

**An Examination of the Carrying Capacity of
Coho Salmon in the south fork Chester Creek,
Anchorage, Alaska**



Master of Science Thesis, Alaska Pacific University

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An Examination of the Carrying Capacity of Coho Salmon in the south fork Chester Creek, Anchorage, Alaska

A Thesis

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Abstract

Urbanization projects, channelization, impassible culverts, and a dam at the mouth of the creek have all contributed to the decline of Chester Creek's native coho salmon (*Oncorhynchus kisutch*) population. While several sections of the creek have been rehabilitated and the dam removed, no studies have been done to understand what the creek's habitat quality is actually like for the coho salmon lifestages. This study was done to assess the habitat quality and quantity of Chester Creek and use the data collected to conduct a carrying capacity study that would identify how many coho smolts the creek can potentially support and which lifestage habitat is possibly limiting smolt numbers. Performing a stream survey to identify the habitat units and their surface areas and applying the surface areas to Thomas Nickelson's 1992 and 1998 Habitat Limiting Factor Models and Marshall and Britton's 1990 carrying capacity equations, I estimate the current coho smolt carrying capacity as being in-between 25,000 and 30,000 smolts with winter habitat being the limiting habitat. Then by performing an in-depth habitat survey on a select number of habitat units to get a representative view of the current habitat quality conditions, I have to conclude that the condition of the spawning substrate is also a limiting factor to the coho population.

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Introduction

Anchorage, Alaska has several small streams that support salmon runs; however, channelization, diversions, culverts, poor water and habitat quality, and other urbanization factors have substantially decreased the fish runs to these streams. Chester Creek, one of these streams, once supported a variety of salmon species and a coho salmon run of several thousand but now supports only a remnant population of coho salmon (Whitman 2002). Poor water quality, urbanization projects, and a barrier at the mouth of the creek have contributed to their decline. In 2009, the Municipality of Anchorage completed rehabilitation work at the mouth of Chester Creek in an attempt to improve salmon passage into the creek. However, only a few studies on the creek and its current habitat have been done and none within the last five years and no studies have been conducted to determine the potential carrying capacity of Chester Creek.

Carrying capacity is the “greatest weight of fishes that a stream can naturally support during the period of the least available habitat” (Burns 1971). A number of studies indicate that carrying capacity is related to a number of parameters, including stream length, area, volume, water flow, and available food supplies, though most seem to indicate that stream length and area are the best parameters for determining carrying capacity (Marshall and Britton 1990). Using surface area, volume, length and flow in seven small streams in Northern California, Burns (1971) determined that the absolute biomass or the total weight of the salmonids in the stream had the highest correlation with surface area due to surface area determining the amount of living space available. Mason and Chapman (1965) found that in Oregon streams, surface area best correlated

with coho biomass. Using data collected up to 1979 on 22 small streams and several ponds and lakes in British Columbia, Marshall and Britton (1990) found that smolt abundance had the highest correlation with either stream area or length. Allen (1968) suggested that the carrying capacity for a stream would be limited not by stream length or available surface area but by the minimum area needed for a fish at each stage of its' life and suitable conditions within that area, such as an adequate food supply and enough shelter while Chapman (1962) suggested that territorial behavior will limit fish number. Bradford et. al. (1997) also found the highest correlation for smolt abundance was with stream length, leading them to hypothesize that the availability of physical habitat is most likely to limit smolt production. The idea that physical habitat can limit how many smolts a stream supports was introduced by Hall and Field-Dodgson (1981). It is based on the concept of a habitat bottleneck, which is defined as the habitat required to support a particular life stage but due to scarcity of this life stage habitat, the number of salmon the stream can support is capped (Nickelson et. al. 1992).

While studies examining carrying capacity have been done for several decades, it has only been in the last two decades that they have been used for restoration work. Carrying capacity studies are essential when attempting to restore salmon habitat because restoration work must increase or enhance the habitat conditions that are limiting the salmon population to address the problems that are limiting the population in order to have an effect. Restoration can be expensive and so it is important to use the limited funds in areas that will have the greatest impact on rehabilitation. For example, restoration and creation of spawning habitat in a stream will have little effect if overwintering habitat is limiting juvenile coho numbers.

Chester Creek historically supported a viable population of several thousand coho salmon (Whitman 2002) but habitat loss, urbanization, channelization, culverts, and other stream alterations have degraded both the water and habitat quality of the creek as Anchorage grew from a population of 82,833 in 1960's to an estimated 279,243 in 2008 (www.census.gov). Additionally, to accommodate the railroad, the Municipality damned the mouth of Chester Creek, creating Westchester Lagoon and installing a fish ladder that was complex, difficult to navigate, and accessible only during high tides (Corps 2004). All of these factors created conditions that made escapement into the creek difficult and reduced the amount of rearing habitat, resulting in a drastic decrease in the native coho population.

Davis and Muhlberg (2002) captured a total of 22 coho salmon during their evaluation of Chester Creek water quality in 2001 and Whitman (2002) captured 100 coho using electrofishing methods. Myers captured 302 coho smolts using minnow traps in a limited survey of the creek in 2008 (Myers, personal communication). However, these counts were minor parts of larger studies and have no bearing on population estimates. No accurate count of returning adult spawners was performed until 2008 when Forsythe used both visual and video recording methods at the Westchester Lagoon weir to determine escapement. Direct observation showed that 497 coho salmon made it into the lagoon between July 31, 2008 and August 20, 2008 and no fish were observed after August 20th until counting observations terminated on the 5th of September (Forsythe and Myers 2009).

In an attempt to restore salmon runs to Chester Creek, the Municipality of Anchorage (MOA) along with the US Fish and Wildlife Agency, the Alaska Department

of Fish+ and Game (AK DF&G), the National Oceanic and Atmospheric Agency (NOAA), the Army Corp of Engineers (Corp), as well as local conservation groups such as the Anchorage Waterways Council have performed restoration work. In order to support the creek's rehabilitation projects, it is important to know what types of habitat are important for coho survival. At different times in their lifecycle, coho salmon need different habitats to survive. In the embryonic and alevin stages, they require areas with pea to orange size substrate that have very little fine material and shallow, fast moving water to remove waste and replenish oxygen supplies. As they mature, salmon move to areas of deeper, slow moving waters until they begin their migration for the ocean (Sandercock 1991; Nickelson et. al. 1992).

The goal of this project is to perform a carrying capacity study that will help guide future rehabilitation efforts of the stream by determining which habitats are potentially limiting salmon numbers. To do this, I modeled this study after the work done by Jeffrey Anderson and Nicholas Hetrick, who performed carrying capacity studies for coho salmon on the Kametlook, Three Star, and Long Beach rivers in Southwest Alaska (Anderson & Hetrick 2004). I also made use of the Habitat Limiting Factor Model (HLFM) developed by Thomas Nickelson (1998), the habitat suitability indexes of McMahon (1983), as well as background information from Sandercock (1991), Bjornn and Reiser (1991), Nickelson et. al. (1992), and others. It should be noted that Anderson and Hetrick's 2004 study took place in the Alaska Peninsula National Wildlife Refuge in southwest Alaska while my study takes place in the urban setting of Anchorage. It should also be noted that much of the background data, suitability indices, and the HLFM were created for use in the Pacific Northwest region of the

United States. The results of this study should give an indication of which seasonal habitat is the limiting habitat, which of the lifecycle habitats are limiting salmon numbers, and information to guide future restoration work.

Coho Salmon Life History

Adult Migration Back to Natal Streams

After spending approximately 18 months in the ocean, coho salmon begin their migration back to their natal streams to spawn. Migration run times vary geographically but the usual rule is that coho that spawn in rivers at higher latitudes begin their migration earlier than those at lower latitudes (Sandercock 1991). For example, Godfry (1965) noted that migration runs in Northern Alaska and Kamchatka begin in July and August while in California runs can be delayed until November or even December (Shapovalov and Taft 1954). Once coho salmon reach the mouths of their natal stream, they will wait weeks, even months for stream conditions (i.e. water velocity, depth, temperature) to become suitable for upstream migration to spawning grounds (Sandercock 1991). However, if conditions continue to be unsuitable for upstream migrations, salmon may migrate to a nearby stream in order to spawn (Sandercock 1991).

Adult Spawning

Timing of spawning varies geographically. In North America, spawning usually occurs between October and March. In southeast Alaska, spawning occurs between October and November (Crone and Bond 1976). In British Columbia, coho spawn between November and December (Neave 1949) while on the Oregon coast, spawning

generally occurs between November and February (Chapman 1965). Spawning in southcentral Alaska and in the Anchorage area usually occurs from late July until September.

Once coho reach their spawning grounds, they may wait days to several weeks to spawn. It is during this time that the female will select a site for her nest or redd. Redds are usually found in the transition zones between pools and riffles (Bjornn and Reiser 1991; Mull and Wilzback 2007) or at the heads of riffles (Bjornn and Reiser 1991; Sandercock 1991). These are areas where the water recirculates to provide the eggs and alevins with enough dissolved oxygen and cooler water temperatures to develop as well as enough current to remove any waste products. The female digs the nest site by rolling onto her side and using her tail to create a depression in the substrate (Sandercock 1991). After the redd is finished, several males will attempt to court the female. Once the courtship phase is complete and the female has chosen a mate, the female and male line up next to each other over the nest and concurrently release the eggs and sperm (Sandercock 1991). The female will then immediately cover up the eggs with the substrate using her body motions to prevent predation and will guard the nest until she is too weak to do so (Briggs 1953). The female may also attempt to spawn several more times, each successive attempt slightly more upstream than the last one (Sandercock 1991).

Incubation of Eggs and Alevins

The incubation time is mainly dependent on dissolved oxygen levels and water temperature (Sandercock 1991; Bjornn and Reiser 1991), however, temperature is considered to be the primary factor for egg and alevin development (Quinn 2005).

Within tolerable limits, the warmer the water, the faster an embryo will develop (Quinn 2005). The opposite is true also; the colder the water, the slower the embryonic development is (Quinn 2005; Sandercock 1991; Bjornn and Reiser 1991). In 2.2°C water, eggs took 137 days to hatch in the Kamchatka (Semko 1954). McPhail and Lindsey (1970) found that it took between 42 to 56 days for salmon eggs to hatch in 8.9°C water in Alaska and Shapovalov and Taft (1954) counted an average of 38 days at 10.7°C in California.

Quinn (2005) states that the development of embryos from spawning to emergence can be estimated by multiplying the number of degrees Celsius above 0 by the number of days in a combined unit known as 'temperature units' or TU. For example, coho hatch at approximately 500 TU's after being fertilized (Quinn 2005). This means there could have been 100 days at 5°C or 50 days at 10°C (Quinn 2005). He estimates that at 2°C, it would take coho approximately 115 TU's to hatch, at 5°C, 87 TU's, at 8°C 63 TU's, at 11°C 42 TU's, and at 14°C 32 TU's (Quinn 2005).

Once hatched, alevins will stay in the spawning gravel until their yolk has been absorbed. Yolk absorption and alevin development is also dependent on the water temperature; the warmer the water, the faster the alevin will develop. Using the data from several studies and sources Quinn (2005) indicates that fry emergence will take four times as long at 2°C than it would at 14°C. Survival during this time to emergence depends on water temperature, dissolved oxygen concentrations, and adequate sub-gravel water flow (Sandercock 1991).

Rearing of Fry

Depending on when the spawning occurred, water temperature, dissolved oxygen concentrations, and sub-gravel water flow, fry emergence from their spawning gravels can be as early as March to as late as July (Sandercock 1991). At this stage, they are an average of 30 mm in length (Gribanov 1948; Quinn 2005), though those that emerge earlier are usually larger than those that emerge later (Sandercock 1991).

After emergence, the fry begin to move and congregate in areas with slow water velocity and adequate cover (i.e., undercut banks, overhanging vegetation, woody debris) from predators (Nickelson et. al. 1992; Sandercock 1991). As the fry mature and grow, they begin to occupy areas along the shore and begin to move to faster moving water areas such as riffles and glides (Lister and Genoe 1970). However, studies done by Nickelson et. al. (1992), Murphy et. al. (1989), and Bisson et. al. (1988) show that fry prefer slow moving water habitats to the faster moving water habitats even as they grow because they are not able to compete with trout for rearing spaces in areas with riffles (Sandercock 1991). Coho from off channel areas begin to migrate to the main stream to continue rearing and will move considerable distances either up or downstream to reach accessible rearing habitats (Godfrey 1965).

During winter, coho abundance is greatest in areas with deep water (greater than 45 cm) and low velocity (less than 15cm/sec), such as pools, alcoves, and beaver ponds (McMahon 1983). Beaver ponds are especially preferred winter habitat as they are usually deeper than dammed pools and lakes (Nickelson et. al. 1992; Murphy et. al. 1989). In the spring, coho will move back to the main stream to feed and continue rearing (Shapovalov and Taft 1954).

Smolt Migration to the Ocean

After spending approximately two to three years rearing in their freshwater habitat, coho will begin to make their way downstream as smolts (Sandercock 1991). Usually solitary, they will begin to form groups as they migrate to the ocean. Migration occurs at night and during this stage, coho become extremely physiologically sensitive to water quality (Johnston et. al. 1998).

Habitat Quality Standards

Upstream Migration of Adults

Access to natal streams and suitable water quality are the biggest factors affecting upstream migration (McMahon 1983). In order to successfully spawn, adult salmon must reach their spawning grounds at the proper time and with enough energy to spawn. Barriers such as physical structures that are higher than 2.2 meters, areas of high water velocity, even debris jams can prevent adult salmon from reaching their spawning grounds (McMahon 1983; Bjornn and Reiser 1991). Poor water quality can directly affect coho salmon by increasing their susceptibility to disease or altering their migration and maturity timings (Bjornn and Reiser 1991).

Water temperatures greater than 25.5°C are considered to be lethal to migrating adults (McMahon 1983). Optimum temperatures for upstream migration are between 7-15°C (Bjornn and Reiser 1991) though it should be noted that the probability of infection and disease increases if water temperatures are above 12.7°C (Wedemeyer 1970). Dissolved oxygen concentrations should be above 7 mg/L (Bjornn and Reiser 1991). Studies show that there is a marked decrease in swimming performance if dissolved oxygen values fall below 6.5 mg/L (Davis et. al. 1963; McMahon 1983). Dissolved

oxygen values 4.5 mg/L and lower have been known to stop spawning migrations altogether (Hallock et. al. 1970; Bjornn and Reiser 1991). Water depth should be a minimum of 0.18 meters and maximum water velocity should be no more than 2.44 meters/second (McMahon 1983; Bjornn and Reiser 1991).

Adult Spawning

Substrate, stream flow, temperature, space, depth and velocity are considered important elements for spawning coho. The average area of a nest is approximately 2.8 m² although it is recommended that each spawning pair have at least 11.7 m² area in which to spawn (Burner 1951). Substrate size should range from 1.3 to 10.2 cm in diameter or from pea to orange size, depending on how large the fish is (Bell 1986). Fines or sediments with a diameter of less than 6.4 mm such as silt and sand should compose less than 15% of the spawning bed (McMahon 1983). Experiments show that fry emergence is high if the spawning bed has less than 5% fines but drops sharply at 15% and once fines make up 50%, alevin mortality is nearly 100% (McMahon 1983; Bjornn and Reiser 1991; Sandercock 1991). Optimum spawning temperatures range from 4.4 to 9.4°C (Bjornn and Reiser 1991) but coho have been observed spawning at temperatures between 2.5 to 12°C (Burner 1951). Water depth should be at least 18 cm deep and velocity should be between 0.30 and .91 m/sec (Bjornn and Reiser 1991).

