UPPER GALLATIN NUTRIENT ASSESSMENT & REDUCTION PLAN

TECHNICAL MEMORANDUM:

Preliminary Estimate of Nutrient Loading and Potential Mitigation Projects

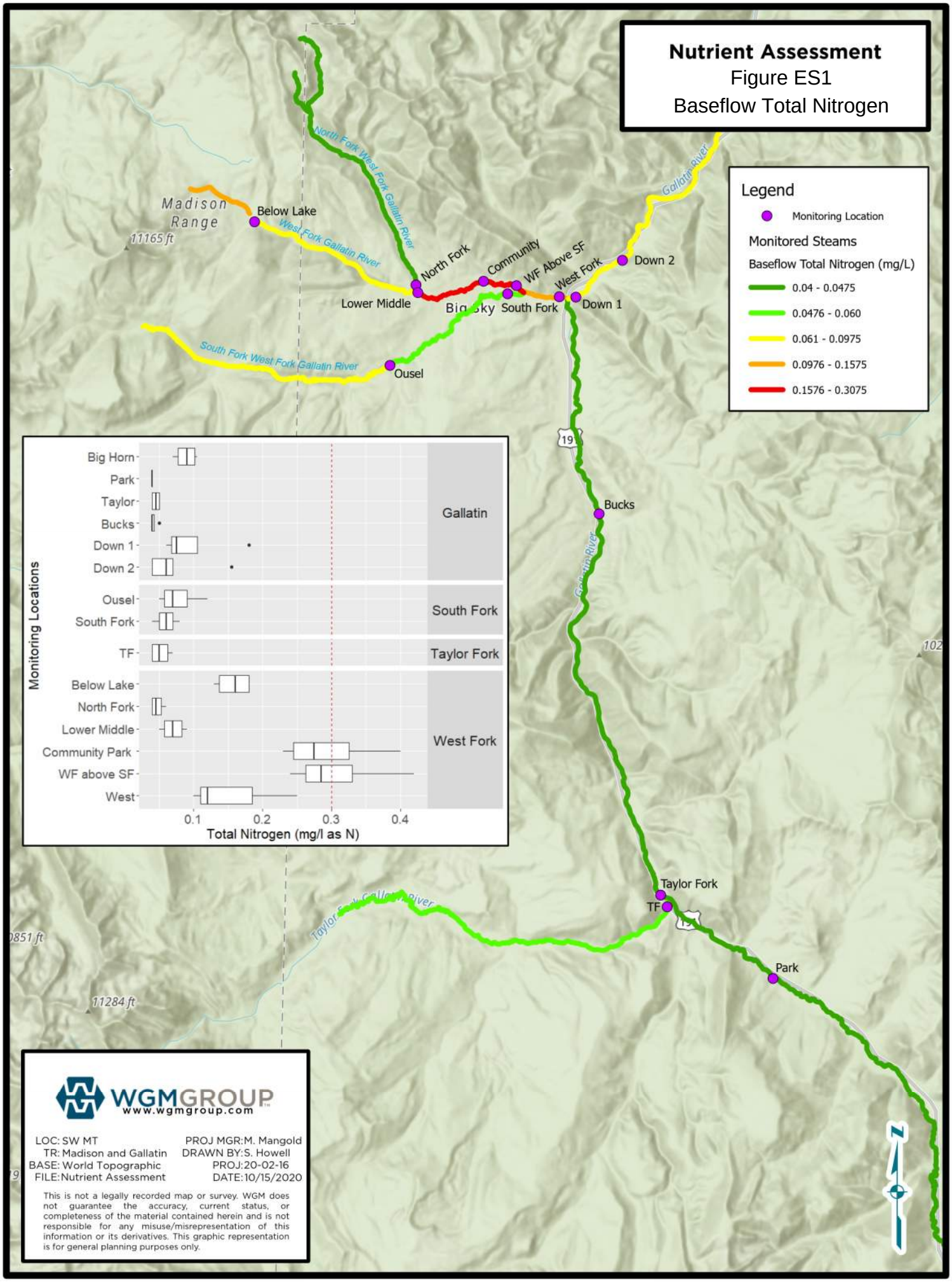
DATE: October 17, 2020

FROM: Chris Allen, Ph.D., PE, Sarah Howell, Scientist

Executive Summary

The study area covers select drainages within the Gallatin River drainage from the headwaters in Yellowstone National Park, to USGS Gage Station 06043500 downstream of the confluence of the Gallatin with Spanish Creek. This scenic river and its tributaries are a vital resource notable for its recreational capacity and fisheries. Small increases in instream nutrients can have significant effects on aquatic organisms altering the aquatic food web, changing the ability of the river to support recreational activities, and promoting the growth of algae that can significantly impact fish populations. To maintain stream health in the region the Montana Department of Environmental Quality (DEQ) has set instream standards of 0.3 mg/l total nitrogen as N and 0.03 mg/l total phosphorus as P during summer baseflow within wadable streams. Ongoing water quality monitoring performed by the Gallatin River Task Force (Task Force) indicates that portions of the West Fork of the Gallatin River have exceeded the threshold values for nitrogen (see **Figure ES1**). On the mainstem Gallatin River, nitrate concentrations downstream of the 'Canyon Area' developed corridor and confluence with the West Fork exceed background concentrations, most notably during base flow. This assessment provides preliminary quantification of nutrient loads and potential mitigation strategies for anthropogenic nutrient sources. Findings are anticipated to be used to prioritize nutrient abatement projects and potentially serve as a framework for establishing a nutrient trading structure with the DEQ to facilitate comprehensive nutrient management and mitigate effects associated with development growth in the Big Sky region.

Nutrients enter and cycle through the ecosystem as a result of both natural processes and human activity. Nitrogen and phosphorus are deposited with precipitation and in wind transported particulate material. Both nitrogen and phosphorus also dissolve into water as a result of rock weathering (Montana DEQ, 2013, Montross, 2013). The regional geology may play an outsized role in nutrient levels for some components of the watershed, especially in the headwaters where geology is influenced by geothermal activity. Even low concentrations of natural nitrogen can result in a large mass loading of nitrogen. During peak runoff the concentration of nutrients in the water is dominated by natural nutrient loads, primarily atmospheric deposition and rock weathering. The total mass of nitrogen added to the ecosystem because of human activity is relatively small compared to natural loading. However, anthropogenic sources of nitrogen from wastewater, domestic animals, and land disturbance have a substantial effect on nutrient concentrations during summer and winter base flow conditions.


Nutrient Assessment
Figure ES1
Baseflow Total Nitrogen
Legend
Monitoring Location
Monitored Steams
Baseflow Total Nitrogen (mg/L)
0.04 - 0.0475
0.0476 - 0.060
0.061 - 0.0975
0.0976 - 0.1575
0.1576 - 0.3075
Madison Range
11165 ft
Below Lake
West Fork Gallatin River
North Fork West Fork Gallatin River
North Fork
Community
WF Above SF
West Fork
Down 2
Down 1
Lower Middle
Big Sky
South Fork
South Fork West Fork Gallatin River
Ousel
Gallatin River
19
Bucks
Taylor Fork
TF
Park
11284 ft
Monitoring Locations
Big Horn
Park
Taylor
Bucks
Down 1
Down 2
Gallatin
Ousel
South Fork
South Fork
TF
Taylor Fork
Below Lake
North Fork
Lower Middle
Community Park
WF above SF
West
West Fork
0.1
0.2
0.3
0.4
Total Nitrogen (mg/l as N)
WGMGROUP
www.wgmgroup.com
LOC: SW MT
TR: Madison and Gallatin
BASE: World Topographic
FILE: Nutrient Assessment
PROJ MGR: M. Mangold
DRAWN BY: S. Howell
PROJ: 20-02-16
DATE: 10/15/2020
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The primary contributions of anthropogenic nitrogen (from largest to smallest) were found to be wastewater irrigation, onsite wastewater treatment systems, equestrian and grazing operations, stormwater/erosion, and domesticated animals. **Table 1** presents estimated annual loading for the Gallatin River and the West Fork (watershed with greatest anthropogenic loading) in comparison to the estimated natural load. Load estimates for the Gallatin River watershed include the load from the West Fork watershed.

TABLE 1. ESTIMATED ANNUAL LOAD OF NITROGEN FROM ASSESSED SOURCES INTO THE WATERSHED*

WATERSHED	NATURAL LOAD	MUNICIPAL WASTE WATER	ONSITE SYSTEMS	GRAZING/ STABLES	STORM WATER	DOMESTIC ANIMALS
West Fork	47,100	12,000	4,400	3,300	2000	1,000
Gallatin	530,900	12,000	12,700	13,000	2000	1,200

**All units N lb/year.*

The loads estimated in the table above do not represent the total load that ends up in the stream. For instance, of the 530,000 pounds of nitrogen deposited naturally onto the watershed per year, only 62,000 pounds of nitrogen is estimated to be exported - an approximate 90% reduction (Schwarz, 2006). Similarly, wastewater irrigation is applied using methods designed to reduce instream loading, with the majority of the load consumed by agronomic uptake and aquifer processes such that only a portion reaches the waterway. The estimated stream load compared to the applied nitrogen to the West Fork watershed can be seen in **Figure ES2**.

The natural processes that govern the transport of nitrogen to the streams are complex. Research conducted on similar systems in conjunction with modeling can be applied to the region to estimate the likely fraction of nitrogen load that ends up in streams. These values can then be compared to loads estimated using measured changes in water quality during base flow when the streams are comprised primarily of resurfacing groundwater. Using the West Fork as an example, the estimated stream load from groundwater sources based on changes in water quality prior to the confluence with the South Fork is approximately 5,000 pounds N per year. **Table 2** presents a summary of estimated instream nitrogen loads for the West Fork and associated concentration increase. Nitrogen loads from the Meadow View Golf Course and onsite systems in the watershed are approximately 2,000 lb N yr^{-1} and 1,500 lb N yr^{-1}, respectively. These estimated loads correspond well to available water quality data (measured concentration increases across individual reaches). The 'Other' load designation in **Table 2** represents an additional 1500 lb N yr^{-1} that could be attributable to other sources (e.g. stables, stormwater, domestic animals) or concentration variability.

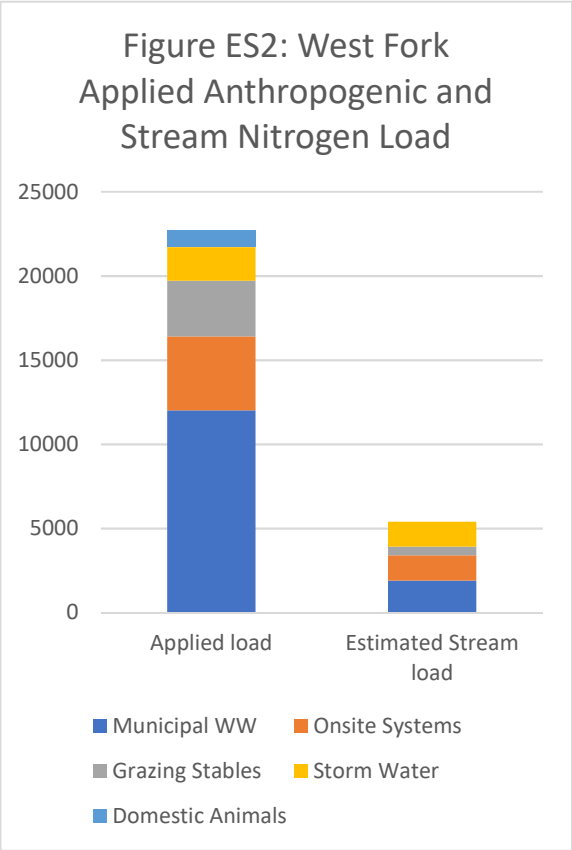


TABLE 2. ESTIMATED ANNUAL INSTREAM LOAD OF NITROGEN FROM ASSESSED SOURCES IN THE WEST FORK DRAINAGE AND MITIGATION POTENTIAL

	ESTIMATED INSTREAM LOAD (N lb/yr)	ANNUALIZED LOAD BASE FLOW CONCENTRATION (mg/l as N)	MITIGATION POTENTIAL
Wastewater Application	2,000	0.08	High
Onsite systems	1,500	0.07	Med
Other	1,500	0.02	High
Measured In-stream Load	5,000	0.23	

The Task Force and Big Sky Headwater Alliance have previously compiled a list of proposed mitigation efforts; these efforts are assessed along with additional potential mitigation strategies (see Nutrient Assessment Results and Recommendations, page 19). The greatest long-term reduction in anthropogenic nitrogen will result from the Big Sky County Water and Sewer District's (District) significant commitment to upgrade the Water Reclamation Facility (WRF). This upgrade will reduce the concentration of effluent to less than 5 mg/l N, representing an approximately 75% reduction compared to the existing treatment plant effluent quality. Further load reduction associated with wastewater irrigation, including accumulated nitrogen load in the aquifer, can be achieved by intercepting and mitigating shallow groundwater utilizing engineered wetlands at known point sources (e.g. chapel spring) and general placement along the West Fork riparian corridor. Finally, careful golf course best management practices (BMPs) can be employed to minimize fertilizer related nutrient loading and stormwater runoff loading. Irrigation practices can be further optimized by the generation of a Hydrus soil profile model to better determine application rates and anticipated leching. Preliminary estimates indicate that as flows increase 10,000 to 16,000 pounds per year of nitrogen loading can be mitigated from golf course related loading, primarily attributable to the ongoing Big Sky WRF upgrade, resulting in potential in-stream nitrogen load reduction in the 4,000 to 6,000 pounds (including all three irrigated golf courses) per year range.

