Lewis River Spawning Gravel Evaluation

Final Report

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1 INTRODUCTION AND PURPOSE

This report is the final component of studies that began in 2005 as part of the Lewis River Spawning Gravel Analysis (Stillwater Sciences 2006). As described in the Scope of Work (Appendix A), there are four fundamental tasks to be completed in this evaluation:

(1) Determine the extent of suitable spawning gravel in the Lewis River below Merwin Dam (RM 19.5) to the downstream end of Eagle Island (RM 9.8)
(2) Develop a spawning gravel monitoring program for measuring future changes in gravel quantity and characteristics, and
(3) Provide a means for determining when spawning gravel augmentation or retention efforts are warranted, and
(4) Propose a gravel augmentation strategy that addresses the quality of gravel to be emplaced, the timing of the augmentation, and the methods to be used.

A report completed in 2006 provides important background information, objectives and initial results (Stillwater Sciences 2006). The results and discussion presented here summarize the results of three years of monitoring spawning habitat on the Lewis River downstream of the Merwin Dam and upstream of the Lewis River Fish Hatchery. Here we present a method for future monitoring of the areal extent of spawning habitat.

Summary of Findings

1. There has been no loss of spawning habitat since 2005. Hence, the immediate addition of spawning gravel is not warranted at present.
2. Spawning habitat area between Merwin Dam and the Lewis River Fish Hatchery is **limited**, but is **stable**.

1.1 Approach and Method

Spawning Habitat Mapping

There are four anadromous fish species of concern in the evaluation area: Chinook salmon, coho salmon, steelhead, and chum salmon. Of the anadromous fish species present, Chinook salmon are the most abundant. There are two distinct runs of Chinook salmon in the Lewis River: the less abundant spring run, and the more abundant fall run. Although coho salmon and steelhead spawn in the mainstem channel, it does not offer ideal spawning habitat for these species given their typical preferences. This spawning gravel evaluation focuses on both spring- and fall-run Chinook salmon because they are the dominant species spawning in the mainstem downstream of Merwin Dam. Direct observation and mapping of this spawning activity correlates with the gravel dunes seen in some parts of the river, and which are the residual physical evidence for spawning. While the spawning activity of coho salmon and steelhead is observable, the evidence of their efforts are overshadowed by the preponderance of spawning Chinook salmon. Furthermore, changes to spawning habitat area in the Lewis River below Merwin Dam will have the greatest impact on Chinook salmon as compared to the other species. In general, many of the results presented here are applicable to coho salmon and steelhead. There is little evidence for spawning of chum salmon in the evaluation area; therefore, they have been left out of the discussion.

The approach for tracking change in spawning habitat area we present here builds upon the findings of modeling and analysis presented in the 2006 report (Stillwater Sciences 2006). Here we assume that the results of our modeling and analysis describe the conditions for sediment transport and spawning habitat use in the Lewis River downstream of Merwin Dam. We explicitly acknowledge that any model has limitations, and is best used as a guide for analysis and understanding. When corroborated with field observation and careful analysis, models are quite useful to discern patterns and process magnitude, especially in the absence of other information, or where time and resources are limited.

We used visual observation of physical evidence of prior and active spawning to indicate areas of suitable spawning gravel. Areas with no evidence of spawning were assumed to be unsuitable. Spawning areas were sketched as polygons of spawning gravel directly onto field maps of high resolution aerial photography that were made in 2005.

Observations were made from a motorized drift boat in 2005 over the course of two days, but no observations were made in 2006 because high discharge obscured visibility and made working on the river unsafe. In 2007 and 2008 observations were made from a jet boat and on each occasion, mapping took about 6 hours. Subsequent to the field effort, the polygons were digitized in a GIS to form overlays of suitable spawning habitat. The new composite GIS data for all years will be sent separately from this memo.

This approach assumes that all available spawning habitat in the river between the Lewis River Fish Hatchery and the Merwin Dam (the "upper river") is being utilized even in years with low adult returns. This assumption is based on redd superimposition modeling and analysis of redd survey data that shows that all available spawning habitat in the upper river is being used for spawning (Stillwater Sciences 2006). We also assume that in the last four years, the total area of available spawning habitat in the upper river has not changed. This assumption is based on high flows from Merwin not exceeding our modeled threshold flow corroborated by first-person observation. In four years of observation on the river, there is no evidence of measurable bedload transport at the reach-scale, or any evidence of obvious large-scale rearrangement of bedforms, gravel bars, and spawning dunes. Hence, we assume that observed spawning activity in each year of observation was a reliable indicator of the total area of suitable spawning gravel and that areal extent has remained unchanged.

