An investigation of hydrology, sediments loads, and contaminant discharge from Brownhill Creek, South Australia: Modelling and data analysis

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Declaration

I hereby declare that this thesis submission does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university, and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed……………………………………………………

Saif ur Rahman

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Acknowledgement

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Executive summary

Water quality implications of the rapidly expanding Urban areas have been a growing concern and Urban hydrologists are continuously seeking ways to mitigate the degradation to water bodies and their habitat. Runoff from the Urban and Rural areas can carry a considerable number of contaminants including major nutrients (e.g., nitrate, sodium, and phosphorus), heavy metals, rubbers, litter from the roads. Despite the presence of various gauging stations in Brownhill Creek and the data for discharge, sediments and nutrients, the temporal and spatial variation and their mutual relationships are yet to be unknown for Brownhill Creek. SWMM hydrological model is developed for the Brownhill Creek Catchment from 1997-2020. The results of the model when compared with the Scotch College and Adelaide Airport gauging stations' data were found diverging and were not matching. This is due to the lack of the most recent and historical land-use data and infiltration data, topographic data etc. Due to some large values, the discharge, sediments and nutrients data is skewed positive not only in the Urban part of the Brownhill Creek but also for the Rural part. Comparison between the Rural and Urban areas in terms of sediments and nutrient generation indicated that the Urban area generated more loads than the Rural part of the Brownhill Creek Catchment. Moreover, a strong correlation exists between, Kjeldahl (TKN), total nitrogen and total phosphorous. More accurate and detailed data can increase the accuracy of the results. Water sensitive design structures are proposed along the Creek and major drains' alignment to improve the water quality of the surface runoff.

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1 Introduction

1.1 Background

Excess nutrients and sediments from the land-based human interventions are the real threat to the marine and coastal life by most of the resource managers, fishers, conservation practitioners, and other downstream resource users (Fredston-Hermann, Brown et al. 2016). Consequently, the marine and coastal areas undergo anthropogenic pressure from local scale (e.g., coastal development, fishing) to global scale (e.g., rising sea, acidification, warming) many of which starts beyond the coastal oceans (Halpern, Walbridge et al. 2008). Nutrients and sediments usually co-occur in surface runoff, even though the impacts and the dynamics of those two are not the same. Nutrient and sediment transportation into the sea may start with a variety of point sources like stormwater outfalls, wastewater effluent, runoff from waste storages–and nonpoint sources–deforestation, atmospheric deposition, land conversion, and surface runoff from agricultural lands (Kroon, Kuhnert et al. 2012). Nutrient discharge to marine and coastal leads to excess phytoplankton, including some harmful algal blooms (Clorern 2001). Also, sediments may impair the larval development of fishes by smoothing natural fishes' habitats (Fabricius 2005).

Brownhill Creek (South Australia) arise on the western steeply sided valleys of the Mount Lofty Ranges and then flow towards the Western and South-Eastern Suburbs of Adelaide towards the Adelaide Airport, before discharging into St Vincent Gulf through the Patawalonga Lake (Stormwater Management Plan 2016). The upper part of Brownhill Creek is Rural whereas the lower part is Urban. Much of the Rural part of Brownhill Creek is modified for cropping, grazing and living (Environmental Protection Authority 2021). Council drainage network defines the Urban part of the Catchment and is heavily modified and influenced by human intervention since a significant length of the Creek passes through the Urban property (Water Data.SA 2021). The change in land use or land cover alter the hydrological conditions of the area and may lead to higher runoff and soil erosion and sediments caused by runoff (Marie Mireille, M. Mwangi et al. 2019). Soil degradation depends on the pattern, intensity and type of land-use change i.e., when a forest is converted into cultivated land (Upper Brownhill Creek Catchment) it can cause depletion or reduction of soil nutrients such as Total Nitrogen, organic matter and Total Phosphorous (Abdel-Magid, Schuman et al. 1987) which then not only pollute the surface runoff water quality but also the source water quality.

1.2 Literature overview

Water quality implications of the rapidly expanding Urban areas have been a growing concern and Urban hydrologists are continuously seeking ways to mitigate the degradation to water bodies and their habitats (McGrane 2016). Runoff from the Urban and Rural areas can carry a considerable number of contaminants including major nutrients (e.g., nitrate, sodium, and phosphorus), heavy metals, rubbers, litter from the roads (Tong and Chen 2002). Action plans to manage issues related to water quality are developed by territory and state government, local government and councils and regional organisations supported by National Water Quality Management Strategy (Environment Protection Authority 2021). Urban streams like Brownhill Creek and Keswick Creek are an important part of the Urban landscape and play a prominent role in stormwater runoff management and flood control. During the rainfall events, surface runoff from the Urban area enters the stream through drainage network carrying high level of nutrients and sediments (Water Quality Australia 2021).

Efforts have been made to address the water quality issues at all levels from the Government to local levels. The government of South Australia (2001) appointed Environment Protection Authority (EPA) to manage Adelaide coastal water studies to develop the understanding to mitigate the seafloor instability, seagrass loss and poor water quality along the Adelaide Metropolitan coast Series of studies were conducted to assess the water quality form rivers, Creeks and drains as part of Adelaide coastal water studies (Goyder 2001). Various studies were carried to estimate the flow from Brownhill and Keswick Creek and associated damages and comprehensive stormwater management plans were prepared to address the adverse effects (Stormwater Management Plan 2016). Alongside Adelaide coastal water studies and stormwater management plans, various gauging stations are available that measure the water quality and discharge data (volume, discharge, salinity, turbidity, total nitrogen, total phosphorus, total Kjeldahl nitrogen etc.) on a daily, monthly and yearly basis at various location in Adelaide. Two gauging stations are in Brownhill Creek Catchment one in Scotch College and another one near the Adelaide Airport (Water data. SA 2021).

Hydrological modelling of the Brownhill Creek has been carried out in various stormwater management projects but in different years and associated work, plans were developed for future storm events (SMP 2016). There is a lack of a comprehensive hydrological model for the brown hill Creek which can demonstrate the rainfall-runoff events along with the water quality for a large past event in the upper and lower Brownhill Creek Catchment. The Gauging station's data available at Scotch college and Adelaide airport is a useful base to assess the sediments and nutrient load transported through upper and lower Brownhill Creek and their mutual relationships from the last 24 years. Hydrological modelling presented in SMP can help to develop the hydrological model for large past events.

1.3 Knowledge gap

Considering the concerns of state and territory government, councils and other organisations over the Brownhill Creek discharge and water quality, various projects and studies have been done in past to address the issues that emerged over the years. But all the studies were carried out either for the scope of the project or studies (SMPs) or for the overall Adelaide regions (ACWS). Despite the presence of various gauging stations in Brownhill Creek and the data for discharge, sediments and nutrients, the temporal and spatial variation and their mutual relationships are yet to be unknown for Brownhill Creek. This thesis will address this knowledge gap with the help of the Stormwater Management Model (SWMM) hydrological model and data analysis.

1.4 Research problems

The historical data for rainfall, runoff, nutrients, sediments and various other hydrologic parameters is available on water data.SA website for the Brownhill Creek for the past 24 years the data contains daily, monthly and yearly values and summaries for the Scotch College and Adelaide Airport gauging station. Also, different studies have made hydrological models and nutrients and sediment analysis at different times, so no one has tried to make the model for the last 24 years and to see the mutual relationship of flow with sediments and nutrients or the relationship of the sediments versus nutrients for the historical record. These relationships coupled with hydrological modelling would give us discharge, sediments, and nutrients load for a different time, location and for different land use (Urban and Rural). The results from the research will help in identifying the locations of high sediments and nutrient generation and in making associated mitigation strategies and plans.

1.5 Scope of the thesis

The hydrological modelling and data analysis of Brownhill Creek has the following study objectives

- Hydrological modelling of the Rural and Urban part for the Brownhill Creek using Storm Water Management Model (SWMM)
- Relative contributions and relationship (discharge and loads) of contaminants for upper and lower Brownhill Creek.
- To determine the temporal and spatial variations of discharge, total suspended solids and nutrients.

1.6 Methodology overview

Methodology is defined in such a way so that the objectives of the thesis are easy to achieve in specified time. Hydrological model has been developed to simulate the rainfall runoff model for the Brownhill Creek (Rural and Urban) for the last 24 years by using HEC-HMS and Stormwater Management Model (SWMM). The discharge values generated by the model are then compared with the discharge values of the gauging station located at downstream of the Urban and Rural Catchment. Also, discharge, and contaminants data of the Scotch College and Adelaide Airport gauging stations has been analysed to understand the spatial and temporal variation.

1.7 Thesis structure

Considering the maximum page limits, this thesis has 5 chapters in total excluding references and appendices.

- Chapter 1 describes the background, literature overview, scope and objectives of the study. It also describes the gap statement and methodology overview as well.
- Chapter 2 briefly describes the similar or related literature published previously related to this topic.
- Chapter 3 explains the methodology in detail by introducing the study area first and then SWMM Modelling, and contaminants analysis is done later in the chapter.
- Chapter 4: Summarises the results and discussion related to Modelling and data
- Chapter 5 has conclusion
- Reference and appendices are provided at the end of the thesis.

2 Literature review

The most common trend in land use is Urban area worldwide, with approximately more than half of the world population residing in the small area of the land (Saier 2007). Water quality implications of the rapidly expanding Urban areas have been a growing concern and Urban hydrologists are continuously seeking ways to mitigate the degradation to water bodies and their habitats (McGrane 2016). The urbanisation of the Catchment is linked with the compaction, degradation, sealing and mixing of natural soil with the imported soils (Doichinova, Zhiyanski et al. 2006) which require sustainable management. Increased runoff, degraded water quality, erosion rates, wetland loss, reduction in biodiversity and eutrophication are a few consequences of urbanisation (Whitehead, Lapworth et al. 2002).

A study of 106 river Catchments worldwide concluded that the part of the Catchment with streamflow disturbed and fragmented by small and large dams in Urban areas is predicted to increase 70% by 2050 (Zhang, Xia et al. 2013). In Australia, Catchments are not in their natural shape and are subject to continuous alteration since European settlement by development and land clearing of cities (Xian, Crane et al. 2007). Almost 90% of the population is residing in Urban areas of Australia and most of the Catchments are facing the risk of high sediments, nutrients and algal blooms (Zoppou 2001).

Urbanisation has considerable impacts not only on hydrological dynamics but also on the meteorology of that area. Excess in particulate matter and artificial thermal properties from the urbanised area altered the rainfall generation process and have increased the downwind precipitation and may enhance the production of summer thunderstorms (Jin and Shepherd 2005). The ongoing expansion and development of Urban areas result in decreased perviousness of natural Catchment and an increase in manmade drainage network that can accommodate substantial changes to timing, pathways and magnitude of runoff at a variable scale from an individual building to huge developments (Fox, Witz et al. 2012). The texture and structure of the building can change the way the precipitation (rainfall) is converted to runoff and the mutual relationship of the imperviousness and perviousness surfaces affect the capacity of the surface drainage during the rainstorm events (Yang, Lerner et al. 1999). Usually, Urban development's reduce the groundwater recharge and base flow of the wet season and increase stormwater runoff in proportion to surface runoff increment (Arnold and Gibbons 1996).

2.1 Water quantity affects water quality

Water quality is driven by water quantity and their mutual relationship is highly complicated and strongly depends on the individual Catchment characteristics like sources of water, instream processes and hydrological variability (Water quality Australia 2013). Human derived Catchment alterations and urbanised land use have not only changed the water quality of natural water sources but also changed the natural water cycle (Baker 2003). For instance, in the Murray-Darling Basin, the water table has risen due to extensive irrigation (Water quality Australia 2013). Also, the construction of large dams on rivers and natural streams have affected the water quality and flow regimes downstream (cold water pollution) (Bunn and Arthington 2002). The water quality is mainly dependent on four Catchment characteristics i.e., percentage of native vegetation (Rutherford, Marsh et al. 2004), nature of agricultural practices coupled with intensity and extent of agriculture (Sauer, Daniel et al. 1999), urbanisation, density of human population and effluent disposal practices (White and Walsh 2020), and mining, erosion and Catchment geology (Water quality Australia 2013).

Stream water quality shows the quick response to the short-term variations in water flow (Poff, Allan et al. 1997). Brownhill Creek flows only for 6 months annually (Towns 1985) which means dry and wet seasons are of 6 months. The wetting and drying cycles are very important not only for water quality but also for ecological purposes as the dry season is favourable for releasing nutrients and carbon that supports the growth of bacteria, algae whereas the wet season refreshes water quality entertains organic matter for the food web, and dilute salinity level (Corrick and Norman 1980). When flow changes in stream drastically during the major flood and droughts, it affects the water quality greatly (Bunn and Arthington 2002). During the drought season, the water bodies within the streams may experience extremes in dissolved oxygen levels, water temperatures, saline or thermal stratification of the water column, warm water conditions, algal growth and concentration of toxins and ions (Bates, Kundzewicz et al. 2008). High flows, like floods, can result in widespread Catchment erosion which results in unparalleled suspended solids, nutrient and toxicant loads to fragile coastal and marine life (Prosser, Rutherfurd et al.

2001). Sewage and sewers can overflow due to the floods and pathogens, toxicants and nutrients may enter the waterways (Howitt, Baldwin et al. 2007)

2.2 SWMM Hydrological Modelling

Rainfall-runoff models play a key role in designing, planning and managing the water resource in different land use. These models can be used in a variety of different ways, ranging from the estimation of runoff from the Catchment to studying the impacts of different land use on runoff generation (Dwarakish and Ganasri 2015). The stormwater management model (SWMM) (Rossman 2010) is one of the most effective and widely used Urban rainfall-runoff and water quality models around the globe (Obropta and Kardos 2007). In addition to the flood analysis of the Catchment, SWMM is very effective in planning, analysis and design of the sanitary sewer as there has been growing concerns of climate change over the degradation of the water infrastructure in a variety of ways (Grimm, Faeth et al. 2008).

SWMM was developed by the US Environmental Protection Agency (USEPA) in 1971 as open-source software to fulfil the demands for the rainfall-runoff quantity and water quality simulation especially in Urban land use (Huber, Dickinson et al. 1988). SWMM divide the whole Catchment into one or smaller sub-Catchments by idealizing each sub-Catchment as a rectangular basin in which overland flow direction is assumed towards the longer side of the rectangle and the assumption that each sub-Catchment is non-linear water balance is made for the whole Catchment (Moskovkin, Serkina et al. 2018). SWMM model uses different methods to estimate the amount of infiltration. SWMM can estimate the infiltration using the Akan and Houghtalen method (Akan and Houghtalen 2003) which is the form of curve number method, or it can use a method developed by Green and Ampt (Green and Ampt 1911). For the Brownhill Creek SWMM Model, the Horton method is used developed by Horton who described the infiltration capacity decreases with the time after the start of the rainfall (Horton 1940).

From 1987-2014, various studies were carried out for flood analysis using SWMM (Dasgupta, Gosain et al. 2013), but most of the studies have been done from 2013 to till now just because of the climate change (Kirshen, Caputo et al. 2015). Previously, utilisation of continuous simulation to estimate the flood in Urban Catchments was done in between 1960s and 1970s (Rawls, Stricker et al. 1980). With human intervention to land use, flood analysis is also of great concern for changing land-use (Camorani, Castellarin et al. 2005). Often flood modelling prediction heavily motivated because of mandatory planning needed during flood warning and evacuation, species protected, rescues performed, resource utilisation and maintenance of ecosystem services (Ford, McFadden et al. 2002). SWMM flood modelling and analysis provide very useful output for example inundation maps which can be very helpful point out the weak points in sewer network and in identification of areas of greater risk (Gersonius, Ashley et al. 2013). Low impact development (LID) or Water Sensitive Urban Design (WSUD) feature was added to examine the surface runoff water quality (Rossman and Huber 2015)

2.3 Discharge and contaminants relationship

To understand the nutrients and sediments dynamics in upstream Catchment to receiving water resources such as estuaries, lakes and coastal water is very important as the export greater than then the permissible limits may affect the marine and coastal life (Sutton, Oenema et al. 2011). Pastoral agriculture such as dairy farming is recognised as major exporter of sediments and nutrients in various places (Smith, Western et al. 2013). In the past and recently, a number of studies has assessed the contribution of farm lands such as Paddocks as the prime source of nutrients to water resources; however farmyards, dairy sheds, farm buildings and barns are worth mentioning sources of organic form of P and N from the animal wastes (Edwards, Kay et al. 2008). Excretion of N and P from the farmyards is still least discussed topic among water quality research topics (Pionke, Gburek et al. 2000). Globally, CSA concept (Critical Source Areas) has been used more extensively for the generation of P (Müller, Srinivasan et al. 2010). In most part of the South Australia farmers uses small dams to store the water (small storage reservoir), this area has variable climates. Very few literature exists which examine the sources of nutrients and sediments and their impacts on the water quality (Brainwood, Burgin et al. 2004)

Annually, large amount of the sediments and the nutrients are exported during the fewer events due to the increased runoff and high concentration (Nash and Murdoch 1997). The quantification of these sediments and nutrients is only possible with help of extensive temporal and spatial monitoring as carried out in Adelaide regions and most part of Australia. Historical data has been maintained at Adelaide Airport Gauging Station and Scotch College gauging Station (EPA

2021). The short-term changes in Catchment can cause long term issues in stream channel in downstream of the Urban Catchment. Due to the urbanisation, erosion increases in the Catchment and ultimately the sediment loads increase int the downstream which can impact marine and coastal life in the long run (Whitehead, Lapworth et al. 2002)

3 Methodology

3.1 Catchment description

Brownhill Creek (BHC) is selected for hydrological modelling and data analysis which is in the South-East of the city (figure 1). The red line represents the boundary of the Catchment, and the blue line represents the alignment of the Creek. Two yellow dots represent the gauging station i.e., Scotch College and Adelaide Airport. The Creek starts on the western side of the Mount lofty ranges and discharges into St Vincent gulf through the Patawalonga outfall (high flows) (SMP 2016). Most of the Creek passes through the private property due to which the Creek has a variable cross-section and different lining. Also, the Creek is in its natural shape in its upper part whereas for the lower part the Creek was a different cross-section (SMP 2012). The channel capacity changes considerably from 15m^3/s to 40 m^3/s just because of the varying channel cross-section and localised obstructions (BHKC SMP 2016).

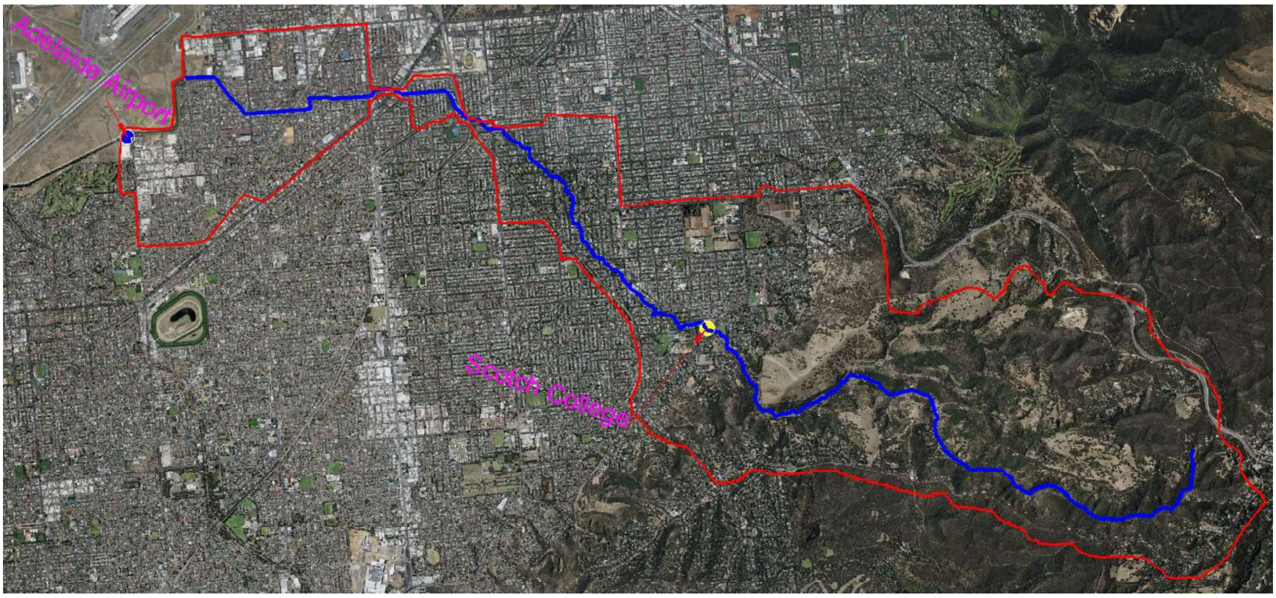

Figure 1: Brownhill Creek locality and topography

Source: Google Earth and Civil 3D

3.1.1 Catchment Area

The Catchment area of the Brownhill Creek a 32km^2 (upstream of the Adelaide Airport) of which 14km2 is Urban whereas 18km^2 is categorised as Rural so a major part of the Creek is a Rural area (Auditor general report 2016). The Brownhill Creek flows through suburbs of West Crafers, and Brown Hill Creek in its upper part whereas it flows through the Torrens Park, Hawthorn, Unley Park, Millswood, Forestville, Ashford, Kurralta Park, Plympton, Netley and Adelaide Airport in its lower part (BHKC SMP 2016).

3.2 Data sources

The data for the analysis includes hydrological modelling data, discharge and contaminants data. As the Catchment is divided into Rural and Urban parts so the data greatly varied in these two parts of the Catchment. Hydrological modelling data includes evaporation, rain gauges, sub-Catchments, infiltration, outfalls, conduits, Creek cross-sectional, and precipitation data. Digital elevation model (5m DEM) was obtained from the Elvis foundation due to its better accuracy as compared to google earth. For the calibration of the SWMM model rainfall data from the Scotch College, and Adelaide airport gauging station and last 24 years rainfall data was obtained from the bureau of meteorology. Catchment and sub-Catchments were generated in HEC-HMS and then georeferenced backdrop image as imported into SWMM. Corrections were made in Catchment delineation as per the previous Stormwater management reports of the Brownhill Creek Catchments. As per the scope of the thesis and limited time, various data like Creek cross-sectional data, imperviousness, Manning's n, infiltration and the evaporation data were found from the recent stormwater management report

Various sources for example Water Connect, Green Adelaide - Water Data Services Water Data SA were considered for the discharge, sediments, contaminants data. But the reliable, continuous, and historical data was only available on Green Adelaide – Water Data Services. Discharge, total suspended solids, total Kjeldahl (TKN), total nitrogen and total phosphorous monthly loading values were obtained from the last 24 years (1997-2020). To check the accuracy of the data points, monthly values were cross-checked by comparing monthly discharge and contaminants loads with the daily discharge and contaminants loads at both gauging stations (Scotch College and Adelaide Airport) which were found correct.

3.3 Hydrological modelling

3.3.1 Catchment delineation

Catchment delineation was carried out using 5m DEM resolution in HEC-HMS. The output was then exported to Civil 3D (figure 2) to further examine the accuracy of the Catchment and sub-Catchments using the previously published literature i.e., stormwater management plans 2012 and 2016. The red line represents the boundary of the whole Catchment whereas the dotted magenta lines represent the sub-Catchments (B1-B13). The thick blue line refers to Brownhill Creek alignment with two gauging stations, Scotch College and Adelaide Airport in yellow and blue dots respectively. The whole Catchment is discretised into 13 sub-Catchments. To see the current drainage system of the Catchment, the drainage network layer is downloaded from the Data.SA is also added as the base layer to the Catchment and sub-Catchment. Most of the upper Brownhill Creek (Rural) is in its natural state with streams in innate form (yellow lines). Also, the lower part of the Catchment is highly altered due to human infrastructural intervention so that the natural flow paths are either converted or diverted to artificial drains.

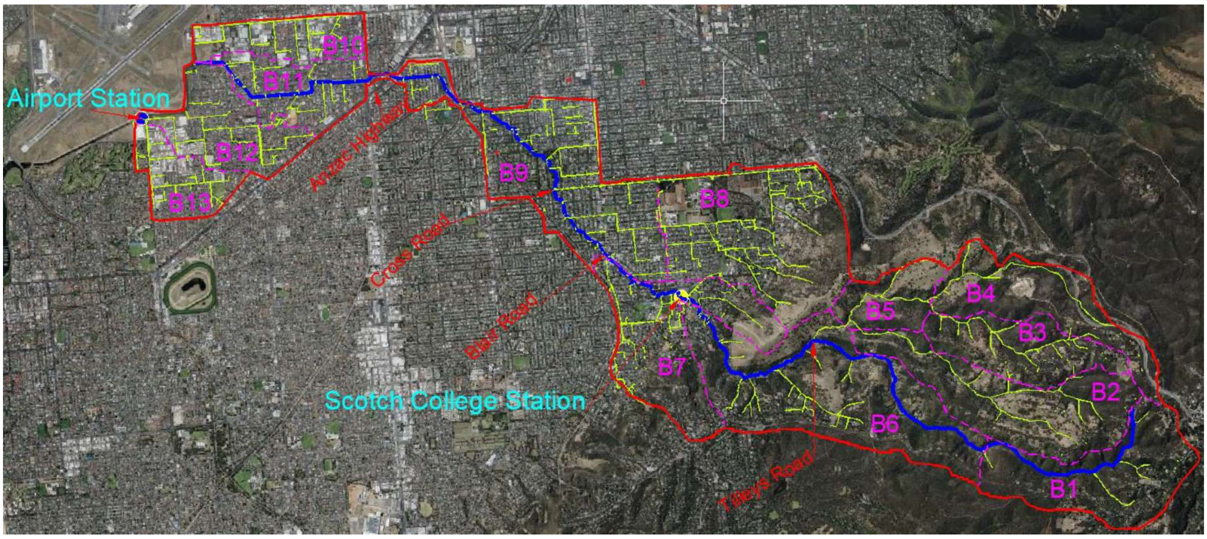

Figure 2: Brownhill Creek Catchment, sub-Catchments and drainage network

Figure 1 was used as a georeferenced backdrop image in SWMM software to mark the sub-Catchments and their geometric properties were compared with HEC-HMS' Catchment out to see the accuracy. The next step is to populate the Catchments with the drainage network by specifying the nodes and conduits. The upper part of the Brownhill Creek is in irregular shape whereas in the lower part it has a trapezoidal and circular cross-section (SMP 2016). The values related to the geometric properties were taken from the stormwater management report of the Brownhill and Keswick Creek Catchment. As there are 13 sub-Catchments so only the major drains are simulated as shown in figure 3.

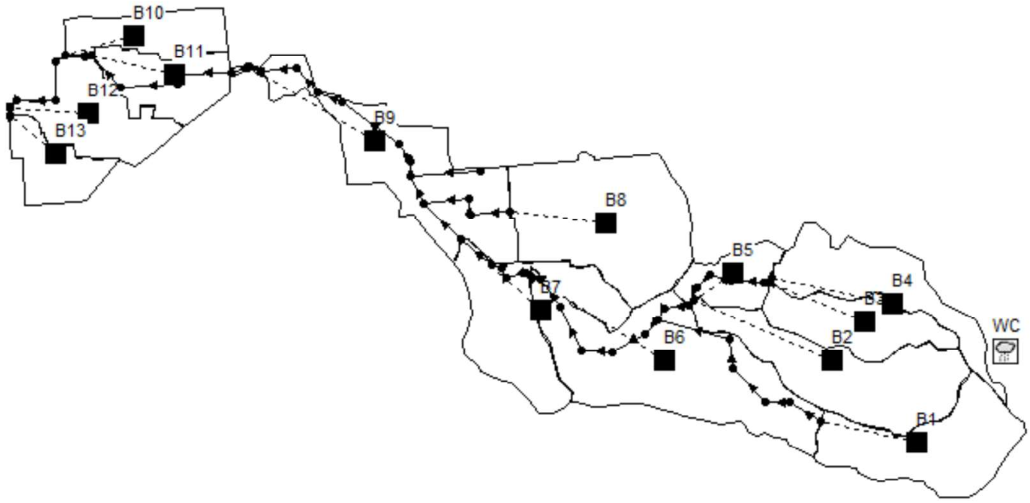

Figure 3: Brownhill Creek SWMM Model
Source: EPA SWMM (5.1)

3.3.2 Parameterisation

To model, the Catchment in the SWMM requires a wide variety of parameters (Tikkanen 2013). Some parameters are easy to obtain (Catchment areas) with some uncertainties involved. In contrast, other Catchment parameters for example slope or width of each Catchment are relatively complex when a large Catchment area is under consideration.