Increasing public awareness and providing testing and maintenance grants for the regions aging onsite systems can have considerable effects in maintaining and/or reducing the present load from onsite systems. Working with residences, communities and businesses that are very near the Gallatin River and its tributaries can have a considerable effect. Looking toward the future, connecting onsite systems to centralized treatment where available, advocating for water quality based design objectives for new development, and mitigating impacts of past development, remains an important endeavor. For example, the recently completed Canyon Area Sewer Feasibility Study (WGM, 2020) identified that growth in the Canyon Area alone could double the instream nitrogen contribution of the area to over 6,000 pounds N per year in the absence of comprehensive sewer planning and central infrastructure. Ongoing stream data collection considering both water quality and flow rates is critical to assessing current nutrient loads and in assessing the efficacy of any mitigation efforts. Lastly the value of providing outreach, education, and incentives for individuals to maintain a healthy relationship with their watershed is not to be underestimated. Improved awareness regarding stormwater management, implementing livestock related BMPs and improved grazing practices, and promoting activities as simple as dog poop pick-up and proper fertilizer application, provide a combined potential of 1500+ pounds per year of nitrogen loading reduction.

Introduction

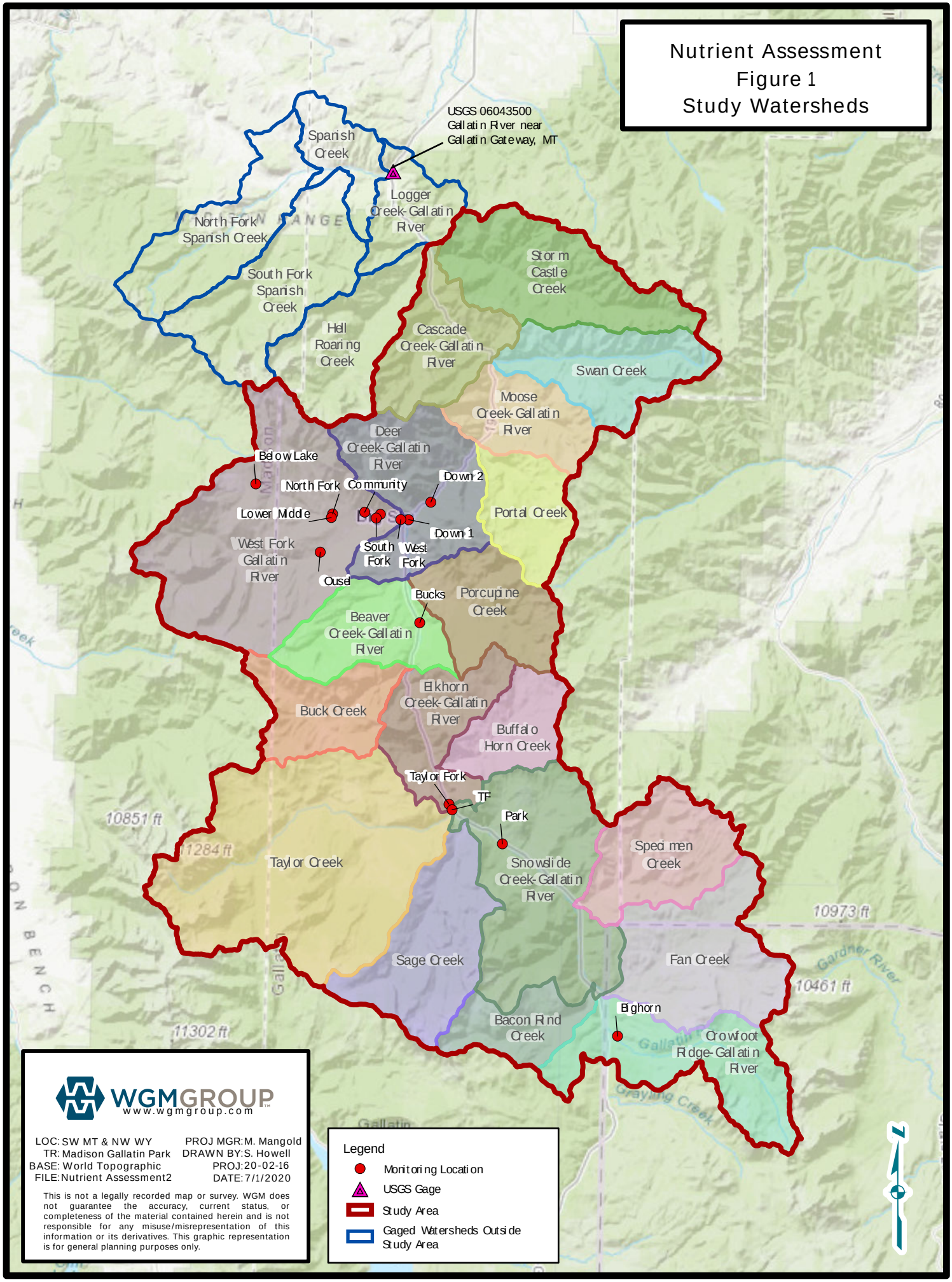
With head waters in Yellowstone National Park, the Gallatin River drains approximately 84 square miles of scenic, mountainous terrain before discharging out into the Gallatin Valley. This scenic river is a vital resource notable for its recreational capacity and fisheries. Small increases in instream nutrients can have significant effects on aquatic organisms, changing the ability of the river to support recreational activities, and promoting the growth of algae that can significantly inhibit some water uses.

The study area for this nutrient assessment covers select drainages from the headwaters of the Gallatin to USGS Gage Station 06043500 which is located downstream of the confluence of the Gallatin River and Spanish Creek. The watershed has been broken into sub-watersheds for analysis which can be found in **Figure 1**, and a table of sub-watershed areas and percent contributing to the gaged watershed found in **Table 3**. In the table, the designation for nutrient analysis level indicates the level of anthropogenic load assessment performed based on available data and/or nutrient transport modeling; watersheds labeled as none were outside the designated study area but contribute hydraulically to USGS Gage Station 06043500.

Water quality data for the Gallatin River and select tributaries has been collected by the Task Force since the year 2000 with select sample locations visible in **Figures 1** and **2**. The community of Big Sky, Big Sky Resort, Spanish Peaks, and most of the Yellowstone Club, which represent the majority of intensified land uses in the area, are situated in the West Fork of the Gallatin sub-watershed. A figure of land use across the watershed can be found in **Figure 2,** noting both the water quality sample locations analyzed in this report and the location of development proximal to the West Fork of the Gallatin River. The West Fork of the Gallatin River is considered an impaired stream which means that nutrient loads into the system are restricted and instream concentrations of nutrients are to be kept below threshold levels set by the DEQ in a Total Maximum Daily Load (TMDL). To maintain stream health in the region, the DEQ has set threshold concentrations of 0.3 mg/l as total nitrogen (N) and 0.03 mg/l as total phosphorus (P) from the beginning of July through September. The main stem of the Gallatin is not considered impaired; however, there is a growing interest to provide increased environmental protection for the Gallatin River with the specific intent to minimize or prevent new nutrient sources proximal to the river.

Nutrient based water quality analysis performed by the Task Force has traditionally focused on nitrate and indicated that portions of the West Fork of the Gallatin River have exceeded the threshold values presented by DEQ. Furthermore, immediately downstream of the West Fork, nitrate values exceed likely background concentrations. This assessment provides a limited inventory of nitrogen sources into the watershed and applies GIS tools, namely the Soil and Water and Assessment Tool (ArcSWAT) and ArcNLET to paint a picture of nutrient transport in the Gallatin River and improve our understanding of the impacts of and potential mitigation strategies for anthropogenic nutrient sources in this watershed.

Streamflow data were made available by the Task Force for multiple sites within the West Fork drainage and pulled from records for USGS Gage Station 06043500.


Nutrient Assessment
Figure 1
Study Watersheds
USGS 06043500
Gallatin River near
Gallatin Gateway, MT
Spanish Creek
Logger Creek-Gallatin River
North Fork Spanish Creek
South Fork Spanish Creek
Hell Roaring Creek
Storm Castle Creek
Cascade Creek-Gallatin River
Swan Creek
Moose Creek-Gallatin River
Deer Creek-Gallatin River
Below Lake
North Fork
Community
Down 2
Lower Middle
Down 1
South Fork
West Fork
Portal Creek
West Fork Gallatin River
Ousel
Bucks
Porcupine Creek
Beaver Creek-Gallatin River
Elkhorn Creek-Gallatin River
Buck Creek
Buffalo Horn Creek
Taylor Fork
TF
Park
10851 ft
11284 ft
Taylor Creek
Snowslide Creek-Gallatin River
Specimen Creek
10973 ft
Sage Creek
Fan Creek
Gardner River
10461 ft
Bighorn
Bacon Rind Creek
11302 ft
Crowfoot Ridge-Gallatin River
Crayling Creek
Gallatin
WGMGROUP
www.wgmgroup.com
LOC: SW MT & NW WY
TR: Madison Gallatin Park
BASE: World Topographic
FILE: Nutrient Assessment2
PROJ MGR: M. Mangold
DRAWN BY: S. Howell
PROJ: 20-02-16
DATE: 7/1/2020
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Legend
Monitoring Location
USGS Gage
Study Area
Gaged Watersheds Outside Study Area
N

