

Potential impacts of hydrologic changes on nutrient loads in the South Platte River Basin

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Abstract. Understanding the potential impacts of hydrologic changes on nutrient loading within a system is paramount to developing adaptation strategies. This case study investigates the impact of varying hydrologic conditions on water quality within the South Platte River Basin in northeastern Colorado. 80% of Colorado's population lives within the South Platte River Basin in addition to providing water for the most productive agricultural landscape in the state. Nutrient concentrations within the river basin depend on seasonality, land type, land use management practices, and point source inputs from wastewater treatment plants. The river basin contains mountainous, urban, and agricultural settings which, in combination with the semi-arid climate of the South Platte River Basin, produces the potential for droughts, fires, and floods to cause significant changes on the hydrology of the river. This study analyzed nutrient data from mountain, urban, and agricultural settings under various stream flow conditions which were present during the period of record. The hypotheses of this study were that water quality is related to stream flow during the time of sampling, the stream flow preceding the sampling date, as well as a relation with the dominant land cover classification of the area immediately upstream of the sampling location. The impact of extreme events, such as drought and fire, on water quality were also investigated. This talk will explore results of these investigations as well as some of the limiting factors such as data availability for long term studies in Colorado.

1. Introduction

Understanding the potential impacts of hydrologic changes on a regional and global basis is paramount to developing adaptation strategies. A common factor driving potential hydrologic changes in literature is climate change (Barnett *et al.*, 2005, Rasmussen *et al.*, 2014). Many models of climate change have been used to predict the impact of temperature and precipitation shifts on the hydrology of a basin (Kang and Ramirez, 2007, Rasmussen *et al.*, 2014). Less understood is the potential impact of climate change on future water quality.

Climate change research generally takes on one of two perspectives: a global perspective or a regional perspective. Global studies typically project temperature or climate variability into the future to determine the potential impacts of these climate effects on different sectors (Adam *et al.*, 1990, Barnett *et al.*, 2005). Such studies show that climate change will have a global impact but invariably, there will be differing regional effects which will define the scope of mitigation and adaptation strategies going forward. In regions such as Colorado, the South Platte River Basin (SPRB) is expected to have an increase in temperature, evapotranspiration, and sediment loading in addition to decreased

runoff and increased variability in snow covered days (Baron *et al.*, 1998, Harpold *et al.*, 2012, Lukas *et al.*, 2014, Murdoch *et al.*, 2000, Rasmussen *et al.*, 2014). Even with a strong emphasis on global and regional climate change impacts on water resources, few papers have studied impacts on water quality.

The SPRB is an ideal location for a study investigating the potential impacts of hydrologic changes on water quality as a result of climate change predictions. The basin contains a diverse array of land cover and water usage (Fig. 1) along with several notable extreme events in the last decade spanning the gambit of possibilities including drought, flood, and fires. Both water quality and water quantity concerns dominate discussions within the basin with the projected impacts of climate change. In addition to projected climate variability, the population in the region is expected to increase approximately 2.5 million by the year 2050 furthering the urban footprint within the basin (CWCB, 2011) (Fig. 1). In addition, the SPRB supplies the most productive agricultural landscape in the state of Colorado (CWCB, 2011).

Nutrient concentrations in the SPRB depend on seasonality, dominant land use of the contributing area, management practices, and point source inputs such as waste water treatment plants (WWTPs) (Pocernich & Litke, 1997). As such, ammonia, nitrite, and nitrate are commonly monitored constituents in the South Platte River; these constituents are known to have hazardous effects for aquatic life, animals, and humans when ingested (Pocernich & Litke, 1997). Recently, new regulations have been adopted in order to limit the nutrient concentrations from these point sources (Regulation 85, 2012). Sprague (2005) investigated the impact of drought on water quality and found that during a drought in 2002, increased nutrient concentrations at some agricultural sites were attributed to decreased dilution of irrigation return flows. It was also noted that dissolved nitrite-plus-nitrate concentrations were significantly different at forested, urban, and agricultural sites attributed to differing water management, stream size, and nutrient sources such as direct fertilizer application on crops (Sprague, 2005).