The percentage of imperviousness relative to the total area of the Catchment is termed imperviousness (Choi and Ball 2002). The values for the percentage imperviousness and Manning's 'n' were taken from the SMP 2016. Horton (1940) Model was used for the infiltration. As per the previous 2016, 2012 and 2008 SMPs the maximum infiltration value of

11.3mm, minimum infiltration value of 5.08, and the decay constant of 4 were used in Horton's model (Horton 1940). To simulate the rainfall-runoff for the last 24 years the precipitation data were obtained from the Bureau of Meteorology from 1997 to 2020.

The final parameter is the slope. In SWMM, sub-Catchments are considered rectangular planes. All the planes are inclined towards a single edge so that flow from all the surfaces is perpendicular. On the other hand, the slope is Catchment inclination. But this might not be true for the Brownhill Creek Catchment due to its large area so finding the Catchment slope is not as easy as it looks. To get the slope values for the sub-Catchments, DEM was imported into Civil 3D and with the help of the slope analysis tool, values were extracted.

3.3.3 Running the model

After putting all the input parameters into the SWMM model. One of the key steps is to set the date and time for which the model will run. The model was run from 1st of Jan 1997 to 31 Dec. 2020 covering all the design periods. The results are presented and discussed in the following chapters.

3.4 Discharge contaminants relationship and variation

Creek discharge and water quality vary temporally and spatially (Moore and Anderholm 2002). This section describes the relationship and variation of the discharge versus contaminants, and the contaminants versus contaminants at Scotch College and Adelaide Airport Gauging Station from 1997 to 2020.

3.4.1 Data availability

To see the spatial variation and relationship among the discharge and contaminants loads, two gauging stations were selected. Green Adelaide – Water Data Service has maintained the most recent hydrological data for each site and Catchment in the Adelaide region (Green Adelaide-Water Data Services 2021). Instead of daily record, monthly data for flow (Q), total suspended solids (TSS), Total Kjeldahl (TKN), Total Nitrogen and Total Phosphorous (P) is maintained which is highly accurate. So, the data for desired parameters obtained from Green Adelaide-Water Data Services

3.4.1.1 Creek discharge

To understand the variation in load and their downward transportation, spatial and temporal variation in discharge is mandatory to understand (Liu, Chen et al. 2012). Temporal variations in Creek discharge can be used to find how inflows and outflows vary from month to month and year to year for the years 1997 -2020. By looking into spatial variation, the change in the discharge of the Creek at Scotch College and Adelaide Airport can be determined. For this study mean monthly flow values are taken to achieve the desired objective of the study. Also, daily discharge values from 2016 to 2020 are obtained to compare with the monthly discharge (ML/mo) at both gauging stations.

3.4.1.2 Contaminant's loads

The mass or weight of a particular constituent transported through a particular for a given period is defined as the load for that constituent (Moore and Anderholm 2002). Instantaneous load is the product of Creek discharge and contaminant concentration and sometimes it is referred to as flux (Niemistö and Lund-Hansen 2019). Change in streamflow or concentration greatly affects the load of a particular contaminant (Moore and Anderholm 2002). A load of a particular constituent can only be increased if the flow increases or the contaminant mass is added. High-velocity flow or resuspension may enhance the contaminant mass directly or stormwater drains, and tributaries increase the contaminant mass indirectly by transportation. Moreover, contaminant load may get decrease via suspension during normal or low flows or via diversion channels e.g., irrigation channels.

3.4.2 Scotch College gauging station

Scotch College is located at the lower end of upper Brownhill Creek which is a very crucial spot as it's the end of the Rural Catchment. The analysis at this location will help us to understand the amount and characteristics of the discharge and contaminants loads from the Rural part of the Catchments. Discharge and sediments load data was for the last 24 years was downloaded and sorted as to achieve the study objectives. The study period of 24 years was further subdivided into three parts to better examine the variation of the discharge and contaminants. The subdivided parts are from 1997 to 2020, 1997 to 2008 and 2009 to 2020. To examine the relationship between the flow and contaminants in a Rural area, all the parameters discharge (ML/month) and contaminants (kg/month) were plotted against each other, and the Pearson coefficient correlation (R^2) was used to describe the relationship among the variables under consideration. Moreover, daily discharge (ML/day), sediments (kg/day), and nutrients loads (kg/day) for the period of 5 years (2016-2020) were also obtained, arranged and plotted against each other to compare daily values with the monthly values in term of variation and mutual relationship. Coefficient of determination R^2 was also used to see the relationship between daily and monthly values from the gauging station.

3.4.3 Adelaide Airport gauging station

This gauging station is located at the lower end of the lower Brownhill Creek which is the end of the Urban Catchment. Analysis at this far end of the Brownhill Creek will help us to understand the contaminants produced by the Urban Catchment and the relationship of the Urban Catchment with the contaminants. So, by analysing the data at two different points for a particular duration spatial and temporal variation can be determined. Similar design periods (1997 to 2020, 1997 to 2008 and 2009 to 2020) were selected, and data was arranged and plotted to get the intended objectives. To examine the relationship among the flow and contaminants in the Urban area (lower Brownhill Creek), all the parameters discharge (ML/month) and contaminants (kg/month) were plotted against each other, and the Pearson coefficient correlation (R^2) was used to describe the relationship among the variables under consideration. Daily and monthly variation and relation were also studied for Adelaide Airport gauging station for the period of 5 years (2016 to 2020). For this, daily discharge (ML/day), sediments (kg/day) and nutrients (kg/day) were obtained and rearranged in Excel to compare with the monthly values for the same period. The coefficient of determination was used to describe the relationship among the different parameters.

4 Results and discussion

4.1 SWMM Modelling

This section provides a detailed description of the SWMM hydrologic modelling carried out from 1997-2020 for the entire Brownhill Creek Catchment including the Urban and Rural areas. The output of the SWMM modelling for the Rural part is summarised in figure 4 whereas for the Urban Catchment the results are summarised in figure 5.

4.1.1 Upper Brownhill Catchment

The comparison between the SWMM discharge and the scotch college gauging station discharge is carried out in figure 4. The SWMM model has produced quite diverging results and is quite different from the measured flow at Scotch College gauging station. Gauged flow is greater than the SWMM discharge, but peaks discharge is similar. There are various reasons for this, one reason can be, the upper Brownhill Creek is a hilly Catchment which means that highly accurate DEM is required to simulate the runoff in this part of the Catchment. Accuracy is also affected as a single land use type has been considered for the whole duration (1997-2020) which is not true as the land use has been changed over time.

4.1.2 Lower Brownhill Creek Catchment

The comparison between the SWMM discharge and the discharge from the Adelaide Airport gauging station is presented in figure 5. Unlike the Upper Brownhill Creek, the SWMM flow is larger than the gauging station discharge. This means that the SWMM Model is not showing the true values and the discharge values are larger than the actual discharge for the years. The good thing is that its maximum peaks for the SWMM discharge and the gauging station discharge are coinciding. For the SWMM model, most of the inputs and Catchment parameters are taken from the stormwater management report for the years 2008, 2012 and 2016 which used values for smaller periods. But in this case SWMM model has been constructed to simulate the entire 24 years so that is why results are diverging. Results can be improved by selecting smaller simulating periods and with the help of accurate and current data.

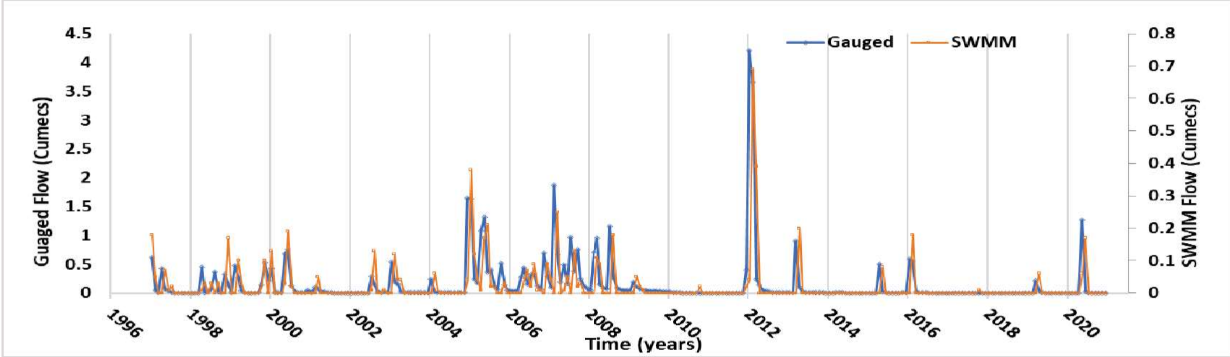

Figure 4: SWMM flow and Scotch College gauging station comparison

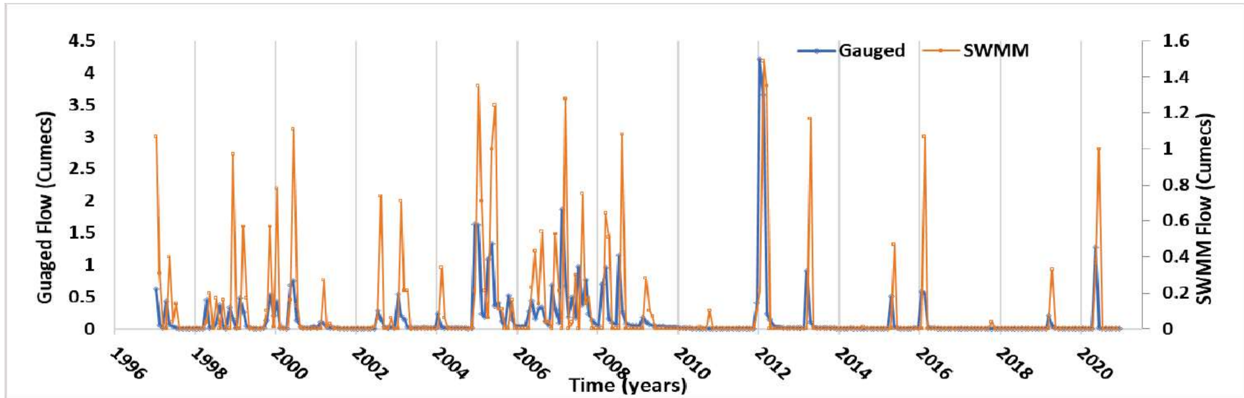

Figure 5: SWMM flow and Adelaide Airport gauging station's flow comparison

4.2 Data analysis

The section provides detailed insight about Spatial-temporal variation and the mutual relationship of the discharge (Q) and contaminants (TSS, TKN, P and N) in Rural (upper Brownhill Creek) and Urban (lower Brownhill) areas of the Catchment. Each parameter is plotted against the other for both gauging stations to see the variation for the different periods.

4.2.1 Upper Brownhill Creek

Aggregate functions of the discharge, sediments and nutrients for the upper Brownhill Creek are summarized in table 4-1. The selected aggregate functions are minimum value, maximum value, average value and median value. Additionally, the sum is also calculated for all the values to now the total amount of discharge and contaminants load transported through the Rural area of the Catchment for the selected study periods. As the data is monthly, that means all the aggregate functions represent the maxim and minimum values that occurred during the whole duration of the study from 1997-2020, 1997-2008 and 2009-2020. The average values represent the sum of all the values divided by the number of months which are 288 (months) for the period 1997-2020 and 144 (months) from 1997 - 2008 and 2009-2020.

The minimum values for all the periods are zero as Brownhill Creek is an intermittent Creek so when no discharge means nothing will be transported through the Creek. The maximum monthly discharge (Q) for the duration 1997-2020 and 2009-2020 is 2087 ML/mo but different for 1997-2008 which is 1255 ML/mo. Also, the maximum total suspended solids (TSS) load (162857 kg/mo) remained the same for 1997-2020 and 2009-2020 but different for the duration 1997-2008 that is 138788 kg/mo. Moreover, TKN does not show a different trend as compared to Q and TSS. The maximum monthly value for the TKN is 1496 kg/mo which is the same for 1997-2020 and 2009-2020 and the TKN value for 1997-2008 is quite less which is 1163kg/mo. Similarly, the maximum Monthly values for the total Phosphorous and total Nitrogen are 266.8kg/mo and 714.7 kg/mo respectively which remained the same from 1997 through 2020 and 2009-2020. Here also, the duration 1997-2008 got lesser values 157.6 kg/mo and 404.5

kg/mo for the P and N respectively. The reason why the values of Q, TSS, TKN, P and N are higher and remained the same in 1997-2020 and 1997-2008 can be associated with the Rural Catchment construction activities, change in land use within the Catchment, human intervention to the natural drainage system and lack of water sensitive Urban design structure. But as per the stormwater management report of Brownhill and Keswick Creek, since the major part passes through the private property so, the activity within those properties greatly affects the Creek water quality. An important contribution of N as P come in form of surface runoff from the lawn irrigation from the residential Catchment (Toor, Occhipinti et al. 2017). Higher trends also exist during the 1997-2020 and 2009-2020 as the period 2009-2020 was the Catchment development period so the whole focus was on development rather than the water quality being discharged to the Creek. In other means, nothing was done to improve the surface runoff water quality.

Mean and Median values are also calculated for all the parameters and periods. After having look at average and median values provided in table 4-1 for the upper Brownhill Creek, some interesting trends can be observed. The average monthly flow of 187.88 (ML/mo) is higher in the 2009-2020 duration as compared to the average flow (151.56 ML/mo) for the duration of 1997-2020 duration. Also, the mean monthly discharge values are higher than the median discharge values for both duration 1997-2008 and 2009-2020. In other words, monthly discharge data is skewed positive, and the data is not normally distributed due to some too much large values as the difference between maximum monthly flow and the average monthly flow is too large. The average monthly TSS load in 1997-2020 is 9285.26kg/mo which is greater than the mean monthly TSS load of 6923.46kg/mo 2009-2020. Also, the average monthly TSS load is higher than the median monthly load so, the data is skewed positive.

TKN, total N and total P are showing different trends as compared to the TSS. The mean monthly TKN load in 2009-2020 is 139.25 kg/mo which is greater than the mean monthly TKN load (111.28 kg/mo) for the duration of 1997-2008. Also, TKN load data is positively skewed as the mean monthly TKN load is greater than the median monthly load. The mean monthly load for the total phosphorous (14.24 kg/mo) for 2009-2020 is greater than the mean monthly phosphorous load (13.54 kg/mo) for the duration of 1997-2008. Moreover, the mean monthly phosphorous load is in 2009-2020 is greater than the median monthly phosphorous load so the total phosphorous load data is also positive skewed. Finally, the mean monthly total nitrogen load for the duration of 2009-2020 is 29.31 kg/mo whereas for 1997-2008 mean the monthly load is 22.47 kg/mo which means more nitrogen load discharge was passed in the Creek during the years 2009-2020. Additionally, the mean monthly total nitrogen values are greater than the median monthly values, so the total nitrogen load data is also skewed positive.

Mean monthly flows are higher in 2009-2020 as compared to mean monthly flows in 1997-2008. In contrast to flow, the mean monthly TSS load is higher in 1997-2008 as compared to the mean monthly TSS load in 2009-2020. This thing can be explained through the low flow with a high velocity which can cause resuspension and erosion in Rural Catchments and within the Creek (Moore and Anderholm 2002). If the Catchment is Rural which is true in the upper Brownhill Creek case, sometimes Rural Catchment can yield more sediments than Urban Catchment. As soil erosion, agricultural land, channel banks and unpaved tracks and gullies generate sediments are potential sources of sediments generation in the Rural Catchment (Stenfert Kroese, Batista et al. 2020). Mean monthly load for the TKN, N and P are higher in the 2009-2020 time period than in 1997-2020. This increase can be associated with the developmental work within the Catchment along with the contribution of TKN, P and N from the surface runoff from the lawns of the private properties along the Creek alignment (Toor, Occhipinti et al. 2017).

4.2.2 Lower Brownhill Creek data

Aggregate functions of the discharge, sediments and nutrients for the Lower Brownhill Creek Catchment are summarized in table 4-2. The selected aggregate functions are minimum value, maximum value, average value and median value. Additionally, the sum is also calculated for all the values to know the total amount of discharge and load transported through the Urban area of the Catchment for the selected study periods. As the data is monthly so that means all the aggregate functions represent the maximum and minimum data values that occurred during the whole study period from 1997-2020, 1997-2008 and 2009-2020. The average values represent the sum of all the values divided by the number of months which are 288 (months) for the period 1997-2020, and 144 (months) from 1997 through 2008 and 2009-2020.

The minimum values for all the periods are zero (table 4-2) as Brownhill Creek is an intermittent Creek so when no discharge means nothing will be transported through the Creek. The maximum monthly discharge (Q) for the duration 1997-2020 and 2009-2020 is 5201 ML/mo but different for 1997-2008 which is 2817ML/mo. Also, the maximum total suspended solids (TSS) load (323,8666 kg/mo) remained the same for 1997-2020 and 2009-2020 but different for the duration 1997-2008 that is 272700 kg/mo. Moreover, TKN does not show a different trend as compared to Q and TSS. The maximum monthly TKN load is 15115 kg/mo which is the same for 1997-2020 and 2009-2020 and the TKN value for 1997-2008 is quite less which is 4074 kg/mo. Similarly, the maximum monthly load for the total Phosphorous and total Nitrogen are 2884 kg/mo and 2110 kg/mo respectively which remained the same from 1997 to 2020 and 2009-2020. Here also, the duration 1997-2008 got lesser loads 580.5 kg/mo and 975 kg/mo for the N and P respectively. The reason why the values of Q, TSS, TKN, P and N are higher and remained the same in 1997-2020 and 1997-2008 can be associated with the Urban Catchment construction activities, change in land use within the Catchment, human intervention to the natural drainage system and lack of water sensitive Urban design structure. But as per the stormwater management report of Brownhill and Keswick Creek, since the major part passes through the private property so, the activity within those properties greatly affects the Creek water quality.

Mean and Median values are also calculated for all the parameters and periods. After having look at average and median values provided in table 4-2 for the lower Brownhill Creek, some interesting trends can be observed. The mean monthly flow of 544.34 ML/mo is higher in the 2009-2020 duration as compared to the average flow of 505.56 ML/mo for the duration of 1997-2020. So, the mean monthly discharge values are higher than the median discharge values for both duration 1997-2008 and 2009-2020. In other words, monthly discharge data is skewed positive, and the data is not normally distributed due to some too much large values as the difference between maximum monthly flow and the average monthly flow is too large. The average monthly TSS load in 2009-2020 is 40732.25 kg/mo which is greater than the monthly TSS load of kg/mo 1997-2008. Also, the average monthly TSS load is higher than the median monthly load so, the data is skewed positive.

TKN, total N and total P are showing different trends as compared to the TSS. The mean monthly TKN load in 2009-2020 is 533.79 kg/mo which is greater than the mean monthly TKN load of 443.88 kg/mo from 1997 through 2008. Also, TKN load data is positively skewed as the mean monthly TKN load is greater than the median monthly load. The mean monthly load for the total phosphorous load of 110.48 kg/mo for 2009-2020 is greater than the mean monthly phosphorous load of 74.22 kg/mo for the duration of 1997-2008. Moreover, the mean monthly phosphorous load is in 2009-2020 is greater than the median monthly phosphorous load so the total phosphorous load data is also positive skewed. Finally, the mean monthly total nitrogen load for the duration of 2009-2020 is 137.79 kg/mo whereas, for 1997-2008, the mean monthly load is 116.05 kg/mo which means more nitrogen load discharge was passed in the Creek during the years 2009-2020. Additionally, the mean monthly total nitrogen values are greater than the median monthly values, so the total nitrogen load data is also skewed positive.

Mean monthly flows are higher in 2009-2020 as compared to mean monthly flows in 1997-2008 because of the urbanisation in form of huge development in the Urban Catchment. This can be observed in the various stormwater management report of the lower Brownhill Creek Catchment (SMP 2016) and Adelaide coastal water studies. Unlike the Rural part of the Catchment, the mean monthly TSS load is higher in 2009-2020 as compared to the mean monthly TSS load in 1997-2008. Mean monthly load for the TKN, N and P are higher in the 2009-2020 time period than in 1997-2020. This can be linked to Catchment development and alteration from Rural to Urban with human intervention in natural drainage in lower Brownhill Creek

Discharge, sediments, TKN, total N and total P results are summarised in table 4-5. The first four rows (excluding title row) of the table represent discharge in mega litters (ML) whereas the load of the sediments and nutrients are given in tonnes. As the analysis duration is 24 years so each data point is denoting 24 years of time length. The third row of the table dictates the discharge, sediments, and nutrient load for the Scotch College which is located at the downstream end of the upper Brownhill Creek and represent Rural Catchment whereas 2nd row has the values from the Adelaide Airport gauging station which is the part of the downstream end of lower Brownhill Creek and responsible for the lower and upper part of the Brownhill Creek.

Row 4th of the table have the values for the whole lower part of the Brownhill Creek (urban) for the last 24 years which is obtained after subtracting the 3rd row from the 4th row. After comparison between 3rd row and 4th row which will give us the comparison between the Rural and Urban part of the Brownhill Creek Catchment. Though the area of the Urban Catchment is smaller than the area of the Rural Catchment still it has generated more discharge, suspended solids and nutrients. After having a quick look, the discharge in the Urban area is around 50% more than that of Rural Catchment this is due to Catchment infrastructural development which increased imperviousness in the Urban Catchment as compared to the Rural Catchment. Hence, the area with greater imperviousness generated larger runoff.

Total suspended solids have shown a very interesting trend in the last 24 years. After careful table review, the difference between the number of suspended solids generated through the Urban Catchment and the Rural Catchment is not large. Generally, greater suspended solids generation is associated with Urban land use of the Catchment but here Rural area has sufficiently produced an equal number of suspended solids due to lack of vegetation, construction activities in the upper part and agricultural activities (Stenfert Kroese, Batista et al. 2020). But in the case of nutrients, there is a clear difference in values of Urban Catchment and Rural Catchment due to differences in land use. For example, the Urban area has generated 104.23 tonnes/24 years, but the Rural Catchment has only generated 35.74 tonnes/24 years depicting a huge difference. The same goes with total P as the Urban area has produced 22.31 tonnes/24 years, but the Rural area has only produced 3.96 tonnes/24 years and the difference is large. Also, the Urban area has generated more Nitrogen loads (28.90 tonnes/24 years) as compared to the Rural area (7.39 tonnes/24 years) for the whole study design.

Discharge, sediments, and load generation have been also considered in terms of km^2 of area for the Rural and Urban Catchment. Here also, the Urban Catchment is leading. Urban area generated 160.12 tonnes per 1 km^2 for the Urban Catchment whereas Rural area generated around 128.12 tonnes per 1 km^2 for the Rural area of the Catchment. This means that the Urban area generated 25 % more load of suspended solids as compared to the Rural area. Also, the Urban area generated 7.45 tonnes/km^2 of TKN load, unlike Rural Catchment which is 1.99 tonnes/km^2. This means the Urban area generated 274% more TKN load as compared to the

Rural area. Additionally, Urban areas generated 1.59 tonnes/km^2 of total P load as compared to 0.22 tonnes/km^2 of P load in the Rural area. And the per cent increase in this time is 622% and that's huge for the last 24 years. Lastly, Urban Catchment produced 2.06 tonnes/km^2 of total N as compared to Rural area which produced 0.41 tonnes/km^2 of total N for the last 24 years. So, the overall, lower part of the Brownhill Creek generated more discharge and contaminants loads than the upper part of the Brownhill Creek Catchment.

Table 4-1:Aggregate function of discharge and contaminants for different periods at Scotch College gauging station

	1997-2020					1997-2008					2009-2020				
	Q (ML/mo)	TSS (kg/mo)	TKN (kg/mo)	P (kg/mo)	N (kg/mo)	Q (ML/mo)	TSS (kg/mo)	TKN (kg/mo)	P (kg/mo)	N (kg/mo)	Q (ML/mo)	TSS (kg/mo)	TKN (kg/mo)	P (kg/mo)	N (kg/mo)
Total	48881.2	2306201	35744.7	3960.7	7389.1	21825.99	1309223	15691.4	1909.2	3168.3	27055.25	996978.9	20053.3	2051.5	4220.8
Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Max	2087	162857	1496	266.8	714.7	1255	138788	1163	157.6	404.5	2087	162857	1496	266.8	714.7
Mean	169.72	8091.93	125.42	13.89	25.92	151.56	9285.26	111.28	13.54	22.47	187.88	6923.46	139.25	14.24	29.31
Median	52.47	752.1	36	2.9	1	57.14	1052	34.2	3.8	1.4	42.61	595.5	37.9	2.65	0.85

Table 4-2: Aggregate function of discharge and contaminants for different periods at Adelaide Airport gauging station

	1997-2020					1997-2008					2009-2020				
	Q (ML/mo)	TSS (kg/mo)	TKN (kg/mo)	P (kg/mo)	N (kg/mo)	Q (ML/mo)	TSS (kg/mo)	TKN (kg/mo)	P (kg/mo)	N (kg/mo)	Q (ML/mo)	TSS (kg/mo)	TKN (kg/mo)	P (kg/mo)	N (kg/mo)
Total	151187	9313914	139899.4	26450.1	36322.9	72801.07	3448469	63032.3	10539.7	16480.4	78386.31	5865445	76867.1	15910.4	19842.5
Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Max	5201	3238666	15115	2884	2110	2817	272700	4074	580.5	975	5201	3238666	15115	2884	2110
Mean	524.95	32566.13	489.15	92.48	127	505.56	24285	443.88	74.22	116.05	544.34	40732.25	533.79	110.48	137.79
Median	308.85	5029	292.65	55	59.45	283.4	8501	314.55	55.1	59.45	336.7	3478.5	245.95	54.9	58.95

Table 4-3: R^2 Values at Scotch College for the different periods

	R^2 Values at Scotch (1997-2020)					R^2 Values at Scotch (1997-2008)					R^2 Values at Scotch (2009-2020)				
	Q (ML/mo)	TSS (kg/mo)	TKN (kg/mo)	P (kg/mo)	N (kg/mo)	Q (ML/mo)	TSS (kg/mo)	TKN (kg/mo)	P (kg/mo)	N (kg/mo)	Q (ML/mo)	TSS (kg/mo)	TKN (kg/mo)	P (kg/mo)	N (kg/mo)
Q (ML/mo)	1	0.38	**0.7**	0.57	**0.71**	1	0.48	**0.84**	**0.76**	**0.77**	1	0.36	0.64	0.49	0.69
TSS (kg/mo)	0.38	1	0.68	**0.83**	0.411	0.48	1	**0.71**	**0.8**	0.67	0.36	1	0.72	**0.94**	0.33
TKN (kg/mo)	**0.7**	0.68	1	**0.86**	0.63	**0.84**	**0.71**	1	**0.95**	**0.89**	0.64	0.72	1	0.82	0.53
P (kg/mo)	0.57	**0.83**	**0.86**	1	0.52	**0.76**	**0.8**	**0.95**	1	**0.86**	0.49	**0.94**	0.82	1	0.4
N (kg/mo)	**0.71**	0.411	0.63	0.52	1	**0.77**	0.67	**0.89**	**0.86**	1	0.69	0.33	0.53	0.4	1

Table 4-4: R2 Values at Adelaide Airport gauging station for different periods

	R^2 Values at Airport (1997-2020)					R^2 Values at Airport (1997-2008)					R^2 Values at Airport (2009-2020)				
	Q (ML/mo)	TSS (kg/mo)	TKN (kg/mo)	P (kg/mo)	N (kg/mo)	Q (ML/mo)	TSS (kg/mo)	TKN (kg/mo)	P (kg/mo)	N (kg/mo)	Q (ML/mo)	TSS (kg/mo)	TKN (kg/mo)	P (kg/mo)	N (kg/mo)
Q (ML/mo)	1		0.57	0.5	0.75	1		0.72	0.7	0.66	1		0.59	0.54	0.8
TSS (kg/mo)		1	0.87	0.88	0.47		1	0.41	0.48	0.4		1	0.93	0.91	0.57
TKN (kg/mo)	0.57	0.87	1	0.97	0.62	0.72	0.41	1	0.96	0.4	0.59	0.93	1	0.98	0.71
P (kg/mo)	0.5	0.88	0.97	1	0.55	0.7	0.48	0.96	1	0.37	0.54	0.91	0.98	1	0.65
N (kg/mo)	0.75	0.47	0.62	0.55	1	0.66	0.4	0.4	0.37	1	0.8	0.57	0.71	0.65	1

Table 4-5: Discharge and contaminants' load summary for lower and upper Brownhill Creek

Site	Duration (year)	Q (ML)	TSS (tonnes)	TKN (tonnes)	P (tonnes)	N (tonnes)
Airport	24	147,598.37	4,547.82	139.98	26.27	36.29
Scotch		50,037.84	2,306.20	35.74	3.96	7.39
Difference (Urban Area)		97,560.53	2,241.62	104.23	22.31	28.90
Total		245,158.90	6,789.44	244.21	48.58	65.19
Area		**Q (ML/km2)**	**tonnes/km2**	**tonnes/km2**	**tonnes/km2**	**tonnes/km2**
Urban Area Load (km2)		6,968.61	160.12	7.45	1.59	2.06
Rural Area Load (km2)		2,779.88	128.12	1.99	0.22	0.41

4.2.3 Discharge, sediments and nutrients relationship

The section provides insight into the relationship which exist among the discharge, sediments and nutrients for different periods for the Rural and Urban Catchments. The coefficient of determination is used to describe the relationship among all the parameters under consideration.

