Monitoring of Tributary Streams in the Swan River Basin, Montana: 2020 Status Report

SF Lost Creek. 2013

SF Lost Creek. 2020

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Abstract

This study quantifies changes in fish habitat and water quality in streams in response to land management (forestry) in the Swan River valley. Since 1997, forty-three stream locations have been monitored on a rotating basis, typically sampled every five years. Sampling design allows contrast of roaded watersheds ("managed") against those that have few or no roads ("reference") and also allows a comparison of trends over time. Results indicate no significant difference between the groups for large woody debris abundance, pool frequency, and median substrate size in riffles (D_{50}). However, managed streams have higher Riffle Stability Index, an indirect indicator of elevated bedload transport. Large woody debris abundance is increasing over time across the board but no change in pool frequency or riffle D_{50}. Reference streams are wider and have shallow pool depths compared to managed stream, which may be due to elevation and do not indicated degraded habitat. Managed streams have warmer Maximum Weekly Maximum Temperatures (MWMT) during the summer than reference streams. Road density is positively correlated to increased MWMT and increased Riffle Stability Index. The increasing abundance of large wood and concern about lack of wildfire disturbance may generate more interest in reducing fuels and re-introducing wildfires to riparian areas. This may be beneficial but pose a conundrum in that the actions may also further increase water temperature and sedimentation.

Background and Project Description

The objective of the monitoring program is to quantify fish habitat and water quality changes in response to land management practices of National Forest system lands at the scale of the Swan River sub-basin. The dominate land management is timber production in cool or cold moist forests (primarily Douglas-fir, Western larch, Lodgepole pine). Earlier management favored stand-replacing harvest but in more recent decades treatments have more diverse retention. Previous harvests often extended to streambanks but since 1995 the Forest Service commonly retained an undisturbed buffer ranging from 15m to 94m. Only a limited amount of harvest was been conducted in riparian areas such as needed to address safety concerns, salvage of dead trees, or access corridors. To facilitate timber management, many roads were constructed in 1960-1970's. Very little new road construction has taken place since 1990 and four watersheds now have fewer roads than when the study began in 1997. Most forest roads are single lane, closed to public use and partially vegetated with forbs or brush. In recent decades, emphasis has been placed on minimizing erosion from the road network by a series of Best Management Practices (BMPs). Additionally, many older culverts that were poorly installed have been replaced with larger ones or removed altogether. This is intended to prevent catastrophic failure of culverts, although actual failure has been only a rare occurrence to date. These road-related investments can generate temporary, localized areas of sediment delivery to streams but ultimately assumed to reduce chronic impacts.

Wildfires have been largely excluded in the Swan River valley since the late 1880's, regardless of land ownership or managed designation. Records as well as approximations from tree rings suggest that only 87,500 acres have experienced a fire since 1889 (approximately 20 percent of the basin). Only 21,500 acres have burned since 1997.

Because of fire suppression, 89 percent of monitored locations have not experienced any wildfire either adjacent or upstream of their location since this project began. Due to concern about lack of fire in fire dependent ecosystems, land managers are increasingly using prescribed fire to return fire to the landscape although they have largely avoided riparian areas.

The Swan River valley has limited mining, very little water withdrawal, very little public land grazing, and the recreational uses (hunting, hiking, etc.) do not appear to have affected fish habitat. Therefore the monitoring program should be able to link stream channel responses to timber management, forest roads, and fire suppression. These are actions that are routinely considered during the agency's analysis of environmental effects. The study design is sampling at the large, basin-wide scale. It is not intended to monitor pre- and post-treatments at any given stream.

This report is the latest is a series of monitoring reports. Previous results of the same study area were reported by Gardner (2011) (2013) (2015) and (2018), although earlier reports did not include all metrics evaluated here. Kendall (2010) and (2014) also reported on habitat monitoring that included Swan River valley as well as other watersheds in the Flathead basin. Whenever consistent methodologies were used, this report will compare current findings with older ones.

Methods

This program monitors conditions at 43 locations distributed around the Swan River valley following written, quantifiable protocols. Using repeatable measurements at marked locations allows statistical rigor to confirm changes (Roper 2004, Archer et al 2004, Al-Chokhachy et al 2011). Several locations were initially established in 1997 and the remainder were gradually added over time. Beginning around 2002, the Forest Service developed a peer-reviewed aquatic habitat monitoring program as a requirement of the PacFish/InFish Biological Opinion for Bull Trout (PIBO). The intent of PIBO monitoring is to address large-scale effectiveness of Forest Service management practices. Protocols changed slightly in subsequent years as described in Kershner et al (2004), Al-Chokhachy et al (2011) and Archer et al (2012). While some of the oldest data is not comparable, this program has selectively retained those that have remained consistent enough to be useful.

Monitoring locations were selected by systematic stratification of the Swan River watershed rather than random placement. All locations are intended to represent the direct or indirect (downstream) effects on management on National Forest system lands, thus deferred locations that could reflect actions on state or private lands. Care was used to distribute them throughout the basin, typically two per HUC12 sub-watershed. All locations were modeled to be at least 2m wide and have less than 5 percent gradient. These channels are considered potentially sensitive to change. A few were subsequently found to have higher gradient than modeled but retained anyway. Locations avoided road crossings, vicinity of lake outlets, beaver dams and highly braided channels. Fish distribution was not considered in selection, but strong preference given to streams with perennial flows. Figure 1 illustrates their locations and Table 1 characterizes the 43 sampled locations.