Nutrient Assessment
Figure 2
West Fork Land Use

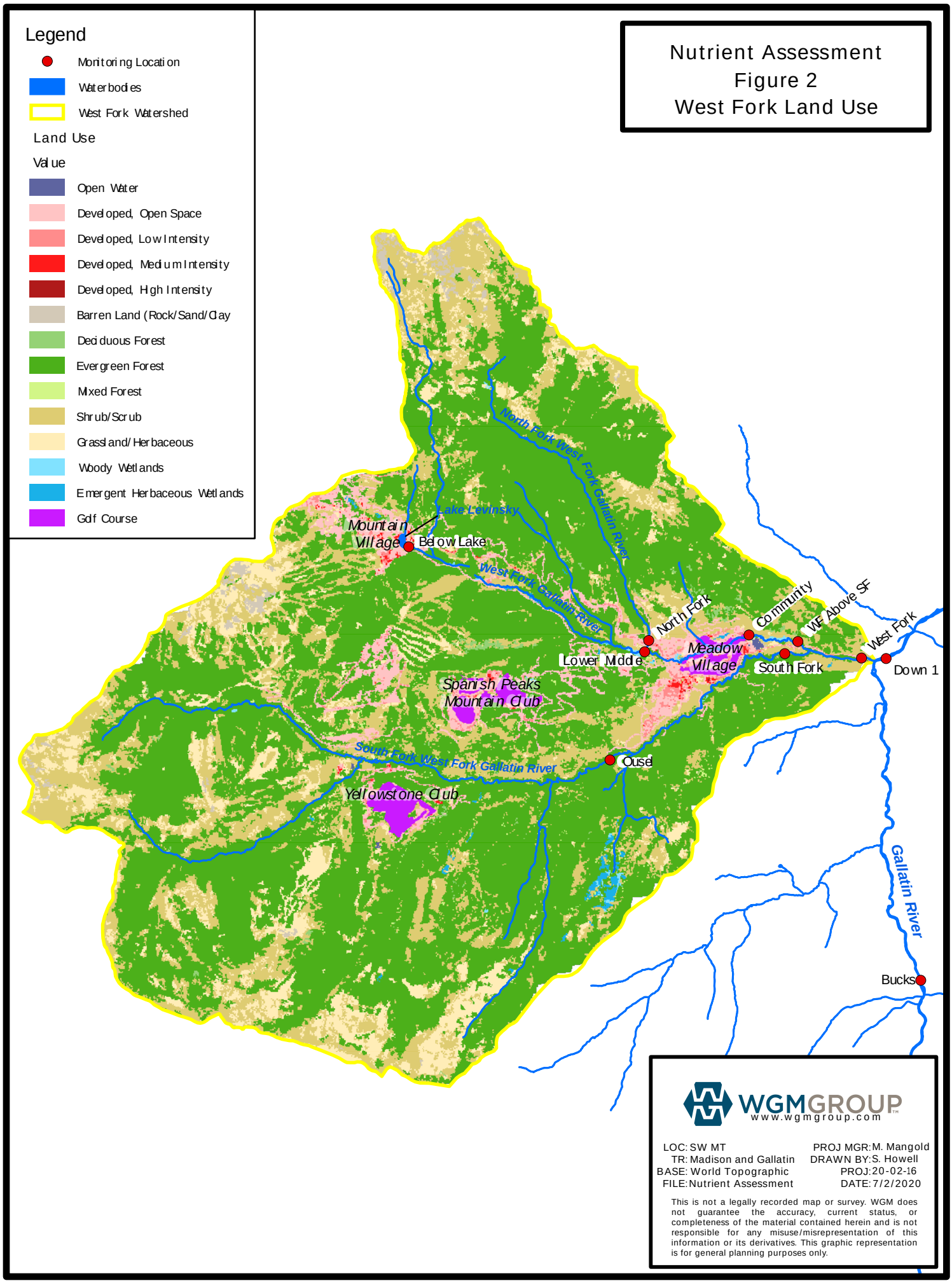


TABLE 3. WATERSHED AREAS

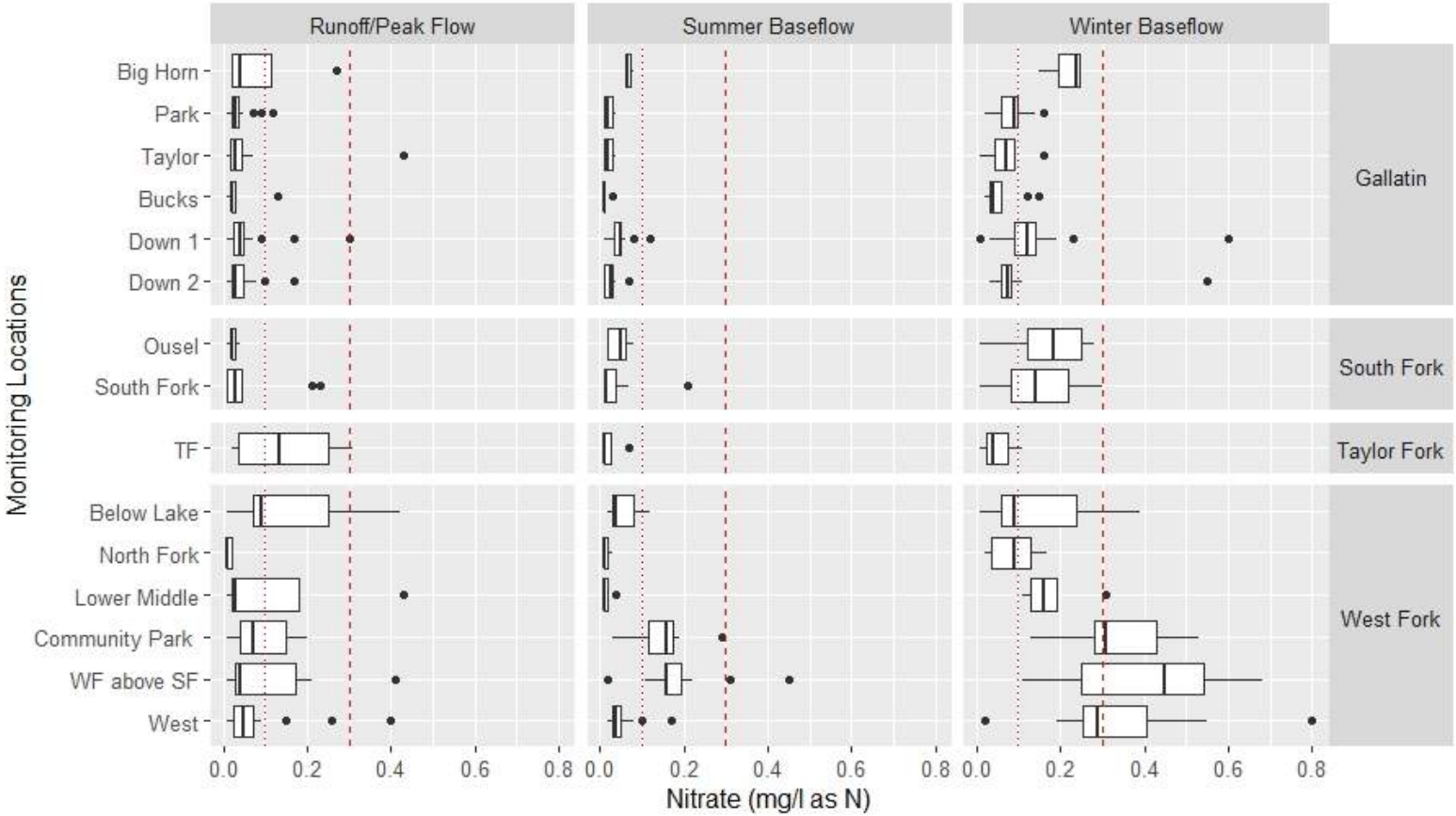
NAME	ACRES	SQUARE MILES	GAGED WATERSHED %	NUTRIENT ANALYSIS LEVEL
Bacon Rind Creek	10,396	42.1	2%	MINOR
Beaver Creek-Gallatin River	16,072	65.0	3%	IN DEPTH
Buck Creek	14,651	59.3	3%	MINOR
Buffalo Horn Creek	11,656	47.2	2%	MINOR
Cascade Creek-Gallatin River	16,875	68.3	3%	MINOR
Crowfoot Ridge-Gallatin River	23,663	95.8	5%	MINOR
Deer Creek-Gallatin River	24,535	99.3	5%	IN DEPTH
Elkhorn Creek-Gallatin River	15,980	64.7	3%	MINOR
Fan Creek	25,826	104.5	5%	MINOR
Hell Roaring Creek	19,065	77.2	4%	NONE
Logger Creek-Gallatin River	10,136	41.0	2%	NONE
Lower Taylor Creek	28,154	113.9	5%	NONE
Moose Creek-Gallatin River	13,451	54.4	3%	IN DEPTH
North Fork Spanish Creek	20,788	84.1	4%	NONE
Porcupine Creek	16,927	68.5	3%	MINOR
Portal Creek	12,330	49.9	2%	MINOR
Sage Creek	23,179	93.8	4%	IN DEPTH
Snowslide Creek-Gallatin River	37,225	150.6	7%	MINOR
South Fork Spanish Creek	25,347	102.6	5%	NONE
Spanish Creek	8,996	36.4	2%	NONE
Specimen Creek	18,975	76.8	4%	MINOR
Storm Castle Creek	25,998	105.2	5%	MINOR
Swan Creek	18,822	76.2	4%	MINOR
Upper Taylor Creek	34,639	140.2	7%	IN DEPTH
West Fork Gallatin River	51,287	207.6	10%	IN DEPTH
TOTAL	524,972	2,124.5	100%	

Existing Stream Water Quality

Existing water quality data collected by the Task Force from 2000 – 2019 was analyzed to assess nitrogen cycling through the watershed. All available data from sample locations collected during flow events labeled as peak runoff, summer base flow and winter base flow, were grouped and presented in a box plot (**Figure 3**). Sample counts for each location and event ranged from 4-24, with most sites having over 10 years of data. The most common nutrient analysis was nitrate, with total nitrogen (TN) available for a subset of the data during summer base flow. The single set of total nitrogen data from 2014 was not used due to the high apparent detection limit (0.2 mg/l) and all TN data were from 2015 or later.

Nitrate concentrations along the main stem of the Gallatin River follow an interesting pattern: nitrate levels begin elevated as water is discharged from relatively pristine headwaters and decrease to an asymptote that appears to represent regional background concentrations until nitrate levels again increase at the confluence of the West Fork of the Gallatin River. Few explanations for elevated nitrate levels in the headwaters could be found in the literature. The regional GIS based geology layers do indicate the presence of geology modified by thermal features, however, this desktop analysis did not confirm any active thermal features in the watershed. Nitrogen levels in Yellowstone thermal feature effluent have been measured to be as high as 600 mg/l and an average of the water quality from thermal springs in the Norris to Mammoth corridor is 2.2 mg/l as N. The nitrogen emanating from these features was attributed to rock weathering, with elevated regions attributable to water passing through organic rich sedimentary deposits (Holloway, 2011). Rock weathering may contribute to elevated levels of nitrate in the region, especially from potentially nitrogen rich shale and sedimentary deposits (Montross, 2013). Minimal correlation between subsurface geology and water quality was determined in this investigation with the potential exception of thermally impacted geology; this is a potential interesting area for future research.

FIGURE 3. INSTREAM NITRATE MEASUREMENTS REPORTED IN MG/L AS NITROGEN



*The box plots are organized by streamflow event and stream reach. The dashed red vertical line represents the total nitrogen threshold value set by DEQ of 0.3 mg N/l total nitrogen. The dotted red vertical line represents the 0.1 mg N/l nitrate threshold value used by the Task Force to assess impact.

Determination of background nitrate and total nitrogen concentrations is difficult as many processes impact the concentration of nitrate and total nitrogen in the stream. Inputs of nitrogen consist of natural and anthropogenic sources. Natural sources include wet and dry deposition, biotic fixation, and rock weathering, while anthropogenic sources include the discharge of wastewater, application of fertilizer, equestrian and agricultural operations, land use change and domesticated animal waste.

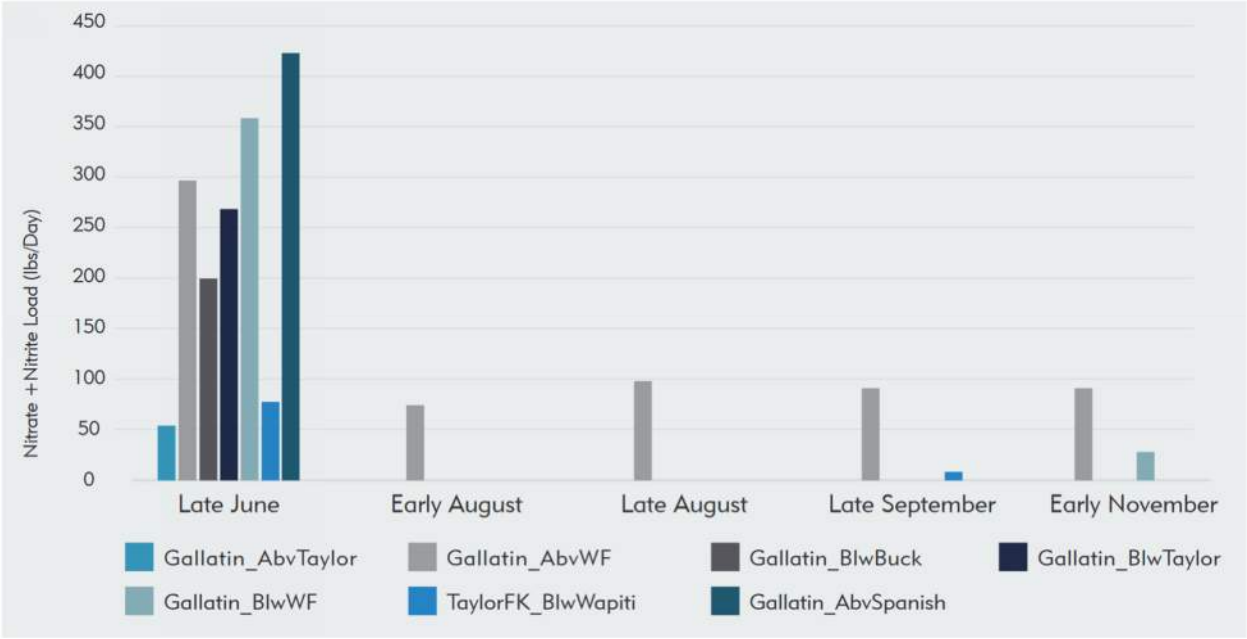
Net deposition of nitrogen into the area is a function of precipitation, and wind patterns. The US SPARROW model suggests a regional deposition rate of 113 kg N / km^2 or, translated to a concentration of N in rainwater, approximately 0.37 mg N /l. This is a total of 240,800 kg N deposited into the Upper Gallatin watershed above USGS Gage Station 06043500 (Schwarz, 2006). For reference, a USGS report for the Gallatin Valley used an estimate of 0.5 mg/l N in precipitation (USGS, 1998). The nitrogen is deposited in the form of nitrate, ammonium, and organic N and enters a complex ecological cycle. Much ammonium is absorbed by soil, taken up by plants and otherwise immobilized until it is microbially transformed to nitrate and able to be easily transported in water. Nitrate is taken up by plants and is used by microorganisms for both cellular growth and to fuel denitrification. Denitrification is a process in which microbes couple nitrate and organic carbon, resulting in energy and the production of N_2 gas which comprises approximately 80% of our atmosphere. The US SPARROW model estimates that only 8.5% of the deposited N (63,200 kg N) washes out of the watershed while the remaining 91.5% cycles within the watershed and/or is removed via denitrification. The mass of nitrogen estimated to be discharged from the US SPARROW model averaged into the total average flow (2004-2016) of the Gallatin River at the USGS Gage 06043500 after the confluence with Spanish creek would be 0.09 mg/l as N.

Understanding the level of nitrogen expected to occur in a stream naturally can help determine where and how human alterations are impacting the ecosystem, which is the first step in generating a mitigation plan. Nitrogen concentrations in a stream can change as the inputs into the stream vary. For instance, peak flow is dominated by snowmelt, while base flow is dominated by the influx of groundwater. Biotic activity in the stream and general ecosystem functions are also important. Plant and microbial growth is significantly slowed in winter by low temperatures and lack of light and, as a result, the biological demand for nitrogen decreases, and little organic nitrogen is produced. Ammonium is chemically attracted to minerals in the soil / subsurface and is still effectively immobilized. As a result, winter nitrate values are relatively representative of instream total nitrogen (total nitrogen is the sum of nitrate, nitrite, organic nitrogen and ammonium). In summer, temperatures increase and there is more light to fuel aquatic plant life, including algae. The increase in activity can drive instream nitrate levels down as the organisms compete for the limited resource. Total nitrogen may remain relatively constant if organic nitrogen compounds and algal cells remain suspended, or may drop if biological uptake effectively immobilizes the nitrogen into attached biomass or the nitrogen is removed via denitrification in stream sediments.