4.2.3.1 Upper Brownhill Creek Catchment

To analyse the relationship among discharge, sediments, and nutrients for the upper Brownhill Catchment the data from the Scotch College was used. The relationships were observed first between the monthly data points and then daily values for the discharge, sediments, and nutrients to see the consistency of the results. Everything (Q, TSS, TKN, and P and N) was plotted against everything (Q, TSS, TKN, and P and N) on a scatter plot and with the help of the coefficient of determination (R^2), the relationships were determined and are summarised into table 4-3 first for the overall period (1997-2020) and then for 1997-2008 and 2009-2020. Two different colours have been used to express the strength of the relationship. Green colours represent the values of R^2 from 0.85 to 1 which means that the associated variables have a good positive correlation whereas the values (light orange colour) from 0.7 to 0.84 suggest that the associated variables have satisfactory relation and below 0.7 means variables have weak correlation while depending on the number of data points analysed (Dawson, Abrahart et al. 2007). Results indicate that a strong relationship exists among TKN, P and N for 1997-2008. Also, a very strong correlation exists between TSS and P (figure 4) during the year 2009-2020 as well. R^2 for the daily and monthly discharge and loadings are also given in table 4-6 interestingly similar trends can also be observed between TKN, P and N from 2016 to 2020. So, this means there is a strong relationship exist between these variables in the upper part of Brownhill Creek. Moreover, satisfactory relation exists between monthly discharge and the monthly nutrients loads in upper Brownhill Creek. The scatter plots for everything versus everything values are presented in appendix A and for the daily values in appendix C.

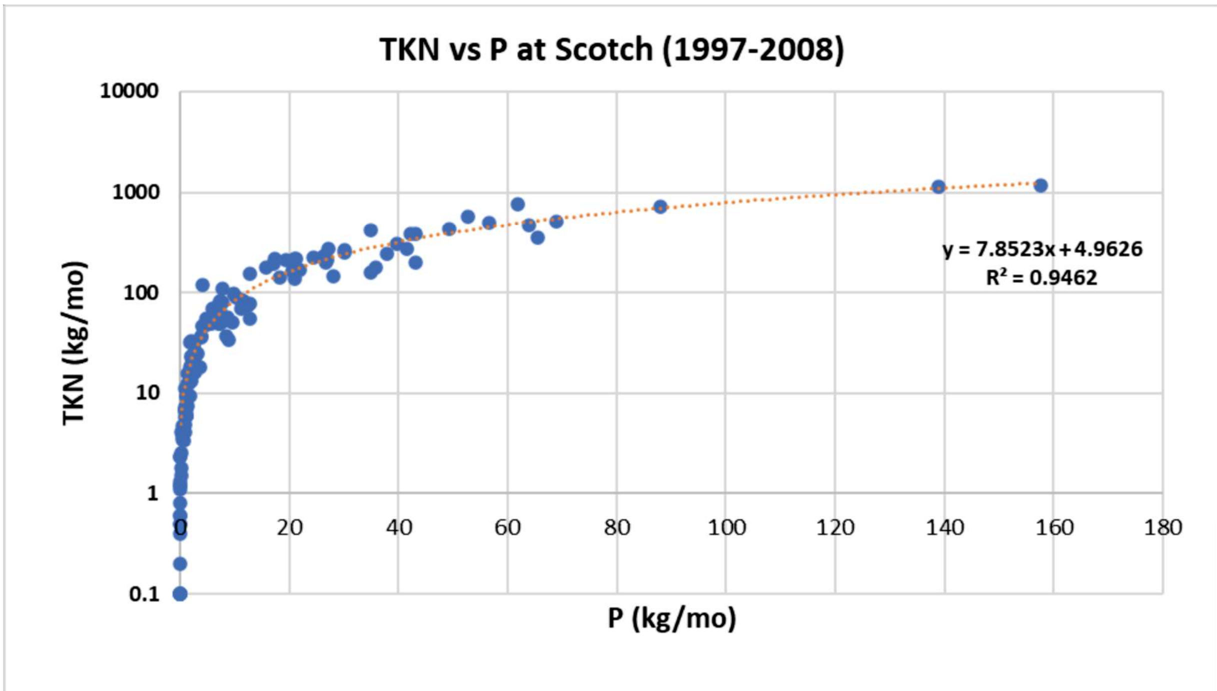

Figure 6: TKN versus P in the Rural Catchment

4.2.3.2 Lower Brownhill Creek

For the lower part of the Brownhill Creek analysis, discharge, sediments, and nutrients data from the Adelaide Airport gauging station was used. The relationships were observed first between the monthly data points and then daily values for the discharge, sediments, and nutrients to observe trends and to see the consistency of the relationship. Everything (Q, TSS, TKN, and P and N) was plotted against everything (Q, TSS, TKN, and P and N), using a scatter plot and with the help of Coefficient of determination (R^2) the relationships were determined and are summarised into table 4-4, first for an overall period (1997-2020) and then for 1997-2008 and 2009-2020. Two different colours have been used to express the strength of the relationship. Green colours represent the values of R^2 from 0.85 to 1 which means that the associated variables have a good positive correlation whereas the values (light orange colour) from 0.7 to 0.84 suggest that the associated variables have satisfactory relation and below 0.7 means variables have weak correlation while depending on the number of data points analysed (Dawson, Abrahart et al. 2007). Results indicate that a strong relationship exists among TSS TKN, and P (Figure 5) for the 2009-2020 and a satisfactory relationship exists between discharge for the 1997-2008 duration. But this thing is partially consistent in daily values as only TKN and P has good relation. Moreover, a very strong correlation exists between TKN and P during the year 1997-2008 duration and a satisfactory correlation among Q, TKN and P for the same duration. For the whole duration good relationship is present among TSS, TKN and P. Hence, for the Urban part of the Brownhill Creek TSS, TKN and P are well correlated. The scatter plots for everything versus everything are given in appendix B (Monthly values) and for the daily values scatter plots are in appendix D.

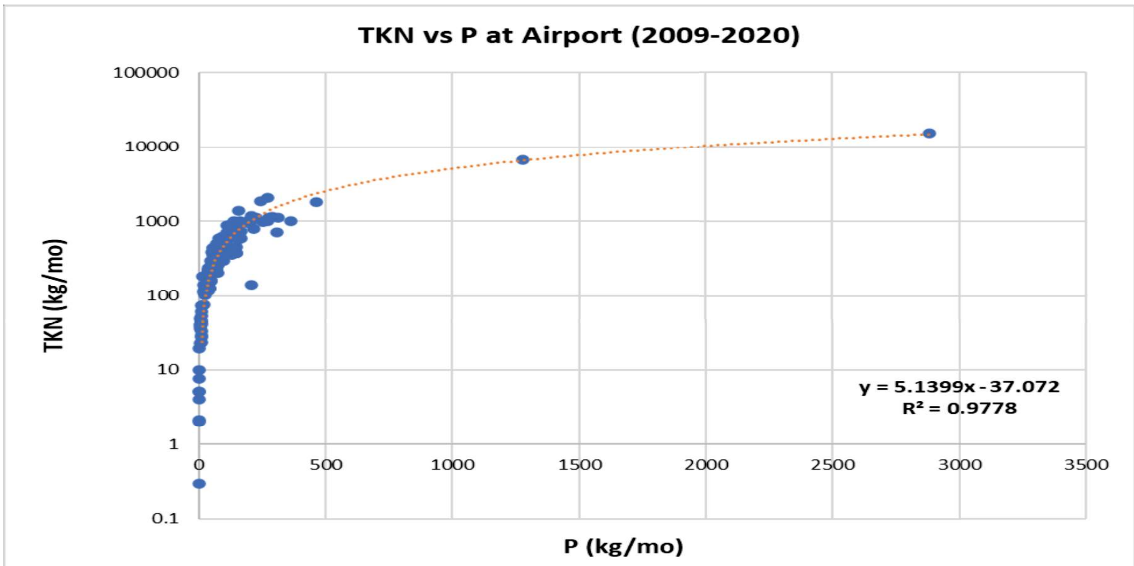

Figure 7: TKN versus P in the Urban Catchment

Table 4-6: R2 Values for monthly and daily data at Scotch College gauging station for 2016-2020

	Monthly R^2 Values at Scotch 2016-2020					Daily R^2 Values at Scotch 2016-2020				
	Q (ML/mo)	TSS (kg/mo)	TKN (kg/mo)	P (kg/mo)	N (kg/mo)	Q (ML/day)	TSS (kg/day)	TKN (kg/day)	P (kg/day)	N (kg/day)
Q (ML/mo)	1	0.39	0.45	0.47	0.59	1	0.45	0.57	0.5	0.53
TSS (kg/mo)	0.39	1	0.6	0.92	0.43	0.45	1	0.76	0.92	0.5
TKN (kg/mo)	0.45	0.6	1	0.67	0.38	0.57	0.76	1	0.82	0.5
P (kg/mo)	0.47	0.92	0.67	1	0.53	0.5	0.92	0.82	1	0.57
N (kg/mo)	0.59	0.43	0.38	0.53	1	0.53	0.5	0.5	0.57	1

Table 4-7:R2 Values for monthly and daily data at Adelaide Airport gauging station for 2016-2020

	Monthly R^2 Values at Airport 2016-2020					Daily R^2 Values at Airport 2016-2020				
	Q (ML/mo)	TSS (kg/mo)	TKN (kg/mo)	P (kg/mo)	N (kg/mo)	Q (ML/day)	TSS (kg/day)	TKN (kg/day)	P (kg/day)	N (kg/day)
Q (ML/mo)	1	0.56	0.7	0.7	0.8	1	0.46	0.79	0.8	0.64
TSS (kg/mo)	0.56	1	0.9	0.88	0.65	0.46	1	0.51	0.57	0.64
TKN (kg/mo)	0.7	0.9	1	0.98	0.71	0.79	0.51	1	0.94	0.56
P (kg/mo)	0.7	0.88	0.98	1	0.74	0.8	0.57	0.94	1	0.64
N (kg/mo)	0.8	0.65	0.71	0.74	1	0.64	0.64	0.56	0.64	1

5 Conclusion

The study investigates the hydrology and analyses the water quality data (discharge, sediments, and nutrients load) across Rural and Urban areas of the Brownhill Creek Catchment for the duration i.e., 1997-2008 and 2009-2020. SWMM hydrological model was developed for the Brownhill Creek Catchment from 1997-2020. The results of the model when compared with the Scotch College and Adelaide Airport gauging stations' data were found diverging and were not matching. This is due to the lack of the most recent and historical land-use data and infiltration data, topographic data etc.

The water discharge, sediments, and nutrients data of Scotch College (Upper Brownhill Creek) is not normally distributed but skewed positive (right-skewed) for both periods. This also means that the data has too many large values and too much smaller values and the large difference between maximum values and the minimum values for the Scotch College verify this. Also, at Adelaide Airport Gauging Station, the whole data is skewed positive just like Scotch College which means that too much large and too much small values also exist in Adelaide Airport Gauging Station's data. Skewness indicates that the data in both the Catchment is not normally distributed and may contain the outliers within it. This also means that the discharge, sediments, and nutrient distribution is not uniform neither in the Rural Catchment and nor in the Urban Catchment. The non-uniform distribution of the sediments and nutrients load can also be related to Brownhill Creek's seasonal flow. As its flow is heavily associated with the rainfall upstream of the Creek. As the Creek flows mainly during the winter rainy season so, the deposition of sediments and nutrients during the summer gives the large load values during the first rain. Moreover, the Lower part of Brownhill Creek has generated more sediments and nutrient loads in the past 24 years as compared to the Upper Brownhill Creek Catchment. This is due to development work within the Catchment during the last 24 years. As. Residential development, human interventions, and alterations to the natural drainage system of the Catchment have increased the discharge, sediments, and nutrients load in this part of the Catchment. Unlike the

Urban part, the Rural part of the Catchment is fairly in a natural state, so this part of the Catchment has contributed less discharge, sediments and nutrients load during the study period.

Monthly values of sediments and nutrient loads are highly correlated in both parts of the Catchment. TSS, TKN, and P are highly correlated temporally and spatially. The variation in one type of nutrient affects the other nutrient exponentially and the scatter plots verify this. Provision of Water sensitive Urban design along the whole alignment of the Creek and the major drains (figure 2) which drains the water into the Creek will not only improve the water quality but will also cause the delay in the peak water discharge. Delay in peak water discharge will not only improve the efficiency of the hydraulic structure but will enhance the life of the structure as well. The water sensitive Urban design structures that can be implemented are rainwater gardens, buffer strips, vegetated swales, bio-retention systems, constructed wetland and swales.

The results of the study could have been better with more accurate topographic data, Catchment parameterisation, discharge, sediments and nutrients data. Single values for pervious and imperviousness were used in SWMM Model for the last 24 years which is not true because the land use has changed greatly especially in the Urban part of the Catchment so the results for the SWMM hydrological modelling are diverging. Also, the accurate land use data was not available and getting the data would have been out of the scope of the thesis.

Considering the future needs, studies suggest that accurate information on land use can improve the model results (Jetten, de Roo et al. 1999). For future studies, it is vital to collect the water quality data alongside the land use information so that the relation between land management and the changes in water quality can be related (Bartley, Wilkinson et al. 2011). High-frequency monitoring data will give more important insights into this process (Bende-Michl and Hairsine 2010) although more intensive monitoring will further uncover the heterogeneity and may need more monitoring (Beck, Kleissen et al. 1990).

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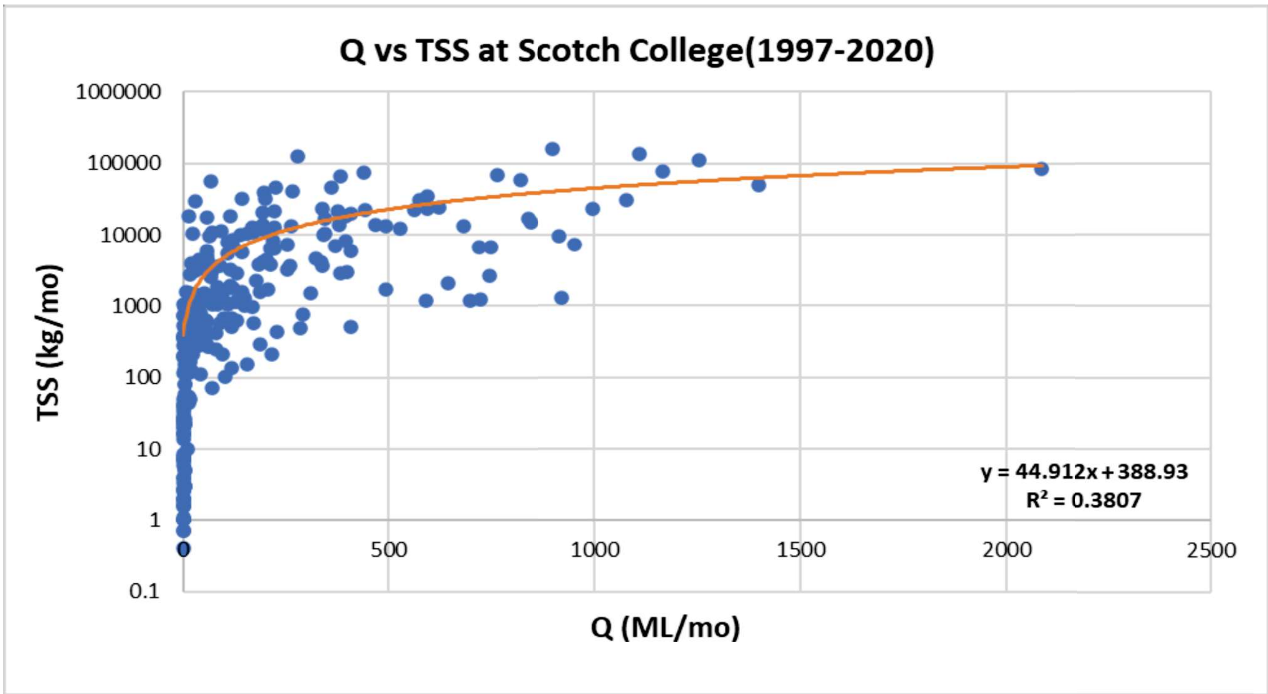
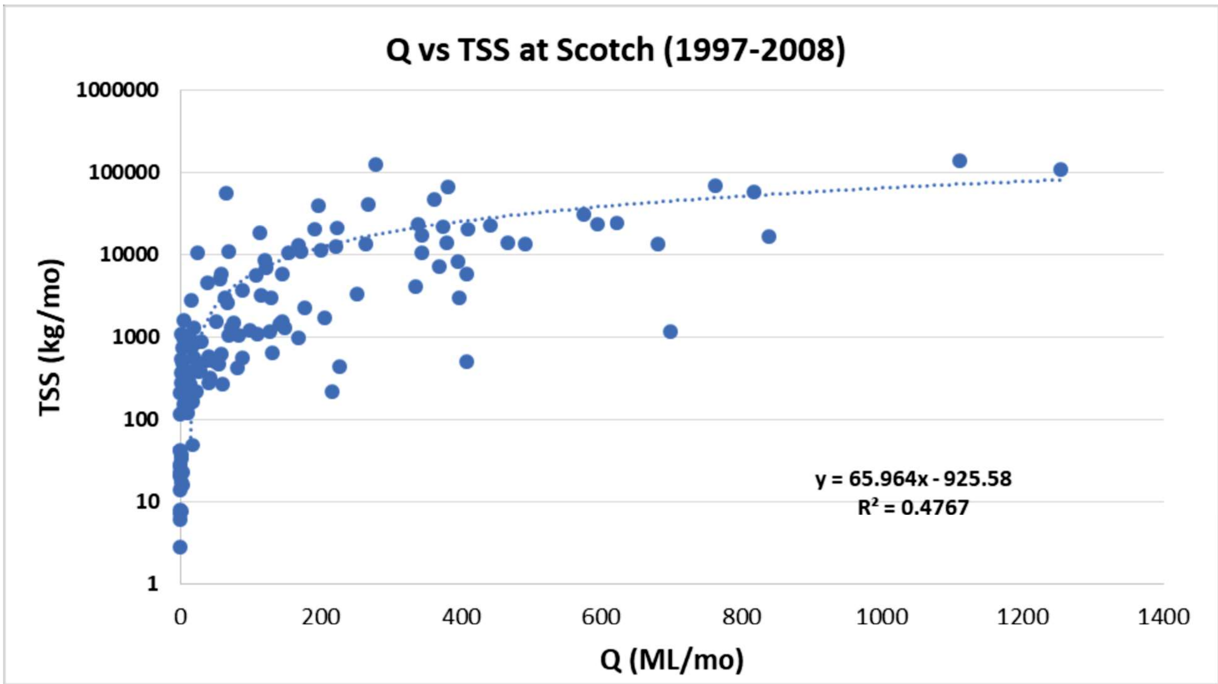
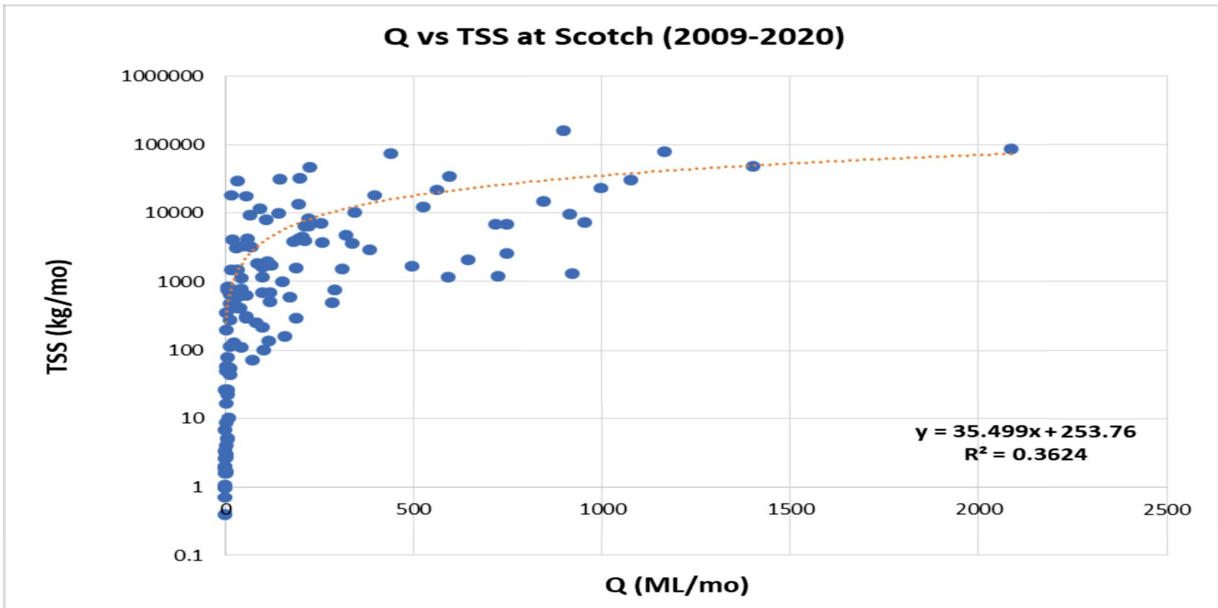
Appendix A

Monthly variation and relationship in data at Scotch College gauging station

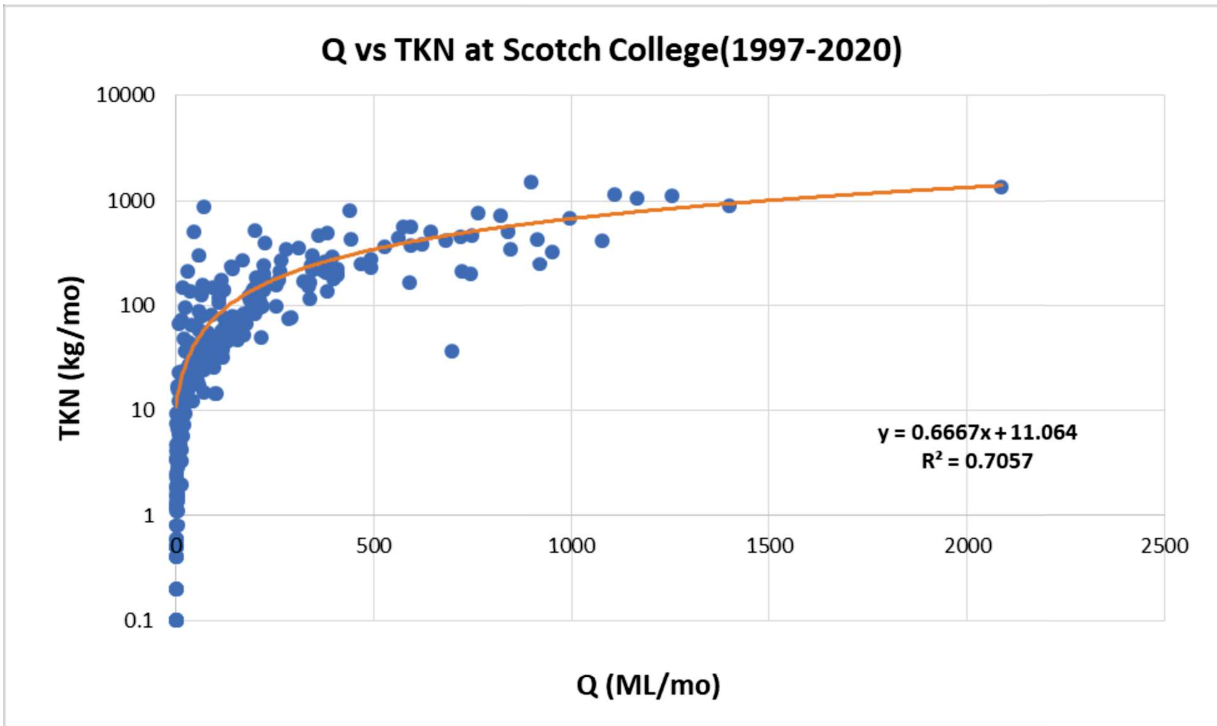
Discharge versus total Suspended Solids (TSS)

