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Evaluation of a Method for Removing Iron Floc to Restore Anadromous Fish Habitat in Duck Creek, Alaska

by

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Problem

Duck Creek is a highly impaired waterbody in Juneau, and is one of numerous surface waterbodies in Alaska that are impaired by urban runoff from non-point source pollutants. The State of Alaska identified Duck Creek as being water quality-limited because of low dissolved oxygen (DO), excess debris, metals (iron), fecal coliform, and turbidity (ADEC 1998). EPA has completed TMDLs on Duck Creek for turbidity (December, 1999), debris (September, 2000), fecal coliform bacteria (December, 2000), and dissolved oxygen and iron (October, 2001) (USEPA 2001). The primary source of iron in the stream is groundwater inflow. Much of the Mendenhall Valley, through which Duck Creek flows, is underlain by glaciomarine deposits that are high in iron. As the groundwater flows through these deposits, it picks up iron which ends up in surface waters. When the dissolved ferrous iron (Fe^{2+}) is exposed to the air in surface waters, it is oxidized to ferric iron (Fe^{3+}) and precipitates as Fe^{3+}oxyhydroxides; the process consumes oxygen and results in an orange-colored precipitate (iron floc). In addition, iron bacteria incorporate dissolved iron into their metabolic processes forming ferric iron (Fe^{3+}) which is insoluble. This insoluble ferric iron is surrounded by filamentous bacteria colonies that create a sticky orange slime which blankets the substrate.

The contribution of low DO from groundwater is compounded by the high dissolved iron content of the groundwater and the iron floc. Blanketing of the substrate by the iron floc impairs the exchange of surface water with intragravel water thus keeping DO levels low. Several reaches in Duck Creek, particularly the headwaters near Taku Boulevard and the East Fork, have visible groundwater seeps and heavy formations of iron floc. As the Mendenhall Watershed has developed, land disturbances and stream channel disturbances have reduced stream flow and the filtering capacities of the peat soils and vegetative cover. Water quality in most of the stream has been severely impacted by the iron floc and anadromous salmon and trout have been directly impacted by the low DO, the elimination of macroinvertebrates (i.e., food source) and the covering of available spawning and rearing habitat.

Background

Efforts to restore Duck Creek have been underway for several years by the Duck Creek Advisory Group and the Mendenhall Watershed Partnership involving both agency and community stakeholders. A Duck Creek Watershed Management Plan (Koski and Lorenz 1999) identified the problems and recommended projects to restore water quality and anadromous fish habitat. Iron floc was identified as a major problem that needed attention and several ideas for controlling the iron floc were recommended. In compliance with the Clean Water Act, EPA established a TMDL for dissolved oxygen and iron in Duck Creek to comply with Alaska=s water quality standards. Because DO and iron impairments in Duck Creek are related and are primarily the result of the groundwater source, a loading capacity and allocation for iron was developed for the stream. EPA calculated an iron loading capacity of 0.27 ton/yr and a load allocation of 0.27 tons/year which represented a reduction (93 percent reduction) of 3.87 tons/year in order to attain water quality standards for iron and DO under low flow conditions (EPA 2001). EPA recommended that ideas in the Duck Creek Watershed Management Plan for controlling iron be followed. Thus, this study was implemented to develop a method for controlling iron floc as recommended by the Plan and EPA=s TMDL. The project was conducted in the headwaters of Duck Creek above Taku Boulevard where the highest concentration of iron floc existed in the main channel of the stream.

Location

Duck Creek is one of several streams located within the Mendenhall Valley watershed in the City and Borough of Juneau, Alaska (Figure 1). The stream is about 5 km long and its watershed and hydrology have been described in detail by Beilharz (1998). The watershed area of Duck Creek is primarily within the floor of Mendenhall Valley, typical of small, low gradient, valley bottom streams of southeast Alaska. Because of urban development and the lack of distinct ridges in the topography, the watershed boundaries were not easily identified. Based on Beilharz (1998) the current drainage is 1080 acres, or 1.7 square miles in size, a reduction of about 50% from the 3.42 square miles mapped in 1969 (McConaghy 1969). In addition to a decreasing watershed, wetlands have declined by at least 60% (Adamus et.al. 1987) and at least 36% of the area is classed as impervious. Development continues and at least 7,000 people now reside in the Duck Creek watershed. The watershed extends from the recessional glacial moraine north of the Backloop Road, east to a divide with Jordan Creek, west to mid-valley, and south to the Mendenhall River near the airport (Figure 2). The highest elevation in the watershed is about 60 feet above sea level, and the lowest is at sea level. The study site just above Taku Boulevard is south of the terminal moraine and is in a 178 acre subbasin that drains into the mainstem of Duck Creek. The area is densely developed with houses but is bordered in part by a city greenbelt from just above Taku Boulevard to Duran street.