Fifteen of the 43 monitoring locations (35%) are reference landscapes and 28 are managed (65%). Reference locations with criteria described above were challenging to find, resulting in an unequal distribution between managed and reference studies. Reference locations are defined as less than 0.1 kilometer of road per watershed square kilometer but they may have hiking or stock trails. Many are in designated or proposed wilderness. The mean elevation of reference locations are higher than managed locations. Road density is the only descriptor of land management impacts. Unfortunately, no quantification of past timber management was possible due to overlapping polygons and incomplete historic records. Increasing road density is assumed to reflect more timber harvest, but it is recognized that road density alone is not a true indicator of land management impacts. Roads have variable effects to streams depending on their age, current traffic level, proximity to streams, soil, slope and type of stream crossing.

Data has been gathered by two separate crews. One crew, called PIBO crew, receive several weeks of training and then travel across Western states, working independently of local personnel. The PIBO crew has monitored 8 locations in the Swan River Valley. The other crew, called Local technicians, monitors conditions at 35 locations. These technicians receive training from the author, who provides consistency over the years. While there is possibility of observer error between these two field crews, this is assumed to be minor since all data collection follows the same written protocols.

Each location is permanently marked with reinforced metal bars driven into floodplains and Global Position coordinated recorded. During the initial survey, crews determined the length of the survey (based on protocols described in Kershner et al 2004), which was at least 20 times the channel width. All subsequent surveys examined the same area. Each location was monitored roughly every 5 years in a rotating basis. Rotating panel design is considered an effective and affordable sampling design (Anlauf et al 2011). The schedule is flexible to allow for additional studies or logistic considerations. The number of monitored locations grew slowly and some original locations had to be abandoned due to beaver activity and excessive gradient. All surveys were collected in base flows, typically July through September.

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

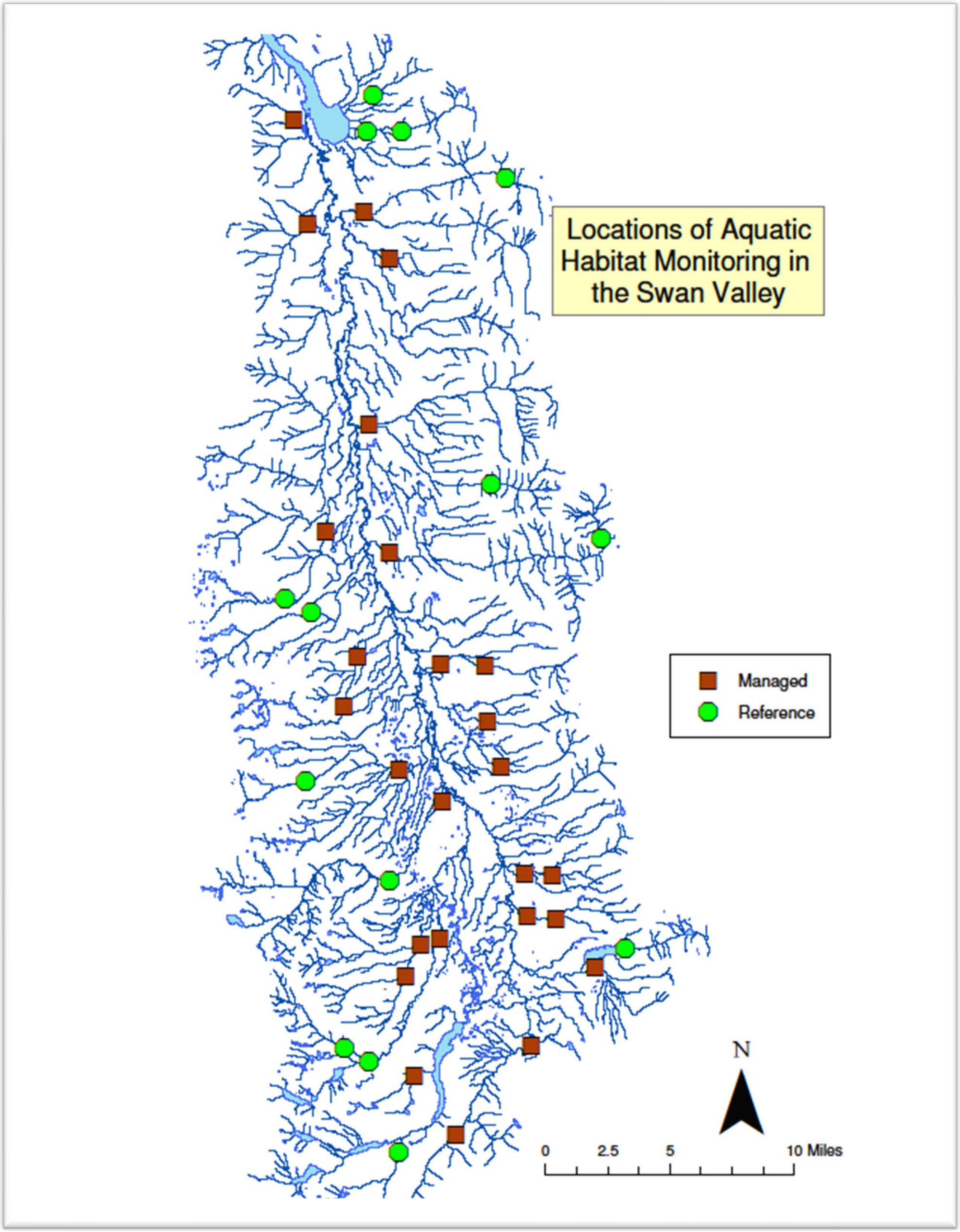


Table 1. Physical descriptions of study locations. Streams listed alphabetically. Gradient is averaged between initial samples. Width and depth reflect most current sample. NA means not available.

