Monitoring of Tributary Streams in the Swan River Basin, Montana:
Findings from 1997-2015

Report Prepared for Swan Valley Connections

Groom Creek. Cross-section. 2010

Groom Creek. Cross-section. 2015

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Abstract

This project monitors a suite of tributary streams of the Swan River Valley within National Forest system lands and compares those with timber management to similar streams in reference condition (either un-roaded or designated wilderness). The general uniformity of National Forest timber management practices offers a chance for a large-scale monitoring program to evaluate whether practices adequately conserve water quality and fish habitat. Forty-four stream reaches have been monitored for physical changes, the oldest reach dating to 1997. Each location is sampled roughly every 5 years on a rotating panel. Results indicate no significant difference between the groups for frequency of pools, residual depth of pools, large woody debris size and abundance, stream bank stability, channel width, or water temperature. However managed streams do tend to have smaller sized substrates than reference streams. This correlation is statistically significant but does not have an obvious linkage with any particular amount of activity, location or sample year. Thus while modern timber management has adequately conserved most aspects of fish habitat, there still appears to be a lingering impact of sedimentation. Another finding is a strong trend towards increasing frequency of large woody debris over time in all locations, a possible indication of growing fuel load in riparian areas. Additionally, despite concern about climate change, water temperature has not changed meaningfully in this study timeframe.

Background and Project Description

The objective of this monitoring program is to validate that current land management practices are adequately protecting aquatic habitat. This is achieved by comparing control streams (“reference”) in wilderness areas or otherwise unmanaged areas, to streams within watersheds that have management activity (“managed”). This general approach is well documented by Kershner et al. (2004).

The program focuses solely on National Forest system lands of the Swan River basin, which currently occupy 74% of the land base. Roughly half of the basin is unroaded or designated wilderness, much of this in high elevation. Dominate land use of lower elevation is timber management with a network of associated forest roads, many of which were constructed in 1960-1970’s. Very little new road construction has taken place since 1990. Since 1995, the Forest Service has generally left un-harvested buffers along streams (ranging from 15m to 94m), although occasionally a limited number of trees were removed for safety concerns, salvage or access needs. The Swan River valley has no mining, very little water withdrawal, very little public land grazing, and the recreational uses (hunting, hiking, etc) are presumed to have almost no impact to streams. This affords the opportunity to monitor the impact of timber harvest and associated road work without confounding land management uses. Selected monitoring areas primarily focus on National Forest system land management and avoid state lands and private lands, which occupy 14% and 9% of the land base, respectively.

This monitoring program utilizes standardized protocols at select, carefully marked locations. Recent peer-reviewed literature has helped define the “best science” of stream monitoring and allows some statistical rigor to interpret data (Roper 2004, Archer et al 2004, Al-Chokhachy et al 2011). Beginning around 2002, the Forest Service developed a peer-reviewed aquatic habitat monitoring program as a requirement of the PacFish/InFish Biological Opinion (PIBO). PIBO surveys have been collected through the Columbia River basin in order to address large-scale effectiveness of Forest Service management practices. This effort happens to have 8 randomly selected reaches in the Swan River basin.

Local interest groups desired a more rigorous and focused monitoring program for the Swan River basin. More sample points and quicker analysis timeframe than the larger PIBO effort would confirm local timber management practices sufficiently protect local aquatic resources. The standardize PIBO protocols are retained but streamlined. Data only focus on physical habitat parameters with no fish or macroinvertebrate sampling.

Seven of the 8 reaches monitored by the larger PIBO effort were retained (one was deferred since it is downstream of state land thus may not represent National Forest land management). The PIBO program independently monitors the 7 reaches and provides data summaries. An additional 37 stream reaches are monitored by local crews. While there is possibility of observer error between these two field crews, this is assumed to be minor since the crew leader follows written protocols.

