West Fork Nitrogen Monitoring Project Data Analysis Final Report

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EXECUTIVE SUMMARY
West Fork Nitrogen Monitoring Project

The West Fork Nitrogen Monitoring Project was conducted to gain better understanding of the nitrogen source areas contributing to excess nitrogen levels in the Upper West Fork of the Gallatin River. These nitrogen levels exceeded the target levels set by the Montana Department of Environmental Quality. The information collected through this study will be used to work with local landowners and land managers to develop restoration strategies that minimize nitrogen loading to the Upper West Fork.

The West Fork Nitrogen Monitoring Project used a combination of ground and surface water monitoring of nitrogen, nitrate isotopes, chloride, boron, and potassium to gain a better understanding of the nitrogen dynamics in the areas surrounding the Upper West Fork. The results presented in Section 4.0 combined with the results of previous studies do not pinpoint a single source area of nitrogen responsible for the rising levels of nitrogen as the West Fork travels through the Big Sky Golf Course. Instead, the source areas likely vary in their locations and impacts on the stream due to the complex nature of the nitrogen dynamics in this human-altered landscape. Fluctuations in the timing, chemistry, and location of irrigation and wastewater release combined with changes in precipitation, groundwater levels, public water supply withdrawals (Figure 2), and soil saturation result in variability in the system. Below are conclusions from the 2011 data collection:

- Nitrate and chloride concentrations increased as the West Fork travels through the Big Sky Golf Course. This observation suggests an increasing contribution from wastewater to this stretch.
- Spikes in chloride and nitrate concentrations at WF-7 in May and August and elevated δ^{15}N values in groundwater wells on the northern region of the Big Sky Golf Course (BSGC-4 and 5) and the West Fork mainstem combined with increasing groundwater levels suggest that wastewater effluent released onto the pastures was impacting the West Fork.
- High levels of nitrate and chloride at BSGC-1 and TR 1 and 1A suggest contribution of nitrogen from treated wastewater applied as irrigation. This southeastern region of the Big Sky Golf Course appears to be nitrogen saturated and sensitive to nitrogen loading.
- Increases in δ^{15}N values in October suggest impacts from wastewater effluent applied onto the pastures.
- Although the tributaries have consistently higher nitrogen and chloride concentrations than the main-stem, they do not account for the increased concentrations below WF-5. This observation suggests that there are gaining reaches in this area that contribute a significant nutrient load to the stream.

Based on the results from 2011 above and those from previous studies, the following recommendations could either provide a better understanding of the system or reduce nitrogen inputs to the West Fork:

- Collect additional groundwater data in the study area to determine losing and gaining reaches of the mainstem and more accurate groundwater flowpaths. This information would be helpful for land managers to concentrate efforts on sensitive areas that have a bigger impact on the stream.
- Plan ahead and aim to spread out the release of excess wastewater in space and time to the pastures and Big Sky Community Park, which the BSWSD just started irrigating in 2012. This will lessen the likelihood that irrigation water is quickly transported directly to the stream by giving time for the biological processing of nitrogen to occur. The golf course irrigation was designed to not exceed the agronomic uptake of vegetation. Releasing large quantities of water to these areas will undoubtedly surpass vegetation and soil uptake rates and quickly transport nitrogen and chloride to the stream.
- Collect additional data on soil percolation rates. Soil percolation data from 1995 [HKM, 2012] indicates that the 608D soil type is highly permeable. Additional data should be collected to characterize specific areas of the golf course that may be more susceptible to nitrogen leaching. For these areas, alternative nutrient and water management practices should be considered to reduce nitrogen from entering the West Fork. If some areas of the golf course are extremely permeable, then this would make a good case for using soil types in developing setback requirements.
- Conduct Best Management Practices on the Big Sky Golf Course [Gardner, 2012; HKM, 2012]
- Improve communication between the Big Sky Water Sewer District and the Big Sky Golf Course management regarding fluctuations in the nutrient chemistry.

1.0 Introduction

Waters in Montana are protected from excessive nutrient concentrations by narrative standards, which stipulate: "State surface waters must be free from substances attributable to municipal, industrial, agricultural practices or other discharges that will create conditions which produce undesirable aquatic life" [ARM 17.30.637 (1)(e)]. The West Fork Nitrogen Monitoring Project implemented a monitoring program involving local landowners and land managers with the purpose of identifying and promoting solutions to excess nitrogen levels in the Upper West Fork of the Gallatin ("Upper West Fork"). In past studies, total nitrogen and nitrate-nitrogen exceeded MTDEQ target levels (0.25 and 0.1 mg/L-N, respectively, applicable between July 1st and September 30th) [MTDEQ, 2011] for the West Fork [Gardner and McGlynn, 2009; MTDEQ, 2010].

The Upper Gallatin TMDL assessments documented increased streamwater nitrogen concentrations and loads and algal growth in the Upper West Fork as it travels 2 kilometers through the Big Sky Golf Course and Big Sky Meadow Village (Figure 1A, B) [Gardner and McGlynn, 2009; PBSJ, 2008]. These findings were confirmed in 2009 [Songline, 2009]. Though these past studies uncovered the general area responsible for increased nitrogen loading, there are multiple scenarios that could cause this increase, including: 1) residential fertilizer use, 2) golf course wastewater irrigation, 3) fertilizer use on the golf course, and 4) leaky irrigation and/or sewer pipes. Recently, the sewer system of the Big Sky Water and Sewer District surrounding the Big Sky Golf Course was videoed and no major leaks were found in the system that could be contributing to the increasing levels of nitrogen in the Upper West Fork.

Better understanding of the nitrogen sources to the stream will be critical to plan and implement successful restoration projects and land management practices to reduce nitrogen loading to the Upper West Fork. This project used a combination of ground and surface water monitoring of nitrogen, nitrate isotopes, chloride, boron, and potassium to gain a better understanding of the nitrogen dynamics in the areas surrounding the Upper West Fork. The information collected through this study will be used to work with local landowners and land managers to develop restoration strategies that minimize nitrogen loading to the Upper West Fork.

2.0 Study Area

The study area is a 2 km stretch of the Upper West Fork of the Gallatin River ("Upper West Fork") and the Big Sky Golf Course, which constitutes the land surrounding this stretch (Figure 1A). The Upper West Fork is a third order stream with a snowmelt-dominated hydrograph. Snowmelt typically occurs in late May and June followed by a general recession throughout the summer, autumn, and winter months. Average annual precipitation is 50 cm near the watershed outlet and sixty percent of this precipitation falls during the winter and spring months [USDA NRCS, 2008].

The Big Sky Golf Course sits on quaternary-age alluvial deposits [Baldwin, 1996]. A map of the soils in the golf course is shown in Appendix A [HKM, 2012]. The predominate soil is designated 280B, a Libeg cobbly loam, which is a welldrained, moderately permeable soil. The Natural

Resource Conservation Service soil report lists the soil as having a saturated conductivity of 0.57 to 1.98 inches per hour. The Libeg soil is reported to have a low water holding capacity of about 5.1 inches. A ring permeameter test conducted on the golf course in 1995 (Figure A-1) showed this soil to have a percolation rate of 3.5 inches per hour. Two additional tests in a similar soil classification, but not on the golf course, showed test results of 1.19 inches per hour and 3.98 inches per hour. The 608B soil borders the Middle Fork West Fork of the Gallatin and is called a Beehive-Mooseflat complex soil. The permeability is classified as moderate in the upper part and rapid in the lower part. The average of the lowest published saturated conductivity values was 3.25 inches per hour with the highest showing a permeability of 17 inches per hour. The third soil in the irrigation area is designated 482C, a Philipsburg-Libeg complex, which is a well-drained soil with a moderately high saturated conductivity of 0.2 to 0.57 inches per hour. A permeameter test showed a percolation rate of 0.33 inches per hour.