Statistical Analysis Using Monte Carlo Simulations

Monte Carlo simulations were used to calculate the probability of detecting a change in spawning gravel area, given a range of potential losses (expressed as percent of total area) in spawning gravel after threshold flows (a threshold flow is a flow that triggers the necessity to monitor the area of spawning habitat, see section 1.6 below). First, the measurements of the baseline value for spawning gravel were simulated using a normal distribution with mean and standard deviation of measurements from 2005, 2007, and 2008 (baseline data set). It was further assumed that the mean of these measurements was the true quantity of spawning gravel area prior to threshold flows. Three values were randomly generated from this distribution using function "rnorm" within the R environment (R 2008) to simulate the process of taking the baseline measurements. The mean of these values was then used to represent baseline conditions.

To test the null hypothesis, which states that spawning gravel area after a threshold flow is identical to the area that existed prior to the incidence of the threshold flow, we assumed a normal distribution of differences between spawning gravel area before and after the threshold flow occurred. These represent conditions with a mean of zero and a standard deviation based on the variance from two identical distributions (each with the mean and standard deviation from the baseline dataset). This distribution was then used to calculate the probability of obtaining a pre- and post-project difference as large as that observed, given that there was no true difference in spawning gravel areas. The observed value of spawning gravel area after a threshold flow was simulated by drawing a single value from a normal distribution of values with a mean value equal to a given level of percent loss (ranging from 5 to 50%), and a standard deviation calculated based on the simulated observed value and assuming a coefficient of variation (i.e., ratio of the standard deviation to the mean) consistent with that calculated using the baseline dataset. The entire process was repeated 5,000 times to estimate the probability of correctly rejecting the null hypothesis (i.e., power).

1.2 Results

Based upon observations over four non-consecutive years, the average areal extent of mapped spawning habitat in the upper river is 154,207 m^2 (Table 1), with a standard deviation of ~ 13%. The general location and spatial extent of mapped polygons of spawning gravel has remained similar each year, but there are differences that reflect the imprecision in the methods used (**Figure 1**, **Figure 2** and **Figure 3**, appended).

Table 1. Mapped spawning habitat area in the Lewis River between Merwin Dam and the Lewis River Fish Hatchery.

Number of Polygons Mapped	2001 spawning habitat area (m^2) [1]	2005 spawning habitat area (m^2)	2007 spawning habitat area (m^2)	2008 spawning habitat area (m^2)
1	17,245	1,448	2,021	6,733
2	4,332	14,517	4,930	6,495
3	7,214	13,153	46,659	1,260
4	9,916	1,936	2,956	921
5	522	49,972	7,426	1,696

6	54,858	15,561	32,521	12,784
7	18,319	23,958	1,045	146
8	--	12,543	12,359	84
9	--	2,441	2,855	29,949
10	--	882	4,851	49,758
11	--	455	5,142	19,494
12	--	10,901	8,946	32,050
13	--	9,933	--	--
14	--	786	--	--
15	--	6,666	--	--
16	--	836	--	--
17	--	1,756	--	--
18	--	1,143	--	--
19	--	650	--	--
Total Area (m^2)	112,407	169,539	131,711	161,371

1. 2001 spawning habitat area is derived from shapefiles generated by BioAnalysts, et al. (2003).

1.3 Discussion

Variability and Repeatability of the Mapping Approach

Fall Chinook escapement in 2005, 2006, and 2007 was 10,668, 11,890 and 3,468 respectively (Groesbeck 2006, Groesbeck 2007, Groesbeck 2007). An estimate of 2008 escapement is not yet available. If we assume that 2008 will have at least as many Fall Chinook returning as 2007, then all available habitat will be utilized for spawning activity because even a few thousand spawners (~ 3,000 males and females) will begin building redds on top of one another according to our analysis (Section 3.1.2 in Stillwater Sciences 2006).

Our sediment transport modeling found that the long-term reach-average onset of sediment transport (incipient motion) begins at about 56,000 cfs in the upper reach and has a recurrence interval of about 7 years (i.e. ~ 14% probability of occurrence in any given year). Incipient motion is the point at which the shear stress associated with the discharge is just high enough to cause particles on the bed surface to be dislodged and translate downstream. Little appreciable sediment transport occurs at incipient motion. Incipient motion is distinct from the condition of measurable bedload transport, when the entire bed surface is in motion and appreciable sediment transport is taking place. Reach-average refers to a generalized estimate applied to the entire reach. Hence, at-a-site onset of incipient motion (and sediment transport) may vary according to local sediment, hydrologic, and planform idiosyncrasies. For example, in 2005 we laid out several arrays of tracer rocks; the upstream-most (~RM 18.7) array is still more or less in the same arrangement as when it was deployed. In contrast, another array that we deployed at the same time near ~RM 16.8 has been mobilized, and the tracer rocks have been either buried or swept downstream into deeper water and have not been recovered. In addition, there is some error associated with any sediment transport equation, therefore our estimate of reach-average onset of incipient motion may be an over- or underestimate of the actual discharge associated with incipient motion in the upper river.