	Type	**Road density (Km/ Km^2)**	**No of samples**	**Observer**	**Gradient (%)**	**Elevation (m)**	**Bankfull Width (m)**	**Bankfull Depth (m)**
Barber, Lower	Managed	1.8	4	Local	1.17	1204	2.48	0.45
Barber, Middle	Managed	1.63	4	Local	1.28	1233	4.16	0.36
Beaver, Lower	Managed	1.85	5	Local	1.04	1252	4.68	0.39
Beaver, Lower 2	Managed	1.98	3	PIBO	4.46	1266	6.3	NA
Beaver, Upper	Managed	0.94	3	Local	4.40	1518	6.45	0.31
Bond, Lower	Managed	0.07	3	PIBO	1.35	944	12.3	NA
Bond, Upper	Reference	0	4	Local	8.06	1057	7.17	0.76
Cedar, Middle	Managed	0.43	3	PIBO	0.72	1087	7.62	NA
Cedar, Upper	Reference	0	3	Local	9.30	1540	5.84	0.48
Cilly	Managed	1.99	3	Local	1.44	997	2.48	0.38
Cold, Middle Fork	Reference	0	3	Local	2.35	1493	8.16	0.58
Cold, North Fork	Managed	0.99	3	Local	0.26	1110	12.12	0.50
Condon	Managed	0.19	4	Local	2.33	1139	4.43	0.46
Crazy Horse	Reference	0	4	PIBO	2.08	1660	9.1	NA
Dog, Lower	Managed	1.23	5	Local	1.27	1087	6.58	0.48
Dog, Middle	Managed	0.37	3	Local	2.90	1219	6.57	0.46
Elk, Lower	Managed	0.26	3	Local	1.15	1118	13.85	0.4
Elk, Upper	Reference	0.04	4	Local	0.59	1259	16.94	0.42
Glacier, Reach B	Reference	0	4	Local	1.52	1496	12.79	0.49
Glacier, Reach C	Managed	0.3	5	Local	2.14	1266	12.02	0.32
Goat	Managed	3.11	4	PIBO	1.37	988	9.36	NA
Groom	Reference	0	4	Local	5.80	1085	4.18	0.31
Herrick Run	Managed	2.29	3	Local	1.64	1546	7.36	0.36
Holland	Reference	0	3	Local	0.80	1235	9.14	0.37
Jim, Lower	Managed	2.06	3	Local	0.86	1102	6.83	0.61
Jim, Middle	Managed	1.43	4	PIBO	2.70	1300	8.16	NA
Kraft, Reach 2	Managed	1.02	6	Local	2.0	1292	9.52	0.44
Kraft, Reach 3	Managed	1.10	4	Local	6.12	1394	6.16	0.4
Lion, Lower	Managed	1.04	3	Local	0.77	1043	13.32	0.87
Lion, Upper	Reference	0	4	PIBO	1.81	1724	8.53	NA
Lost, Lower	Managed	0.66	3	PIBO	0.79	960	14.22	NA
Lost, North Fork	Reference	0	3	Local	2.69	1321	6.72	0.36
Lost, South Fork	Reference	0	2	Local	3.03	1495	8.0	0.42
Owl	Managed	1.17	5	Local	1.52	1243	6.38	0.33
Piper, Lower	Managed	0.93	4	Local	1.59	1055	6.8	0.44
Piper, Upper	Reference	0	3	Local	3.79	1334	7.78	0.51
Porcupine	Managed	1.12	3	Local	3.23	975	2.1	0.42
Sketch	Managed	1.51	4	Local	2.56	1239	2.57	0.34
Smith	Managed	0.86	5	Local	2.33	1161	5.03	0.3
Squeezer	Reference	0	3	Local	4.6	1444	8.48	0.68
Upper Swan River	Reference	0	3	Local	3.7	1473	10.9	0.45
Yew	Managed	1.85	3	Local	10.57	1011	4.26	0.36
Wolf	Reference	0	2	Local	4.21	1193	6.72	0.52

Six habitat attributes are reviewed in this report, specifically channel width, residual depth of pools, pool frequency, large woody debris frequency, stream substrate size and water temperature. This study has dual objectives of quantifying differences between managed and reference stream groups, as well as determining changes over time. Statistical analysis was done in Microsoft Excel software. All statistical summaries use alpha level of 0.05 for test of significance. Student's *t* test was used to compare if differences in means between groups were significant. Multiple regression with Analysis of Variance (ANOVA) was selected to determine correlations between values.