The Big Sky Golf Course is irrigated with treated wastewater effluent that is stored in three lined sewer detention ponds until late spring when it is released onto the golf course. Golf course irrigation begins in mid spring when the ground thaws and continues through mid fall, when the ground again freezes. Some years the district is forced to apply irrigation water onto pastures to the northwest of the golf course (Figure 1B) because the storage ponds are full and there is no need for irrigation water on the golf course.

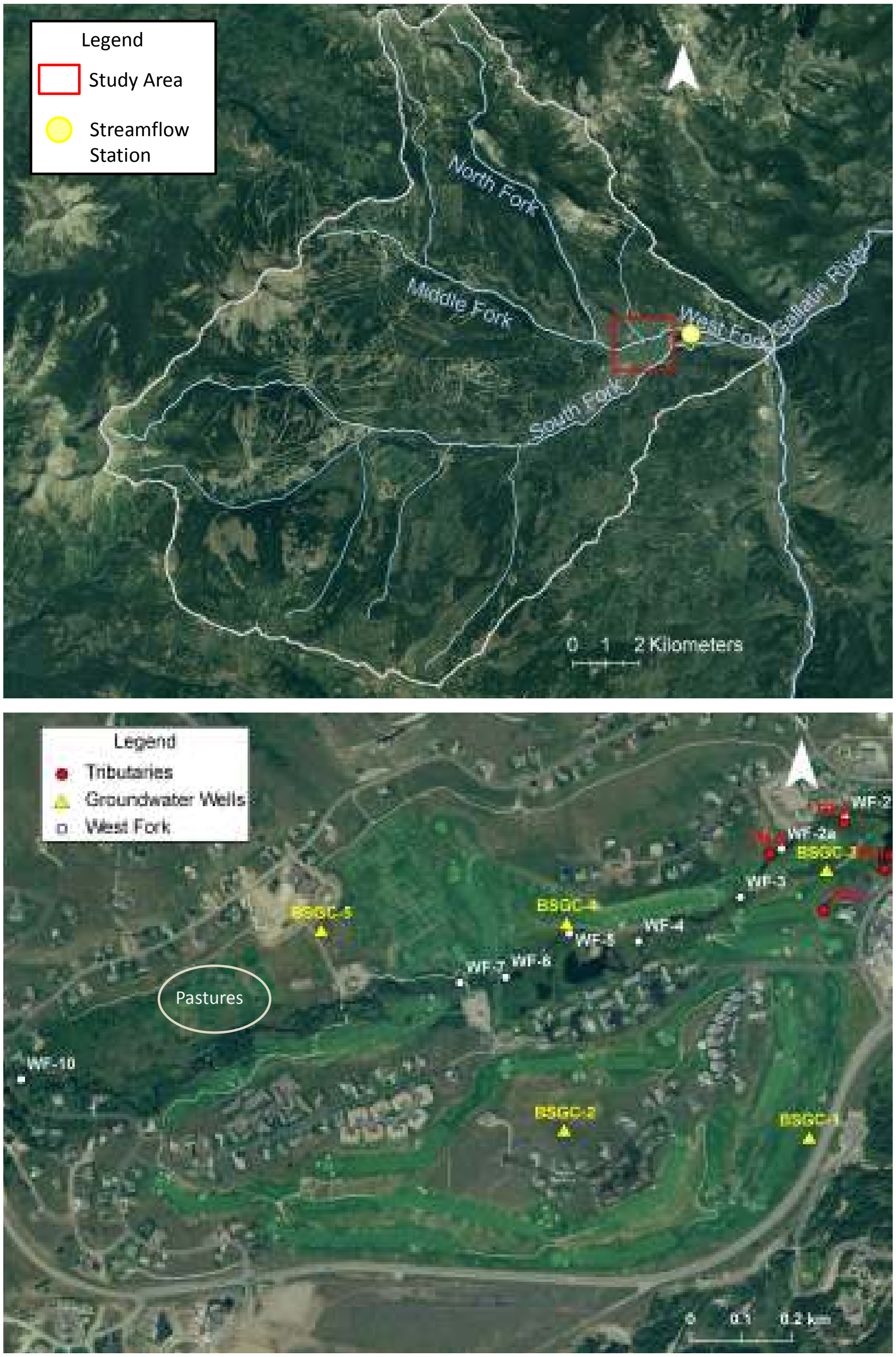

Figure 1: (A) The West Fork Watershed (212 km2), which encompasses the Big Sky Community, is a major tributary of the Gallatin River. Outlined in red is the study area. (B) The study area is the Upper West Fork and the surrounding lands of the Big Sky Golf Course. Monitoring sites are depicted as red circles for tributaries, yellow triangles for groundwater wells, and white circles for sites on the mainstem West Fork. The pasture area is enclosed by a white circle.

Figure 2: Estimated groundwater contours (LaFave, unpublished data) and public supply wells on the Big Sky Golf Course.

3.0 Methods

The objective of this assessment was to define the source areas of nitrogen along a 2 km stretch of the Upper West Fork, which is surrounded on both sides by the Big Sky Golf Course. Additional information regarding monitoring parameters, assessment sites and methodologies is available in the sampling and analysis plan for this project [Gardner, 2011]:

3.1 Monitoring Sites

Groundwater and surfacewater samples were collected on February 28th, May 18th, August 17th, and October 21st, 2011. Wastewater influent and irrigation water samples were collected on August 30th. All samples were analyzed for nitrate + nitrite (noted as "nitrate"), chloride, boron (in May, August, and October), potassium, and nitrate isotopes ($\delta^{15}N$ and $\delta^{18}O$). Nitrate was measured because it is the contaminant of concern. Chloride and boron were measured as tracers of wastewater. Potassium was measured as a tracer of fertilizer. Nitrate isotopes were analyzed to trace nitrogen sources. Additional information is available in the sampling and analysis plan for this project [Gardner, 2011]:

3.1.1 Groundwater
A total of five groundwater wells were monitored (Figure 1B).

3.1.2 Surfacewater
Eight sites on the mainstem West Fork and six tributaries were monitored (Figure 1B). Continuous stage was monitored approximately 1 km downstream from WF-2 (Figure 1A,B). Stream discharge was calculated from stage-discharge rating curves developed from discharge measurements collected over the full range of streamflow. Synoptic streamflow measurements were taken on October 2012 to compare streamflow among sites.

3.1.2 Wastewater
One sample of wastewater influent and irrigation water was collected by the BSWSD treatment manager, Grant Burroughs. In addition, monthly water quality data of the raw wastewater and irrigation water over the study period was obtained from the Big Sky Water and Sewer District [Burroughs, 2011, unpublished data]. These samples were analyzed by Energy Laboratories, Inc. in Helena.

4.0 Results

4.1 Nitrate Data

4.1.1 Groundwater
Over the study period, groundwater nitrate concentrations varied between zero and five mg/L-N (Figure 3B). Median nitrate concentrations were highest in May (3.65 mg/L-N) and lowest in October (1.85 mg/L-N) (Table 1). Nitrate trends in time varied among wells. BSGC-1 was consistently high and increased from May to August, and then remained relatively constant between August and October, when concentrations were 3.63 to 4.59 and 4.61 mg/L-N, respectively. The other wells (BSGC-2, 3, 4 and 5) saw a decrease from May to August and were relatively constant between August and October. Nitrate concentrations at BSGC-2 were low throughout the study period.