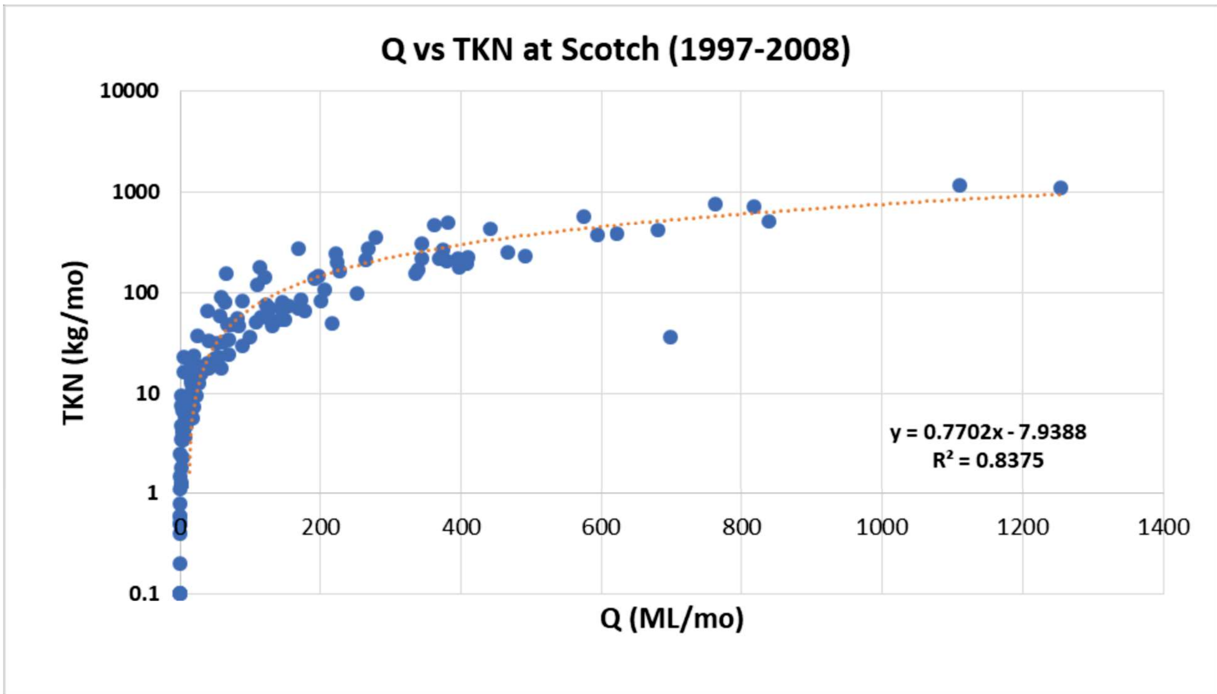


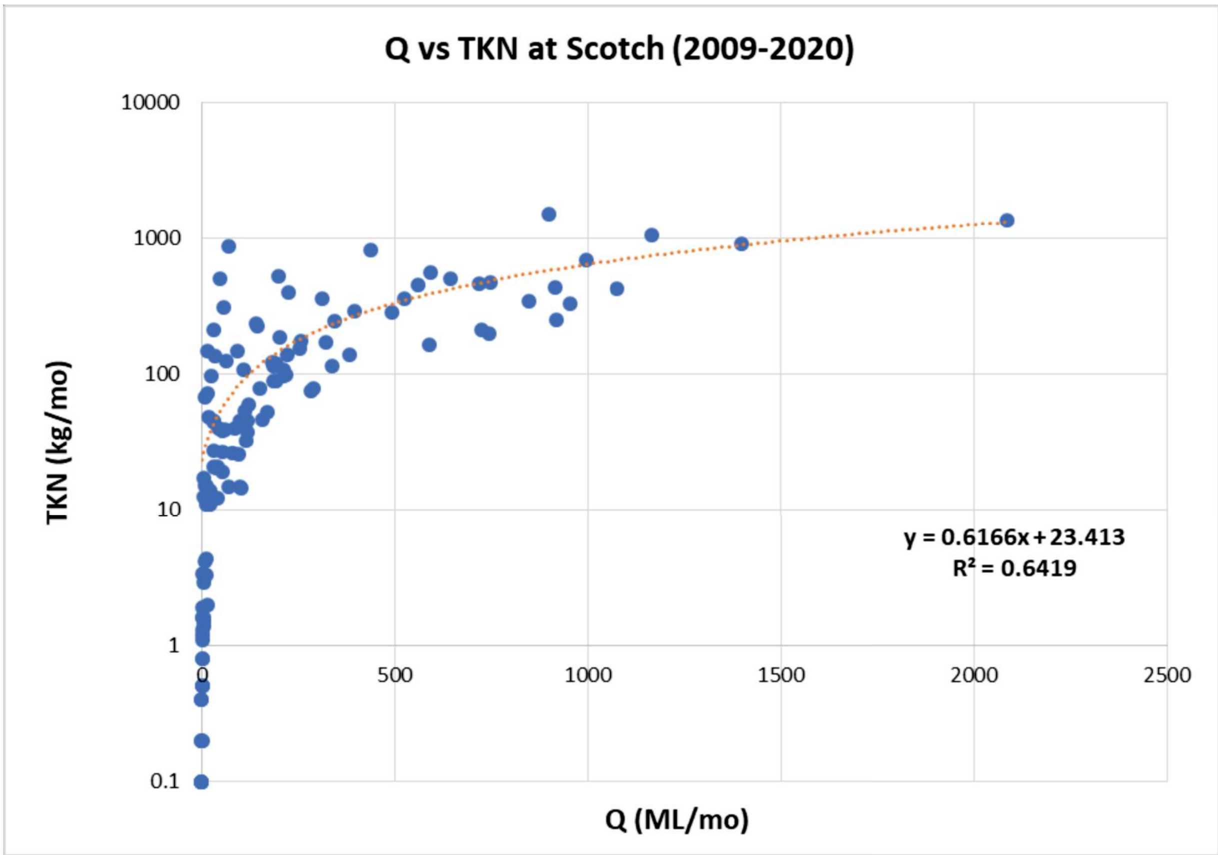




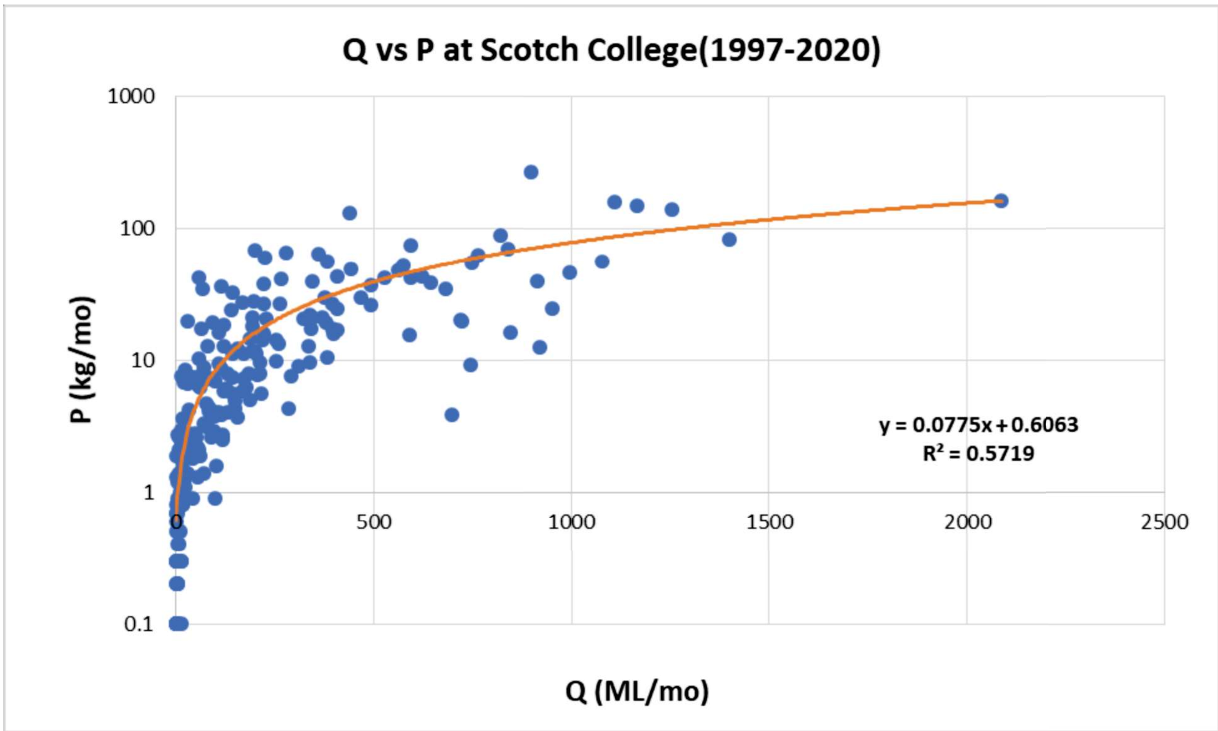
Discharge versus total Kjeldahl (TKN)

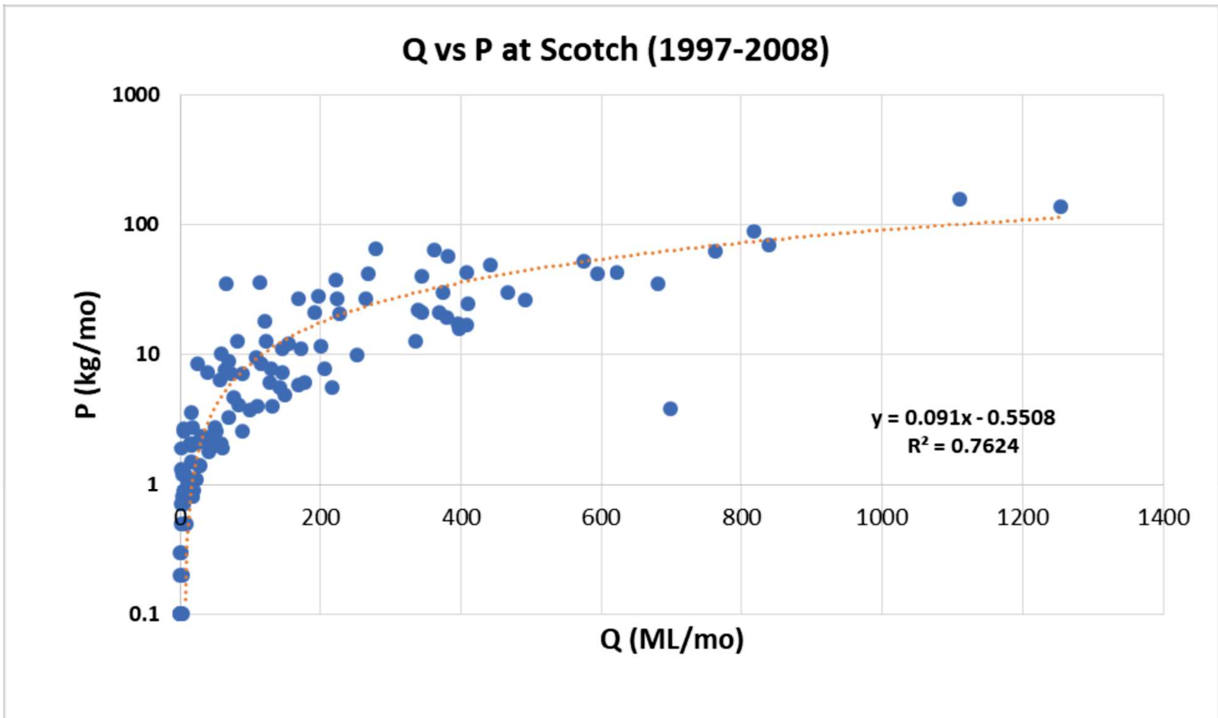

Q vs TKN at Scotch College(1997-2020)
10000
1000
100
10
1
0.1
TKN (kg/mo)
0
500
1000
1500
2000
2500
Q (ML/mo)
y = 0.6667x + 11.064
R² = 0.7057

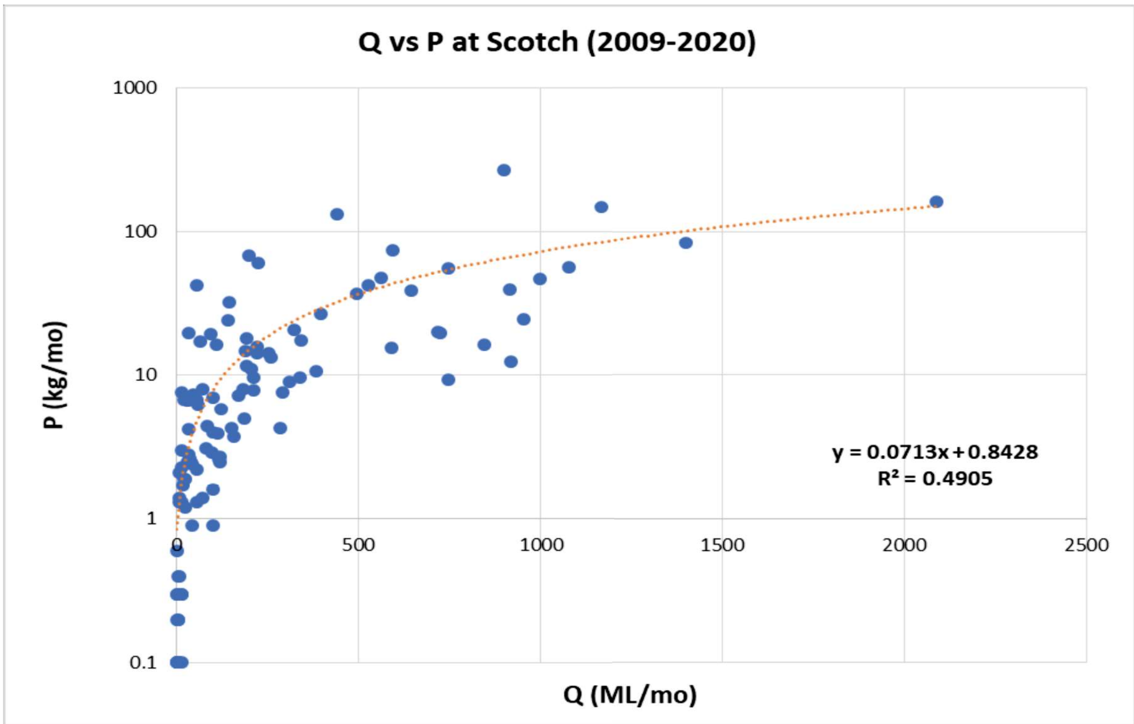

Q vs TKN at Scotch (1997-2008)
10000
1000
100
10
1
0.1
TKN (kg/mo)
0
200
400
600
800
1000
1200
1400
Q (ML/mo)
y = 0.7702x - 7.9388
R² = 0.8375



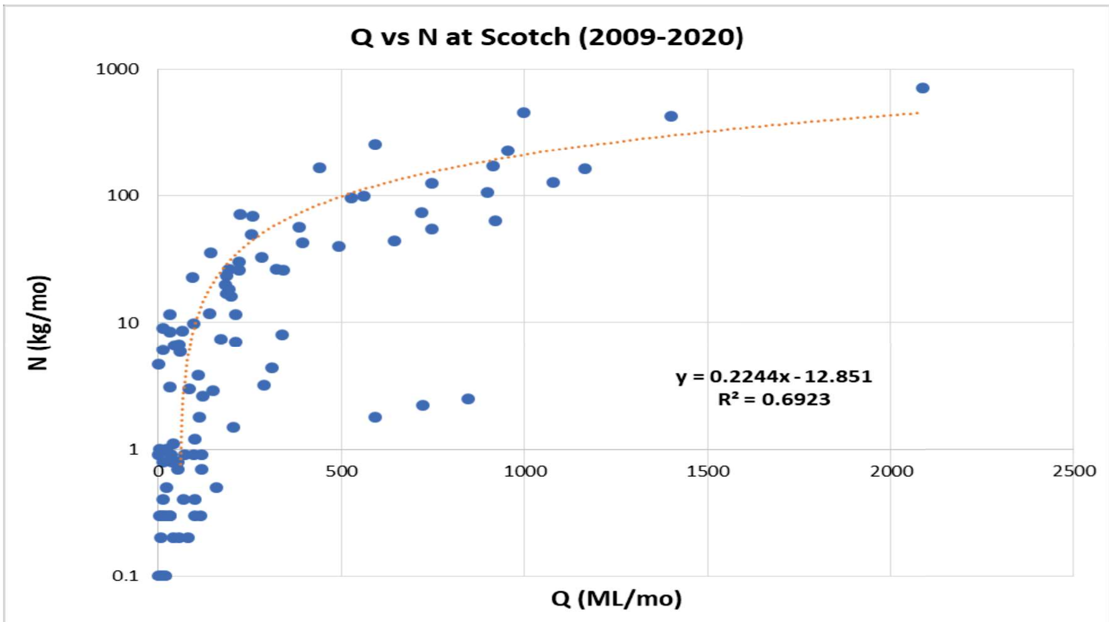
Discharge versus total Phosphorus (P)


Q vs P at Scotch College(1997-2020)
1000
100
10
1
0.1
P (kg/mo)
0
500
1000
1500
2000
2500
Q (ML/mo)
y = 0.0775x + 0.6063
R² = 0.5719

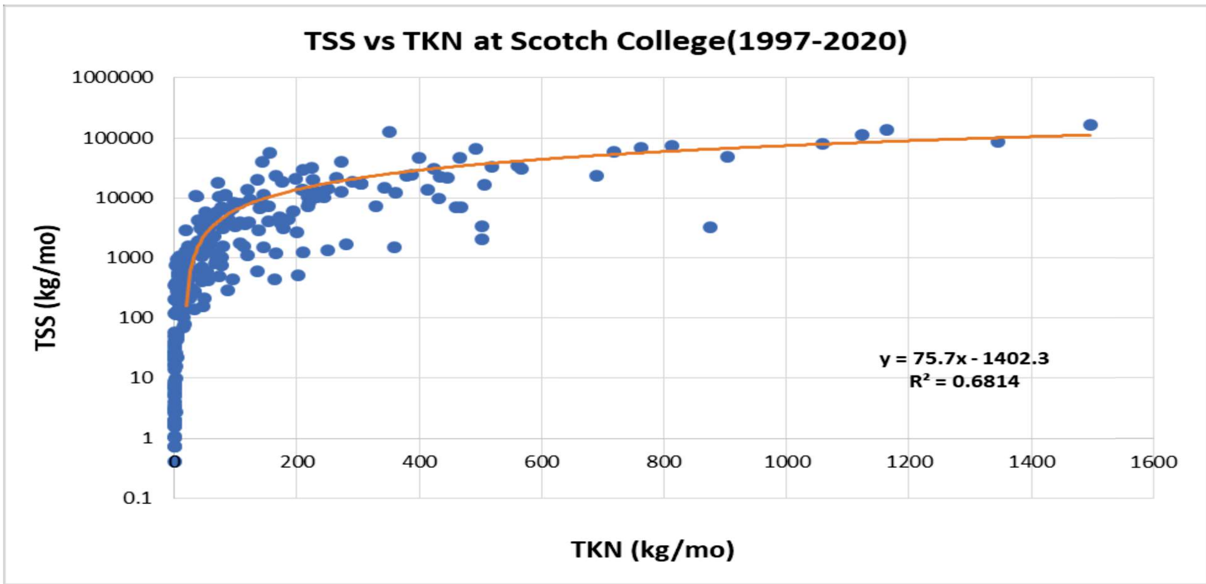

Q vs P at Scotch (1997-2008)
1000
100
10
1
0.1
P (kg/mo)
0
200
400
600
800
1000
1200
1400
Q (ML/mo)
y = 0.091x - 0.5508
R² = 0.7624

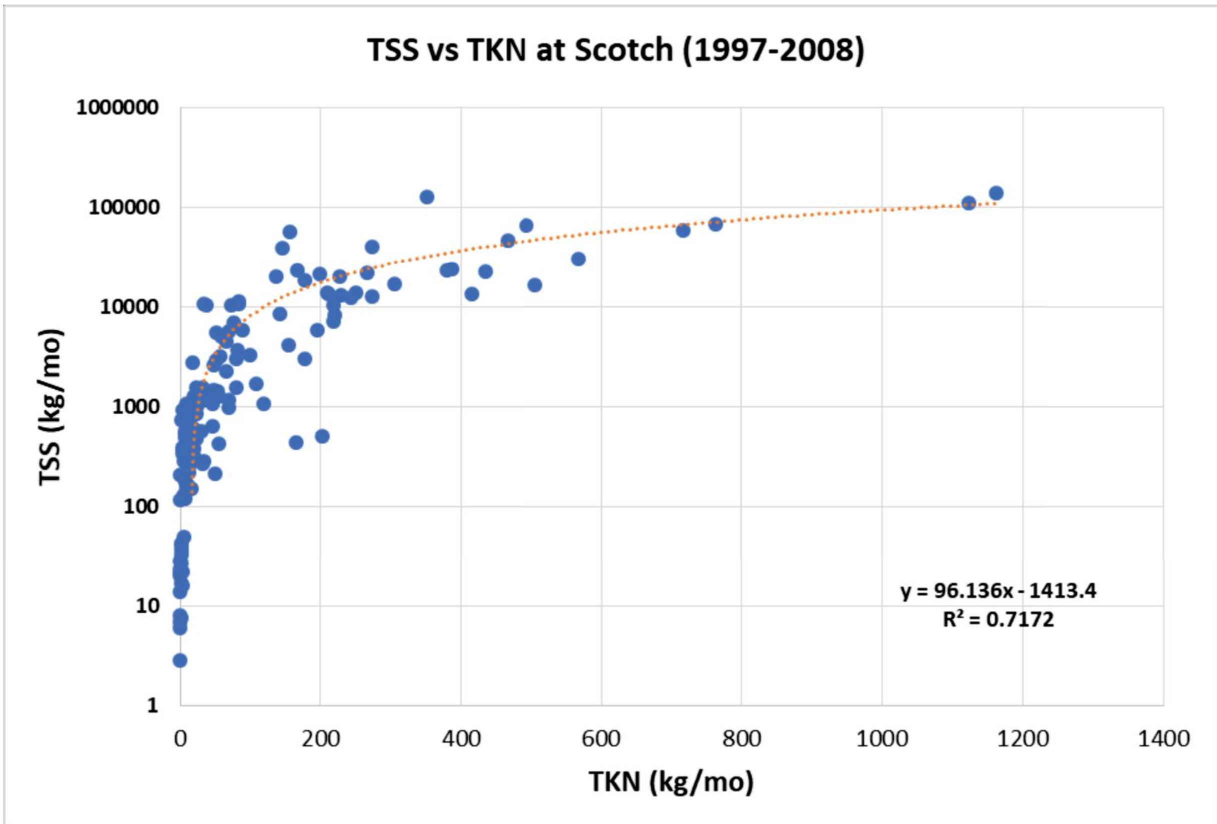


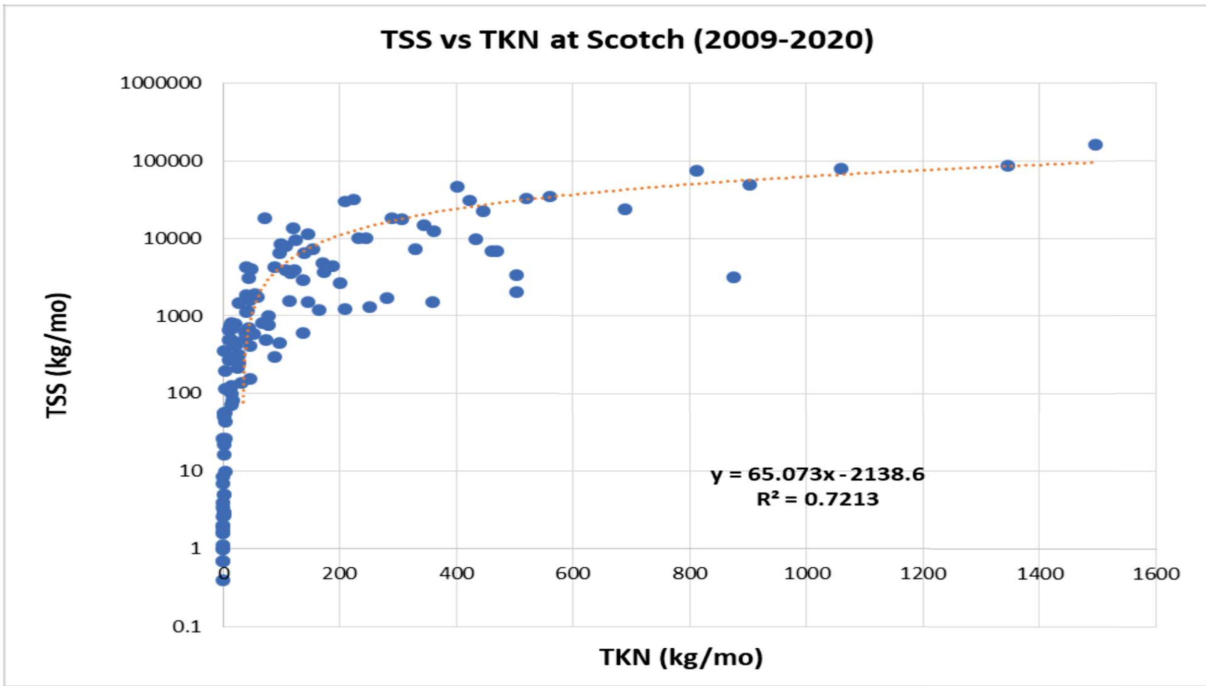
Discharge versus total Nitrogen (N)



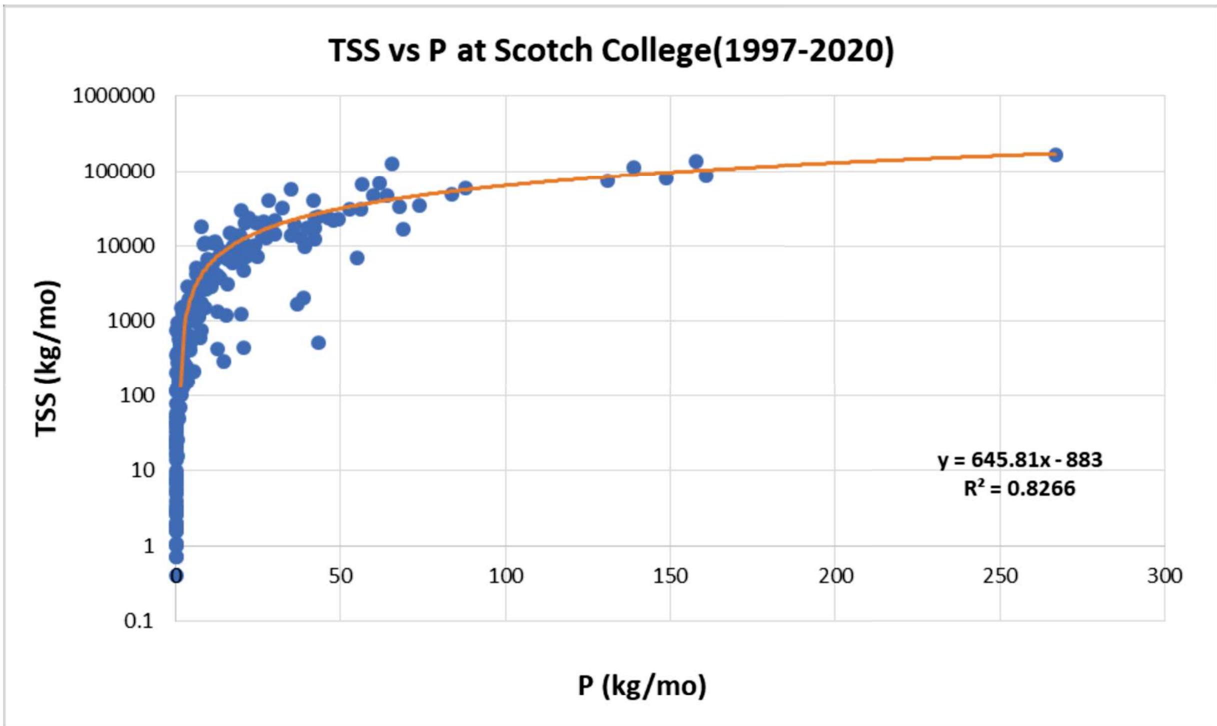
Total Suspended Solids (TSS) versus total Kjeldahl (TKN)