A recurrence interval of this probability (e.g. ~7 years) is characteristic of a regulated river such as the Lewis River where a combination of bed coarsening and flow regulation reduces the chance of high flows sufficient to initiate sediment transport. Our sediment transport model (EASI, see Appendix D in Stillwater Sciences 2006) uses daily discharge (the average flow for a 24-hour period) to develop the sediment rating curve and predict incipient motion. Since 2005 when the initial component of this study was completed, the maximum daily discharges in each calendar year have been 35,200 cfs, 17,100 cfs, and 19,100 cfs, respectively. Peak flows in WY 2005, 2006, and 2007 were 16,500 cfs, 29,900 cfs, and 39,900 cfs. So, there has not been a discharge of sufficient magnitude to initiate measureable reach-scale sediment transport in the upper river since 2005, and thus the total available spawning gravel available in the upper reach has not changed.

In our mapping we found that the total available spawning area in the upper river has not changed appreciably. Given that high flow events during the three years of observations were too low to account for sediment transport and thus cannot account for differences in spawning areas, we conclude that all of the variability in the mapped spawning habitat is a consequence of inherent error in the mapping method, rather than underutilization by spawners or sediment transport. Factors affecting the repeatability (and hence the variability) of the mapping method include: differences in water clarity between years, run timing and degree of spawning activity, map scale verses sketching scale, inherent error in sketching, and inherent error in digitizing.

We have no empirical measure of the actual area of spawning habitat that may be lost at a given flow; we can only predict the sediment flux using our sediment transport model. For example, in water year 2006 there was one day that had a daily discharge of 39,900 cfs; the sediment flux on that day was estimated to be 1.6 tons/day. For the discharge at which incipient motion is predicted to begin in the upper reach, 56,000 cfs, the sediment flux for one day at the flow is estimated to be 30 tons/day.

Detecting Actual Losses in Spawning Areas over Time
We do know that generally speaking, sediment translates from upstream to downstream; in which case spawning area loss would likely to occur from upstream to downstream. However, during a large flood, the entire bed of the river is likely to mobilize leading to possible rearrangement and loss of spawning habitat throughout the upper river. Whether spawning habitat is lost, or how much is lost, is unpredictable, but it is largely a function of recurrence of large flows which are typically of low probability. However, we can estimate our ability to detect a change in area of spawning habitat by comparison with our baseline habitat area surveys (Table 1).

Our analysis shows that as spawning habitat area loss increases, our ability to discriminate the loss also increases (Table 2). Small losses in spawning area are difficult to detect not only because of underlying error of the method, but also because small changes in spawning area would be expected to accompany lower discharges when less sediment is moving. In contrast, our method does well at detecting large losses in spawning habitat that would be expected to follow large flood events, when the sediment flux is high. For example, if there was 25% loss of total spawning habitat area, then we have a 56% chance of correctly discriminating the loss; in contrast, if there is a 40% loss of spawning habitat area, then we have 94% chance of correctly discriminating the loss (**Table 2**). Cumulative loss of spawning area over the course of several episodes of lower discharges could also be discriminated once a larger total area had been lost. The power of the monitoring techniques to detect a smaller degree of change would increase as more years are added to the accumulated samples.

Table 2. Probability of detecting a given percent change in spawning habitat area in the Lewis River between Merwin Dam and the Lewis River Fish Hatchery.

Percent Spawning Area Lost	Probability of Correctly Detecting a Loss
5	0.10
10	0.17
15	0.27
20	0.40
25	0.56
30	0.71
35	0.85
40	0.94
45	0.98
50	0.99

1.4 Effects of Spawning Area Loss

Since 2005, there has been no appreciable change in the area of spawning habitat in the upper river (Table 1); therefore we do not find that the addition of spawning gravel is warranted at this time. However, a discussion of the effects of the potential of future loss of spawning habitat is presented to support future decision-making discussions, should they be warranted.

We posit that for Fall Chinook, at existing escapement levels, available spawning and rearing habitat is currently saturated and therefore limiting productivity in the Lewis River between Merwin Dam and the Lewis River Hatchery. As few as one thousand pairs (e.g. 2,000 adults) of Fall Chinook spawning in the upper reach between Merwin Dam and the Lewis River Fish Hatchery would produce as many as 4 million eggs (Figure 4 below; also see discussion section 3.1 in Stillwater Science 2006), and a similar number of fry depending on fecundity and density-independent mortality of eggs and larvae. Beyond about 3,000 adults, density dependant effects (i.e. redd superimposition) begin to limit the number of eggs that can be produced. Despite limited available spawning habitat, spawning habitat loss would need to be fairly high in the upper river below Merwin Dam to begin to have effects on the number fry in the river because so few adults are required to produce millions of juveniles, given the typical number of returning adults.

A concurrent lack of rearing habitat suitable to provide for the needs of a large cohort of Chinook juveniles in the lower Lewis River may also be limiting productivity. A full analysis of these density-dependent limiting factors is beyond the scope of this study, and therefore is left to the fisheries managers to investigate.