Incubation of Eggs and Alevins

The successful incubation of eggs and alevins depends primarily on water temperature, dissolved oxygen, and substrate. As mentioned above, substrate should be 1.3 and 10.2 cm in diameter and the spawning redd should be composed of less

than 10% fines because fine particles will settle into the interstitial spaces of the substrate during this time, affecting the rate of water exchange between the redd and eggs, reducing the amount of dissolved oxygen available to embryos and alevins, inhibiting waste removal, and restricting the movements of alevins (Quinn 2005; Bjornn and Reiser 1991). Studies indicate that egg and alevin survival decreases dramatically if nests are composed of 15% fines (McMahon 1983; Bjornn and Reiser 1991; Sandercock 1991). Temperature affects the developmental rate of the embryos and alevins; the warmer the water temperature, the faster the embryos and alevins develop and the shorter their incubation period (Bjornn and Reiser 1991). Optimal temperatures are between 4.4 and 13.3°C (Quinn 2005; McMahon 1983). Temperatures above 17°C and below 2°C are considered to be lethal (McMahon 1983). Dissolved oxygen levels should be near or at saturation levels (8 mg/L or higher) for a high survival and emergence rate. Embryo survival drops when oxygen levels are at or below 6.5 mg/L and that levels below 3 mg/L are considered to be lethal (Davis 1975; McMahon 1983; Bjornn and Reiser 1991).

Another factor that can affect the incubation and developmental period and possible increase mortality is streambed movement or scouring. High water velocities can move substrate across the streambed, sometimes covering redds and eggs with excess materials and at other times, uncovering the eggs and leaving them vulnerable to predation and the elements (Quinn 2005).

Once the eggs have hatched, the alevins will stay in the spawning gravel until their yolk sack has been absorbed. Alevin development into fry during this time is also primarily dependent on water temperatures. Studies indicate that it can take nearly 4

times as long for an alevin to develop in 2°C water as it does in 14°C water (Quinn 2006). Dissolved oxygen also plays an important role in alevin development and survival (Sandercock 1991). As the embryo grows, so does its' need for oxygen. A study by Alderdice et. al. (1958) indicated that dissolved oxygen demand went from approximately 1 mg/L just after being fertilized to 7 mg/L just before hatching. Decreased oxygen levels will delay an embryo's hatching. Shumway et al. (1964) revealed that low oxygen levels could cause a 15% delay in the hatching time at 10°C. The study also indicated that low oxygen levels could cause embryos to be smaller and weigh less (Shumway et al 1964). A third factor that affects embryo and alevin survival is sub-gravel water flow as it helps to remove wastes and circulate oxygen (Sandercock 1991).

Rearing of Fry

Once alevins emerge from the gravel, physical habitat begins to define what is suitable for their rearing stage. Juvenile coho require an abundance of food to sustain their growth and cover to avoid predation and displacement (McMahon 1983). The number of suitable territories that are available will limit the amount of coho that a stream can successfully support (Larkin 1977; Sandercock 1991). Streams that contain large rocks and high amounts of woody debris can support larger numbers of coho than those lacking them (Scrivener and Anderson 1982). Many studies also indicate that as coho mature, they show a preference for pools and other slow moving water habitats rather than riffles or rapids (Hartman 1965; Bisson et. al. 1982; Nickelson et. al. 1992); therefore, the amount of pool abundance and quality have frequently been used to evaluate rearing habitat (Bisson et. al. 1982; McMahon 1983). Ruggles (1966) found

coho abundance to be greatest in stream channels that are composed of 50% pools and 50% riffles. McMahon (1983) indicates that fry are most abundant in pools that are at least 0.30 m deep and have a surface area of 50 to 250 m² with adequate cover (woody debris, overhanging vegetation, undercut banks). However, if the canopy is extremely dense, coho abundance can be reduced (Ruggles 1966; Chapman and Knudsen 1980). Bisson et. al. (1983) indicate that coho select areas with overhanging vegetation not only because these areas will provide shade but because they provide the fish with more food. Coho are also considered to be territorial and as they grow, so does the size of their territories (Bjornn and Reiser 1991; Sandercock 1991). For a fry that is 40 mm in length or about 1 month old, the size of their territory is approximately 0.34 m² (Allen 1969), at four months, their territory increases to 0.79 m², and at 110 mm in length, it is between 3.7 and 5.5 m² (Allen 1969).

Substrate composition affects the production of aquatic and terrestrial insects, which live in the interstitial spaces (Mundie 1969; Reiser and Bjornn 1991). Research by Pennak and Van Gerpen (1947) indicate that invertebrate production decreases from rubble to bedrock to gravel and finally sand (McMahon 1983). Brusven and Prather (1974) found that invertebrate production decreases when larger substrate particles were fully embedded by fines and Crouse et. al. (1981) reported that if substrate less than 2.0 mm exceeds 26%, invertebrate production decreases.

Suitable water quality is also a requirement for coho rearing. Optimal temperatures are between 10 and 13°C (McMahon 1983). Temperatures 25°C and greater are considered to be lethal (Brett 1952). When temperatures drop to 9°C, coho will become less active and begin seeking deeper, slow moving waters. The habitat

suitability indices of McMahon (1983) indicate that anything below 4°C is lethal. Dissolved oxygen levels should be at least 8 mg/L or higher (McMahon 1983) but studies indicate that coho may be able to survive at levels around 5 mg/L though growth, food conversion, and swimming performance would be affected (Bjornn and Reiser 1991). Oxygen levels below 4 mg/L are considered lethal (McMahon 1983). Water depth depends on what is available for the coho to use but preferred water depth is between 0.30 and 1.22 m (Thompson 1972; Nickelson and Reisenbichler 1977) and velocity should be between 5 and 24 cm/sec (Thompson 1972) but less than 30 cm/sec (Nickelson and Reisenbichler 1977).

Smolt Migration to the Ocean

As they prepare to enter the mature stage of their life cycle, salmon undergo smoltification and the physiological changes that occur during this time make coho at this stage particularly sensitive to environmental stress (McMahon 1983). Timing of smolt migration appears to be regulated by day length (Bjornn and Reiser 1991), however other factors that may affect migration timing include smolt size, water flow conditions, water temperature, dissolved oxygen levels, and food availability (Sandercock 1991). Blockages and delays by dams, unsuitable water quality conditions, and predation are just a few of the conditions that can interfere with a coho's smoltification process and cause mortality (McMahon 1983; Bjornn and Reiser 1991).

Table 1 summarizes the habitat parameters that coho salmon require during the freshwater portion of their life.

Table 1 – Summary of the parameters needed for quality habitat for coho salmon in fresh water streams.

Life Stage	Habitat Parameter	Standards
Adult Spawning	Substrate	Substrate should be between 1.3 and 10.2 cm in diameter (Bjornn and Reiser 1991). Fines (substrate less than 6.4 mm in diameter, such as sand) should compose less than 15% of the redd (Quinn 2005; McMahon 1983).
Adult Spawning	Temperature	Optimal spawning temperatures are between 4.4-9.4°C (Bjornn and Reiser 1991). AK DEC regulations state that salmonid stream temperatures should not exceed 13°C.
Adult Spawning	Dissolved Oxygen	Dissolved oxygen levels should be at 8 mg/L or higher (McMahon 1983).
Adult Spawning	Water Velocity	Water velocity should be between 0.3 and 0.91 m/sec (Bjornn and Reiser 1991; Thompson 1972)
Adult Spawning	Water Depth	Water should be deep enough to cover the fish during their spawning time. The minimum depth is 18 cm (Bjornn and Reiser 1991; Thompson 1972).
Egg/Alevin Incubation	Temperature	Optimal temperatures are between 4.4-13.3°C; anything below 2°C or above 17°C should be considered lethal (McMahon 1983). AK DEC regulations state that maximum water temperature for incubation is 13°C.
Egg/Alevin Incubation	Dissolved Oxygen	Dissolved oxygen levels should be 8 mg/L or higher (Bjornn and Reiser 1991). Studies indicate that dissolved oxygen levels below 3 mg/L are lethal. AK DEC regulations state the DO levels should greater than 7 mg/L.
Egg/Alevin Incubation	Substrate	Substrate should be between 1.3 and 10.2 cm in diameter (Bjornn and Reiser 1991). Fines (substrate less than 6.4 mm in diameter, such as sand) should compose less than 15% of the redd (Quinn 2005; McMahon 1983).

Fry/Fingerling	Temperature	Optimal temperatures are between 9-14°C (Bjornn and Reiser 1991; McMahon 1983). Anything above 26°C is considered lethal (Bjornn and Reiser 1991). AK DEC standards state that water temperatures should not exceed 15°C.
Fry/Fingerling	Dissolved Oxygen	Dissolved oxygen levels should be 7 mg/L or higher and anything below 4 mg/L is considered to be lethal (McMahon 1983). AK DEC regulations state that the minimum DO levels for a stream are 7 mg/L.
Fry/Fingerling	Water Depth	Preferred water depth is between 0.30 and 1.22 m (Thompson 1972). During the winter, coho will move to areas with a depth of 0.45 m or greater, such as pools or beaver ponds (McMahon 1983).
Fry/Fingerling	Water Velocity	Preferred water velocity is less than 30 cm/sec (Nickelson and Reisenbichler 1977). During the winter, coho will usually be found in areas with velocities of 15 cm/sec or less (McMahon 1983).
Fry/Fingerling	Canopy Cover	McMahon (1983) indicates that canopy cover between 50 and 75% is optimal for food production for coho.
Fry/Fingerling	Cover (woody debris, undercut banks, boulders, ect..)	Cover is important as it gives juvenile coho protection from predators and water torrents while providing food and shade (Bjornn and Reiser 1991; McMahon 1983).
Smolt	Temperature	Temperatures during the smoltification period should be between 6-12°C (McMahon 1983). Elevated temperatures can decrease the smolting period and result in early migration (McMahon 1983).
Smolt	Dissolved Oxygen	Dissolved oxygen levels should be 7 mg/L or higher but specific DO requirements are still unknown (McMahon 1983). AK DEC regulations state that the minimum DO levels for a stream are 7 mg/L.

Study site

The Chester Creek watershed basin has an area of approximately 73 km² (Glass and Ourso 2006) and the South Fork Chester Creek is approximately 16 km long. The South fork originates in the Chugach Mountains, where it naturally flows across the Fort Richardson military base before entering Anchorage in the Muldoon area, where it begins to the major modifications due to urbanization begin. Alterations include channelizations, culverts, diversions, storm sewers, and urbanization (Brabets 1987; - Davis and Muhlberg 2001). Inside of the city limits, there are three major impoundments that Chester Creek runs through: University Lake, Hillstrand Pond, and Westchester Lagoon (Figure 1).

Approximately 46% of the basin has been urbanized (Glass and Ourso 2006). GIS data from a 2000 Municipality survey indicates that the Chester Creek watershed contains 329 km of sewer lines, 444 km of roads, and that 69% of the creek is considered to be moderately to severely modified. The 2000 census indicate that approximately 78,000 people live within the boundaries of the Chester Creek watershed, making it one of the more densely populated watersheds in the Anchorage area (Glass and Ourso 2006). Since the 1960's, Chester Creek has been affected by pollution due to lax environmental laws (Whitman 2002). Brabets (1987) found that levels of chloride, dissolved solids, and fecal coliform bacteria exceeded Alaska state drinking water standards. An USGS study from 1998 to 2001 found that the stream contained high levels of phosphorous and fecal bacteria and during spring run-off and rain falls, contained high amounts of inorganic and organic elements (Glass and Ourso 2006). A total maximum daily load (TMDL) report from the Alaska Department of

Environmental Conservation (2005) found that levels of fecal coliform bacteria in Westchester Lagoon, University Lake, and Chester Creek did not meet state water quality standards for either drinking or recreational purposes (<http://www.epa.gov/waters/tmdl/docs/chestercrwatershedTMDLEPAFinal.pdf>). In 1994, Chester Creek was placed on the EPA's impaired waterbody list under section 303(d) of the Clean Water Act and as of 2008 was still listed on the impaired waterbody list (<http://www.dec.state.ak.us/water/wqsar/waterbody/2008ImpairedWaters.pdf>).

For the past several years, several governmental and non-governmental agencies have been performing restoration work on Chester Creek with the goal of improving salmon escapement numbers and instream conditions. While the creek is not a direct source of drinking water, it recharges nearby aquifers that supply public and domestic wells (Glass and Ourso 2006). In October 2008, a weir at the mouth of Chester Creek was removed, a direct channel connecting Westchester Lagoon to the Knik Arm was completed and several small associated restoration projects were finished. The rehabilitated channel was finished in 2009 and now provides a direct connection from the ocean to Chester Creek for the first time in nearly forty years.

My objectives for doing this study is to answer three main questions: 1) using Thomas Nickelson's Habitat Limiting Factor Model, what is the potential carrying capacity of the South Fork Chester Creek, 2) which habitat is possibly limiting coho numbers, and 3) what is the possible number of juvenile coho salmon the creek will produce in its current state.