The chemical quality of water in the Mendenhall Valley varies with source and location. Generally, surface water is soft and of good quality; ground water, however, is of poor quality, is moderately hard, and contains iron. The amount of iron taken into solution may be related to the amount of organic materials in the sediments and possibly to the length of time water has been moving the subsurface rocks. Groundwater obtained from the northeastern side of the valley contains less iron than water from the central part of the valley (Barnwell and Boning 1968). The Mendenhall Valley floor is composed of fluvially deposited material overlying old marine sediments (Conner and O=Haire 1988). At the upper reaches near Taku Boulevard, it flows through soils derived from glacial till. These soils contain many rocks and cobbles. In the middle reaches it flows through soils that are predominantly silts overlying sands. Near the lower end of the creek, it flows through silty material overlain by gravel. The ground water chemistry reflects the reactivity of the materials it flows through. The source of the iron can be from the weathering of the granodiorite and similar rocks that are common in this area or from the marine sediments that underlay the regolith. Development in the Valley including excavation and fill has redirected both surface and ground waters. Consequently, Duck Creek now has reduced flow and relatively high iron content in both surface and ground waters. The iron enters the stream in ground water, floc formation being clearly evident at seeps along the streambank, particularly in the Taku and Mendenhall reaches of the stream (Figure 3).

The iron floc is of concern because it reduces DO, increases turbidity, covers the substrate, is toxic to some invertebrates and degrades estuarine habitat downstream. Historically, Duck Creek had relatively good populations of salmonids, but now has only remnant wild populations including pink (*Oncorhynchus gorbuscha*), and coho (*O. kisutch*) salmon, cutthroat trout (*O. clarki*), and Dolly Varden char (*Salvelinus malma*). The once abundant native chum salmon (*O. keta*) are now extinct.

Methods

Efforts to remove iron floc on Duck Creek have involved the creation of a wetland within a tributary to cap and filter iron (Koski and Lorenz 1999) and the use of plants to immobilize iron in the root rhizosphere (Stahl 1999). This project focused on developing a mechanical method of reducing or controlling the iron floc in the upper reaches of Duck Creek. The initial proposal incorporated oxidation-sedimentation-filtration as a means of controlling the iron floc similar to one of the concepts described by (Bar 200_). Our plan called for the use of aerators to increase the rate of iron floc oxidation and precipitation, to allow sedimentation of the floc in a streambed basin or vault, and then to collect the floc by pumping to a streamside filter mounted on a trailer. Preliminary studies at the site, however, indicated that most of the dissolved iron in the ground water had oxidized and precipitated as iron floc once it reached the surface waters of the stream because of sufficient dissolved oxygen. Consequently, our efforts refocused on ways to collect and remove the oxidized iron floc from the stream. In the process of developing this concept, we found a new product manufactured by Streamside Systems, Inc. that was designed to collect sediment as it moves naturally downstream with streamflow. We believed this device would also work for iron floc and would simplify the installation of equipment and not disrupt the streambed as much as our original design.

The Streamside System, Inc., device consisted of a 48"x 48" Series II Contractor Collector w/o prescreen, constructed of 11 ga stainless steel with a 2" suction pipe (Figure 4). The Collector was set flush with the stream bottom and with the attached wings spanned the width of the stream. The Collector was configured similar to a flume with a small trough in the center to collect sediment or iron floc as it moved naturally downstream with the current (Figure 5). A 2 hp motor driven diaphragm pump controlled with a variable speed controller was connected to the Collector with a 2" suction hose. The iron floc was pumped through a 2" discharge hose to a sediment dewatering bag (i.e., filter) with 100 micron mesh to retain the iron floc (Figure 6). The water was routed back to the stream via the culvert. The programmable controller allowed the pump to run at specific or variable speeds, and to regulate the duration and frequency of pumping.