Table 1: Median nitrate and chloride concentrations over the study period (2011).

	Median Nitrate (mg/L-N)				Median Chloride (mg/L-N)			
Sites	Feb	May	Aug	Oct	Feb	May	Aug	Oct
Groundwater	na	3.65	2.01	1.85	na	28.3	32.1	32.9
West Fork Mainstem	0.29	0.17	0.17	0.18	7.88	8.39	3.69	5.64
West Fork Tributaries	na	3.6	2.69	2.67	na	30.6	28.1	28.3

4.1.2 Surfacewater
In the West Fork mainstem, median nitrate concentrations were highest in February (0.268 mg/L-N) and lowest during runoff (May) and during the summer growing season (August), when

concentrations were 0.17 mg/L-N (Table 1). Nitrate concentrations at WF-10 were consistently the lowest of all sites for each sampling event (Figure 3C). At the next downstream site, WF-7, there was a spike in nitrate concentrations in May and August, when concentrations were 1.10 mg/L-N and 0.507 mg/L-N, respectively. Generally, nitrate concentrations were highest at the most downstream sites, WF-2, 2a, and 3.

Nitrate concentrations were much higher in the tributaries than in the West Fork mainstem. Nitrate concentrations were highest in May (median = 3.6 mg/L-N) and lowest in October (median = 2.65 mg/L-N) (Table 1). TR-1 exhibited the highest nitrate concentrations, with a median of 4.33 mg/L-N, followed by TR-1a, with a median of 3.69 mg/L-N. Nitrate concentrations at TR 2 and 3 were considerably less than TR-1 and TR-1a and ranged between 0.95 and 2.51 mg/L-N over the three sampling events. TR-4 and 5 were dry the entire study period.

4.1.3 Wastewater

Nitrate concentrations of wastewater influent and irrigation water were 0.129 mg/L-N and 0.414 mg/L-N, respectively (Table 2). Median total nitrogen concentration of the wastewater influent over the study period was 54 mg/L-N, while that of the irrigation water was 7.35 mg/L-N (Big Sky Water and Sewer District, unpublished data).

Table 2: Nitrogen, chloride, boron, and potassium concentrations for wastewater influent and irrigation water (sampled August 30, 2011).

	Nitrate (mg/L)	Chloride (mg/L)	Boron (mg/L)	Potassium (mg/L)	Median Total Nitrogen (mg/L)*
Wastewater influent	0.129	62.9	0.24	13.6	54
Irrigation water	0.414	80.29	0.13	10.4	7.35

*The median Total Nitrogen was calculated from unpublished BSWSD data.

4.2 Chloride Data

4.2.1 Groundwater

Median chloride concentrations in the groundwater wells increased over the study period (Table 1). Chloride concentrations varied from 10.2 to 60.7 mg/L (Figure 4B) and were highest at BSGC-1, which were greater than 50 mg/L-N throughout the study period. A small but noticeable increase in chloride concentrations was observed at BSGC-2 and BSGC-3 from May to August to October. These two wells exhibited the lowest chloride concentrations of all the wells and ranged between 10 mg/L and 22.9 mg/L. At BSGC-5, a big increase in chloride concentrations was documented from May to August (18.3 mg/L to 43.4 mg/L, respectively) and then a decrease to 31.1 mg/L in October. Chloride concentrations in BSGC-4 decreased from 36.2 mg/L in May to 23.7 mg/L in August and then increased to 29.6 mg/L in October.

4.2.2 Surfacewater

Chloride concentrations in the mainstem West Fork were lowest in August (median = 4.07 mg/L) and highest in February and May when the median concentrations were 7.65 and 7.95

mg/L, respectively (Figure 4C). In general, chloride concentration patterns were similar to nitrogen; the highest concentrations were found in the lower section of the study reach (WF-2, 2a, and 3) and the lowest at WF-10.

Median chloride concentrations in the tributaries were highest in May (30.6 mg/L) and lowest in August (28.1 mg/L) (Table 1). Like nitrate concentrations, chloride concentrations were highest in TR 1 and 1a (median = 32.7 mg/L) compared to TR 2 and 3 (median = 24.1 mg/L).

4.2.3 Wastewater

Chloride concentrations of raw wastewater and irrigated wastewater collected in June were 62.9 mg/L and 80.29 mg/L, respectively (Table 2).

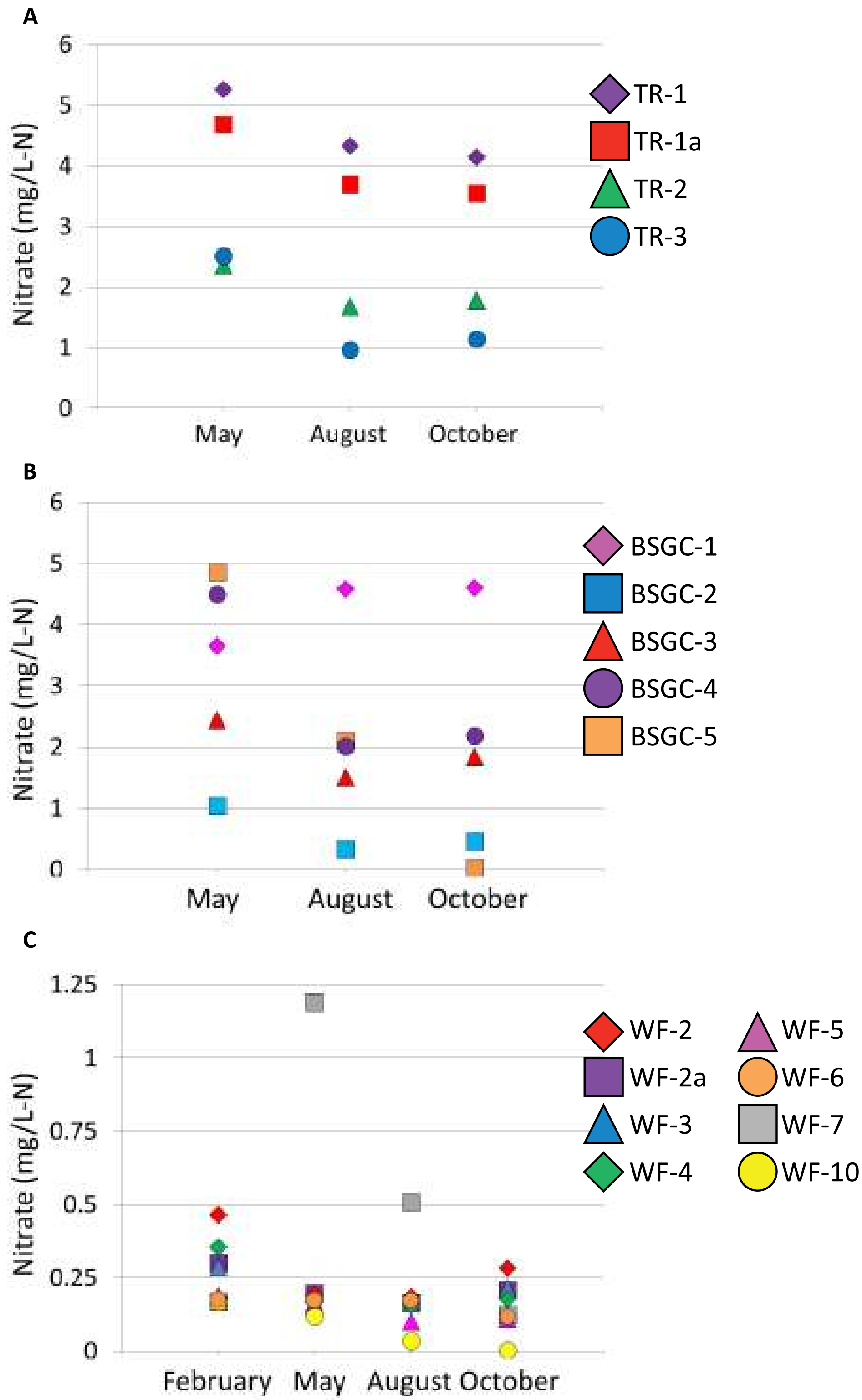

Figure 3: Nitrate concentrations in February, May, August, and October of 2011 in A) the West Fork tributaries, B) groundwater wells, and C) the mainstem West Fork. In February, samples were not collected in the tributaries or groundwater. See Figure 1B for site locations.