This study seeks to determine the potential impacts of hydrologic changes, resulting from climate change, on water quality in terms of nutrients within the SPRB in Colorado. The objectives of the study are to: explore the relationship between water quality and land use, determine possible impacts of extreme events on water quality, and project vulnerability of the SPRB to hydrologic changes projected under climate change estimates. The hypotheses are that water quality will show a relation with stream flow, land cover/use, and extreme events.

2. Methods

Water quality data from the National Water Quality Assessment Program (NAWQA) (USGS, 2007) was utilized in order to determine water quality trends occurring in the SPRB. Sites for this study were analyzed only if the period of record included a minimum of 30 sample dates. This selection criterion resulted in seven locations analyzed representing comparisons between mountain, urban, and agricultural settings (Fig. 1, Table 1) (Jin *et al.*, 2013). This 30 data point minimum criterion additionally reduced this study to analyze primarily phosphorous and ammonia-plus-organic nitrogen for nutrient concentrations.

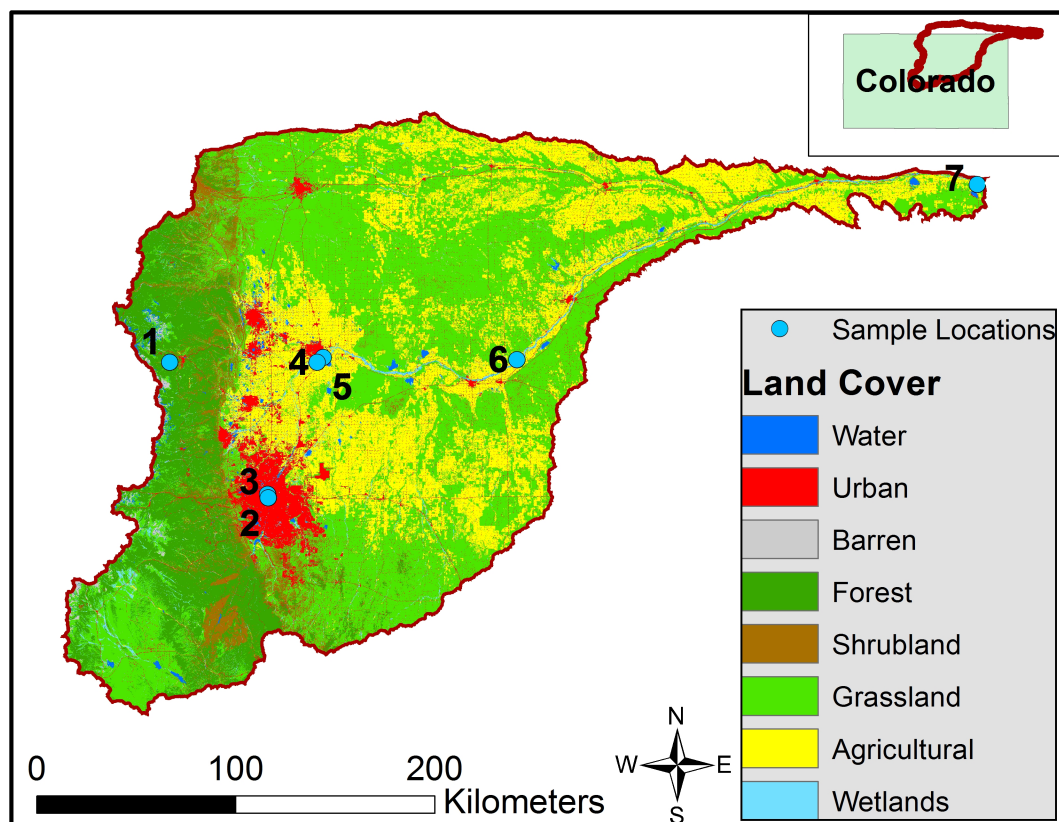


Figure 1. Area map of the South Platte River Basin depicting the land cover classification (Jin *et al.*, 2013), location within Colorado, as well as the locations of the sites used for this study.

Table 1. Sample locations and classification used for this study.