The Collector was installed in the stream in August, 2002 and evaluations were conducted in the fall, 2002, and in summer-fall, 2003. Several types of polyester cloth filters with apparent opening sizes ranging from 100-200 microns were tested in a variety of configurations to facilitate filtering and returning water to the stream. An 18 inch diameter x 10 feet long, plastic culvert worked best to hold the sediment dewatering bag and route water back to the stream (Figure 7). About 3' of the upper half of the culvert near one end was removed to facilitate installation and replacement of the filter bag .

The sediment dewatering bags selected for use were 6 feet long x 12 inches diameter made from nonwoven polypropylene with an apparent opening size of 0.150 mm (150 microns) and were purchased from Ten Cate Nolan (Mirafi Number 1160N and 1120N) and Ultra Tech International, Inc. (Ultra-PipeSock). The bags were constructed or modified with open ends and ties for attaching to the pump discharge hose and for closing the bag during operation. The ties also facilitated changing bags and removing the floc. Two bags were used to collect a sample of iron floc to determine the amount collected for a given time period. The bags were dried in an oven until all moisture was gone and the dry weight of iron floc determined.

Plastic standpipes (1 inch diameter x 36 inch length) with perforations 6-8" from the bottom were driven into the streambed and into areas of the floodplain with groundwater seeps (Figure 8). The concentration of dissolved iron and of dissolved oxygen were routinely sampled from the standpipes and from the surface water in the study reach during the period of evaluation.

Additional baselines for invertebrate fauna, salmon egg survival, and dissolved oxygen were developed for this study reach in 1996-97 as part of the Duck Creek Watershed Plan study approach (Koski and Lorenz 1999). The baselines at that time revealed very low concentrations of dissolved oxygen in the intragravel environment.

Results

The amount of iron floc that had precipitated from the groundwater in the Taku Boulevard study reach (Figure 9) was extensive because of the accumulation resulting from low streamflow and a widened channel that prevented flushing. Consequently, the iron floc depth in the reach ranged from a few inches in the riffles to about 24 inches in the pools. Total dissolved iron concentrations in the surface water at the Taku reach ranged from less than 1.0 to over 7.0 mg/l as shown in Figure 10 (Hoferkamp, unpublished data[1]). In earlier sampling at this reach, the total dissolved iron concentrations in surface water averaged about 10 mg/l (Beilharz 1998). The concentrations

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of dissolved iron from standpipes in groundwater seeps in the Taku reach ranged as high as 25 mg/l. Dissolved oxygen in surface waters in the Taku reach were typically below 6.0 mg/l. and averaged about 4.0 mg/l (Figure 11; Hoferkamp, unpublished data[1]) . Though the iron floc accumulations in the Taku reach resembled acid mine drainage, the pH of the surface water was not very acidic and averaged between 6.5 and 7.0.

The Collector was initially run with the pump cycling on every 10 minutes and running for 2 minutes at 1000 rpm. After many trials, it was determined visually that this time was not sufficient to remove the build up of iron floc. The pump was finally adjusted to run continuously for 24 h at 1200 rpm in order to demonstrate that the iron floc level around the Collector was being reduced. A method of quantifying the amount of iron floc covering the streambed in the study reach was not developed and only visual changes were noted.

The bags eventually clogged with the fine iron floc after about 5-6 days. A filter with a larger apparent opening mesh may have worked better but we were concerned about losing floc through to large of an opening. A filter made from an orange monofilament geotextile (i.e., Mirafi Dandy Pipe Sock) with an apparent opening size of 0.425 mm collected the heavier iron precipitate (Fe^{3+}) but passed the lighter floc.