Hydrology plays a significant role in instream nitrogen concentrations, especially where anthropogenic sources are concerned. Peak flow in the system is dominated by snowmelt. During snowmelt, stored precipitation melts and runs overland. It also percolates through the snowpack and down into the shallow groundwater of slowly warming soils. Large volumes of water move through the watershed with relatively low nutrient concentrations. During peak runoff, measured nitrate levels in the main stem of

the Gallatin average around 0.05 mg/l as N (sample locations Park through Bucks). To compare within the main stem of the Gallatin, summer base flow nitrate concentrations drop to an average 0.03 mg/l as N and, in winter, climb to 0.1 mg/l. Most nutrients are discharged from the system during peak flow which, on average, is over 10 times greater than base flow conditions. This can be seen in **Figure 4** which shows the bulk nitrate-nitrite load associated with runoff in June compared to the lower flows later in the summer and fall (Chart courtesy of the Gallatin River Task Force 2019) .The instream concentrations of nutrients are most critical during the summer base flow conditions when temperatures warm and nitrogen concentrations above 0.3 mg/l can significantly diminish the quality of aquatic habitat. During both summer and winter base flow conditions, surface runoff is at a minimum and the rivers consist largely of resurfacing groundwater.

FIGURE 4. Nitrate + Nitrite loads at various Task Force monitoring sites



(Gallatin River Task Force, 2019)

The majority of anthropogenic sources for nutrients into the watershed are from treated wastewater strategically land applied to maximize the total removal of nitrogen and phosphorous prior to the water surfacing in the stream. Groundwater below land application sites and downgradient of septic drainfields moves relatively slowly through the catchments compared to surface water. As a result, groundwater can act as a year-round source of nutrients to the streams as the cumulative nutrient load is slowly and relatively evenly discharged into the gaining reaches of the receiving streams. From this perspective analyzing water quality during baseflow conditions can provide an estimate of the cumulative annual nutrient load on the stream by anthropogenic sources, and provide a critical assessment of how groundwater quality impacts stream water quality. The limitations of this analysis include an assumption that groundwater flux into the stream is constant and it explicitly ignores stream nutrient influxes due to stormwater runoff which represents a short-term acute load not captured by base flow sampling.

The bulk of the anthropogenic nitrogen is added to the West Fork sub-watershed and water quality results from the West Fork indicate nitrogen levels that exceed the 0.3 mg/l as N threshold, with elevated concentrations in the main stem below the confluence with the West Fork. For this reason, the majority of the detailed analysis for the larger watershed is restricted to the West Fork. It is important to note that, as designed, the wastewater disposal and septic systems that produce the anthropogenic load in the watershed are following the best practices prescribed by DEQ, however, the summation of all the systems appears to be having a measurable impact of stream water quality.

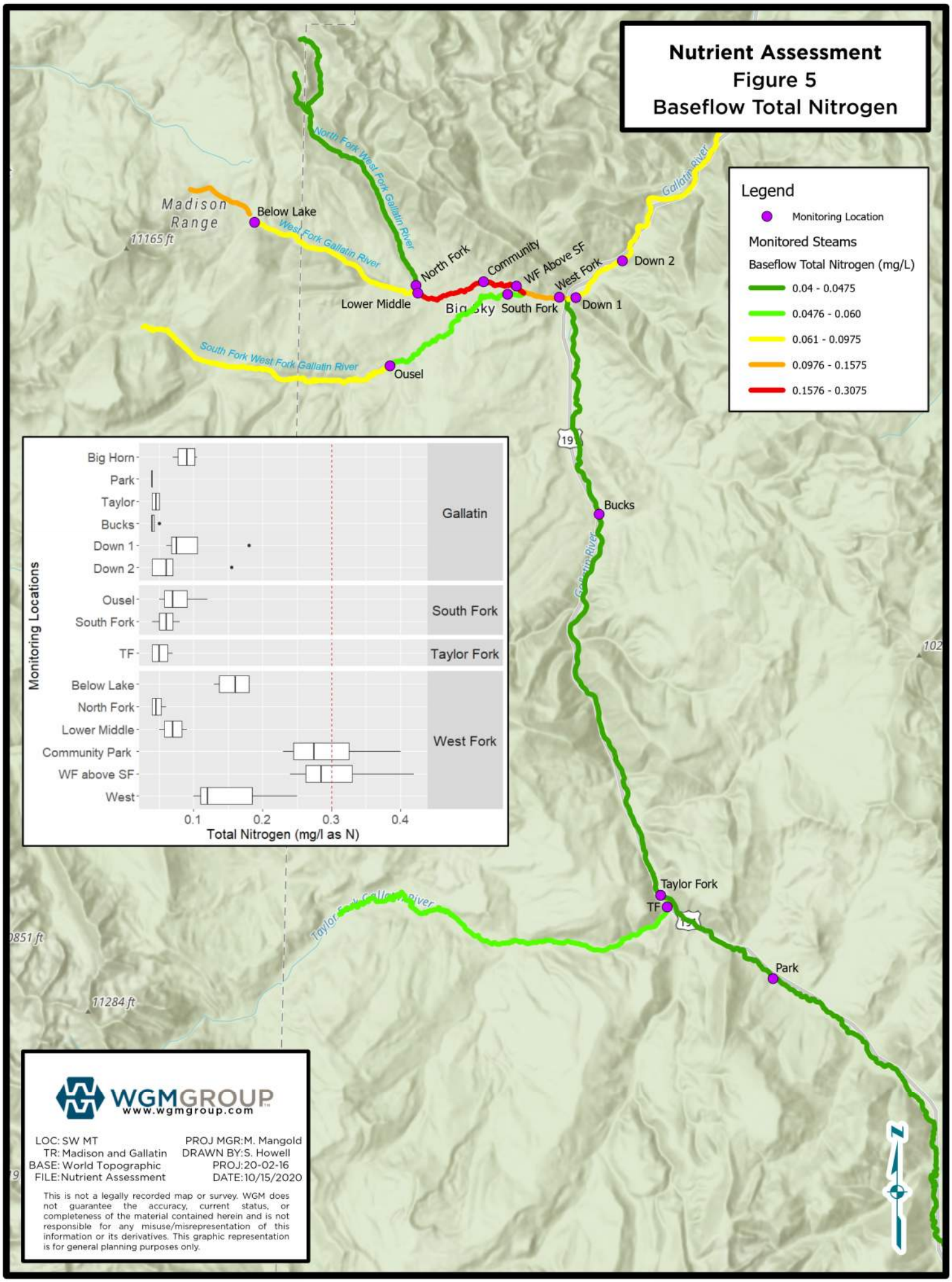
Water Quality in the West Fork

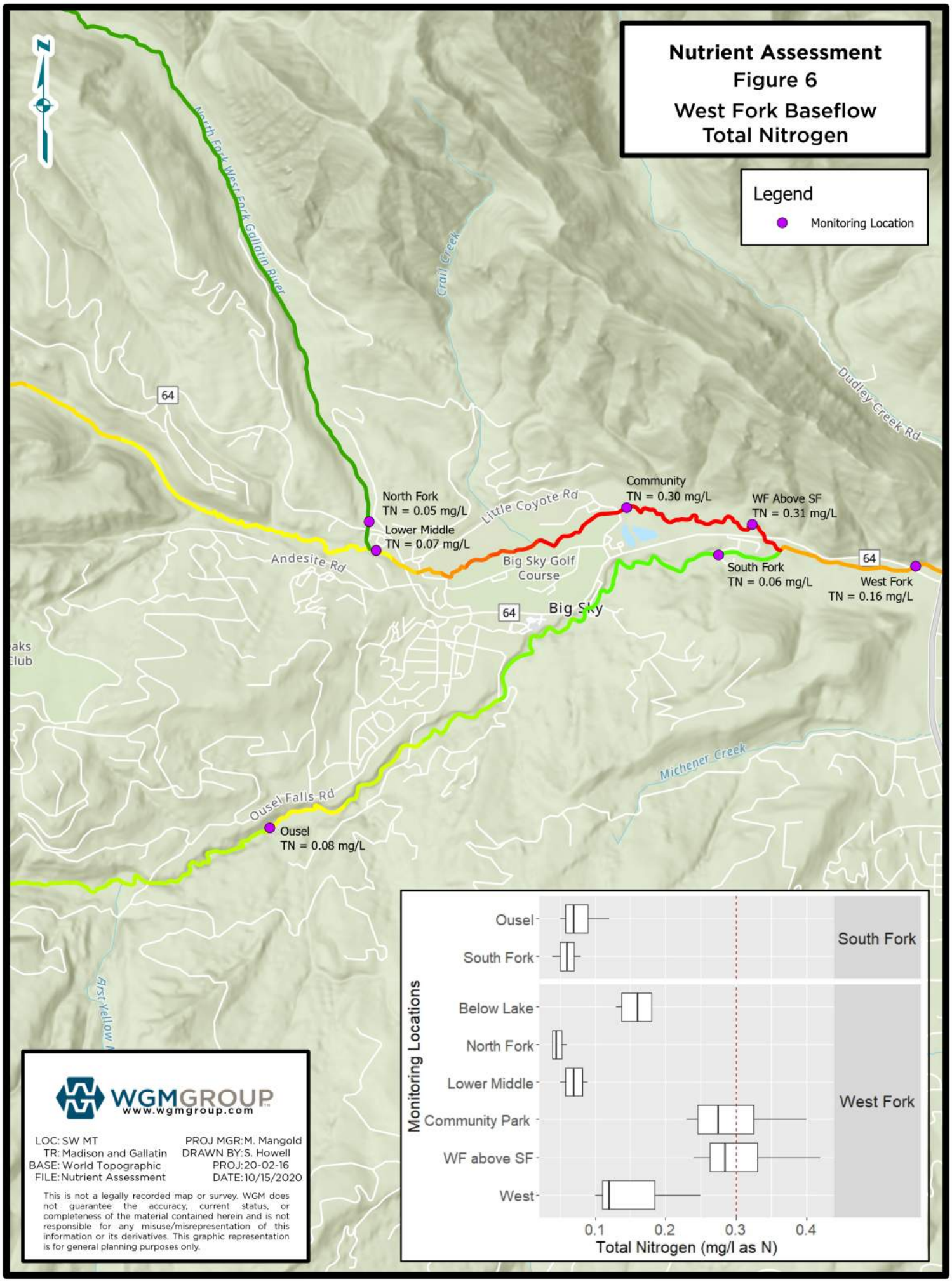
Most water quality sample sites within the West Fork, including stations in the South Fork of the West Fork watershed, receive water that could have been impacted by anthropogenic sources. **Figure 2** illustrates selected water quality monitoring sample locations and the distribution of land use within the watershed. Notable is the amount of developed land above Lake Levinsky and the concentration of developed land in the Meadow Village area that drains into the West Fork, prior to the confluence with the South Fork. Water quality in Lake Levinsky is regularly elevated by an average of 0.13 mg/l as N in nitrate compared to the North Fork. This increase could be attributable to anthropogenic sources, different geology, and/or different land uses. Water quality averages measured at the Middle Fork station is comparable to values measured in the Gallatin River main stem above the confluence with the West Fork where human impact is low in the majority of the watershed.

During base flow conditions in summer and winter, the downstream water sampling locations along the West Fork return significantly elevated nitrogen levels, peaking in concentration prior to the confluence with the South Fork. Water quality from three locations—Community Park, West Fork above the South Fork, and the West Fork (prior to Gallatin River confluence)—all indicate significantly elevated levels of nitrate that cannot be explained by natural processes alone. Both water quality measuring stations along the South Fork are located far enough down the watershed to be potentially influenced by anthropogenic nitrogen addition from developed areas including Yellowstone Club Golf Course irrigation water. Both sample locations in the South Fork indicate levels of nitrate that are elevated compared to the main stem of the Gallatin, but are still in line with measurements observed at the headwaters of the Gallatin.

Figures 5 and 6 provides a visual representation of summer base flow concentrations of total nitrogen in stream reaches for the study area. Stream reaches are color coded to represent mean total nitrogen concentrations, while a box plot of the available data is inset to illustrate data variability. The dashed vertical line in the box plots represents the in-stream total nitrogen limit of 0.3 mg N/L. It is important to note that winter base flow nitrate conditions present a very similar picture of instream water quality.

Nutrient Assessment
Figure 5
Baseflow Total Nitrogen




Nutrient Assessment
Figure 6
West Fork Baseflow
Total Nitrogen
Legend
Monitoring Location
North Fork West Fork Gallatin River
Crail Creek
Dudley Creek Rd
64
North Fork
TN = 0.05 mg/L
Lower Middle
TN = 0.07 mg/L
Little Coyote Rd
Community
TN = 0.30 mg/L
WF Above SF
TN = 0.31 mg/L
Andesite Rd
Big Sky Golf Course
South Fork
TN = 0.06 mg/L
West Fork
TN = 0.16 mg/L
Big Sky
Michener Creek
Ousel Falls Rd
Ousel
TN = 0.08 mg/L
First Yellow
Ousel
South Fork
Below Lake
North Fork
Lower Middle
Community Park
WF above SF
West
Monitoring Locations
South Fork
West Fork
0.1
0.2
0.3
0.4
Total Nitrogen (mg/l as N)
WGMGROUP
www.wgmgroup.com
LOC: SW MT
TR: Madison and Gallatin
BASE: World Topographic
FILE: Nutrient Assessment
PROJ MGR: M. Mangold
DRAWN BY: S. Howell
PROJ: 20-02-16
DATE: 10/15/2020
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Estimated Stream Load

An analysis of water quality and quantity during base flow was performed to estimate currently observed anthropogenic load into the main stem and West Fork of the Gallatin. Using flow data collected by the Task Force, summer base flow in the West Fork prior to the confluence with the Gallatin was estimated to be 26 cfs, with the South Fork contributing roughly 15 cfs and the West Fork contributing the remaining 11 cfs. Winter base flow measurements were unavailable. To model winter base flow in the West Fork, the ratio of winter base flow to summer base flow at the USGS Gage Station 06043500 was applied to the measured summer base flow in the West Fork, resulting in an estimated average winter base flow of 17 cfs. Flows in the main stem of the Gallatin were estimated by applying the contributing percentage of the total drainage area to the flow value measured at the USGS Gage Station 06043500. Stream load within a reach was estimated by multiplying the change in concentration along the reach by the estimated flow at the downstream measuring station. Load estimations are subject to variability that comes from estimations in the flow rate and the precision of water quality values that are often on the low end of the experimental methods detection limits. Measurement variability is significantly reduced when concentrations exceed 0.1 mg/l as N. Potential measurement variability of +/- 0.01 mg/l as N can significantly impact loading values when water quality values are less than 0.1 mg/l as N.