Site No.	Name	Upstream Classification
1	Big Thompson below Moraine Park	Mountain
2	Cherry Creek at Denver	Urban
3	SPR at Denver	Urban
4	SPR at Henderson	Agricultural/Urban
5	SPR near Kersey	Agricultural/Urban
6	SPR at Cooper's Bridge near Balza	Agricultural
7	South Platte at North Platte	Agricultural

In order to determine whether water quality data displays a relation to stream flow, USGS daily stream gage data was additionally utilized. Water quality data were first compared to the daily discharge data occurring the same date as the water quality sampling. The second comparison was that of the 30-day cumulative discharge prior to the water sampling date. These analyses were conducted for nutrient concentrations as well as estimated nutrient loading based upon the discharge data. Extreme events for this study were limited to fires (MTBS, 2014). Extreme events for this study were limited to fires due to the available period of record which exists within the water quality data as well as the land cover dataset.

3. Results

The analysis of the seven sampling sites (1 mountain, 2 urban, and 4 agricultural) clearly display nutrient variability among the different land use settings. The mountain setting displayed the lowest observed nutrient concentrations (Fig. 2). The mountain location did not have a collocated stream gage for discharge data as well as only having data for phosphorus concentrations. The phosphorus concentrations remained relatively low during the nearly 11 year period of record (January 1995 – August 2006) with a maximum of 0.05 mg/L and average of 0.01 mg/L.

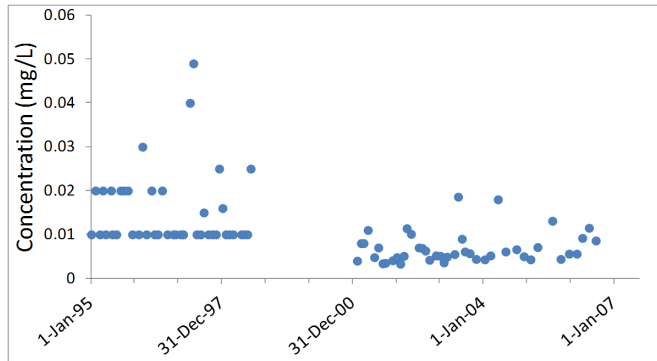


Figure 2. Time series of phosphorus concentrations for the Big Thompson below Moraine Park sampling location (mountain setting).

Urban locations (South Platte at Denver and Cherry Creek at Denver) showed higher concentrations of phosphorus with a maximum of 3.0 mg/L. However, the concentrations were consistently below 2.0 mg/L with an average concentration of 0.2 mg/L for Cherry Creek at Denver and 0.7 mg/L for South Platte at Denver (Fig. 3). No stream flow data were available for the Cherry Creek sampling location. However, the South Platte at Denver location displays a clear dilution of concentrations with stream flow for both phosphorus and $\text{NH}_3\text{-plus-orgN}$, particularly with respect to the 30 day cumulative discharge prior to the sampling date (Fig. 3). The highest concentration of $\text{NH}_3\text{-plus-orgN}$ at this location was 9.3 mg/L as N with an average of 4.3 mg/L as N for the period of record (June 1995 – January 2001).

Two locations were considered to rest within an agricultural/urban setting (South Platte near Kersey and South Platte at Henderson). The South Platte at Henderson location observed higher concentrations of both phosphorus and $\text{NH}_3\text{-plus-orgN}$ relative to the South Platte near Kersey location. The maximum concentrations observed between the two locations were 3.0 mg/L of phosphorus and 8.8 mg/L as N of $\text{NH}_3\text{-plus-orgN}$, both being observed at the Henderson location. Average phosphorus concentrations were 0.8 mg/L and 1.6 mg/L for South Platte near Kersey and at Henderson, respectively. Average $\text{NH}_3\text{-plus-orgN}$ concentrations were 1.7 mg/L and 4.4 mg/L as N for South Platte near Kersey and at Henderson, respectively. Both sample locations also displayed a dilution of nutrient concentrations with higher stream flow rates (Fig. 4).

