# Production Capacity Assessment for Summer Steelhead (Oncorynchus mykiss) Produced At the Hagerman National Fish Hatchery



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### **Executive Summary**

The Lower Snake River Fish and Wildlife Compensation Plan (LSRCP) has a mitigation goal of 13,600 summer steelhead above Lower Granite Dam for the Hagerman National Fish Hatchery (Hatchery). The Hatchery currently produces 1.45 million steelhead smolts to fulfill its role for this mitigation objective.

Although a number of factors affect the carrying capacity of a fish hatchery; water supply is the most critical. The water supply for the Hatchery has been declining at a rate of nearly one cfs per year from 2000 to 2006. Since the inception of the LSRCP steelhead program in 1985, the Hatchery has used a Flow Index of 1.2 as the recommended steelhead production capacity. The Flow Index is a carrying capacity criterion from *Fish Hatchery Management* (Piper et al. 1982), calculated by dividing weight of fish production (lbs) by flow (gallons per minute) and fish length (inches). In response to the declining water supply, the Hatchery conducted a review of current literature on carrying capacity recommendations for salmonid hatcheries to evaluate the Flow Index criterion. The literature review estimated an annual production potential range of 800,000 to 2.1 million smolts based on the March 2006 rearing conditions of 61 cfs of water, 200,000 ft<sup>3</sup> of rearing space, and a target smolt size of 4.5 fish per pound (fpp).

Because of the large range of production capacity estimates, the Hatchery conducted a Production Capacity Assessment (PCA) in Brood Years 2005 and 2006 to experimentally estimate production capacity. The PCA is a bioassay that determines maximum fish production by examining growth rate reductions. For the purpose of this study, the maximum production capacity for the Hatchery was estimated at the first point that steelhead growth was inhibited. The PCA bioassay estimated maximum production capacity at a Flow Index of 1.47 or 12.6 pounds/gpm. At the current water decline rate, a mathematically calculated Flow Index of 1.47 will be reached in Brood Year 2009 at a production water supply of 58 cfs and a maximum production of 1.45 million smolts at 4.5 fish per pound. In the interim, the Hatchery will continue its annual production goal with careful monitoring of smolt quality.

The Hatchery continues to monitor Dissolved Oxygen (DO) concentrations during peak loading. Influent DO has averaged 8.95 ppm and effluent DO has averaged 6.95 ppm for Brood Years 2004 and 2005 during peak loading periods. However, instantaneous DO levels have been recorded as low as 4.93 ppm. The Hatchery has preliminarily investigated the increased production potential of an oxygen injection or mechanical aeration system. Assuming an unlimited oxygen supply, the Hatchery could support 3 million smolts before the un-ionized ammonia criterion of 0.0125 would be exceeded.

The Hatchery Evaluation Team (HET) plans to further investigate total production capacity by evaluating the Smolt to Adult Return (SAR) of smolts reared in first-use production water to the SAR of smolts reared in third-use production water with Coded Wire Tags (CWT). This modification to the existing CWT program will conserve the existing evaluation goals, enhance the understanding of rearing capacities on SAR, and can be accommodated into the current tagging program at little to no additional expense.

#### Introduction

As described by the LSRCP, the mitigation objective of the Hatchery is to provide 13,600 adult summer steelhead above Lower Granite Dam for sport harvest and hatchery broodstock requirements. At this time, based on water availability, water temperature, and the current understanding of Hatchery carrying capacity, the Hatchery produces 1,450,000 steelhead smolts to the size of 4.5 fpp. To meet the mitigation objective at this production level, a SAR of 0.94% would be needed. SAR's of this magnitude are rarely realized, and then, only when optimum riverine and ocean conditions exist during the respective life histories of the fish (Table 1).

#### Fish Production

The Hatchery currently operates two outside fish rearing systems. The largest system is 66, 10' x 100' concrete raceways referred to as the Steelhead Raceways (37-100). The Steelhead Raceways are arranged in three decks of 22 raceways each. Water from the first deck is serially reused in the next two decks. In addition, the plumbing system allows for fresh water to be bypassed into the second and third deck of raceways. These raceways are dedicated to the production of steelhead for the LSRCP program. The second system of raceways is 12, 8' x 80' concrete raceways, referred to as the Trout Raceways (1-12), which receive single pass water. These raceways are operated to meet the needs of the Dworshak Reservoir Mitigation program. The two rearing systems are separate from each other and both were constructed during the Corps of Engineers' Hatchery remodel/expansion project in 1984. At the time of the remodel, the Trout Raceways were constructed to provide rearing space for Fish and Wildlife Service programs apart from the LSRCP steelhead program. During 2006, 24 older (circa 1950) 8' x 80' concrete raceways (13 – 36) were demolished due to their state of disrepair and lack of sufficient water supply.

The Hatchery receives eyed summer steelhead eggs in May and June from the Sawtooth, Pahsimeroi, and Clearwater Fish Hatcheries operated by Idaho Department of Fish and Game (IDF&G). During times of low steelhead returns to the Salmon River basin, eggs are obtained from the Oxbow trap operated by IDF&G. The eyed eggs are incubated in upwelling incubators and then transferred to tanks after hatching. The Hatchery has two nursery buildings with 60 tanks for this purpose. After the fish reach 100 fpp in late July and early August, those destined for marking are adipose clipped and Coded-Wire-Tagged (CWT) by the IDF&G. By mid-August, all of the steelhead fingerlings are ponded in the Steelhead Raceways for final rearing. Steelhead releases start in late March and continue until early May.

During the planning stages for the LSRCP program, a number of assumptions were used to calculate and model the Hatchery production requirements to meet the summer steelhead mitigation goal (Herrig 1990). Based on the initial model for the LSRCP steelhead program, the Hatchery would rear 2.7 million steelhead smolts at 8 fpp for a total production of 340,000 pounds with the assumption of a 0.54% SAR. However, once the steelhead production program was underway in 1985 in the new facility, the number of smolts produced was much lower than the original model estimates. The Hatchery averaged an annual production of 290,000 pounds and smolt release numbers ranged from 1.3 to 1.5 million at 4.5 fpp (Table 2). In addition to the

steelhead program, the Hatchery was expected to produce 100,000 lbs of rainbow trout to address other Federal mitigation or Tribal needs for resident fish. However, the water supply would not support that level of rainbow trout production concurrent with the steelhead production.