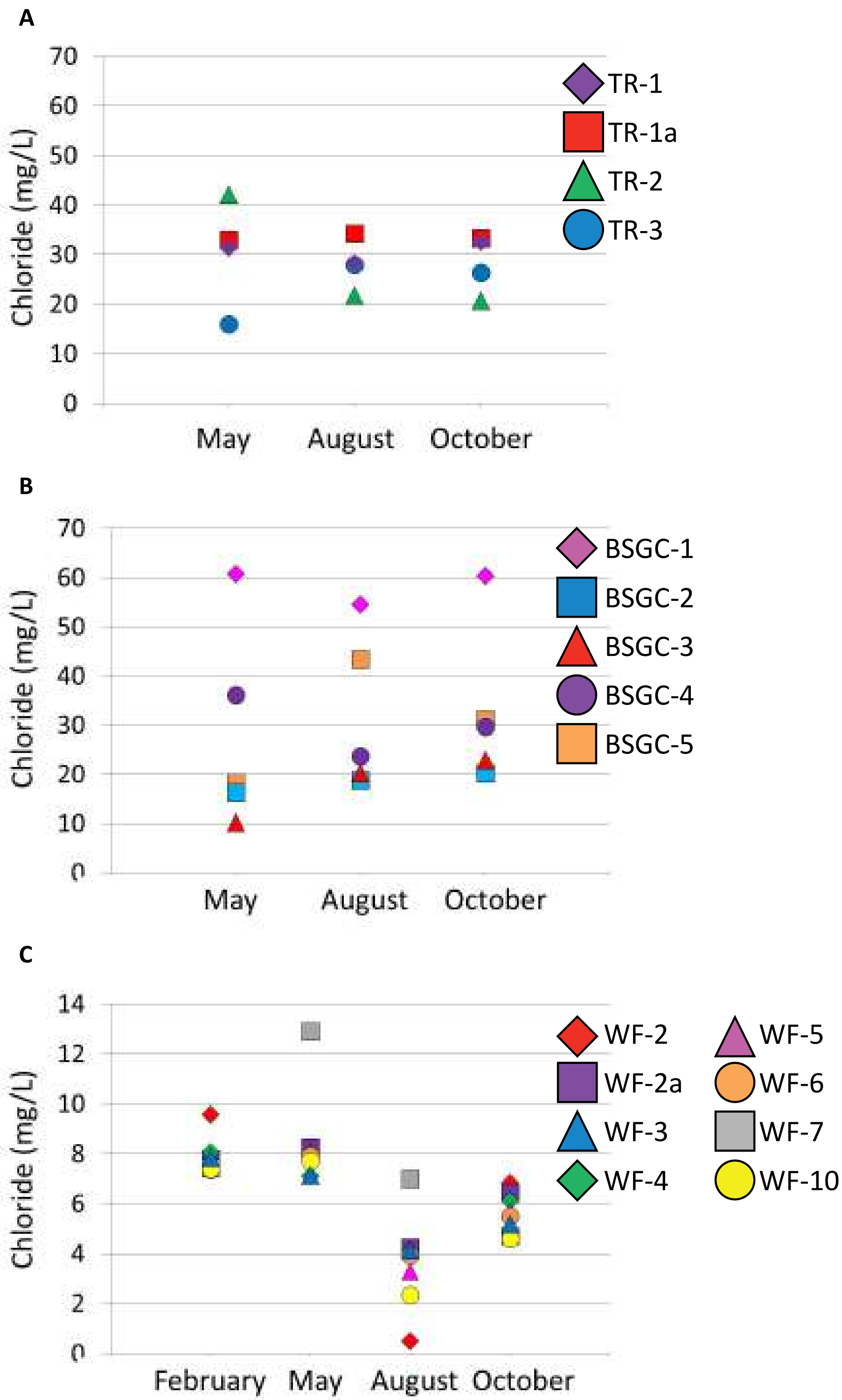

Figure 4: Chloride concentrations in February, May, August, and October of 2011 in A) the West Fork tributaries, B) groundwater wells, and C) the mainstem West Fork. In February, samples were not collected in the tributaries or groundwater. See Figure 1B for site locations.

4.3 Boron Data

Median boron levels are shown in Table 3. Boron levels increased slightly over the irrigation season suggesting wastewater contamination. No noticeable spatial trends existed for the boron data. Boron concentration of the wastewater influent was 0.24 mg/L, while the irrigation water was 0.13 mg/L.

Table 3: Median boron levels in the West Fork, its tributaries, and groundwater

Median Boron (mg/L)		
	August	**October**
West Fork	ND	0.01
Groundwater	0.02	0.03
Tributaries	0.02	0.03

4.4 Potassium Data

Median potassium levels are shown in Table 4. No noticeable spatial trends existed for potassium data. Potassium level of the wastewater influent was 13.6 mg/L, while the irrigation water was 10.4 mg/L.

Table 4: Median potassium levels in the West Fork, it's tributaries, and groundwater

Median Potassium (mg/L)				
	February	**May**	**August**	**October**
West Fork	1.2	1.1	1.0	1.1
Groundwater	N/A	2.5	2.0	1.8
Tributaries	N/A	2.0	1.8	1.6

4.5 Nitrate Isotopes Data

4.5.1 Groundwater

The median $\delta^{15}N$ value of groundwater at all wells except for BSGC-3 increased in time over the study period (Figure 5B). The highest values of $\delta^{15}N$ were observed at BSGC-5 and BSGC-4; although it does appear denitrification could have be responsible for the elevated October $\delta^{15}N$ value at BSGC-5 since both $\delta^{18}O$ and $\delta^{15}N$ were enriched [Kendall and McDonnell, 1998].

4.5.2 Surfacewater

The $\delta^{15}N$ value of surface water increased in time over the study period in the mainstem West Fork at all sites except for WF-10 and in all the tributaries except for TR-2 (Figure 5A,C,D). In the mainstem, all sites saw a significant enrichment in $\delta^{15}N$ in October. In May, $\delta^{15}N$ hovered around +5 $^{o}/_{oo}$ at all sites except WF-7, in which it was measured at +9 $^{o}/_{oo}$.

$\delta^{15}N$ values of the tributaries remained relatively constant throughout the study period and appeared to have some wastewater influence (Figure 5A). The exception was TR-3, which exhibited a large increase in August and October, however, this increase may be explained by denitrification since both $\delta^{18}O$ and $\delta^{15}N$ were enriched [Kendall and McDonnell, 1998].

4.5.3 Wastewater

The $\delta^{15}N$ value of wastewater influent was +8.79$^{o}/_{oo}$, while $\delta^{15}N$ values of irrigation water were +4.64$^{o}/_{oo}$ in August 2011 and +12.2$^{o}/_{oo}$ in August of 2007 [Gardner and McGlynn, 2009].