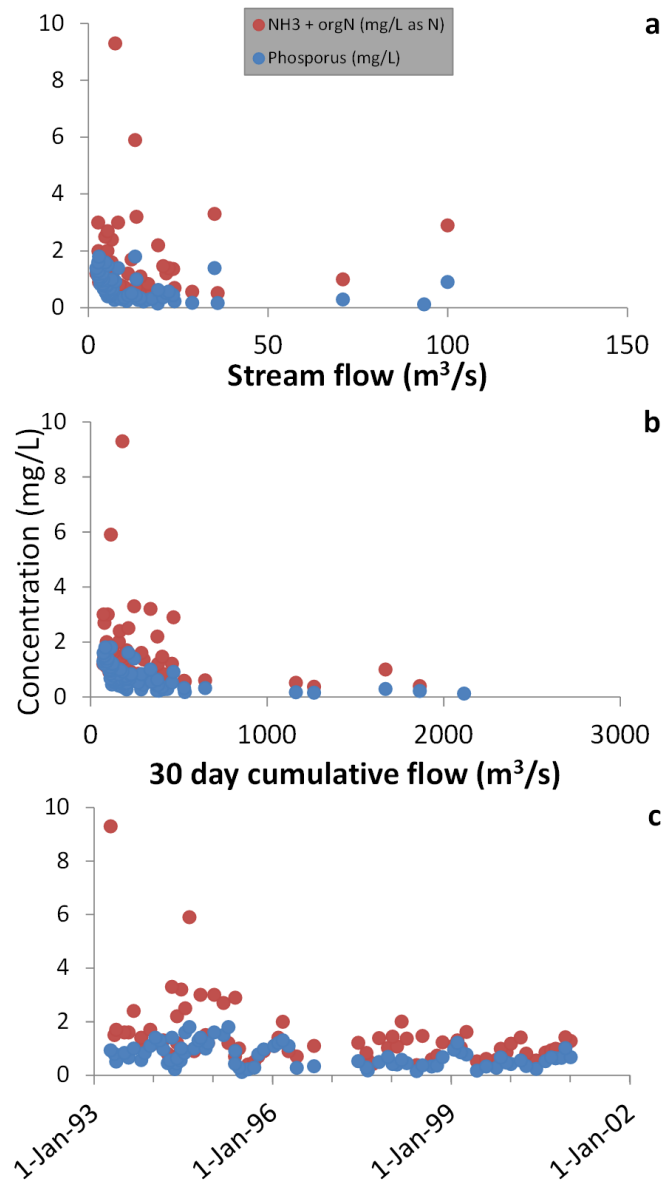


Figure 3. Concentrations for the South Platte River at Denver location (urban setting) with respect to a) stream flow on the sampling date, b) 30-day cumulative discharge prior to sampling data, and c) in time.

