACKBIRD ISLAND

The Blackbird Island site is located in the town of Leavenworth in a designated open space area within the Wenatchee River floodplain. The site is actually not on Blackbird Island but rather on the mainland southwest of the island on the other side of the Wenatchee River oxbow channel that forms the island.

The site is comprised of an off-channel slough that has been the subject of extensive restoration for salmon, steelhead and bull trout rearing habitat undertaken by the WDFW. The ponded area within the slough is connected to an oxbow channel of the Wenatchee River by an engineered pond outlet and this invert elevation maintains the impoundment. The oxbow channel and slough both have year-round hydrology and the outlet appears to flow year-round as well. Water velocities within the pond are very slow, though not completely stagnant as there does appear to be year-round flow-through.

The ponded part of the slough is more than 500 feet in length and approximately 100 feet at its widest. Hydrology originates in a floodplain wetland over 700 feet south of the site, adjacent to the ball fields and golf course located to the southwest. Water flows from this wetland to the northeast in what appears to be a constructed channel with engineered log jams and other LWD; flow also passes through a culvert under a recreational trail and maintenance access road. The source of hydrology within the wetland appears to originate from high groundwater and seepage from the Wenatchee River; there did not appear to be an upstream surface connection to it.

Sediment within the ponded area is sand and gravel near the shore and appears to contain finer sediments as well as a substantial amount of organic detritus in deeper habitats. Surrounding upland habitat is forested with deciduous trees that contribute organic leaf litter into the aquatic environment. This habitat is likely very suitable for lamprey rearing. There is excellent juvenile rearing habitat in depositional areas associated with the Wenatchee River oxbow downstream of the site that could be utilized by juveniles released from the site. The mainstem river may provide some spawning habitat.

Vehicle access to the site currently exists via the recreational trails in the open space park, which also function as maintenance access roads. Access and use agreements would need to be coordinated with the current owner of the site, which is the City of Leavenworth. Retention and recovery of lamprey rearing in the pond would be relatively straightforward and would only require a simple structure at the pond outlet to restrict egress by juveniles. There is a history of overbank flooding from the Wenatchee River into the Blackbird Island recreational area, though the extent and velocities of flow that reach the slough would need further monitoring and investigation. There may also be backwater flow into the pond outlet from the Wenatchee River oxbow during less extreme high water events. Overall, the site shows promise as a riverine rearing facility.

4.3.4.5. LAKE JOLANDA

Lake Jolanda is a large impoundment in the Wenatchee River formed behind the Tumwater dam. It is located in Tumwater Canyon adjacent to US 2 approximately five miles west of Leavenworth, Washington.

Sediment in the lake is comprised primarily of sand and there is very little organic detritus. Because of the generally high gradient in this reach of the Wenatchee River, sediment in the lake likely has high turnover and instability, which limits the suitability of the site for lamprey rearing. It is unknown if water temperature, hydraulics and productivity at the site would limit success of juvenile lamprey at the site and these parameters would need additional monitoring. Downstream habitat is also very high gradient, generally, with large boulder and cobble substrates, although there are short occasional glides with lower gradient and finer sediments.

Vehicle access to the site is good. The lake is adjacent to US 2 and there are existing pullouts and parking areas associated with the dam as well as tourist viewing and recreational opportunities. The dam is currently operated by the Chelan County PUD and therefore permission for site access is favorable. Due to the large size of the lake and the spillover dam at its outlet, retention and recovery of juvenile lamprey would likely require construction of net-pen structures to restrict them to a smaller portion of the lake.

4.3.4.6. NASON CREEK OXBOW

This oxbow of Nason Creek, which is approximately 2/3 mile in length, is located on the southeast side of SR 207 between Cole's Corner and Lake Wenatchee. The oxbow was disconnected from Nason Creek up until 2007 by the SR 207 road prism which blocked hydrologic flow into it. New open-bottom corrugated metal arch culverts were installed under the highway at the up- and downstream ends of the oxbow in 2007, reconnecting it to the creek and providing year-round hydrology in the off channel habitat.

The oxbow now contains diverse habitat including: shallow riffles and glide habitats with gravel and cobble substrate; pools with slow water velocities, fine substrates and more organic accumulation; and backwater eddies, additional side channels and wetland fringe habitats at the margins. Substrate, flow velocities and water quality are likely very good for lamprey rearing in some parts of the oxbow. Nason Creek in the vicinity of the oxbow is dominated by gravel and cobble substrates with very little fine sediment deposition and may not have adequate juvenile rearing habitat, but likely has suitable spawning habitat.

Hydrology and hydraulics in the oxbow appear to be stable, with year-round flow, and habitat appears unlikely to blow-out during high water events. Additional monitoring would be needed to confirm this. The oxbow is not accessible by vehicles. Also of primary concern at the site would be the ability to retain and recover juvenile lamprey. The site is well-connected to Nason Creek through the downstream culvert, which is large in diameter. The ability to restrict lamprey egress through this culvert is limited.

4.4. Monitoring Strategy

Each site identified above includes variations of natural land forms that could be employed for propagation in place of, or as supplementation to, artificial sites being developed for similar purposes. Based on the information obtained from the visual surveys it was determined that eight of the 16 sites observed appear to have the most promising characteristics to meet the goals of the Pacific lamprey Artificial Propagation Project. Therefore it was further determined that these eight sites warranted further investigation and evaluation. The following summarizes observations made at each of the sights observed, and suggests monitoring and analyses to further evaluate the sites.

- Methow River Basin
  - WDFW Methow State Wildlife Area
    - Perform hydraulic analysis to determine if groundwater seepage volumes would be sufficient for goal needs.
    - Perform a flood study to determine overflow activities at high water.
    - Conduct further inspection to determine if vehicle access is adequate using the existing MSWA access road and what modifications would be required.
    - Conduct a study on structure placement and design. The existing structure and arrangement of the ponds appears to be conducive to retention and recovery of macropthalmia. However, with the addition of a small structure at the outlet could enable regulation of ingress/egress of juvenile and adult lamprey to the site at a variety of water levels.
    - Perform verification of pond substrate through sampling to determine proper use. Currently appears to consist of silts, sands and some organic material, is highly suitable to juvenile lamprey rearing, though therefore less so for adult spawning.
    - Perform verification that the availability of suitable habitat for both adult spawning and juvenile rearing in the adjacent mainstem river was also very high.
  - Biddle Pond
    - Conduct a hydraulic analysis on water velocity.

- Perform verification of pond substrate through sampling to determine proper use. Substrate currently consists of fine sediments with some aquatic vegetation.
- Conduct water temperature sampling based on the understanding that winter temperatures may drop significantly during the winter.
- Conduct a study on structure placement and design. Adult lamprey have unimpeded access to the site via the Methow River, Wolf Creek and the pond outlet channel.

- Chelan River Basin
  - Beebe Springs
    - Perform hydraulic analysis to determine if lands adjacent to the existing constructed channels could be modified to produce Type 1 rearing habitat.
    - Collect and analyze water quantity and water quality data from the Beebe Springs hatchery to further evaluate the suitability of water at the site.
    - Conduct plankton and invertebrate sampling studies to assess productivity of the water.
    - Install traps and monitor adult lamprey use of the newly created channels to determine baseline natural production.
    - Assess species interactions. The site is presently used by steelhead. This may be an indicator of suitability for lamprey, but negative interspecific interactions should be avoided.
    - Perform habitat assessments to verify the availability of suitability of habitat for both adult spawning and juvenile rearing in the adjacent mainstem Columbia River.
    - If in-channel structures are proposed to achieve management objectives, use the hydraulic model to evaluate effect on in-channel structures on existing and proposed habitat.
  - Chelan River
    - Adult and juvenile lamprey trapping and electrofishing might be completed at this site to assess existing baseline utilization. This site might serve as a baseline monitoring site, serving as a "control" site, as lamprey management and enhancement actions are not recommended at this site.
    - This site is not recommended for further analysis, assessment, or investigations at this time. Higher priority sites are available for more detailed studies of lamprey management suitability.
- Entiat River Basin
  - Dillwater
    - Adult and juvenile lamprey trapping and electrofishing might be completed at this site to assess existing baseline utilization. This site might serve as a baseline

monitoring site, serving as a "control" site, as lamprey management and enhancement actions are not recommended at this site.

- This site is not recommended for further analysis, assessment, or investigations at this time. Higher priority sites are available for more detailed studies of lamprey management suitability.

- Shamel Creek
  - Perform hydraulic analysis to determine if lands adjacent to the existing backwaters could be modified to produce an adequate amount of Type 1 rearing habitat to meet management goals.
  - Geomorphic investigations (e.g. historic channel occupancy and channel migration analyses) should be completed to determine the likelihood of the Entiat River migrating away from the existing backwater area.
  - Collect and analyze water quantity and water quality data from Shamel Creek and the Entiat River to further evaluate the suitability of water at the site.
  - Use existing Forward Looking Infra-Red (FLIR) information to further refine site utilization plans, taking maximum advantage of cool-water upwelling areas.
  - Conduct plankton and invertebrate sampling studies to assess productivity of the water within the backwater area.
  - Install traps and monitor adult and juvenile lamprey use of the existing habitat to determine baseline natural production.
  - Assess species interactions. The Stormy Creek-Entiat River confluence area (which includes the Shamel Creek and Stormy Gage sites) is presently used by steelhead, Chinook, bull trout and other salmonid species. Use of this area by steelhead may be an indicator of suitability for lamprey, and use by other species suggests the availability of complex and quality habitat, but negative interspecific interactions should be avoided.
  - Perform habitat assessments to verify the availability of suitability of habitat for both adult spawning and juvenile rearing in the adjacent Entiat River. The overall "Stillwaters" reach of the Entiat River should be assessed.
- Stormy Gage
  - Perform hydraulic analysis to determine if lands adjacent to the existing backwaters could be modified to produce an adequate amount of Type 1 rearing habitat to meet management goals.
  - Geomorphic investigations (e.g. historic channel occupancy and channel migration analyses) should be completed to determine the likelihood of the Entiat River migrating away from the existing backwater area.
  - Collect and analyze water quantity and water quality data from the Entiat River to further evaluate the suitability of water at the site.
  - Use existing Forward Looking Infra-Red (FLIR) information to further refine site utilization plans, taking maximum advantage of cool-water upwelling areas.

    - Conduct plankton and invertebrate sampling studies to assess productivity of the water within the backwater area.
    - Install traps and monitor adult and juvenile lamprey use of the existing habitat to determine baseline natural production.
    - Assess species interactions. The Stormy Creek-Entiat River confluence area (which includes the Shamel Creek and Stormy Gage sites) is presently used by steelhead, Chinook, bull trout and other salmonid species. Use of this area by steelhead may be an indicator of suitability for lamprey, and use by other species suggests the availability of complex and quality habitat, but negative interspecific interactions should be avoided.
    - Perform habitat assessments to verify the availability of suitability of habitat for both adult spawning and juvenile rearing in the adjacent Entiat River. The overall "Stillwaters" reach of the Entiat River should be assessed.
  - Cottonwood
    - Adult and juvenile lamprey trapping and electrofishing might be completed at this site, as part of the overall "Stillwaters" investigation, to assess existing baseline utilization of the Entiat River by lamprey. Other investigations are not recommended at this site.
    - This site is not recommended for further analysis, assessment, or investigations at this time. Higher priority sites are available for more detailed studies of lamprey management suitability.
- Wenatchee River
  - Cashmere Pond
    - Perform hydraulic analysis to determine if sufficient groundwater seepage volumes would be sufficient for goal needs.
    - Perform a flood study to determine overflow activities at high water. Additional hydrologic modeling may be necessary to determine flood elevation and risk at this site.
    - Perform verification of pond substrate through sampling to determine proper use. Substrate currently consists of fine sediments with some aquatic vegetation. The pond substrate is currently dominated by sand with some finer (silt) particles and moderate amounts of organic detritus.
    - Conduct temperature monitoring is to confirm site suitability.
    - Conduct a study on structure placement and design. Retention and recovery of lamprey at the site would be relatively straightforward due to the constricted pond outlet and rare overbank flooding; however, rare flood events could result in loss of stock when they do occur.
    - Conduct further inspection to determine if vehicle access can be obtained.
  - Blackbird Island

- Perform hydraulic analysis to determine if water volumes, flows would be sufficient for goal needs.
- Perform verification of pond substrate through sampling to determine proper use. Sediment within the ponded area is sand and gravel near the shore and appears to contain finer sediments as well as a substantial amount of organic detritus in deeper habitats.
- Conduct further inspection to determine if vehicle access can be obtained.
- Conduct a study on structure placement and design. Retention and recovery of lamprey rearing in the pond would be relatively straightforward and would only require a simple structure at the pond outlet to restrict egress by juveniles.
- Perform a flood study to determine overflow activities at high water. Additional hydrologic modeling may be necessary to determine flood elevation and risk at this site.