4.6 Streamflow Data

Peak streamflow in the West Fork occurred on June 30th and was 905 cubic feet per second (cfs) (Figure 6). The study reach appears to be a series of gaining and losing reaches, but there is very limited data available to map these dynamics in detail (Figure 7). Streamflow in all tributaries was less than 0.5 cfs. TR 2 and 3 were observed to be ephemeral in October 2012, when they were not flowing. These tributaries were flowing for all sampling events in 2011.

4.7 Groundwater Level Data

Groundwater levels decreased for all wells from May to August to October except for BSGC-4, which had a small increase in October (Figure 8). Generally, the biggest drops in water level occurred between May and August, except for BSGC-5. The shallowest well, BSGC-3, exhibited the smallest fluctuation in groundwater level over the study period.

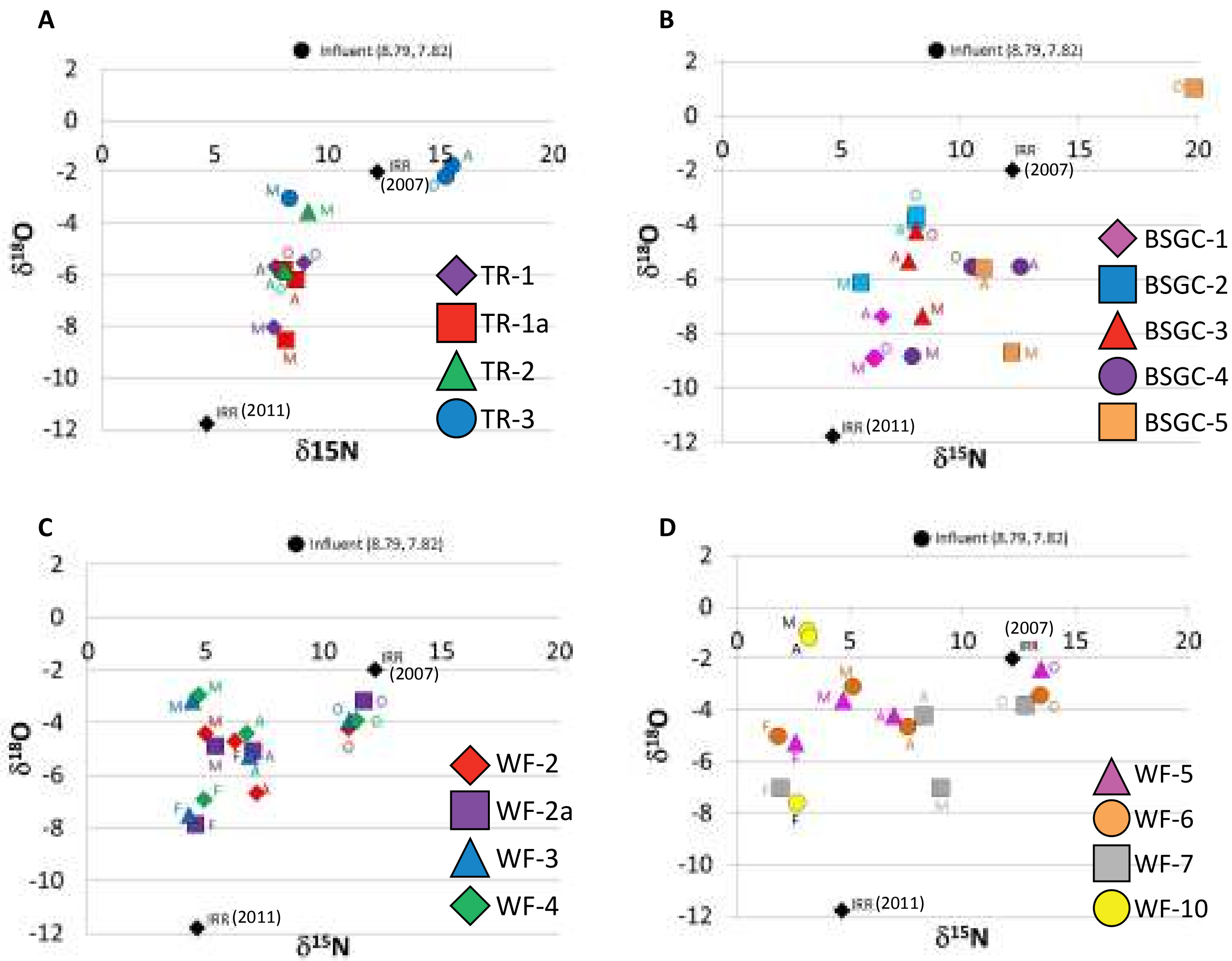

Figure 5: Plots of $\delta^{15}N$ and $\delta^{18}O$ for (A) the West Fork tributaries, (B) groundwater, and (C&D) the West Fork mainstem. Months are labeled "F" for February, "M" for May, "A" for August, and "O" for October. See Figure 1B for site locations. Wastewater influent and irrigation ("IRR") are shown as a black circle and diamond, respectively.