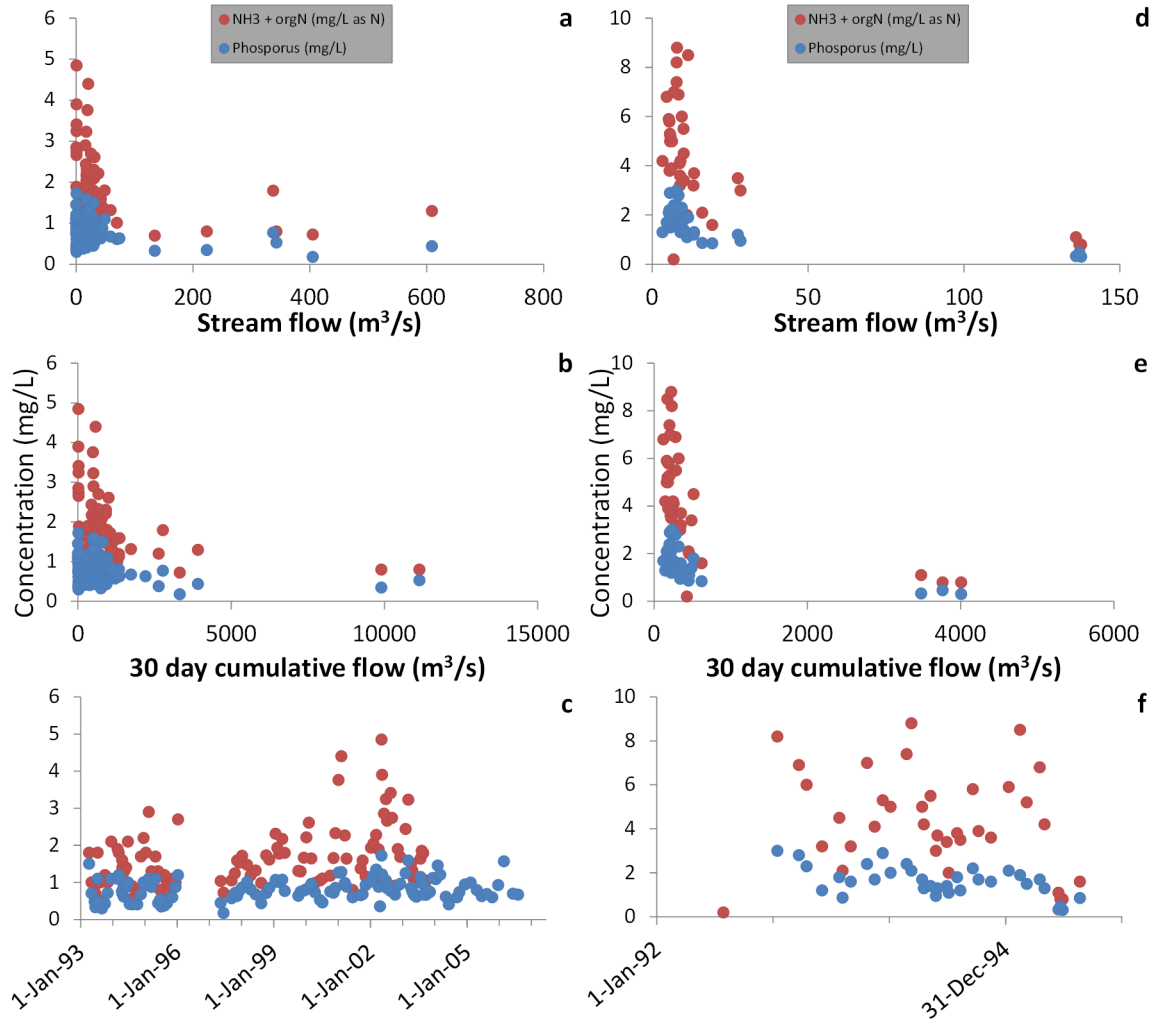


Figure 4. Concentrations for the South Platte River near Kersey location with respect to a) stream flow on the sampling date, b) 30-day cumulative discharge prior to sampling data, and c) in time in addition to the South Platte River at Henderson location with respect to d) stream flow on the sampling date, e) 30-day cumulative discharge prior to sampling data, and e) in time. (Urban/Agricultural setting).

The agricultural locations (SPR at Cooper's Bridge near Balza and South Platte at North Platte) displayed results for only phosphorus concentrations. No discharge data was available for the SPR at Cooper's Bridge location. The period of record was relatively short for these locations (April 1993 – February 1996). However, fluctuations of phosphorus concentrations were still observed relative to streamflow for the South Platte at North Platte location (Fig. 5). The South Platte at North Platte is the only location with discharge data which displays an increase in phosphorus concentrations with relation to stream flow, both discharge the same day of sampling, and 30 day cumulative discharge prior to sampling (Fig. 5). Additionally, the year which the highest phosphorus concentrations were observed (1995) is considered to be a year with higher flows following lower flow years (Davitt, 2011). The maximum phosphorus concentration observed at these two locations was 1.2 mg/L at the SPR at Cooper's Bridge site. The average concentrations for the locations were 0.4 mg/L and 0.1 mg/L for SPR at Cooper's Bridge and South Platte at North

Platte, respectively. Though it is difficult to make conclusions with only partial temporal overlap between sites, the agricultural locations have noticeably lower phosphorus concentrations, suggesting WWTPs have a higher contribution towards these concentrations.