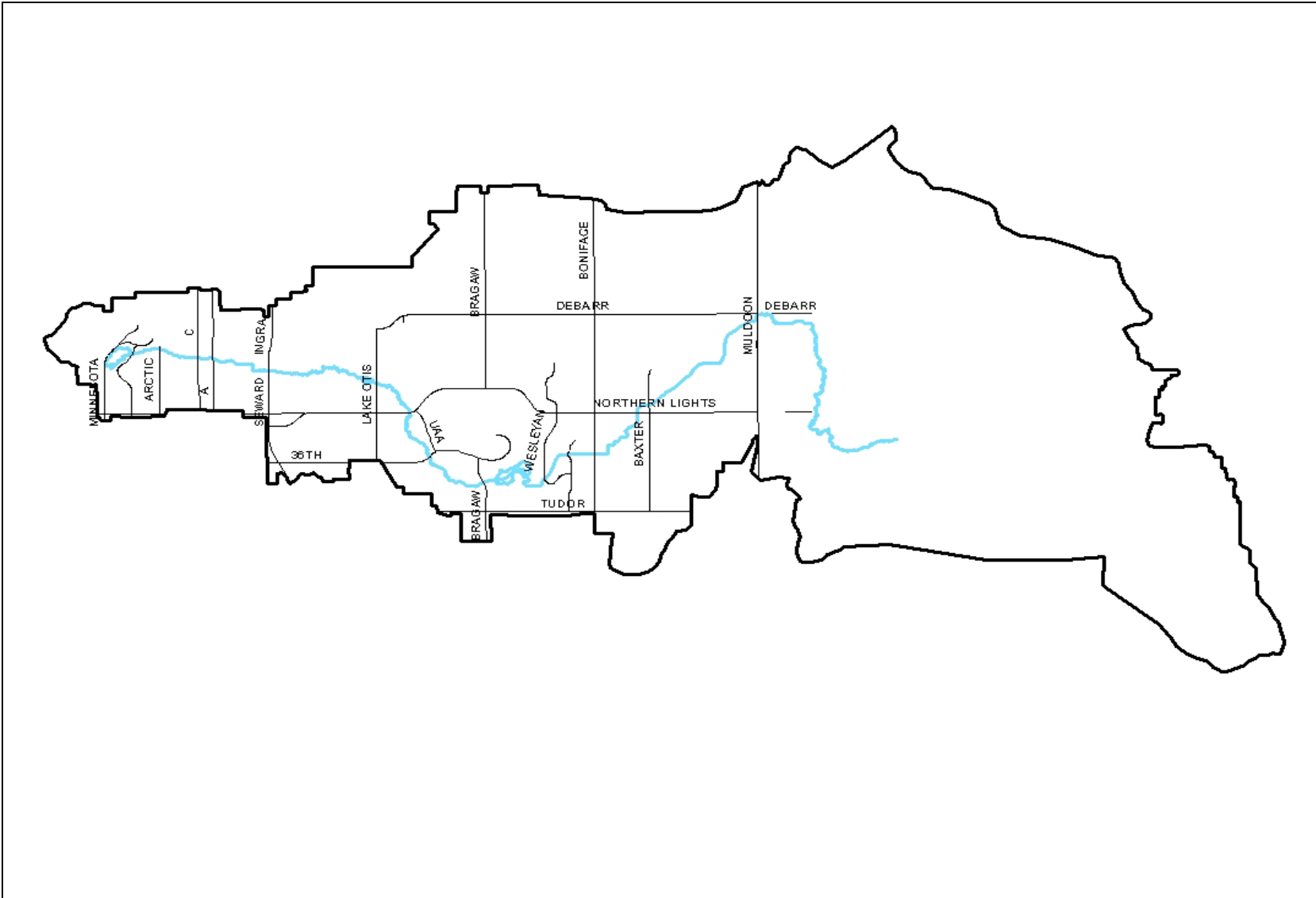


Figure 1 - The Chester Creek Watershed and the South Fork of Chester Creek.

Methods

Data Collection

A habitat inventory for Chester Creek was conducted during the summer of 2008 using a combination of methods from Bisson et. al. (1982), Overton et. al. (1997), and the EPA's Environmental Monitoring and Assessment Program (EMAP) protocols for wadeable streams (www.epa.gov/). The habitat inventory was divided into two separate parts. Part one consisted of surveying Chester Creek starting from Westchester Lagoon and moving upstream to near where the headwaters are located in the Chugach Mountains on the Fort Richardson Military Reservation. The inventory was terminated at a point where it was determined that salmon could not reach due to the steep grade and extremely fast moving water. Starting at Westchester Lagoon and moving upstream, the habitat units in the creek were identified as either a glide, riffle, or pool by using the definitions from Overton et. al. (1997). Using two people and a Leica Disto™ laser distometer, the habitat unit's length was measured in the center of the stream to the nearest 0.10 meters. One person would stand at the beginning of the unit holding the distometer at chest height and the second person would stand upstream holding a black clipboard to use as a target at chest height. Depending on the amount of sunlight present, which affected how far the laser beam could be seen on the clipboard, the distometer could measure a maximum distance of 25 to 45 meters. When more than one length measurement was required per unit, the person using the distometer would move to the target person's position then the target person would move ahead. Width measurements were taken perpendicular to the length from the wetted width to the nearest 0.10 meter. Width measurements consisted of one person

standing on the left bank at the water's edge holding the clip board and a second standing on the right bank water's edge using the distometer to take the measurement. Width measurements were taken at the beginning and the end of the unit. When multiple length measurements for each unit were needed, width measurements were taken at the beginning of each length. The mean width was then calculated by adding together all of the habitat unit's width measurements and dividing by the number of measurements taken. Surface area (m^2) was calculated by multiplying the length of the unit by the mean width. This was repeated for all habitat units. Habitat units were tagged with colored tape at the beginning of each unit and consecutively numbered. For example the first glide was labeled G1 and the second glide was labeled G2. Riffles were labeled with a R and the riffle number and pools were labeled with a P and the pool number.

All habitat units were surveyed using a Trimble™ GPS. Using the Trimble™, one person would start collecting points at the beginning of the marked habitat unit and walking the middle of the stream, stop the point collection at the end of the habitat unit. The points collected were downloaded to the Trimble™ software, converted into ArcView™ GIS polygons, and used to create a map of Chester Creek and its' habitat units (Figures 2 & 3).

The second part of the study involved a more detailed survey on selected habitat units. A sample of 20 units was selected, stratified to represent the number of each type of unit in the preliminary survey: 14 glides, 5 riffles, and 1 pool. Based on McMahon (1983), Sandercock (1991), Bjornn and Reiser (1991), and Nickelson et. al. (1992), riffles were considered spawning and incubation habitat for eggs and alevins

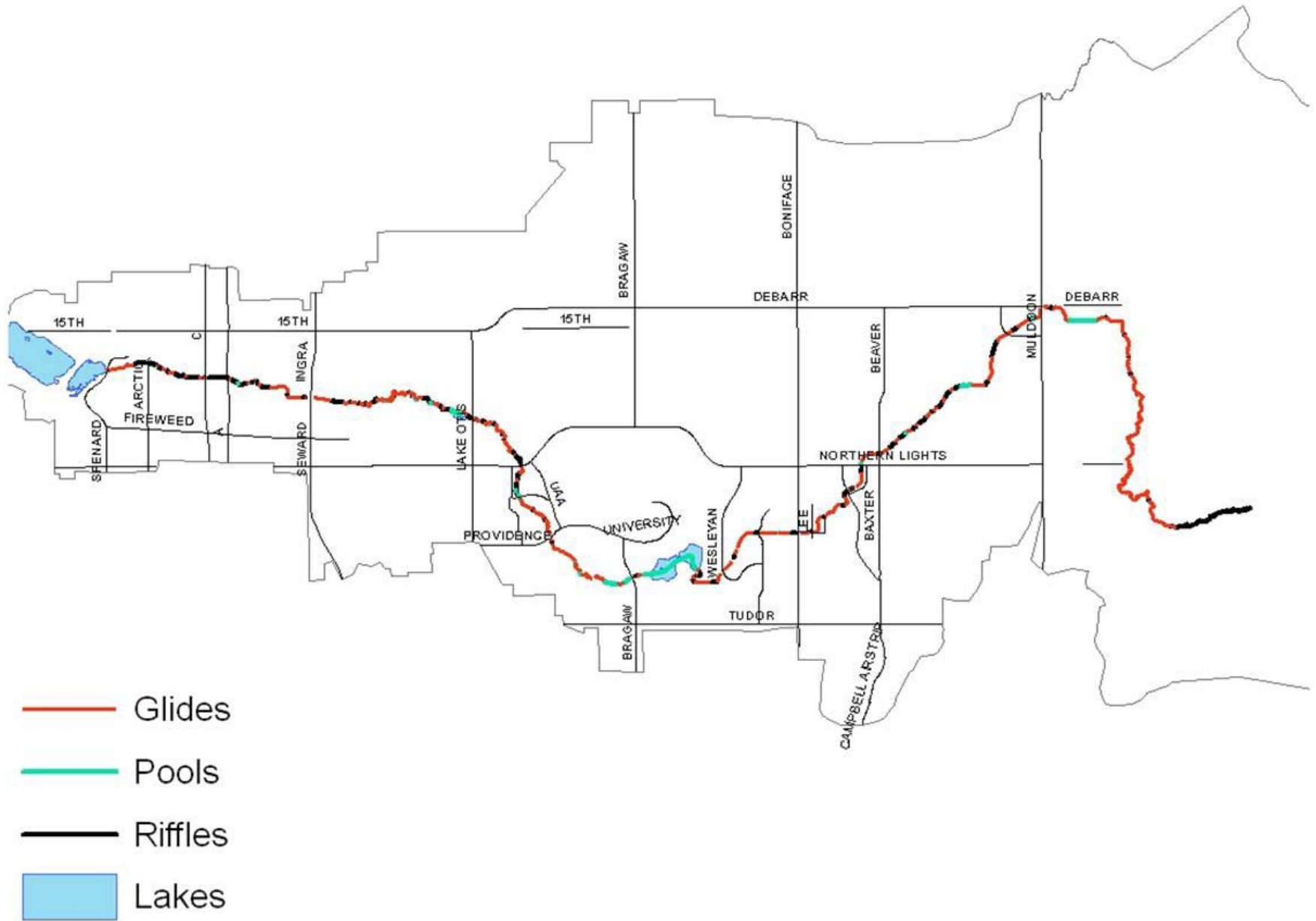


Figure 2 – Surveyed South Fork Chester Creek glides, riffles, and pools.

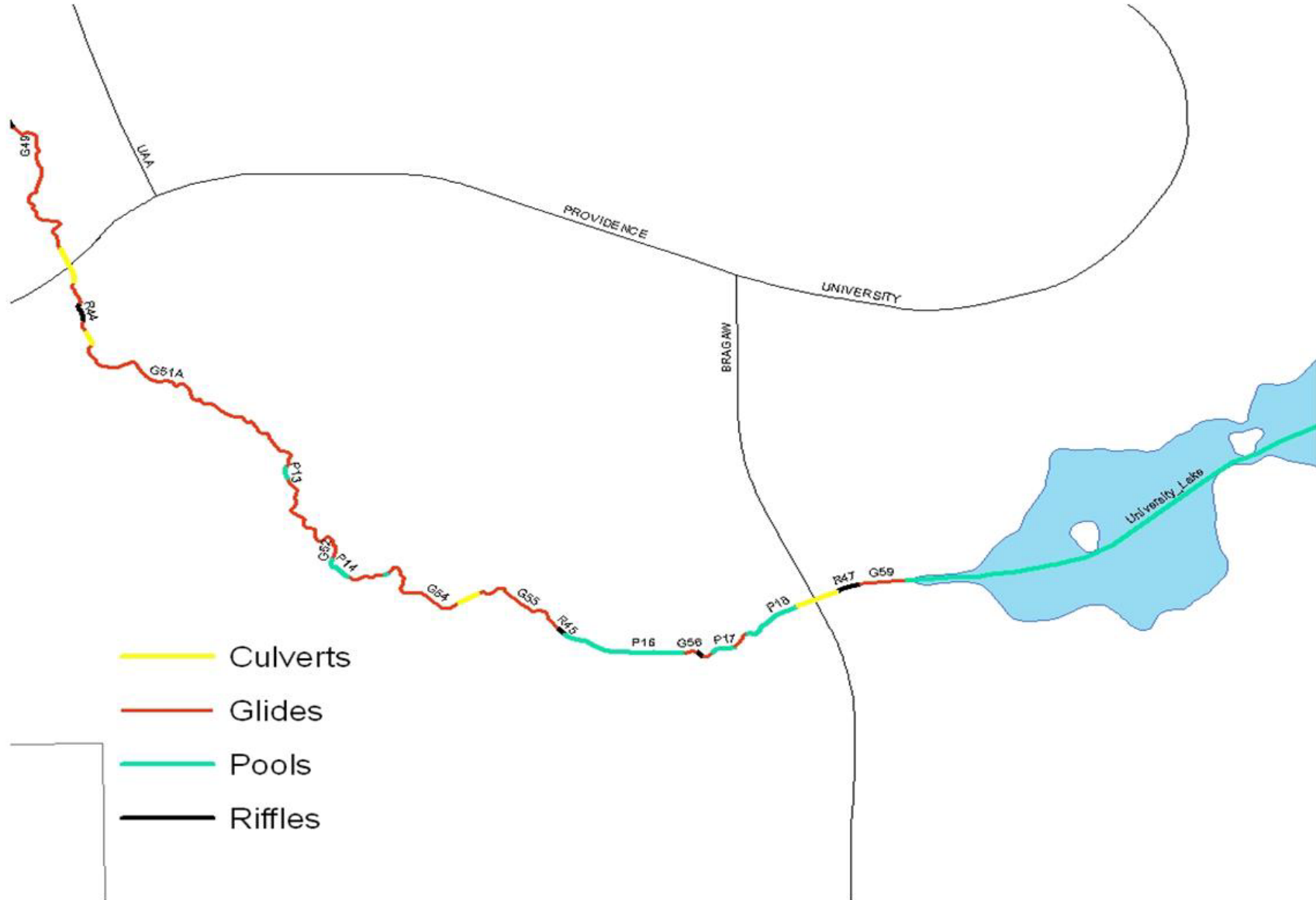


Figure 3 – A close-up example of the glides, riffles, and pools as collected by a GPS.

while glides, pools, and the three impoundments (University Lake, Hillstrand Pond, and Westchester Lagoon) were considered primarily as summer rearing and wintering habitat for both fry and juveniles. Physical parameters that were measured are listed in Table 2. These parameters were selected based on work done by McMahon (1983) and Bjornn and Reiser (1991) as they are the most important for the life stages considered in this study.

Table 2 – Physical parameters measured for riffles, pools, and glides.

Habitat	Physical Parameters
Riffles	Substrate
	Dissolved Oxygen (mg/L)
	Temperature (°C)
	Water Velocity (m/sec)
	Water Depth (m)
	Embeddedness (%)
Glides/Pools	Dissolved Oxygen (mg/L)
	Temperature (°C)
	Water Velocity (m/sec)
	Water Depth (m)
	Canopy Cover
	Cover
	Large Woody Debris

With the exception of the pool and three small glides, each habitat unit was divided up into five transects. The pool was divided into three transects, one glide was divided into four transects, and the remaining two glides were divided into two transects.

At each transect, water depth was measured to the nearest 0.10 meter using a 2-meter wading rod that was marked off every 0.10 meter. For glides and riffles, depth was measured at $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ distance across the unit, added together and then divided by 4, to account for a 0 measurement at the banks (Overton et. al. 1997). For pools, the maximum and crest depths were measured to the nearest 0.10-meter added

together and divided by 2 (Overton et. al. 1997). Water velocity measurements were made with a wading rod and an USGS Type AA Pygmy Current Meter. Water temperature and dissolved oxygen were measured using a Bunte YSI Dissolved Oxygen Meter DO 200. Substrate and embeddedness were measured in the riffles. Substrate was measured employing two different methods. The first was by performing a pebble count (Wolman 1954). Walking heel to toe for seven steps across the riffle, the pebble beneath the front toe was picked up and measured using the US SAH-97 HandHeld Particle Size Analyzer TM (Figure 4). The US SAH-97 HandHeld Particle Size Analyzer TM is a handheld device that is used to measure sediment particles ranging from 2 mm to 180 mm in the field. Pebbles were picked up and passed through the smallest hole through which it would fit. The hole's size determines the pebble's sieve diameter, also known as its' b-axis or the intermediate axis or width, which controls whether it will pass through a sieve or not (<http://fisp.wes.army.mil>). They were then categorized using a modified version of the Wentworth Scale as displayed in Table 3.

The second method was to take a sample at the head of the riffle by using a McNeil sampler (McNeil & Annell 1960). At the head of the riffle, the McNeil sampler was placed into the riffle substrate as far down as it could go, then the sediment in the barrel was scooped out by hand and placed into a bucket, where it was allowed to dry for several weeks before being sieved. The substrate was placed into a set of USGS sieves and an automated shaker was used to sort the substrate before it was weighed.