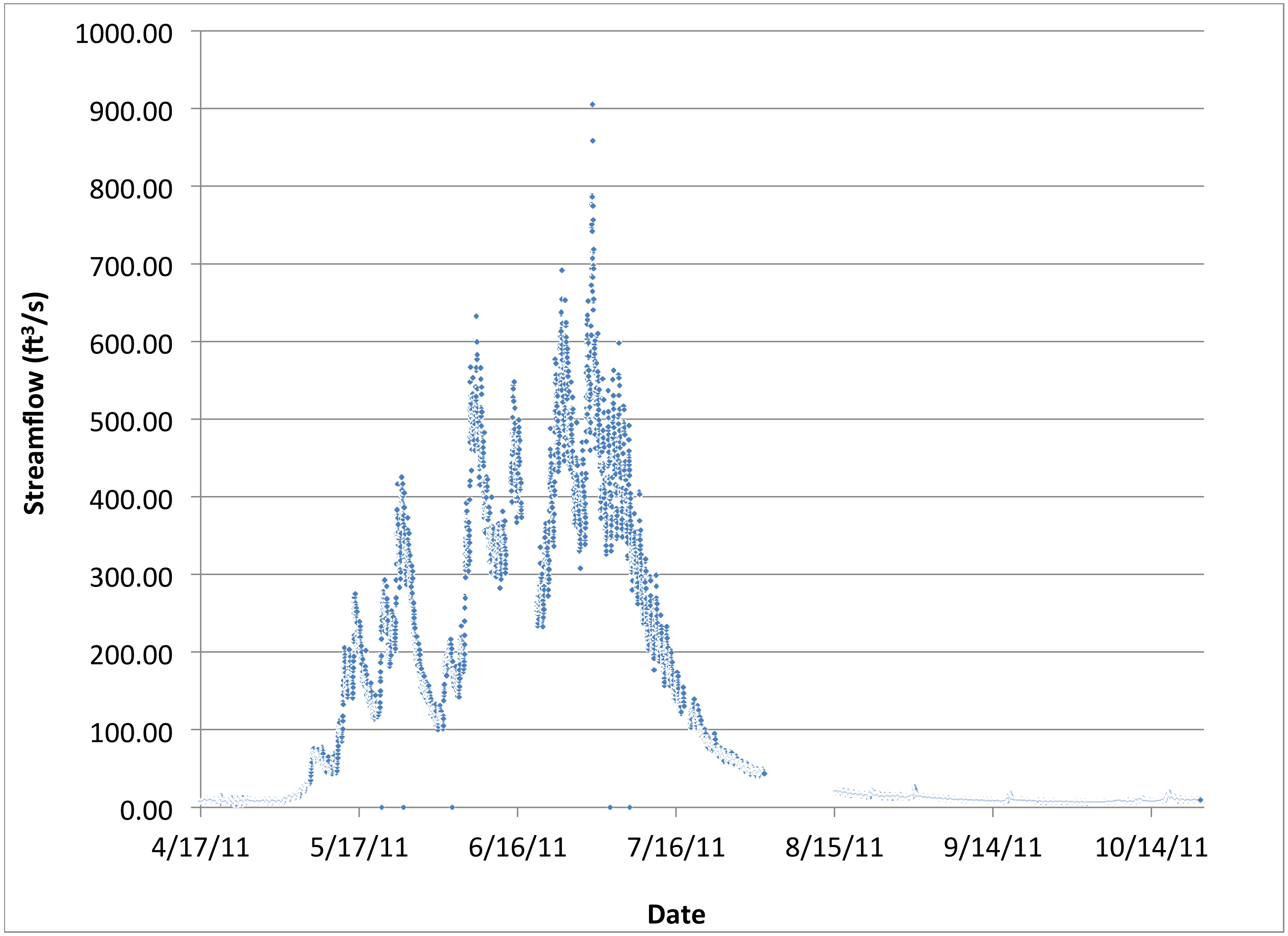

Figure 6: Streamflow on the Upper West Fork during the study period. Stage height was recorded from continuous data recorder. See Figure 1A for the gauge location.

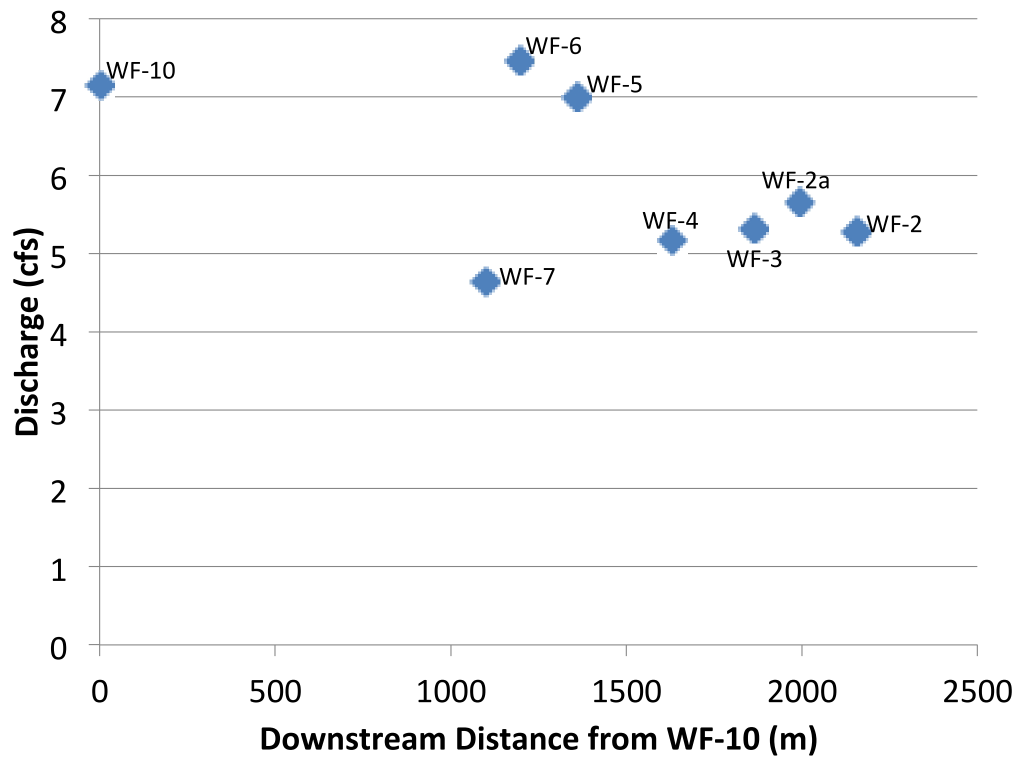

Figure 7: Streamflow measured on the mainstem West Fork on the Upper West Fork on October 2012. Sites are plotted in a downstream direction from the most upstream site WF-10. See Figure 1B for site locations.

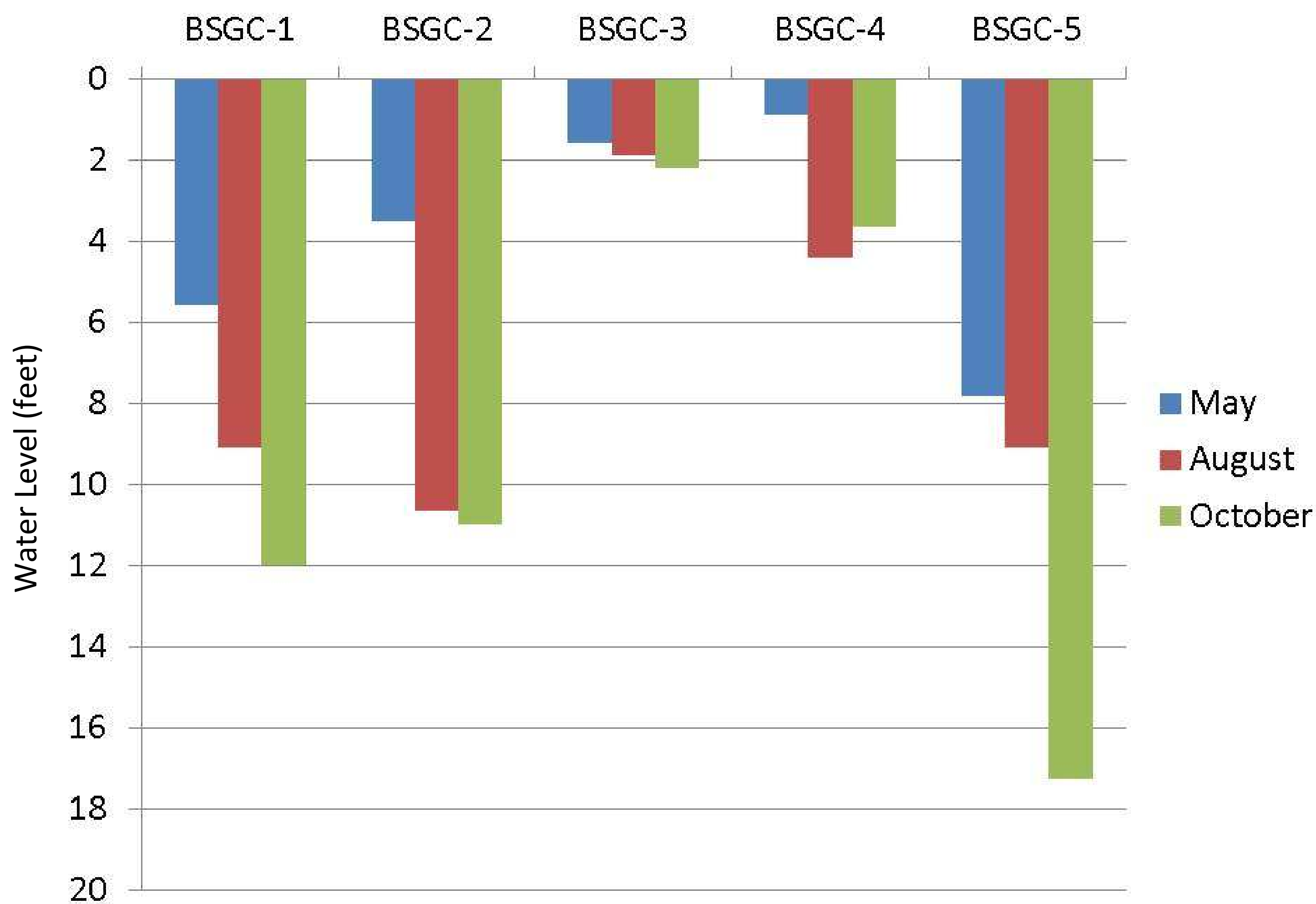

Figure 8: Groundwater levels at the five monitoring wells on the Big Sky Golf Course in May, August, and October of 2011. See Figure 1B for well locations.