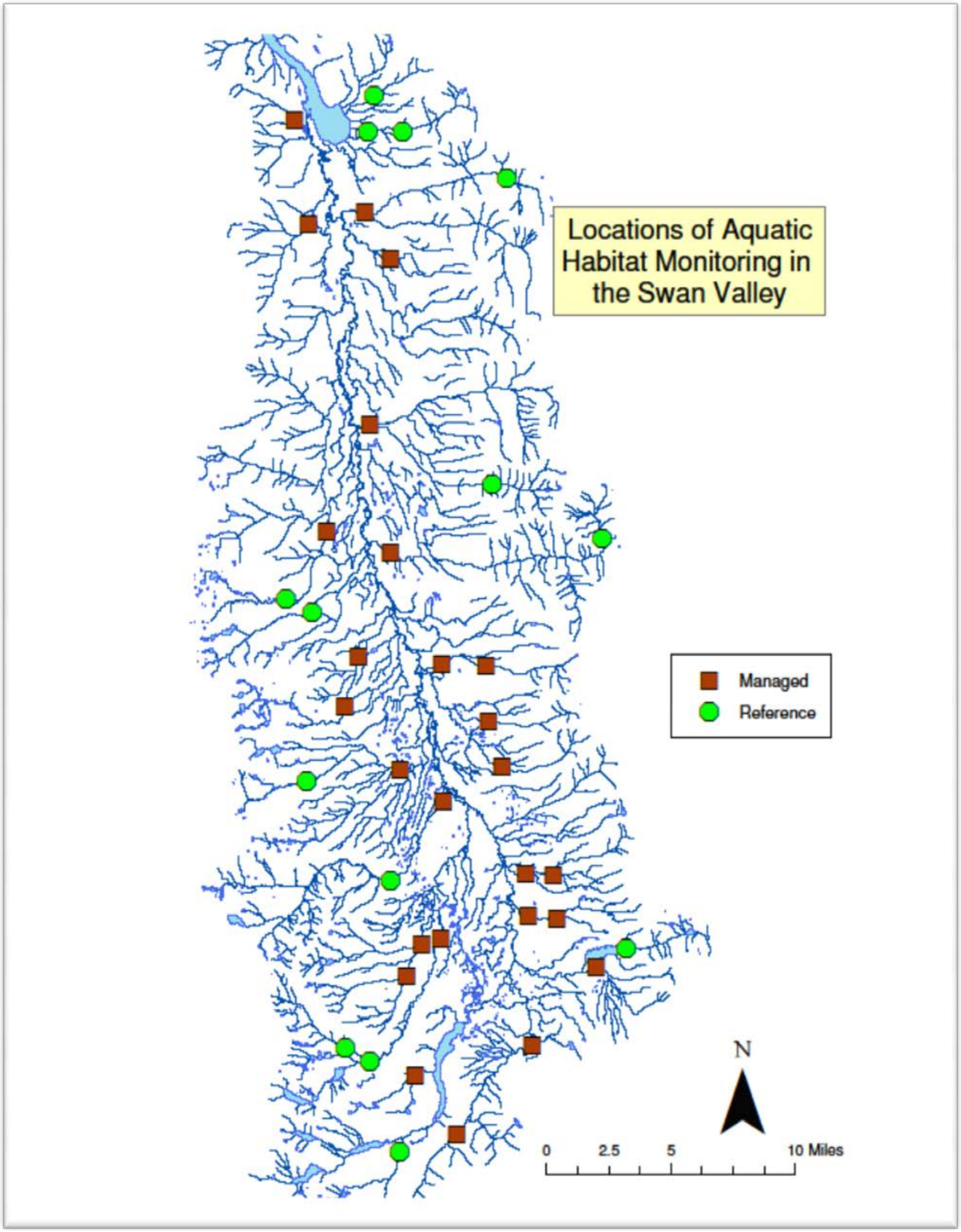
The additional 37 monitored reaches were selected by systematic stratification instead of random placement. Figure 1 illustrates the locations of the 44 monitoring reaches. Care was used to distribute them throughout the basin, typically two per 6th code HUC. All reaches are in areas modeled to have low-gradient (less than 5% gradient) which are considered potentially sensitive to change, although field determination found some were slightly higher than predicted in GIS. Sampling reaches vary between Rosgen channel types A, B, and C (Rosgen 1994). Locations avoided road crossings, vicinity of lake outlets, beaver dams and highly braided channels.

Once sampling locations were selected, GIS analysis computed their contributing watershed size and elevation. Unfortunately the location and harvest intensity could not be easily categorized due to overlapping polygons and incomplete historic records. Therefore, road density (kilometers of roads per square kilometer of land) was incorporated as a surrogate for land management. Increasing road density is assumed to reflect more timber harvest, although it is recognized that this is not always true since some roads may be a legacy of older, inefficient harvest practices and some provide recreation or private land access. It is also recognized that roads do not necessarily have the same ecological impact as vegetation management. Un-roaded areas, whether designated as wilderness or not, are considered reference areas with essentially no past land management. No effort was made to categorize streams by wildfire history. During this monitoring effort, several streams had stand-replacing wildfires but this is presumed to be a normal event with a channel response that mutes over time.

Fifteen of the 44 monitoring reaches (34%) are reference landscapes and 29 are managed (66%). Reference locations with criteria described above were challenging to find, resulting in an unequal distribution between managed and reference studies. Fish distribution was not considered in selection, but strong preference given to streams with perennial flows. Channel widths averaged 8.03m, ranging from 2.2m (unnamed tributary of Buck Creek) to 45m (Upper Elk Creek). All surveys were collected in base flows, typically July through September. Although effort is made to retain original locations, some flexibility is incorporated. Two locations had to be abandoned due to beaver activity or undesirable channel type and were replaced elsewhere.

Al-Chokhachy et al (2011) estimated temporal variance of PIBO measurements and cautioned that simple, one-time sampling will not adequately contrast managed streams to reference streams. Thus not only is it important to sample the right locations with careful methodology, but these locations must be monitored over many years. The monitoring is conducted on a rotating panel system where each stream is sampled about once every 5 years. The oldest monitoring reaches were established in 1997, predating the PIBO protocols. Only those habitat measurements that follow modern PIBO protocol were included in this dataset. As this monitoring effort ages, the information increases in value.

Figure 1. Locations of Monitoring Reaches. Wolf Creek is just north of Swan Lake and not shown.



Methods and Results

Six habitat attributes are reviewed in the following discussion. Additional data is collected at each location but not summarized in this report. Specifically; channel gradient, sinuosity and entrenchment are recorded primarily for classification. Wetted perimeter transects are recorded opportunistically to compare older fish habitat surveys but actual discharge conditions on date of survey are not of value for monitoring. At least six digital photographs are taken at standard intervals for each reach and these have proven interesting to observe changes but they do not lend themselves to quantitative review in this report. An example of photograph monitoring is on the title page. All statistical summaries use alpha level of 0.05 for test of significance.