Embeddedness definition and measurements followed the EPA's EMAP protocol (www.epa.gov), which uses visual estimates. Placing the wading rod at five equally spaced points along the transect and visualizing a 10 centimeter circle around the rod,

embeddedness was visually estimated from 0% to 100%, with 0% being completely non-embedded and 100% being completely embedded.

Cover was placed into five categories: overhanging vegetation, undercut banks, water turbulence, woody debris, and boulders. Overhanging vegetation was defined as being at least one meter off of the water's surface and its density was measured using a densitometer also following EMAP protocols (www.epa.gov). Undercut banks were measured to the nearest 0.10-meter by placing the measuring rod beneath the undercut bank and reading off the length hidden by the bank. Woody debris was divided into rootwads, log jams, debris piles, and singles and counted.

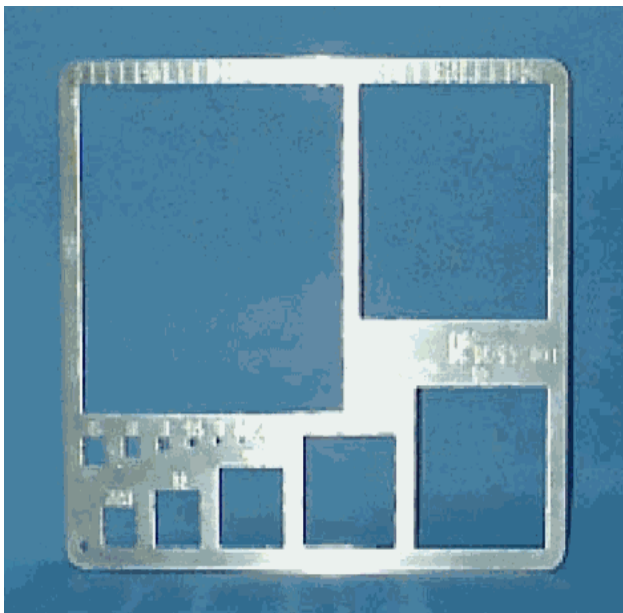


Figure 4 – US SAH-77 handheld particle size analyzer tm. Photo courtesy of http://fisp.wes.army.mil/Instructions%20US_SAH-97_040412.pdf

Table 3: Modified version of the Wentworth scale for classifying substrate using the US SAH-97 HandHeld Particle Size Analyzer TM.

Substrate	Size (mm)
Sand	<1
Very Fine Gravel	<2.8
Fine Gravel	<5.6
Med Gravel	<11.3
Coarse Gravel	<22.6
Very Coarse Gravel	<45.4
Small Cobble	<64
Med Cobble	<90.5
Large Cobble	<128
Very Large Cobble	<182
Small Boulder	<256
Boulder	>255

For data analysis, 2 different models were used to estimate the carrying capacity. The first model was developed by Thomas Nickelson in 1992 and expanded upon in 1998 and is the habitat limiting factor model (HLFM). The theory behind the HLFM (Nickelson 1992) is that the limiting habitat or the bottleneck can be identified by simultaneously comparing the “potential of a stream system’s habitat for each life stage.” The first step in the HLFM is to estimate the potential coho population abundance for each of the life stages by multiplying habitat specific densities (Table 4) by the surface areas of the habitat types collected during the stream inventory and simultaneously comparing the various life stage population estimates to determine which seasonal habitat will possibly support the least amount of coho. The three lakes (Westchester Lagoon, Hillstrand Pond, and University Lake) were included in the study as they are considered to be important habitat for juvenile coho salmon, especially during the winter months (Bisson et al. 1989; Sandercock 1991; Bjornn and Resier 1991; Nickelson et al. 1992; Anderson and Hetrick 2004) and as they contain nearly 84% of the available surface area, it seemed inappropriate not to include them. Though

not created by beavers, the lakes were classified as beaver ponds for the HLFM, indicating that they should be considered to have the potential of supporting high densities of juvenile salmon (Anderson and Hetrick 2004). Although Nickelson (1998) uses a value of 1.84 fish/m² for potential density, it was suggested that I use a value of 1.00 fish/m² (Anderson, personal communication). Anderson and Hetrick (2004) used a density of 1.00 fish/m² for their habitat analysis of the Kametolook, Three Star, and Long Beach Rivers as they determined it to be more consistent with fish densities observed in rivers where winter stream flows are lower than spring or fall flows.

The second step estimates the potential smolt population through time (i.e., the life stages) by multiplying density-independent survival rates (Table 5) to the life stage population estimates generated from the above equation. The life stage that produces the least amount of predicted smolts is considered to be the limiting life stage.

Once the bottleneck has been identified and an estimated smolt production is obtained, back calculations are performed to determine the adult escapement needed to fully seed the available habitats (Nickelson 1998).

Table 4 – Potential densities (fish/m²) by season used for Nickelson's (1992) habitat limiting factor model.

Habitat Type	Spring	Summer	Winter
Cascade	0.00	0.24	0.00
Rapid	0.60	0.14	0.01
Riffle	1.20	0.12	0.01
Glide	1.81	0.77	0.12
Trench Pool	0.99	1.79	0.15
Plunge Pool	0.84	1.51	0.28
Scour Pool	1.29	1.74	0.35
Dammed Pool	2.56	1.84	0.56
Alcove	5.75	0.92	1.84
Beaver Pond	2.56	1.84	1.84
Backwater	5.75	1.18	0.58

Table 5 – Density independent survival rates by life stage used for Nickelson’s (1992) habitat limiting factor model.

Life Stage	Survival Rate to Smolt
Spring Fry	0.46
Summer Parr	0.72
Winter Pre-smolt	0.90

The following equations and constants were also generated by Nickelson (1998) and used to determine the number of adult coho needed to fully seed a stream.

Potential smolt density (C , fish/m²) is calculated as:

$$C = M / SA$$

where M is the maximum smolt capacity calculated above by the HLFM and SA is the total available surface area of the stream in m². The survival to smolt (S_{smolt}) is then calculated as:

$$S_{smolt} = S_{egg} * S_{ow}$$

where S_{egg} is the egg to summer parr survival rate constant of .072 and S_{ow} is the overwinter survival rate that is calculated as:

$$S_{ow} = 0.1361 * \log_e C + 0.487$$

Egg deposition (D_m) needed to produce the maximum smolt capacity (M) is calculated as:

$$D_m = M / S_{smolt}$$

The number of spawners needed to produce the egg deposition (A_m) to produce the maximum amount of smolts is then calculated as:

$$A_m = (D_m / 2500) * 2$$

The production potential (PP) for the creek is:

$$PP = M * S_{mar}$$

where M is the maximum smolt capacity and S_{mar} is the marine survival rate calculated at 10, 5, and 3 percent. This final equation tells us that out of all of the smolts produced, what number of them need to survive in the ocean and return to Chester Creek in order to fully seed it.

The second model was developed by Marshall and Britton (1990) for calculating a stream's carrying capacity by comparing smolt yields (numbers and biomass) and rearing space (length and area). Using data from 21 streams located in Oregon, Washington, British Columbia, and California, they found that stream length and surface area tended to be the best indicators of carrying capacity and created two equations that expressed the annual smolt yield (Y) as related to either stream length (X , km):

$$Y = 1,134.4X^{1.1507}$$

or area (A , m^2):

$$Y = 3.1001A^{0.7899}$$

Both models were found to have a p-value of less than 0.05 with $r > 0.90$.

Results

For the HLFM calculations of Chester Creek it should be noted that there were only four types of habitats: pools, riffles, glides, and lakes. There were no cascades, only one active beaver pond, and pool habitat was scarce. This greatly simplifies the Nickelson model. Use of the HLFM suggests that overwintering habitat is the limiting habitat (Table 6) but use of the density independent survival rates indicate that the summer life stage limiting the amount of potential coho smolt (Table 7).

The HLFM indicates that the maximum amount of juvenile coho the South Fork Chester Creek could support is 320,291 (Table 7 & 8). The minimum number of adults needed to produce the 320,291 juveniles will be 8,541, which would indicate that at least a 3% marine survival rate is required for the stream to be seeded at full carrying capacity (Table 8).

Table 6 – The potential carrying capacities of juvenile coho salmon by season as calculated by the habitat limiting factor model (Nickelson 1998).

Season	South Fork Chester Creek
Spring	1,141,262
Summer	444,853
Winter	404,815

Table 7 – Results of the density independent survival rates (Nickelson 1992) showing how many juvenile coho salmon each season can support giving the maximum smolt capacity (M) Chester Creek can support.

Life Stage	South Fork Chester Creek
Spring	524,981
Summer	320,291
Winter	364,334

Table 8 – Results of the habitat limiting factor model (Nickelson 1998).

HLFM Parameter	South Fork Chester Creek
Surface Area (m ²)	474,013
Stream Length (km)	16.3
Maximum Smolt Capacity (M, fish)	320,291

Potential Smolt Density (C, fish/m ²)	0.68
Overwinter Survival (Sow)	0.43
Egg to Summer Survival Rate (Segg)	0.072
Egg to Smolt Survival (Ssmolt)	0.03
Egg Deposition (Dm)	10,676,366
Minimum Adult Numbers (Am)	8,541
<hr/>	
Potential Adult Production (PPx)	
<hr/>	
10% Marine Survival	32,029
5% Marine Survival	16,014
3% Marine Survival	9608
<hr/>	

The models developed by Marshall and Britton (1990) using length and area to determine carrying capacity give 28,157 and 94,333 respectively, a much lower estimate than the one given by the HLFM, however, Anderson and Hetrick (2004) found that Marshall and Britton models tended to underestimate potential coho production. One reason for the differences are that unlike the HLFM (Nickelson 1998), the Marshall and Britton model does not take into account habitat types, i.e. lakes, glides, and riffles, nor their different coho productivity values (Anderson and Hetrick 2004). For example, according to the Marshall and Britton model (1990), a riffle will support the same number of juvenile coho as a beaver pond.

The estimates generated from the HLFM (Nickelson 1998) and Marshall and Britton (1990) models are still significantly higher than the estimates that Anderson and Hetrick (2004) generated from their carrying capacity study in the Alaska Peninsula National Wildlife Refuge but I am assuming that is because Chester Creek has three fairly large lakes associated with it that allow for more rearing space than the four creeks they surveyed. Table 9 summarizes the carrying capacity estimates generated by the HLFM (Nickelson 1998) and Marshall and Britton (1990)

Table 9 – Summary of the carrying capacity estimates.

MODEL	CARRYING CAPACITY ESTIMATE
HLFM TOTAL SURFACE AREA	320,291
MARSHALL AND BRITTON LENGTH	28,157
MARSHALL AND BRITTON TOTAL SURFACE AREA	94,337

A total of 14.9 kilometers of the 16.3 km of the South Fork Chester Creek was inventoried and divided into 207 habitat units: 102 glides, 81 riffles, and 24 pools. Along with three small lakes, Westchester Lagoon, Hillstrand Pond, and University Lake, evidence of two old beaver dams were found; one being off of Lake Otis Parkway, another behind the University of Alaska Anchorage's Common Building. A third active beaver dam is located just past Muldoon Road in the vicinity of east 16th and Carolyn Drive. The three lakes account for 84% of the surface area available while glides account for 11%, riffles for 5%, and pools for 1%. No significant cascades and rapids were observed and the only pool types observed were either scour or damned. Of the

207 glides, riffles, and pools surveyed, 14 glides, 5 riffles, and 1 pool were selected for the in-depth habitat survey (Table 10). Figure 5 is a map of the locations of the selected sites. Measurements for the in-depth survey were taken between July and August.

Table 10 – Location of surveyed habitat units

Habitat	Location	Coordinates	Date
Riffle 2	Valley of the Moon Park	61°12'16" N 149°53'49" W	7/15/2008
Glide 2	Valley of the Moon Park	61°12'16" N 149°53'46" W	7/28/2008
Glide 11	Across from Ben Boeke Sports Park	61°12'10" N 149°52'38" W	8/14/2008
Riffle 16	East of Seward Hwy	61°12'04" N 149°51'50" W	8/14/2008
Glide 19	Greenbelt area	61°12'03" N 149°51'31" W	8/16/2008
Glide 21	Greenbelt area	61°12'05" N 149°51'21" W	8/16/2008
Glide 36	Just off of Lake Otis Parkway	61°11'58" N 149°50'16" W	7/26/2008
Glide 38	Just off of Lake Otis Parkway	61°11'57" N 149°50'09" W	8/16/2008
Riffle 35	Greenbelt area	61°11'53" N 149°49'57" W	7/26/2008
Glide 47	Career Center Road	61°11'31" N 149°49'45" W	8/26/2008
Glide 52	Behind Providence Hospital	61°11'10" N 149°49'09" W	8/26/2008
Glide 64	Weslyan and Pawn	61°11'05" N 149°47'35" W	8/14/2008
Riffle 52	Queen's Court	61°12'02" N 149°45'08" W	8/14/2008

Glide 71	Lee Street Trailer Park	61°11'21" N 149°46'30" W	8/19/2008
Glide 76	Camby and Ambergate	61°11'35" N 149°46'05" W	8/19/2008
Pool 20	Off Baxter St and Northern Lights	61°11'13" N 149°47'24" W	8/18/2008
Riffle 66	Off Colgate Drive	61°12'02" N 149°45'08" W	8/18/2008
Glide 86	Off Colgate Drive	61°12'04" N 149°45'05" W	8/18/2008
Glide 93	Across from Muldoon Fred Meyer	61°12'34" N 149°43'57" W	9/18/2008
Glide 100	Fort Richardson	61°12'12" N 149°43'01" W	9/18/2008