5.0 Discussion

5.1 Groundwater

Groundwater nitrate concentrations were well below 10 mg/L-N, which is the Environmental Protection Agency's maximum contaminant level for drinking water; however, the concern of this study is not drinking water, but rather it is the potential for groundwater to influence instream concentrations. Nitrate concentrations above the 2 mg/L-N level commonly demonstrating impact by human activity [Meuller and Helsel, 1996] were found in all wells except BSGC-2 (Figure 3B). Nitrate and chloride concentrations were consistently high in BSGC-1 suggesting wastewater contamination. This well is on the southeastern edge of the golf course and appears to derive water from the southwestern section of the golf course (Figure 2); however, caution must be taken when interpreting the delineated groundwater flowpaths as they are rough estimates delineated from a limited number of wells. BSGC-1 is the only well in which nitrate increased consistently over the study period. At the other wells, the decrease in nitrate from May to August was likely due to biological uptake of nitrogen. This is because chloride, which is a relatively conservative tracer of wastewater influence, increased between May and August.

Elevated chloride concentrations in all of the wells combined with high levels of chloride in top soil layers from soil samples taken in October 2012 (BWTF, unpublished data) suggests contamination from irrigation water. Background chloride concentration should be in the 5-10 mg/L range (LaFave, personal communication) and in all wells the concentrations were significantly higher (Figure 4B).

BSGC-2 and 3 appear to be the least impacted wells exhibiting the lowest nitrate and chloride concentrations (Figure 3B). At BSGC-2, low concentrations could be explained by a lower percentage of golf course contributing area (Figure 2). As for BSGC-3, it is possible that this site is within the stream side mixing zone and therefore, its chemistry may be influenced by surfacewater. This well is within five feet of surfacewater and the groundwater level was consistently shallow with considerably less variability than other wells within the study period (Figures 1B and 8).

There is evidence that substantial watering of the pastures might have influenced the groundwater at BSGC5-4 and 5 (Figure 8). At BSGC-5, the groundwater level drop was greatest between August and October compared to between May and August in the other wells. Historical data from Montana Bureau of Mines and Geology (MBMG) has shown irrigation watering to influence this well (Richter, MBMG, unpublished data). The influence of pasture watering could also explain the increase in chloride and enriched δ^{15}N values in this well in August. At BSGC-4, which is downgradient from the pastures and BSGC-5, pasture irrigation could explain the enriched δ^{15}N values in August and October and the increase in groundwater level in October.

Boron and potassium concentrations were low in groundwater, tributaries, and the mainstem as compared to irrigation concentrations. Movement of both boron and potassium is related to soil texture. As clay content increases, movement decreases. It is possible that available boron and potassium was assimilated by vegetation or stored in the soils.

5.2 Surfacewater

5.2.1 West Fork Mainstem

As a general rule, nitrate and chloride concentrations in the Upper West Fork increased as the stream bisects the Big Sky Golf Course throughout the study period. This phenomenon was also documented in data collected from other studies [Gardner and McGlynn, 2009; Songline, 2009; MTDEQ, 2010]. This observation suggests an increasing wastewater contribution to the West Fork as it travels through the Big Sky Golf Course. Elevated chloride levels and $\delta^{15}N$ values in the West Fork in October indicated an increase in wastewater contribution of nitrate during a period when groundwater dominates streamflow (Figure 6). This correlates to a significant increase in nitrogen concentration of the irrigation water in October [BSWSD, unpublished data, Table B1] and the pastures are frequently heavily watered in October.

The high spike in nitrate concentrations at WF-7 in May and August and the small jump in October had not been observed in past studies [Gardner and McGlynn, 2009; Songline, 2009; MTDEQ, 2010]. These spikes may be explained by the substantial watering of the pastures in the spring prior to the May sampling. 2010-2011 was a big snow year with high runoff and consequently, the BSWSD was forced to release a great quantity of water onto the pastures in May because the storage ponds were full [R. Edwards, personal communication and personal observation]. Saturating these near-stream pasture areas likely transported irrigation water quickly to the stream. The elevated May $\delta^{15}N$ for WF-7 (at +9 $^{o}/_{oo}$ compared to other sites, which hovered around +5 $^{o}/_{oo}$) supports this hypothesis.

The highest chloride concentrations in the West Fork mainstem in the winter and during spring runoff do not correlate to enriched $\delta^{15}N$ values and therefore, these high concentrations may be caused by chloride application for winter road maintenance.

5.2.2 West Fork Tributaries

Nitrate and chloride concentrations in the tributaries were an order of magnitude greater than the mainstem, and more resembled groundwater concentrations. For this reason and that these tributaries originate from pipes, they are considered to have a primary groundwater component (either constructed drains, or lowland wetland drainage points).

Although the nitrate and chloride concentrations of TR-1 and TR-2 are high, they are not responsible for the measured increase of nitrogen and chloride in the mainstem West Fork. This is because these tributaries enter the mainstem downstream of the area of a measurable increase in nitrate and chloride concentrations (Figure 1B). High nitrate and chloride in TR-1, TR-1A and BSGC-1 suggest groundwater from the southeastern area of the golf course may be contributing to the elevated levels of nitrate and chloride in the West Fork. Historically, this area was a saturated lowland, which was overlain with fill upon development of Big Sky Resort in the 1970s. These lowland areas may transport irrigation water along with nutrients more quickly than other watershed areas due to frequent hydrologic connectivity to the stream [Jencso et al., 2009; Pacific et al., 2010].

5.3 Wastewater

Nitrogen concentrations throughout the study period (Table B-1) and nitrate isotopic values for the two sampled dates (Section 4.53) exhibited variability (Figure 5, and Tables 2 and B-1). The δ^{15}N value of the irrigation water measured in 2011 was unexpectedly low compared to the value measured in 2007. One possible explanation was dilution by snowmelt. Irrigation water that sits over the winter may be diluted by snowmelt and therefore, likely to exhibit lower δ^{15}N values. 2011 was a big snow year and presumably, the wastewater influent and the wastewater ponds were diluted with snowmelt. Irrigation water collected towards the end of the irrigation season is likely to be "fresh" and therefore, have higher a wastewater content and δ^{15}N value. In addition, nitrogen concentrations and nitrate isotopes might fluctuate with any changes in wastewater treatment process. Such variability could include variability in the content and strength of the influent or a malfunction within the treatment process.

5.4 Recommendations

The results presented in Section 4.0 combined with the results of previous studies do not pinpoint a single source area of nitrogen responsible for the rising levels of nitrogen as the West Fork travels through the Big Sky Golf Course. Rather, the source areas likely vary in their impact on the stream due to the complex nature of the nitrogen dynamics in this human-altered landscape. Fluctuations in the timing, chemistry, and location of irrigation combined with changes in precipitation, groundwater levels, public water supply withdrawal (Figure 2), and soil saturation result in variability in the system. Below are recommendations that could either provide a better understanding of the system or reduce nitrogen inputs to the West Fork.