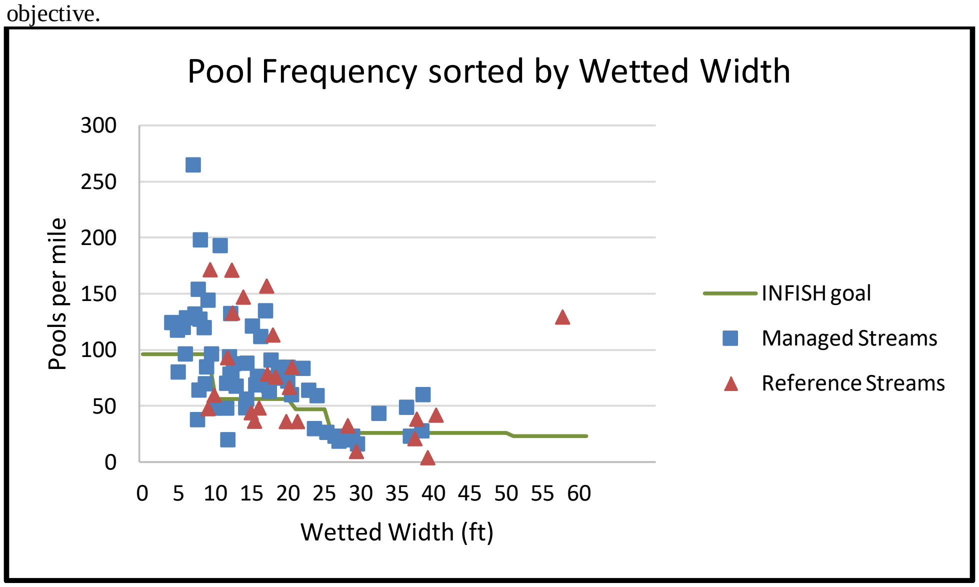
A. Pools

Pool habitat is vitally important to native fish such as cutthroat trout, bull trout, and mountain whitefish. There are several different measurements of pool habitat. One measurement is the frequency of pools which is expressed as the number of pools per lineal mile. Simplified channels that are devoid of pools tend to have lower carrying capacity. INFISH provides an objective of a minimum number of pools that varies by wetted width (feet).

Figure 2. An example of a qualifying pool. North Fork Lost Creek, 2012.

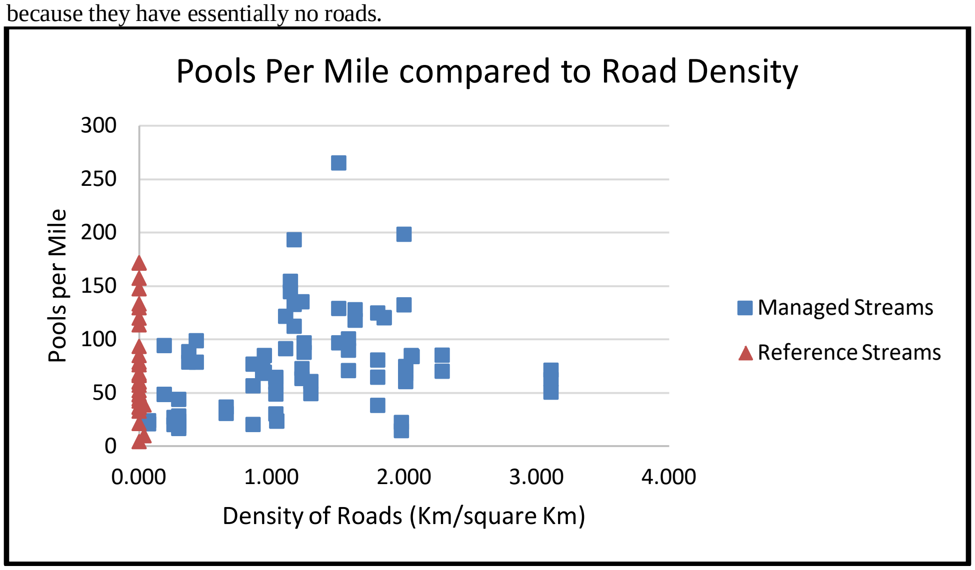
Data indicates that only 56% of all surveyed reaches meet the INFISH objective, regardless if reference or managed stream (Figure 2). This implies that the INFISH objective is not feasible and does not match local natural conditions. ANOVA found no difference in a simple comparison of pool frequency between reference streams and managed streams (p = .75, F obt .09, F crit 3.93, df 104).

Figure 3. Pool frequency plotted against wetted width. Data points above the green light are meeting INFISH objective.



Data was also queried to test the hypothesis that increasing road density would negatively correlate with pool frequency. Multiple regression did not support this, in other words, there appears to be no correlation of pool frequency with road density (p=.06) (figure 3). One further hypothesis was tested to be certain that unequal distribution of channel widths (reference streams tend to be larger) was not obscuring a signal. Because pool frequency does significantly correlate with wetted width and bankfull width (p = <.0001 for both), data was converted into a pools/width ratio and then plotted against road density. This found a significant correlation in that increasing road density actually increased pool frequency (p = .001). This surprising finding does not necessarily mean that building more roads equates to better fish habitat but simply there is no evidence that land management is reducing pool frequency.