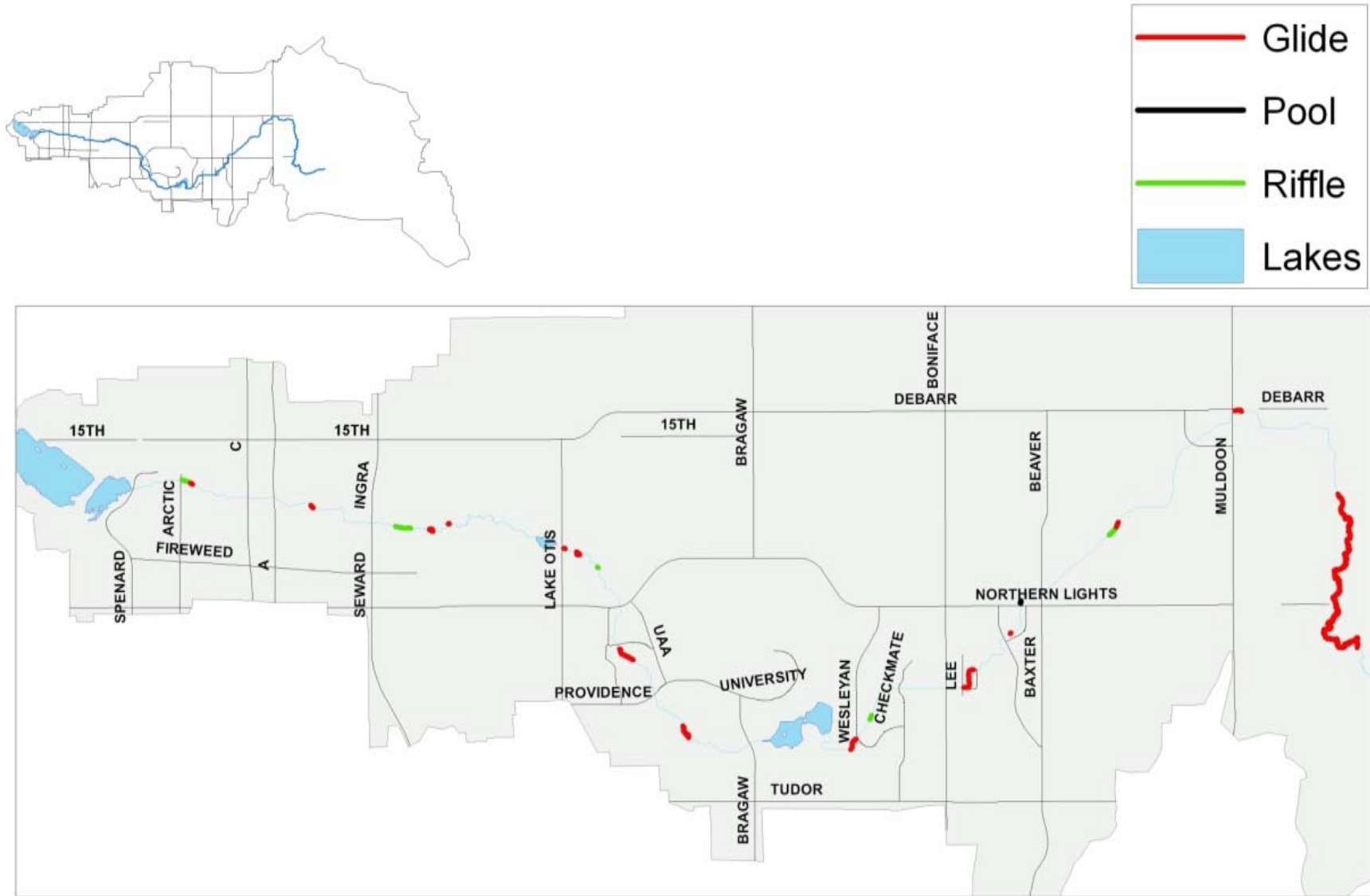


Figure 5 – Location of surveyed habitat units on Chester Creek.

For glides, mean temperature was 9.6°C, the lowest temperature measurement being 5.6°C at glide 100 and 11.8°C at glide 21 (Figure 6). The mean dissolved oxygen level was 11.5 mg/L, with ranges between 10.3 and 12.8 mg/L (Figure 7), well above the Alaska Department of Environmental Conservation (ADEC) minimum DO levels for salmonid streams of 7 mg/L while mean depth and velocity were 0.3 m and 0.5 m/sec respectively (Figure 8 and 9).

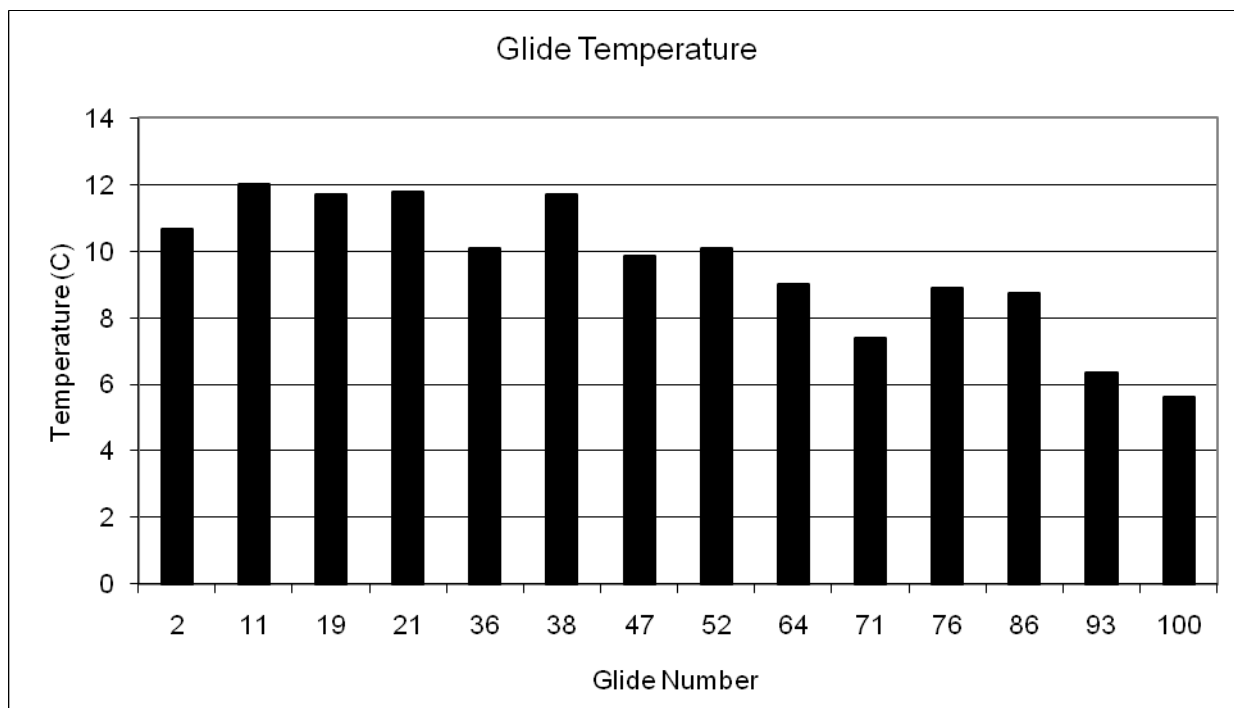


Figure 6 –Temperature values (°C) for the individual glides.

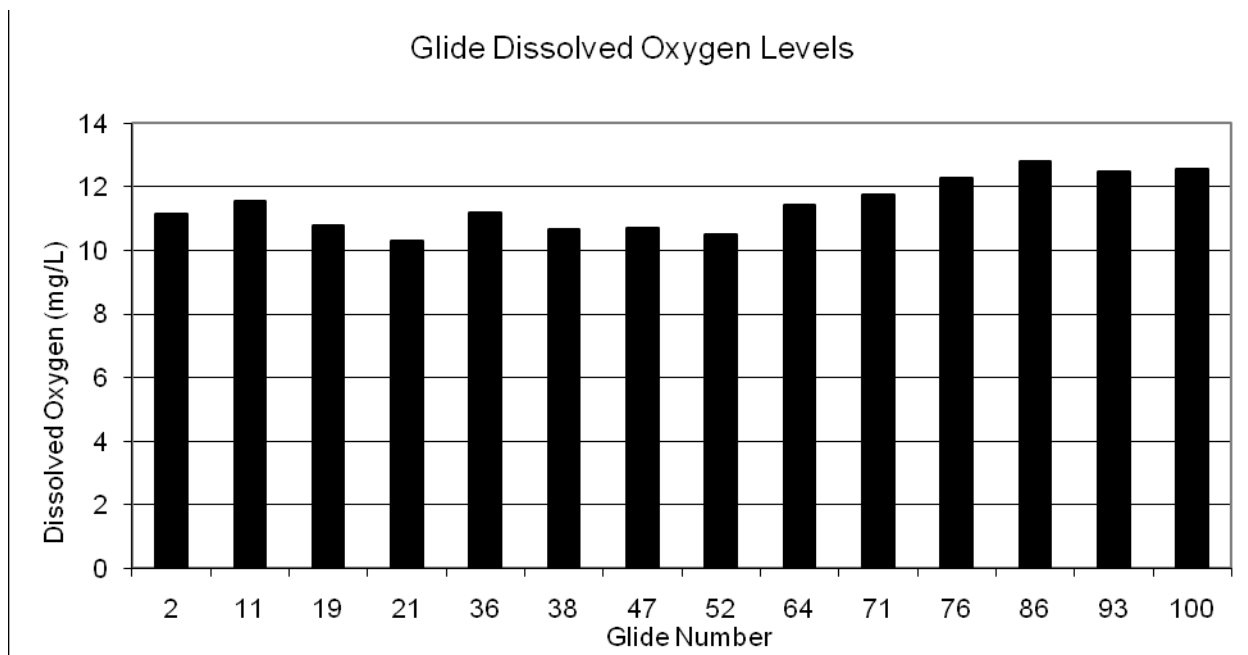


Figure 7 – Dissolved oxygen values (mg/L) for the individual glides

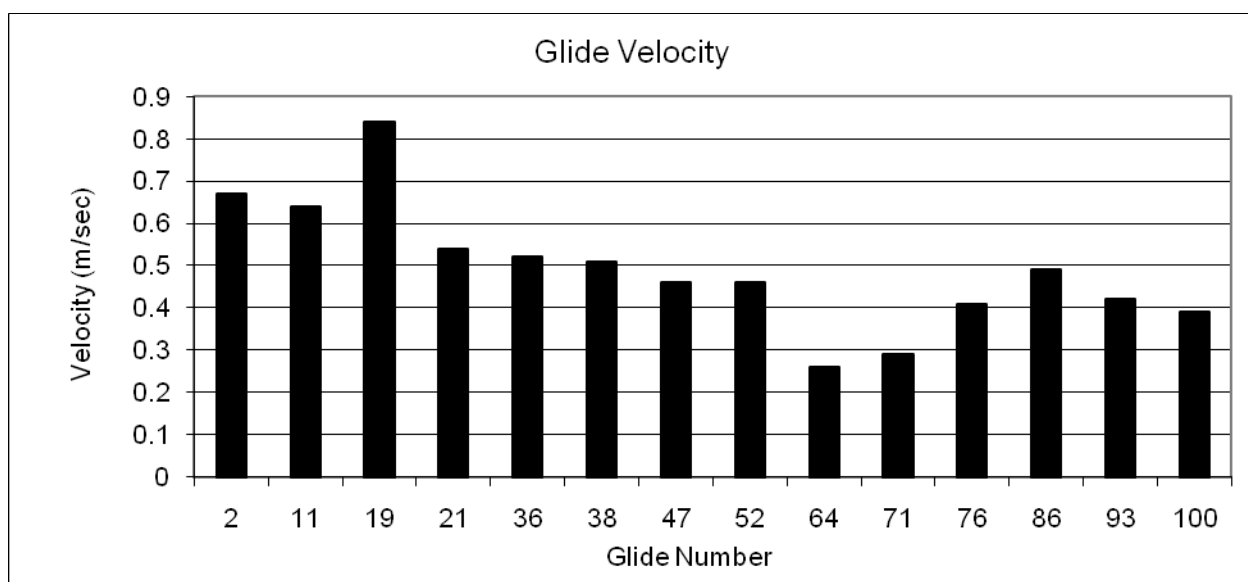


Figure 8 – Mean velocity (m/sec) for individual glides.

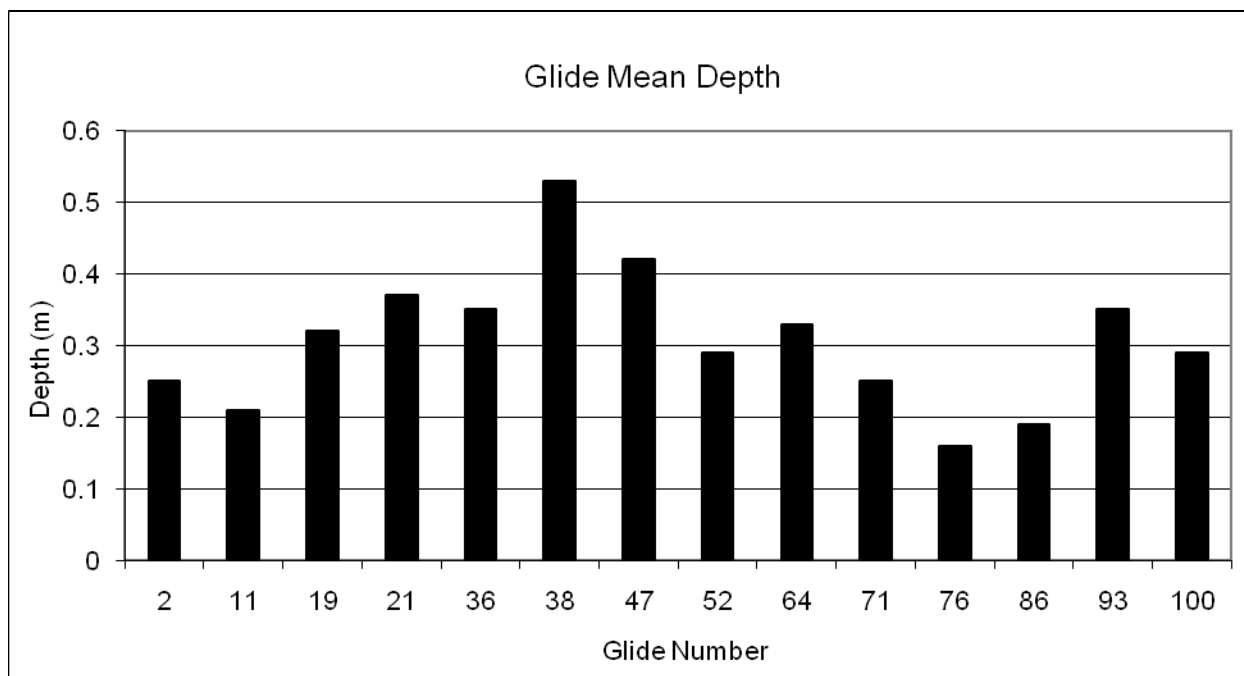


Figure 9 – Mean depth (cm) for the individual glides.

Cover availability is important in the rearing stages because it provides protection from predators and a source of food (McMahon 1983; Bjornn and Reiser 1991).

Turbulence was the least found type of cover. A total of 124 boulders were counted but most were found to be at glide 93 in the Muldoon area and seemed to have been strategically placed against the banks rather than being natural features. Undercut banks averaged 15 cm deep for both the right and the left banks. Three hundred and thirty four single woody debris pieces were counted along with 46 debris piles and 5 rootwads (Figures 10 and 11). Both single pieces of woody debris and debris piles increased in number going upstream towards Fort Richardson, except at glide 76, where no large woody debris was found.