By its nature, the total available spawning habitat in the upper reach below Merwin Dam is limited, because it is confined by bounding bedrock terraces and is relatively steep compared to the reach below the Lewis River Fish Hatchery. Much of the apparent available habitat in the upper river appears to be being used. Historically, seemingly ideal spawning habitat between the Lewis River Hatchery and eagle Island is not frequently selected by returning Fall Chinook either because it is not suitable, because of enduring site fidelity to the upper river, or for other unknown reasons. In any event, spawning habitat in the lower river is effectively non-existent because the fish are not using it. Making the extensive potential spawning habitat upstream of Merwin Dam available is likely to have a far larger impact on the population than increasing spawning habitat downstream. In the near-term, addressing potential rearing habitat limitations below Merwin Dam may ultimately be a more beneficial approach to consider as a way to increase smolt escapement than the addition of spawning gravel.

None the less, some threshold of “acceptable” loss of spawning habitat should be determined for the sake of maintaining a minimum level of spawning habitat, especially in light of the expense and effort involved in adding spawning gravel to the upper reach as compensatory mitigation for the loss. Determination of the threshold level of spawning habitat loss would need to take into consideration the change detection limits inherent to the assessment methods currently available. While these detection limits will improve over time with repeated measurements, at present it seems that a change in habitat area of ~ 35% would seem a reasonable interim threshold.

1.5 Monitoring Plan

The spawning gravel monitoring plan we recommend should consist of two components. The first component is monitoring of stream discharge that reaches or exceeds a minimum discharge (termed spawning gravel monitoring discharge). The second component would consist of spawning habitat mapping in the spawning season following the year that the spawning gravel monitoring discharge occurs.

1.6 Minimum Discharge

The results of the EASI modeling (Section 2.5, Stillwater Sciences 2006) indicate the daily average discharge at which incipient motion occurs at approximately 56,000 cfs for the upper reach and 42,000 cfs for the lower reach. We propose setting a spawning gravel monitoring discharge within the study reach of 42,000 cfs (instantaneous discharge), which is approximately a 4-year flow event.

1.7 Spawning Habitat Use Monitoring

Mapping of spawning habitat use in the upper reach should occur during the spawning season following the spawning gravel monitoring discharge. The method used to map the spawning habitat will be identical to that used and presented in this report. Very low escapement is required to saturate the available spawning habitat in the upper reach, so in most years under-representation of available spawning habitat is a low risk.

1.8 Spawning Gravel Augmentation Strategy Options

Since 2005, there has been no appreciable change in the area of spawning habitat in the upper river (Table 1; see section 1.3 and 1.4); therefore we do not find that the immediate addition of spawning gravel is warranted at this time. If however, as discussed below, subsequent spawning habitat monitoring revealed a loss of ~ 35%, then initiation of gravel augmentation would seem justified.

The general design guidelines for future gravel augmentation, should it be required, may consist of one or a combination of the following two options:

1) An annual input of gravel equal to the average annual sediment transport rate for the upper reach, as determined by application of the results of the EASI modeling. The gravel should be introduced just below the dam, and the river would naturally entrain and route the sediment from upstream to downstream.
2) Site-specific augmentation of gravel should be targeted to areas with documented loss of spawning gravel. The volume and extent of gravel to be added will be determined on a case-by-case basis in the event gravel augmentation is required.

Option 1, introducing the sediment just below the dam and allowing the river to route it downstream, has three advantages. First, there is road access to the river immediately below the dam, making delivery relatively easy, with no need for heavy equipment to operate within the stream channel itself. Secondly, the section of the river immediately below the dam (RM 19.5 to RM 19.35) is not a key spawning area, so the addition of gravel will have low impact on spawning habitat. Thirdly, allowing the river to route the sediment will allow coarsened areas to fill in and be shaped as they would under natural conditions, eliminating the need for more costly and questionable engineering solutions. The potential disadvantage of this option is that if substantial channel incision has occurred, routing of the added gravel to critical downstream spawning areas may take many years because high flows with the capacity for transporting sediment under these conditions are relatively rare. In the interim, spawning habitat limitations may continue to substantially limit salmon production. This could be remedied by immediate addition of gravel to the channel, which is described below.

Option 2 would more immediately replace local gravels lost during the last flood event; however, it is difficult to determine the extent to which gravel loss has occurred and thus the amount to add to the channel. The main problem with this approach is that access to the channel to add gravel may be difficult or impossible in certain reaches, particularly in the gorge of the upper reach. Gaining access through private property may further complicate implementation of this option.

A third option is the immediate addition of gravel at RM 19.3 to create a spawning riffle and enhance available spawning habitat. This option has three advantages. In the near term, creating a new spawning riffle in the uppermost spawning area of the upper reach would increase spawning habitat quantity and quality in one of the most heavily used spawning areas, which already exhibits evidence of density-dependent habitat limitations (Section 3.1). In addition, while the new spawning riffle would be designed to be stable at most high flows, in the event of a very large flood event, it could act as a source of gravel for replenishing areas downstream that have lost gravel. If this occurred after spawning had occurred, the redds would likely be lost. Access to the upper reach is good and heavy equipment impacts to existing spawning habitat would be negligible. A third and most important advantage is that the gravel remaining within the reach after a high flow event could be used to indicate whether more gravel augmentation is needed. The main disadvantage of this option is that it requires equipment and cost outlay in the near term.