Additional data was collected that helped characterized the location. Furthermore at least six digital photographs are taken at standard intervals for each reach. These have helped understand changes (or lack of change) but they do not lend themselves to quantitative review in this report. An example of photograph monitoring is on the title page.

Channel width is is measured to the nearest decameter with a tape stretched from bankfull stage indicators across the stream. Any islands encountered that were higher elevation than bankfull were deleted from total. Channel width can be measured at any discharge stage less than bankfull. Five measurements are taken spaced 16m apart and then averaged to provide a single value. PIBO crews initially collected five measurements but increased to 21-25 measurements in 2012. Despite this different protocol, data is assumed comparible and included all stream samples.

Residual depth of pools is the maximum depth minus the crest depth of each pool. Measurements are to the nearest centimeter. Measurements from each of the first 10 pools encountered (if that many) are averaged. Residual depths can be measured at any discharge stage, even when dry.

Pool frequency is expressed as the number of pools per linear kilometer. All pools that meet minimal definitions encountered in the monitored area were numerated and then extrapolated per kilometer. Pool frequency can be sensitive to discharge stage and while all surveys are done during low flows, data does not include discharge measurements and some error is likely. Surveyors originally delineated pools using protocols established by Overton et al (1997) but then transitioned to Kershner et al (2004) protocols in 2005. Given the more restrictive later protocols, the oldest surveys may be biased for higher pool frequency but are still utilized.

Large woody debris frequency is the number of qualifying pieces of wood per linear kilometer. All wood at least 1m long and 0.1m diameter and at least partially within the bankfull channel were numerated and then extrapolated per kilometer. Woody debris can be measured at any discharge stage.

Stream substrate is monitored by two methods, the pebble count and Riffle Stability Index. Only stream reaches sampled by local crews are utilized in this study (n=35). Methodology used by the PIBO crews has changed over time and is not comparible and thus removed from this dataset.

During a pebble count, observers measured the medial axis of the first encountered particle at a set distance as they move across multiple transects from bank to bank. Data only records particles on the surface of the streambed, not buried or interstitual particles. Four riffles were initially selected for operational ease and then relocated and monitored over time. Occasionally a riffle experiend a profound change (such a converted to a pool) and a nearby riffle henceforth replaced it. Each sampled particle was assigned to Φ category described in Bunte and Abt (2001) such as <2mm, 2-4mm, 6-8mm, 8-12mm, etc. The Φ categories allow lognormal transformation which simplify statistics. Initially a minimum of 25 particles at each riffle was sampled but later increased to at least 100 particles, thus often yielding 400-500 measurements per reach. All measurements for all transects in all four riffles are then cumulated. The median (not mean) Φ category is computed as D_{50}. Streams with smaller D_{50} have more fine sized sediments than larger D_{50}. D_{50} is superior to other commonly encountered descriptions of substrate, such as percent of fine sediments, because of minimal observer variance (Archer et al 2004).

The second substrate measurement is Riffle Stability Index (RSI). If the stream has a lateral or point bar, crews determined the mean diameter of the 30 largest mobile substrates on it to the nearest millimeter. This value is then compared to the relative abundance Φ category of the nearby riffles. The resulting RSI provides a relative index of the sediment supply from upstream. For example an RSI value of 75 means that the lateral or point bar substrate is the same size as the D_{75} of the riffle. A stream with low RSI indicates a dynamic equilibrium but a stream with high RSI has increasing bedload transport and deposition in riffles and pools (Kappesser 2002). This index can work in low gradient systems on sedimentary geology such as the Swan River valley but not every channel type creates bars. Roughly half of all samples to date were able to compute RSI.

Water temperature is is recorded hourly with a probe submerged in a pool, typically from June to September. One probe was assumed adequate to characterize the whole stream reach and measurements are to the nearest hundredth degree centigrade. The early years had few probes but technological advances have made probes more affordable and efficient, thus allowing a leap in data after 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 (Sugden et al 1998). Software since 2002 has facilitated MWMT computation to one thousanth degree centigrade but older data relied on visual examination of charts and precision is 0.5 degree centigrade.

MWMT can vary between years, even without any habitat change, presumably due to climate conditions such as ambient air temperature or runoff duration (Kaushal et al 2010). Thus relying on simple paired samples over time may not be able to identify trends without an adjustment for the particular calendar year. For example, 2007 had unusually warm temperatures in the Swan River valley and 2011 had unusually cold temperatures. A stream reach that happened to have only 2007 and 2011 data might incorrectly conclude a strong decline in MWMT. Fortunately, concurrent annual monitoring data from multiple locations along the Swan River is available to understand the influence of the calendar year. Data is provided by Swan Valley Connections (swanvalleyconnections.org) and is independent of this study. This local, annual dataset faciltates estimation of the mean MWMT for the Swan River from 2005 to 2020 and then the annual deviation from the mean. This annual deviation was then added/subtracted from the MWMT for an "Adjusted MWMT". For example, 2020 the Swan River averaged 0.4801 C warmer than the mean and therefore all 2020 in this study had 0.4801 C subtracted from MWMT. Data from years that do not have Swan River monitoring (such as prior to 2005) cannot be adjusted and assumed sufficient. Using Adjusted MWMT facilitates a comparison of changes of managed or reference stream locations but obscures any trend caused by global climate change.