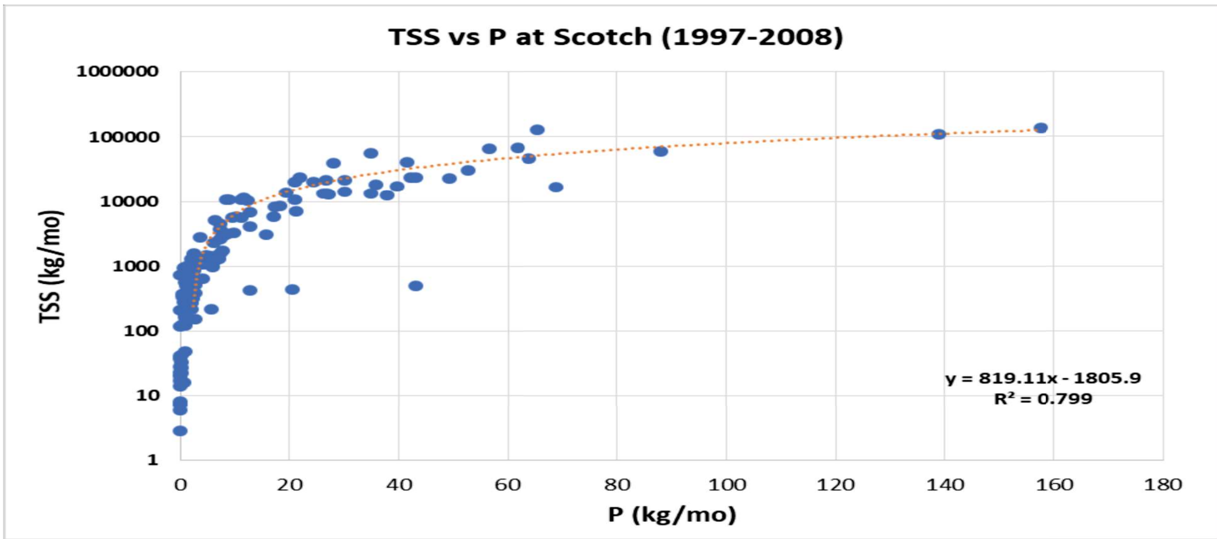




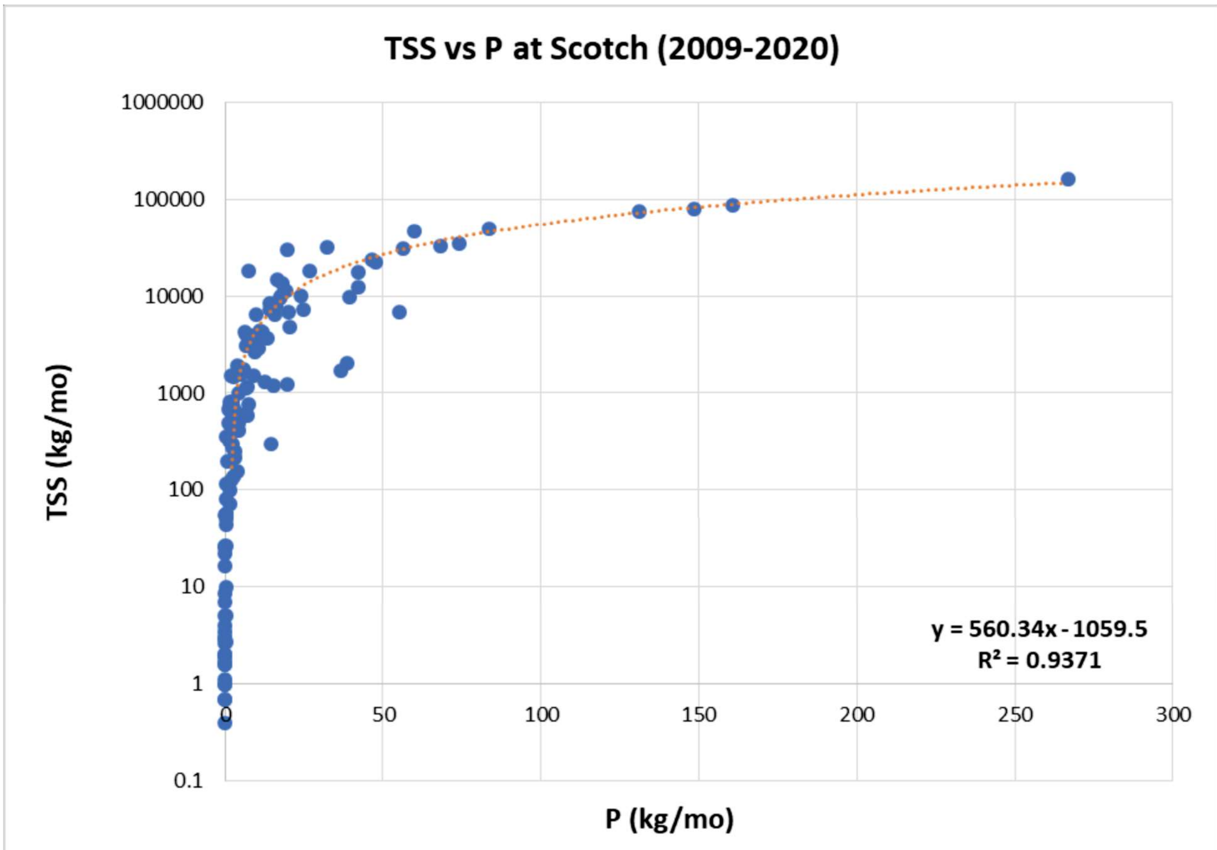


Total Suspended Solids (TSS) versus total Phosphorus (P)



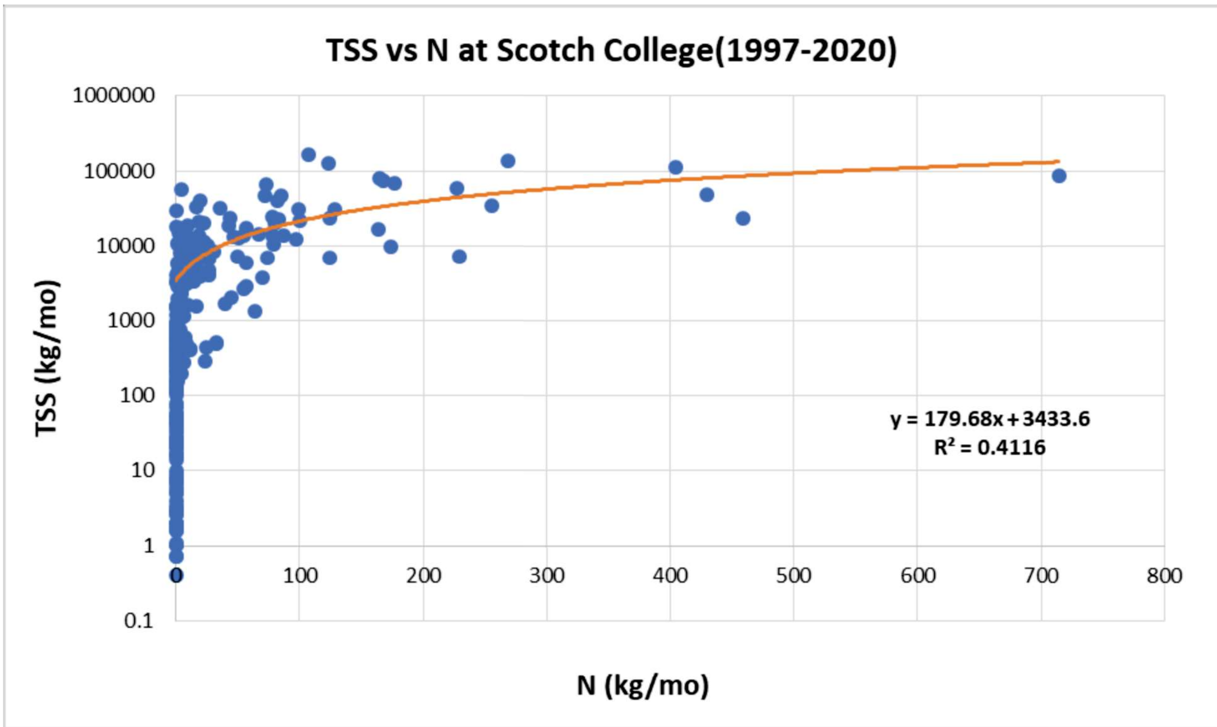


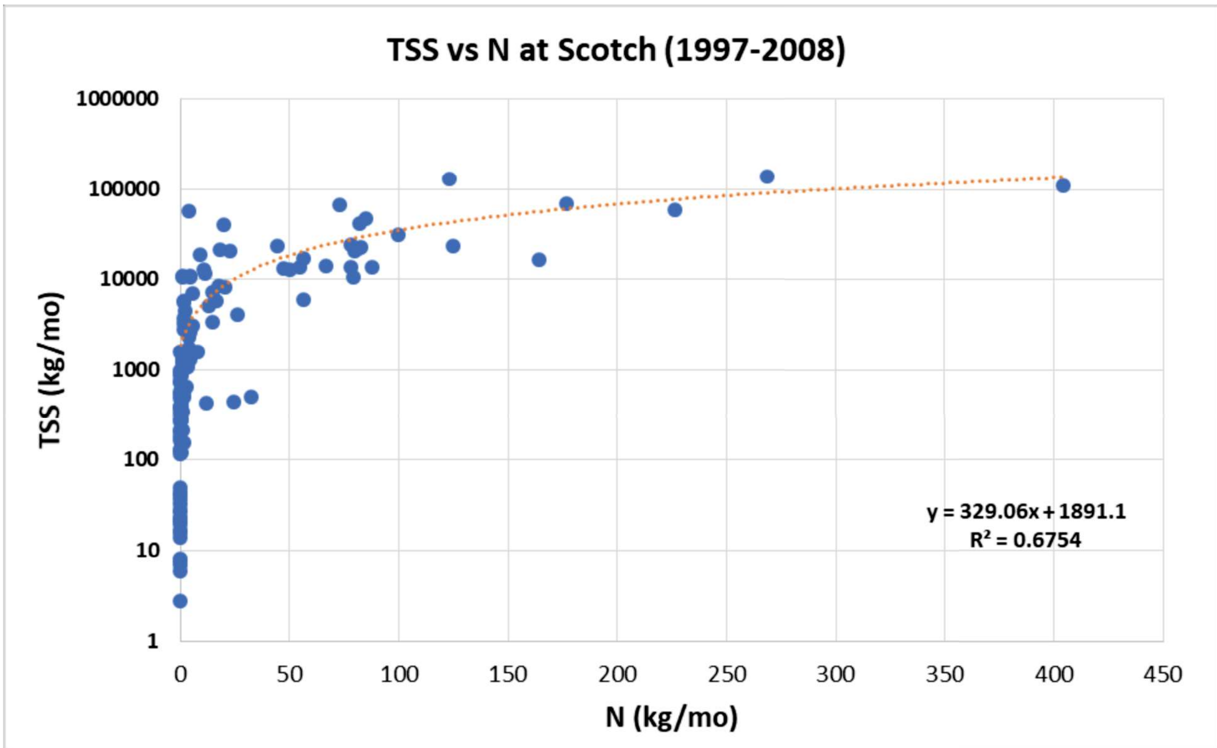
TSS vs P at Scotch (1997-2008)
TSS (kg/mo)
P (kg/mo)
1000000
100000
10000
1000
100
10
1
0
20
40
60
80
100
120
140
160
180
y = 819.11x - 1805.9
R² = 0.799

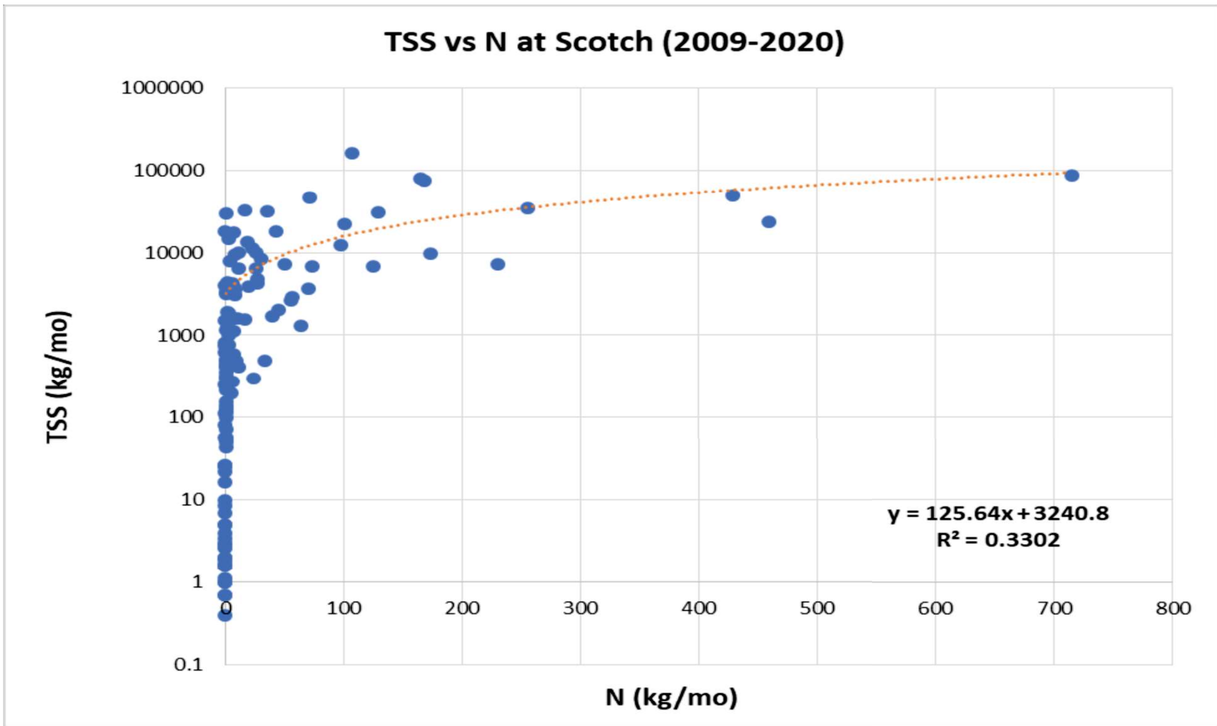


TSS vs P at Scotch (2009-2020)
TSS (kg/mo)
P (kg/mo)
1000000
100000
10000
1000
100
10
1
0.1
0
50
100
150
200
250
300
y = 560.34x - 1059.5
R² = 0.9371

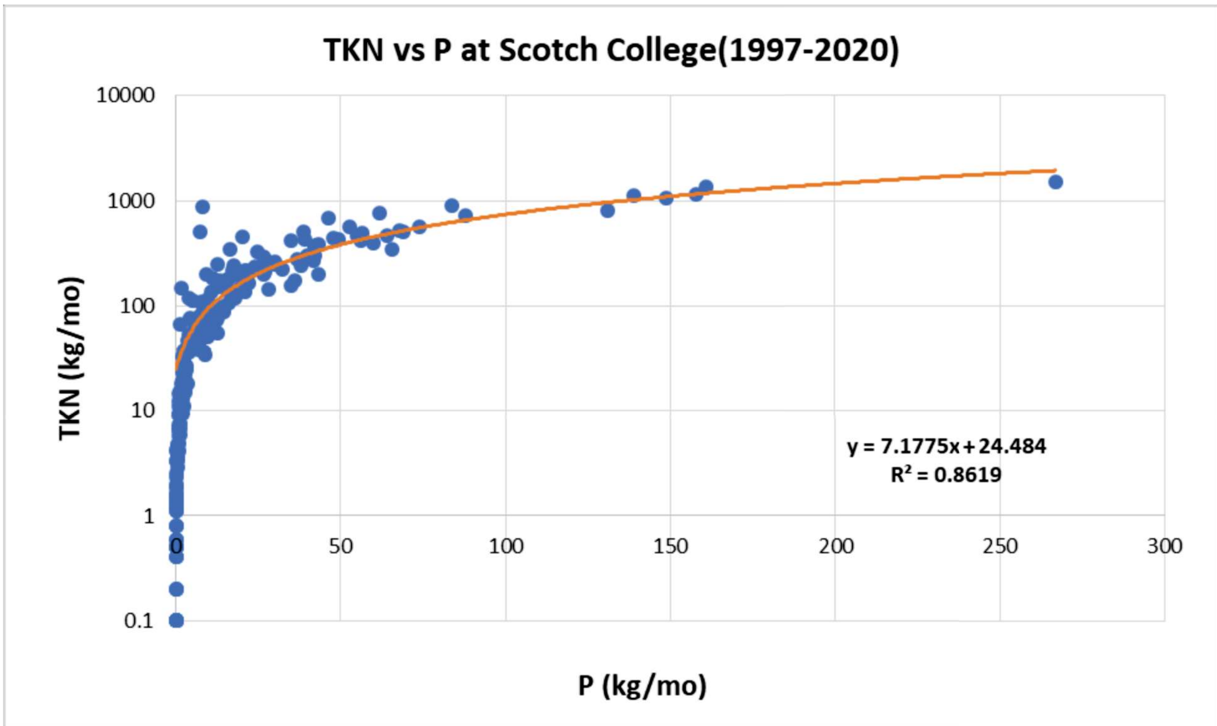
Total Suspended Solids (TSS) versus total Nitrogen (N)

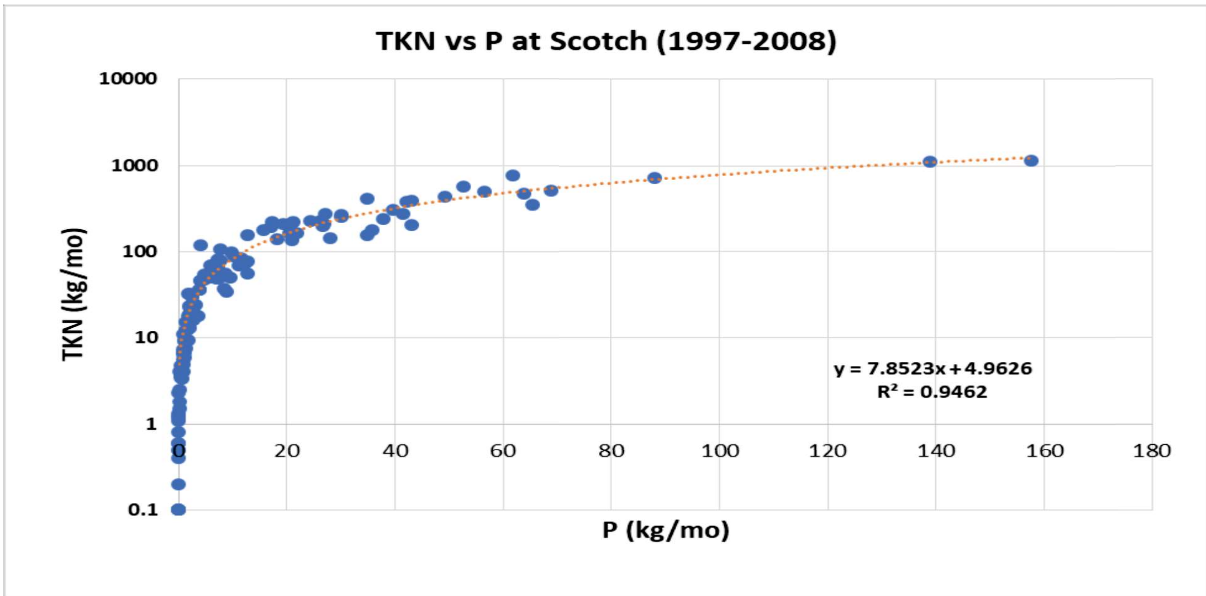


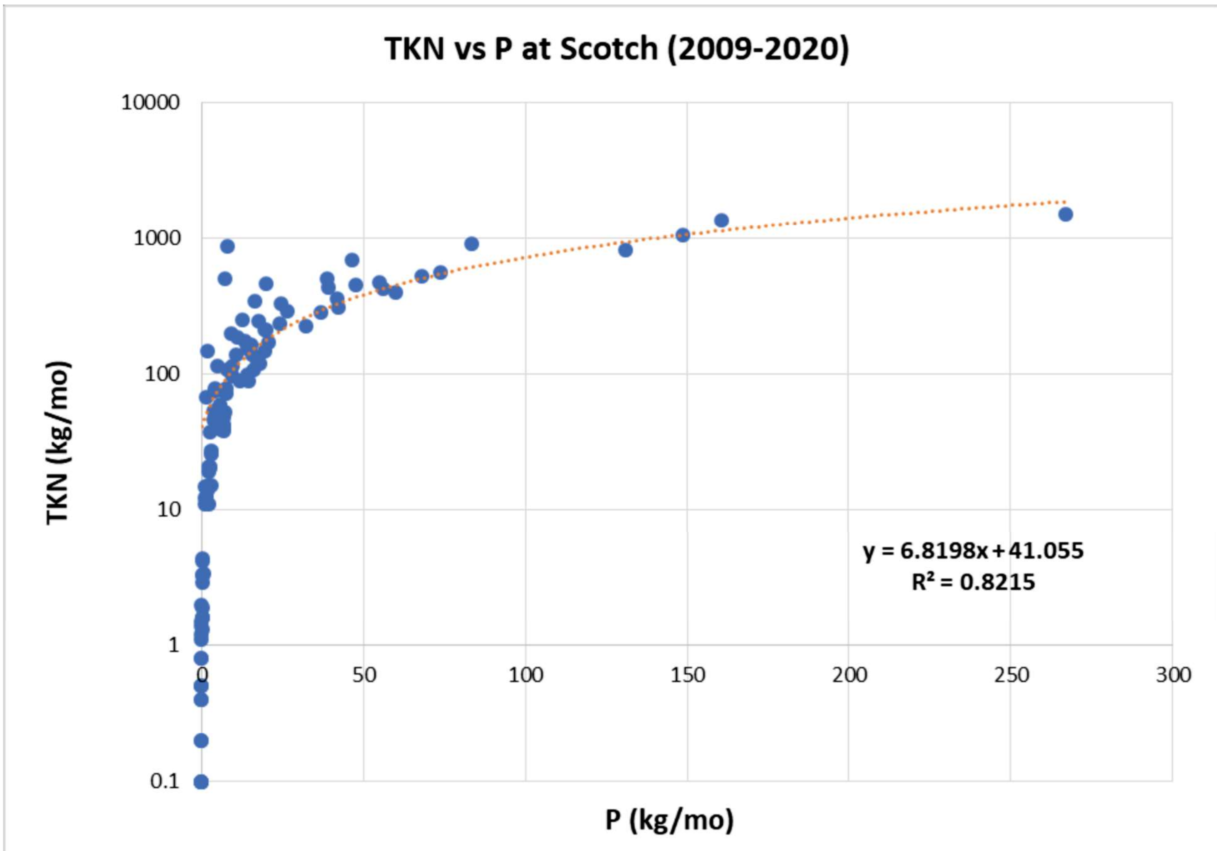




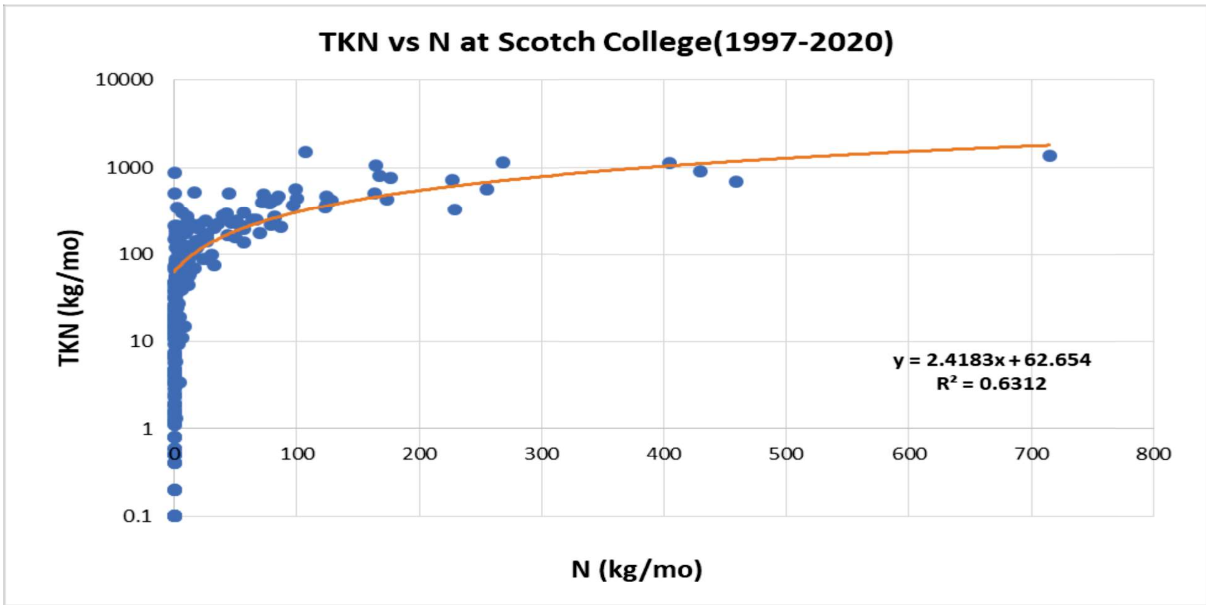
Total Kjeldahl (TSS) versus total Phosphorus (P)

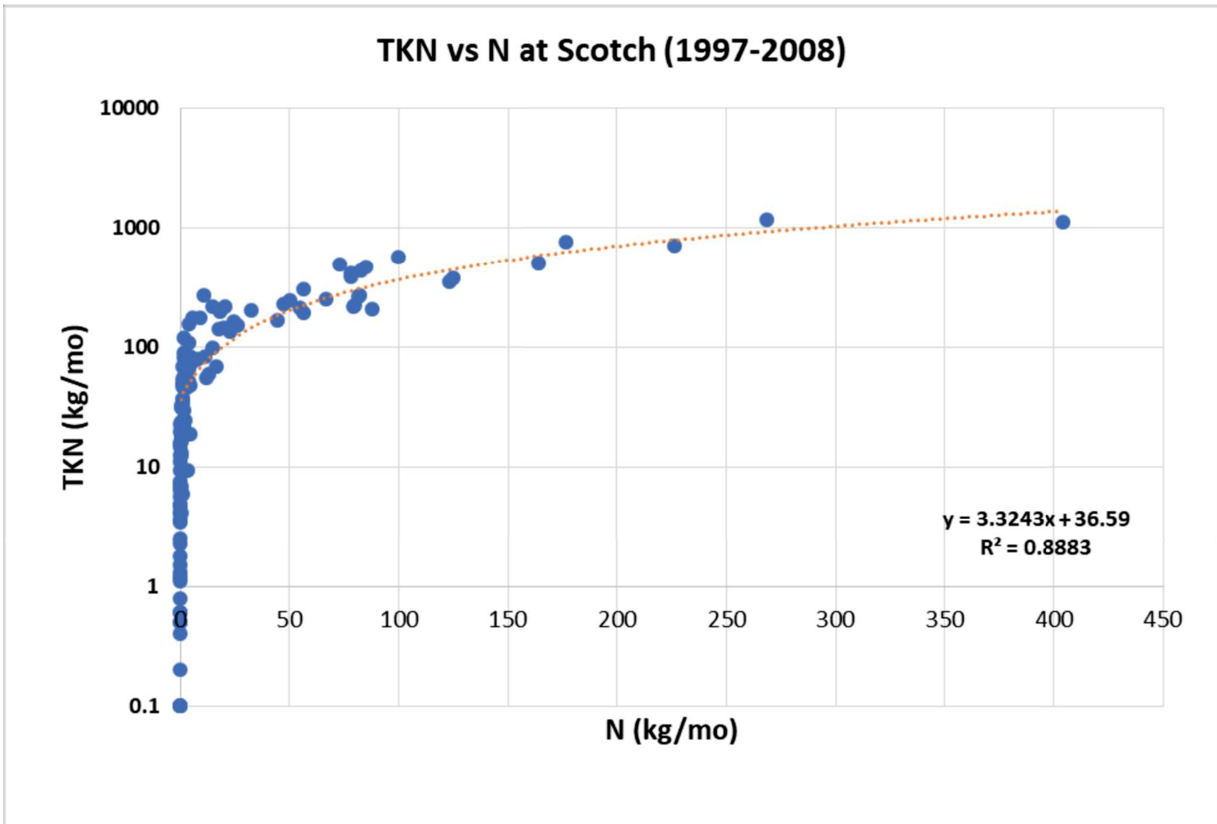


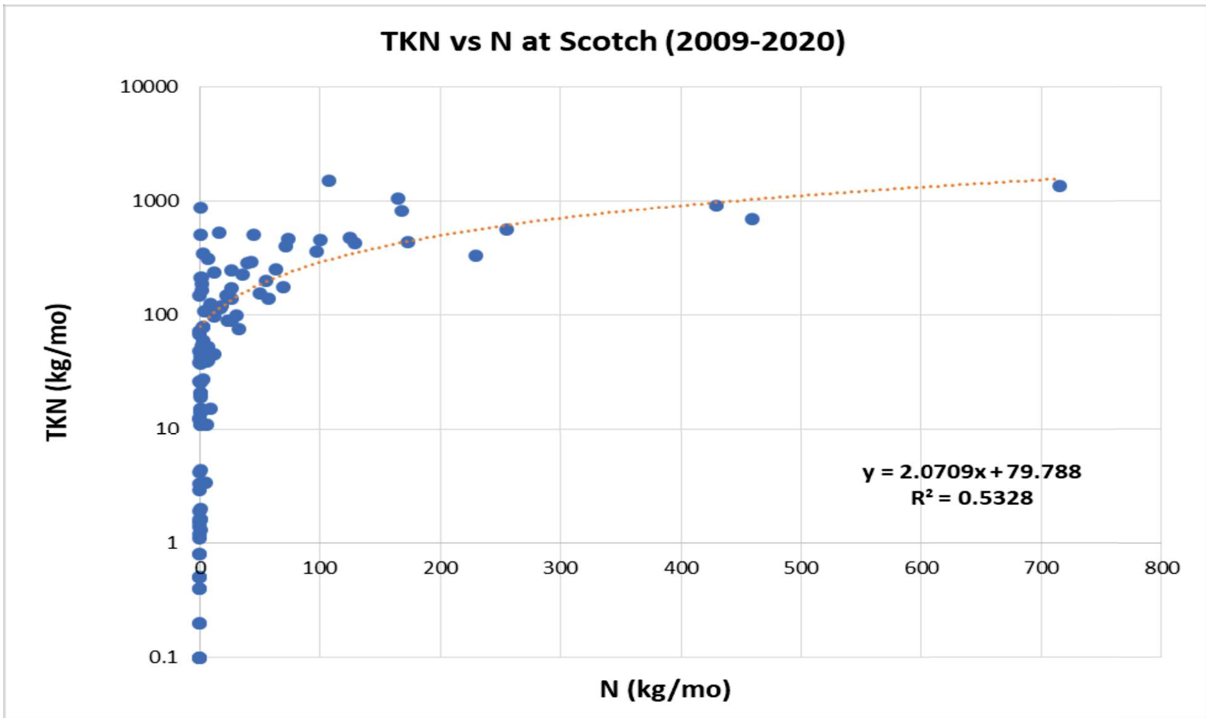

TKN vs P at Scotch (1997-2008)
10000
1000
100
10
1
0.1
TKN (kg/mo)
0
20
40
60
80
100
120
140
160
180
P (kg/mo)
y = 7.8523x + 4.9626
R² = 0.9462