1.9 Conclusion

The immediate addition of spawning gravel to the Lewis River below Merwin Dam is not warranted at this time. Three options for future gravel augmentation should it be required have been presented.

The three options for gravel augmentation presented correspond to different philosophies: option 1 assumes that future gravel losses will be minor and that the purpose of augmentation is to maintain existing habitat; option 2 is more expensive but would increase spawning habitat quality and quantity for Chinook salmon; and option 3 preemptively increases spawning habitat and provides insurance against potential future losses. We believe option 3 can accomplish the objective with relatively small risk of damaging the habitat and a reasonable budget.

Before future gravel augmentation occurs a detailed plan should be developed and submitted for review. The detailed design should contain at minimum the following components: a bulk particle size analysis of the present river bed, a gravel particle size distribution for gravel to be added based on native bulk samples and desired outcome, and a risk evaluation of potential effects of gravel augmentation.

1.10 References

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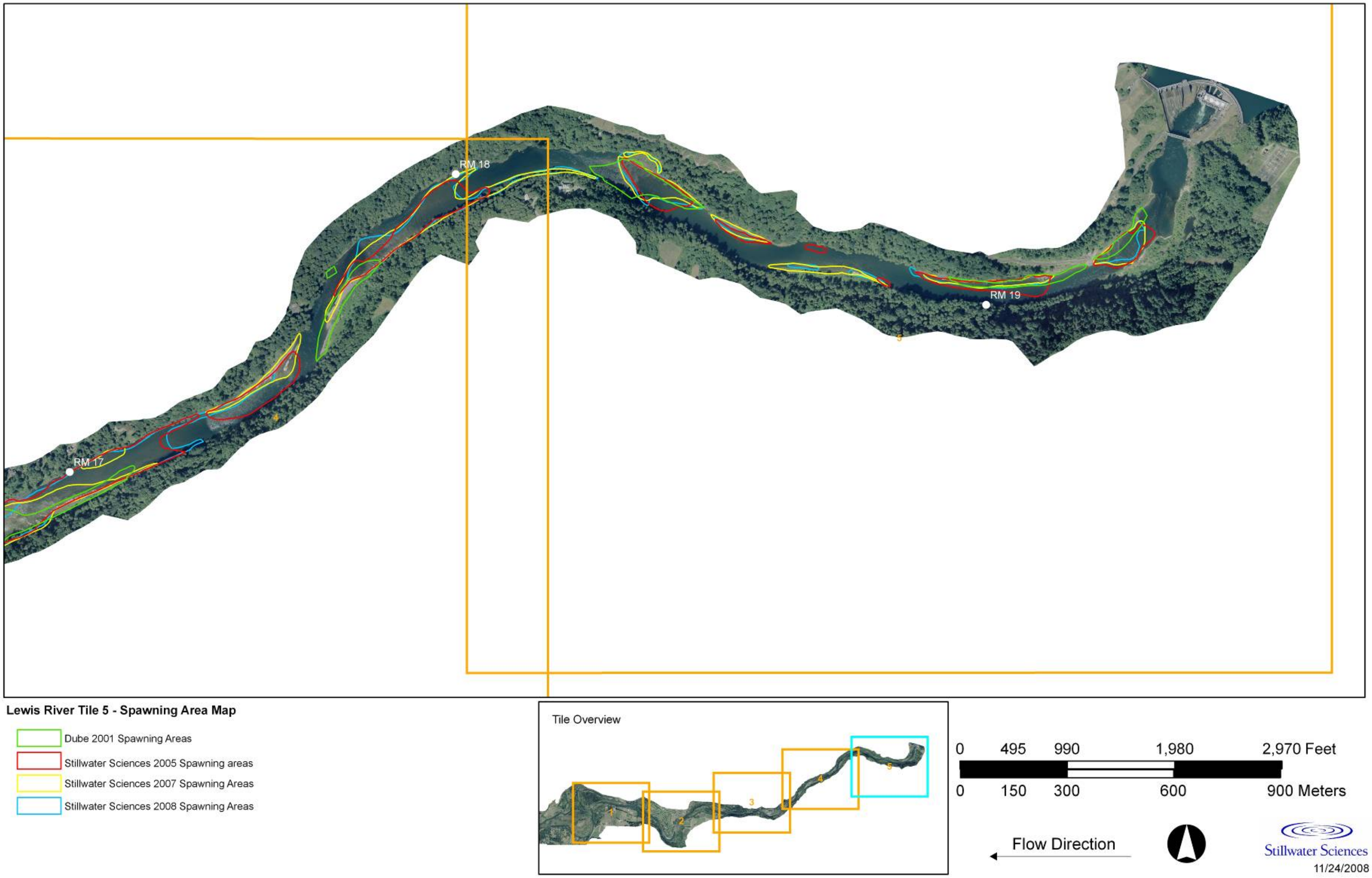

Figure 1. Mapped spawning habitat in the Lewis River between Merwin Dam and the Lewis River Fish Hatchery in 2001, 2005, 2007 and 2008. For the complete length of river surveyed, also see figures 2 and 3. Mapped habitat in 2001 derived from shapefiles generated by BioAnalysts, et al. (2003).