A review of the Hatchery's 1985 Operational Plan (Hagerman 1982) and the 1985 through 1988 Annual Reports, indicated a number of obstacles to achieving the production goal of 2.7 million smolts at 8 fpp. Most significantly, the relatively warm water temperature (59° F) accelerated fish growth, which made it difficult to hold growth back to meet the 8 fpp target size in April. It became apparent that with the increased growth rate, the total number of smolts produced within the available space had to be reduced. Hence, the Hatchery smolt size was adjusted to 4 to 5 fpp for an annual total of 1.3 to 1.7 million smolts at the Hatchery. During the Fiscal Year (FY) 1984 rearing season, the Hatchery reared 949,900 steelhead smolts to a size of 3.14 fpp, for a total weight of 302,468 pounds. It was noted in the Operational Plan that an epizootic of Bacterial Gill Disease occurred in the 3<sup>rd</sup> deck of the Steelhead Raceways at this production level. The following year the total steelhead production in the Steelhead Raceways was 1,131,570 smolts at 4.40 fpp and 257,100 total pounds with no reported disease incidence. The Hatchery plan was to gradually increase the number of fish per raceway to establish a safe carrying capacity. The goal was to achieve an annual rearing program of 340,000 pounds of steelhead smolts at a size of 4 to 5 fpp for a total of 1.3 to 1.7 million smolts at the Hatchery.

The Hatchery raised steelhead in both the Fish and Wildlife Service raceways (1-36) and the Steelhead Raceways (37-102) until 1987. During FY1987, a 36" pipeline was constructed to supply additional water from the Main Spring pool to the Steelhead Raceways. This pipeline corrected a deficiency in overflow from Springs 13 and 14 to the Brailsford Ditch intake structure. With the additional water supply, the steelhead production was reared entirely in the Steelhead Raceways in Brood Year (BY) 1987. From BY1987 until BY1993, steelhead smolt production ranged from 300,000 to 340,000 pounds and 1.4 to 1.6 million smolts (Table 2).

During the early history of the steelhead program, the rearing criteria used at the Hatchery was a maximum Flow Index of 1.5 and a recommended Flow Index of 1.2 as outlined in Piper et al. (1982). The recommended Flow Index of 1.2 ensures that average Dissolved Oxygen levels will be maintained above 5 ppm. These production criteria were maintained when an adequate supply of water was available; Greater than 60 cfs for a Flow Index of 1.5 and greater than 74 cfs for a Flow Index of 1.2 to meet the production goal of 340,000 pounds of 8.5 inch smolts (4 to 5 fpp). During the rearing of BY1993, the instantaneous Flow Index reached 1.76 due to a water call by the Brailsford Ditch Company, a senior water right holder on the Len Lewis Spring. They called for their full 18 cfs of water in March 1994 for irrigation. During this time, the Hatchery staff employed careful water management and manipulation of cleaning and feeding schedules to ensure fish health and survivability. Because of the uncertain future availability of the Brailsford Ditch Company water during the critical rearing periods, the Hatchery smolt production was decreased by nearly 25% to 1.15 million smolts in BY1994. The Hatchery continued at this production level until BY1998 when the Department of Justice reached a Court approved stipulated agreement with the Brailsford Ditch Company to secure the Hatchery's water supply between the beginning of the irrigation season (February 15) and early April at which time the hatchery loading would be reduced due to the fish being distributed off station.

During BY1994, the Hatchery reported epizootics of Enteric Redmouth (ERM) (*Yersinia ruckeri*) and Furunculosis (*Aeromonas salmonicida*). These epizootics occurred at relatively low production levels and a Flow Index of 1.04. The Hatchery suspected that draining of Bickel Spring to remove sculpins and excessive fish handling during rearing may have contributed to the susceptibility to these diseases. This disease episode provided an additional reason to keep the production at reduced levels in the face of uncertain water supplies from the Brailsford Ditch Company. Another factor which may be a confounding contributor to fish mortality is Nucleospora salmonis (NS) which is a microsporidian parasite that is present in the Hatchery's water supply. Very little is known about the etiology of this organism. It does cause pathological signs in fish, particularly the Clearwater stock of steelhead and the Hayspur strain of rainbow trout. Mortality results from this infection or from other opportunistic infections brought about from the suppressed immune systems of the affected fish. There is no known treatment for this pathogen.

In 1995, the *Proposed Recovery Plan for Snake River Salmon* by the National Marine Fisheries Service (NMFS 1995) recommended all steelhead released in the Snake River Basin be between 170 and 220 mm total length. That size range was established to reduce impacts of hatchery steelhead on listed salmon. Further data analysis by the IDF&G suggested that the maximum allowable size at release should be increased (Rhine *et al.* 1997). Based on this and other information, the NMFS modified their recommended steelhead size at release range to 180mm - 250mm total length in 1999 (NMFS 1999). Hence, from this point forward, the Hatchery targeted a smolt size of 4.5 fpp (220 mm).

After BY1998, steelhead production was slowly ramped up to 1.29 million smolts at 4.5 fpp. This production assumed a 1.05% SAR to meet the LSRCP goal of 13,600 returning adults. The Hatchery reared around 1.29 million smolts annually until BY2005.

During the Annual Operating Plan (AOP) meeting for BY2005, the LSRCP Cooperators transferred a 100,000 smolt commitment from the Magic Valley Fish Hatchery (MVFH) steelhead program to the Hatchery. These additional smolts raised the BY2005 Hatchery production goal to 1.39 million smolts. This change in production was necessitated by the precipitous decline in the spring water flow supplying the MVFH, which also receives its water supply from the Eastern Snake River Plain Aquifer (Aquifer). MVFH has experienced spring flow declines of 3.4 cfs per year from 1995 – 2005 (pers. comm. Rick Lowell). During the AOP meeting for BY2006, another 60,000 smolt commitment was transferred to the Hatchery from MVFH steelhead program. These additional smolts raised the BY2006 Hatchery production goal to 1.45 million smolts.

#### Water Supply

The Hatchery is located in the Thousand Springs Reach of the Snake River in south central Idaho. The water supply for the Hatchery emanates from the Aquifer through a complex of springs diverted for Hatchery operations. Under the administration of the Idaho Department of Water Resources, the U.S. Fish and Wildlife Service has surface water rights for 109.74 cubic feet per second (cfs) flow for fish propagation, irrigation, domestic use and stock water (Table

3). However, this is not an accumulative total because the Hatchery has multiple rights to several spring diversions with different priority dates and for different places of use or, in the case of Spring 16, subordinate to a senior user during the irrigation season (February 15 to November 30). Moreover, not all water sources can be diverted to all outside rearing units. Spring 17 is only plumbed to the Trout Raceways; Riley Creek and Bickel Spring Creek springs are only plumbed to the Steelhead Raceways. The priority dates for the Hatchery's water rights range from 1889 to 2002, the majority of which are in the early 1930's to 1950. Assuming the springs were flowing at the full water right, of the total, 84.59 cfs could be diverted for fish production at the Hatchery; and, another 4.6 cfs are diverted to operations at the Hagerman Fish Culture Experiment Station (HFCES). Water diverted to the HFCES is agreed to under a Memorandum of Understanding with the University of Idaho. Of the water available for fish production, approximately one cfs is diverted below the Main Spring pool to maintain habitat for the Bliss Rapids snail (*Taylorconcha serpenticola*), listed as Threatened under the Endangered Species Act.