TKN vs P at Scotch (2009-2020)
10000
1000
100
10
1
0.1
TKN (kg/mo)
0
50
100
150
200
250
300
P (kg/mo)
y = 6.8198x + 41.055
R² = 0.8215

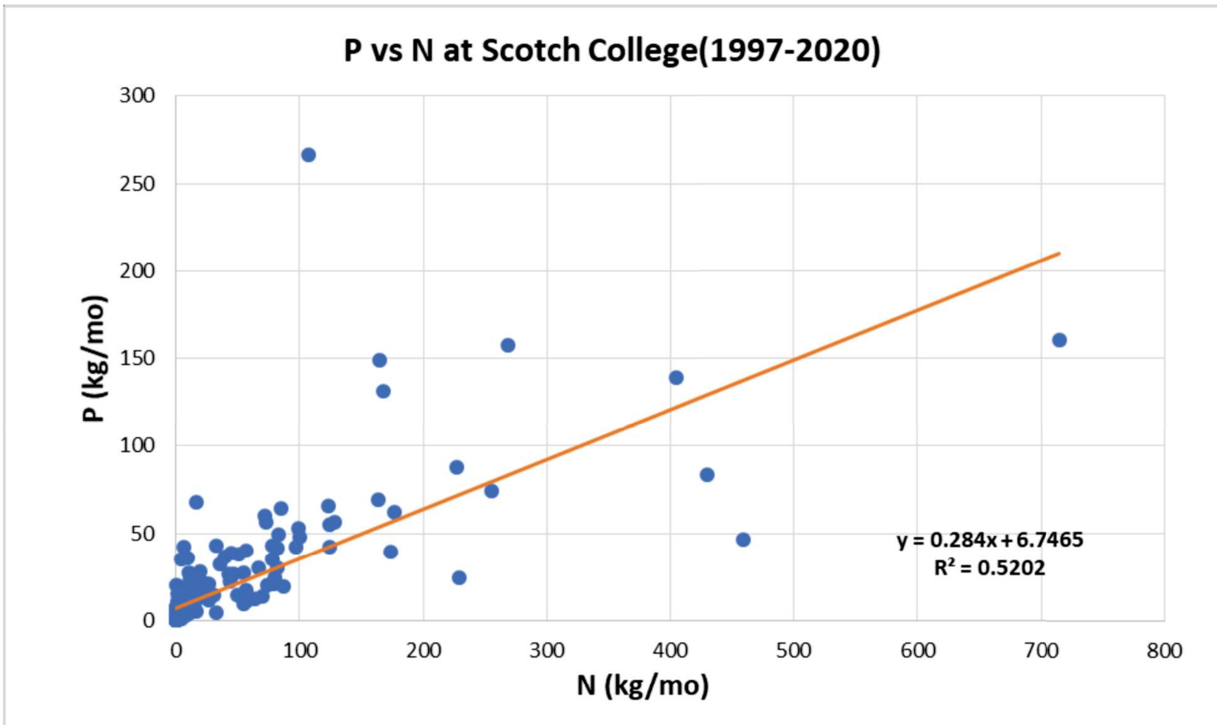
Total Kjeldahl (TSS) versus total Nitrogen (N)

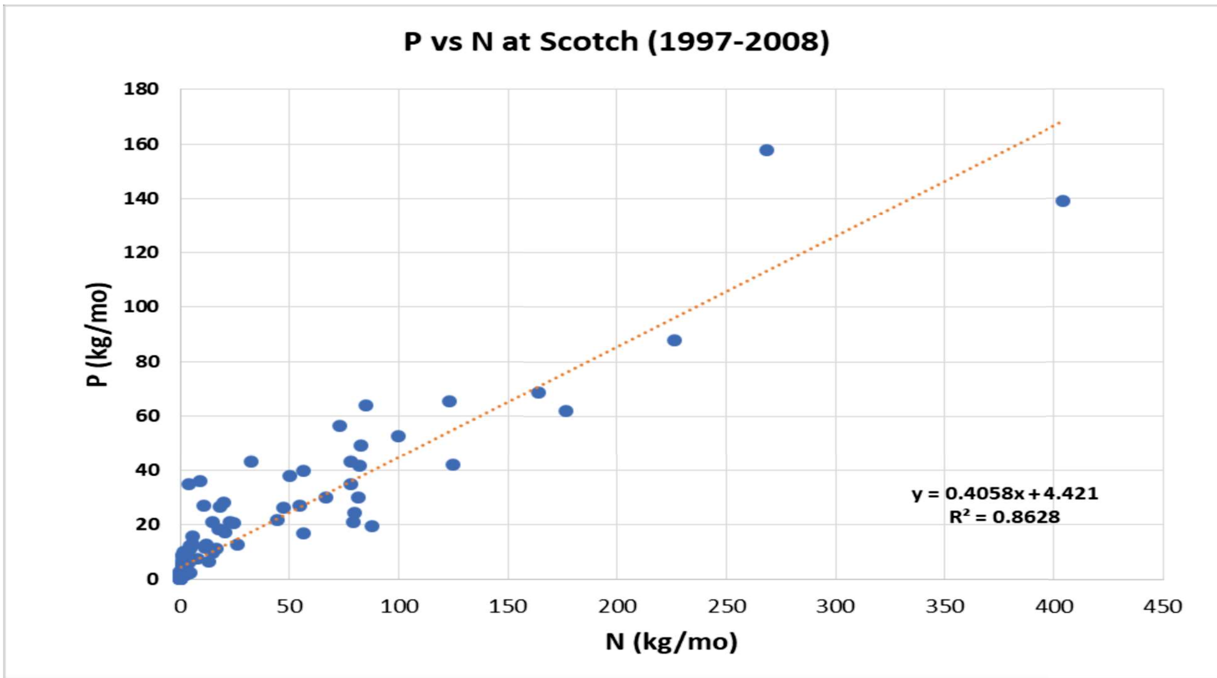


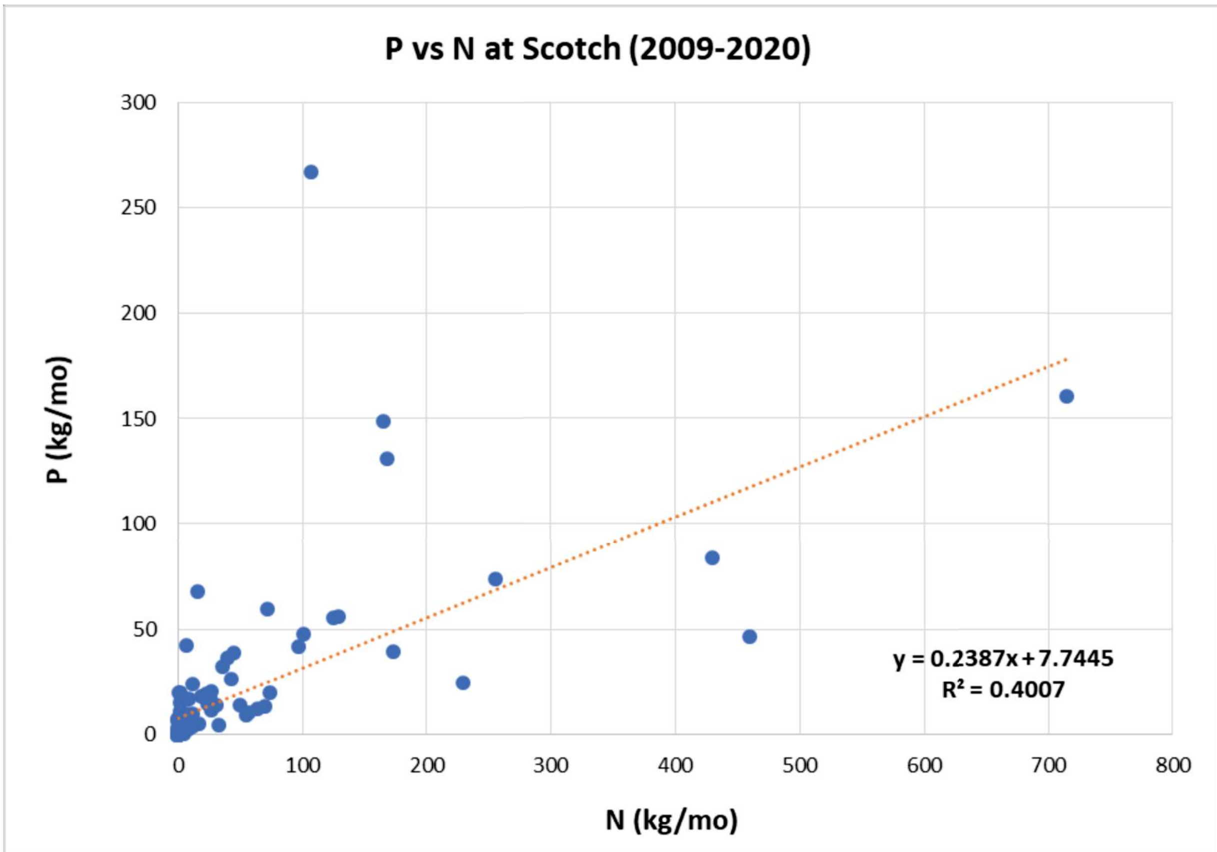




Total Phosphorus (P) versus total Nitrogen (N)



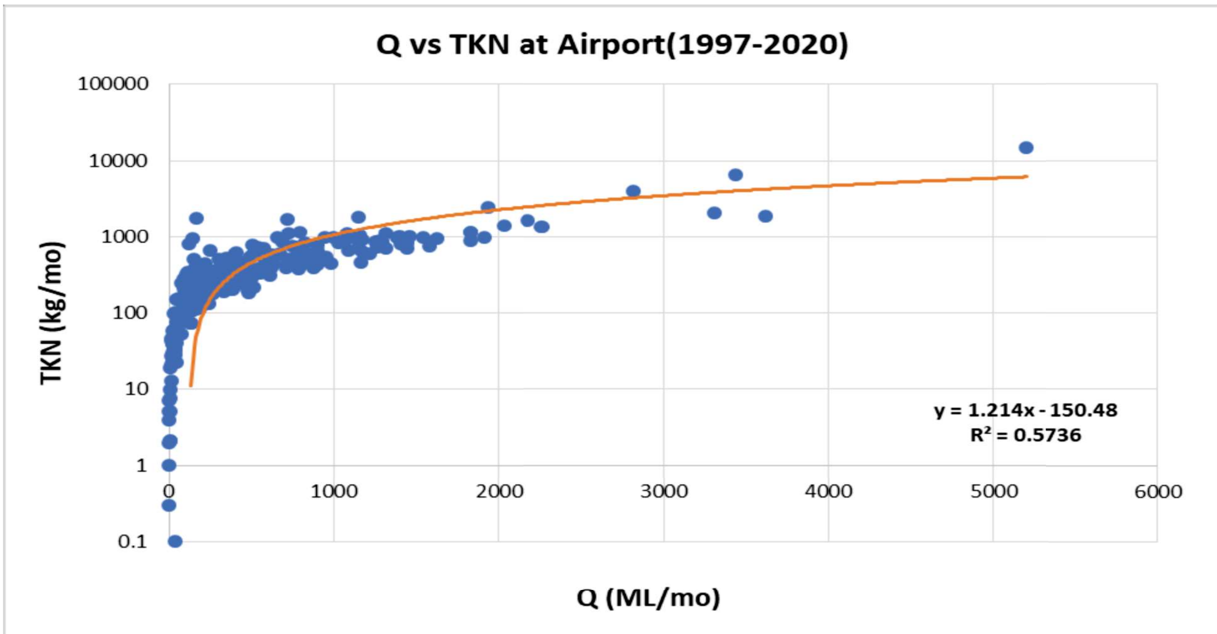

P vs N at Scotch (1997-2008)
P (kg/mo)
N (kg/mo)
y = 0.4058x + 4.421
R² = 0.8628
180
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
450

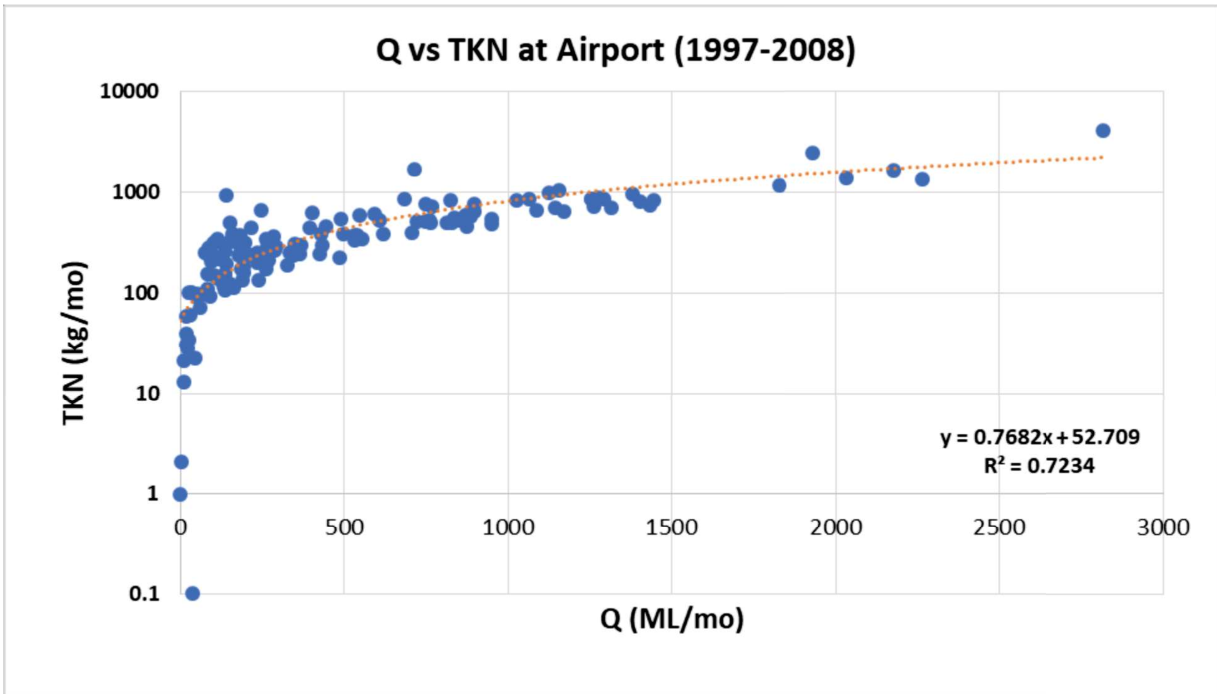

P vs N at Scotch (2009-2020)
P (kg/mo)
N (kg/mo)
y = 0.2387x + 7.7445
R² = 0.4007
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800

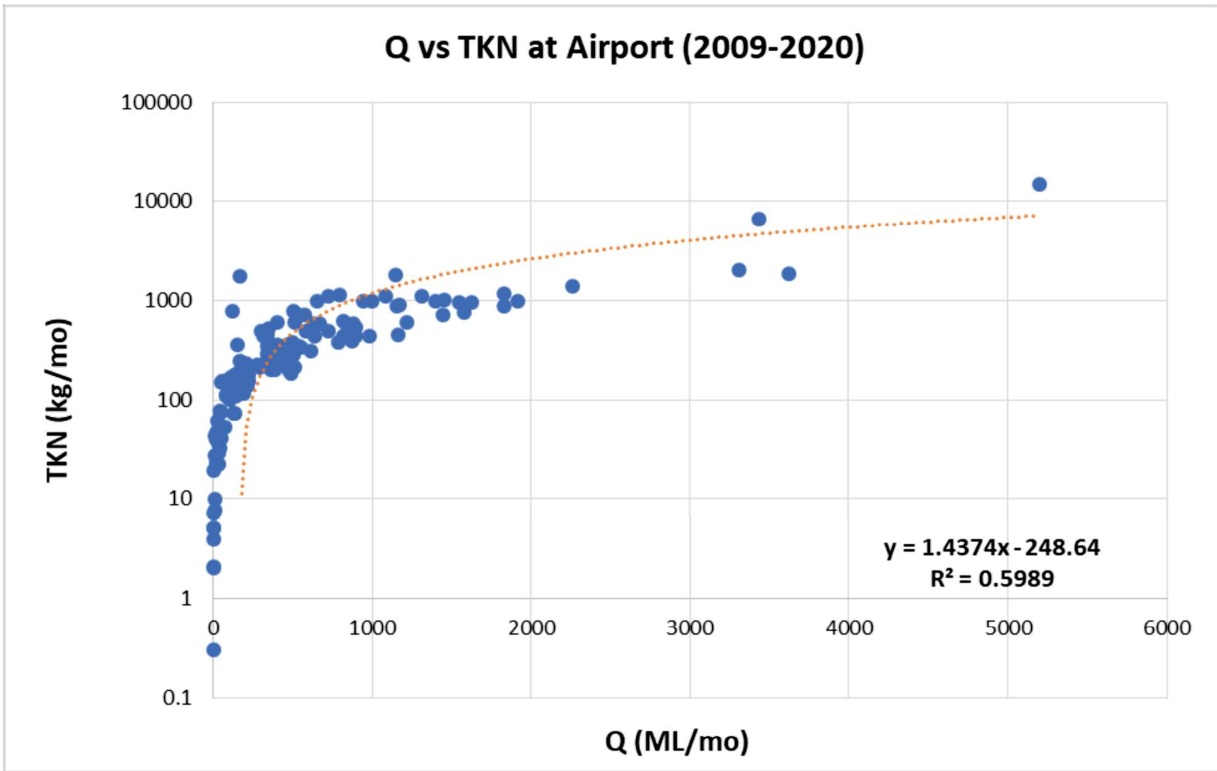
Appendix B

Monthly variation and relationship in data at Adelaide Airport gauging station

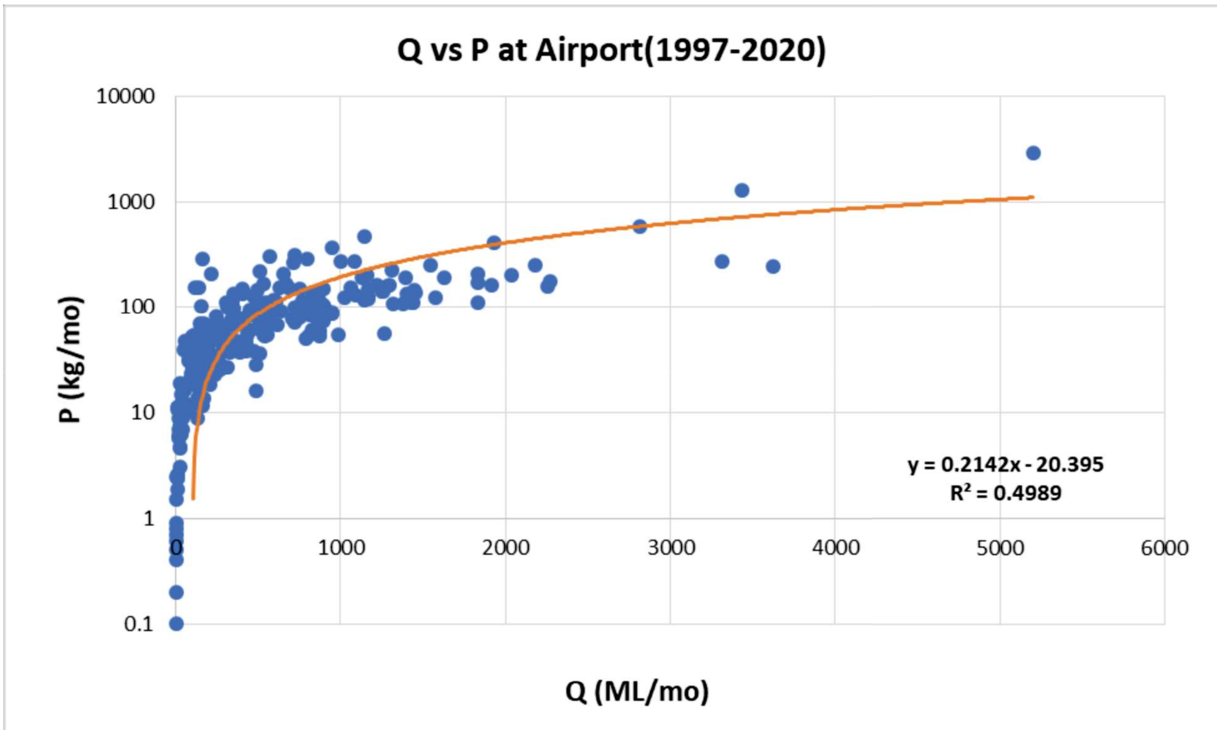
Total Discharged (Q) versus total Kjeldahl (TKN)

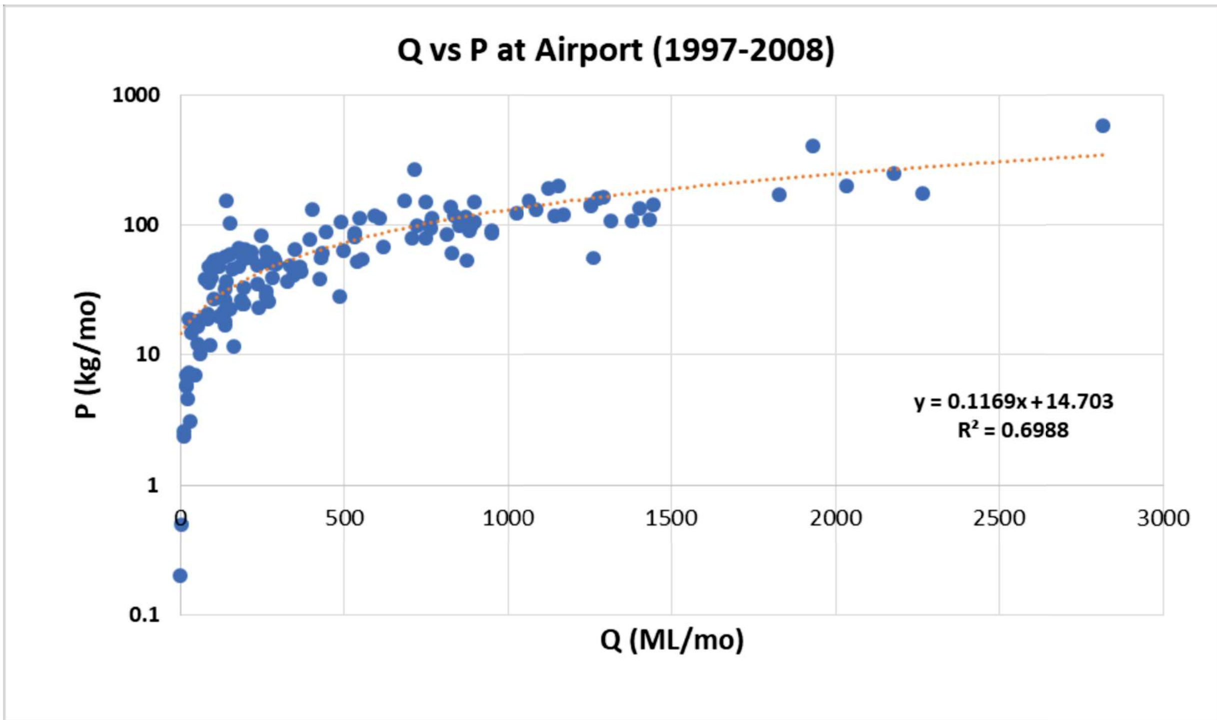


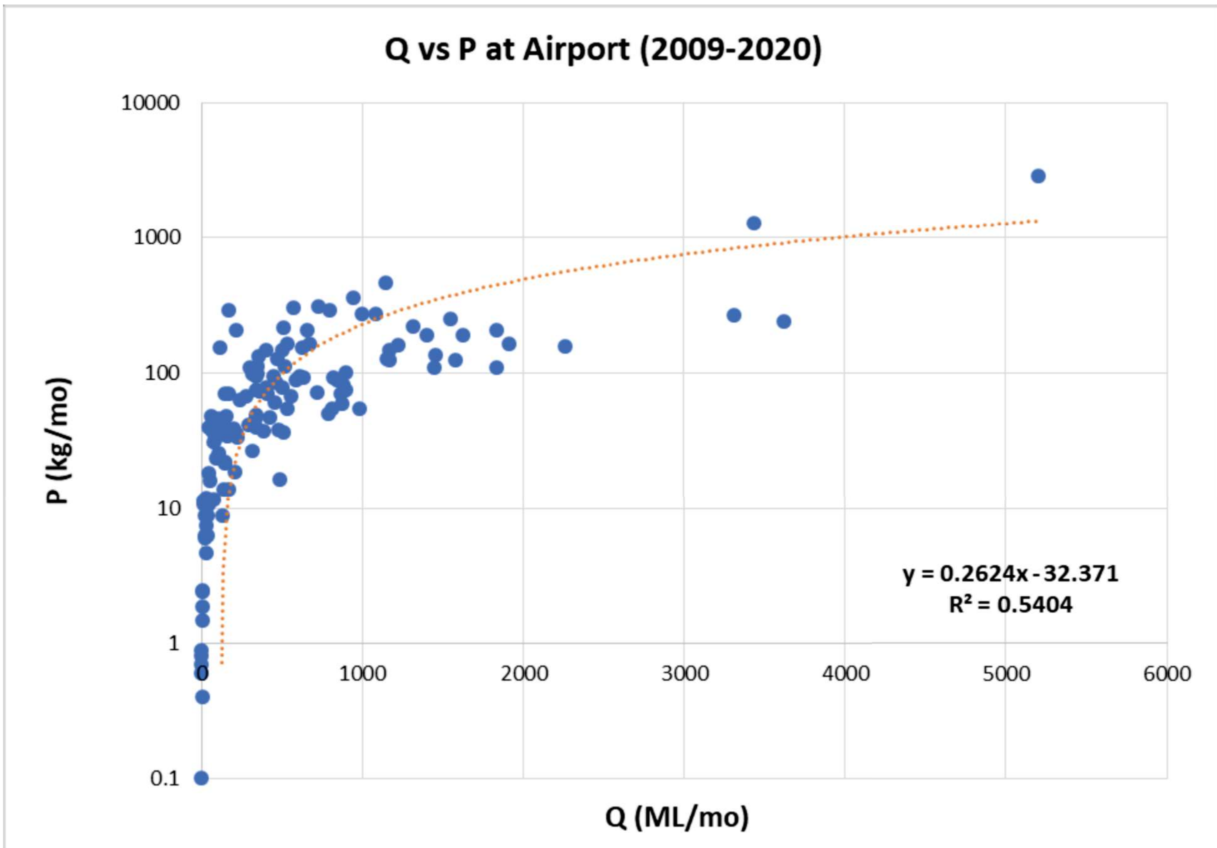




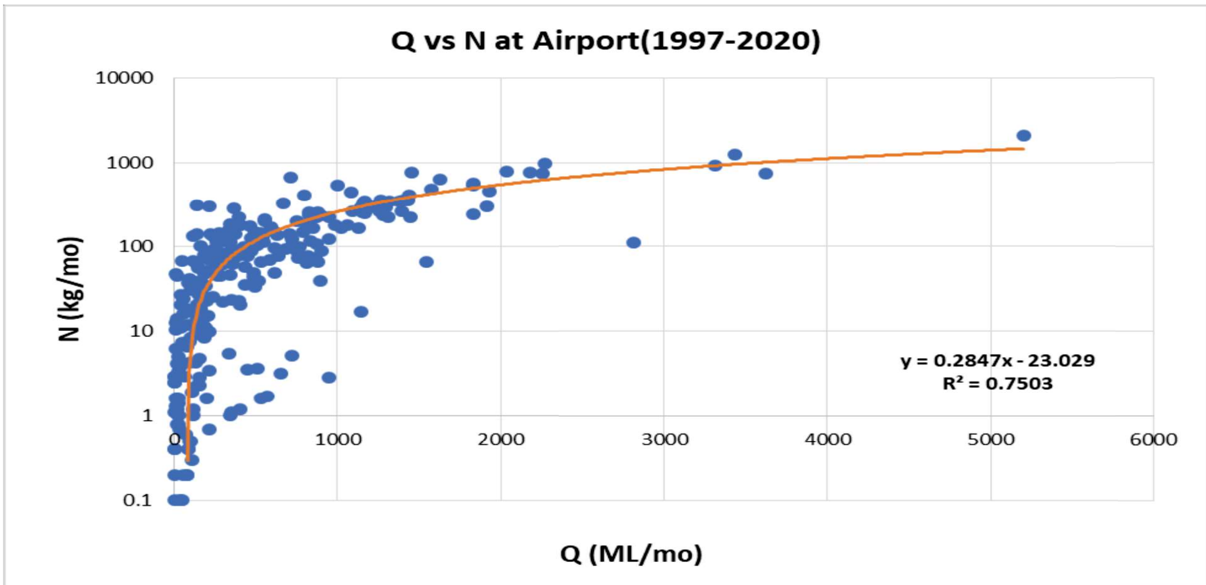
Total Discharged (Q) versus total Phosphorus (P)