Changes in base flow nitrogen concentrations along a stream reach can help determine areas where anthropogenic nitrogen that has accrued in groundwater impacts the receiving stream. During both summer and winter base flow, overland flow is at a minimum and most water in the stream is resurfacing groundwater. Therefore, base flow concentrations are most heavily impacted by groundwater quality. This is significant because groundwater is intentionally the recipient of most of the watersheds anthropogenic nitrogen loads. To account for the effective stream load, we assume that anthropogenic nitrogen inputs into groundwater as nitrate and flows into the stream at a relatively constant rate throughout the year. Groundwater flux into stream reaches does vary by season, but base flow conditions provide a conservative estimate.

To estimate total nitrogen input into stream reaches, both summer base flow total nitrogen data and winter base flow nitrate data were used independently. Winter stream nitrate concentrations can illustrate the input of nitrogen stored in regional groundwater. Nitrogen generally enters and accumulates in groundwater as nitrate regardless of original nitrogen source. Once in the form of nitrate, the nitrogen can move freely in groundwater and can resurface as streams gain water from the surrounding subsurface reserves. In winter, biotic processes that transform nitrate are significantly inhibited, enabling changes in nitrate to be correlated to the influx of total nitrogen from groundwater. In warm seasons, biotic processes can quickly uptake the nitrate and as a result, instream nitrate concentrations can underestimate nitrate additions. In warm periods, total nitrogen concentrations along a stream reach should reduce more slowly. Much of the consumed nitrate is transformed to dissolved organic compounds and suspended biomass which is accounted for in the total nitrogen measurement; total nitrogen is reduced as fixed biotic life either uptake the nitrogen or is lost as a result of denitrification. Water quality in the stream reach bounded by the Middle Fork and West Fork before the confluence with the South Fork sample stations illustrates this relationship. Average summer nitrate levels increase from 0.02 mg/l to 0.19 mg/l while total nitrogen numbers increase from 0.07 to 0.31 mg/l as N. The increase in total nitrogen of 0.24 mg/l in the summer, matches the winter average increase in nitrate for

the same reach which changed from 0.18 mg/l at the Middle Fork to 0.41 mg/l as N prior to the South Fork confluence. These values indicate a significant increase in nitrogen levels as the West Fork moves through the Meadow Village area.

Nitrogen increases were estimated down the West Fork of the Gallatin and from above the Big Sky Canyon Area to below the confluence with the West Fork. Paired data (data from the same sample date) were used to calculate a measured difference in water nitrate or total nitrogen concentrations across the reach. A student's t-test in the program R was then applied to determine an estimate of the mean, 95% confidence levels and P values which determines if a significant change in water quality was observed. A summary of model results can be found in **Table 4**.

TABLE 4. CHANGE IN WATER QUALITY MODEL RESULTS FROM THE UPPER MEASUREMENT LOCATION TO THE LOWER MEASUREMENT LOCATION.

UPPER MEASUREMENT LOCATION	LOWER MEASUREMENT LOCATION	MEAN INCREASE IN WINTER BASE FLOW NITRATE				MEAN INCREASE IN SUMMER BASE FLOW TOTAL NITROGEN			
		mg/l	(+/-)	N	p ≤0.05	mg/l	(+/-)	N	p ≤ 0.05
Middle Fork	West Fork above South Fork	0.23	0.23	6	Yes	0.23	0.1	4	Yes
North Fork	West Fork above South Fork	0.32	0.14	11	Yes	0.26	0.1	4	Yes
Flow averaged Middle Fork and Ousel	West Fork	0.18	0.14	6	Yes	0.08	0.1	3	No
Bucks	Down 1	0.04	0.04	11	Yes	0.05	0.1	4	No
Park	Down1	0.05	0.04	21	Yes	0.06	0.1	4	No

Most models (i.e. statistical datasets) run in the West Fork watershed indicate a significant increase in nitrogen concentrations during both summer and winter base flow conditions. The magnitude of increase is the greatest as water passes through the Meadow Area of Big Sky. This increase can be observed from both the Middle Fork station and the North Fork station. The North Fork of the Gallatin is characterized by relatively low nitrate concentrations, while the water that comes from Lake Levinsky, and the Middle Fork, generally has nitrate levels that are on average 0.08 mg/l higher than the North Fork. Model results for the main stem of the Gallatin also indicate a significant increase in winter nitrate levels as the river moves through the Canyon Area and mixes with the West Fork, but not a significant increase in total nitrogen.

An instream load calculation was performed for three scenarios in the West Fork watershed and can be found in **Table 5**. Load calculations were not calculated for models that lacked statistical significance. To calculate loading, the increase in instream concentration of nitrogen was multiplied by an assumed seasonal base flow daily flow volume, resulting in a daily nitrogen load. This load was then multiplied by 365 days per year. The assumption in this calculation is that groundwater contribution of nitrogen to the stream is constant year-round.

TABLE 5. MODELED STREAM REACH NITROGEN LOAD ESTIMATES

UPPER MEASUREMENT LOCATION	LOWER MEASUREMENT LOCATION	MODELED WINTER INCREASE	MODELED SUMMER INCREASE
		(lb N /yr)	(lb N /yr)
Middle Fork	West Fork above South Fork	4,981	4,981
North Fork	West Fork above South Fork	6,930	5,631
Flow averaged Middle Fork and Ousel	West Fork	9,214	NS
Bucks	Down 1	15,592	NS
Park	Down 1	19,136	NS

**NS indicates a non-significant change in water quality along the reach.*

Measured stream nitrogen in the West fork indicate that there is a source of nitrogen in the lower reaches of the watershed contributing roughly 5,000 lbs N per year above the confluence with the South Fork, and roughly 9,000 lbs N per year to the entire West Fork watershed. The 95% confidence limits present significant potential ranges. A modeled flow rate for the winter base flow also detracts from the validity of the model results.

Two loading models remain when we require supporting measured streamflow data, and require the model return significant change in water quality. The two remaining models include the summer base flow total nitrogen from the Middle Fork and North Fork to the West Fork above the South Fork. These models support each other well and predict a 95% confidence that the annual additional nitrogen added to the system ranges between 2,500 and 7,500 lbs N per year with an estimate of approximately 5,000 lbs N per year. This nitrogen load pales in comparison to the estimated 62,000 lbs N per year estimated to be discharged by the watershed of the Gallatin above USGS Gage station 06043500; however, the impact that the increase has on instream concentrations during base flow has pushed the stream above water quality thresholds on the West Fork. Additionally, this analysis highlights the importance of continuing to acquire stream water quality and quantity data. The Task Force has built a sizable database, however, expanding the total nitrogen dataset will enable analysis of regulated TN opposed to the surrogate nitrate which may underestimate TN. Streamflow rate at multiple points along the West Fork in conjunction with continued and/or expanded TN testing will better facilitate mitigation planning and measure the impact of any nutrient abatement strategies.

Nutrient Assessment Results and Recommendations

Both natural and anthropogenic loads are input in the Gallatin River watershed and a summary of loads for the watershed can be found in **Table 6**. Natural sources include wet and dry deposition, biotic fixation, and rock weathering, while anthropogenic sources include municipal waste water, onsite systems, grazing/stable operations, stormwater, and domestic animals. Net deposition of nitrogen into the area is a function of storm, precipitation, and wind patterns. The US SPARROW model suggests a regional deposition rate of 113 kg N / km^2, for a total of 240,800 kg N deposited into the watershed terminating below Spanish Creek, with a net export of 63,000 lbs N per year (Schwarz, 2006).

TABLE 6. ESTIMATE ANNUAL LOAD OF NITROGEN FROM ASSESSED SOURCES INTO THE WATERSHED (REPEAT OF TABLE 1)

WATER SHED	NATURAL LOAD	MUNICIPAL WASTE WATER	ONSITE SYSTEMS	GRAZING/ STABLES	STORM WATER	DOMESTIC ANIMALS
West Fork	47,100	12,000	4,400	3,300	2000	1,000
Gallatin	530,900	12,000	12,700	13,000	2000	1,200

**All units N lb/year.*

Human induced, or anthropogenic loads, were estimated for a subset of watersheds within the watershed of the Gallatin River above the USGS gage station downstream of the confluence with Spanish creek, with a focus on the West Fork watershed. In the region, primary anthropogenic sources were found to be application of treated municipal wastewater to three golf courses and discharge from onsite wastewater treatment systems, discharging approximately 12,000 and 12,700 lbs N per year respectively. Equestrian and grazing operations also represent a large load at watershed scale, contributing between 7,000 and 13,000 lbs N annually. Stormwater and domesticated animal sourced (e.g. dog poop) load were also considered. Notably some of the load from grazing operations, and most of the load from stormwater and domestic animals were not captured in the baseflow analysis as baseflow by definition does not include surface flow from storm events (stormwater) which transports most of the nutrients from these sources. The majority of the anthropogenic loading occurs in the West Fork Drainage, including all of the application of municipal wastewater and 4,400 lbs N per year from onsite systems. The remainder of the onsite systems are distributed across the watershed, as outlined by basin in Table 6, with most clustered in the Canyon Area of Big Sky. These contribute an estimated load of 4,600 lb N per yr. Further details on each estimated anthropogenic load and potential mitigation strategies are outlined in the sections below.

MUNICIPAL WASTEWATER DISCHARGE

SUMMARY: The application of municipal wastewater represents one of the largest anthropogenic source of nitrogen, estimated to be approximately 12,000 lbs N per year irrigating three golf courses: Meadow View, Yellowstone Club and Spanish Peaks. Application rates to the golf courses are designed to ensure zero discharge of nutrients to the groundwater, however, research on golf courses used for wastewater disposal indicated that an average of 30% of the applied nutrients from the applied irrigation water can enter groundwater (Devitt, 2008). Applying this assumption to the Meadow View Golf

Course, 1,900 lb N /yr in the West Fork could be attributable to leaching of nutrients from irrigation water. The instream estimate for the Yellowstone Club golf course is approximately 600 lb N / yr and Spanish Peaks course is estimated to be less than 400 lb N / yr if we apply similar first order removal assumptions as the onsite system analysis to account for potential subsurface denitrification. Details and potential mitigation options are proposed as follows and expanded upon below.

Mitigation 1: WWTP upgrade reducing the load by 70%

Mitigation 2: Dispose of wastewater outside the West Fork watershed (e.g. Canyon Area groundwater disposal per the Feasibility Study)

Mitigation 3: Improve Golf Course Irrigation BMP's by creating a Hydrus model of the soil profile to more accurately determine application rates that can be altered based on soil water moisture.

Mitigation 4: Intercept the 'pool' of nitrogen in the subsurface prior to discharge.

- Chapel Spring mitigation
- Investigate locations for additional nitrate mitigation measures including near stream groundwater upwellings proximal to the Yellowstone Club and Spanish Peaks Golf Courses.
- Collaborate with MBMG and current groundwater modelers to see what impact leaching from Spanish Peaks may be having on groundwater and to determine hot spots for mitigation.

Nitrogen loading resulting from the disposal of treated municipal wastewater on the Meadow Village, Yellowstone Club, and Spanish Peaks golf courses was estimated using annual wastewater flows from 2013 – 2017 and average discharge water quality. The mean annual flow was estimated to be approximately 0.36 million gallons per day (MGD) for a total of 131 million gallons per year and effluent quality assumed to be 17 mg/l total nitrogen as N. The load from irrigation was then averaged to a daily load and distributed to each golf course according to their permitted or design capacity as outlined in a 2015 WGM report with Meadow Village receiving approximately 53% of the load (69 million gallons per year), Yellowstone Club receiving approximately 21% and Spanish Peaks 26% (WGM, 2015). The use of treated wastewater as irrigation water is the primary method of water disposal for the District and was designed to significantly reduce the load of nutrients on the West Fork of the Gallatin River. Land application of the water is designed to maximize plant uptake and minimize the transport of nutrients to groundwater and in turn the West Fork of the Gallatin.

Design criteria for land application systems are set by DEQ and application rates are designed to not exceed levels of plant uptake or to oversaturate soil to reduce the transport of nutrients into groundwater. By adhering to the design criteria, the assumption is that minimal nutrients are lost to groundwater because absorption, plant uptake and microbial processes bind or remove all applied nutrients. Standards for land application vary from state to state, but most localities have similar requirements for the application of treated wastewater for irrigation. A study of nine golf courses that utilized treated wastewater for irrigation showed that the leaching factor, or fraction of applied nitrogen that left the system via groundwater, could exceed 30% under normal operating conditions (Devitt, 2008). This is a notable proportion of the nutrients applied. In the case of The Meadow View Golf course alone, this could represent an annual output of

approximately 1,900 lbs nitrogen per year. This value does not include any additional nitrogen added to the system in the form of fertilizer. Fertilizer is applied to 30 acres of the Meadow View Golf Course at a rate of 0.5 lbs per 1000 ft^2 bi-annually in June and August resulting in an additional annual surface load of 1,300 lbs (personal communication with Kristin Gardner).