The dry weight of iron floc collected from the sediment dewatering bags ranged from about 11 to 22 grams/hour. Under low flow conditions, the incremental flow for the Taku reach segment was estimated to be 0.158 cfs (EPA 2001). Based on this flow, it is estimated that the production of iron (Fe^{3+}) from the dissolved iron in surface water would amount to about 5.97 pounds/day as compared to the maximum rate of filtering at about 1.2/pounds/day (i.e.,22 grams/hour). Since all of the flow in the Taku reach is from groundwater, and all the visible seeps were relatively high in dissolved iron (Fe^{2+}), it is likely that the actual production of Fe^{3+} would be much higher than the 5.97 pounds/day calculated for surface dissolved iron. For example, if the dissolved iron (Fe^{2+}) in the groundwater was 15mg/l, there could be nearly 13 pounds of Fe^{3+} produced each day. Consequently, a more efficient collection and filtering system would be required to remove this quantity of iron floc.

A tributary entering a few feet below the Taku study reach from an adjacent subbasin without the glacial moraine had dissolved oxygen levels from 6.0 to 12.0 mg/l (Figure 10) and total iron concentration below 1.0 mg/l (Figure 11). The effects of the dissolved iron and floc on reducing the dissolved oxygen in intragravel water in the Taku reach is shown in Figure 12. DO was monitored in 1996 in the Taku reach for a baseline on salmon egg survival and the concentrations of DO varied from about 1.0 mg/l to about 4.0 mg/l.

The effects of the low dissolved oxygen concentrations and high iron concentrations in both the surface and intragravel waters have resulted in a nearly sterile environment in the Taku and

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Mendenhall reaches. Baseline data for these reaches on macroinvertebrates and salmonid egg survival confirm the detrimental affects of dissolved iron and low. A three-year baseline of the macroinvertebrate community in Duck Creek (1994-96) provided a strong dataset to evaluate the stream=s condition. The bioassessment metric scores and the almost total absence of EPT genera, indicated that Duck Creek and the site at Taku Boulevard were significantly impaired with respect to water quality (Milner 1997).

The capability of the spawning habitat to incubate salmon eggs was also developed as a baseline using Whitlock-Vibert incubation boxes. Boxes containing eyed coho salmon eggs were buried in several reaches of Duck Creek and two other streams in 1996 and 1998. Survival in all reaches of Duck Creek was 0 % in both years as compared to a range in survival from 27 % to 99 % for the other two streams. Survival of the eggs was directly correlated with the concentration of dissolved oxygen in the streambed (Koski, unpublished data[2]).

Discussion and Conclusions

In freshwaters, iron is an important nutrient for algae and other organisms. Due to its high abundance within the earth=s crust, iron is ubiquitous in all freshwater environments and often reaches significantly higher concentrations in waters and sediments than other trace metals (Vouri, 1995). However, high iron concentrations in fresh waters have long been considered a problem, particularly in domestic use and mining of iron-rich ores (Vouri, 1995). The mining of iron-rich ores has caused the degradation of many river ecosystems (Dahl 1963). Acid mine drainage that expose pyrite to weathering air, water, and microbial processes has been considered one of the mining industries toughest problems to solve (Smith 1997; Evangelou and Zhang 1995). Some iron deposit problems referred to as ochre, also occur in well water where the groundwater aquifers are formed mainly of sandy soils or organic muck soils usually with a pH of below 7.0 and in the absence of dissolved oxygen. These waters that contain dissolved iron with as little as 0.15-0.22 mg/l serve as raw material for slime production by iron bacteria and are considered a hazard for certain irrigation systems involving drippers (Bar 200_).

The accumulation of iron floc and slime in the upper reaches of Duck Creek is similar to the problems described above for acid mining and irrigation. Alaska=s listing of Duck Creek as an impaired waterbody is partially related to its high level of dissolved iron. Because dissolved iron is a source of oxygen demand, the dissolved iron in Duck Creek is also related to its listing as impaired for dissolved oxygen. For a perspective on the problem, the iron criterion in Alaska=s water quality standards is 0.3 mg/l of dissolved iron (USEPA 1996) compared to the 10.0 mg/l of iron found in the surface water of upper Duck Creek. Alaska=s dissolved oxygen standard for the growth and propagation of fish, shellfish, other aquatic life and wildlife states that: ADO must be

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greater than 7.0 mg/l in waters used by anadromous and resident fish. In no case may DO be less than 5 mg/l to a depth of 20 cm in the interstitial waters of gravel used by anadromous or resident fish for spawning@. DO values in the interstitial waters of Duck Creek in the upper reaches of Taku and Mendenhall Boulevard are consistently below the State standard, and values of DO in the surface waters fluctuate above and below the standard.