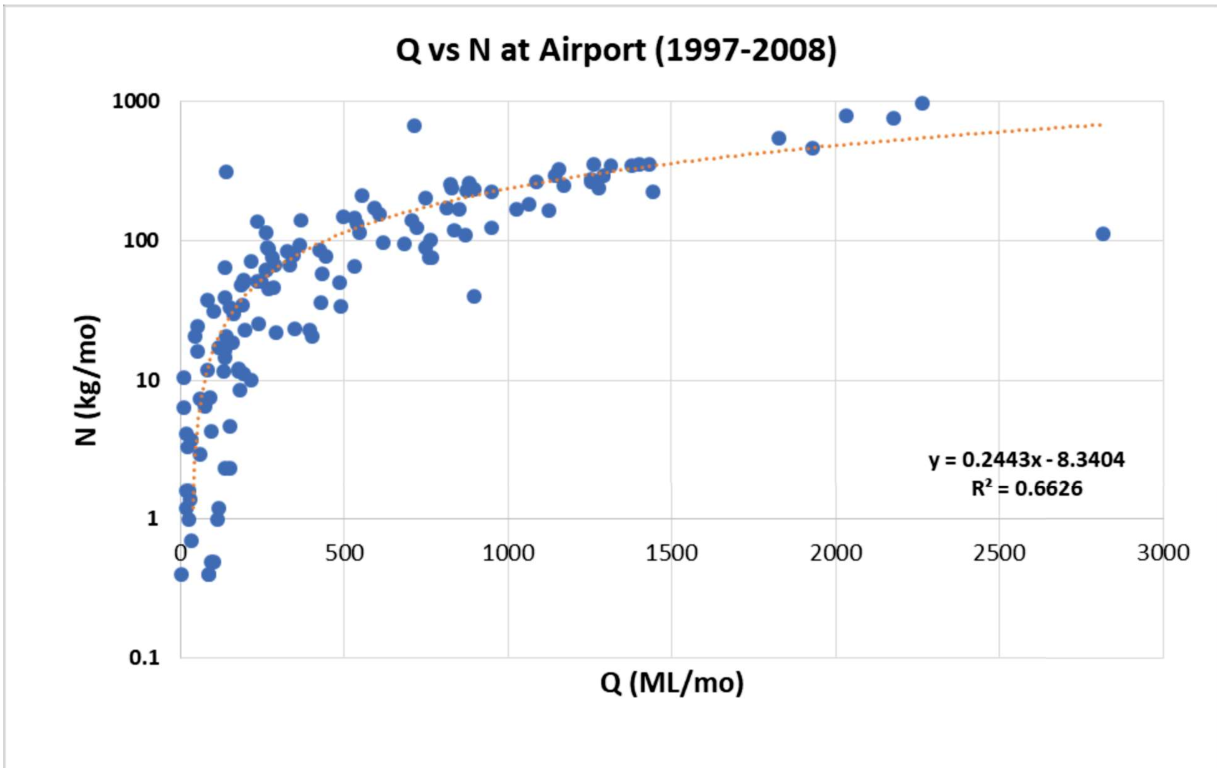


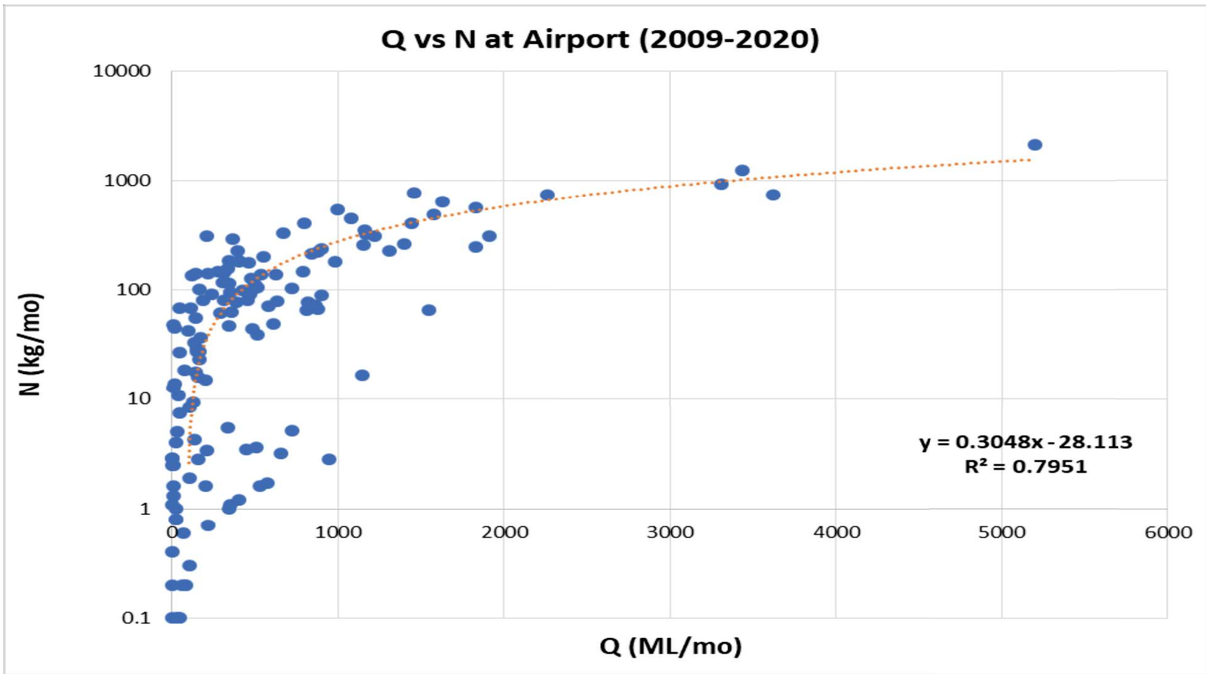

Q vs P at Airport (1997-2008)
1000
100
10
1
0.1
P (kg/mo)
0
500
1000
1500
2000
2500
3000
Q (ML/mo)
y = 0.1169x + 14.703
R² = 0.6988


Q vs P at Airport (2009-2020)
10000
1000
100
10
1
0.1
P (kg/mo)
0
1000
2000
3000
4000
5000
6000
Q (ML/mo)
y = 0.2624x - 32.371
R² = 0.5404

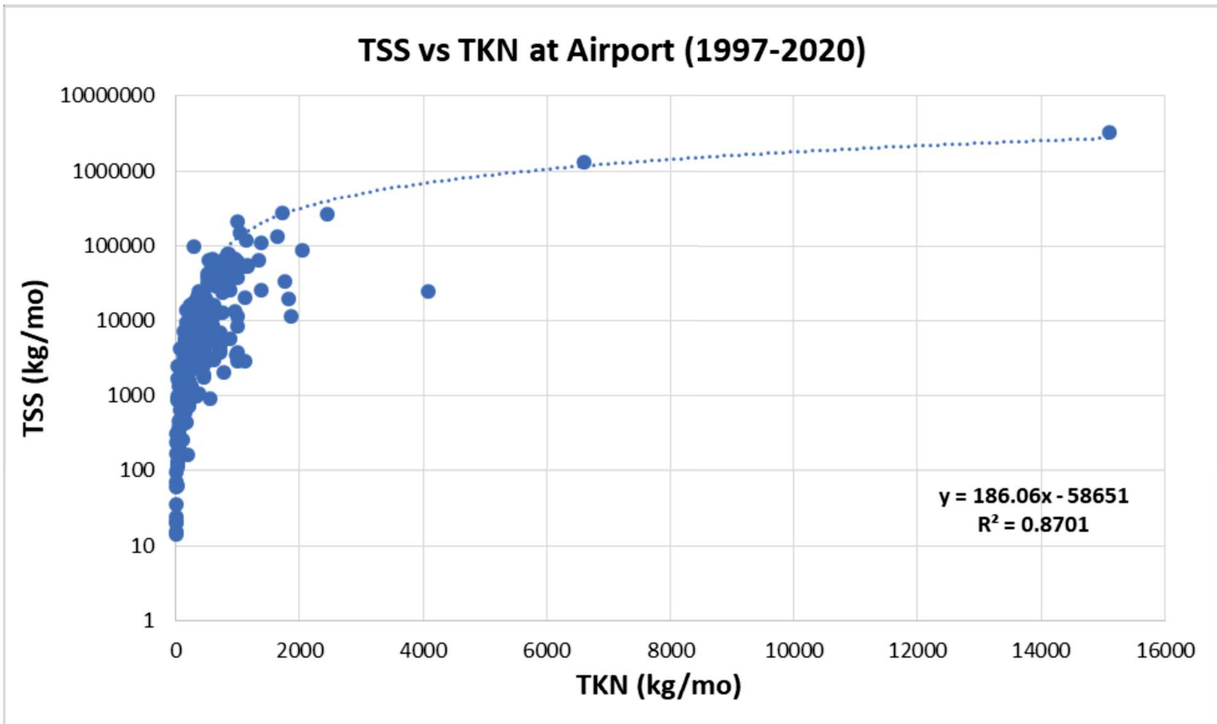
Total Discharged (Q) versus total Nitrogen (N)

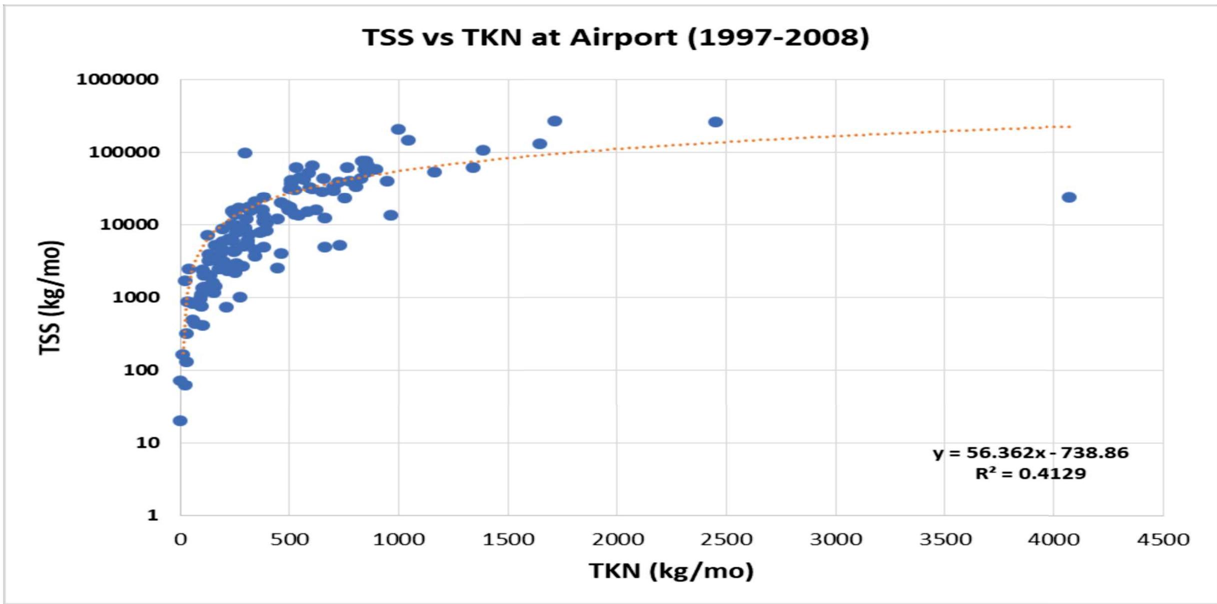


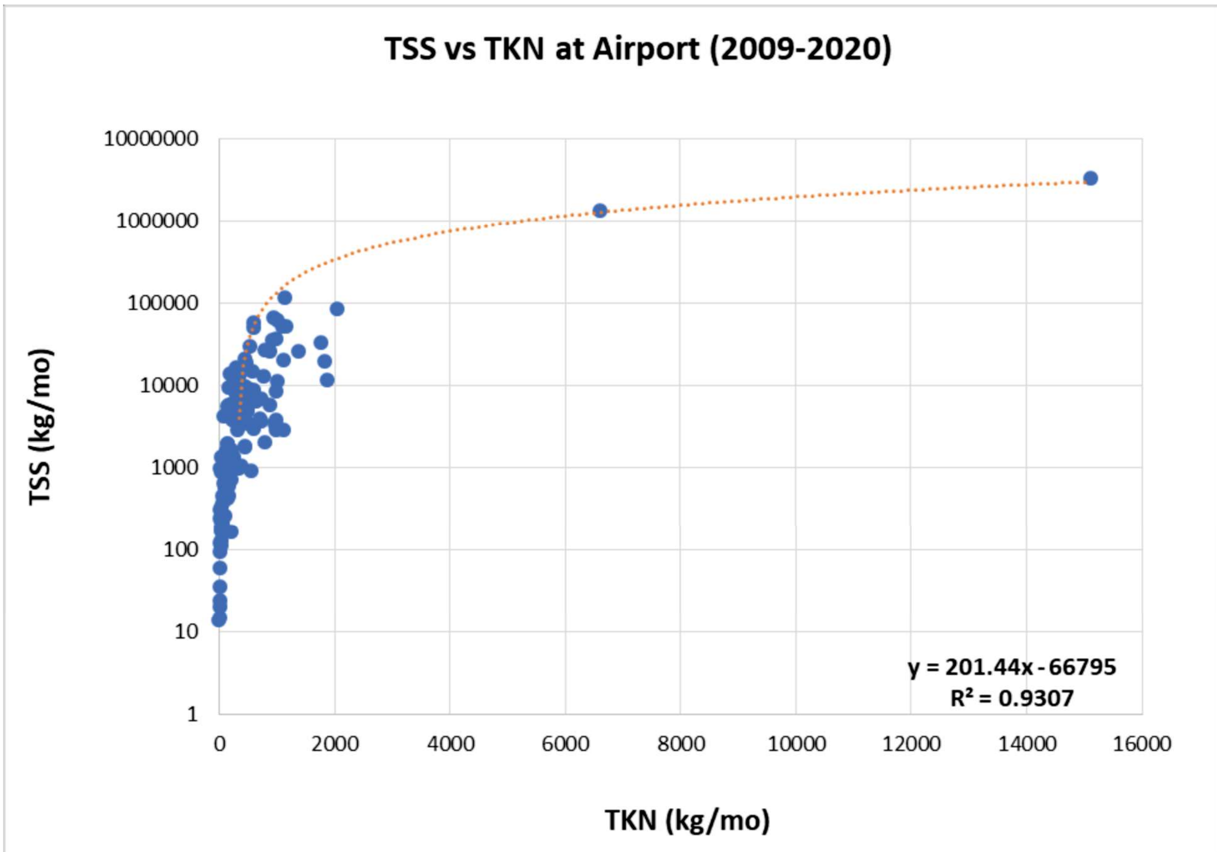




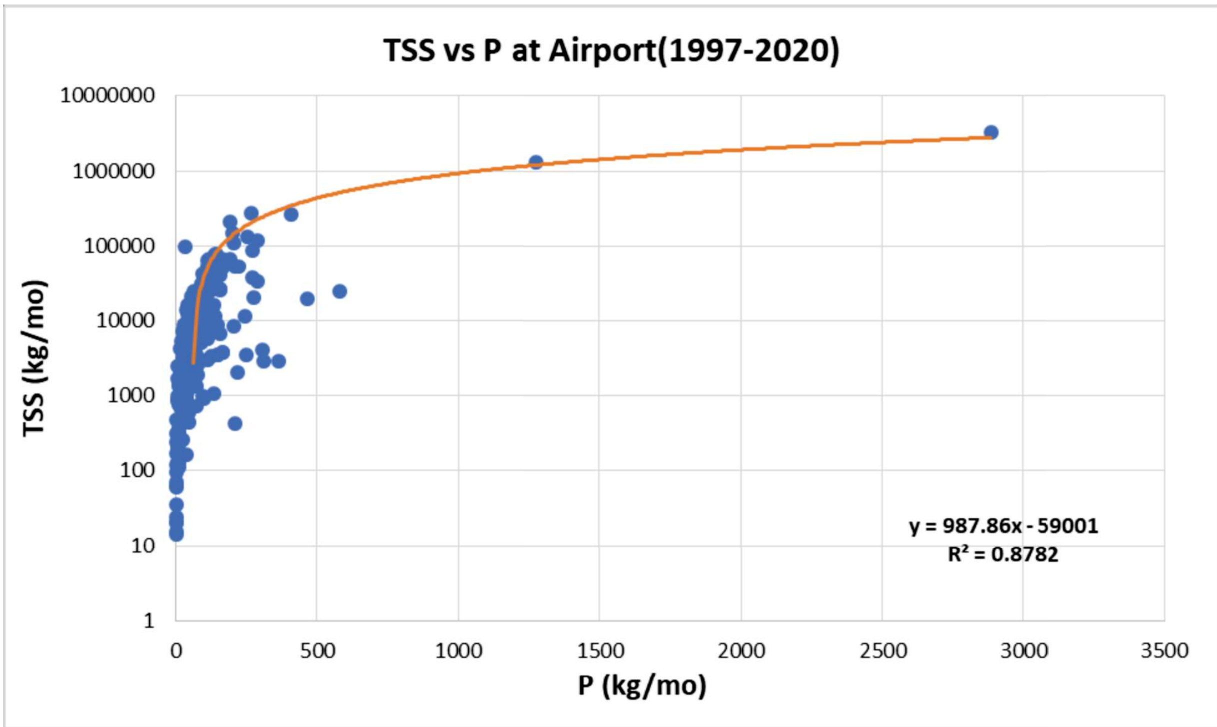
Total Suspended Solids (TSS) versus total Kjeldahl (TKN)

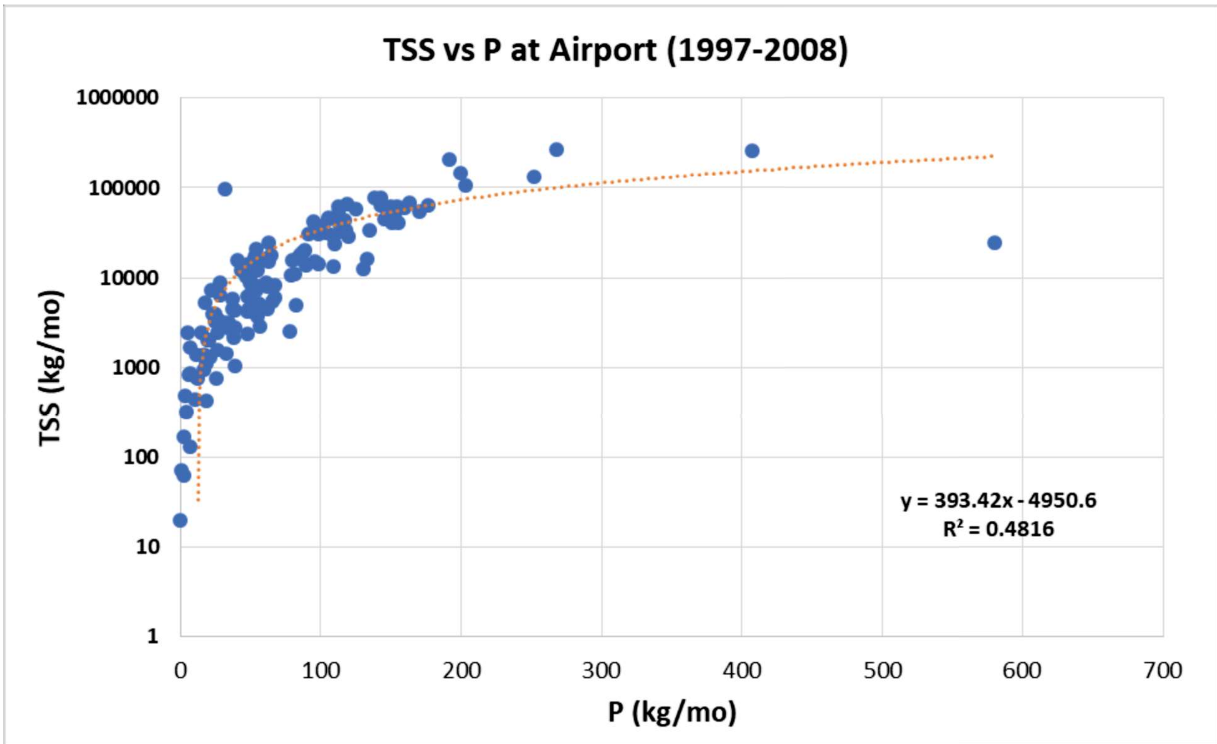


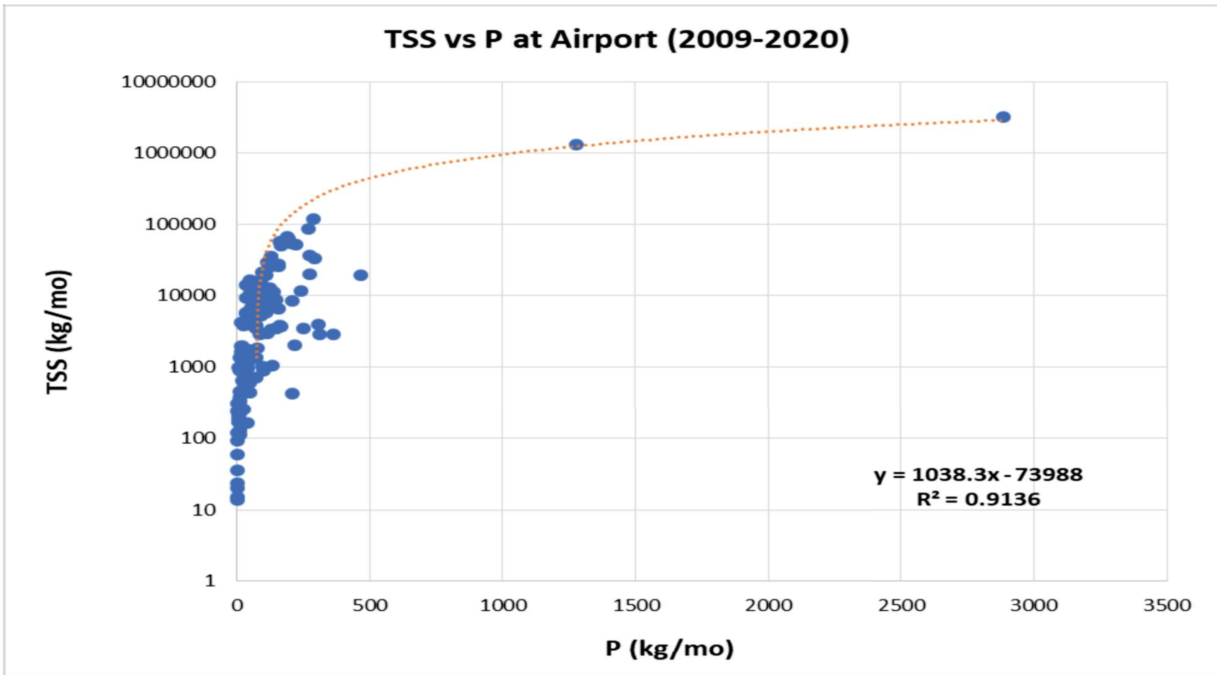

TSS vs TKN at Airport (1997-2008)
1000000
100000
10000
1000
100
10
1
TSS (kg/mo)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TKN (kg/mo)
y = 56.362x - 738.86
R² = 0.4129


TSS vs TKN at Airport (2009-2020)
10000000
1000000
100000
10000
1000
100
10
1
TSS (kg/mo)
0
2000
4000
6000
8000
10000
12000
14000
16000
TKN (kg/mo)
y = 201.44x - 66795
R² = 0.9307