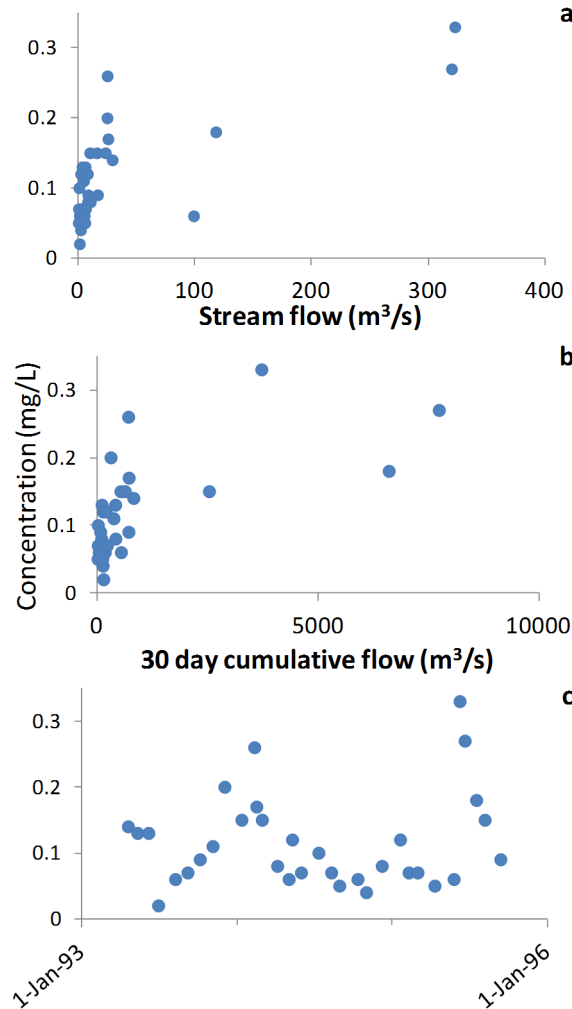


Figure 5. Phosphorus concentrations for the South Platte River at North Platte location with respect to a) stream flow on the sampling date, b) 30-day cumulative discharge prior to sampling data, and c) in time.

The only extreme event which occurred in the SPRB within the nutrient periods of record available for this study was the Hayman fire. The Hayman fire occurred during the summer of 2002, burning a total area of 138,000 acres (MTBS, 2014). Only one of the sample locations for this study has samples taken at the appropriate times and would have been impacted by this event. This location is the South Platte near Kersey. However, it is unclear if the results of the fire can be seen in the data due to high concentrations occurring prior to the fire as well as the fire occurring upstream from multiple controls. It is certain, though, that events such as fire can alter land cover types over large areas and will alter the hydrologic processes of the burned areas (Fig. 6).

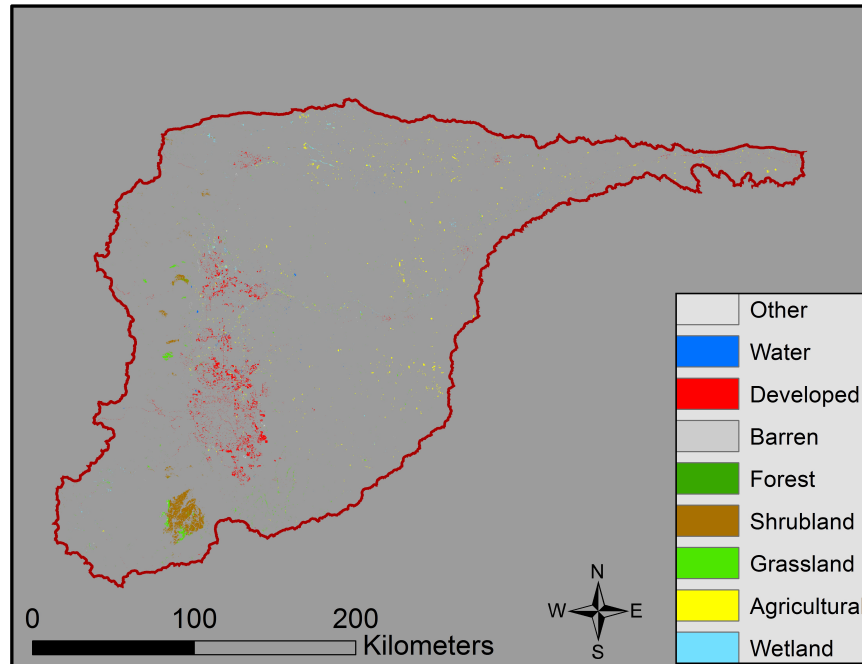


Figure 6. Land cover changes from 2001 to 2011 within the South Platte River Basin. The symbology displays the new land cover classification is according to the 2011 dataset. No symbology represents no change in land cover over the ten year period. (JIN *et al.*, 2013)