▪ Nason Creek Oxbow

- Perform verification of pond substrate through sampling to determine proper use. Nason Creek in the vicinity of the oxbow is dominated by gravel and cobble substrates with very little fine sediment deposition and may not have adequate juvenile rearing habitat, but likely has suitable spawning habitat.
- Perform a flood study to determine overflow activities at high water. Additional hydrologic modeling may be necessary to determine flood elevation and risk at this site.
- Conduct further inspection to determine if vehicle access can be obtained. The oxbow is not currently accessible by vehicles.
- Conduct a study on structure placement and design. The primary concern at the site would be the ability to retain and recover juvenile lamprey.

As mentioned above, each of the sites may vary structural from one another requiring a variety of further evaluation. However, each site should also have water quality sampling conducted for the following constituents:

- Water temperature
- Total suspended solids / organics (TSS)
- Dissolved oxygen (DO)
- pH
- Ammonia
- Nitrate
- Salinity

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1. Introduction

This report represents the efforts taken to establish a plan that defines the magnitude and scope of a lamprey aquaculture program within the Upper Columbia Region and to identify facility requirements and research needs for such a program. The information gathered by the USGS and GeoEngineers was compared with the USFWS outlined Pacific lamprey biological needs and requirements to identify tentative recommendations as to how to initiate the next step in the propagation process.

Initial observations indicate that lamprey rearing within "riverine facilities" would not be as beneficial as rearing within "structural facilities." Although the concept is viable, environmental factors and predation are not controllable. Within structural rearing facilities it becomes easier to manage environmental factors such as temperature and water quality while completely removing predation factors. We believe that Pacific lamprey propagation would be most viable when using structural facilities that are in close proximity to riverine sites. For example, it would be proposed that incubation, rearing and tagging could potentially take place at the Leavenworth National Fish Hatchery with lamprey released at any one of the riverine sites identified in the Wenatchee River basin.

5.2. Structural Rearing Facilities

The following are structural rearing facilities identified by the USGS as centers with capability and interest in Pacific lamprey propagation:

- Entiat National Fish Hatchery
- Leavenworth National Fish Hatchery
- Columbia Basin State Hatchery
- Ringold/Meseberg State Hatchery
- Columbia River Research Laboratory
- Oregon Hatchery Research Center
- Abernathy Fish Technology Center

5.3. Riverine Rearing Facilities

The following are riverine facilities identified by GeoEngineers and which are recommended as having the highest habitat value/potential needed for Pacific lamprey release sites.

- Methow River Basin
  - WDFW Methow State Wildlife Area
  - Biddle Pond
- Chelan River Basin
  - Beebe Springs

- Entiat River
  - Shamel Creek
  - Stormy Gage
- Wenatchee River Basin
  - Cashmere Pond
  - Blackbird Island
  - Nason Creek Oxbow

The Beebe Springs site may have the highest overall potential if structural rearing facilities can be established at the Chelan Hatchery, and if additional habitat enhancements can be made to create sufficient Type 1 habitat in or associated with the Beebe Springs channels. The benefits of designing and operating a "closed system" within Beebe Springs, coupling structual and natural elements within one area is worthy of carful consideration. Such a program could minimize the potential for interactions of lamprey propagation efforts with protected salmonids species, and maximize the likihood of being able to detect changes in lamprey populations to assess efficacy of lamprey propagation efforts. Beebe Springs, would, therefore, afford fishery managers the opportunity to test lamprey propogation programs prior to rolling out programs in larger watersheds where landuse, fishery management, ESA protected species efforts, and complex habitat could confound development, impmenetation, and assessment of the efficacy of lamprey propagation efforts.

5.4. Research and Monitoring Needs

5.4.1. Research

Based on USFWS/USGS experience and review of the literature, the potential for the artificial propagation of Pacific lampreys seems high, at least for spawning and initial rearing of larvae . Although the learning curve for intensive lamprey aquaculture will be steep, one can find confidence simply by perusing the Table of Contents of the recent volume *Aquaculture in 21st Century* (Kelly and Silverstein 2006), where everything from bay scallops to sea urchins to white suckers is being cultured. For Pacific lampreys, anticipated progress in the development of techniques and methods for aquaculture will come from the combined efforts of fisheries researchers, culturists, and nutritionists. Although there will be many issues to address, some initial priorities might include further research:

- The influence of rearing density, photoperiod, and water temperature on fish growth and health
- Identification and development of foods and rations for optimal growth and nutrition.
- Determine a means that accelerates or manipulates the gonadal maturation of adult Pacific lamprey so they do not have to be held for long periods of time prior to spawning. This research should include artificial manipulation of light, water temperature, and salinity concentrations to induce gonad maturation. Research should also be inclusive of gonadotropin-releasing hormone, luteinizing hormone, follicle stimulating hormone and sex steroids (androgens and estogens) as an artificial means to induce gonadal maturation.

- Determine if there is a precise physiological indicator of spawning readiness. This research should evaluate non-lethal means to determine if eggs and milt can be readily stripped from adults.
- Determine if endocrinological treatments induce metamorphosis so that ammocoete rearing can be shortened. This research should include the evaluation of corticotropin-releasing hormone, Thyrotropin-releasing hormone, thyrotropin, and thyroid hormones (thyroxine, T4 and triiodothyronine, T3), growth hormone, corticosteroids, sex steroids, cortisol, and kisspeptin.
- Evaluation of specific growth rates, health, and survival of fish reared at various densities should be conducted to determine space requirements for culture of various life history stages, particularly ammocoetes.
- Determine the variability of growth within a cohort and their developmental synchrony so that force release may be a future option.
- Release timing, size at release, and release of various life history stages should be evaluated to determine the most successful time and stage for fish stocking.
- Optimal artificial feeds should be developed to enhance growth rates at all life history stages.
- Polyculture should be considered and evaluated. This evaluation should include examination of second pass water as a potential source for ammocoete rearing.

5.4.1. Monitoring

With regards to monitoring, as addressed above in Section 4.4, Monitoring Strategy, there will be many technical issues to address while evaluating different rearing environments and developing effective protocols. The riverine site will require additional monitoring efforts. Each riverine site identified in Section 5.3 will require varying degrees of monitoring and initial study in an effort to move lamprey aquaculture from small-scale, experimental, laboratory-based efforts to large-scale, production-level, intensive culture. We believe that the structural and riverine facilities described above would be capable of conducting lamprey aquaculture, while the research facilities should be useful for detailed studies of the critical uncertainties.

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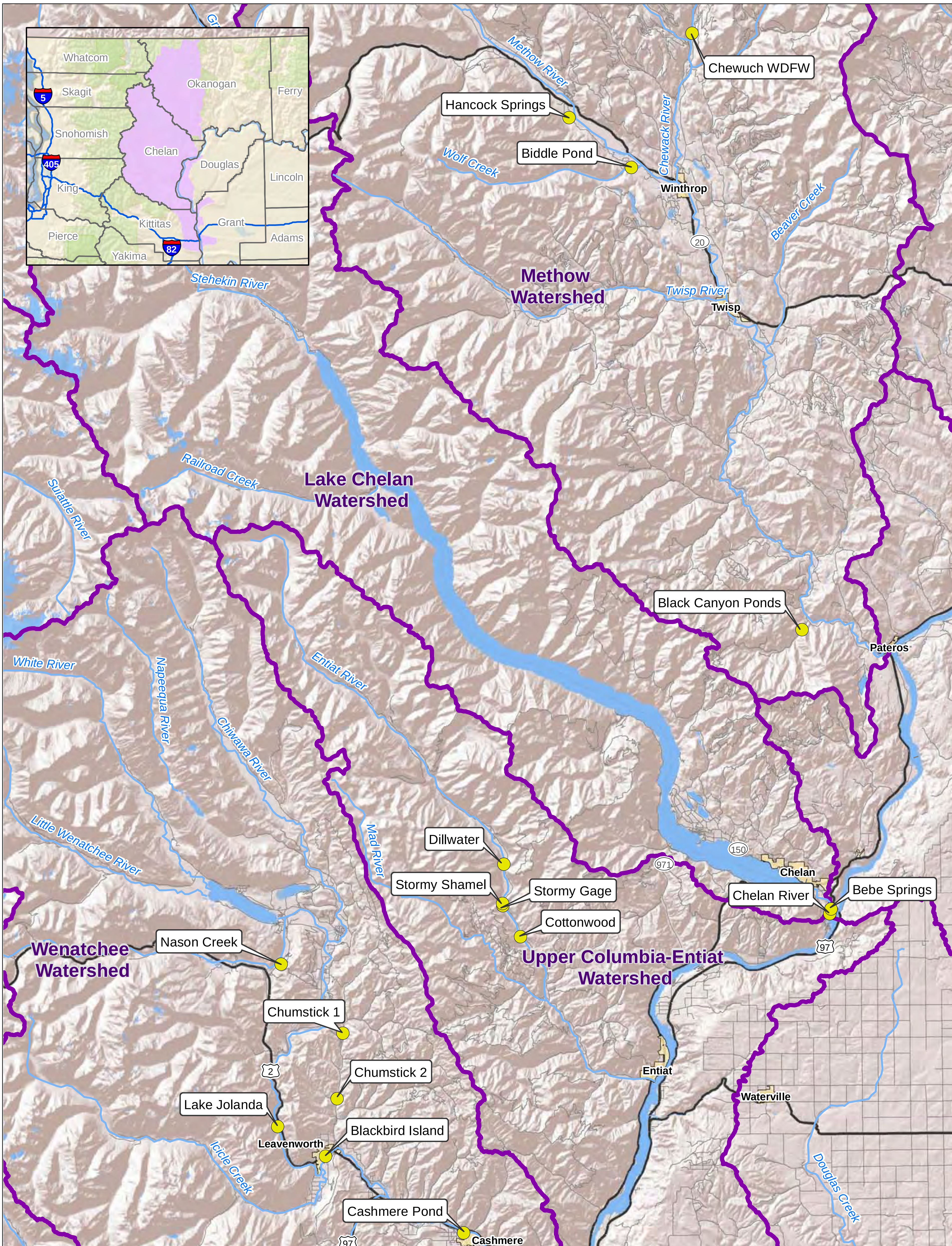
Map Revised: 2011/04/02, crc



Site Locations

4th-Field HUC Boundary

Cities

6 0 6

Miles

N W E S

Field Site Locations and 6th-Field HUCs within Entiat & Chelan Areas

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

GeoEngineers

Figure 1

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: ESRI Shaded Relief, ESRI Streets and Maps (roads, water features), Oregon BLM (HUCs).