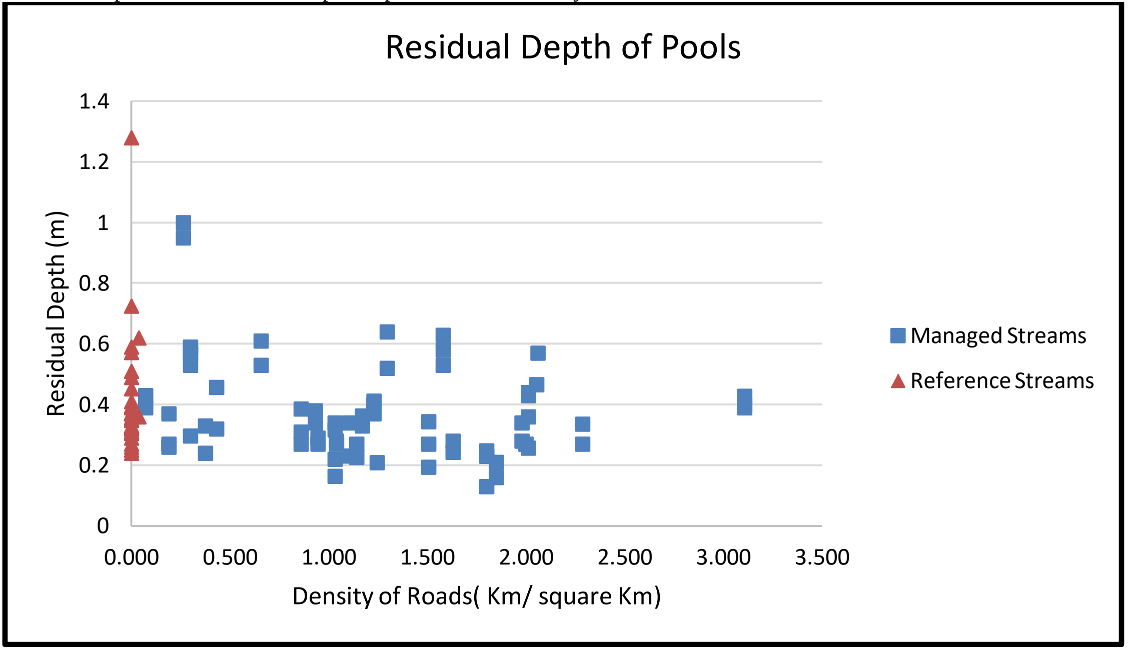
Figure 4. Comparison of pool frequency with road density. Reference streams are clustered on left side of X axis because they have essentially no roads.



Another way to evaluate pool quality is computing the residual depth of pools. The residual depth of a pool is simply the maximum depth minus the crest depth, thus it can be consistently measured at any discharge stage. The measurements of up to the first 10 pools encountered are averaged for a single value and results have little observer error (Archer et al 2004)(Bauer and Ralph 2001). Residual depth of pool can rapidly change due to natural events such as fire or floods but usually the change tends to be slow and gradual. Thus, any significant change may be an indicator of human-caused impacts. Cumulative effects of land management such as road construction and timber harvest may result in changes in evapotranspiration, groundwater movement and stream discharge patterns. These in turn could alter stream power and channel stability, causing the stream simplify its habitat. Unstable, simplified channels typically have shallow pools.

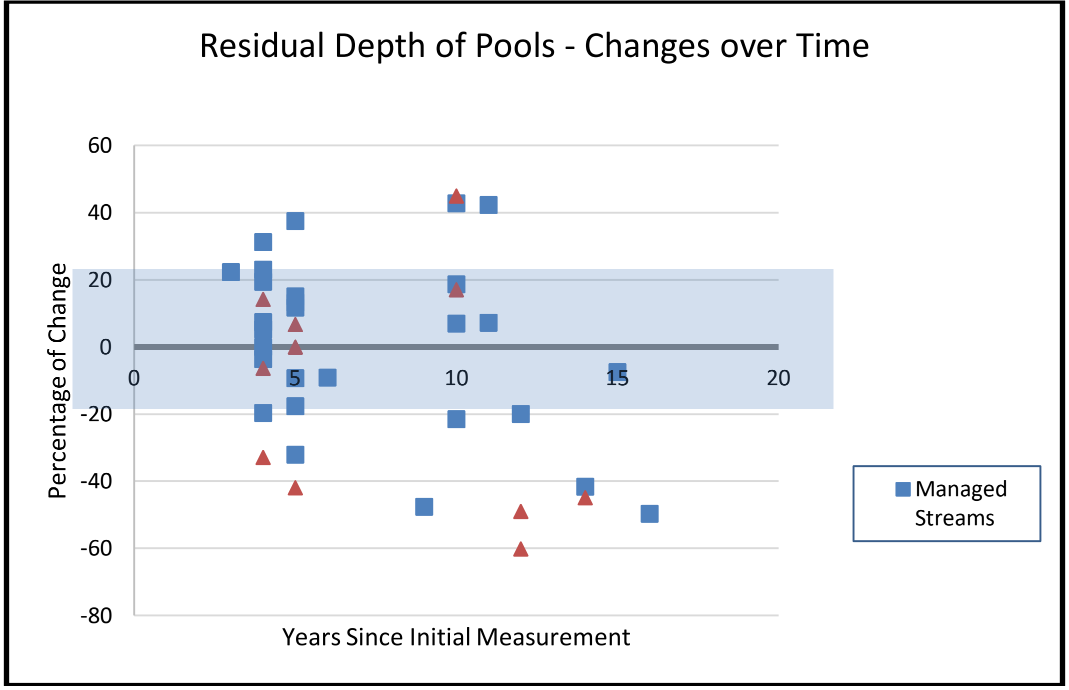
Data indicates there is no difference in residual depth between the two groups of managed verses reference (f obt= 1.342, f crit = 3.94, df 101). In other words, the mean variance between streams was greater than between the management classification. This finding agrees with a similar review of 70 stream reaches collected elsewhere on the Flathead National Forest. Kendall (2014) found no significant difference in residual depth of pools between managed and reference streams throughout the Flathead basin. Furthermore multiple regression found no significant correlation of residual depth of pools to road density (p = 9.7) (Figure 4). Residual depth of pools does have a positive significant correlation with bankfull width whereas the wider streams tend to have the deeper pools. Residual depth of pools does not correlate with pool frequency, large woody frequency or gradient.