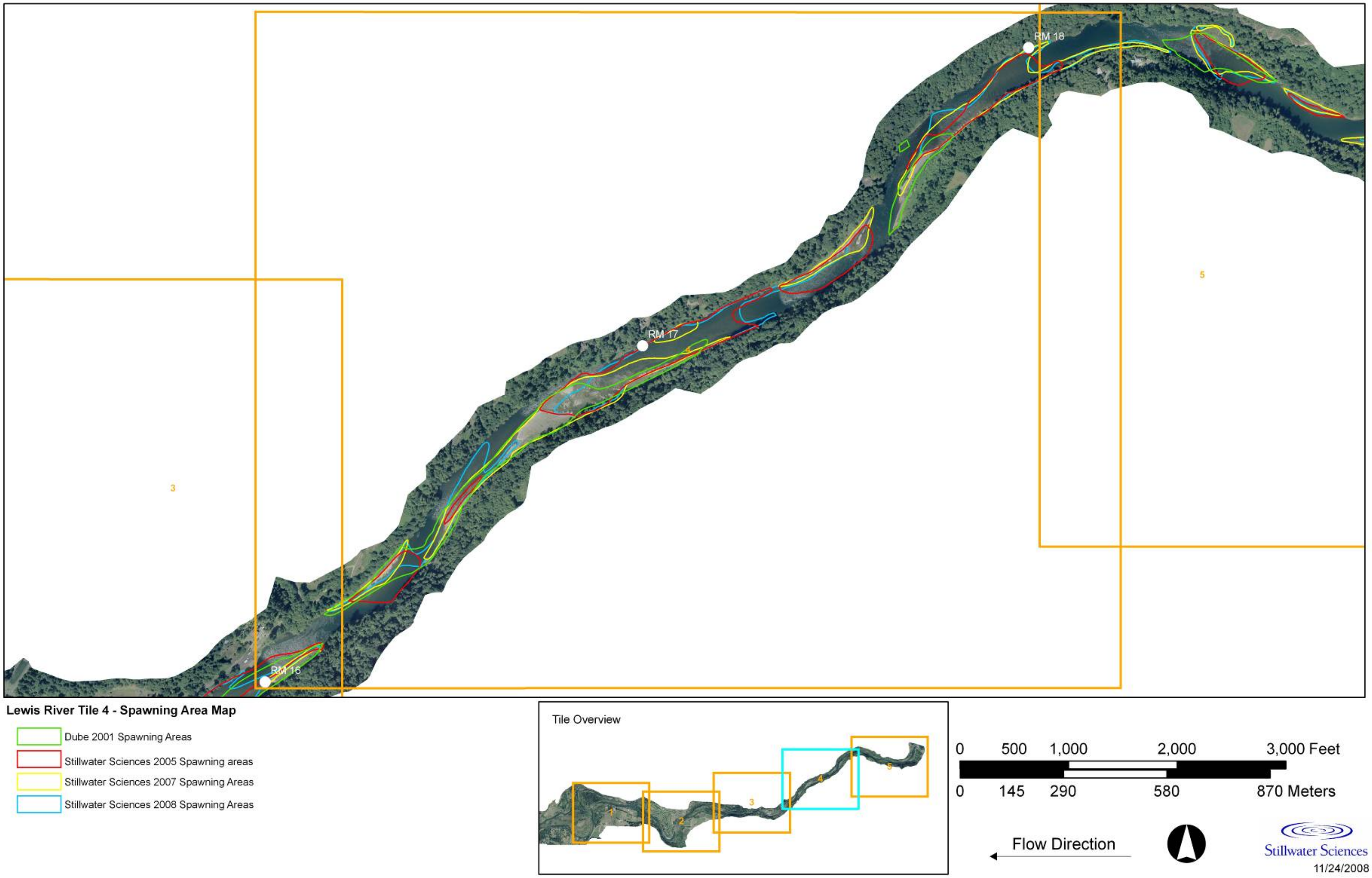

Figure 2. Mapped spawning habitat in the Lewis River between Merwin Dam and the Lewis River Fish Hatchery in 2001, 2005, 2007 and 2008. For the complete length of river surveyed, also see figures 1 and 3. Mapped habitat in 2001 derived from shapefiles generated by BioAnalysts, et al. (2003).