During the later part of the last century, increased groundwater withdrawals, irrigation efficiencies and drought have combined to diminish the volume of water stored in the Aquifer. The University of Idaho Water Resources Research Institute reports that "the average rate of decline in ground water storage between 1975 and 1995 is about 350,000 acre feet/year" (Johnson et al. 1998). This diminished storage capacity has resulted in a decline in spring flows throughout the Thousand Springs Reach. In its 1995 Annual Report, the Hatchery reported that a review of flow data for the period of 1974 through 1994 for two of the Hatchery's spring sources, Riley Creek and Bickel Spring Creek, showed a decline in flow of 9.6% and 21.5%, respectively. At this time, the Hatchery's spring water winter supply (Dec – Mar, 2006) is approximately 14% (9 cfs) below its water right and has been declining at a rate of nearly one cfs per year from 1999 to 2006 (Figure 1).

#### Production Capacity

Because intensive fish culture can affect the growth, health, survival, and migratory ability of anadromous salmonids (Wedemeyer 1996), the Hatchery staff continuously monitors and evaluates the fish production program relevant to hatchery practices, fish health, rearing parameters and water supply. In the mid 1990's, in response to the water call by the Brailsford Ditch Company and the uncertainty of its water supply, the Hatchery staff established carrying capacity criteria for its steelhead rearing program (Table 4). The criteria are based on Flow and Density Index concepts from Piper et al. (1982). The Flow Index is a measure of the volume of water provided to a fish culture unit in relation to fish weight and length, whereas the Density Index is the amount of space within the rearing unit in relation to fish weight and length. These Indices are based on the current environmental parameters at the Hatchery; water temperature of 59° F, elevation of 2900 feet, 198,000 ft³ of rearing space in the 66 Steelhead Raceways, and a minimum of 5 ppm Dissolved Oxygen in the effluent of the third deck of raceways.

Rearing pond sanitation is also an important aspect of establishing and maintaining the Hatchery's carrying capacity. Periodic cleaning by sweeping the entire length of the raceway is necessary to physically remove solids from the raceways and the quiescent zones. This process diverts water and solids through standpipes into the Hatchery's pollution abatement pond.

Insufficient cleaning leads to accumulation of solids within the raceway and a subsequent increase in the biological oxygen demand. Cleaning too frequently diverts excessive amounts of water (and oxygen) from the system. Hatchery practices focused at either end of this spectrum can stress the fish and promote disease. To avoid these problems, and to allow for a margin of safety, the Hatchery staff have established a protocol which requires that only four raceways are cleaned concurrently and that pond cleaning activities occur on non-feed days.

Water management is a critical aspect of Hatchery operations when the steelhead smolts reach an average size of 15 fpp in December and continue to grow to their final stocking size of 4.5 fpp (180 - 250 mm) during March and April. The Flow Index continues to be the most critical component of the Hatchery's carrying capacity. At a production commitment of 1,450,000 smolts at 4.5 fpp, the mathematically calculated Flow Index is 1.35, approximately 11% above the recommended 1.2 level. However, the actual Flow Index is maintained at or about the 1.2 level by adjusting the growth rates for specific release groups over the six week distribution season to ensure not all fish reach the target size at release at the same time. Furthermore, the Hatchery has implemented Best Management Practices (BMP's) that manage biomass inputs/outputs and the subsequent demand on available oxygen. The implementation of these BMP's provides the Hatchery with a margin of safety at a critical period in the production cycle.

## Hagerman National Fish Hatchery Best Management Practices

- Fill demand feeders for only ½ of the production twice/week and the other ½ on two alternate days.
- Clean raceways only on days they have not been fed.
- Clean no more than 4 raceways at any one time.
- Maintain a target size at 4.5 fpp.
- Program fish growth to stagger peak loading and corresponding Flow Index over a six week distribution time frame in April and May.

#### Rainbow Trout Production

During the past 4 years, the Hatchery has diverted an average of 62 cfs to the Steelhead Raceways. The remaining water available for fish production is diverted from Spring 17 ( $\approx$ 3.0cfs) to the Trout Raceways and from Main Spring ( $\approx$ 1.0cfs) into nursery tanks for early rearing for the rainbow trout program. As stated earlier, spring 17 is only plumbed to the trout raceways. The Hatchery's current rainbow trout program is 90,000 fingerlings (5-inch fish) released in May and 40,000 catchables (9-inch fish) released in September. During early March, 90,000 fingerlings are ponded in the Rainbow trout raceways and utilize  $\approx$ 3.0 cfs available from Spring 17. At the same time, 40,000 fingerlings of the fall group are utilizing  $\approx$ 1.0 cfs diverted from the Brailsford Intake into the nursery tanks. If it was necessary to use more water for steelhead production, the spring production of 90,000 Rainbow trout fingerlings could be suspended and approximately 50,000 steelhead smolts could be reared in the Rainbow trout raceways with the flow from Spring 17.

In anticipation of a continued decline in Aquifer storage and the subsequent reduction in spring flow, the following analysis has been undertaken to assess the Hatchery's carrying capacity and

its capability to meet its fish production commitments in the future. This analysis will focus on the winter/spring season when the fish weight on hand is at its maximum in the outside rearing facilities.

#### **Methods**

The potential carrying capacity was determined by modeling loading equations described by Westers (2001) and Flow and Density indexes described by Piper et al. (1982). The indices were based on rearing parameters at the Hatchery: water temperature of 59°F, elevation of 2,900 feet, 198,000 ft³ of rearing space in 66 Steelhead Raceways, and a minimum average of 5 ppm Dissolved Oxygen (DO) in the effluent of the third deck of raceways. We conducted additional analyses using minimum DO concentrations of 5.5 ppm (60 % saturation) and 6.4 ppm (70% saturation) suggested by Westers (2001), and 7 ppm (80% saturation) recommended by Wedemeyer (1996). We also determined carrying capacity as a function of ammonia production by metabolic processes. To determine the ammonia concentration we estimated the total ammonia nitrogen generated per kg of feed (TAN<sub>F</sub>), the percent un-ionized ammonia (%UA), and the allowable maximum concentration of un-ionized ammonia (AUA). TAN<sub>F</sub> generally ranges from 20 to 30 g/kg (Westers 2001).