Phosphorus loading on the golf courses is also significant and results in a total of 2,200 lbs P per year assuming a phosphorus concentration of 2.0 mg/l as P. Phosphorus is physically bound to soil and rock particles as the water flows in the subsurface. Over time the ability of the subsurface to absorb phosphorus decreases as the absorption capacity of the subsurface is filled, however, there is currently no evidence of phosphorus breakthrough in the water quality near the golf courses.

The stream data loading models predict an instream load to the West Fork as it passes through the Meadow Village area of approximately 5,000 lbs N per year, and research from other courses suggest it is reasonable to attribute 1,900 lbs N per year to current irrigation practices. At a base flow of 11 cfs, this correlates to an instream increase in total nitrogen concentration of 0.08 mg/l, which is approximately one-quarter of the 0.3 mg/l threshold concentration value. Mitigating the load at the Meadow View Golf Course is likely the single most effective step in reducing nitrogen concentrations in the West Fork of the Gallatin River.

Mitigation efforts to reduce the mass of nitrogen applied to the golf courses are already underway. Current plans for wastewater treatment plant upgrades are set to be operational in 2022 and incorporates a design discharge that is less than 5 mg/l total nitrogen. The lower discharge standard alone eliminates at least 70% of the nitrogen load compared to current concentrations. At the current average flow volume, this would reduce the instream baseflow nitrogen increase to 0.04 mg/l as N. Flow projections for the area are set to increase above what can be disposed of on the golf courses. As the flow increases, the leach rate of nitrogen from the golf courses will also likely increase as more water is applied, further taxing the already overloaded natural removal processes. The fraction of nutrients leached may be reduced by increasing the area over which the nutrients are applied and optimizing irrigation application. Better modeling of the soil profile using a program such as Hydrus can enable smarter irrigation practices, make better use of nutrients in the soil profile reducing fertilizer application and inform irrigation BMPs to minimize nutrient leeching. Additionally, discharging a portion of the wastewater outside of the West Fork drainage would also reduce nutrient loading in the West Fork. Low summer base flows in the West Fork provide limited dilution. The same mass of nutrients released into the Gallatin with a base flow that is approximately 10 times greater would result in instream nitrate concentrations that are 10 times lower than the equivalent mass in the West Fork. While dilution is not always the solution to pollution, the increased flow coupled with the plans to improve treatment maximize water quality in all reaches of the watershed.

Nitrate levels in the groundwater around the Meadow Village golf course are currently elevated and represent a significant store of residual nitrogen. Removing the source of the nitrogen loading will improve conditions long term, but the stored reservoir could take decades to move into the stream. Mitigating the residual nitrate in the shallow groundwater under the Meadow Village golf course can provide a means of reducing the nitrogen load to the West Fork during summer base flow. This mitigation action can take

the form of installing nitrate mitigation systems like nitrate abatement treatment wetlands for artesian groundwater sources, and systems that passively treat groundwater like permeable reactive barriers.

Similarly, creating an inventory of areas around the Yellowstone Club and Spanish Peaks golf courses where shallow groundwater can be intercepted and mitigated can greatly improve nitrogen loading in the watershed. This inventory coupled with groundwater measurement and modeling can lead to a targeted and effective mitigation strategy. While the two courses are further from surface water, if similar leaching rates are observed, irrigation at the Yellowstone Club golf course could be having an outsized effect on the South Fork of the Gallatin and Spanish Peaks could be a significant contributor to elevated nitrate groundwater measurements along the groundwater flow path beneath the Meadow Village area.

ONSITE SYSTEMS: ArcNLET FATE & TRANSPORT MODEL

SUMMARY: Watershed loading from onsite systems is estimated to be 12,676 lbs N per year with an estimated instream load of 6,900 lbs N per year to the Gallatin, including 1,500 lbs N per year from the West Fork. Details and potential mitigation options are proposed as follows and expanded upon below.

> **Mitigation 1:** Promote connecting existing and new developments to centralized treatment in Big Sky and the Canyon Area, reducing current onsite loads and the impact of future developments.
>
> **Mitigation 2:** Advocate for on-site system maintenance.
>
> **Mitigation 3:** Advocate for Level II treatment for new homes on individual septic systems.
>
> **Mitigation 4**: Fund effluent testing and system support for permitted systems to promote good maintenance, especially for community scale systems.

Understanding the impacts of multiple onsite systems on groundwater is an inherently complicated process. Multiple platforms exist to model the processes that drive the fate and transport of contaminants in the subsurface and the modeling options range significantly in the complexity and cost of application. ArcNLET (applied model) is a simplified nitrogen specific fate and transport model within an ArcGIS platform. The model was developed to give decision makers a cost-effective visualization and analytical tool to model the cumulative effects of onsite systems on groundwater and receiving water bodies (Rios et al., 2011). The analysis in this report describes the results of an ArcNLET model used as an accounting of point loads to the aquifer associated with existing septic systems and a fate-transport depiction of cumulative effects and nitrate conveyance to the Gallatin River.

The ArcNLET model is based in ArcGIS and inputs elevation data, soil data, waterbodies, and a map of onsite wastewater treatment systems (OWTS) to generate a visual representation of regional nitrate plumes and calculate the resulting nitrogen load to surface water bodies. A 10-meter digital elevation model of the area was obtained from the USGS. Soil data was pulled from the NRCS Web Soil Survey to account for spatially varying porosity and hydraulic conductivity. An ArcNLET model was prepared for the Canyon Area Feasibility Study in March 2020 so the Canyon Study Area was excluded when creating the new model to reduce processing time, although the results are incorporated.

The Gallatin County Environmental Health and GIS Department databases were utilized to determine locations of on-site septic systems within the Study Watersheds. Because the databases are not complete and do not include Madison County, "ground truthing" was conducted via 2017 aerial imagery. If there was a house within a parcel, it was assumed it had an on-site septic system unless it fell within the District service boundary or was part of sewered subdivisions within the Yellowstone Club or Moonlight Basin. The following table (**Table 7**) shows the number of systems per watershed used in the subsurface nutrient analysis and how many were identified in the databases versus through aerial analysis.

TABLE 7. ONSITE SYSTEMS DISTRIBUTED BY WATERSHED AND METHOD OF DETERMINATION

WATERSHED	SYSTEMS COUNT	SYSTEMS IN GIS DATABASE	SYSTEMS FROM AERIAL ANALYSIS
Beaver Creek-Gallatin River	68	23	45
Buffalo Horn Creek	1	1	0
Cascade Creek-Gallatin River	35	21	14
Deer Creek-Gallatin River	41	11	30
Elkhorn Creek-Gallatin River	25	12	13
Moose Creek-Gallatin River	47	12	35
Snowslide Creek-Gallatin River	1	1	0
Storm Castle Creek	3	3	0
West Fork Gallatin River	200	62	138
Canyon Study Area	125	62	63
TOTALS	546	**208**	**338**

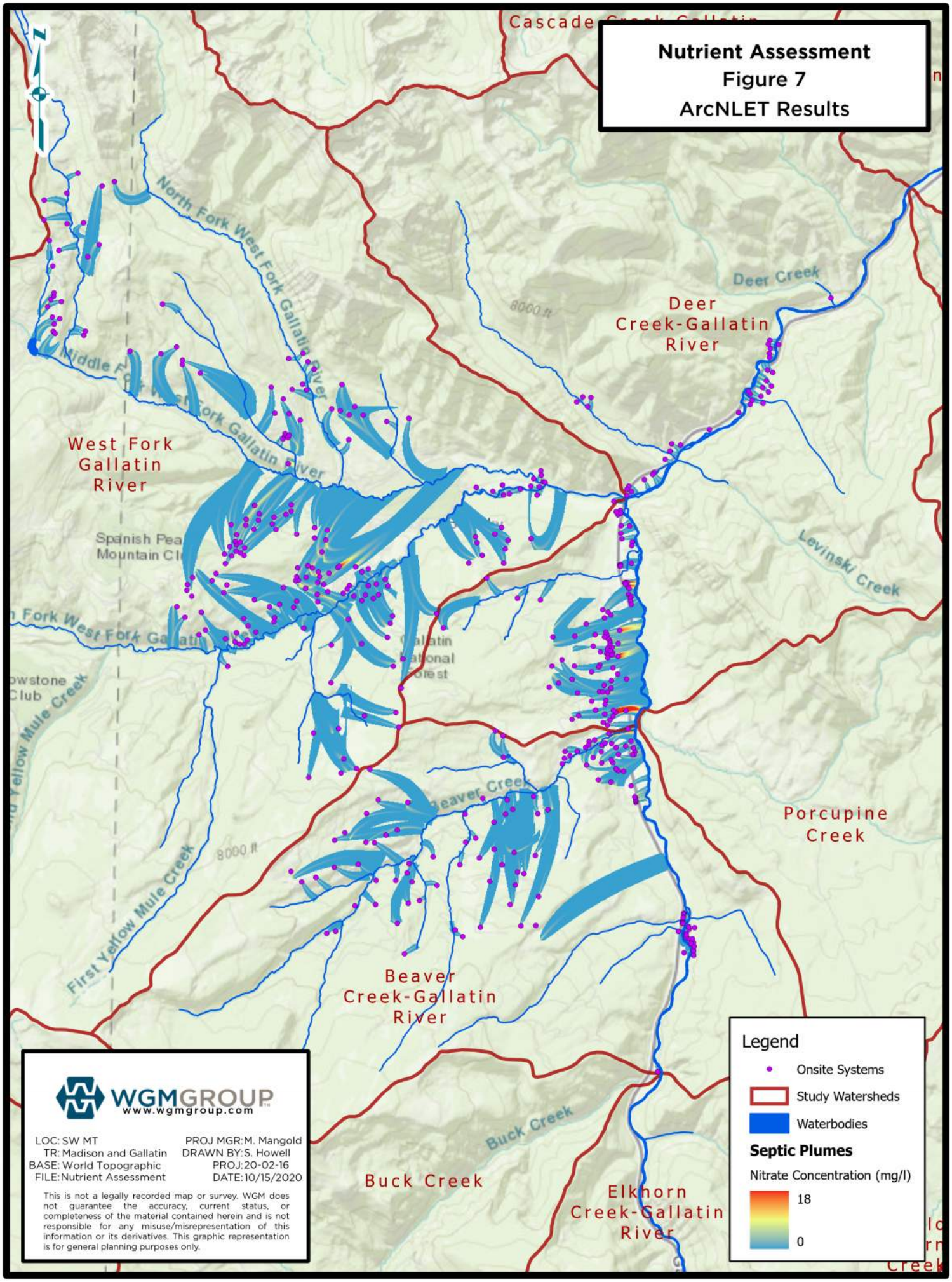
*Each residence not connected to a communal system was assigned a population equivalent of 2.5 individuals resulting in a load to the groundwater of 20.16 grams nitrogen per residence per day.

Two community systems; Firelight Meadows and Antler Ridge subdivisions, were also included in the ArcNLET model. The Firelight Meadows subdivision has three drainfields with Level II treatment and Antler Ridge has a recirculating trickling filter bed (also Level II). Each drainfield was assigned a population equivalent of 87.5 individuals resulting in a load to the groundwater of 392 grams nitrogen per day. It is important to note that the treatment system at Firelight Meadows has been shown to be discharging wastewater with total nitrogen values that exceed the assumptions of a Level II treatment system. For the purpose of this rough-cut analysis, the system was assumed to be functioning correctly.

ArcNLET Model Results

The ArcNLET Results map presented in **Figure 7** illustrates nitrate plumes for a subset of onsite systems within the West Fork, Beaver Creek and Deer Creek watersheds. The greater watershed was subset into smaller model areas and run separately. Results include model results prepared separately for the Canyon Area. An example of model results have been provided in **Figure 7**, and a summary of loading for each watershed provided in **Table 8**. The total load into the aquifer was estimated at 12,676 lbs per year.

To generate nitrogen plumes, the model applies what is known as the Domenico solution for groundwater transport, which simplifies the partial differential equation for groundwater flow to allow an analytical solution and accounts for denitrification modeled as a first order reaction (only a function of time). This simplified conceptual model provides the basis for multiple EPA models for contaminate transport analysis including BIOSCREEN and BIOCHLOR (Rios et al., 2011). The fate and transport model is solved individually for each OWTS, and the results for each OWTS superimposed on the map to estimate groundwater concentrations.


Nutrient Assessment
Figure 7
ArcNLET Results
Cascade Creek-Gallatin
North Fork West Fork Gallatin River
Middle Fork West Fork Gallatin River
West Fork Gallatin River
Spanish Peak Mountain Club
Deer Creek
Deer Creek-Gallatin River
Levinski Creek
Gallatin National Forest
Beaver Creek
Beaver Creek-Gallatin River
Porcupine Creek
First Yellow Mule Creek
Buck Creek
Elkhorn Creek-Gallatin River
8000 ft
Legend
Onsite Systems
Study Watersheds
Waterbodies
Septic Plumes
Nitrate Concentration (mg/l)
18
0
WGMGROUP
www.wgmgroup.com
LOC: SW MT
TR: Madison and Gallatin
BASE: World Topographic
FILE: Nutrient Assessment
PROJ MGR: M. Mangold
DRAWN BY: S. Howell
PROJ: 20-02-16
DATE: 10/15/2020
This is not a legally recorded map or survey. WGM does not guarantee the accuracy, current status, or completeness of the material contained herein and is not responsible for any misuse/misrepresentation of this information or its derivatives. This graphic representation is for general planning purposes only.