Results

The 43 locations have been sampled an average of 3.6 times (range 2 to 6 samples). Principal findings are summarized in Table 2 below.

Table 2. Key monitoring findings.

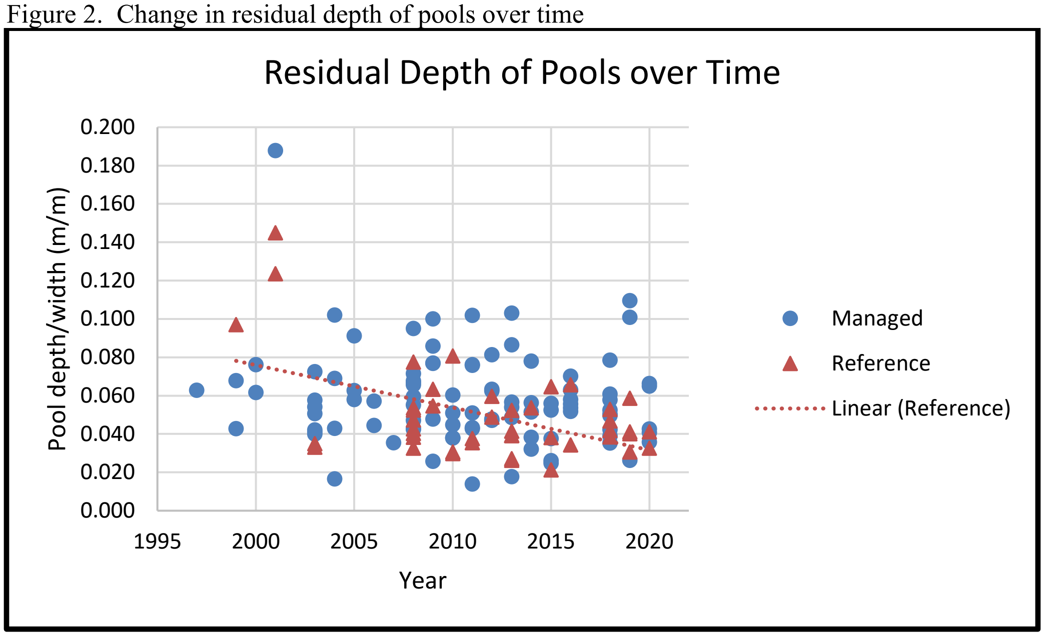
Habitat attribute	**Difference between managed and reference streams?**	**Changing over time?**
Channel width	Managed streams are narrower	No
Residual depth of pool	Managed streams are deeper	Reference streams are trending shallower. No change for managed
Pool frequency	No difference	No
Large woody debris frequency	No difference	Yes. Both groups are trending towards more wood
Substrate: D_{50} of riffles	No difference	No
Substrate: Riffle Stability Index (RSI)	Managed streams have higher RSI (more bedload mobility)	No
Water Temperature: MWMT	Managed streams are warmer	Managed streams are trending colder. No change for reference

Channel width dataset has a total of 153 samples on all 43 locations. As expected, channel width strongly correlates with watershed size ($p < 0.01$, df= 152). Therefore, channel width is normalized as width/area to contrast groups. Managed streams have significantly narrower normalized channel widths than reference streams ($p < 0.01$, df = 95 for all surveys, and $p < 0.01$, df = 32 for most recent surveys only). Furthermore, reference streams are increasing roughly 8 percent per year, while managed streams are essentially unchanged, but this is not yet a significant change over time ($p = 0.34$, df =

15). Channel width/area also strongly correlates with elevation ($p < 0.01$, df = 153) and reference streams are significantly higher in elevation than managed ($p < 0.01$, df = 23).

Residual depth of pools dataset has a total of 138 samples from all 43 locations. The residual depth of pools has a significant, negative correlation with pool frequency ($p < 0.01$, df = 137) and a significant, negative correlation with channel width ($p < 0.01$, df = 137). These confounding variables are not surprising since channel width also influences pool frequency. Residual depth of pools is thus normalized by dividing it by channel width. Results are inconsistent. When examining all samples to date, reference streams have deeper pools ($p < 0.01$, df = 84) but when just examining the most recent sample, then reference streams have shallower pools ($p = 0.04$, df = 40). Trend analysis reflect this change since reference streams have significantly declined in depth over time ($p < 0.01$, df = 42) but managed streams have not ($p=0.13$, df = 93) (figure 2).