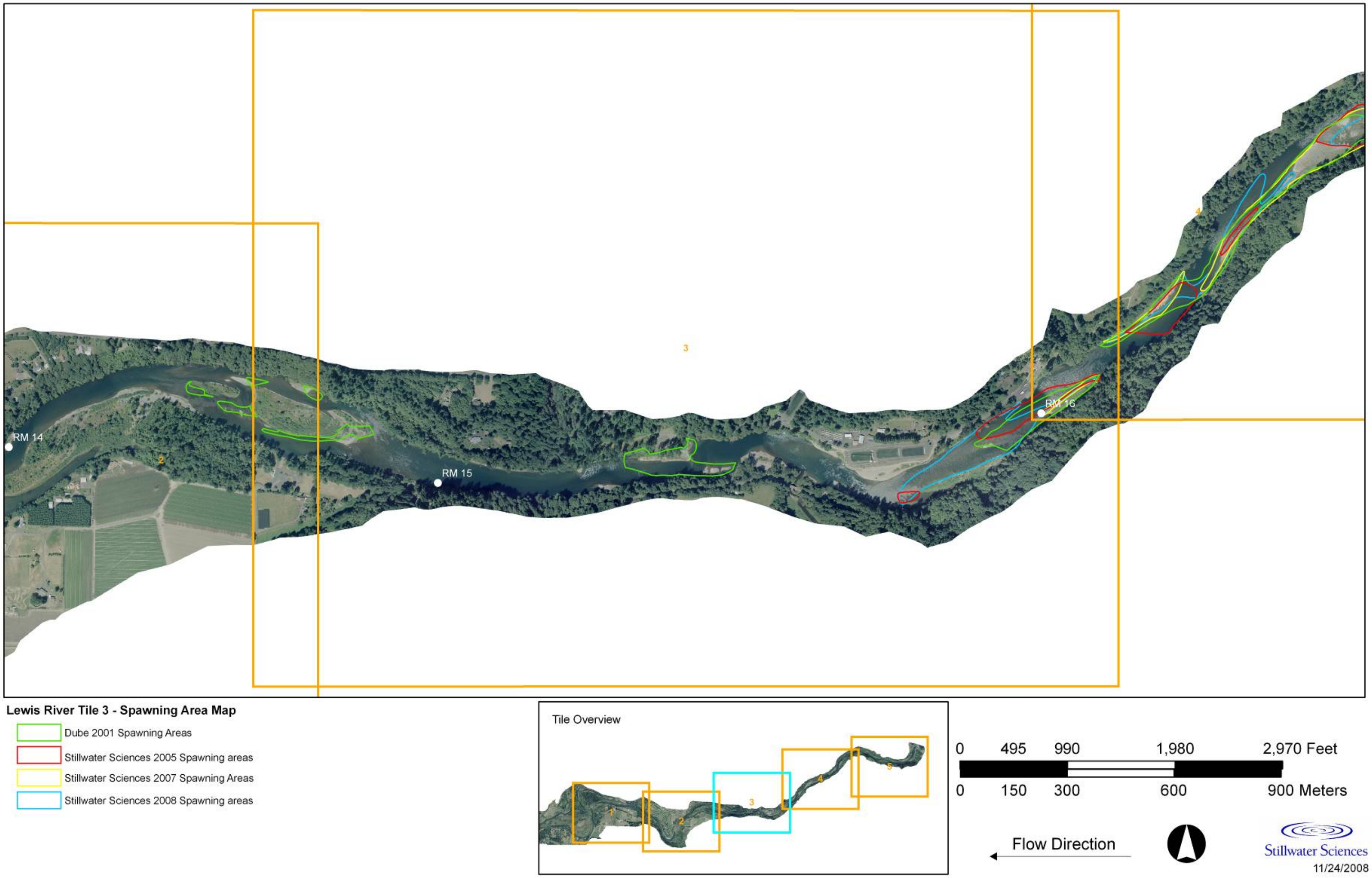

Figure 3. Mapped spawning habitat in the Lewis River between Merwin Dam and the Lewis River Fish Hatchery in 2001, 2005, 2007 and 2008. For the complete length of river surveyed, also see figures 1 and 2. Mapped habitat in 2001 derived from shapefiles generated by BioAnalysts, et al. (2003).