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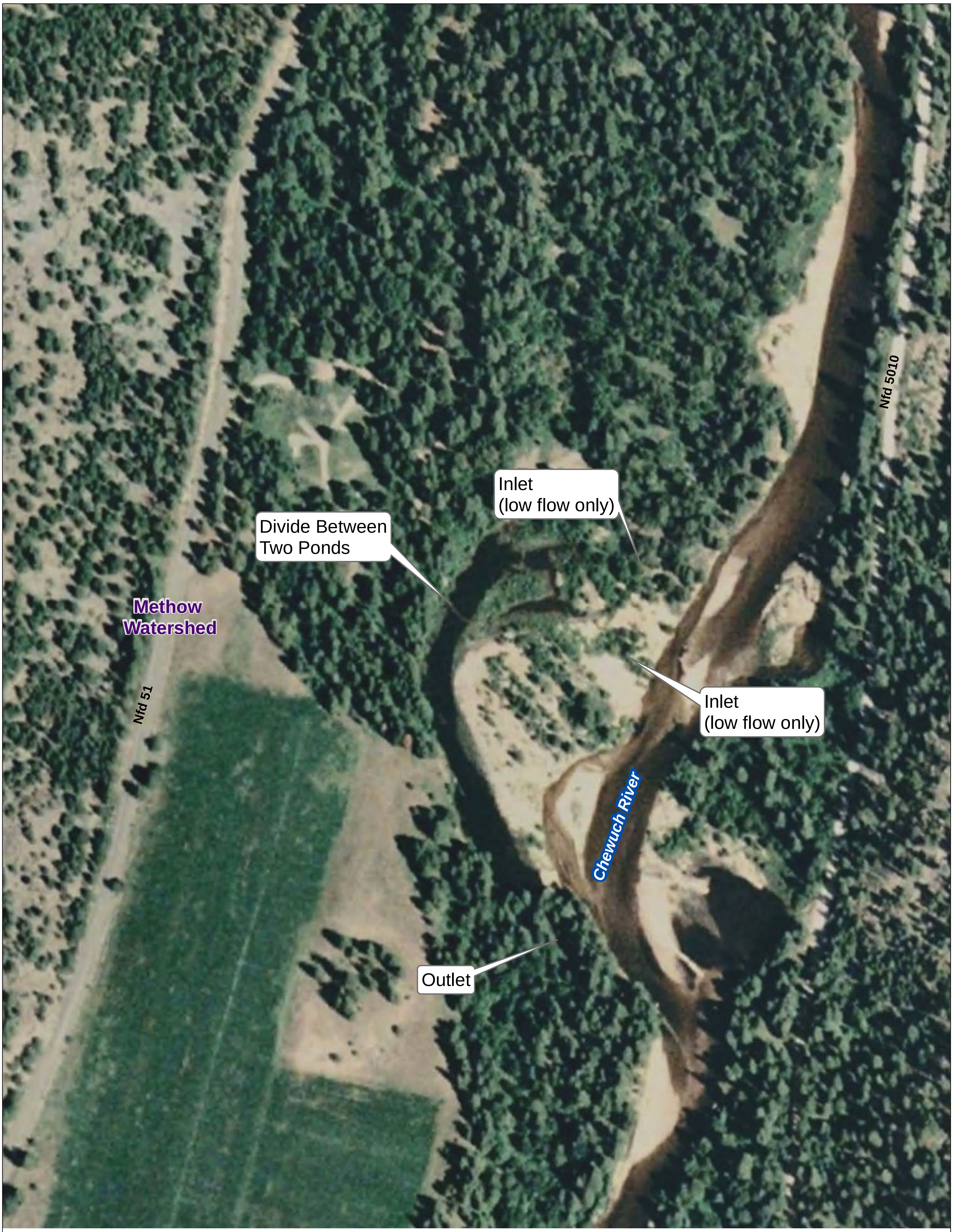
Map Revised: May 2, 2011 MLT



200 0 200
Feet

N W E S

Chewuch - WDFW

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

GEOENGINEERS

Figure 2

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: ESRI Bing Maps (aerial photograph), Oregon BLM (HUC Labels).

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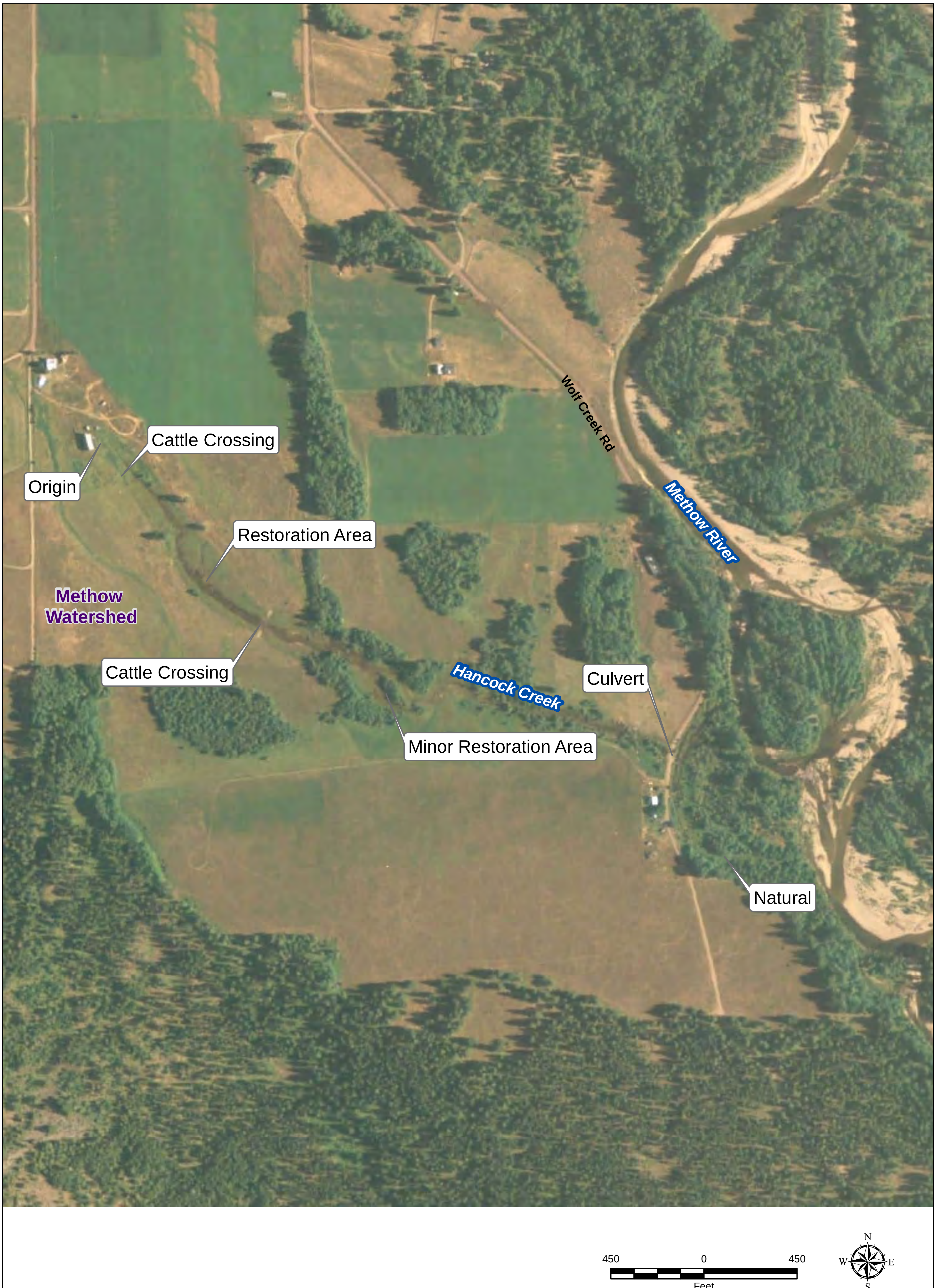
Map Revised: April 3, 2011



Hancock Springs

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

GEOENGINEERS

Figure 3

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Reference: ESRI I3 Imagery (aerial photograph), Oregon BLM (HUC Labels).

Path: \\bam\Projects\9\9335009\GIS\9335009_BiddlePond.mxd

Map Revised: May 2, 2011 MLT

200 0 200

Feet

N W E S

Biddle Pond

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

GeoEngineers

Figure 4

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
Reference: ESRI Bing Maps (aerial photograph), Oregon BLM (HUC Labels).

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Map Revised: May 2, 2011 MLT

Black Canyon Ponds

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

GeoEngineers

Figure 5

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
Reference: ESRI Bing Maps (aerial photograph), Oregon BLM (HUC Labels).

Existing Project

200 0 200
Feet

N W E S

Bebe Springs

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

GEOENGINEERS

Figure 6

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
Reference: Orthophotos from NAIP (2006 aerial photograph), Oregon BLM (HUC Labels).

Potential Lamprey Rearing Area

Cobble Boulder

150 0 150

Feet

N W E S

Chelan River

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

GEOENGINEERS

Figure 7

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Orthophotos from NAIP (2006 aerial photograph), Oregon BLM (HUC Labels).

Path: \\bam\Projects\9\9335009\GIS\9335009_Dillwater.mxd

Map Revised: May 3, 2011 MLT

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Orthophotos from USBOR (2006 aerial photograph), Oregon BLM (HUC Labels).

Dillwater

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

GEOENGINEERS

Figure 8

Path: \\bam\Projects\9\9335009\GIS\9335009_StormyShamel.mxd

Map Revised: May 3, 2011 MLT

Stormy Shamel

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

GEOENGINEERS

Figure 9

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
Reference: Orthophotos from USBOR (2006 aerial photograph), Oregon BLM (HUC Labels).

Path: \\bam\Projects\9\9335009\GIS\9335009_StormyGage.mxd

Map Revised: May 2, 2011 MLT

Active Channel Migration

Viable Backwater

Pond

100 0 100

Feet

N W E S

Stormy Gage

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

GEOENGINEERS

Figure 10

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: Orthophotos from USBOR (2006 aerial photograph), Oregon BLM (HUC Labels).

Cottonwood

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

GEOENGINEERS

Figure 11

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
Reference: ESRI Bing Maps (aerial photograph), Oregon BLM (HUC Labels).

Path: \\bam\Projects\9\9335009\GIS\9335009_Chumstick1.mxd

Map Revised: May 3, 2011 MLT

150 0 150
Feet

N W E S

Chumstick 1

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

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Figure 12

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
Reference: NAIP 2006 (aerial photograph), Oregon BLM (HUC Labels).

Path: \\bam\Projects\9\9335009\GIS\9335009_Chumstick_2.mxd

Map Revised: May 3, 2011 MLT

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
Reference: NAIP 2006 (aerial photograph), Oregon BLM (HUC Labels).

Chumstick 2

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

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Figure 13

Path: \\bam\Projects\9\9335009\GIS\9335009_NasonCreek.mxd

Map Revised: May 3, 2011 MLT

400 0 400

Feet

N W E S

Nason Creek

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

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Figure 14

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.

Reference: NAIP 2006 (aerial photograph), Oregon BLM (HUC Labels).

Lake Jolanda

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

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Figure15

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
Reference: USDA NAIP Imagery (2006 aerial photograph), Oregon BLM (HUC Labels).