In addition, we conducted a PCA described by Meade (1989). The PCA method was modified to model the production conditions encountered at the Hatchery. Three linear plug-flow rearing tanks were used in a stepwise series to mimic the serial reuse design of the steelhead production raceways. Fresh water entered the upper tank and was serially reused through the middle and bottom tanks. Water flowed through the production section of the tank and then entered a quiescent zone before exiting a top-drain standpipe and draining to the next tank. No appreciable re-oxygenation occurred between tanks. Three replicates (3 tanks each) were used for the experiment.

The Flow Index for the experiment was calculated as outlined in Piper (1982). The Flow Index was cumulative across the upper, middle, and bottom tanks. The total weight of the middle tank included the middle and upper tank weights. Similarly, the total weight of the bottom tank included the bottom, middle, and upper tank weights. The permissible Flow Index was not increased between tanks because no appreciable re-oxygenation occurred between tanks.

BY2005 Sawtooth stock steelhead (n = 189) were acclimated to the experimental tanks with a flow of 10 gpm four weeks prior to the study. The experiment started on January 1, 2006 at a Flow Index of 1.14 and 0.12 Density Index, and continued for 14 weeks until April 17, 2006. The experiment was repeated in BY2006. Each rearing unit utilized 21 steelhead at 12.5 fpp. The upper tanks of the rearing units were supplied with 0.75 gpm of spring water for an exchange rate of 2.44 exchanges/hr. Steelhead were fed by hand daily at a Hatchery Constant of 7.50 so that projected growth would reach 4.5 fpp at a Flow Index of 2.0 and a Density Index not exceeding 0.2. Tanks were cleaned by siphoning twice per week and additional water was added to maintain flow to the subsequent tanks during cleaning operations.

Instantaneous DO concentration and temperature were recorded on Mondays and Thursdays one hour after feeding activities with a YSI 85 Dissolved Oxygen meter. Ammonia samples were taken once every two weeks and sent to Rangen Research Laboratory for analysis during Brood Year 2006. Growth rates were recorded every two weeks by group weighing steelhead from each tank in the rearing units. Changes in fish behavior, disease problems, and mortalities were noted daily. Growth rates by length, feed conversion ratios, and fish condition factors were compared at the end of the experiment between treatments (upper, middle, and bottom) and to Sawtooth steelhead raised in the outdoor production raceways. The steelhead were also examined by Kathy Clemens, Idaho Fish Health Center, for the prevalence of fish pathogens and parasites at the end of the experiment. All experimental fish were individually enumerated for lengths and weights at the conclusion of the experiment to determine average condition factors per treatment. Maximum production capacity was determined by examining growth reduction.

#### **Results and Discussion**

The production capacity models from and Westers (2001) and Piper et al. (1982) estimated between 41 to 68 cfs of water, respectively, would be needed to sustain the current Hatchery production while maintaining a minimum average DO of 5 ppm. This analysis assumed that water exchange rates could go as low as 2.24 exchanges per hour. The current water exchange rate is below the 4 exchanges per hour recommended by Westers and Pratt (1977). Density indices were not limiting in the analysis. Sample calculations are included in Appendix I.

Although more steelhead could be reared at the Hatchery using the estimated production capacity calculated by Westers (2001), the results should be interpreted with caution. The calculated estimates are drastically influenced by minimum DO concentrations (Figure 2). Several authors have suggested a wide range of acceptable minimum DO concentrations from 5 – 7 ppm (Piper et al. 1982, Westers 2001, Wedemeyer 1996). Although average DO concentrations of 5 ppm may be acceptable according to Piper et al. (1982), he also states, "In raceway systems, where large numbers of fish are cultured intensively, oxygen contents of the water should not drop below 80% saturation". A level of 5 ppm does not leave any margin of safety for pond cleaning activities, fluctuations in flow, or other unforeseen events. On the other hand, a minimum average DO outflow concentration of 7 ppm is likely too conservative and would be viewed by the commercial aquaculture industry as an inefficient use of the water.

Quantifying maximum production capacity can be contradictory because there is not a defined point that indicates when maximum capacity has been reached. However, the Flow Index of 1.2 and Density Index of 0.20 have been used at the Hatchery as quantifiable measures of production capacity with good success. The recommended Flow Index of 1.2 converts to an average DO concentration of 6 ppm using Westers (2001) modeling. An average DO concentration of 6 ppm falls between the recommendations given by other references (Figure 2). As Flow Index measures exceed 1.2 and minimum DO concentrations drop below 6 ppm, the Hatchery will expect to encounter difficulties in maintaining smolt quality. The Hatchery will continue to monitor the Flow Index and DO concentrations as the spring flows decline and observe how these factors affect fish quality.

Un-ionized ammonia does not appear to be a problem in the near future for the Hatchery. The loading equations from Westers (2001) estimated between 1.31 to 1.96 million smolts can be reared on the current water supply given total ammonia nitrogen generated per kg of feed  $(TAN_F)$ . However, observed un-ionized ammonia levels have been only 15% of the maximum allowable ammonia during the past five years. Furthermore, no fish health issues have been attributed to ammonia concentrations. Hence, modeling estimates may be conservative relative to the actual un-ionized ammonia levels.

Because modeling provides a large range of production capacity estimates, the PCA may provide a better estimate of the true carrying capacity. The results of the PCA experiment suggest that steelhead growth is unaffected up to a Flow Index of 1.47. A summary of the measured parameters of the PCA experiment are presented in Table 5. At the current rate of water decline, the mathematically calculated Flow Index of 1.47 will be reached in BY2009 at a production water supply of 58 cfs. The mathematically calculated Flow Index is derived using total annual stocking weight based on available water flow. The instantaneous Flow Index is lower than the mathematical Flow Index because the Hatchery's stocking schedule occurs over a 6 week period and the total weight of fish produced is never accumulated in all the Hatchery raceways at one time. The instantaneous Flow Index will reach 1.47 in BY2012 at a production water supply of 55 cfs. At this point, the Hatchery will be unable to manage the rearing program without detrimental effects on smolt quality.

Several obstacles may prevent maintaining the current Hatchery production levels in the face of declining water availability. Proposed phosphorus limits in the draft National Pollutant Elimination System permit (NPDES Permit 2006) have been reached at the current production levels during the months of March and April. To maintain production, the Hatchery may have to acquire additional phosphorous credits via pollution trading or modification of other Hatchery practices to meet the phosphorous effluent limits.