Figure 5. Comparison of residual depth of pools to road density.



Because residual depth of pools is regarded as a sensitive indicator of habitat impacts, analysis was completed to see if these have changed over the course of this monitoring program. Those streams sampled at least twice are displayed on Figure 5 below. While ANOVA did not find any significant differences between managed and reference groups (f obt = 1.485, f crit = 4.17, df = 32), the amount of change does seem more variable than what Roper et al (2007) observed in a 15 year study in Idaho. The reason for such variable responses in Swan River Valley streams is uncertain, although possibly an indicator of effect from recent wildfires.

Figure 6. Illustration of changes in residual depth of pools over time. Each point represents the total amount of change in one particular stream reach over time. Trends moving above the y axis indicate the pools are getting deeper and thus below are becoming shallower.



B. *Stream channel shape*

Changes in a stream channel’s width and depth over time indicates a change in the stream’s power. A stream that gradually narrows means it is now transported less water and bedload than before, allowing the stream banks to encroach. Conversely, a stream that needs to transport more water or bedload would erode its stream banks outward and become wider. A stream with a small width/depth ratio is generally considered to reflect stable conditions and offers better trout habitat. A single value of a stream’s width has little use, but when monitored over time it can be an indicator of changes in the watershed. Stream channels can become dramatically wider after a flood and then gradually recover and narrow over time. Actions that remove vegetation in the watershed, such as timber harvest or private land development, can indirectly alter stream power, which in turn can affect stream channel shape.

Channel shape is monitored by recording the channel width (at bankfull stage) at five evenly-spaced transects. Average channel depth is calculated from three depth measurements at each transect. These five transects yield an average width/depth ratio for the stream.

As expected, the channel width does correlate with watershed size in that larger watersheds tend to have larger streams. However, data indicates no correlation with road density and average bankfull width or width/depth ratio. Nor is there any correlation with width or width/depth ratio over time. Both managed and reference streams have equal probability of increasing or decreasing their widths or width/depth ratios. Unlike the 2013 report which noted a trend of increasing channel width throughout the Swan Valley, the additional of more samples erased that trend.

C. Large Woody Debris

The quantity of large woody debris in streams is recognized as essential for trout hiding cover as well as crucial for the formation of pool habitat. The abundance of large woody debris (LWD) is described as the number of pieces per lineal mile of stream. Protocols for numerating wood is unchanged since the initial 1997 surveys and in recent years, surveyors have also randomly measured length and diameter of some pieces. Although it may seem simple to just enumerate wood, it is surprisingly challenging. Monitoring woody debris is the least precise parameter that Archer et al (2004) studied, human error possibly accounting for 23% variation.

Figure 7. Example of Large Woody Debris in Upper Beaver Creek, 2012.

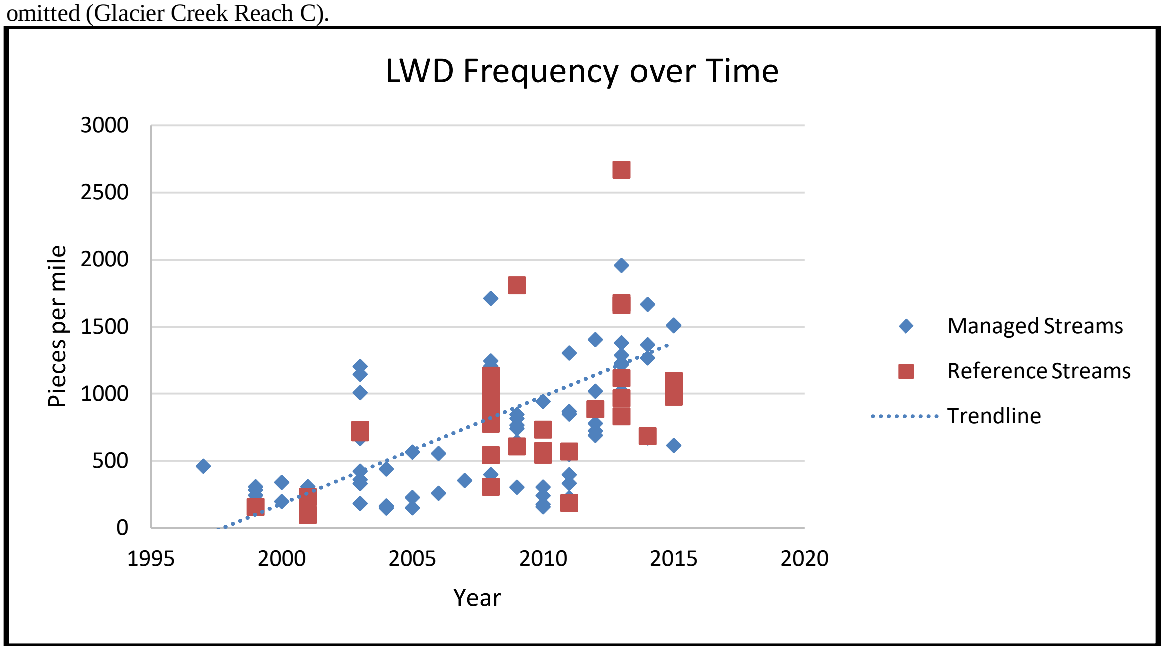
There is no known “upper limit” of how much wood is needed for fish habitat but INFISH defines a minimum of 20 pieces per mile. Data indicates that every stream in every year has far exceeded the INFISH objective. The average of all survey reaches is 839 pieces per mile.