Path: \\bam\Projects\9\9335009\GIS\9335009_Blackbird.mxd

Map Revised: May 3, 2011 MLT

200 0 200
Feet

N W E S

Blackbird Island

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

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Figure 16

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
Reference: NAIP 2006 (aerial photograph), Oregon BLM (HUC Labels).

Cashmere Pond

Chelan County Public Utility District
Pacific Lamprey Artificial Propagation
and Rearing Investigation

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Figure 17

Notes: 1. The locations of all features shown are approximate. 2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. cannot guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
Reference: NAIP 2006 (aerial photograph), Oregon BLM (HUC Labels).

APPENDIX A
DRAFT Criteria for Potential Lamprey Propagation Site Selection and Field Notes

DRAFT - TOP 5 Site Examples by Watershed
Rocky Reach Fish Forum Pacific Lamprey Propagation Workshop
August 24, 2010

DRAFT CRITERIA FOR POTENTIAL LAMPREY PROPAGATION SITE SELECTION

Please note – this work is for preliminary planning purposes only. Ideas and approach are all in conceptual stages and not an indication of any commitment to implement actions at a site. However, we need help with relatively specific locations that would serve as "really good" opportunities that would have favorable answers to the following criteria.

"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish): Y N U Notes:____________
2. Land ownership/accessibility (get on/work on site): Y N U Notes:____________
3. Site vehicular accessibility (provide description/photo to get folks to the site) Y N U Notes:____________
4. Suitable thermal, flow regimes, substrate
    a. Water temperature about 60 degrees F Y N U Notes:____________
    b. Year-round flow Y N U Notes:____________
    c. Low water velocities – 0 to 1.0 ft./sec. Y N U Notes:____________
    d. Sand/silt substrate suitability Y N U Notes:____________
    e. Stable Hydraulics: substrate/flow regime Y N U Notes:____________
    f. Productive, nutrient rich water Y N U Notes:____________
5. Oxbow/ high-flow side channel? Y N U Notes:____________
6. Associated Downstream Habitat
   (e.g. type 1 habitat downstream, as fish move down they have a place to go) Y N U Notes:____________
7. Implications of attracting adult lamprey to area
    a. Favorable conditions (get them where wanted) Y N U Notes:____________
    b. Unfavorable conditions (attracted to unwanted) Y N U Notes:____________
8. Predation Risk Y N U Notes:____________
9. Other?

Watershed: SITE WATERSHED____________ Site Name: SITE NAME____________

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"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish):	<u>Y</u> N U	Notes:
2. Land ownership/accessibility (get on/work on site):	Y N <u>U</u>	Notes: Land ownership unknown.
3. Site vehicular accessibility (provide description/photo to get folks to the site)	<u>Y</u> N U	Notes: Adjacent to public road.
4. Suitable thermal, flow regimes, substrate		
a. Water temperature about 60 degrees F	Y N <u>U</u>	Notes:
b. Year-round flow	<u>Y</u> N U	Notes: Appears stable – ponded.
c. Low water velocities – 0 to 1.0 ft./sec.	<u>Y</u> N U	Notes:
d. Sand/silt substrate suitability	<u>Y</u> N U	Notes: Silt/sand and organic.
e. Stable Hydraulics: substrate/flow regime	<u>Y</u> N U	Notes:
f. Productive, nutrient rich water	<u>Y</u> N U	Notes: Lots of aquatic vegetation.
5. Oxbow/ high-flow side channel?	Y <u>N</u> U	Notes:
6. Associated Downstream Habitat (e.g. type 1 habitat downstream, as fish move down they have a place to go)	Y N <u>U</u>	Notes: Black Canyon Creek, small stream-relatively high gradient.
7. Implications of attracting adult lamprey to area		
a. Favorable conditions (get them where wanted)	Y N <u>U</u>	Notes: Do they come up Black Canyon Creek?
b. Unfavorable conditions (attracted to unwanted)	Y N <u>U</u>	Notes:
8. Predation Risk	Y N <u>U</u>	Notes:
9. Other?		

Watershed: <u>Methow</u>

Site Name: <u>Black Canyon Pond</u>

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"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish):	<u>Y</u> N U	Notes: Constricted outlet; barrier; groundwater 2 ponds.
2. Land ownership/accessibility (get on/work on site):	<u>Y</u> N U	Notes: WDFW managed.
3. Site vehicular accessibility (provide description/photo to get folks to the site)	<u>Y</u> N U	Notes: Trail extends to pond edge; may need to widen.
4. Suitable thermal, flow regimes, substrate		
a. Water temperature about 60 degrees F	Y N <u>U</u>	Notes:
b. Year-round flow	<u>Y</u> N U	Notes: Groundwater and overbank flooding.
c. Low water velocities – 0 to 1.0 ft./sec.	<u>Y</u> N U	Notes: Ponded impoundments maintained by beaver.
d. Sand/silt substrate suitability	<u>Y</u> N U	Notes: Great.
e. Stable Hydraulics: substrate/flow regime	Y N <u>U</u>	Notes: Overbank flooding from mainstem at high flows.
f. Productive, nutrient rich water	<u>Y</u> N U	Notes:
5. Oxbow/ high-flow side channel?	<u>Y</u> N U	Notes:
6. Associated Downstream Habitat (e.g. type 1 habitat downstream, as fish move down they have a place to go)	<u>Y</u> N U	Notes: Much off-channel habitat associated with Chewuch
7. Implications of attracting adult lamprey to area		
a. Favorable conditions (get them where wanted)	<u>Y</u> N U	Notes:
b. Unfavorable conditions (attracted to unwanted)	Y N <u>U</u>	Notes:
8. Predation Risk	Y N <u>U</u>	Notes:
9. Other?		

Other Note: Overbank flow occurs at +3 feet river elevation relative to current flows.

Watershed: <u>Methow</u>

Site Name: <u>Chewuch – WDFW MSWA</u>

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"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish): Y N <u>U</u> Notes: Channel flows freely to Methow River.
2. Land ownership/accessibility (get on/work on site): <u>Y</u> N U Notes: Conservation easement.
3. Site vehicular accessibility (provide description/photo to get folks to the site) Y <u>N</u> U Notes: Only accessible at top and bridge/culvert.
4. Suitable thermal, flow regimes, substrate
    a. Water temperature about 60 degrees F <u>Y</u> N U Notes: Stable water temp year round due to spring source.
    b. Year-round flow <u>Y</u> N U Notes:
    c. Low water velocities – 0 to 1.0 ft./sec. Y N <u>U</u> Notes: In places.
    d. Sand/silt substrate suitability <u>Y</u> N U Notes: Sand/silt and organics.
    e. Stable Hydraulics: substrate/flow regime <u>Y</u> N U Notes:
    f. Productive, nutrient rich water Y N <u>U</u> Notes:
5. Oxbow/ high-flow side channel? Y <u>N</u> U Notes:
6. Associated Downstream Habitat
   (e.g. type 1 habitat downstream, as fish move down they have a place to go) Y N <u>U</u> Notes: Yes in Hancock Springs, Unknown in Methow.
7. Implications of attracting adult lamprey to area
    a. Favorable conditions (get them where wanted) <u>Y</u> N U Notes:
    b. Unfavorable conditions (attracted to unwanted) Y <u>N</u> U Notes:
8. Predation Risk Y N <u>U</u> Notes:
9. Other?

Other Notes: Cattle crossing still active.

Watershed: <u>Methow</u> Site Name: <u>Hancock Springs</u>

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"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish): **Y** N U Notes: Constricted outlet.
2. Land ownership/accessibility (get on/work on site): **Y** N U Notes: Cooperative land owner.
3. Site vehicular accessibility (provide description/photo to get folks to the site) **Y** N U Notes: Good access to pond.
4. Suitable thermal, flow regimes, substrate
   a. Water temperature about 60 degrees F Y N **U** Notes:
   b. Year-round flow **Y** N U Notes: Currently used by Yakima Nation Coho-Hydro data.
   c. Low water velocities – 0 to 1.0 ft./sec. **Y** N U Notes: Ponded.
   d. Sand/silt substrate suitability **Y** N U Notes: Sand/silt/organics predominantly.
   e. Stable Hydraulics: substrate/flow regime **Y** N U Notes: Substrate stable; Yakima Nation has hydro data.
   f. Productive, nutrient rich water **Y** N U Notes:
5. Oxbow/ high-flow side channel? **Y** N U Notes: Adjacent to Wolf Creek.
6. Associated Downstream Habitat
   (e.g. type 1 habitat downstream, as fish move down they have a place to go) Y N **U** Notes: Wolf Creek?
7. Implications of attracting adult lamprey to area
   a. Favorable conditions (get them where wanted) **Y** N U Notes:
   b. Unfavorable conditions (attracted to unwanted) Y **N** U Notes:
8. Predation Risk Y N **U** Notes:
9. Other?

Watershed: Methow

Site Name: Biddle Pond

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August 24, 2010

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"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish): — Y N U — Notes: Depends on location
2. Land ownership/accessibility (get on/work on site): — Y N U — Notes:
3. Site vehicular accessibility (provide description/photo to get folks to the site) — Y N U — Notes:
4. Suitable thermal, flow regimes, substrate
   a. Water temperature about 60 degrees F — Y N U — Notes: Needs more data
   b. Year-round flow — Y N U — Notes:
   c. Low water velocities – 0 to 1.0 ft./sec. — Y N U — Notes: Refer to hydrograph
   d. Sand/silt substrate suitability — Y N U — Notes: Needs more data
   e. Stable Hydraulics: substrate/flow regime — Y N U — Notes: but could use more research and study
   f. Productive, nutrient rich water — Y N U — Notes:
5. Oxbow/ high-flow side channel? — Y N U — Notes: Side channels
6. Associated Downstream Habitat
   (e.g. type 1 habitat downstream, as fish move down they have a place to go) — Y N U — Notes: Columbia River
7. Implications of attracting adult lamprey to area
   a. Favorable conditions (get them where wanted) — Y N U — Notes:
   b. Unfavorable conditions (attracted to unwanted) — Y N U — Notes:
8. Predation Risk — Y N U — Notes:
9. Other? — Relatively big "closed system"

Watershed: Lake Chelan

Site Name: Beebe Springs

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DRAFT CRITERIA FOR POTENTIAL LAMPREY PROPAGATION SITE SELECTION

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"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish): — Y **N** U — Notes:
2. Land ownership/accessibility (get on/work on site): — **Y** N U — Notes:
3. Site vehicular accessibility (provide description/photo to get folks to the site) — **Y** N U — Notes:
4. Suitable thermal, flow regimes, substrate
    a. Water temperature about 60 degrees F — **Y** N U — Notes: Needs more data
    b. Year-round flow — **Y** N U — Notes:
    c. Low water velocities – 0 to 1.0 ft./sec. — **Y** N U — Notes:
    d. Sand/silt substrate suitability — **Y** N U — Notes: Needs more data
    e. Stable Hydraulics: substrate/flow regime — **Y** N U — Notes: Variable depending on site location
    f. Productive, nutrient rich water — **Y** N U — Notes:
5. Oxbow/ high-flow side channel? — **Y** N U — Notes: Off channel "arm"
6. Associated Downstream Habitat
   (e.g. type 1 habitat downstream, as fish move down they have a place to go) — **Y** N U — Notes: On Columbia River
7. Implications of attracting adult lamprey to area
    a. Favorable conditions (get them where wanted) — Y N **U** — Notes:
    b. Unfavorable conditions (attracted to unwanted) — Y N **U** — Notes:
8. Predation Risk — Y N **U** — Notes:
9. Other? — Relatively large river system