DO may be another obstacle to maintaining Hatchery production levels. DO concentrations must not fall below 6 ppm in receiving waters as specified in the Fact Sheet of the proposed National Pollutant Elimination System permit (NPDES Fact Sheet 2006). Throughout the PCA experiment, the effluent DO concentrations were routinely below 6 ppm (Figure 3). However, these measurements were purposely taken near the lowest daily DO concentrations. In the Steelhead Raceways, the Hatchery BMP's of feeding no more than half of the raceways on a given day (Hagerman HET 2006) improve effluent Dissolved Oxygen conditions. During March of 2005 and 2006, the Hatchery influent averaged 8.95 ppm DO concentration and the effluent averaged 6.75 ppm (Figure 5). Daily instantaneous DO levels for some samples were below 6.0 ppm to low of 4.79 ppm in the effluent from individual raceways. However, the aggregate discharge from the Hatchery never went below 6 ppm. The variation in minimum DO concentration may be reduced by modifying the Hatchery Feeding practices. The Hatchery may also want to consider DO supplementation strategies in the future (Appendix II).

An additional obstacle to maintaining Hatchery production levels is water loss during cleaning operations. The Hatchery should explore vacuuming cleaning systems rather than the current

method of flushing large volumes of water through standpipes. These systems could reduce the quantity of water diverted from the rearing system during cleaning.

#### Future Hatchery Monitoring and Evaluation

The ultimate goal of the Hatchery is to release smolts that produce the maximum adult steelhead return rates to meet the mitigation goals of the LSRCP. A balance is struck between smolt quality and quantity to meet the goal of maximum adult return. This balance is constrained by the water supply and existing infrastructure of the Hatchery. The maximum carrying capacity of the Hatchery should ultimately be determined by the differences in adult return rates from a low Flow Index (upper bank, first-use water) to a maximum Flow Index (bottom bank, third-use water). At this maximum carrying capacity level, the Hatchery will be operating at peak efficiency.

The HET has recommended a CWT evaluation study to assess SAR rates as the Hatchery water supply declines. The Hatchery rears smolts in serial reuse raceways with smolts in 1<sup>st</sup>, 2<sup>nd</sup>, and 3<sup>rd</sup> use water during peak production. The Hagerman HET hypothesizes that smolts in 3<sup>rd</sup> use water will exhibit diminishing SAR rates compared to smolts in 1<sup>st</sup> use water as established production capacities are exceeded due to the decline of the water supply.

The Hatchery currently tags 80,000 Sawtooth A-strain smolts with CWTs for release at the Sawtooth Fish Hatchery weir. The tags are split into 20,000 smolt groups in four raceways on 2<sup>nd</sup> use water to represent the "average" smolt produced on the Hatchery. These tags are used for IDF&G LSRCP Steelhead Fish Hatchery Evaluations.

The HagermanHET has recommended these tags be split into 40,000 smolt groups. One 40,000 smolt group will be randomly assigned to 1<sup>st</sup> use water (control group) and the other 40,000 smolt group will be randomly assigned to 3<sup>rd</sup> use water (experiment group). The statistical power of this experiment will be weak because of the few replicates. However, the use of the CWTs in this manner will incur little to no additional cost to the Fish Hatchery Evaluation program and will continue to represent the "average" smolt produced at the Hatchery.

The information gathered from this experiment may provide insight into the loading capacity effect on SAR's. This data could be extrapolated to estimate the cost/benefit analysis of increasing or decreasing the production goal at the Hatchery.

#### Hatchery Recommendations

- Maintain a production level of 1.45 million smolts despite declining water availability until the Hatchery reaches an instantaneous 1.47 Flow Index.
- Continue DO monitoring in production raceways.
- Explore alternate cleaning techniques and schedules to conserve production water.

- Conduct additional phosphorus discharge sampling throughout the heaviest loading months of March and April.
- Evaluate the affect of fish loading on adult steelhead return rates by differential CWT smolts in first-use and third-use production raceways.

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# **Tables and Figures**

Table 1. Sawtooth A-Stock summer steelhead Smolt to Adult Return (SAR) rates at the Sawtooth Weir from Hagerman National Fish Hatchery releases, 1993-2002 a

Release Year	ease Year Smolts Released					
2001	707,834	$0.64^{b}$				
2000	727,798	1.60				
1999	714,789	0.78				
1998	684,937	0.96				
1997	662,272	0.35				
1996	705,731	0.40				
1995	685,006	0.75				
1994	711,710	0.34				
1993	140,626	0.54				
Mean	637,856	0.72				
a Data collected from Harrington (2003 – In Press) reports b 3-ocean fish were not available for inclusion in estimate						

Table 2. Weight and number of steelhead stocked (All Stocks) from Hagerman National Fish Hatchery, BY1987-2006

			Steelhead					Fish
Brood	Wt. of fish			Water Flow			Production	
Year	(Pounds)	#/lb	Number	Inches	$(cfs)^1$	Index <sup>2</sup>	lbs/gpm	Water (cfs) <sup>3</sup>
1987	332,325	4.66	1,550,031	8.34	65.1	1.37	11.4	78.4
1988	299,425	4.94	1,478,830	8.18	74.2	1.10	9.0	80.5
1989	339,520	4.24	1,439,266	8.60	68.6	1.28	11.0	76.1
1990	325,550	4.41	1,436,909	8.49	70.1	1.22	10.4	75.5
1991	314,255	4.62	1,453,058	8.36	65.7	1.28	10.7	72.9
1992	308,520	4.82	1,487,842	8.24	62.3	1.34	11.0	69.2
1993	329,538	4.61	1,519,168	8.37	57.3	1.53	12.8	62.9
1994	243,182	4.74	1,151,544	8.29	63.0	1.04	8.6	68.7
1995	255,750	5.20	1,329,226	8.04	63.4	1.12	9.0	70.0
1996	247,194	4.69	1,158,658	8.32	64.6	1.03	8.5	76.1
1997	233,292	4.43	1,032,407	8.48	63.4	0.97	8.2	72.6
1998	238,805	4.67	1,131,409	8.33	61.5	1.04	8.7	70.3
1999	280,805	4.18	1,174,883	8.65	62.3	1.16	10.1	71.3
2000	274,644	4.48	1,229,286	8.45	65.9	1.10	9.3	75.1
2001	306,715	4.30	1,317,888	8.57	60.4	1.32	11.3	67.4
2002	295,090	4.29	1,265,544	8.57	62.4	1.23	10.5	68.6
2003	302,622	4.38	1,324,263	8.51	62.1	1.28	10.9	66.3
2004	302,845	4.22	1,279,273	8.62	62.4	1.26	10.8	67.7
2005	277,123	5.03	1,393,929	8.13	60.7	1.25	10.2	66.0
2006	336,248	4.35	1,461,422	8.53	60.9	1.44	12.3	66.2
Average	289,853	4.57	1,323,864	8.40	64.0	1.21	10.1	71.4