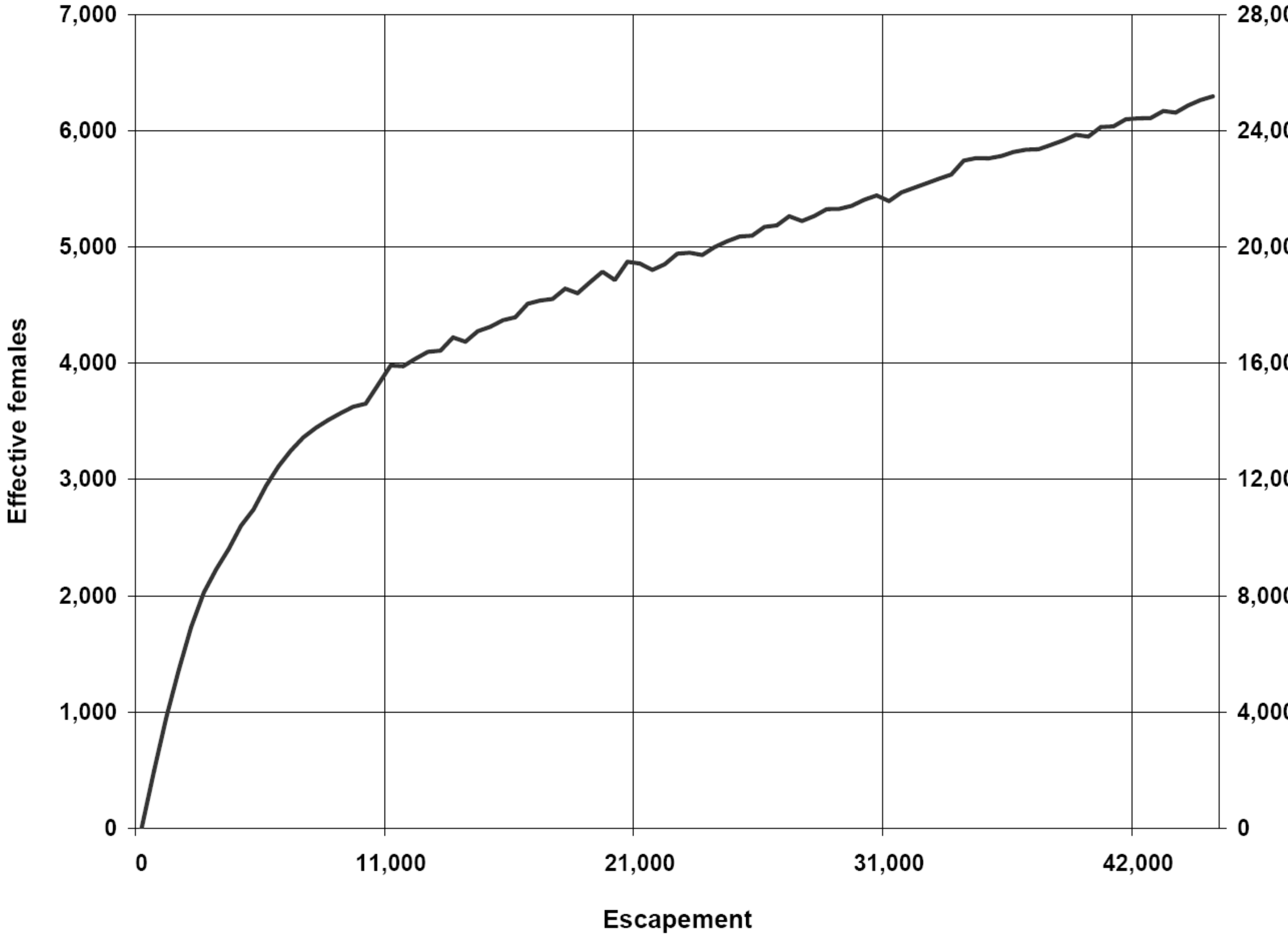

Figure 4. Chinook salmon effective females and effective eggs versus escapement from ESCAPE output (Figure 3 from Stillwater Sciences 2006).

Appendix A

Schedule 7.2 from the Lewis River Hydroelectric Projects Settlement Agreement

Schedule 7.2: Scope of Spawning Gravel Study

Study objective: (1) Provide a monitoring program to provide a reliable basis to judge present conditions and changes over time in spawning habitat area in the Lewis River below Merwin Dam, and (2) Provide a means to determine when spawning gravel supplementation efforts to preserve or expand such areas is warranted.

An independent consultant will perform the following tasks:

Task 1 – Develop a long-term monitoring program to assess the retention of gravel of suitable size for salmon spawning in areas downstream of Merwin Dam. This evaluation should evaluate present spawning areas and areas that may be used once salmon populations are recovered. The spatial extent of the evaluation will be based on a geomorphic analysis of how far downstream the effects of reduced gravel supply on spawning habitat might extend. The goal is to find a methodology that (1) quantifies the amount of suitable gravel, (2) indicates where there is a change, and (3) is repeatable. Assessments would occur annually for the first 3 years. Follow up assessments will occur following flood events. The consultant will determine the recurrence interval of floods necessary to trigger an assessment.

Task 2 – Develop a scheme (stating assumptions and rationale) to determine when gravel augmentation would need to occur. In developing this scheme, the consultant should consider the habitat requirements of a recovered population rather than the current population, subject to the limitations in Section 7.2 (d) of the Settlement Agreement.

Task 3 – Propose a gravel augmentation program that addresses the quality of gravel to be augmented, the timing of the augmentation, and the methods to be used. The program shall be flexible enough to allow for incorporation of new technology or knowledge into the means by which gravel augmentation could occur.

Reporting

Study plan development and implementation schedule to be set forth in Settlement Agreement. A draft report will be sent out to parties for review. Prepare a final report, incorporating comments from interested parties.