Watershed: Lake Chelan

Site Name: Chelan River

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DRAFT CRITERIA FOR POTENTIAL LAMPREY PROPAGATION SITE SELECTION

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"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish): <u>Y</u> N U Notes: Could use further study
2. Land ownership/accessibility (get on/work on site): <u>Y</u> N U Notes: Land owned by Chelan Douglas Land Trust
3. Site vehicular accessibility (provide description/photo to get folks to the site) <u>Y</u> N U Notes:
4. Suitable thermal, flow regimes, substrate
   a. Water temperature about 60 degrees F <u>Y</u> N U Notes: Cobbles up to an ½ inch
   b. Year-round flow <u>Y</u> N U Notes: Depends on location
   c. Low water velocities – 0 to 1.0 ft./sec. <u>Y</u> N U Notes: Depends on location
   d. Sand/silt substrate suitability <u>Y</u> N U Notes:
   e. Stable Hydraulics: substrate/flow regime <u>Y</u> N U Notes: If channel does not move
   f. Productive, nutrient rich water <u>Y</u> N U Notes: Low benthic/macro-invertebrates. Further study needed.
5. Oxbow/ high-flow side channel? Y **<u>N</u>** U Notes:
6. Associated Downstream Habitat
   (e.g. type 1 habitat downstream, as fish move down they have a place to go) Y **<u>N</u>** U Notes:
7. Implications of attracting adult lamprey to area
   a. Favorable conditions (get them where wanted) Y N **<u>U</u>** Notes:
   b. Unfavorable conditions (attracted to unwanted) Y N **<u>U</u>** Notes:
8. Predation Risk Y N **<u>U</u>** Notes:
9. Other? Size is adequate (relative)

Watershed: <u>Entiat</u>

Site Name: <u>Dillwater</u>

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August 24, 2010

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"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish): **Y** N U Notes:
2. Land ownership/accessibility (get on/work on site): **Y** N U Notes: Owned by Chelan Douglas Land Trust
3. Site vehicular accessibility (provide description/photo to get folks to the site) **Y** N U Notes:
4. Suitable thermal, flow regimes, substrate
    a. Water temperature about 60 degrees F **Y** N U Notes: Have data and Forward looking inferred
    b. Year-round flow **Y** N U Notes:
    c. Low water velocities – 0 to 1.0 ft./sec. **Y** N U Notes:
    d. Sand/silt substrate suitability **Y** N U Notes:
    e. Stable Hydraulics: substrate/flow regime **Y** N U Notes: Channel migrates. Further research needed.
    f. Productive, nutrient rich water **Y N** U Notes: low benthic/macro-invertebrate. Further research needed
5. Oxbow/ high-flow side channel? Y **N** U Notes:
6. Associated Downstream Habitat
   (e.g. type 1 habitat downstream, as fish move down they have a place to go) Y **N** U Notes:
7. Implications of attracting adult lamprey to area
    a. Favorable conditions (get them where wanted) Y N **U** Notes:
    b. Unfavorable conditions (attracted to unwanted) Y N **U** Notes:
8. Predation Risk Y N **U** Notes:
9. Other?

Watershed: Enitat

Site Name: Stormy Shemel

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"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish): <u>Y</u> N U Notes:
2. Land ownership/accessibility (get on/work on site): <u>Y</u> N U Notes: Owned by Chelan Douglas Land Trust
3. Site vehicular accessibility (provide description/photo to get folks to the site) <u>Y</u> N U Notes:
4. Suitable thermal, flow regimes, substrate
   a. Water temperature about 60 degrees F Y N <u>U</u> Notes: Have forward looking inferred. Need to research
   b. Year-round flow <u>Y</u> N U Notes: Most likely from observations
   c. Low water velocities – 0 to 1.0 ft./sec. <u>Y</u> N U Notes:
   d. Sand/silt substrate suitability <u>Y</u> N U Notes:
   e. Stable Hydraulics: substrate/flow regime <u>Y</u> N U Notes:
   f. Productive, nutrient rich water <u>Y</u> N U Notes:
5. Oxbow/ high-flow side channel? Y <u>N</u> U Notes: Somewhat of an oxbow
6. Associated Downstream Habitat
   (e.g. type 1 habitat downstream, as fish move down they have a place to go) <u>Y</u> N U Notes:
7. Implications of attracting adult lamprey to area
   a. Favorable conditions (get them where wanted) Y N <u>U</u> Notes: Needs further research
   b. Unfavorable conditions (attracted to unwanted) Y N <u>U</u> Notes: Needs further research
8. Predation Risk Y N <u>U</u> Notes: Needs further research
9. Other?

Watershed: <u>Entiat</u> Site Name: <u>Stormy Gage</u>

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"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish): <u>Y</u> N U Notes:
2. Land ownership/accessibility (get on/work on site): <u>Y</u> N U Notes: Land is owned by the Chelan Douglas Land Trust
3. Site vehicular accessibility (provide description/photo to get folks to the site) <u>Y</u> N U Notes: Some work is needed on the bridge
4. Suitable thermal, flow regimes, substrate
    a. Water temperature about 60 degrees F <u>Y</u> N U Notes: Have data
    b. Year-round flow <u>Y</u> N U Notes: If hydraulically connected
    c. Low water velocities – 0 to 1.0 ft./sec. <u>Y</u> N U Notes: Depends on location
    d. Sand/silt substrate suitability <u>Y</u> N U Notes: Lots of sand and silt
    e. Stable Hydraulics: substrate/flow regime <u>Y</u> N U Notes: Depends on location
    f. Productive, nutrient rich water <u>Y</u> N U Notes: Entiat appears to be
5. Oxbow/ high-flow side channel? <u>Y</u> N U Notes: Low benthic/macro-invertebrates. Further study needed.
6. Associated Downstream Habitat
   (e.g. type 1 habitat downstream, as fish move down they have a place to go) <u>Y</u> N U Notes:
7. Implications of attracting adult lamprey to area
    a. Favorable conditions (get them where wanted) Y N <u>U</u> Notes:
    b. Unfavorable conditions (attracted to unwanted) Y N <u>U</u> Notes:
8. Predation Risk Y N <u>U</u> Notes:
9. Other? Stream size adequate (relative)

Watershed: <u>Entiat</u>

Site Name: <u>Cottonwood</u>

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"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish): **Y** N U Notes: Island ponds.
2. Land ownership/accessibility (get on/work on site): **Y** N U Notes: Landowner cooperative.
3. Site vehicular accessibility (provide description/photo to get folks to the site) **Y** N U Notes:
4. Suitable thermal, flow regimes, substrate
   a. Water temperature about 60 degrees F Y **N** U Notes: Doubtful.
   b. Year-round flow Y **N** U Notes: Pond almost dry at the time of the site visit.
   c. Low water velocities – 0 to 1.0 ft./sec. **Y** N U Notes:
   d. Sand/silt substrate suitability **Y** N U Notes: Silt/organic.
   e. Stable Hydraulics: substrate/flow regime Y **N** U Notes: Likely dramatic seasonal variation in water level.
   f. Productive, nutrient rich water **Y** N U Notes:
5. Oxbow/ high-flow side channel? Y **N** U Notes: Isolated pond with constructed inlet/outlet.
6. Associated Downstream Habitat
   (e.g. type 1 habitat downstream, as fish move down they have a place to go) Y N **U** Notes: Chumstick Creek - Same
7. Implications of attracting adult lamprey to area
   a. Favorable conditions (get them where wanted) Y N **U** Notes: Are they in basin?
   b. Unfavorable conditions (attracted to unwanted) Y **N** U Notes:
8. Predation Risk Y N **U** Notes:
9. Other?

Watershed: Wenatchee Site Name: Chumstick 2

DRAFT - TOP 5 Site Examples by Watershed
Rocky Reach Fish Forum Pacific Lamprey Propagation Workshop
August 24, 2010

DRAFT CRITERIA FOR POTENTIAL LAMPREY PROPAGATION SITE SELECTION

Please note – this work is for preliminary planning purposes only. Ideas and approach are all in conceptual stages and not an indication of any commitment to implement actions at a site. However, we need help with relatively specific locations that would serve as "really good" opportunities that would have favorable answers to the following criteria.

"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish): Y N <u>U</u> Notes: No obvious pinch point connected to Nason Creek.
2. Land ownership/accessibility (get on/work on site): Y N <u>U</u> Notes: Land owner – unknown.
3. Site vehicular accessibility (provide description/photo to get folks to the site) Y <u>N</u> U Notes: Oxbow is not vehicle accessible.
4. Suitable thermal, flow regimes, substrate
   a. Water temperature about 60 degrees F Y N <u>U</u> Notes:
   b. Year-round flow <u>Y</u> N U Notes: Appears to be connection even at low flows.
   c. Low water velocities – 0 to 1.0 ft./sec. <u>Y</u> N U Notes: "Still water" section at current flow level.
   d. Sand/silt substrate suitability <u>Y</u> N U Notes: Sand silt and organics.
   e. Stable Hydraulics: substrate/flow regime Y N <u>U</u> Notes: Water level fluctuates seasonally?
   f. Productive, nutrient rich water <u>Y</u> N U Notes: Evidence of organic accumulation.
5. Oxbow/ high-flow side channel? <u>Y</u> N U Notes:
6. Associated Downstream Habitat
   (e.g. type 1 habitat downstream, as fish move down they have a place to go) Y <u>N</u> U Notes: Nason Creek dominated by gravel/cobble substrates.
7. Implications of attracting adult lamprey to area
   a. Favorable conditions (get them where wanted) Y N <u>U</u> Notes: How common are lamprey this high? Access past dam?
   b. Unfavorable conditions (attracted to unwanted) Y N <u>U</u> Notes:
8. Predation Risk Y N <u>U</u> Notes:
9. Other?

Watershed: <u>Wenatchee</u>

Site Name: <u>Nason Oxbow</u>

DRAFT - TOP 5 Site Examples by Watershed
Rocky Reach Fish Forum Pacific Lamprey Propagation Workshop
August 24, 2010

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"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish): Y N **U** Notes:
2. Land ownership/accessibility (get on/work on site): Y N **U** Notes:
3. Site vehicular accessibility (provide description/photo to get folks to the site) **Y** N U Notes: Access from dam.
4. Suitable thermal, flow regimes, substrate
   a. Water temperature about 60 degrees F Y N **U** Notes:
   b. Year-round flow **Y** N U Notes:
   c. Low water velocities – 0 to 1.0 ft./sec. Y N **U** Notes: Sometimes?
   d. Sand/silt substrate suitability **Y** N U Notes: Sandy.
   e. Stable Hydraulics: substrate/flow regime Y N **U** Notes: High gradient rapids.
   f. Productive, nutrient rich water Y **N** U Notes:
5. Oxbow/ high-flow side channel? Y **N** U Notes:
6. Associated Downstream Habitat
   (e.g. type 1 habitat downstream, as fish move down they have a place to go) Y **N** U Notes:
7. Implications of attracting adult lamprey to area
   a. Favorable conditions (get them where wanted) Y N **U** Notes: Dam passage?
   b. Unfavorable conditions (attracted to unwanted) Y N **U** Notes:
8. Predation Risk Y N **U** Notes:
9. Other?