4. Discussion

The analysis of the seven locations within the SPRB clearly displays nutrient variability between the different settings. The mountain setting displayed the lowest observed nutrient concentrations and likely had the lowest flow rates, although no discharge data were available. The urban and urban/agricultural settings resulted in higher nutrient concentrations, likely from WWTPs. Although nutrients are monitored at nearly all WWTPs in Colorado, ammonia is the only nutrient with an in-stream standard for the SPRB during the period of record of this study. New standards, such as Regulation 85 on point and non-point sources are likely to drive nutrient levels within the SPRB going forward. With future population increases expected throughout the Colorado Front Range and imminent water scarcities, WWTPs along the urban corridor will be forced to deal with rising nutrient concentrations which can pose a threat to stream health and downstream water users. Regulation 85, limiting nitrogen and phosphorus loadings to the river, was adopted in June 2012 by the Colorado Department of Public Health and Environment Water Quality Control Commission as an instrument to control pollution from both point and non-point sources. This regulation extended existing legislation setting lower limits for nutrient pollution from WWTPs while at the same time including the previously un-regulated non-point sectors such as urban storm water and agriculture. Much of the nutrient levels in the mountain areas were commonly below the standard of 0.1 mg/L for phosphorus whereas agricultural and urban segments often exceeded these limits by factors ranging from one to three for the agricultural setting and as much as 20 for the urban settings.

Flow regulation and runoff characteristics have an influence on nutrient concentrations. This can be seen at the South Platte at North Platte location. This location had an inverse

relation between phosphorus and stream flow relative to other sites. This is likely due to the relatively low flow years prior to the high flow year which produced the increased concentrations at the furthest downstream site. Phosphorus can often be attached to sediment loads (Xinzhong *et al.*, 2014) which is known to be a dynamic process, particularly after events such as forest fires (Moody and Martin, 2001). It is likely that the sediment loads and adsorbed phosphorus was being deposited along the streambed during low flow events which did not produce enough energy to move the sediment through the entire basin. Then, during the higher flow year in 1995, enough energy existed within the river to transport the sediment and adsorbed phosphorus through the South Platte at North Platte sampling location and out of the basin. With the higher number of drought years in the future predicted as a result of climate change (Barnett *et al.*, 2005, Harpold *et al.*, 2012); it is important to understand that with a reprieve from the drought in the form of a higher flow event, the result may be increased nutrient loads such as phosphorus. Further investigation and analysis of more robust datasets are necessary in order to test and further support this predicted increase in nutrient loading.

Data availability proved to be a major limiting factor in this study. There are a number of sampling locations within the SPRB which have produced less than ten publically available data points over the past 25 years. This is insufficient to produce any significant analysis. The seven locations used for this study often had periods of record which did not coincide with other sampling sites or were not continuous, thus creating a difficult dataset to test for trends and compare between locations during similar hydrologic conditions. With the various climate change scenarios projected and the potential impacts that could occur on the nutrient cycles, predicting the effects on nutrient loadings with insufficient datasets will produce erroneously large margins of error. Proper planning for future nutrient regulations would require more robust datasets in order to draw more significant conclusions.

4. Conclusions

The results of this study indicate that extreme events such as fire and droughts can have an impact on the nutrient loading of the SPRB. Years of lower flow rates within the South Platte River may deposit phosphorus at locations within the river bed and hyporheic zone to be stored until a higher flow event produces the energy to transport the nutrient through and out of the basin. WWTPs have a clear impact on nutrient concentrations in the urban and urban/agricultural settings of the sites analyzed in this study. However, the anthropogenic component of the SPRB cannot be ignored because this part will most certainly set the tone of water quality issues in the coming years. Farmers and WWTPs are currently aware of water quality issues related to nutrients and it will be largely their responsibility to be leaders of best management practices on this issue in the face of climate change.

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