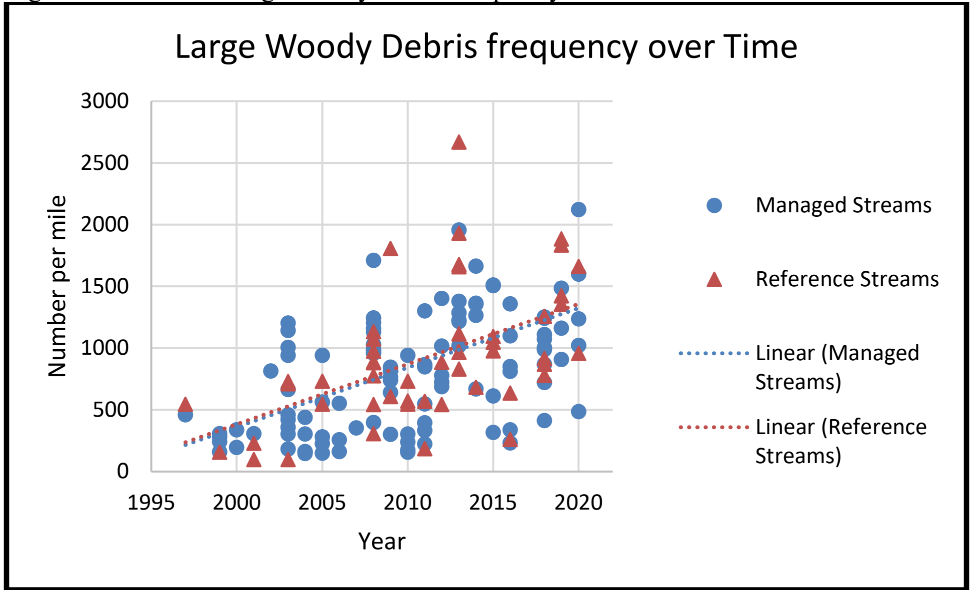
Figure 2. Change in residual depth of pools over time



Pool frequency dataset has a total of 153 samples from all 43 locations. Pool frequency has a significant, negative correlation with channel width ($p < 0.01$, df = 152). Once pool frequency is divided by channel width, the most recent sample finds no significant difference between managed and reference streams ($p = 0.08$, df = 36). Furthermore, there is no significant change in pool frequency/width over time for both groups ($p= 0.19$, df = 103 managed streams and $p = 0.28$, df= 47 reference streams)

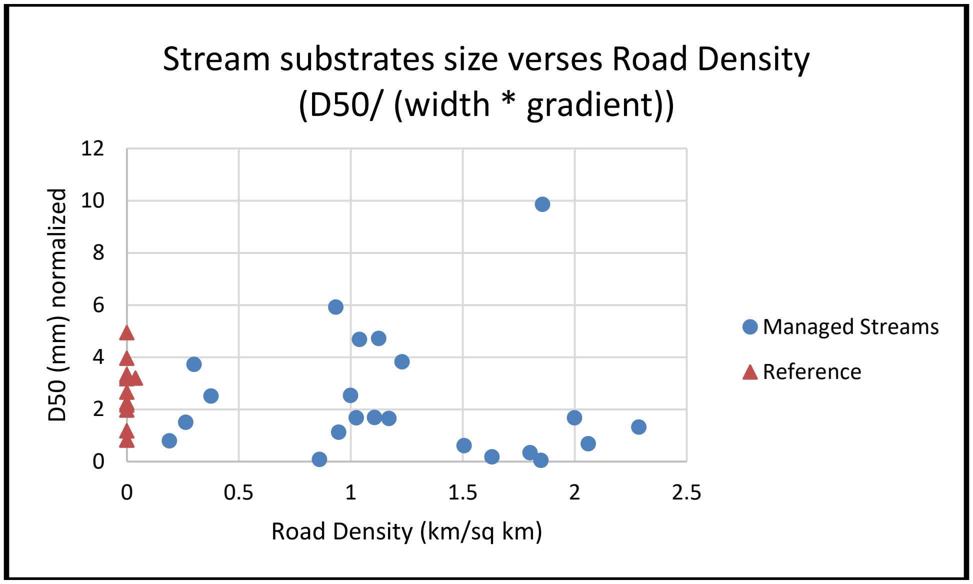
Large woody debris frequency dataset has a total of 153 samples from all 43 locations. Large woody debris does not have any confounding variance with channel width, gradient or forest vegetation type. No difference between groups is noted in a comparison of most recent samples ($p=0.37$, df = 39) or regression of wood frequency with road density ($p=0.44$, df = 152). However, large woody debris frequency is increasing over time (Figure 3). Both managed streams and reference streams have experienced significant increase in large woody debris over time ($p< 0.01$, df= 103 managed streams and $p<0.01$, df=47 reference streams).