<sup>1</sup> Steelhead Water is production water available to the 66 steelhead raceways during March of each year 2 Flow Index is the mathematically calculated Flow Index using total stocking weight and available Steelhead Water

<sup>&</sup>lt;sup>3</sup> Fish Production Water includes the Display Pond and Trout Water and was estimated for Spring 17 for BY1987-1989

Table 3. U.S. Fish and Wildlife Service Water Rights at Hagerman National Fish Hatchery

Sping Name	IDWR No. Volume		Purpose	Priority Date		
Bickel Spring Creek	36-00128	2.00	Fish Propagation	01/18/1889		
Riley Creek	36-00130	1.50	Fish Propagation	01/18/1889		
Springs 11 & 13*	36-00132	6.00	Fish Propagation 6.0 cfs, Domestic 0.89 cfs, Irrigation 0.22 cfs; Stockwater 0.02 cfs	6/15/1910		
Bickel Spring Creek	36-15444	20.30	Fish Propagation	1/1/1933		
Riley Creek	36-15446	4.50	Fish Propagation	1/1/1933		
Spring (Main) & Springs 12,13, &14	36-15448A	11.43	Fish Propagation	1/1/1933		
Spring (Main) & Springs 12, 13, & 14	36-15448B	8.57	Fish Propagation	1/1/1950		
Spring 15	36-15449	4.50	Fish Propagation	1/1/1933		
Len Lewis Spring 16	36-15450	21.20	21.2 cfs for fish propagation during non-irrigation season and 8.0 cfs for fish propagation during irrigation season.	1/1/1950		
Spring 17	36-15451	4.59	Fish Propagation	1/1/1959		
Springs 8 & 9*	36-00131	1.00	Fish Propagation	6/15/1910		
Springs 8 & 9*	36-15447	0.50	Fish Propagation	1/1/1966		
Spring 10*	36-00129	1.00	Fish Propagation	01/18/1899		
Spring 10*	36-15445	0.60	Fish Propagation	1/1/1966		
Springs 8, 9, & 11*	36-08354	1.50	Fish Propagation	5/6/1988		
Groundwater	36-08750	0.04	Domestic (Year-round)	3/13/1996		
Bickel Spring & Riley Creek	36-15961	20.55	Fish Propagation (5/6 to 6/19)	11/19/2001		

<sup>\*</sup> Water diverted for use at the University of Idaho, Hagerman Fish Culture Experiment Station includes Spring 8, 9, 10, & 11 and that portion of Spring 13 used for irrigation.

Table 4. Performance measures for Hagerman National Fish Hatchery using Piper's (1982) indices.

	Density Index	Flow Index		
Hatchery Tanks	$0.8^{2}$	1.0		
Raceways	0.2	-		
Smaller than 80 fpp <sup>1</sup>	-	0.8		
From 80 to 15 fpp	-	1.0		
Larger than 15 fpp	0.2	1.2		

 <sup>&</sup>lt;sup>1</sup> fpp is Fish Per Pound.
 <sup>2</sup> Changes in hatchery practices within the last three years do not allow the Density index to exceed 0.5 during rearing in the Hatchery Tanks.

Table 5. Comparison of average (n = 3) ending parameters for the Production Capacity Assessment (PCA) and Sawtooth stock fish reared at Hagerman NFH, BY2005

	PCA						Hatchery Production
_	Upper Tanks		Middle Tanks	Bottom Tanks		-	Sawtooth
Start Length (in)	6.05		6.04		5.94		
End Length (in)	8.33	а	8.30	а	8.02	b	8.27
Fish Per Pound (FPP)	4.67	а	4.69	а	5.10	b	5.00
End Dissolved Oxygen (mg/l)	5.61		3.72		2.82		6.87 1
Start Flow Index <sup>3</sup>	0.38		0.76		1.14		0.57
End Flow Index <sup>3</sup>	0.72		1.44		2.09		1.12 <sup>2</sup>
End Density Index	0.22		0.22		0.20		$0.16^{2}$
Feed Conversion Ratio (FCR)	1.08	а	1.10		1.26	b	1.02
Condition factor	0.000373	а	0.000362	b	0.000354	b	0.000345 °

<sup>&</sup>lt;sup>1</sup> Instantaneous end Dissolved Oxygen (mg/l) from the bottom deck of raceways

<sup>&</sup>lt;sup>2</sup> End of March 2006

<sup>&</sup>lt;sup>3</sup> Flow Index is cumulative

<sup>&</sup>lt;sup>a,b,c</sup> Denote significant differences (p<0.05)

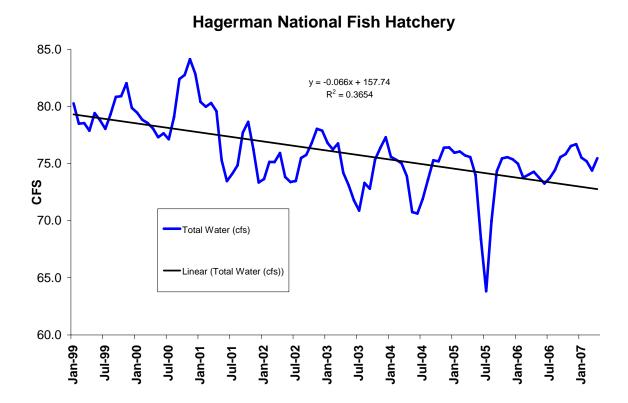


Figure 1. Monthly average spring flow at the Hagerman National Fish Hatchery, 1999-2007.

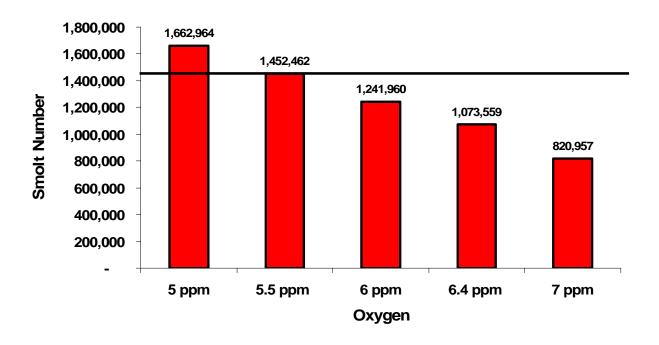


Figure 2. Potential smolt production according to loading equations by Westers (2001) at the Hagerman National Fish Hatchery with 61 cfs of production water given minimum dissolved oxygen concentrations of 5.0 ppm (Piper et al. 1982), 5.5 ppm and 6.4 ppm (Westers 2001), 6.0 ppm (NPDES requirement), and 7 ppm (Wedemeyer 1996) compared to the production goal line of 1.45 million smolts.