The data set was queried to test the hypothesis is that managed landscapes would have fewer pieces and/or smaller LWD than reference streams. An ANOVA rejected the hypothesis, in other words, there is no evidence that managed streams have fewer or smaller pieces of wood. The frequency of LWD was not significantly different (p= 0.54, F = 0.37, Fcrit = 3.93, df = 105) nor was the average diameter (p=0.07, F = 0.37, Fcrit = 3.99, df = 62). Curiously, the average length of LWD was actually longer in managed streams (6.7m) than reference streams (5.1m) and this was significantly different (p = 0.013, F = 6.53, Fcrit = 3.99, df 62). Given the potential for observer bias accounting for 23% of the variation, this difference may not be real.

In reference streams only, the frequency of LWD does positively and significantly correlate with the frequency of pools ($R^2 = 0.23$) but when managed streams are added, the correlation is not significant. This implies that LWD in managed streams is not successfully creating the same number of pools. Multiple regression analysis found no significant relationship with LWD and bankfull width or residual depth of pools. The frequency of LWD aggregates (clusters of 2 or more pieces of wood) strongly correlates with LWD frequency but does not provide any more insight to pool frequency or depth.

One striking finding is that the LWD frequency in streams is increasing over time (Figure 8 below). This change is highly significant (p=<.001) and happening with both managed and reference streams. The amount of change excceds what could be attributed to observer bias. It is unlikely that the retention of unharvested streamside buffers is the cause of this change because reference streams are also changing. A possible explanation is that fire suppression has allowed increased tree density which in turn increases LWD in streams.

Figure 8. LWD Frequency in all surveyed reaches over time. One outliter in 2015 had 6,612 pieces per mile and was omitted (Glacier Creek Reach C).



D. Bank Stability

The stability of a streambank can be an indirect tool to assess channel changes or changes in riparian vegetation. A stream that needs to accommodate a large runoff will typically widen its banks and cause, at least temporarily, unstable stream banks. Changes in riparian vegetation such as tree mortality or ungulate grazing can also weaken stream banks. Due to the highly variable nature of streambanks over distance and time, there is no perscriptive minimum amount of stability expected in forested streams.

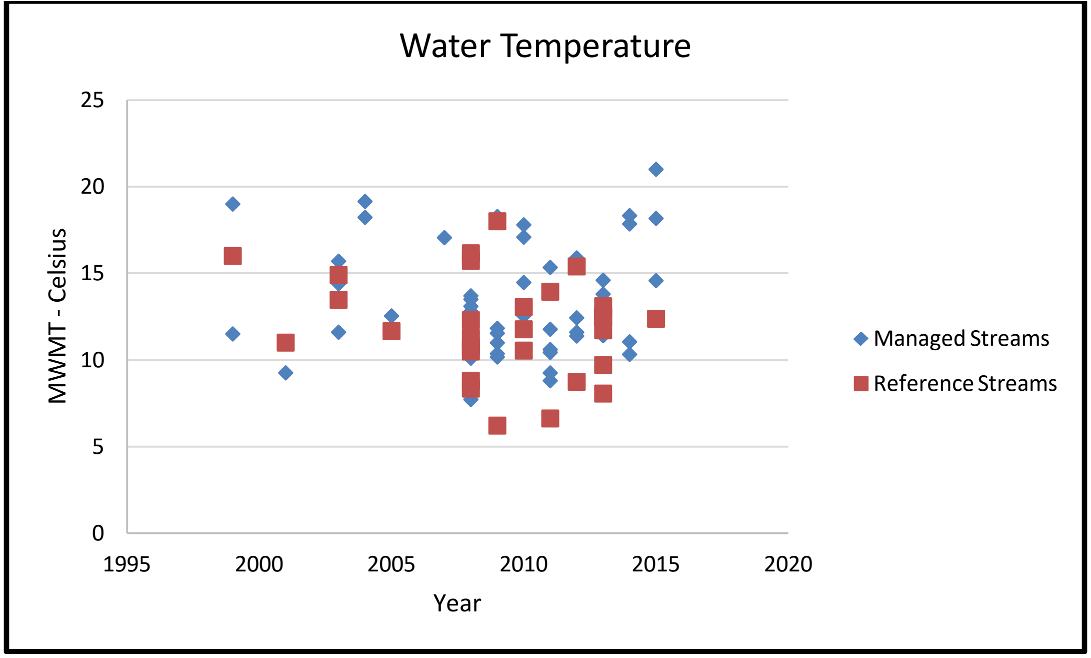
This project examined the hypothesis that managed streams might have more stressors on streambanks than reference streams due to increased water yields or cattle grazing or other management actions. Streambank stability was recorded at 21-25 evenly spaced intervals throughout the sample reach and averaged for one value. Both managed and reference stream tended to have very stable banks (typically 93-96% stable) and ANOVA found no significant difference between them. Furthermore a regression analysis found no significant pattern of streambank stability over time. All sampled reaches were largely stable regardless of location, year, channel size or wildfire history and the hypothesis that they are affected by land management is not supported.