Figure 3. Trends in Large Woody Debris frequency over time



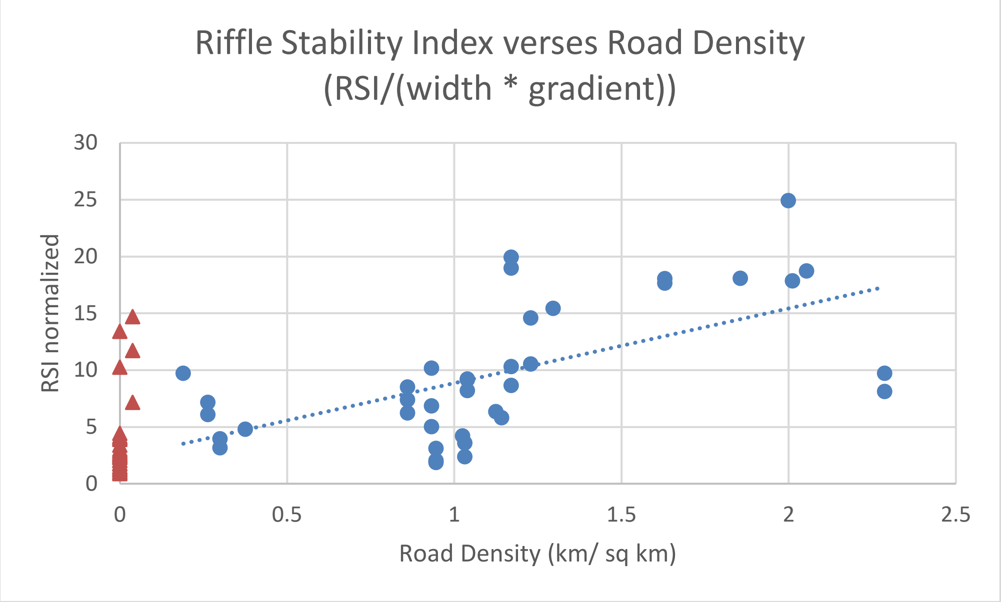
Stream substrate monitoring had a total of 121 observations over time across 35 stream reaches to compute D_{50}. As expected, stream substrates are sensitive to channel dimensions. D_{50} positively correlates both with channel width and gradient, and especially channel width multiplied by gradient ($p < 0.01$, df = 120). Therefore, D_{50} is normalized by dividing D_{50} by width * gradient. Normalized D_{50} does not significantly differ between groups, regardless if all samples were reviewed (p=0.90, df = 118) or just the most recent (p=0.65, df = 33). No correlation of normalized D50 with road density is observed (p=0.88, df = 120). No trend over time is apparent. Neither the managed streams nor the reference streams experienced significant changes in D_{50} over time (p = 0.71, df = 22 managed and p = 0.46, df = 13 reference).

Figure 4. Comparison of normalized D_{50} with Road Density. Most recent sample (regardless of year) per stream reach shown



Twenty-six stream reaches have at least two RSI calculations over time, some with more than two (n=68). Similar to D_{50}, regression of all RSI calculations finds it is sensitive to the channel width * gradient (p=0.01, df =68). Therefore, RSI is normalized by dividing the RSI calculation by width * gradient. One outlier was removed (2007 sample of North Fork Cold Creek) which appears to be inaccurate gradient measurement. Managed streams have significantly higher normalized RSI ($p < 0.01$, df = 63 for all samples and P = 0.01, df = 24 for just most recent). Road density is significantly, positively correlated with normalized RSI (Figure 5), although R^2 value is only 0.09. No significant change in RSI over time is apparent (p = 0.69, df = 12 for managed streams and p = 0.38, df = 11 for reference streams). This may be due to minimal change in the point bars or insignificant change in D50 as describe above, or both.

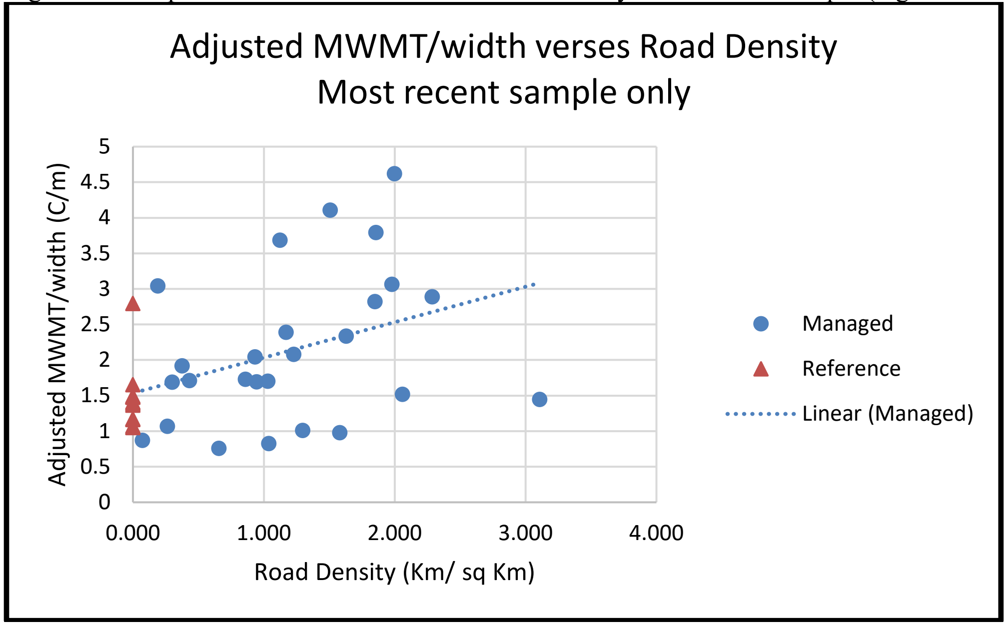
Figure 5. Comparison of normalized RSI values with road density (all samples)



The *Water Temperature* dataset has 100 samples of Maximum Weekly Maximum Temperature (MWMT) for 42 locations. Seventeen locations had 3 or more samples over time, 21 locations had 2 samples and 4 had only one sample. No correlation is apparent between MWMT and the survey year (p=0.24, df=98), e.g. no indication of warming temperatures since 1997. As described earlier, MWMT was subsequently adjusted by calendar year to remove annual variance. Adjusted MWMT does not correlate with elevation (p = 0.08, df = 98). MWMT does have a significant negative correlation with channel width (p < 0.01 df = 98). Therefore Adjusted MWMT/channel width (C/m) is necessary to contrast groups.