Watershed: Wenatchee

Site Name: Lake Jolanda

DRAFT - TOP 5 Site Examples by Watershed
Rocky Reach Fish Forum Pacific Lamprey Propagation Workshop
August 24, 2010

DRAFT CRITERIA FOR POTENTIAL LAMPREY PROPAGATION SITE SELECTION

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"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish): <u>Y</u> N U Notes:
2. Land ownership/accessibility (get on/work on site): Y N <u>U</u> Notes: Would require vehicle access to park.
3. Site vehicular accessibility (provide description/photo to get folks to the site) <u>Y</u> N U Notes: Maintenance roads.
4. Suitable thermal, flow regimes, substrate
   a. Water temperature about 60 degrees F Y N <u>U</u> Notes:
   b. Year-round flow <u>Y</u> N U Notes: Appears hydraulically stable.
   c. Low water velocities – 0 to 1.0 ft./sec. <u>Y</u> N U Notes: Ponded.
   d. Sand/silt substrate suitability <u>Y</u> N U Notes: Sand/gravel and silty organics.
   e. Stable Hydraulics: substrate/flow regime <u>Y</u> N U Notes: Outlet elevations - maintained impoundment.
   f. Productive, nutrient rich water <u>Y</u> N U Notes:
5. Oxbow/ high-flow side channel? <u>Y</u> N U Notes:
6. Associated Downstream Habitat
   (e.g. type 1 habitat downstream, as fish move down they have a place to go) <u>Y</u> N U Notes: Excellent in Wenatchee right side channel.
7. Implications of attracting adult lamprey to area
   a. Favorable conditions (get them where wanted) <u>Y</u> N U Notes:
   b. Unfavorable conditions (attracted to unwanted) Y <u>N</u> U Notes:
8. Predation Risk Y N <u>U</u> Notes:
9. Other?

Watershed: <u>Wenatchee</u> Site Name: <u>Blackbird Island</u>

DRAFT - TOP 5 Site Examples by Watershed
Rocky Reach Fish Forum Pacific Lamprey Propagation Workshop
August 24, 2010

DRAFT CRITERIA FOR POTENTIAL LAMPREY PROPAGATION SITE SELECTION

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"Really Good" opportunity criteria/checklist:

1. Recover macropthalmia (ability to get hands on fish): **Y** N U Notes: Screen outlet?
2. Land ownership/accessibility (get on/work on site): Y N **U** Notes: Access from highway difficult.
3. Site vehicular accessibility (provide description/photo to get folks to the site) Y **N** U Notes:
4. Suitable thermal, flow regimes, substrate
    a. Water temperature about 60 degrees F Y N **U** Notes: Date?
    b. Year-round flow **Y** N U Notes: Believe so based on current site conditions.
    c. Low water velocities – 0 to 1.0 ft./sec. **Y** N U Notes: Pond.
    d. Sand/silt substrate suitability **Y** N U Notes: Primarily sand.
    e. Stable Hydraulics: substrate/flow regime **Y** N U Notes: Believe so.
    f. Productive, nutrient rich water Y N **U** Notes:
5. Oxbow/ high-flow side channel? **Y** N U Notes:
6. Associated Downstream Habitat
   (e.g. type 1 habitat downstream, as fish move down they have a place to go) **Y** N U Notes: Outlet channel has varied habitat; Wenatchee River.
7. Implications of attracting adult lamprey to area
    a. Favorable conditions (get them where wanted) **Y** N U Notes: Constructed outlet channel with woody debris.
    b. Unfavorable conditions (attracted to unwanted) Y **N** U Notes:
8. Predation Risk Y **N** U Notes: ?
9. Other?

Watershed: Wenatchee

Site Name: Cashmere Pond

Appendix B
Aquaculture Questionnaire

United States Department of the Interior

U.S. GEOLOGICAL SURVEY

Columbia River Research Laboratory
5501A Cook-Underwood Road
Cook, WA 98605 USA

(509) 538-2299

Lamprey Aquaculture Questionnaire

The purpose of this questionnaire is to evaluate the potential of selected Pacific Northwest fish hatcheries and research facilities for the culture of Pacific lampreys. This questionnaire was developed as part of a project being conducted by the U.S. Geological Survey under contract with the Chelan County PUD. The scope of this project includes an inventory of existing facilities that might be used for the artificial propagation of lampreys, their potential efficacy, and development of a manual of standard operating procedures for the spawning, hatching, and rearing of lampreys in captivity. We thank you in advance for taking the time to fill out this questionnaire. You will be receiving a copy of our report upon its completion.

Name of hatchery:

Name of person filling out this questionnaire:

Phone number:

Email address:

1) Would your hatchery be interested in participating in an aquaculture program for Pacific lampreys? *(If no, then please stop here and send the questionnaire back; if yes, then please continue)*

2) Does your facility have experience spawning fish and incubating and hatching eggs?

3) Are your egg incubation and hatching facilities available in May-June?

4) What indoor facilities do you have available? How many square feet (meters) of room space could be allocated to a new project?

5) Do you have indoor or outdoor tanks and/or raceways available for holding adult lampreys for up to one year? If so, what size (dimensions and tank volume)?

6) What is your water source?

7) What is the range of seasonal variation in water temperature at your site?

8) What specifics can you give about your water quality? Do you have any known problems with contaminants?

9) Do you have any capabilities for heating water? If so, what are they (e.g., capacity and range of temperatures)? Would your system be available for use by a new project?

Thank you again for your time. You will receive detailed results of this questionnaire upon receipt of our report, which should be available in early summer.

APPENDIX C
Site Photographs

Aquatic Vegetation and Substrate.

Chewuch mainstem.

Chewuch mainstem (2).

Chewuch mainstem (3).

Chewuch mainstem (4).

Chewuch mainstem (5).

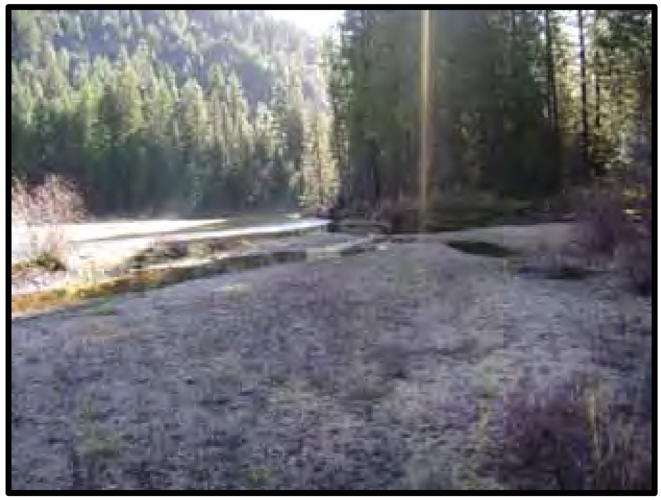
Site Photographs

Methow Sites
Chewuch WDFW

GeoEngineers | Plate C-1

09335-009-00 JM:JEP

Chewuch side channel.



Chewuch side channels and pond outlet..

Inlet.

Inlet – bank overflow along mainstem.

Inlet – bank overflow along mainstem (2)

Inlet area.

Site Photographs

Methow Sites
Chewuch WDFW

GeoEngineers | **Plate C-2**

09335-009-00 JM:JEP

Inlet area (2).

Inlet area (3).

Inlet from mainstem.

Lower Pond.

Lower Pond (2).

Lower Pond substrate.

Site Photographs

Methow Sites
Chewuch WDFW

GeoEngineers | **Plate C-3**

09335-009-00 JM:JEP

Off-channel habitat along mainstem.

Pond divider.

Pond looking downstream towards divide.

Pond outlet.

Pond outlet (2).

Pond outlet (3).

Site Photographs

Methow Sites
Chewuch WDFW

GeoEngineers | **Plate C-4**

09335-009-00 JM:JEP

Pond outlet (4).

Pond outlet (5).

Side channel associated with Chewuch.

Substrate.

Substrate (2).

Upper Pond.

Site Photographs

Methow Sites
Chewuch WDFW

GeoEngineers

Plate C-5

09335-009-00 JM:JEP

Upper Pond (2).

Upstream end of pond.

Upstream end of pond (2).

Upstream end of pond (3).

Upstream end of pond (5).

Site Photographs

Methow Sites
Chewuch WDFW

GeoEngineers

Plate C-6

09335-009-00 JM:JEP

Bank in lower section.

Cattle access in lower section

Cattle crossing near source.

Confluence of springs.

Culvert under Wolf Creek Road.

Lower cattle crossing.

09335-009-00 JM:JEP

Site Photographs

Methow Sites
Hancock Springs

GeoEngineers

Plate C-7

Lower middle section.

Lower middle section (2).

Lower middle section (3).

Lower section.

Lower section (2).

Lower section (3).

Site Photographs

Methow Sites
Hancock Springs

GeoEngineers | Plate C-8

09335-009-00 JM:JEP

Lower section (4).

Lower section (5).

Lower Section (6).

Lower section (7).

Lower section (8).

Lower section (9).

Site Photographs

Methow Sites
Hancock Springs

GeoEngineers | **Plate C-9**

09335-009-00 JM:JEP

Lower section (10).

Lower section (11).

Lower section (12).

Lower section (13).

Major spring tributary.

Middle restoration section.

Site Photographs

Methow Sites
Hancock Springs

GeoEngineers

Plate C-10

Middle section looking upstream.

Milk shed – spring source.

Origin of spring tributary to middle section.

Overview of middle section.

Section below road.

Section below road (2).

Site Photographs

Methow Sites
Hancock Springs

GeoEngineers | Plate C-11

09335-009-00 JM:JEP

Section below road (3).

Section below road (4).

Section below road (5).

Section below road (6).

Section below road (7).

Stream near source.

Site Photographs

Methow Sites
Hancock Springs

GeoEngineers | Plate C-12

Substrate in lower section (5).

Substrate in middle section.

Substrate in lower middle section.

Substrate in lower section.

Substrate in lower section (4).

Substrate in middle section.

Site Photographs

Methow Sites
Hancock Springs

GeoEngineers

Plate C-13

09335-009-00 JM:JEP

Substrate in middle section (2).

Substrate near source.

Substrate near source (2).

Withdrawal pump.

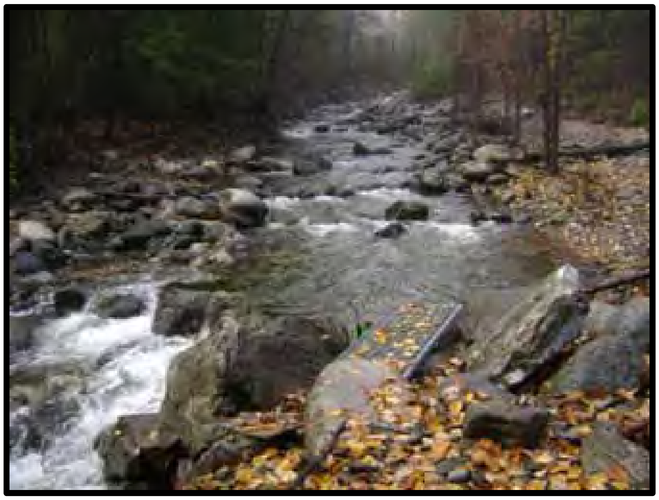
Site Photographs

Methow Sites
Hancock Springs

GeoEngineers

Plate C-14

09335-009-00 JM:JEP



Diversion at Wolf Creek.

Diversion at Wolf Creek (2).

Diversion at Wolf Creek (3).

Diversion Channel above upper pond.

Lower Pond.

Lower Pond (2).

Site Photographs

Methow Sites
Biddle Pond

GeoEngineers | **Plate C-15**

09335-009-00 JM:JEP


Lower Pond (3).


Lower Pond (4).


Lower Pond (5).


Lower Pond (6).


Lower Pond inlet.


Lower Pond inlet (2).

Site Photographs

Methow Sites
Biddle Pond

GeoEngineers | Plate C-16


Lower Pond inlet (3).


Lower Pond outlet.