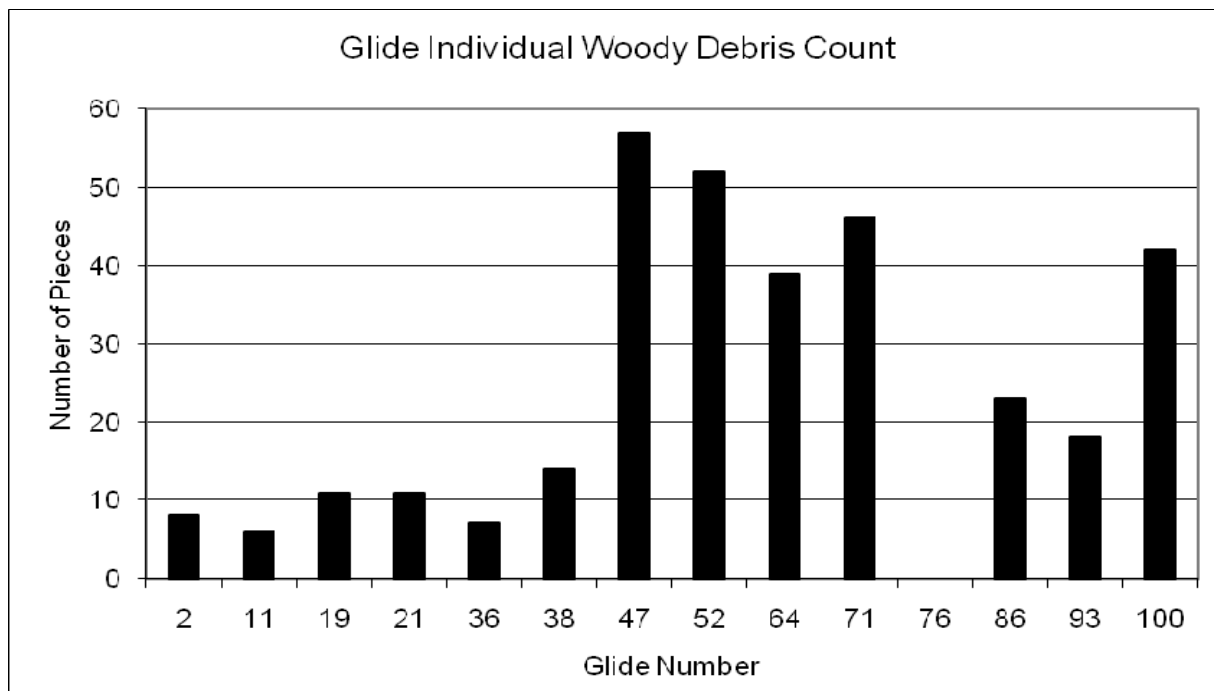


Figure 10 – Single pieces of woody debris counted by glide

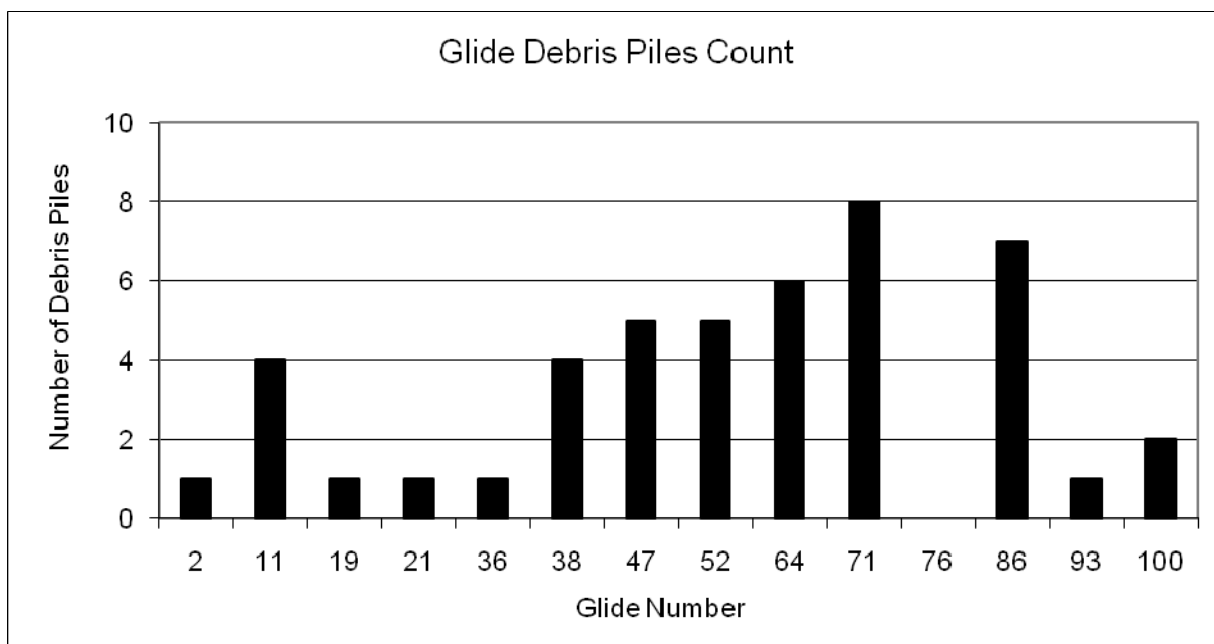


Figure 11 – Number of debris piles counted by glide

Pool temperature was recorded at 7.1°C with the dissolved oxygen level at 12.3 mg/L. Water velocity was measured at 0.2 m/sec and water depth was 0.3 m. Looking at cover availability, no turbulence or boulders were found while canopy cover was

measured to be 11. The substrate was mainly composed of silt and litter from overhanging trees. Three single pieces of woody debris were counted and the left bank was undercut by an average of 15 cm while the right bank was not undercut at all.

Mean temperature for the five riffles was 9.2°C, with temperatures ranging between 3.9°C and 12.6°C (Figure 12). The mean dissolved oxygen level was 11.7 mg/L, once again, above the ADEC's minimum DO levels (Figure 13). Mean water velocity and depth were measured as 0.7 m/sec and 0.3 cm respectively (Figure 14 and 15) while mean embeddedness was estimated to be 67% over all the riffles.

The pebble count performed at each of the riffles found that 13% of the substrate counted was 5.6 mm in diameter or less. However, use of the McNeil sampler found that fines made up an average of 42.5% of each sample taken from the riffles, with ranges between 38% and 52%. Table 11 is a summary of the substrate composition found in the selected inventoried riffles using the McNeil sampler.

While temperature is important in the incubation process, substrate must also be considered as fry emergence is directly related to substrate composition (McMahon 1983). McMahon (1983) developed a suitability index (SI) to determine how suitable a stream's substrate is for spawning. To determine this, he developed the equation $SI = (A+B) / 2$, where A is the percent of gravel (10-60 mm) and rubble (61-250 mm) present and B is the percent fines (<6 mm) or percent embeddedness. Using the figures obtained from the McNeil sampler, the mean percent of gravel and rubble and for the fines were 58% and 42% respectively and using the visual EMAP method for embeddedness, the mean percent embeddedness was calculated at 67%. By first applying the percent fines, then the percent embeddedness to the equation, 62.5

percent and 50 percent are respectively calculated. Using McMahon's SI graph for substrate composition (McMahon 1983), suitability index numbers of approximately 0.15 for percent embeddedness and 0 for percent fines are calculated, both indicating that the substrate is in poor condition.

Table 11 – The substrate composition found in the selected inventoried riffles of Chester Creek using the McNeil Sampler.

Substrate (mm)	R2		R16		R35		R52		R66	
	Weight (g)	% Composition	Weight (g)	% Composition	Weight (g)	% Composition	Weight (g)	% Composition	Weight (g)	% Composition
Cobble (>64-128)	0	0	0	0	0	0	0	0	0	0
Large Gravel (>32-64)	269.3	4	1147.3	16	528.6	9	1547.5	25	624.7	18
Medium Gravel (>4-32)	3508.9	53	3329	44	2405.5	40	2393.6	38	1573.9	44
Small Gravel (>2-4)	968.9	15	1008.9	13	822.2	14	583.2	9	380.3	11
Fine Gravel (>.063-2)	656.6	10	851.1	12	573.9	10	573.9	9	353.9	9
Sand/Silt (<.063)	1147.3	18	1151.6	15	1653.4	27	1188.8	19	629.5	18

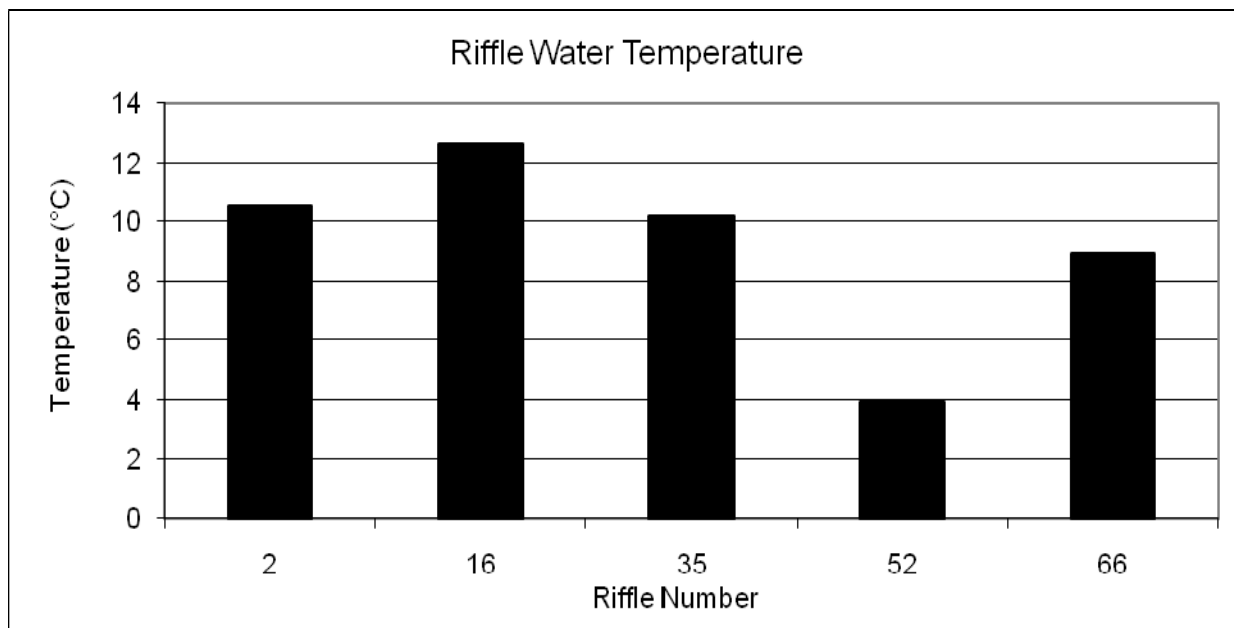


Figure 12 – Temperatures (°C) for individual riffles.

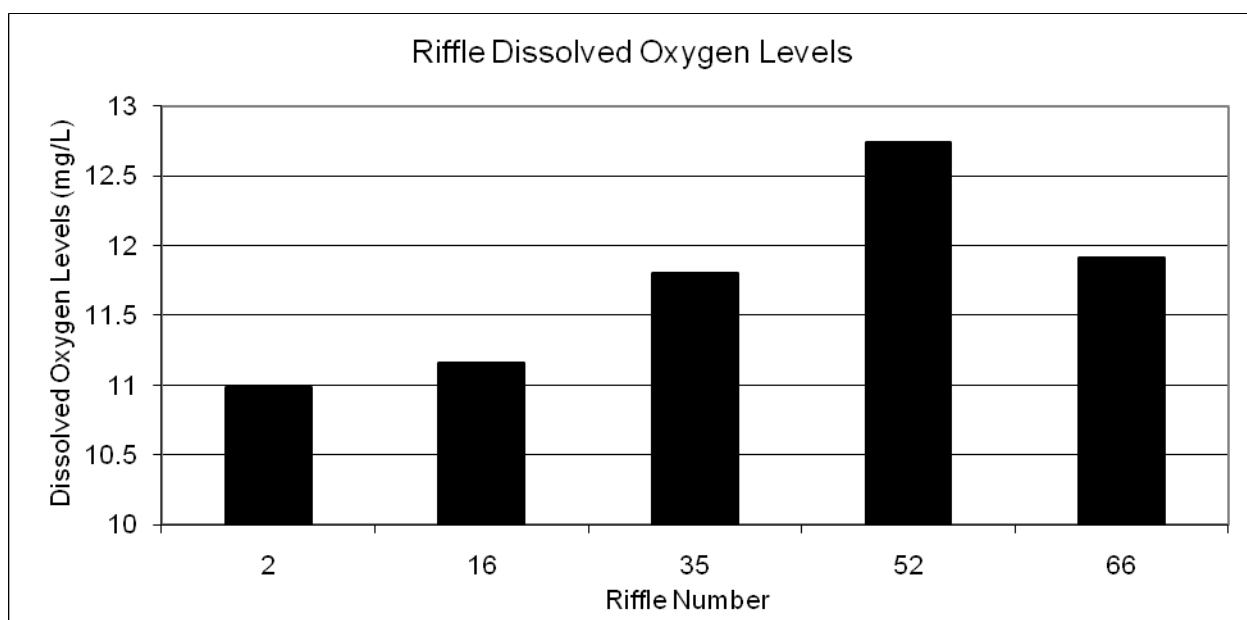


Figure 13 – Dissolved oxygen levels (mg/L) for individual riffles.

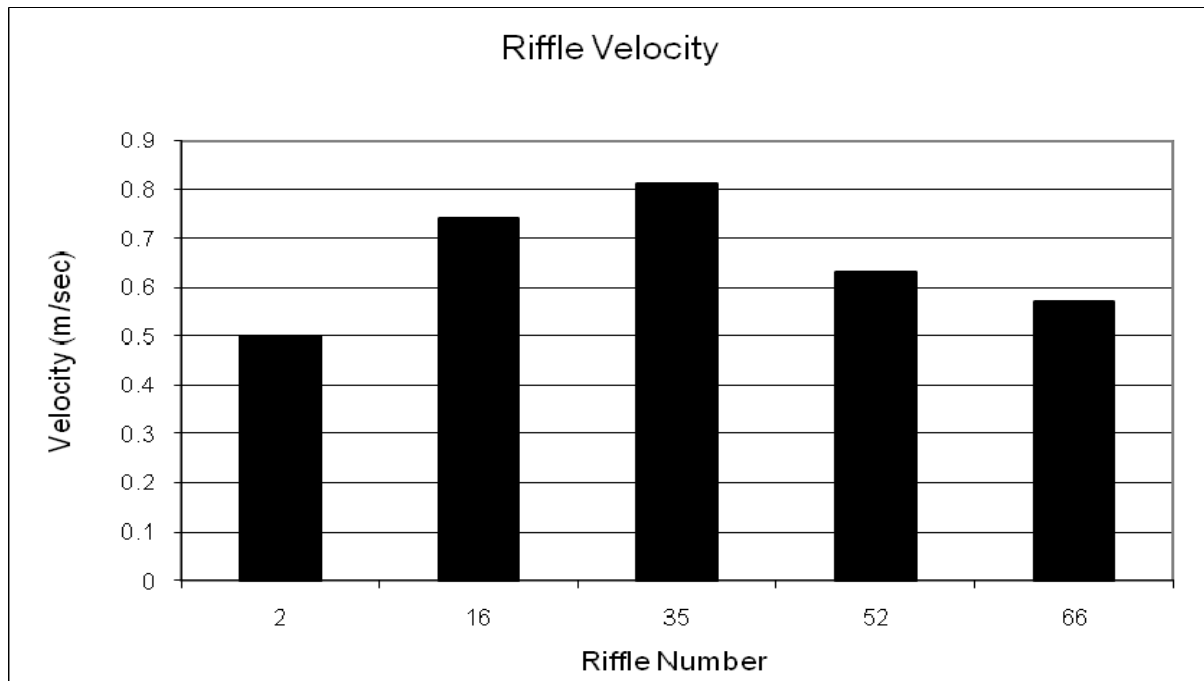


Figure 14 – Mean water velocity (m/sec) for individual riffles.