A significant difference exists between managed and reference locations Adjusted MWMT/width (p < 0.01, df = 90 for all samples in time and p < 0.01, df = 36 for most recent only). Managed streams have warmer MWMT. Road density also positively correlates with Adjusted MWMT (Figure 6) although the R^2 value is weak (0.12). Change in time is apparent for managed streams. When pairing the original with most recent sample (regardless of year), the Adjusted MWMT/width for managed streams has declined significantly (e.g. getting colder)(p = 0.01, df – 25). No change is discernable for reference streams over time (p = .14, df = 11).

Figure 5. Comparison of MWMT/width with road density. Most recent sample (regarless of year) shown



Discussion

The finding of significantly wider channels in reference streams seems to be a growing phenomenon. Earlier monitoring reports (2011; 2013; 2015) did not observe any difference between groups but wider reference streams were noted in 2018 and Kendall (2010). Timber harvest can potentially alter water yields, which in turn can affect channel width, but this does not appear to be happening in the Swan River valley. Elevation has a significance positive correlation with channel width. Thus, the finding that reference streams are wider may be function of elevation rather than actual difference in land management.

The residual depths of pools appear to be shifting in reference streams and becoming shallower in recent years. Kendall (2010) also noted reference pools with less residual depth, but other monitoring reports did not observe any difference between groups (2011, 2015, 2018 reports) (Kendall 2014). Residual depths of pools seem to be linked to channel width. Bauer and Ralph (2001) reported that deteriorating residual depths of pools can be a good indicator of indirect effects from land management. Montana DEQ also utilize residual depths of pools in consideration of impaired streams (Kusnierz et al 2013). Yet both channel width and residual depth of pool data indicate that timber management and road construction has not adversely affected streams in the Swan River valley.

The similarity of large woody debris frequency between managed and reference streams is not surprising. All previous monitoring reports likewise found large woody debris frequency appears unaffected by land management (2011; 2013; 2015; 2018) (Kendall 2014). The unilateral increase in woody debris over time is noticeable and has been highlighted in previous reports since 2013. This may be reflecting the widespread lack of wildfire disturbance and increasing density of trees in riparian areas. The frequency of pools is also similar between managed and reference streams. This finding was also reported in 2015 and 2018. It is curious that the increasing wood load has not created many more pools. The data only tallies the amount of wood within the bankfull channel perimeter and does not inform how much is submerged or perpendicular to flow. The streams may be waiting for a change in flow conditions, such as after a fire or flood, to incorporate the wood.

Previous monitoring reports varied in whether the D_{50} of riffles was different between groups. The 2011 and 2013 reports and Kendall (2010) did not detect a difference but the 2015 report, 2018 report, and Kendall (2014) observed smaller D_{50} in managed streams. This most recent data does not detect any significant difference, nor is there any apparent trend over time. This gives hope that land management no longer is contributing sedimentation to channels. The significant difference in RSI, however, is perplexing. The higher RSI in managed streams implies an indirect effect of more sediment transport and filling of pools and riffles. Yet managed streams have deeper pools than reference streams and riffles appear unaffected. This is the first study to examine RSI and no trend over time is apparent. Cautious is needed with RSI in that it has a smaller dataset than D_{50} and it is an index, not a direct measurement of bedload movement. Natural disturbances, such as a post-fire runoff, may also temporarily increase RSI. Further monitoring of both D_{50} and RSI will be needed before any firm conclusion can be made about land management impacts on stream substrates.

The finding of significantly warmer MWMT in managed streams was not observed in 2015 but first reported in 2018. Watersheds with more road density generally have warmer summer temperatures. The cause is uncertain. This may be caused by roads having a cumulatively converting groundwater to surface water and thus indirectly affecting temperature. It may be the number of crossings with cleared areas. Curiously, managed streams are significantly trending towards colder conditions over time, perhaps an indication of improving road Best Management Practices. Best Management Practices minimize the volume of water in road ditches so to retain groundwater in the ground. Another possible explanation is that previously riparian areas experienced more timber harvest and the loss of streamside shade may have elevated temperatures. As the forest recovers, water temperature recovers as well and therefore fits the pattern of colder trends in managed streams. No gross trend of MWMT changing over time is apparent. While climate change is predicted to result in warmer water temperatures (Isaak et al 2011), this monitor has not observed that. Caution is needed in that the nature of periodic samples on a rotating bases are not well suited to detect climate patterns.

As the size and severity of wildfires have increased across the Western United States, land managers have increasing sought to mitigate this by simultaneously reducing fuels (commercial harvest or non-commercial thinning and burning) and igniting low intensity fires. Given the apparent increasing fuel load in riparian areas, it may be desirable to reduce fuels and set fires in riparian areas as well. This poses a conundrum. Reducing fuels should reduce the severity of any subsequent wildfire and thus may prevent extreme sedimentation and bedload transports. Severe wildfires can also substantially increase water temperature and channel widths for decades. But these very actions require sufficient road access and remove shade trees from the riparian area. Thus, they could also increase water temperature, reduce large woody debris frequency and introduce sedimentation. Adding these stressors to streams that already are experiencing change comes with a difficult choice. The best restoration actions may be those which simultaneously seek to reduce both fuel loading and road density (or road-related impacts) and additionally do not remove large woody debris that could recruit to the channel.

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