- Collect additional groundwater data in the study area to determine losing and gaining reaches of the mainstem and more accurate groundwater flowpaths. This information will be helpful for land managers to concentrate efforts on areas that have more impact on the stream.
- Plan ahead and aim to spread out the release of excess wastewater in space and time to the pastures and Big Sky Community Park, which the BSWSD just started irrigating in 2012. This will lessen the likelihood that irrigation water is quickly transported directly to the stream by giving time for the biological processing of nitrogen to occur. The golf course irrigation was designed to not exceed the agronomic uptake of vegetation. Releasing large quantities of water to these areas will undoubtedly surpass the uptake rate and quickly transport nitrogen and chloride to the stream.
- Collect additional data on soil percolation rates. Soil percolation data from 1995 [HKM, 2012] indicates that the 608D soil type is highly permeable. Additional data should be collected to characterize specific areas of the golf course that may be more susceptible to nitrogen leaching. If some areas of the golf course are extremely permeable, alternative nutrient and water management practices should be considered to reduce nitrogen from entering the West Fork. If some areas of the golf course are extremely permeable, then this would make a good case for using soil types in developing setback requirements.
- Conduct Best Management Practices on the Big Sky Golf Course [Gardner, 2012; HKM, 2012]

- Improve communication between the Big Sky Water Sewer District and the Big Sky Golf Course management regarding fluctuations in the nutrient chemistry.

6.0 Conclusions

- Nitrate and chloride concentrations increased as the West Fork travels through the Big Sky Golf Course. This observation suggests an increasing contribution from wastewater to this stretch.
- Spikes in chloride and nitrate concentrations at WF-7 in May and August and elevated $\delta^{15}N$ values in groundwater wells on the northern region of the Big Sky Golf Course (BSGC-4 and 5) and the West Fork mainstem combined with increasing groundwater levels suggest that wastewater effluent released onto the pastures was impacting the West Fork.
- High levels of nitrate and chloride at BSGC-1 and TR 1 and 1A suggest contribution of nitrogen from treated wastewater applied as irrigation. This southeastern region of the Big Sky Golf Course appears to be nitrogen saturated and sensitive to nitrogen loading.
- Increases in $\delta^{15}N$ values in October suggests impacts from wastewater effluent applied onto the pastures.
- Although the tributaries have consistently higher nitrogen and chloride concentrations than the main-stem, they do not account for the increased concentrations below WF-5. This observation suggests that there are gaining reaches in this area that contribute a significant nutrient load to the stream.

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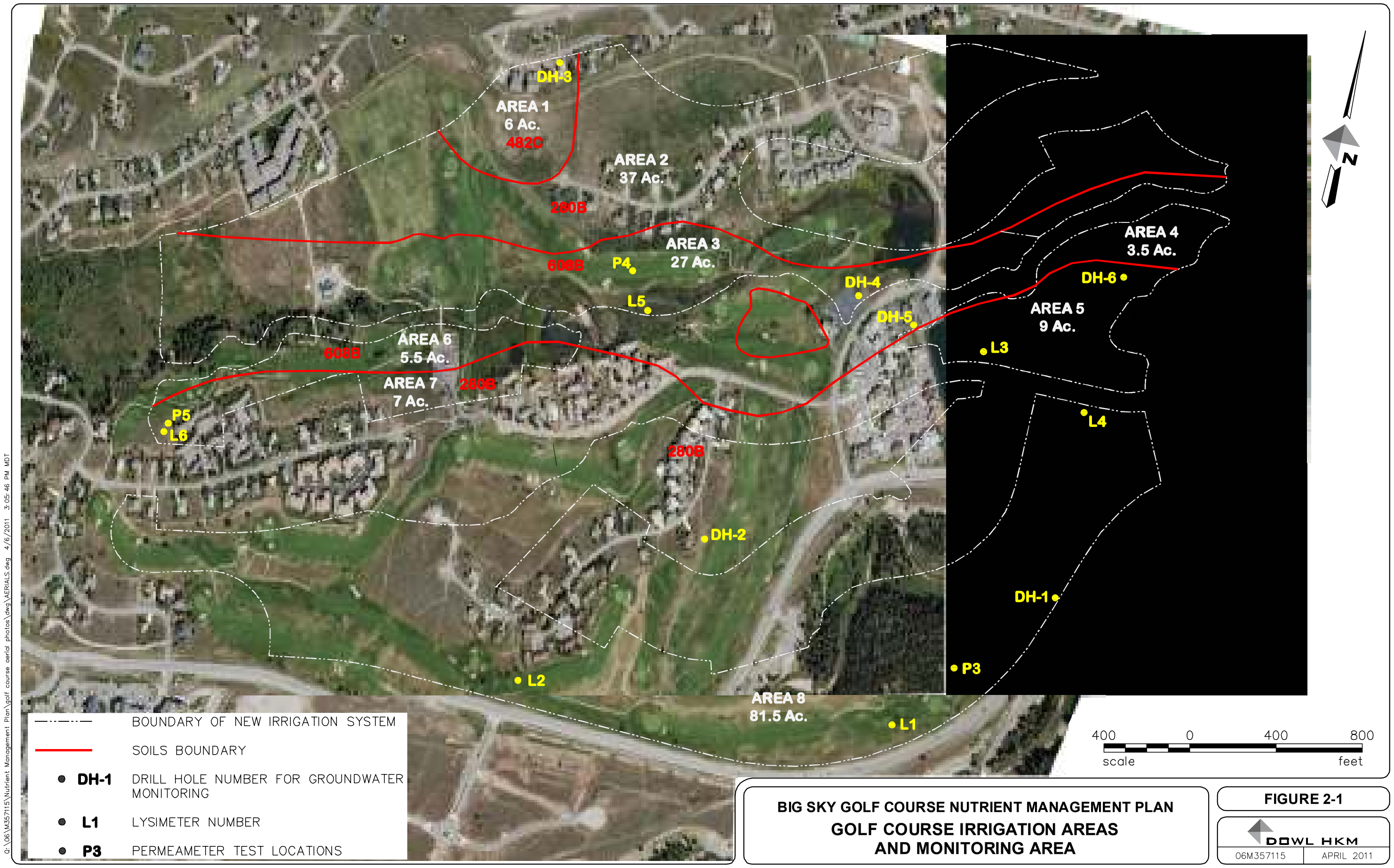
Appendix A

Big Sky Golf Course Soil Map

Figure A-1: (Figure 2-1 from HKM, 2012)



Appendix B
Nitrogen Concentrations of Irrigation Water
[Big Sky Water and Sewer District, Unpublished Data]

Table B1: Chemistry of effluent irrigation water

Date	Nitrate + Nitrite (mg/L-N)	TKN (mg/L)	Total N (mg/L)	Fecal Coliform
26-May-11	0.55	8.6	9.2	ND
9-Jun-11	1.76	5	6.8	ND
16-Jun-11	1.67	3.2	4.9	ND
23-Jun-11	1.46	2.9	4.4	16
30-Jun-11	1.01	3.3	4.3	ND
7-Jul-11	0.66	3.8	4.5	4
4-Aug-11	0.32	3.3	3.6	ND
11-Aug-11	0.43	8.1	8.5	ND
18-Aug-11	0.5	8.6	9.1	1
25-Aug-11	0.41	8.2	8.6	ND
30-Aug-11	0.37	7.9	8.3	ND
8-Sep-11				7
15-Sep-11	1.14	6.8	7.9	2
22-Sep-11	2.59	4	6.6	1
29-Sep-11	4.22	2.6	6.8	3
6-Oct-11	2.54	10.9	13.4	ND
13-Oct-11	1.47	12.9	14.4	ND