E. Water Temperature

Water temperature is key habitat parameter since it is regulates growth and survival of cold-blooded species such as fish. Temperature is recorded hourly with probes submerged in pools, typically from June to September. The early years had few probes but technological advances have made probes more affordable and efficient, thus allowing a leap in data since 2005. Data is summarized by finding the seven warmest consecutive days (typically late July) and then averaging their maximum temperature each day. This "Maximum Weekly Maximum Temperature" (MWMT) provides a more rigorous way to compare trends than occasional erratic spikes in temperature.

Water temperature is governed by climate, elevation, aspect, topography, groundwater input, shade and channel width. While land management presumably has no influence on climate, elevation, aspect or topography, it is possible that removal of streamside shade trees or construction of roads or increase in water yields could indirectly impact water temperature. However, a regression of road density to all MWMT found no significant correlation. This is not a surprise in that Swan Valley streams tend to be heavily forested and the Forest Service has only rarely harvested riparian trees in the past few decades. Data indicates that MWMT is in fact sensitive to channel width (and less so, elevation) but there is no evidence that land management has increased channel width or subsequent water temperature.

Figure 9. MWMT findings at all locations over time.



Climate change is a growing concern in that anticipated increased air temperatures and earlier spring runoff could affect water temperature. However, no trend is apparent since the earliest data (1997). Monitoring of stream temperatures found sometimes streams get warmer, other times colder and it makes no difference if it is managed or reference. The Swan Valley Connections (a non-profit group) has maintained eight continuous recording thermometers since 2005. This information could be used to "correct" single year water temperatures. For example, 2011 was the coldest on record and thus all MWMT collected that year could have 1.731 C added to it in order to fairly compare it to other years. Likewise the warmer years, would have a reduction factor from MWMT. Re-analyzing the MWMT with "correction factors", there still was no significance of road density to water temperature. A hypothesis that land management has affected water temperature is not supported, even if annual climate variance is removed.

F. Stream Substrate

Evaluation of stream substrate condition is an important component of any fish habitat surveys. Sedimentation is a common concern and considered the most pravelent water pollutant throughout the United States (Bauer and Ralph 2001). Fine-sized sediments such as silt, sand and clay can be the result of erosion from land management activities such as road construction, timber harvest, grazing and prescribed burning. Excessive amounts of fine sediments can be deleterious to native fish, including bull trout (Bowerman and Budy 2012). Although sedimentation is a key consideration, there are no regulatory standard on what is acceptable to a stream. This is due to the natural variation due to gradient, geology, landscape disturbance and even variation from riffle to riffle. Efforts to define stream substrate objectives on the Flathead National Forest have been largely unsuccessful. Gardner et al (2007) and Kendall (2010) found more variance than can be explained.

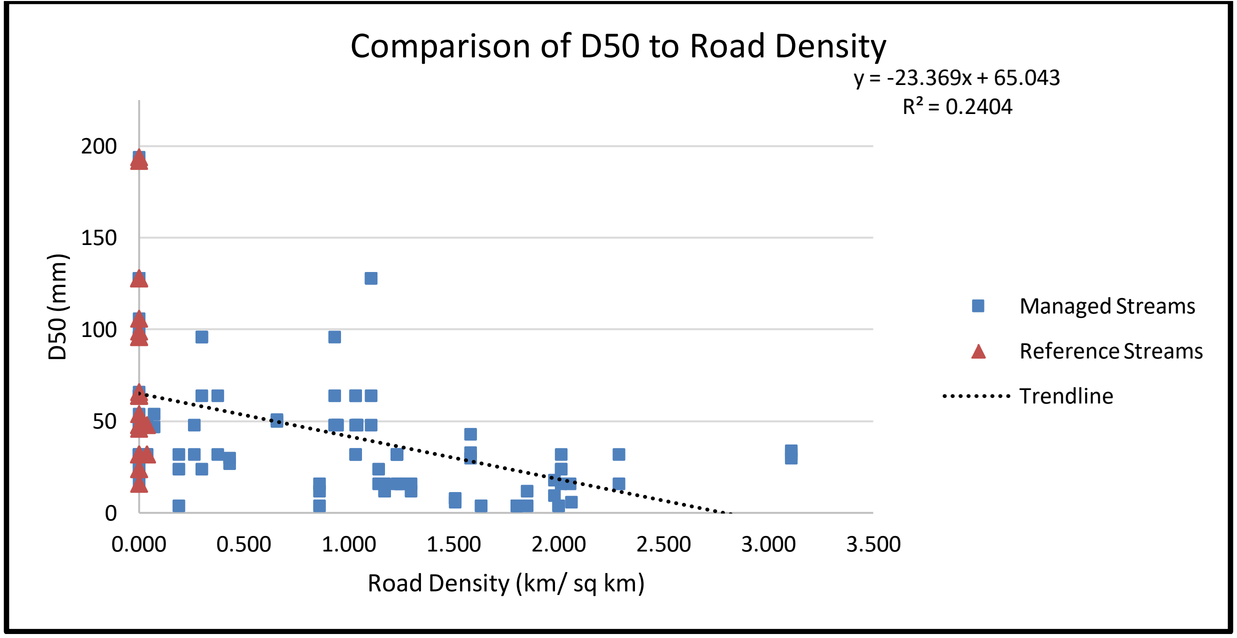
Consistent, quantitative monitoring of stream substrate is challenging and every sampling methodology has its shortfalls (Bunte and Abt 2001). This project utilizes the pebble count methodology because it is widely used and cost effective. Surveyors measure the bed substrates at evenly spaced intervals across four riffles. The medial axis of each substrate is assigned to a category (such as <6mm, 6-8mm, 8-12mm, and so forth). A simple averaging of the amount of fine sediments is not productive because of the extreme variability in nature (Archer et al 2004). Likewise Al-Chokhachy et al (2011) found percentage of fine sediment such high temporal variability, it did not link well to any model of land management, geology or stream characteristic.