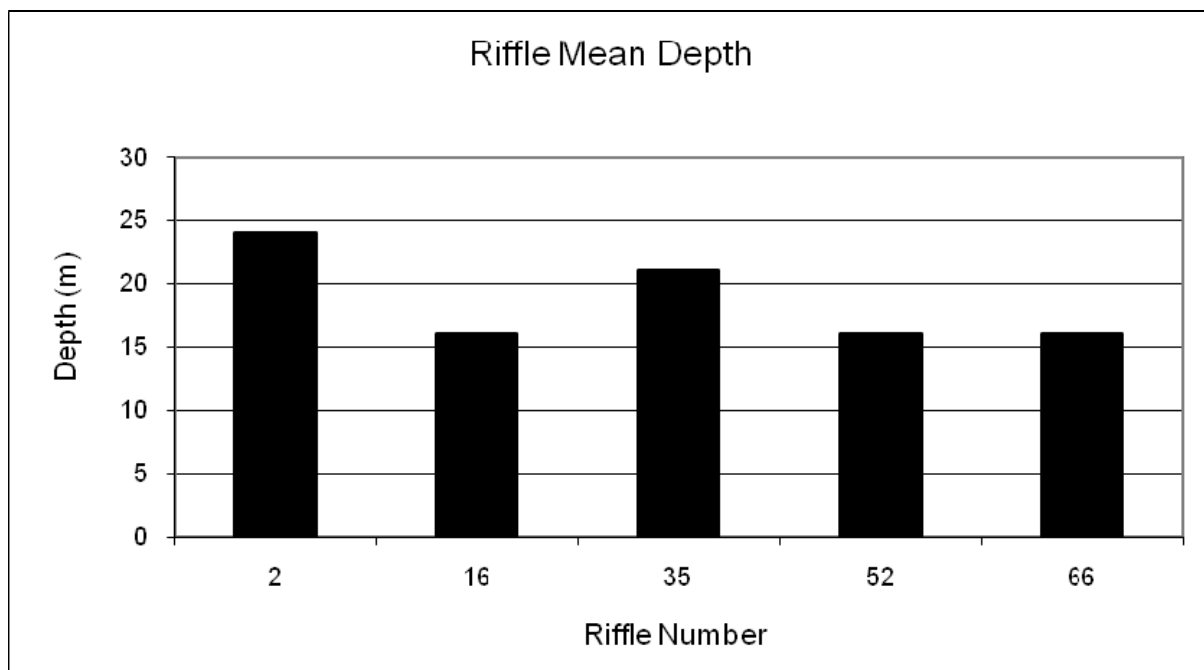


Figure 15 – Mean depth (cm) for individual riffles

Discussion

Results for the HLFM (Table 8) likely overestimate Chester Creek's carrying capacity. While beaver ponds have ample woody debris supplies, they are typically much smaller than the three lakes present, which would have most of their woody debris closer to the shoreline rather than spread out over the entire surface area, resulting in the coho using the lake as rearing habitat staying closer to shore, where there would be places to hide from predators and an abundant food supply. Assuming only the area around the shoreline of the lakes would provide the rearing habitat needed, I recalculated the carrying capacity again, using only the surface area out to 5 meters. This cut the surface area of the three lakes from 397,395 m² to 33,057 m² and brought the total surface area of Chester Creek down to 109,675 m². Applying the new surface area to the HLFM, the new carrying capacity is calculated as being 36,431 smolts with winter now being the limiting habitat (Table 12). Table 13 shows the new values calculated for the HLFM and the supporting back calculations using the new surface area numbers.

Table 12 – Results of the density independent survival rates using the new surface areas showing how many smolts each season can support giving the maximum smolt capacity (M) (Nickelson 1998).

LifeStage	South Fork Chester Creek
Spring	95,937
Summer	57,972
Winter	36,431

Table 13 – Results of the habitat limiting factor model (Nickelson 1998) using the newly calculated surface area numbers.

HLFM Parameter	South Fork Chester Creek
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Surface Area (m ²)	109,675
Stream Length (km)	16.3
Maximum Smolt Capacity (M, fish)	36,431
Potential Smolt Density (C, fish/m ²)	0.33
Overwinter Survival (Sow)	0.34
Egg to Summer Survival Rate (Segg)	0.072
Egg to Smolt Survival (Ssmolt)	0.02
Egg Deposition (Dm)	1,821,550
Minimum Adult Numbers (Am)	1,457

Potential Adult Production (PPx)

10% Marine Survival	1,093
5% Marine Survival	1,822
3% Marine Survival	3,643

The Marshall and Britton (1991) equation for surface area now predicts that the smolt carrying capacity should be 29,686. By recalculating the surface area, the models now predict that the smolt carrying capacity for Chester Creek should fall inbetween 26,000 to 36,000. While these numbers give a more realistic view of the potential carrying capacity with the new surface area of the three lakes that the coho will mostly use, I still believe that they are an overestimation for several reasons. First, the smolts might not be able to utilize all of the available habitat. The habitat near the upper

reaches of the creek near the origin tend to have a steeper gradient and high water velocities. The habitat found between Lake Otis Blvd and Northern Lights is still very channelized, meaning the stream channel is straight and narrow, the water velocity is higher than coho fry like, even within the glide areas, and there is very little in the way of off-channel habitat for coho to rear in. Secondly, obstacles, such as culverts, can impede a coho's access to rearing grounds either up or downstream. Thirdly, the shoreline of the lakes are not all wooded and undeveloped, so even using 5 meters out can still be an overestimation. A trapping study at Potter's Marsh found that out of 506 juvenile coho caught, only 5 were caught more than 2 meters from the shore (A. Frothingham, Personal Communication). And lastly, winter is when stream flows in Alaska are typically at a minimum (Milner and Petts 1994; Murphy et al 1997; Anderson and Hetrick 2004). Stream discharge data from the USGS Arctic Blvd station on Chester Creek indicates that the average low flows take place between the months of November and March (<http://alaska.usgs.gov>). In addition, discharge data for Campbell Creek and Bird Creek also indicate that average low flows take place at around the same time (<http://alaska.usgs.gov>). With decreased flows during the winter months, I would assume some habitat areas that are usually available during summer peak flows, such as backwater areas or alcoves, would either disappear or become unusable during winter due to depth, velocity, or inaccessibility. Most carrying capacity studies suggest performing a habitat inventory during the winter months to get an idea of the types of habitat and surface area available to the fry but because many places don't have winter habitat data available or it is impracticable to collect it, Nickelson's 1998 included an equation to calculate winter carrying capacity using summer habitat data: $C = (0.4 -$

$0.0682\log_e W - 0.0332G + 0.1030B + 0.2020L)^2$ where C is the predicted smolt density (fish/m²), W is the channel width (m), G is the percent gradient, B is the number of beaver dams, and L is the arcsine square root transformation of the percent pools. This equation indicates that the winter habitat is still the limiting habitat and that Chester Creek should be able to successfully support approximately 19,000 smolts, about 8,000 less than the 1992 HLFM predicts. Table 14 summarizes the carrying capacity estimates generated.

Table 14 – Summary of the carrying capacity estimates generated using the total surface areas and the reduced surface areas.

MODEL	CARRYING CAPACITY ESTIMATES
HLFM (TOTAL SURFACE AREA)	320,291
HLFM (REDUCED SURFACE AREA)	36,431
HLFM WINTER EST. (REDUCED SURFACE AREA)	19,000
MARSHALL AND BRITTON (LENGTH)	28,157
MARSHALL AND BRITTON (TOTAL SURFACE AREA)	94,337
MARSHALL AND BRITTON (REDUCED SURFACE AREA)	29,686

In order to assess the carrying capacity estimates, the 2008 escapement data can be used to determine the smolt population by rearranging Nickelson's 1998 production potential calculation: $M = PP / S_{\text{mar}}$. In 2008, 500 spawners entered into Chester Creek. By applying a 5% marine survival rate, which is the approximate

survival rate found in the Ship and Campbell Creek coho returns (Bosch and Evans 2006), the maximum number of smolts in the stream is 10,000, about 30% of the stream's estimated carrying capacity. However, because coho tend to stay in freshwater streams for 2 to 4 years, it will not be until 2013 when we start to see if the coho population is increasing.

For rearing coho, accessible winter habitat is important. Off-channel habitat such as overflow channels and floodplains improve coho overwintering survival (Quinn and Peterson 1996). Instream woody debris creates the deep pools and low velocities needed during the winter months (McMahon 1983; Sandercock 1991; Bjornn and Reiser 1991); Nickelson et. al. 1992; Quinn and Peterson 1996). Alterations to the riparian zone, such as the removal of streambank trees, and the addition of culverts have reduced the number of woody debris in the stream and in some places, eliminated it all together. Since pools are sparse and the main habitat types of riffles and glides (neither of which are conducive for winter habitat), it may be that many of the juvenile coho are migrating to the three lakes for winter (Bisson et al. 1982; McMahon 1983; Sandercock 1991; Bjornn and Reiser 1991; Nickelson et al. 1992), thus making them an extremely important part in the number of fry that survive to smoltification.

The main disadvantage to both the HLFM (Nickelson 1992) and the Marshall and Britton (1990) models are that they don't take into account habitat quality which was why I undertook an in-depth habitat survey on 15 glides, 4 riffles, and 1 pool to see if I could get a representative view of the current stream conditions. As mentioned previously, in order to successfully survive in their freshwater habitat, coho need certain habitat and water quality parameters. Water temperature for incubation should be

between 4.4 and 13.3°C and for rearing between 9 and 14°C (McMahon 1983; Bjornn and Reiser 1991). Dissolved oxygen levels should be above 7 mg/L (Bjornn and Reiser 1991), spawning substrate should be between 1.3 to 10.2 cm in diameter with fines or substrate 6.4 mm and less composing less than 15% of the substrate (McMahon 1983), and lastly, cover because it offers protection from predators and high water velocities.

Water temperature and dissolved oxygen levels were within the recommended coho spawning and rearing ranges. Additionally, temperature data collected by Chris Arp of the USGS for Goose Lake, the upper and lower sections of University Lake, and East Chester Lagoon show that 2008 water temperatures within the Chester Creek lake system were within the recommended temperature ranges with mean temperatures of 8.9°C, 9.3°C, 10.1°C, and 9.5°C respectively and temperature HOBO's (HOBOWare™) placed at Eastchester Lagoon and off of Lake Otis Blvd between July and October also indicated that water temperatures were within recommended ranges, showing mean temperatures of 8.9°C and 9.7°C respectively. Still, stressful temperature levels have been observed. Temperature data collected by Anchorage Waterways Council volunteer monitors between 1999 and 2006 indicates that stressful water temperatures usually occur between June and September and in the downstream areas heading towards Westchester Lagoon (www.anchoragecreeks.org).

Mean dissolved oxygen levels collected during the inventory fell well above the recommended ranges. Dissolved oxygen data collected between 1999 and 2005 by the Anchorage Waterways Council indicate that oxygen levels are normally above the recommended 8 mg/L (www.anchoragecreeks.org). However, levels that fall below the recommended 8 mg/L have been recorded (www.anchoragecreeks.org). Dissolved

oxygen levels are affected not only by water temperatures but also by sewage and industrial effluents that can lower the solubility of oxygen in water (Slaney et al. 1996; Whitman 2002). Past studies by Brabets (1987), Whitman (2002), and the USGS (Glass and Ourso 2006) have all indicated that the creek contains excessive amounts of phosphorous and inorganic and organic elements, especially during spring run-off and the rainy season. While high nutrients may lead to the low oxygen levels recorded, no studies comparing these factors to one another have been done.

Average water velocity measurements fall between 0.31 m/s and 0.81 m/s, slightly above the recommended 0.30 m/s for the summer season and well above the .15 m/s for winter rearing (Nickelson and Reisenbichler 1977; McMahon 1983). Though no measurements could be found for the winter months, it's likely that velocity could slow during the colder months due to lower water flows. The high velocity measurements are not really surprising. As a highly modified urban stream, Chester Creek is relatively narrow and straight and in many areas has houses and other impervious surfaces built close to the stream banks. Surface runoff likely increases flow especially during August when Anchorage experiences its highest precipitation.

Overhanging vegetation averaged 56% for the glides and 73% at the pool, though it should be noted that at the 2 glides surveyed just past Muldoon, no overhanging vegetation was measured. Undercut banks averaged 15cm for both L and R glide banks, and 46 debris piles, 5 rootswads, 124 boulders, and 334 woody debris were counted. Other than the canopy cover, 3 woody debris pieces, and the right undercut bank, no other cover was found at the pool. For riffles, the Wolman pebble count indicated that only 13% of the substrate was composed of fines less than 6 mm,

however, the McNeil sampler indicates that 42.5% of the substrate is fines less than 6 mm. I tend to agree more with the McNeil sampler percentage than the Wolman pebble count as there's more of a tendency to pick up the larger, gravel sized substrate than the smaller, sand sized. Embeddedness was visually measured at 72%. Table 15 gives a comprehensive look at the results of the in-depth habitat survey.

Table15 – The results of the in-depth habitat survey.

Parameter	Glides	Pool	Riffles
Depth (m)	0.3	0.3	0.3
Velocity (m/sec)	0.5	0.2	0.7
Temperature (°C)	9.6	7.1	9.2
DO (mg/L)	11.5	12.3	11.7
Canopy Cover (%)	56	73	N/A
Undercut Banks (cm)	15	15 (RB)	N/A
Boulders	124	0	N/A
LWD	334	3	N/A
Debris Piles	46	0	N/A
Rootwads	5	0	N/A
Wolman Pebble Count	N/A*	N/A*	13% < 6 mm
McNeil Sampler	N/A*	N/A*	42.5% < 6 mm
Embeddedness (%)	N/A*	N/A*	72%

*N/A – Not Available

While I would tend to agree with the results from the HLFM stating that winter is limiting the coho population, my observations during the in-depth habitat survey would lead me to disagree. I believe that the actual limiting habitat in Chester Creek is the spawning habitat. While 4.8 kilometers of Chester Creek is composed of riffles, habitat

preferred for spawning salmon (McMahon 1983; Bjornn and Reiser 1991; Sandercock 1991; Quinn 2006), much of it is badly degraded, especially heading downstream towards Westchester Lagoon and the spawning habitat upstream past the Muldoon area is extremely hard, if not impossible, for the adult spawners to get to due to a beaver dam (Myers, personal communication). The pool-riffle sequence favored by coho for spawning redds (Bjornn and Reiser 1991; Sandercock 1991) is practically non-existent in the stream. The pool-riffle sequence allows for water to circulate downwards into the gravel to the eggs, bringing in fresh oxygen and removing any waste products before they can accumulate (Bjornn and Reiser 1991). However, if the substrate contains a significant amount of fine material, the fines settle into the interstitial spaces, reducing the amount of water flow and oxygen that can get into the redd and allowing waste products to accumulate. As shown in Table 14, results from the McNeil sampler indicate that around 42.5% of the substrate is composed of fines 6.4 mm and less. To give an idea of how substrate can affect the mortality rate of embryos and alevins, Philips et. al. (1975) showed that if fines 3 mm or less composed 20% of the substrate, the emergence rate of alevins is 65%. If they make up 30% of the substrate, the emergence rate is 40% and if they make up 70% of the substrate, the emergence rate drops to 8%. By looking at the substrate data collected by the McNeil sampler, fines 3 mm or less make up an average of 31%, meaning that approximately 40% of the eggs laid in the substrate will hatch as alevins and emerge as fry. So if I use the HLFM reduced surface area carrying capacity estimate of 36,431, according to the 1998 back calculations, around 1.8 million eggs will need to be laid in order to reach the stream's

carrying capacity. However, if I apply the Philips et. al. (1975) study, then out of the 1.8 million eggs laid only 720,000 of them will emerge from the redd as fry.