Lower Pond outlet (2).


Lower Pond outlet (3).


Lower Pond substrate.


Lower Pond substrate (2).

Site Photographs

Methow Sites
Biddle Pond

GeoEngineers | **Plate C-17**

09335-009-00 JM:JEP

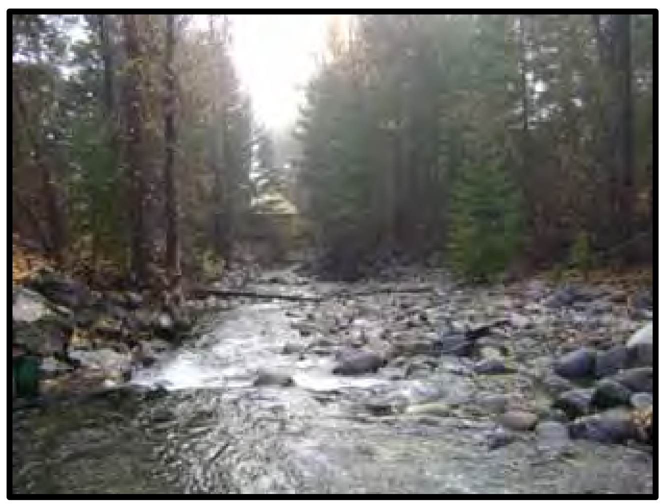

Lower Pond substrate (3).


Lower Pond substrate (4).


Outlet of Upper Pond.


Upper Pond.


Upper Pond Inlet.


Wolf Creek.

Site Photographs

Methow Sites
Biddle Pond

GeoEngineers | Plate C-18

09335-009-00 JM:JEP

Black Canyon Pond.

Black Canyon Pond (2).

Site Photographs

Methow Sites
Black Canyon Pond

GeoEngineers | **Plate C-19**

Beebe Springs near Chelan Falls.

Beebe Springs channel.

Beebe Springs and new channel.

Site Photographs

Lake Chelan River Basin
Beebe

GeoEngineers

Plate C-20

09335-009-00 JM:JEP

Columbia River side channel at Chelan River Confluence

Chelan River at Powerhouse Park.

Chelan River below falls.

Chelan Powerhouse Park substrate.

Chelan river substrate – cobbles and boulders.

Site Photographs

Lake Chelan River Basin
Chelan River

GeoEngineers | **Plate C-21**

View southwest down channel toward outlet to Entiat River.

Medium sand in confluence area.

Sandy backwater of Entiat downstream of high flow channel.

Sandy substrate in confluence area.

View southwest at outlet to Entiat – note poor connectivity.

Dillwater confluence area facing south downstream Entiate.

Site Photographs

Entiat Sites
Dillwater

GeoEngineers | **Plate C-22**

09335-009-00 JM:JEP

Dillwater outlet channel, frozen shallow and narrow.

Frozen channel over substrate with fines and organics.

Frozen relict side channel.

View east-northeast up frozen high flow channel.

View southwest down frozen high flow channel toward Entiat.

Evidence of Beaver activity.

Site Photographs

Entiat Sites
Dillwater

GeoEngineers

Plate C-23

09335-009-00 JM:JEP

View southwest down relict high flow channel.

Site Photographs

Entiat Sites
Dillwater

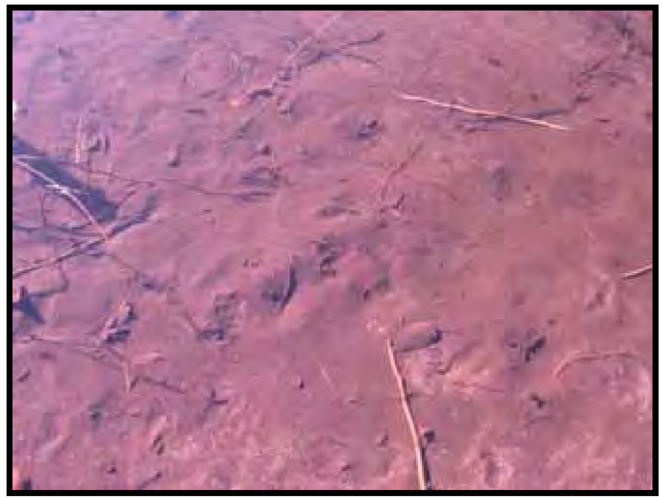
GeoEngineers | Plate C-24

09335-009-00 JM:JEP

View downstream from slough.

Entiat backwater downstream of Shamel slough outlet.

Entiat River downstream from Shamel Creek confluence



Entiat substrate immediately form Shael south.

Entiat River, view of right bank downstream of Shamel Creek slough.

View south across Entiat River.

Site Photographs

Entiat Sites
Shamel Creek

GeoEngineers | **Plate C-25**

09335-009-00 JM:JEP

General view of Shamel Creek and slough confluence.

General view northwest across Shamel Creek confluence.

General view f Entiat River backwater at Shamel slough outlet.

General view east across slough meander.

Slough bottom – silts and organic substrate.

General view north-northwest across slough meander at outlet.

Site Photographs	
Entiat Sites Shamel Creek	
GeoEngineers	Plate C-26

09335-009-00 JM:JEP

General view northwest from head of slough to Shamel Cr. Confluence and outlet.

View across slough meander in general downstream drection.

Entiat River and slough confluence.

Slough confluence area – narrow with silt and organic substrate.

General view northwest.

General view of substrate at slough outlet.

Site Photographs

Entiat Sites
Shamel Creek

GeoEngineers

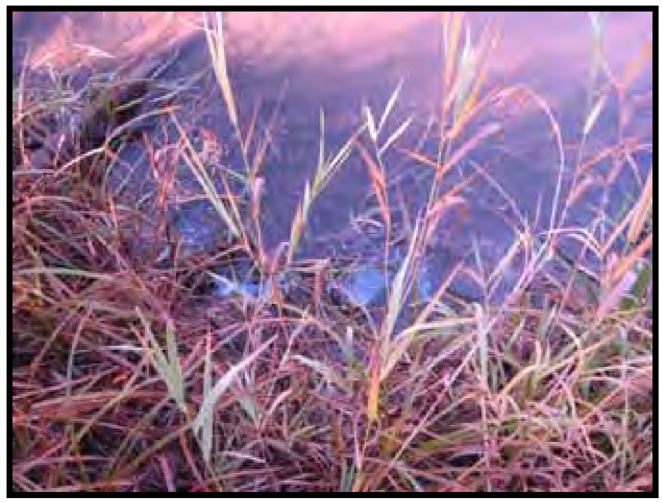
Plate C-27

09335-009-00 JM:JEP

General view across backwater and river confluence.

Adjacent backwater fines and organics.

General view of the backwater area facing east.



Backwater areas with sheen and orange duff.

Deep backwater high flow pool.

Duplicate backwater substrate holes and rivulets.

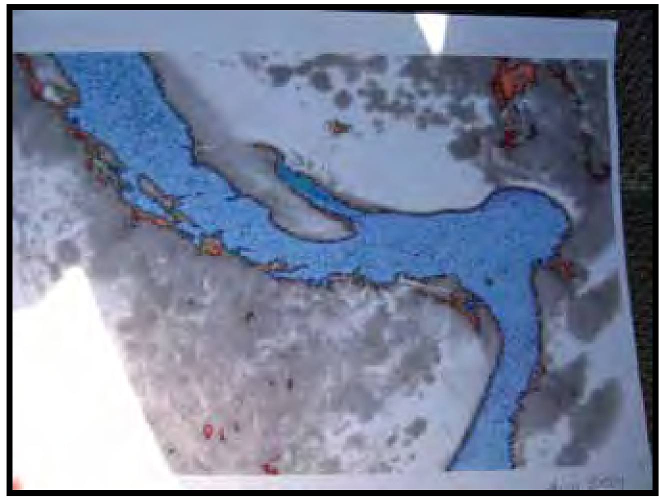
Site Photographs

Entiat Sites
Stormy Gage

GEOENGINEERS | **Plate C-28**

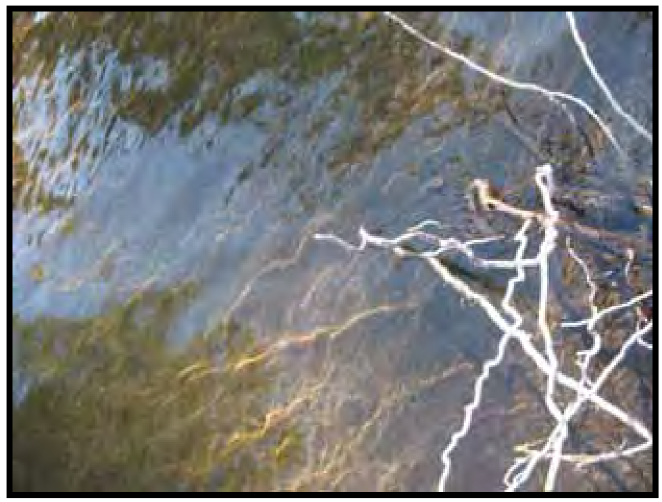
09335-009-00 JM:JEP

Fines substrate with upwelling (holes/mounds)

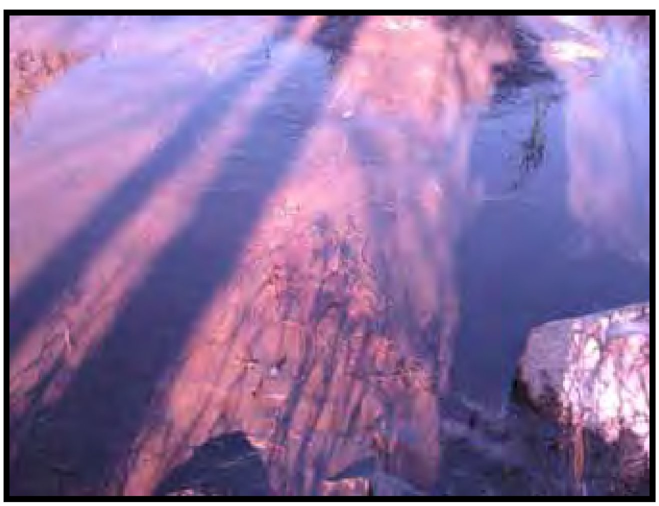


FLIR image of backwater area.

General view of high flow backwater area.



Substrate in Entiat adjacent to backwater – high percent of fines.



Substrate sand and silt- noted potential iron metab bacteria.

Substrate and silt with upwelling.

Site Photographs

Entiat Sites
Stormy Gage

GeoEngineers | **Plate C-29**

09335-009-00 JM:JEP

Substrate with upwelling.

2001 aerial photograph of backwater area.

Upwelling rivulets at head of backwater.

General view of backwater downstream to Entiat River.

General view north-northeast upstream into backwater area.

General view across backwater rearing area.

Site Photographs

Entiat Sites
Stormy Gage

GeoEngineers | **Plate C-30**

09335-009-00 JM:JEP

General view northwest across backwater and up Entiat River.

View of outlet at base flow.

General view downstream along Entiat River – backwater area along right bank.