However, tracking the median diameter of all pebbles counted in a riffle (known as D_{50}) offers a better tool because it has less observer error and is less prone to change quickly (Archer et al 2004). Riffle D_{50} indirectly relates to sedimentation. A declining riffle D_{50} indicates smaller median size which may (but not always) reflect increasing fine sedimentation. Changing D_{50} could reflect land management impacts or natural disturbance events or both (Al-Chokhachy et al 2011)(Roper et al 2007). This project also incorporated “Riffle Stability Index” whenever possible (Kappesser 1993). A Riffle Stability Index is an average diameter of 30 largest cobbles left on a point bar and reflects the largest materials the stream moved in the most recent bankful event. If no point bar is located, the Index cannot be recorded.

Kendall (2010) observed a correlation of riffle D_{50} to sheer stress in various Flathead National Forest streams. Sheer stress is a computation of gradient, bankfull depth (in leu of hydraulic radius) and the specific weight of water. Typically the higher the sheer stress, the greater the force of water to mobilize smaller materials and leave only large materials. Yet this dataset did not find a correlation of riffle D_{50} to gradient or bankfull depth or sheer stress ($R^2 = 0$). However, sheer stress does significantly correlate with Riffle Stability Index values. Increasing sheer stress does equate to increasing cobble size on the point bars but not D_{50} in riffles. Curiously there is no pattern to changing riffle D_{50} over the years with Riffle Stability Index. The D_{50} in riffles appears quite independent of sheer stress and thus it remains impossible to assign a “standard” or “objective” for streams to achieve.

A previous review of Swan valley riffle D_{50} data did not observe any pattern of managed verses reference streams (Gardner 2013). However with the addition of more samples and a change of metric (using road density instread of simple categories of managed and reference), this dataset did find a significant negative correlation of road density with D_{50}, shown on Figure 10 below ($p = <.001$). This finding concurs with assessments of the Flathead Lake basin scale (Kendall 2014) and regional scale (Kershner and Roper 2010).

Figure 10. Mean diameter (D50) of riffles against road density.



The correlation of D_{50} to road density encorporated all samples in all years equally. No pattern is observed with changes over time. This is somewhat unexpected. Stream riffles appear to change chaotically over time, ranging from a low of 88% reduction of D_{50} (ie. increased fines) to a high of 66% increase to no change at all. No pattern is observed regardless of road density, year of survey or number of repeat visits. Thus while there appears to be a link of road density with D_{50}, it cannot be certain this is the situation every year or if there is any trend towards aggrading or degrading over time. This study is an emphirical review and cannot offer any causal explaination on the linkage of road density.

Discussion

The findings of this monitoring program strongly suggest that current land management practices are adequately protecting most aquatic habitat features. There are no significant differences in numbers or trends with residual pool depths, channel width, large woody debris, bank stability or water temperature between managed or reference streams. This study largely agrees with Kendall (2010) findings for the broader Flathead National Forest although Kendall did observe differences in residual pool depth that this study did not detect. Both this study and Kendall (2010) findings imply that retaining un-harvested riparian areas has successfully maintain fish habitat even though adjacent upland lands are harvested. However, the trend of increasing woody debris in all streams may be a reflection that fuel loads are increasing. Fire suppression (even in un-roaded areas) and deferring harvest in riparian areas may be a mixed blessing. While large amounts of woody debris provides superior fish habitat, it may be setting the stage for larger fires in the future.

Both this study and Kendall (2010) did find a negative correlation of road density with D_{50}, thus implying more fine sediments in managed streams. Given the unharvested buffers it seems unlikely the sedimentaiton is directly from vegetation management itself. It is also unlikely that this is due to increasing woody debris which would cause the channels to scour new areas, because stream banks have been consistently stable in all streams. Fine sediments may be coming from the roads themselves. In recend decades the Forest Service has invested substantial effort to remove or replace poorly performing culverts, reduce sediment point-sources and decommission unnecessary roads. It is possible that either the recent effort is not sufficent or perhaps insufficient time has passed for benefits to be realized. This study does not identify any particular stream needing restoration. No stream appears to be an outliter or have a deteriorating trend over time.

Water temperature does not appear to be increasing in Swan Valley streams, which is perhaps surprising given the large-scale trend observed by Issak et al (2011) in the Columbia River basin. A possible explaination is that the the Swan Valley has considerable groundwater input and may not be as sensitive to climate change. It is also recognize that a majority of water temperature data only extends roughly 15 years which is a very short timeframe for climate change analysis.

Given the perhaps unexpected findings of sedimentation impact and the unexpected resilience of water temperature, these habitat features should be continued to be monitored in the future. The importance and sensitivity of residual pool depth also suggest the importance of future monitoring. Large woody debris, channel shape and stream bank monitoirng are desirable but perhaps not as important in future efforts.

Acknowledgements

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