Unfortunately, degradation of urban salmon streams is not unusual. As urban areas grow, so do impervious surfaces, which do not allow excess water to soak into the ground and slowly trickle back into the stream via the water table but instead allow excess water, and anything in the water, to flow directly back to the stream. Roads especially are considered good conduits for putting excess sediments into streams (Meghan and Kidd 1972). The increased amount impervious surfaces lead to floods occurring more frequently and higher flows, which causes excessive bank erosion and scours or deposits the sediment on the streambed (Wang et. al. 2001), which can expose salmon eggs to the elements or smother them. May et. al. (1997) noted that the larger stream flows of urban areas tend to increase the amount of fine sediment that is normally washed downstream. Research done by Whitman (2002) indicates that the flood intensity for Chester Creek has increased as the urbanization of the Chester Creek watershed increased. Studies by Furniss et al. (1991), Arnold and Gibbons (1996), and Wear et al. (1998) all indicate that human activities can also increase the amount of fine sediments that are put into a stream.

When the stream capacity to transport these excess sediments is exceeded, the stream will usually respond by depositing the extra sediments in areas of low energy, such as sides of channels (side bars), and the backs of eddies and pools, areas where salmon usually select to incubate their eggs (Jackson and Beschta 1982, McHenry et al. 1994). Excess sediments on the spawning gravels can cover the eggs, lowering oxygen levels, reducing waste transport, and even physically trap alevins in the

sediment so that they can't emerge (Sandercock 1991; Bjornn and Reiser 1991, McHenry et al 1994).

During both the habitat survey and the inventories, it was noticed by all the observers that the stream bank was highly eroded in many places and several plausible explanations were considered. In many places, the Chester Creek trail runs next to the creek, allowing easy access to the water for runners, bikers, etc. Footpaths along water's edge were often observed. Construction, especially between A Street and the Seward Highway, was occurring during the habitat inventory and there were few, if any, preventive measures taken to keep exposed sediment from these sites from running into the stream. It was in this area that we measured the highest percentage of fine sediment and embeddedness. Many small storm culverts that drain the excess water from rain and snow events were observed leading into the stream. And finally, in many places, residential homes were built close to the stream banks and the natural buffer zone and flood plain were replaced with lawns.

The results from this study should provide a basis on where rehabilitation efforts should focus now that the weir at Westchester Lagoon is gone. The first improvement done should be to add more large woody debris into the stream, allowing for deep pools to form in the channels which would create some much needed winter habitat. It is suggested that there be 2 pieces of woody debris for every bankful width and while 337 pieces were counted during the in-depth habitat study, most of them were counted in the greenbelt area located between Lake Otis and Northern Lights. Subtracting those glides, an average of 10 pieces of woody debris was counted per glide. Whitman (2002) noted a lack of woody debris during his study of Chester Creek. Davis and

Muhlberg (2001) counted 10 pieces of woody debris on 8 of their 10 reaches. Woody debris added to the North Fork Porter Creek in Washington showed that as pool surface area increased, so did the winter population of juvenile coho (Cederholm et. al. 1997). However, the problem with adding woody debris to a stream is that home owners that live next to the creek tend to remove it in an attempt to beautify the stream. As a personal observation, I noticed that much of the large woody debris that had been present before the yearly stream clean-up had been removed from several of the sites in which the in-depth habitat survey took place. The second rehabilitation effort should be to examine the culverts that channel the stream. Whitman (2002) identified 10 culverts on the south fork that could restrict access to additional habitat for coho salmon less than 55 mm in length. The ADFG fish passage inventory indicated a number of red flagged or non-passable culverts on the south fork of Chester Creek (http://gis.sf.adfg.state.ak.us/culvert_IMFviewer.htm) In addition, many of the culverts seen while walking the stream were found to be partially blocked by debris or several feet above the water or had water exiting at a high velocity, all conditions which can make fish passage to other habitats extremely difficult in some places. Culverts can also block the downstream movement of large woody debris that can create suitable pool habitat for juvenile salmon which can account for the lack of woody debris at some of the sights. Another rehabilitation effort to consider is dismantling the beaver dam above Muldoon. While walking the creek this summer, Rusty Myers noticed that the beaver dam was so large that the fish could not get past it to get to the spawning grounds upstream (R. Myers, Personal Communication). It was also at this site

approximately 50 adult salmon were found on the banks dead, most likely due to illegal fishing practices.

One of the most difficult aspects of the rehabilitation work will be to improve the degraded state of the spawning grounds, which will support the rehabilitation at the creek mouth and improve the survival rates of the eggs and embryos. Unfortunately, restoring the creek's spawning grounds is not really a practical idea because of the cost and the time requirement. Whitman (2002) suggested maintaining and improving upstream spawning grounds, especially in the Fort Richardson area while focusing on the improvement of the rearing and overwintering habitat in the lower reaches.

I emphasize that once Chester Creek's carrying capacity for its' current state has been reached, the addition of more coho salmon into the system will not increase the number of smolts turned out. Increases in the coho population will come through habitat rehabilitation and habitat rehabilitation projects often fail because there is a lack of understanding on where the true problems lie and the factors that are affecting the population (Nickelson et. al. 1992). In order to successfully manage a population of wild coho salmon in any stream, Nickelson et. al. (1992) indicate that there are three main points that need to be addressed: one, what is the current carrying capacity of the stream for the salmon; two, what habitats and their limiting factors are critical to the survival and sustainability of the salmon in the stream; and three, what is the status of the habitat quality. Once these have been addressed, then rehabilitation efforts can be better planned, implemented, and monitored (Nickelson et. al. 1992).

What is the carrying capacity of Chester Creek in its' current state? Based on the calculations from the HLFM (Nickelson 1998) and Marshall and Britton (1990), I believe

the current habitat of the South Fork Chester Creek can support between 25,000 and 30,000 coho smolts, however, due to the substrate condition, I think the actual number of smolts produced will be far less (Philips et. al. 1975; McMahon 1983). The HLFM indicates that winter habitat should be considered the critical habitat, which makes sense since winter in Alaska seems to be when stream flows are lowest (Milner and Petts 1994; Murphy et. al. 1997; Anderson and Hetrick 2004) and habitat normally available in the spring and summer will dry up or become inaccessible during winter months. In addition, the sediment samples collected using the McNeil sampler and the estimated percent embeddedness at the in-depth surveyed sites suggests that spawning habitat could be another possible limiting factor to the smolt population since much of the likely areas for spawning have been degraded due to sedimentation and urbanization.

My goal for performing this project was to determine the potential carrying capacity for Chester Creek and what habitat is limiting their numbers. The estimates that were calculated by the HLFM (1992) tended to be on the high side but there are 2 possible reasons for that. One is that the calculated surface area used was too great. For the reduced surface area calculations, the three lakes surface areas were cut down so that only the area from the shoreline to 5 meters out were used but that could be a generous estimate. It could be that coho fry will only use less than 5 meters. And secondly and more importantly, the HLFM was designed for use in coastal Oregon streams. The fish per m² that an Oregon stream can support might be too high for what an urban stream in Anchorage, Alaska can support. However, since carrying capacity studies are not yet common in Alaska and I could not locate any data on fish per m² for

Alaska urban streams, the HLFM and Oregon centered data was the best available data I had to use.

While water quality data was collected, it was used more to help determine the amount of fish the creek can support rather than to determine whether or not the habitat is truly livable. Water quality data is, unfortunately, a component that my project and many other carrying capacity projects do not delve deeply into and it is only in the last decade that researchers have begun to understand how important the water quality is to the successful restoration of salmon populations in urban streams. A good example of this took place on the Longfellow Creek located in Seattle, Washington, one of the many urban streams in the Pacific Northwest that have been the focus of intensive restoration work in hopes of increasing their dwindling salmon populations (McCarthy et. al. 2006). Because salmon were returning in greater numbers to spawn in the rehabilitated habitat, the restoration work was considered a success until field biologists with the Wild Fish Conservancy began to notice that salmon in the stream exhibited erratic behavior and had an unusually high pre-spawning mortality rate, despite their healthy appearances (McCarthy et. al. 2008). A five-year investigation has suggested that the pollution from nonpoint source stormwater run-off was the cause, however, whether it is one pollutant or a combination of many was still under investigation as of 2008 (McCarthy et. al. 2008).

While I did not measure any other water quality parameters other than dissolved oxygen and temperature readings, its importance in the role of salmon habitat should not be overlooked. Suspended sediments can cause fry to display avoidance behaviour for the area (Bisson and Bilby 1982). Excess phosphorous and nitrogen can cause

algae blooms that can cause dissolved oxygen levels to drop to dangerously low levels and cause fish kills. In fact, Davis and Mulberg (2001) found that levels of phosphorous and nitrogen in Chester Creek increased going downstream and were significantly higher than what is normally found in Alaska streams. Whitman (2002) found levels of phosphorous exceeding the EPA's recommendation of 0.04 mg/L at his downstream cross-sections. This leads into the discussion that even if the physical habitat is successfully rehabilitated, water quality may limit coho abundance. However, like the spawning grounds, improving water quality is an issue that will most likely be expensive and time consuming, as many of the sources of the pollution are non-point sources, such as from cars and roads, and much of the land around the creek is privately owned.

This project answers two of the three criteria Nickelson et. al. (1992) put forth in order to successfully manage and increase a wild salmon population. This then leaves the door open for future work on the water quality data collection, something that is seriously lacking on the South Fork Chester Creek. It also leads into more questions and projects, such as where do the fry overwinter, what areas of the stream do the fry rear in during the spring, summer, and winter, what is the current smolt population, and where are current and historical spawning areas located.

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Appendix A. Habitat Limiting Factor Model Equations

Appendix A is an explanation of how the carrying capacity numbers (Tables 8 & 20) were obtained using the HLFM (Nickelson 1998). The equations can be found on pages 27-29.

Table A-1 – The surface area (m²) of the individual habitat types identified and surveyed on the South Fork Chester Creek and used in the Habitat Limiting Factor Models. Surface area 1 is the total surface area of all of the habitat types while surface area 2 is area of the glides, riffles, and pools plus the adjusted surface area of the lakes using only the area from the shore to 5 meters out.

	Surface Area 1 (m²)	Surface Area 2 (m²)
Glides	52,043	52,043
Riffles	21,838	21,838
Pools	2,739	2,739
Lakes	<u>397,393</u>	<u>33,057</u>
Total	474,013	109,677

Tables A-2 and A-3 and the following equations show how the population estimates and the back calculations were calculated for the Habitat Limiting Factor Model for Surface Area 1 (Table A-1).

Table A-2 – The estimated potential population abundance by season calculated by multiplying the individual habitat's surface area by habitat specific densities (Table 4).

	Spring	Summer	Winter
Glides	94,196	40,072	6,245
Riffles	26,204	2,620	218
Pools	3,533	4,766	959
Lakes	<u>1,017,331</u>	<u>397,395</u>	<u>397,395</u>
Total	1,141,262	444,849	404,816

Table A-3 – The estimated smolt population thru the coho's freshwater lifestage by multiplying the density independent rates (Table 5) by the estimated potential population abundance calculated above.

Spring Summer Winter

524,981 320,291 364,334

Potential Smolt Density (C; fish/m²):
 $C = 320,291 / 474,013 = 0.68 \text{ fish/m}^2$

Egg to Summer Survival Rate:
 0.072

Survival to Smolt (S_{smolt}):
 $S_s = 0.072 * 0.43 = 0.03$

Overwinter Survival (S_{ow}):
 $S_{\text{ow}} = .1361 * \ln.68 + .487 = .43$

Egg Deposition (D_m):
 $D_m = 320,291 / .03 = 10,676,366$

Minimum Number of Spawners (A_m):
 $A_m = (10,676,366 / 2,500) * 2 = 8,541$

Potential Adult Production (PPx):
 10% = 32,029
 5% = 16,014
 3% = 9,608

Tables A-4 and A-5 and the following equations show how the population estimates and the back calculations were calculated for the Habitat Limiting Factor Model for Surface Area 2 (Table A-1).

Table A-4 - The estimated potential population abundance by season calculated by multiplying the individual habitat's surface area by habitat specific densities (Table 4).

	Spring	Summer	Winter
Glides	94,196	40,072	6,245
Riffles	26,204	2,620	218
Pools	3,533	4,766	959
Lakes	<u>84,626</u>	<u>33,507</u>	<u>33,507</u>
Total	208,559	80,515	40,479

Table A-4 – The estimated smolt population thru the coho's freshwater lifestage by multiplying the density independent rates (Table 5) by the estimated potential population abundance calculated above.

Spring Summer Winter

95,937 57,970 36,431

Potential Smolt Density (C; fish/m²):

$$C = 36,431 / 474,013 = 0.33 \text{ fish/m}^2$$

Egg to Summer Survival Rate:

0.072

Survival to Smolt (S_{smolt}):

$$S_s = 0.072 * 0.34 = 0.02$$

Overwinter Survival (S_{ow}):

$$S_{ow} = .1361 * \ln.33 + .487 = .34$$

Egg Deposition (D_m):

$$D_m = 36,431 / 0.02 = 1,821,550$$

Minimum Number of Spawners (Am):

$$A_m = (1,821,550 / 2,500) * 2 = 1,457$$

Potential Adult Production (PPx):

$$10\% = 3,643$$

$$5\% = 1,822$$

$$3\% = 1,091$$

Appendix B – Photographs

Figure B-1 – Salmon fry photographed in one of the side pools just above Lake Otis Parkway.



Figure B-2 – The culverts taking the water under Lake Otis Parkway to Hillstrand Pond. Note the extremely high velocity in which the water is exiting the culverts.



Figure B-3 – One of the many trails leading down to the water's edge. Many of the trails leading to the water were devoid of vegetation, allowing for more fines to find their way into the water.



Figure B-4 – An example of how embedded the streambed is in some places, especially heading towards the more urbanized, downstream area.



Figure B-5 – An example of one of the debris piles found in Chester Creek. These debris piles were often a combination of large woody debris and garbage that had been thrown into the waters. Debris piles can create pools and slow water habitat for juvenile coho but if they grow large enough, they can impede a salmon's progress to upstream spawning grounds or downstream migration.



Figure B-6 – One of the many channelized portions of the South Fork Chester Creek. This one is located behind the APU campus and is approximately 200 feet long. There is no woody debris or slow water habitat for coho to use.