Site Photographs

Entiat Sites
Stormy Gage

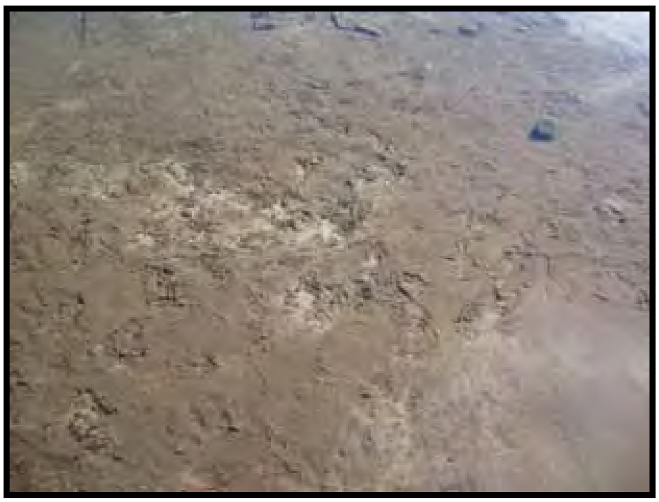
GeoEngineers

Plate C-31

09335-009-00 JM:JEP

Backwater of Entiat River looking north and upstream at outlet.

Entiat River below backwater confluence / substrate large gravel.



Entiat River substrate downstream of boulder along right bank.

Large boulder with deep sand backwater .

Secondary high flow channel disconnected from Entiat River.

Secondary high flow channel silty and pond-duckweed.

Site Photographs	
Entiat Sites Cottonwood	
GeoEngineers	Plate C-32

09335-009-00 JM:JEP

Substrate at backwater outlet – silt over large gravel.

Substrate behind boulder – silt organics and evidence of beaver.

View across Entiat River looking north.

View up backwater slough of Entiat River along right bank.

Cottonwood site – northern view across Entiat River.

Site Photographs

Entiat Sites
Cottonwood

GeoEngineers

Plate C-33

09335-009-00 JM:JEP

Shields Pond.

Shields Pond (2).

Shields Pond (3).

Site Photographs

Wenatchee Sites
Shields

GeoEngineers

Plate C-34

09335-009-00 JM:JEP

Adjacent wetlands.

Beaver lodge.

Culvert outlet.

Deep/slow still-water area in main channel of oxbow.

General view.

Looking back at inlet culvert.

Site Photographs

Wenatchee Sites
Nelson Creek Oxbow

GeoEngineers | Plate C-35

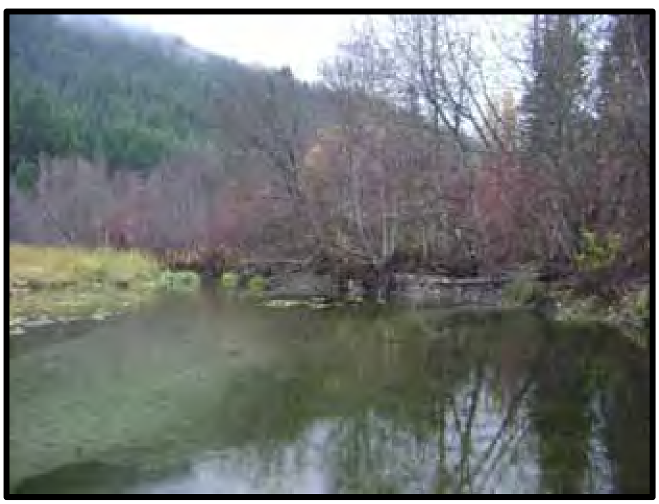
09335-009-00 JM:JEP

Looking back at inlet culvert (2).

Lower channel.

Lower channel (2).

Lower channel (3).



Lower channel (4).

Lower channel (5).

Site Photographs

Wenatchee Sites
Nelson Creek Oxbow

GeoEngineers | **Plate C-36**

09335-009-00 JM:JEP

Lower channel (6).

Lower channel (7).

Nason Creek at oxbow inlet culvert.

Nason Creek mainstem.

Nason Creek mainstem (2).

Nason Creek mainstem near oxbow outlet.

09335-009-00 JM:JEP

Site Photographs

Wenatchee Sites
Nelson Creek Oxbow

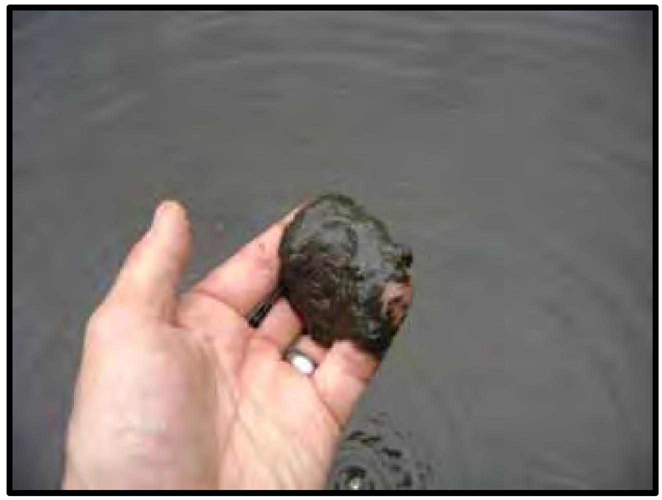
GEOENGINEERS

Plate C-37

Nason Creek mainstem near oxbow inlet (2).

Nason Creek culvert inlet.

Organic, silty/sand substrate.



Organic, silty/sand substrate (2).

Outlet downstream of culvert.

Riffle glides.

Site Photographs

Wenatchee Sites
Nelson Creek Oxbow

GeoEngineers | Plate C-38

09335-009-00 JM:JEP

Side channel and backwater habitat.

Upper portion of channel.

Upper oxbow channel.

Upper oxbow channel (2).

Upper oxbow channel (3).

Site Photographs

Wenatchee Sites
Nelson Creek Oxbow

GeoEngineers | **Plate C-39**

09335-009-00 JM:JEP

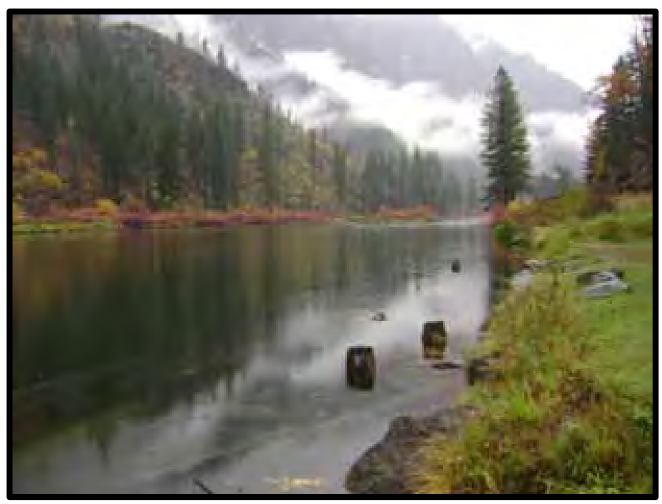
Lake Jolanda.

Lake Jolanda (2).

Lake Jolanda (3).

Lake Jolanda (4).

Lake Jolanda (5).



Lake Jolanda (6).

Site Photographs

Wenatchee Sites
Lake Jolanda

GeoEngineers | Plate C-40

09335-009-00 JM:JEP

Tumwater Dam.

Lake Jolanda sediment, logs and vegetation.

Lake Jolanda substrate.

Tumwater dam (2).

Site Photographs

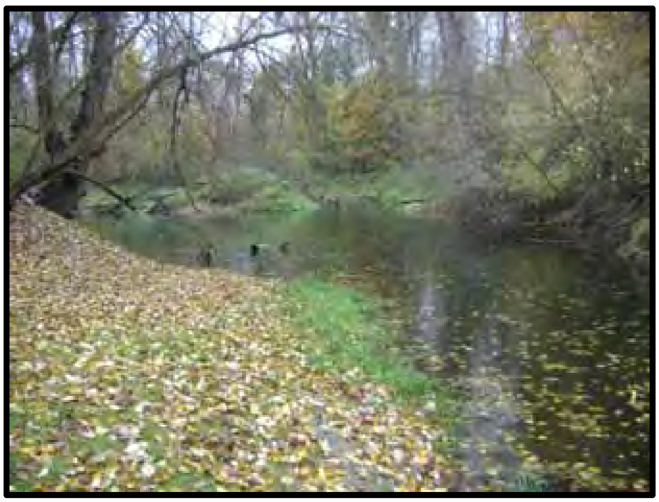
Wenatchee Sites
Lake Jolanda

GeoEngineers | **Plate C-41**

09335-009-00 JM:JEP

Looking north to outlet.

Looking towards outlet and Wenatchee.



Looking west.

General view of pond and sign.

Fish project sign.

Looking back at pond from outlet.

Site Photographs

Wenatchee Sites
Blackbird Pond

GEOENGINEERS

Plate C-42

09335-009-00 JM:JEP

Looking up outlet toward pond.

Outlet and Wenatchee side channel.

Interpretive sign.

Channel leading to Blackbird Pond and culvert under trail.

Channel leading to Blackbird Pond.

Channel leading to wetland from Wenatchee River.

Site Photographs

Wenatchee Sites
Blackbird Pond

GeoEngineers | **Plate C-43**

09335-009-00 JM:JEP

Looking across side channel from Blackbird Pond.

Side channel looking toward confluence with Wenatchee River.

Looking up-channel from trail towards wetland.

Looking up side channel from information kiosk.

Looking up side channel from information kiosk (2).

General view of LWD.

Site Photographs

Wenatchee Sites
Blackbird Pond

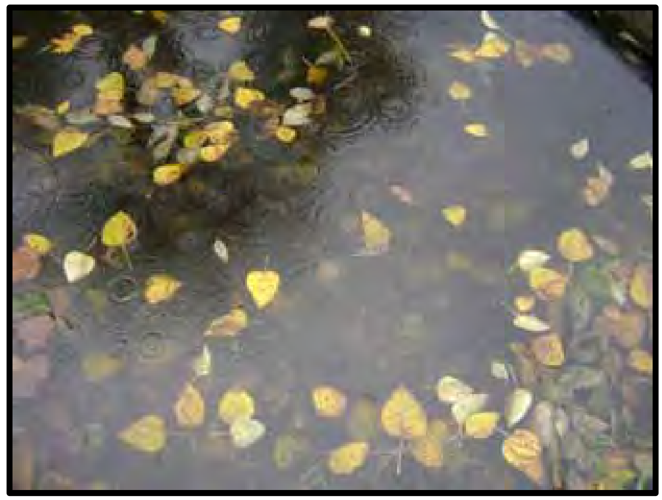
GeoEngineers | Plate C-44

09335-009-00 JM:JEP

Pond outlet.

Random pipe at Wenatchee River.

Random Pipe at Wenatchee River.



Sediment organics.

Trail where culvert crosses.

Wenatchee River.

Site Photographs

Wenatchee Sites
Blackbird Pond

GeoEngineers | **Plate C-45**

Wenatchee River fork with side channel.

Wenatchee River side channel.

Wetland where pond hydrology originates.

Site Photographs

Wenatchee Sites
Blackbird Pond

GeoEngineers

Plate C-46

09335-009-00 JM:JEP

Beaver lodge .

Beaver lodge (2).

Cashmere Pond from Highway.

Cashmere Pond from the north.

Cashmere Pond from the north (2)

Cashmere Pond from the northwest.

Site Photographs	
Wenatchee Sites Cashmere Pond	
GeoEngineers	Plate C-47

09335-009-00 JM:JEP

Cashmere Pond from the northwest (2),

Drainage channels.

From wetland looking east to pond.

Looking down outlet channel.

Looking down outlet channel (2).

Looking up at outlet.

Site Photographs

Wenatchee Sites
Cashmere Pond

GeoEngineers | **Plate C-48**

09335-009-00 JM:JEP

South bank.

South bank and inlet from wetland.

Site Photographs

Wenatchee Sites
Cashmere Pond

GeoEngineers

Plate C-49

09335-009-00 JM:JEP