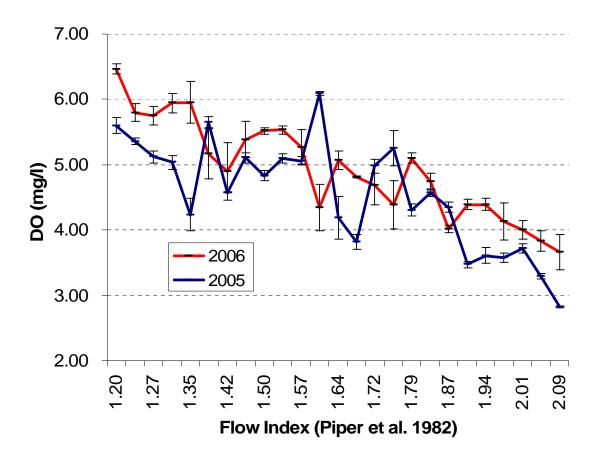


Figure 3. Average minimum Dissolved Oxygen concentrations (mg/l)  $\pm$  one Standard Deviation of the effluent water in the Production Capacity Assessment during Brood Years 2005 and 2006, Hagerman National Fish Hatchery.

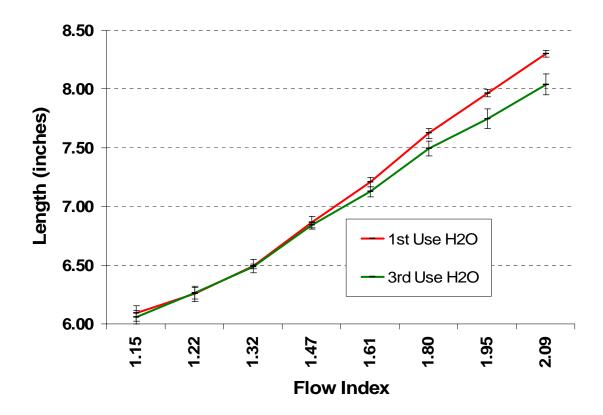


Figure 4. Average growth (inches)  $\pm$  one Standard Deviation for steelhead reared in first-use (control) and third-use production water with increasing Flow Indices during a Production Capacity Assessment using combined results from Brood Years 2005 and 2006, Hagerman National Fish Hatchery.

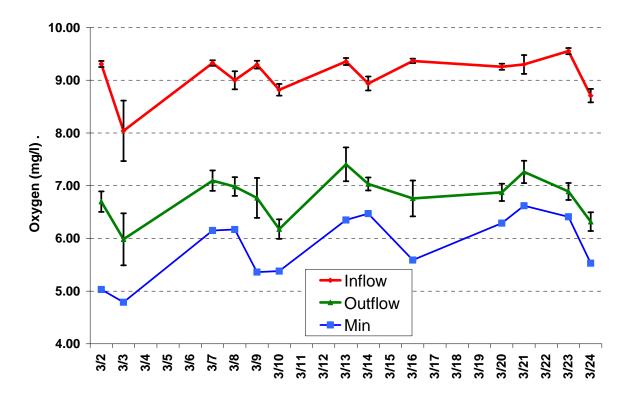


Figure 5. Average and minimum daily dissolved oxygen (ppm)  $\pm$  one Standard Deviation for influent and effluent of Steelhead Raceways during peak production at the Hagerman National Fish Hatchery, March 2005 and March 2006.

## **Appendices**

Appendix I. Example calculations of Production Capacity at Hagerman National Fish Hatchery.

*Westers* (2001)

The most recent rearing conditions at the Hagerman National Fish Hatchery (Hatchery) during March 2006 were: 60.7 cfs of water, 198,000 ft<sup>3</sup> of rearing space, 8.95 mg/l O<sub>2</sub> of inflow, 5.0 mg/l O<sub>2</sub> minimum outflow concentration, 250 g O<sub>2</sub>/kg of feed fed (Westers 2001), 1 % of body weight per day feeding rate, and a production goal of 1,450,000 smolts at 4.5 fish per pound. The Hatchery is at an elevation of 2900 feet and has a water temperature of 59<sup>0</sup> F.

An example of the potential production at the Hagerman NFH using Westers' (2001) carrying capacity equations for raceway loading is as follows:

Carrying Capacity

Carrying capacity is determined by loading (Ld), density (D), or as annual production (AP). Loading can be expressed as lb/gpm, density as lb/ft<sup>3</sup>, and a relationship is developed between Ld and D with water exchange rate (R) expressed as water turnovers per hour.

$$Ld = (D*8.02)/R$$
 (1)

Water Exchange Rate

The Hatchery had 60.7 cfs of water available for the Steelhead Raceways in March of 2006. The water turnover for the first pass of Steelhead Raceways can be determined by dividing the available water at the Steelhead Raceways (cfs) by 22 initial raceways. Each raceway is 10 x 100 x 3 ft (3000ft<sup>3</sup>).

$$R = \frac{60.7cfs*60s*60\min*1raceway}{22raceways*3000 ft^3*1\min*1hr} = 3.3exchanges/hr$$

Westers and Pratt (1977) recommended that raceways have a water exchange rate of 4 exchanges/hr for waste removal. The R value for the Hatchery is 18% below this value.

Feed Loading Rate

From Westers (2001) loading can further be defined as a function of feeding rate:

$$Ld = \frac{AO*100}{O_f *\%BW} \tag{2}$$

AO = Available Oxygen in mg/L as the difference between inflow DO and minimum acceptable effluent concentrations (5 mg/L for steelhead from Piper et al. (1982)).

 $O_f = g O_2$  required per kg feed per day that ranges from 200 to 250 g/kg for salmonids

%BW = feeding level as a percent of body weight (1% for the Hatchery)

AO was determined by using average influent readings taken during March 2005 at the head end of each of the 22 raceways in the upper deck and subtracting the acceptable minimum from Piper et al. (1982). Hence AO for HNFH equals 3.95 mg/L (8.95 mg/L – 5 mg/L).

$$Ld = \frac{3.95mg / L*100}{250g / kg*1\%} = 1.58 \text{ kg/Lpm} = 13.50 \text{ lbs/gpm} = 6,058 \text{ lbs/cfs} * 60.7 \text{ cfs} =$$

405,896 lbs of steelhead \* 4.5 fpp

#### = 1.7 million smolts

If O<sub>f</sub> was reduced to 200 g/kg the resulting loading would be:

$$Ld = \frac{3.95mg / L*100}{200g / kg*1\%} = 16.9 \text{ lbs/gpm} * 60.7 \text{ cfs} = 460,000 \text{ lbs} * 4.5 \text{ fpp}$$

#### = 2.1 million smolts

For the remainder of this exercise an O<sub>f</sub> value of 250 g/kg will be used as a more conservative estimate.