Currently the stream reach above Taku Boulevard has the greatest accumulation of iron floc and the most visible seeps of groundwater containing iron than any other site on the stream. The accumulation of iron floc and iron oxyhydroxides has significantly reduced the dissolved oxygen concentration in surface and intragravel waters and covered the substrate with a blanket of material effectively smothering nearly all invertebrate life and preventing survival of incubating salmon eggs. The reduction in streamflow which has prevented dilution and flushing of the iron floc is probably the primary reason for the current problem with iron in the upper watershed. Urban development has altered the hydrology of Duck Creek by reducing streamflow and redirecting groundwater. Natural upliff associated with glacier rebound has also affected streamflow in several streams in the Mendenhall Valley. Construction of roads, dikes, ditches, and stormwater conduits have changed the watershed boundaries of Duck Creek and adjacent sections of Jordan Creek and the Mendenhall River. In the Dredge Lakes above the Taku Boulevard reach, flood control and surface drainage systems designed to reduce flooding and divert water to a common outfall at Mendenhall River may have depleted the supply of water to Duck Creek=s headwater springs. Long-time residents report that discharge from headwater springs declined soon after a dike and surface drainage system was constructed in the Dredge Lakes area (Koski and Lorenz 1999). Based on the presence of abandoned channels and the narrative history of the area told by residents, until at least the 1950s significant flow into Duck Creek originated from drainage off Thunder Mountain. Consequently, the Duck Creek basin may have decreased in size by as much as 60 percent between 1940 and 1970.

The approach using the Streamside Systems Inc. Collector worked well in collecting the iron floc and pumping it to the dewatering bags; however, the dewatering bags required frequent changing or cleaning. The practicality of frequent cleaning or changing of filter requires a better filtration system. Bar (200_) recommends a sand filter in controlling iron floc in irrigation systems. Although from a practical viewpoint, cost would likely prevent a more elaborate filtering system from being installed and maintained. One of the problems confounding the evaluation of the approach used was the Alegacy@ of iron floc that had accumulated in the study reach. This accumulation of floc provided a continuous drift of floc downstream and into the Collector. To evaluate only the dissolved iron contribution to the iron floc, a crew of several people used water pumps and a suction dredge to flush and remove the accumulated floc in an area just upstream and downstream of the Collector. The 11-to 22 grams dry weight of iron floc collected in the filter bags was after this cleaning. Cost prevented cleaning the accumulated floc from the entire Taku reach (about 300 feet of stream channel) in order to obtain the best evaluation of the method=s efficiency.

Several options exist for continuing work to resolve the iron floc problem on upper Duck Creek.

Augmenting the streamflow as recommended by Koski and Lorenz (1999) would dilute the groundwater iron source and help flush the oxidized iron from the reach. The use of a sand filter or other type of filter that would allow the Collector to run continuously with little or no interruption should be investigated. Because the channel has widened from past development or sediment accrual, reconfiguring the channel to a much narrow one would increase water velocity and help flush the iron floc. Narrowing the channel, as is currently being done in the downstream Mendenhall reach, would allow the flood plain to be filled with material that might cap some of the groundwater seeps rich in dissolved iron. In addition, planting the riparian or flood plain with wetland and riparian plants capable of oxidizing iron at the root rhizosphere might also help to reduce the amount of dissolved iron reaching the stream. Research has shown that certain species of plants are capable of immobilizing dissolved iron (Stahl 1999; Wang and Peverly 1999).