The nutrient load applied to the aquifer and the resulting nutrient load to hydraulically connected receiving water bodies is often different. In the context of phosphorus, the amount of phosphorus adsorption capacity in the soil should prevent breakthrough of phosphorus into the water body for a minimum of 50 years assuming that the OWTS system has been properly sited and designed. For mobile nitrogen compounds like nitrate, the subsurface fate and transport is more difficult to characterize. Nitrate is subject to removal via denitrification, which is a microbially mediated process in which microbes couple nitrate with organic carbon and emit di-nitrogen gas, effectively removing the nitrogen from the system. Denitrification has been proven to occur in the subsurface, with the rate dependent on the amount of carbon available in the subsurface, as well as temperature and other environmental factors (Otis et al., 2009). ArcNLET accounts for denitrification using a first order removal function, which means that nitrogen removal is only a function of how long the nitrate is in the subsurface (Rios et al., 2011). Applying a model with a strong variable parameter like a denitrification rate requires data to calibrate the model. In this region very limited data was available. A denitrification rate of 0.0005 per year was applied based on WGM experience evaluating denitrification rates in a similar alluvial aquifer in Montana's Bitterroot Valley. Using this hypothetical denitrification rate, the nitrogen loading from OWSTs to the Gallatin River would be approximately 6,870 lbs per year, representing 54% of the total nitrogen applied to the watershed via onsite systems.

TABLE 8. ONSITE SYSTEM COUNT, AQUIFER LOAD, AND ESTIMATE INSTREAM LOAD BY WATERSHED

WATERSHED	SYSTEMS COUNT	LBS N/YEAR	ESTIMATE LOAD TO STREAM (lbs N/year)
Beaver Creek-Gallatin River	68	1103	421
Buffalo Horn Creek	1	16	-
Cascade Creek-Gallatin River	35	568	440
Deer Creek-Gallatin River	41	665	408
Elkhorn Creek-Gallatin River	25	406	380
Moose Creek-Gallatin River	47	762	711
Snowslide Creek-Gallatin River	1	16	-
Storm Castle Creek	3	49	-
West Fork Gallatin River	200	4449	1481
Canyon Study Area	125	4642	3030
TOTALS	**546**	**12676**	**6871**

It is important to note the limitations of this methodology. Subsurface transport times impact nitrogen removal and this methodology provides only an approximate estimation to aid in decision making and provide a visual reference of nitrate transport. Estimation of denitrification is an important tool to determine the real impacts on receiving water bodies. To adequately calibrate the model, groundwater quality data is required and can be incorporated into the model to transform the conceptual scenario results to more reliable

estimations. Alternatively, if detailed quantification of load from specific systems or regions is desired, a more robust and labor intensive MODFLOW model may be warranted.

Aquifer Nutrient Mitigation

The total estimated nitrogen load from onsite systems is estimated to be 12,676 lbs N per year with and instream load estimated to be on the order of 6,900 lb/yr including 1,500 lb N in the West Fork. The approximately 45% reduction from total load to instream load is an estimation based on engineering judgement. Characterization of nitrate degradation in the regional groundwater would impact loading estimates from onsite systems and have larger impacts on groundwater discharge of wastewater. While not a direct mitigation, the information would inform future mitigation options. Advocacy for reducing the impacts of onsite systems is critical to maintain, especially when looking to the future. Connecting existing system and new developments to the existing centralized treatment system will significantly increase the level of nutrient removal and protect regional groundwater which impacts stream health. The Canyon Area Sewer Feasibility Study estimated that the instream loading from the Canyon Area could double in the next 20 years under current wastewater management practices (septic systems in lieu of central collection and treatment). Onsite systems also have an average life of 20-30 years which means that many systems built in the 90's are reaching the end of their design life. Healthy, well-sited septic systems have been shown to remove up to 80% of the TN applied, while poorly located and unmaintained systems may remove as little as 10%. While public information advocacy is already present, a short summary of on-site system maintenance has been provided.

Recommended Onsite System Maintenance

Septic systems should be pumped regularly by a licensed septic pumper to avoid excessive solids accumulation. Overfull septic tanks can push solids into the drainfield, which can cause premature clogging and failure of the system. For most single family homes, pumping every 3-5 years is appropriate. For more precise timing, homeowners can observe the annual rate of solids accumulation in the tank, or ask their pumper to provide a recommendation. Tanks installed after 2001 typically have effluent filters, which help prolong the drainfield lifespan. These effluent filters should be cleaned annually. This can be done by the homeowner or a professional. **Table 9** provides a recommended septic maintenance schedule.

TABLE 9. ONSITE SYSTEM COUNT MAINTENANCE SCHEDULE

RECOMMENDED SEPTIC MAINTENANCE SCHEDULE	
ACTIVITY	FREQUENCY
Get a copy of your septic system permit from the Gallatin City County Health Department, if you don't already have a copy	Once
Review septic owner outreach materials	Yearly
Clean outlet filter (if applicable)	Yearly
Pump and inspect septic tank	Every 3-5 years
Consider replacing system	Every 25-30 years

In addition to regular pumping and filter cleaning, septic system owners should avoid driving and parking over the system, routing stormwater over the system, or planting

trees or other deep-rooted plants grow close to the system. Inputs beyond water, human waste and toilet paper should be minimized as well. Septic systems are not designed to handle food waste, trash, medications and large doses of household chemicals.

EQUESTION AND GRAZING OPERATIONS

SUMMARY: The total nutrient load to the watershed from equestrian and grazing operations is sizeable and estimated to range from 7,000 to 12,000 lbs/yr; however, the proportion that enters streams is very difficult to estimate, depends heavily on management practices, and is likely significantly lower within large grazing areas. Livestock stable operations concentrate animals and produce a nutrient rich waste stream that requires active efforts to prevent it from reaching surface and groundwater. These concentrated operations represent the greatest potential for effectively mitigating stock related loading. Details and potential mitigation options are proposed as follows and expanded upon below.

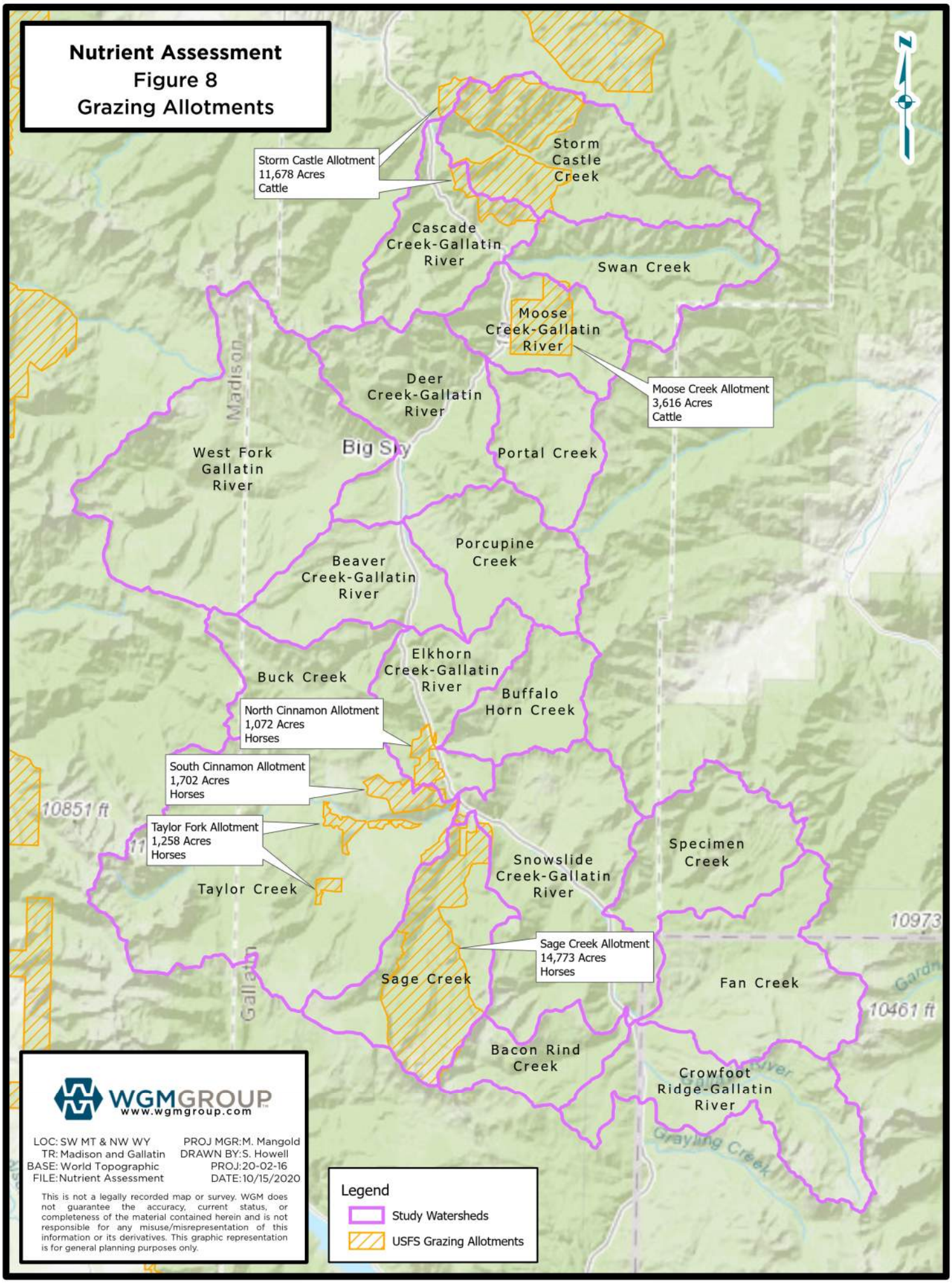
Mitigation 1: Work with stable operations to promote good waste management and stormwater practices such as manure management (covered composting), riparian buffers, and stormwater interception ponds.

Mitigation 2: Educate and provide assistance constructing or operating watering stations away from stream reaches.

The Forest Service manages the National Forests for multiple uses, with one being livestock grazing. Spatial data of grazing allotments was obtained from the USDA Forest Service FSGeodata Clearinghouse (USFS, 2020). Six grazing allotments are located within the study area watersheds, totaling approximately 34,000 acres or 53 square miles (**Figure 8**). **Table 10** lists the allotments and their respective acreage and permitted livestock class.

TABLE 10. GRAZING ALLOTMENTS

ALLOTMENT	ACRES	PERMITTED LIVESTOCK TYPE
Storm Castle	11,678	Cattle
Moose Creek	3,616	Cattle
North Cinnamon	1,072	Horses
South Cinnamon	1,702	Horses
Taylor Fork	1,258	Horses
Sage Creek	14,773	Horses


Nutrient Assessment
Figure 8
Grazing Allotments
Storm Castle Allotment
11,678 Acres
Cattle
Storm Castle Creek
Cascade Creek-Gallatin River
Swan Creek
Moose Creek-Gallatin River
Moose Creek Allotment
3,616 Acres
Cattle
Deer Creek-Gallatin River
Madison
West Fork Gallatin River
Big Sky
Portal Creek
Porcupine Creek
Beaver Creek-Gallatin River
Elkhorn Creek-Gallatin River
Buck Creek
Buffalo Horn Creek
North Cinnamon Allotment
1,072 Acres
Horses
South Cinnamon Allotment
1,702 Acres
Horses
10851 ft
Taylor Fork Allotment
1,258 Acres
Horses
Taylor Creek
Snowslide Creek-Gallatin River
Specimen Creek
10973
Sage Creek Allotment
14,773 Acres
Horses
Sage Creek
Fan Creek
10461 ft
Gallatin
Bacon Rind Creek
Crowfoot Ridge-Gallatin River
Grayling Creek
WGMGROUP
www.wgmgroup.com
LOC: SW MT & NW WY
TR: Madison and Gallatin
BASE: World Topographic
FILE: Nutrient Assessment
PROJ MGR: M. Mangold
DRAWN BY: S. Howell
PROJ: 20-02-16
DATE: 10/15/2020
This is not a legally recorded map or survey. WGM does not guarantee the accuracy, current status, or completeness of the material contained herein and is not responsible for any misuse/misrepresentation of this information or its derivatives. This graphic representation is for general planning purposes only.
Legend
Study Watersheds
USFS Grazing Allotments

Livestock grazing can contribute nutrients to the watershed through animal waste and soil erosion. The number, type of livestock, and permitted season dates were found for four of the six grazing allotments (Reid, 2016). An analysis was performed on these allotments to estimate nitrogen and phosphorus loading from animal waste using waste characterization estimates from the Agricultural Waste Management Field Handbook (NRCS, 2008). According to the analysis, between 7,208 and 12,254 pounds of nitrogen and between 1,045 and 2,631 pounds of phosphorus could be produced by livestock within the four grazing allotments per year (**Table 11**).