### Ammonia Loading

Raceway loading can also be determined as a function of ammonia production by metabolic processes. To determine the ammonia concentration we need an estimate of total ammonia nitrogen generated per kg of feed ( $TAN_F$ ), the percent un-ionized ammonia (%UA), and the allowable maximum concentration of un-ionized ammonia (AUA).  $TAN_F$  generally ranges from 20 to 30 g/kg from Westers (2001). To calculate the ammonia concentration in mg/L ( $TAN_C$ ), the following equation is used:

$$TAN_C = TAN_F / O_f$$

 $TAN_F$  and  $O_f$  were estimated from Westers (2001).

$$TAN_C = 20 \text{ g/kg} / 250 \text{ g/kg} = 0.08 \text{ mg/L}$$

This value is for one AO unit. To adjust for all the AO units the following equation is used:

$$TAN_C = AO (TAN_F / O_f)$$

$$TAN_C = 3.95 \text{ mg/l} (20 \text{ g/kg} / 250 \text{ g/kg}) = 0.316 \text{ mg/L}$$

The concentration of un-ionized ammonia ( $UA_c$ ) is calculated by using fractional ammonia to un-ionized ammonia (%UA) from tables found in Wedemeyer (2001) for a temperature of 15 C and average pH of 7.6 from 2005 sample data.

$$UA_C = (TAN_C * \% UA) / 100$$

$$UA_C = (0.316 \text{ mg/l} * 0.93\%) / 100 = 0.0029 \text{ mg/L unionized ammonia}$$

The Hatchery's maximum allowable concentration of unionized ammonia (AUA) is 0.0125, thus the maximum available oxygen (MAO) that can be utilized before the ammonia threshold is reached is explained by the following equation:

$$MAO = AUA/UA_C$$

$$MAO = 0.0125 \text{ mg/L} / 0.0029 \text{ mg/L} = 4.24 \text{ mg/L}$$

Using equation (2), the maximum allowable loading for MAO of 4.24 and 1.0 %BW is:

$$Ld = \frac{AO*100}{O_f*\%BW} = \frac{4.24 \frac{mg}{L}*100}{250 \frac{g}{Lpm}*1} = 1.70 kg / Lpm$$

$$Ld = 14.5 \text{ lb/gpm} * 27,244 \text{ gpm} (60.7 \text{cfs}) = 395,038 \text{ lbs}$$

#### = 1.78 million smolts

However, if TAN<sub>F</sub> is changed from a minimum of 20 g/kg to the maximum of 30 g/kg from Westers (2001) the resulting Loading is:

$$Ld = \frac{AO*100}{O_f*\%BW} = \frac{2.83 \frac{mg}{L}*100}{250 \frac{g}{Lpm}*1} = 1.13kg/Lpm =$$

$$Ld = 9.6 \text{ lb/gpm} * 27,244 \text{ gpm} (60.7 \text{cfs}) = 261,542 \text{ lbs}$$

#### = 1.18 million smolts

Density Loading

Using equation (1) Density can be defined as:

$$D = (Ld * R)/8.02$$

Ld can be determined from equation (2) for 60.7 cfs where Ld = 13.5 lbs/gpm

$$D = (13.5 \text{ lbs/gpm} * 3.5)/8.02$$

$$D = 6.89 \text{ lb/ft}^3 * 198,000 \text{ ft}^3 = 1.2 \text{ million pounds}$$

#### = 5.2 million smolts

This density would require a water inflow of 193 cfs using equation (2).

*Piper et al.* (1982)

An example of calculating carrying capacity using Density and Flow Indices from Piper et al. (1982) is as follows:

Density Index

Density Index = 
$$\frac{\text{weight of fish}}{\text{(average length of fish) (cu. ft. water)}}$$

Density Index = 
$$\frac{322,000 \text{ pounds steelhead}}{(8.6 \text{ inches length}) (198,000 \text{ cu. ft. water})} = 0.19$$

Flow Index

Flow Index = 
$$\frac{\text{weight of fish}}{\text{(average length of fish) (GPM flow)}}$$

Flow Index = 
$$\frac{322,000 \text{ pounds steelhead}}{(8.6 \text{ inches length})(68 \text{ cfs}*448 \text{ GPM/cfs})} = 1.2$$

Appendix II. Dissolved Oxygen Supplementation at Hagerman National Fish Hatchery.

The Hageman National Fish Hatchery (Hatchery) fish production is limited by spring water supplies and the corresponding Dissolved Oxygen (DO) concentrations. The Hatchery could increase fish production by increasing the DO concentrations by securing more water supplies or installing a mechanical aeration system.

The Hatchery can theoretically estimate the potential fish production increase as a result of increased DO concentrations by calculating the maximum allowable ammonia concentration. Ammonia is considered the second limiting factor in fish production to DO concentrations. The un-ionized form of ammonia is considered harmful to steelhead at concentrations above 0.0125 ppm. The fractional amount of un-ionized ammonia in a system is highly dependent on temperature and pH.

The Hatchery previously calculated a maximum production capacity of 1.8 million smolts based on an un-ionized ammonia fraction of 0.93%. This un-ionized ammonia fraction was based on a temperature of  $15^{\circ}$  C and a pH of 7.6 units. However, when oxygen is added to a fish production system it is possible for concentrations of  $CO_2$  from fish respiration to lower the working pH.

# Hatchery Conditions:

Influent DO = 8.95 mg/l Effluent DO = 5.00 mg/l Influent pH = 7.6 Temp = 15 C Alkalinity = 140 mg/l

The Henderson-Hasselbalch equation can be used to predict the  $CO_2$  concentration of the influent (8.14 mg/l) and the effluent  $CO_2$  concentration (13.64 mg/l). The resulting pH (7.37) from the increased  $CO_2$  concentration reduces the un-ionized form of ammonia to about 0.6%.

Hence, based on ammonia limitations, the potential loading of the Hatchery could be increased to nearly 3 million smolts per year if the production system was supplied with unlimited DO. However, the Density Index of 0.2 would be exceeded (Table 4).