Scientists working on Duck Creek conducted a project in 1996 to reduce the iron floc and improve water quality and fish habitat in the East Fork of Duck Creek by creating a wetland within an old borrow pit. Several borrow pits were excavated in Duck Creek in the 1950s as a source of gravel for development and the resultant ponds have attracted anadromous fish because of the warm groundwater. These borrow pit ponds have become important overwinter habitat for anadromous fish; however, high iron content and low DO in some of them have caused high mortality during the winter. As a pilot restoration project, one of the ponds was filled with soil and gravel, graded to a desired topography, topped with an organic layer of peat, and planted with native wetland plants. The concept was to cover the source of dissolved iron in the groundwater aquifer with fill material and use aquatic plants to filter sediment and iron floc from the water column. After several years of monitoring the wetland, the dissolved iron appears to be decreasing and the dissolved oxygen appears to be increasing. However, the iron in the stream is a complex issue confounded by development and alteration of stream hydrology.

Stahl (1999) has summarized the iron chemistry occurring in Duck Creek as follows. AThe iron in soil solution has a rather complex chemistry. The iron in marine sediments commonly exists as pyrite (FeS_2) in the +2 oxidation state. The iron can be released by acid dissolution of the pyrite. In the presence of oxygen the iron is oxidized to the +3 oxidation state. Depending on the type and concentration of the anions present, a number of minerals can precipitate. Common minerals are amorphous iron oxyhydroxide ($Fe(OH)_3$), goethite (FeOOH), and ferrhydrite ($Fe_5(O_4H_3)_3$). These all can precipitate due to the hydrolysis of water by the iron and do not have to be microbially mediated. The rates for these reactions are not large compared to the rates of oxidation in the presence of sulfur bacteria. *Thiobacillus* sp. can use the sulfur as well as the iron in pyrite as an electron source (Nordstrom, 1982). The iron is oxidized to sulfate. The iron can then either move through the ground water as Fe^{2+} or be oxidized to Fe^{3+}. The rate for the oxidation of Fe^{2+} to Fe^{3+} in the absence of bacteria is quite slow (Singer and Stumm 1970).@ According to Bar (200_), iron bacteria, mainly from the filamentous genuses such as *Gallionella Sp. Leptothris* and *Sphaerotilus* and less from the rod type, like *Psendomonas* and *Enterobacter*, when present in the water react with the ferrous iron (Fe^{2+}) through an oxidation process. This changes the iron form to ferric iron (Fe^{3+}) which is insoluble. The insoluble ferric iron is surrounded by the filamentous bacteria colonies and creates the sticky iron slime gel that clogs irrigation pipes and also covers the substrate in reaches of Duck Creek that have low stream flow.

The Fe $^{+2}$ ion is fairly soluble in water and can move through the ground water. Fe $^{+3}$ is highly insoluble and rapidly hydrolyzes water precipitating from solution as an oxide. The hydrolysis of water by Fe $^{3+}$ releases hydrogen cations which acid weathers surrounding minerals further releasing iron. The presence of iron deposits in the Mendenhall Valley surrounding Duck Creek provide potentially large amounts of iron sulfide minerals (Stahl 1999). The ground water with its load of iron from the weathering of the iron containing minerals drains into Duck Creek and the process can continue to occur.

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Figure Captions.

Figure 1. Aerial View of Mendenhall Valley Near Juneau Alaska.

Figure 2. Aerial View of Duck Creek and Taku Boulevard Reach shown at Northern Most Intersection that Crosses Stream.

Figure 3. Iron Seep Draining Into Duck Creek at Taku Reach.

Figure 4. Streamside Systems, Inc. ACollector@ before installation.

Figure 5. ACollector@ with Wings Installed in Duck Creek.

Figure 6. Type of Sediment Dewatering Bag Used to Filter Iron Floc.

Figure 7. Study Site at Taku Reach Showing Modified Plastic Culvert Containing Dewatering Bag.

Figure 8. Using Meter to Determine Dissolved Oxygen in Streambed Using Plastic Standpipes.

Figure 9. Accumulation of Iron Floc in Taku Boulevard Study Reach..

Figure 10. Total Dissolved Iron Concentrations (mg/l) from Surface Water in Taku Reach (TB2) Compared to Downstream Clearwater Tributary (TB1).

Figure 11. Surface Dissolved Oxygen Concentrations (mg/l) in Taku Reach (TB2) Compared to Downstream Clearwater Tributary (TB1).

Figure 12. Surface and Intragravel Dissolved Concentrations (mg/l) in the Taku Reach in 1996.