TABLE 11. ESTIMATED NUTRIENT LOAD FROM GRAZING ALLOTMENTS

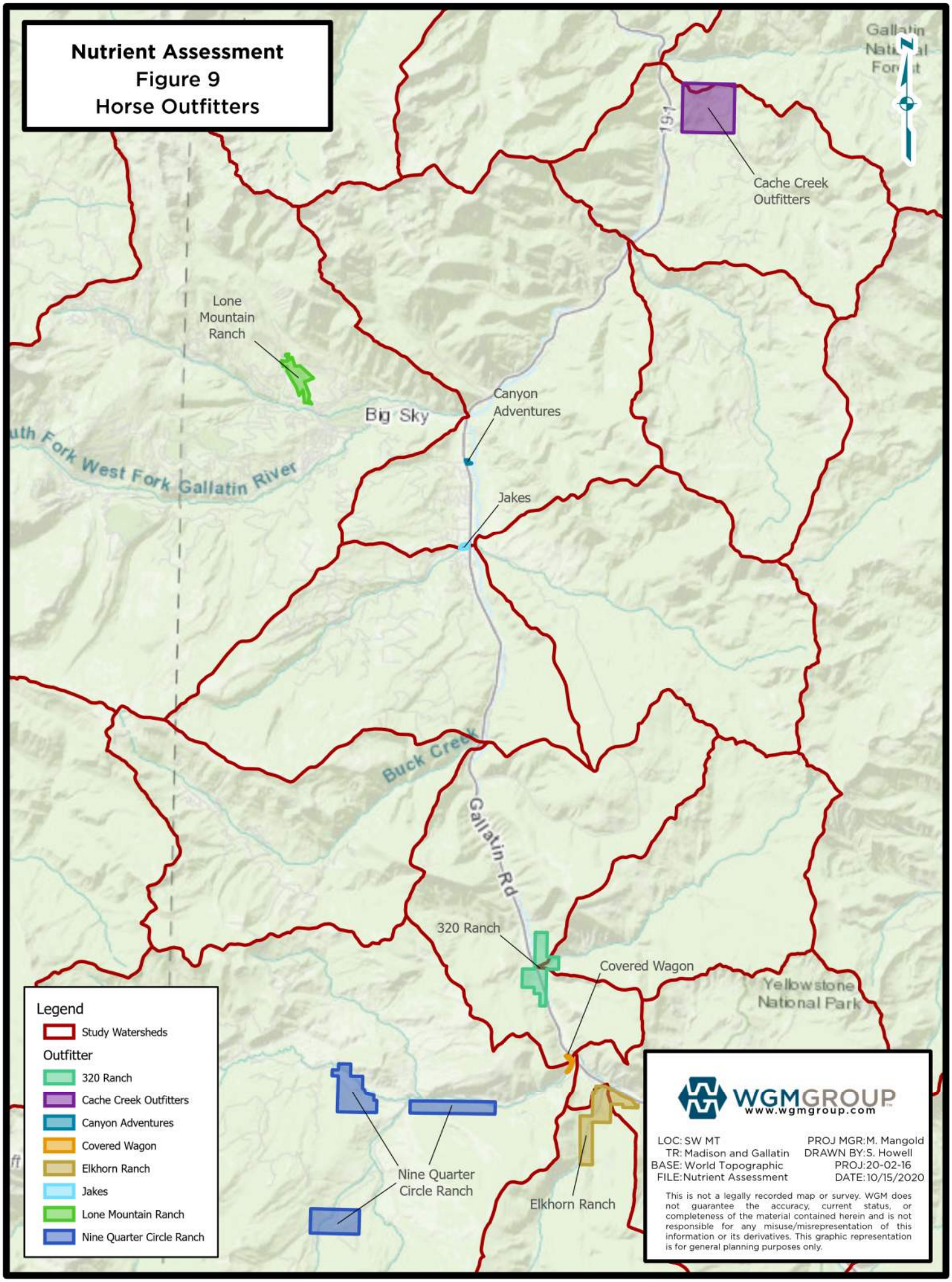
ALLOTMENT	SAGE CREEK	NORTH CINNAMON	SOUTH CINNAMON	TAYLOR FORK	TOTAL
Acres	14,773	1,072	1,702	1,258	**18,805**
Number of Livestock	129	60	35	90	**314**
Class	Horses	Horses	Horses	Horses	-
Permitted Season	6/15 - 10/15	7/1 - 9/18	6/20 - 10/20	6/15 - 10/15	-
Days per season	123	80	123	123	-
N (lb/d) Sedentary	25.8	12	7	18	**62.8**
N (lb/d) Exercised	43.9	20.4	11.9	30.6	**106.8**
N (lb/season) Sedentary	3173	960	861	2214	**7,208**
N (lb/season) Exercised	5395	1632	1464	3764	**12,254**
P (lb/d) Sedentary	3.7	1.7	1.0	2.6	**9**
P (lb/d) Exercised	9.4	4.4	2.6	6.6	**23**
P (lb/season) Sedentary	460	139	125	321	**1,045**
P (lb/season) Exercised	1158	350	314	808	**2,631**

Proper grazing management can minimize the amount of nutrients that reach surface waterbodies. While riparian areas provide an important source of forage and water for grazing livestock, they also are important for filtering nutrients and pathogens from shallow groundwater and surface water runoff. Riparian areas can be protected with fencing or by attracting livestock away from riparian areas with off-stream water and shade areas (Haan and Bartlett, 2010).

This study also found eight outfitters operating in the watershed that provide horses for recreational use (**Figure 9**). Stable operations can occur proximal to areas with grazing rights, or be managed on private land. Stables can concentrate animal waste and represent a net input of nitrogen as feed is brought into the watershed. There were not operations that qualify as a confined feeding operation (>150 head), however the

potential impact is worth noting with estimates for Lone Mountain Ranch ranging from 2,000 to 4,000 pounds nitrogen per year. Estimations for animal numbers were not available for all operations and a value of 35 used when the size of the operation was unknown.

The total nutrient load from equestrian and grazing operations is sizeable and estimated to range from 7,000 to 12,000 lbs/yr, however, the proportion that enters streams is very difficult to estimate and depends heavily on management practices. Western grazing distributes the animals over the landscape, enabling nutrients to naturally cycle and preventing the nutrients from entering the stream in appreciable quantities. Areas where animals congregate around waterbodies to access water or forage can experience significant degradation both in terms of sediment dispersal and nutrient loading. Similarly, stable operations concentrate the animals and produce a nutrient rich waste stream that requires active efforts to prevent it from reaching surface and ground waters. These concentrated operations represent the greatest potential for effectively mitigating stock related loading. Recommended mitigation measures to explore further include moving manure away from stream corridors, improved biosolids management such as covered active composting and engineered wetlands to treat runoff or shallow groundwater from pens and areas with high animal density.


Nutrient Assessment
Figure 9
Horse Outfitters
Gallatin National Forest
19-1
Cache Creek Outfitters
Lone Mountain Ranch
Big Sky
Canyon Adventures
South Fork West Fork Gallatin River
Jakes
Buck Creek
Gallatin Rd
320 Ranch
Covered Wagon
Yellowstone National Park
Nine Quarter Circle Ranch
Elkhorn Ranch
Legend
Study Watersheds
Outfitter
320 Ranch
Cache Creek Outfitters
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Stormwater Management

A detailed analysis or inventory of existing stormwater mitigations in the watershed was outside the scope of this report, however, generalities can be reported. Land use change associated with development often includes the transition of land that would absorb precipitation and process nutrients to impermeable surfaces like roads and roofs that quickly shed the water as runoff and channel that runoff to nearby streams. The runoff picks up sediment, nutrients, and other pollutants which are quickly routed into streams, minimizing interaction with the natural processes that would otherwise immobilize or remove the pollutants. Nitrogen concentrations in runoff from land use impacted by humans has been reported to vary from the background concentrations in precipitation in rooftop runoff to over 15 mg/L as N in runoff from high density roads. A research effort in North Carolina estimated that the nutrient load in medium density urban land use was 0.476 g N per m^2 per yr. Extrapolating that value to the low and medium density urban spaces in the West Fork of the Gallatin a potential stormwater load of 2,000 lb N per year, however, this extrapolation may not be regionally relevant. Furthermore, runoff from golf courses may represent a substantially greater loading rate. Field data is recommended to be collected in order to support better loading estimates and better determine the scale of potential runoff related loading and the types of BMPs recommended to mitigate impacts.

Most stormwater pollution enters with runoff in a pulse and the sources are distributed. Mitigation efforts involve intercepting runoff in facilities that provide treatment for excess nutrients. Often, the mitigation occurs on individual properties. The Gallatin Valley TMDL report lists several best management practices BMPs to reduce nutrient loads (Table 12).

TABLE 12. STORMWATER BEST MANAGEMENT PRACTICES

BMP	TN LOAD REDUCTION	TP LOAD REDUCTION
Bioretention	12%	
Retention Ponds	27%	59%
Filter Strips	13%	
Wetland Basins*		33%
Wetland Channels		22%
Media Filters		47%

*Table percentages represent estimated performance based on a general BMP database. Engineered treatment wetlands can be optimized for significant (<50%) TN reduction.

Effective mitigation efforts may start with a more detailed assessment and inventory of existing stormwater infrastructure from which hot spots (large paved areas, golf courses) can then be assessed as candidates for mitigation efforts. Decisions of individual landowners and occupants impact the rate at which nutrients and other pollutants enter the watershed. As a result, community education consistent with past efforts is productive. Lastly, advocating for nutrient removal based BMPs for all new stormwater management facilities has the potential to mitigate notable loading from future development.

Domestic Animal Waste

Domesticated animals, specifically dogs, can contribute a significant nitrogen load when their feces is not properly disposed of. According to the 2017-2018 U.S. Pet Ownership and Demographics Sourcebook, there are an average of 0.614 dogs per occupied household. Each dog produces an average of 0.75 lbs of feces per day which is 0.7% nitrogen. This results in an annual loading of 1,200 lbs of nitrogen per year according to the number of occupied homes in Big Sky using 2010 census data. While much of this load is distributed across the watershed, targeted dog poop pick-up days especially in areas where surface runoff can enter streams can significantly reduce nitrogen and e-coli loading. For every 150 lbs of fresh dog feces picked up, a pound of nitrogen is removed from the watershed.

Summary and Conclusions

There is strong evidence that anthropogenic nutrient sources are negatively impacting stream water quality in the West Fork of the Gallatin River during base flow conditions. These conclusions are able to be drawn using the stream monitoring data gathered by the Task Force. Maintaining and increasing water quality and quantity monitoring, especially in the West Fork, will enable targeted mitigation strategies and projects.

Excess nitrogen observed in the West Fork was estimated to be approximately 5,000 lbs per year nitrogen. This data corresponds well with modeled estimates for the contribution of nitrogen from onsite systems in the West Fork (1,500 lbs N per year) summed with a literature based estimation of the contribution of nitrogen from the Meadow Village golf and Spanish Peaks Golf courses (2,000 lbs N per year). Sources such as livestock stables, stormwater, and domestic animals have the potential to contribute additional nitrogen loading on the 1500 lbs per year scale, all of which could be substantially mitigated. A table of load sources in the West Fork drainage and the potential for mitigation has been provided in **Table 13.**

TABLE 13. MITIGATABLE LOAD SUMMARY

	Estimated Total Load (lb N /yr)	Mitigatable Fraction
Wastewater Application	12,000	75%
Onsite systems	4,400	10%
Stable Operations	3,300	33%
Stormwater	2,000	27%

As seen in **Table 13**, the greatest long-term reduction in anthropogenic nitrogen will result from improvements to the Big Sky WRF to treat effluent to less than 5 mg/l N, representing an approximately 70% reduction. Further load reduction associated with wastewater irrigation, including accumulated N load in the aquifer, can be achieved by intercepting and mitigating shallow groundwater utilizing engineered wetlands at known point sources (e.g. chapel spring) and general placement along the West Fork riparian corridor. Finally, careful golf course BMPs can be employed to minimize fertilizer related nutrient loading and stormwater runoff loading. Preliminary estimates indicate that 10,000 to 16,000 pounds per year of nitrogen loading (source load, not instream load) can be mitigated from golf course related loading, primarily attributable to the ongoing Big Sky WRF upgrade.

Increasing public awareness and providing testing and maintenance grants for the regions aging onsite systems can have considerable effect in maintaining and/or reducing the present load from onsite systems. Proximity to surface water is a relatively good way to prioritize potential mitigation opportunities. Working with residences, communities and businesses that are very near the Gallatin River and its tributaries can have an outsized effect. **Table 13** indicates a low potential to mitigate existing loads from onsite systems, however, maintaining current loading levels over time will require significant effort but may be a critical endeavor. Looking toward the future, advocating for water quality in the face of development is important. The recently completed Canyon Area Sewer Feasibility Study (WGM, 2020) identified that growth in the Canyon

Area alone could double the instream nitrogen contribution of the area to over 6,000 lbs N per year in the absence of comprehensive sewer planning and central infrastructure.

The impact of animal grazing and equestrian operations can vary significantly. Targeting areas that have high animal density or areas where animals access streams can have significant effects. Working with local ranchers and guest ranch operations to promote healthy grazing practices and assess how waste streams are handled can significantly reduce stock related loading that can impact both surface and groundwater quality.

Lastly the power of providing outreach, education, and incentives for individuals to maintain a healthy relationship with their watershed is not to be underestimated. Helping people connect their love of the environment to their everyday actions is critical in maintaining good stream health, from water use to reducing litter and the nutrients and coliforms that emerge from uncollected dog feces.

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