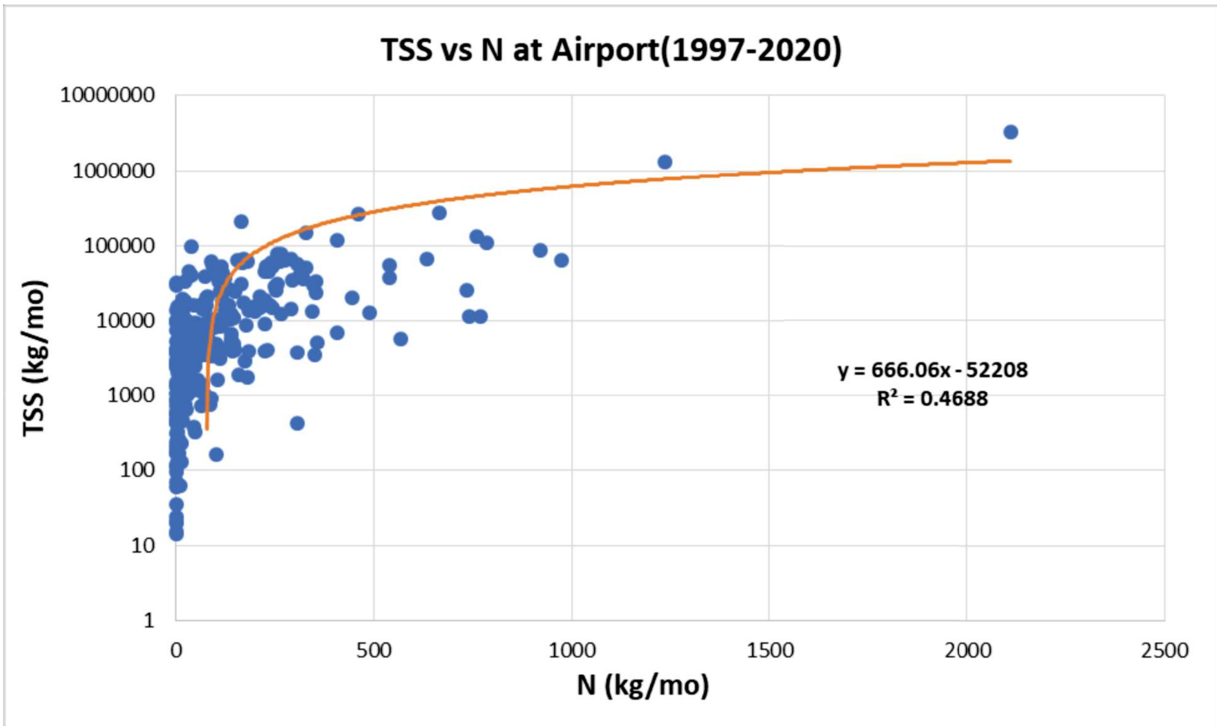
Total Suspended Solids (TSS) versus total Phosphorus (P)

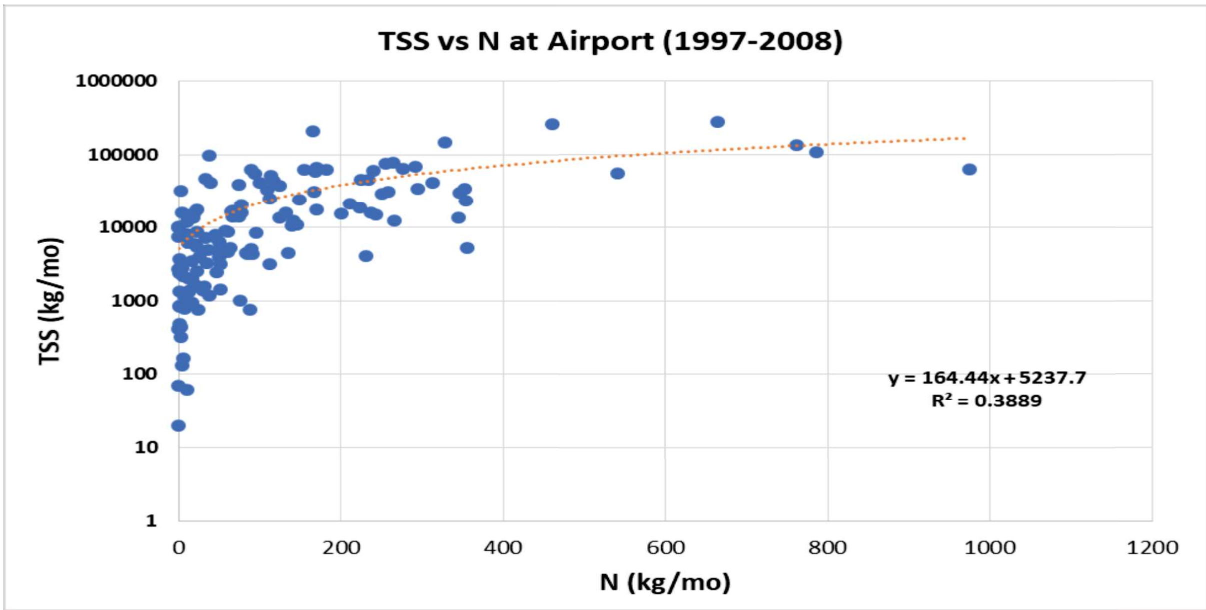


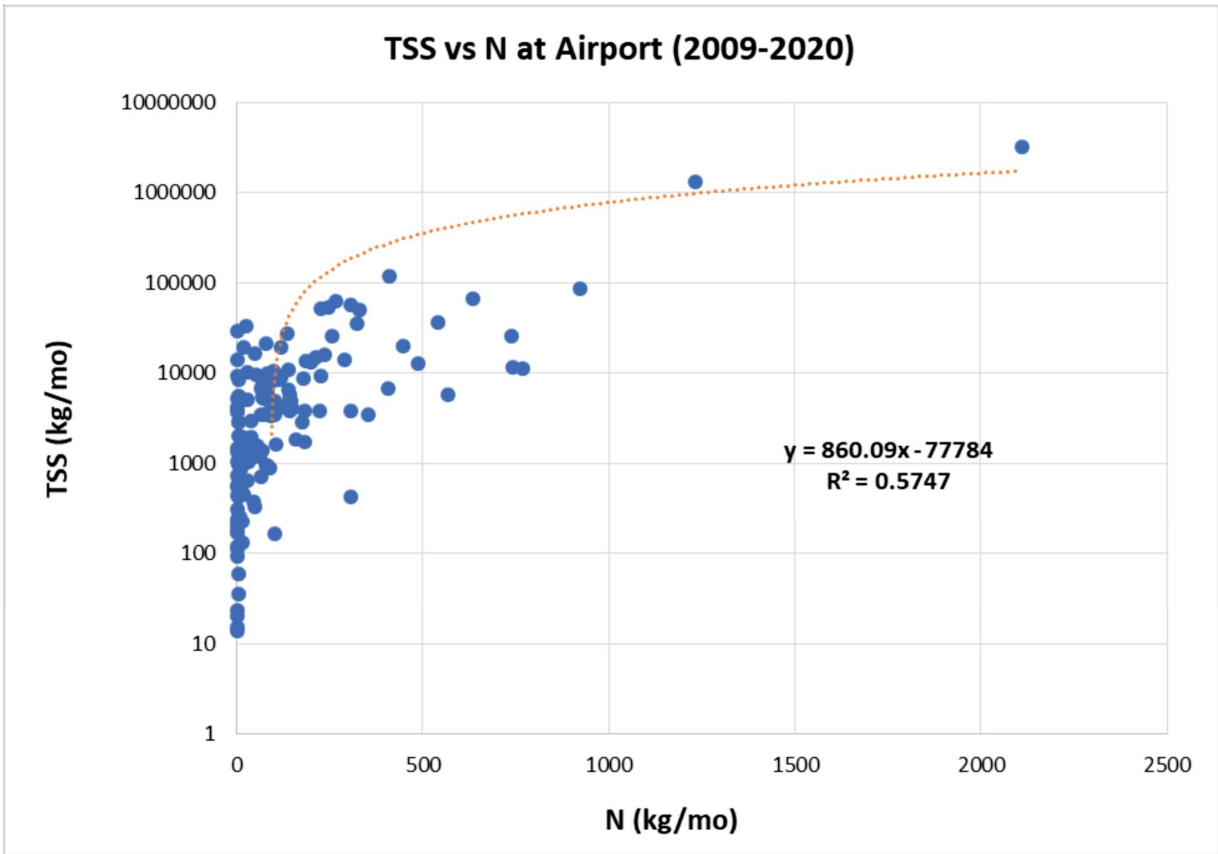




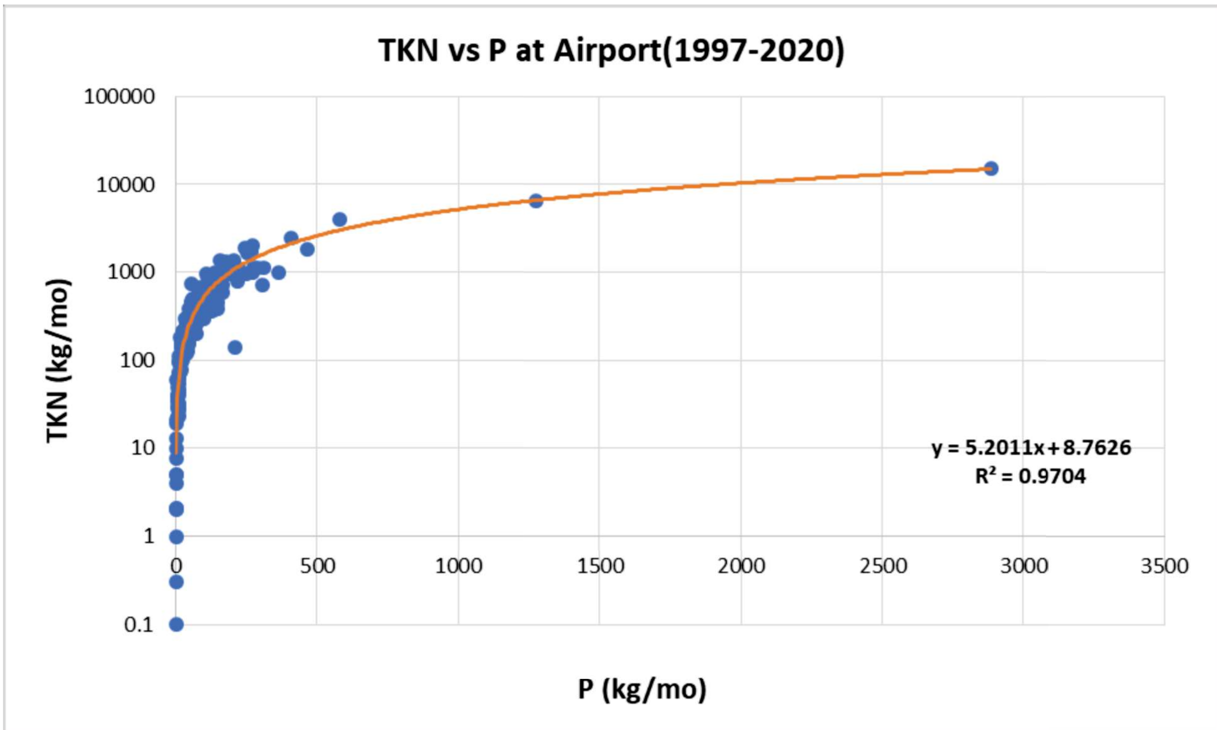
Total Suspended Solids (TSS) versus total Nitrogen (N)

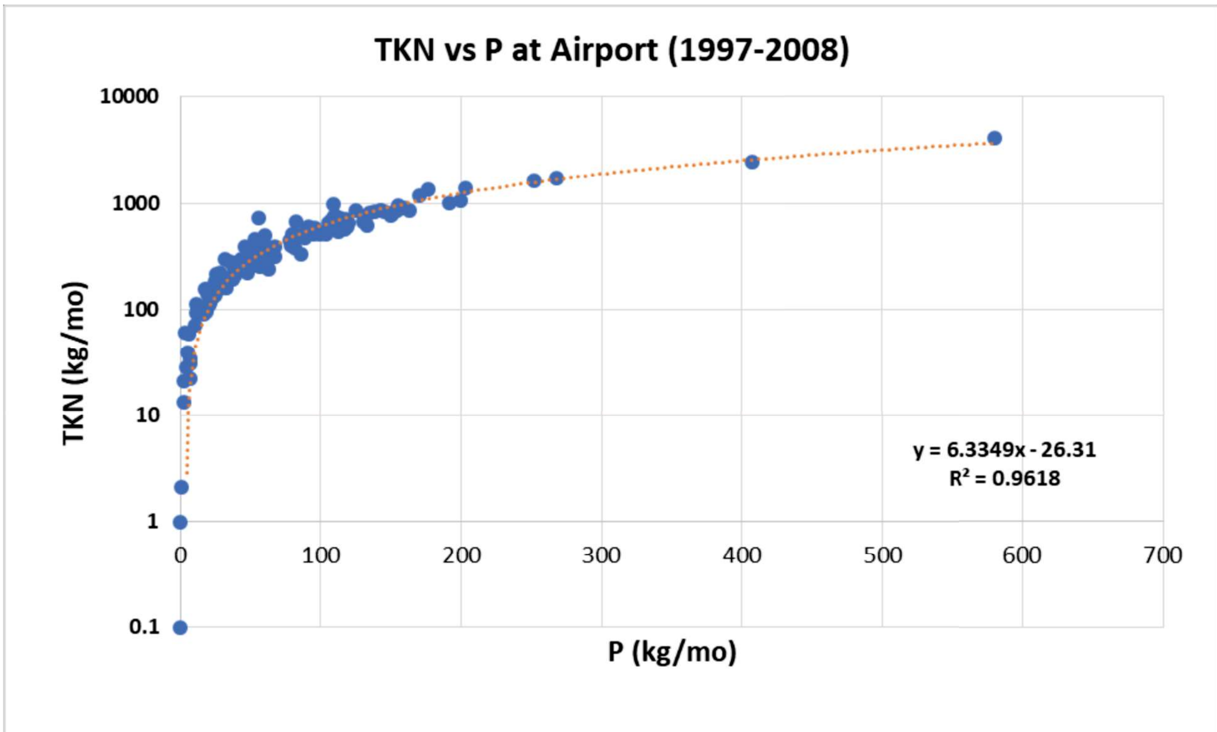


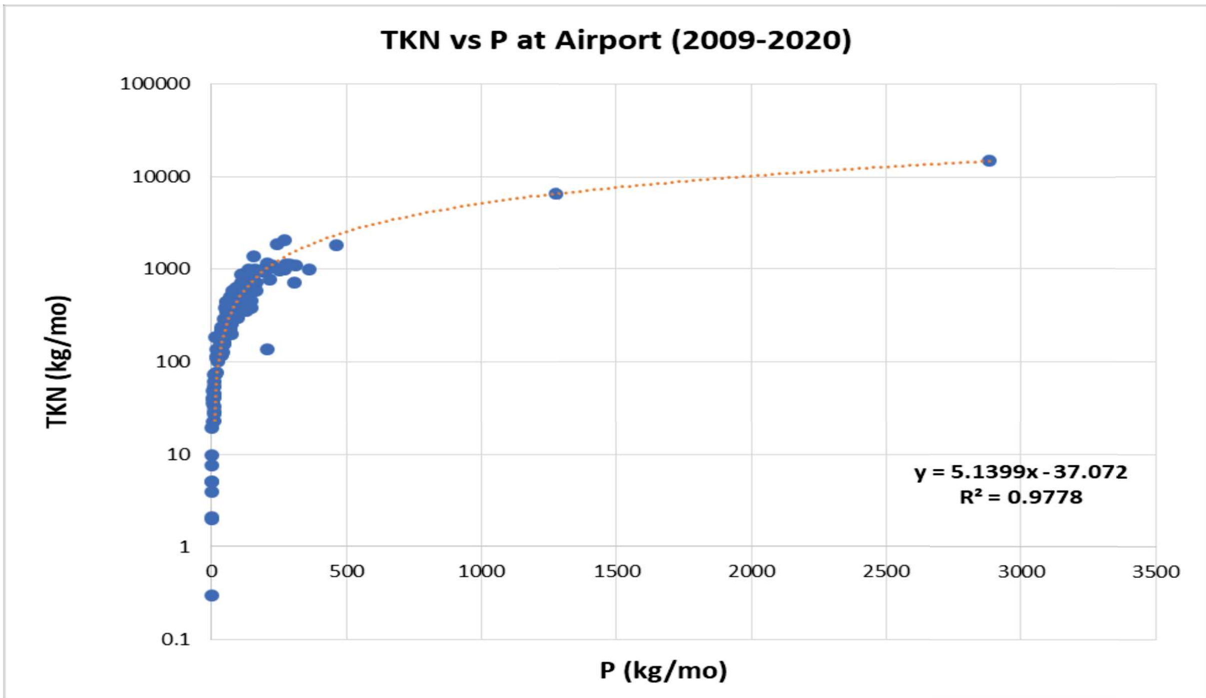

TSS vs N at Airport (1997-2008)
TSS (kg/mo)
N (kg/mo)
y = 164.44x + 5237.7
R² = 0.3889
1000000
100000
10000
1000
100
10
1
0
200
400
600
800
1000
1200


TSS vs N at Airport (2009-2020)
TSS (kg/mo)
N (kg/mo)
y = 860.09x - 77784
R² = 0.5747
10000000
1000000
100000
10000
1000
100
10
1
0
500
1000
1500
2000
2500

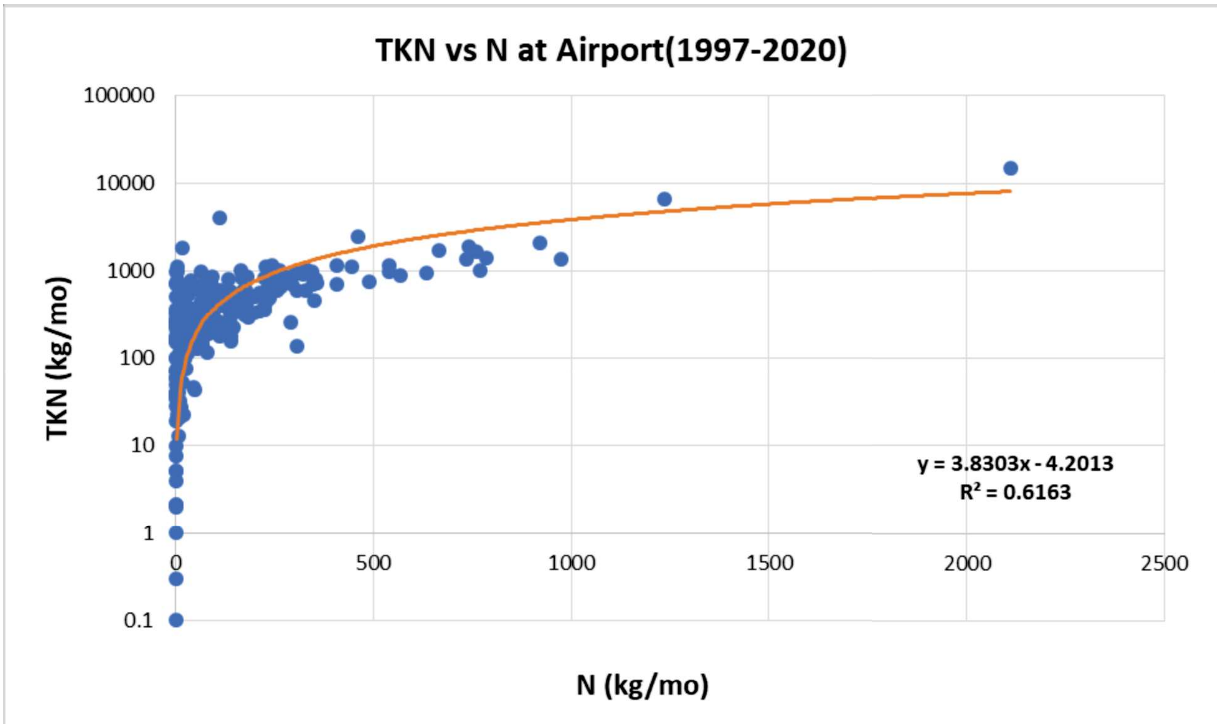
Total Kjeldahl (TKN) versus total Phosphorus (P)

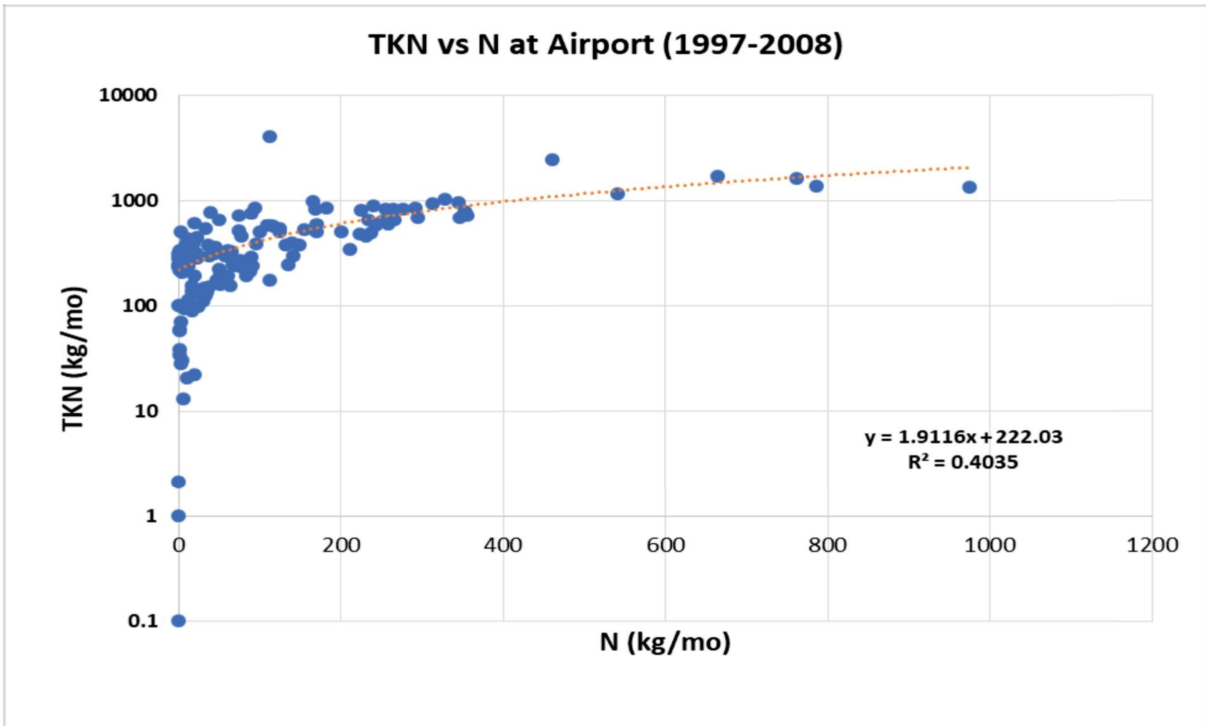


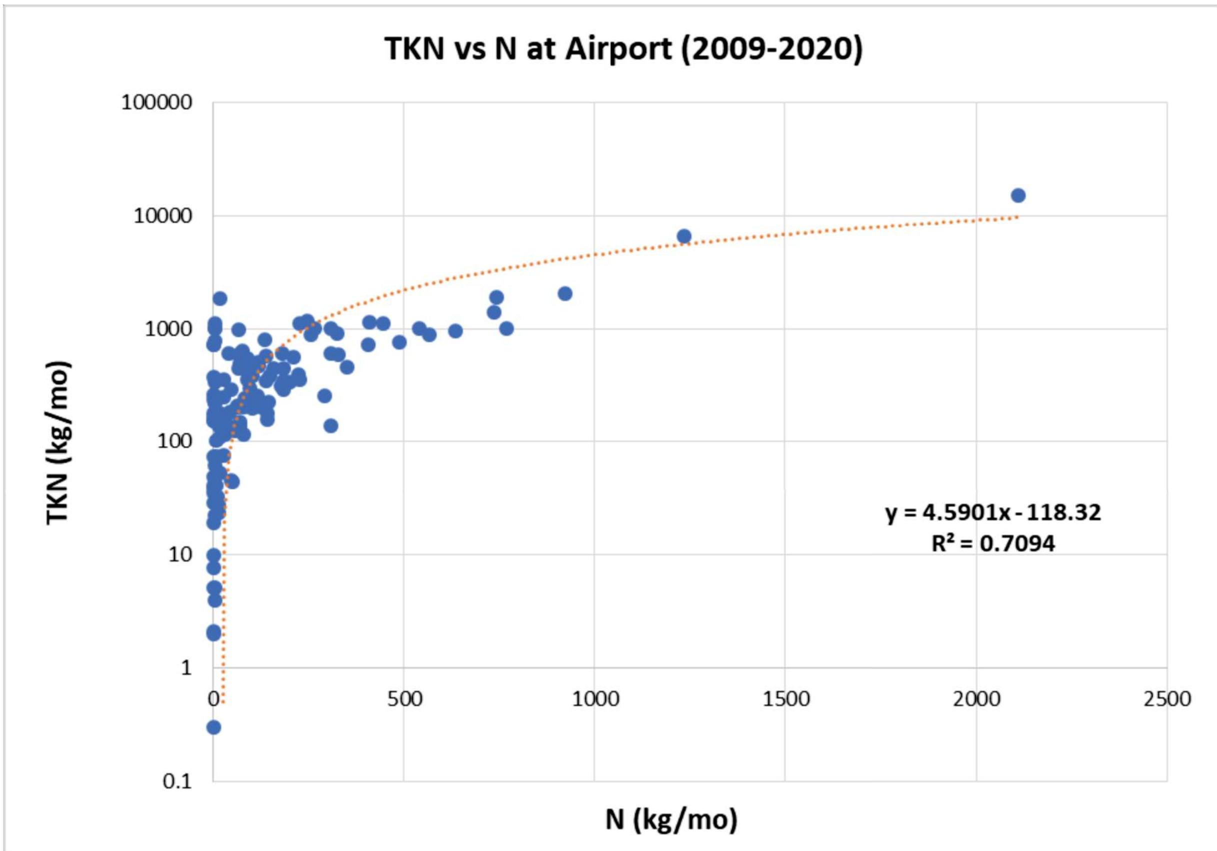




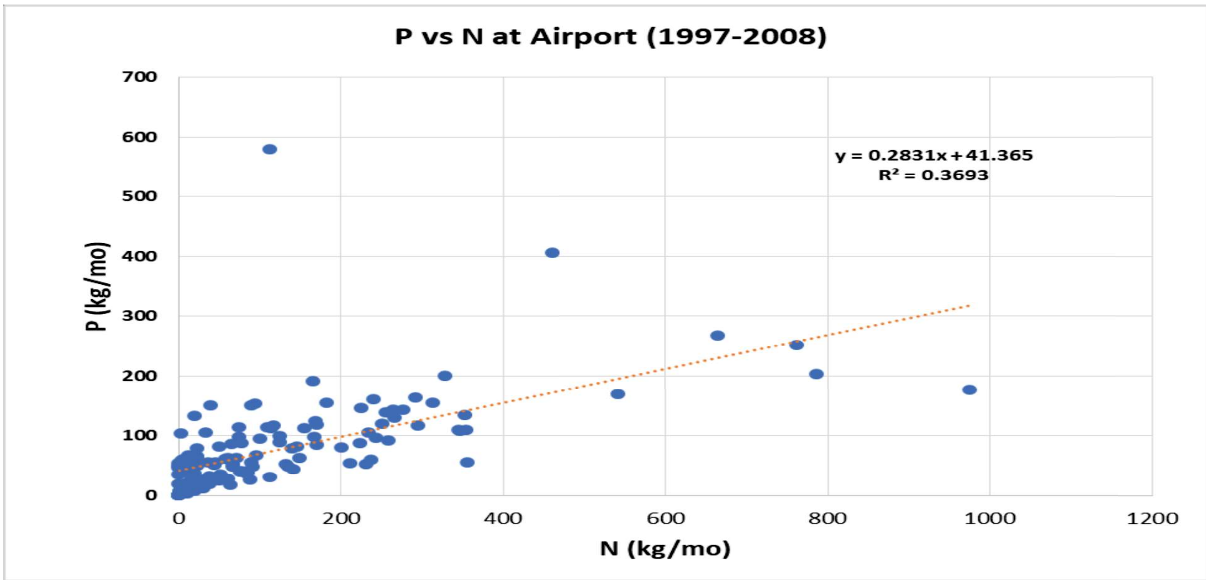
Total Kjeldahl (TKN) versus total Nitrogen (N)

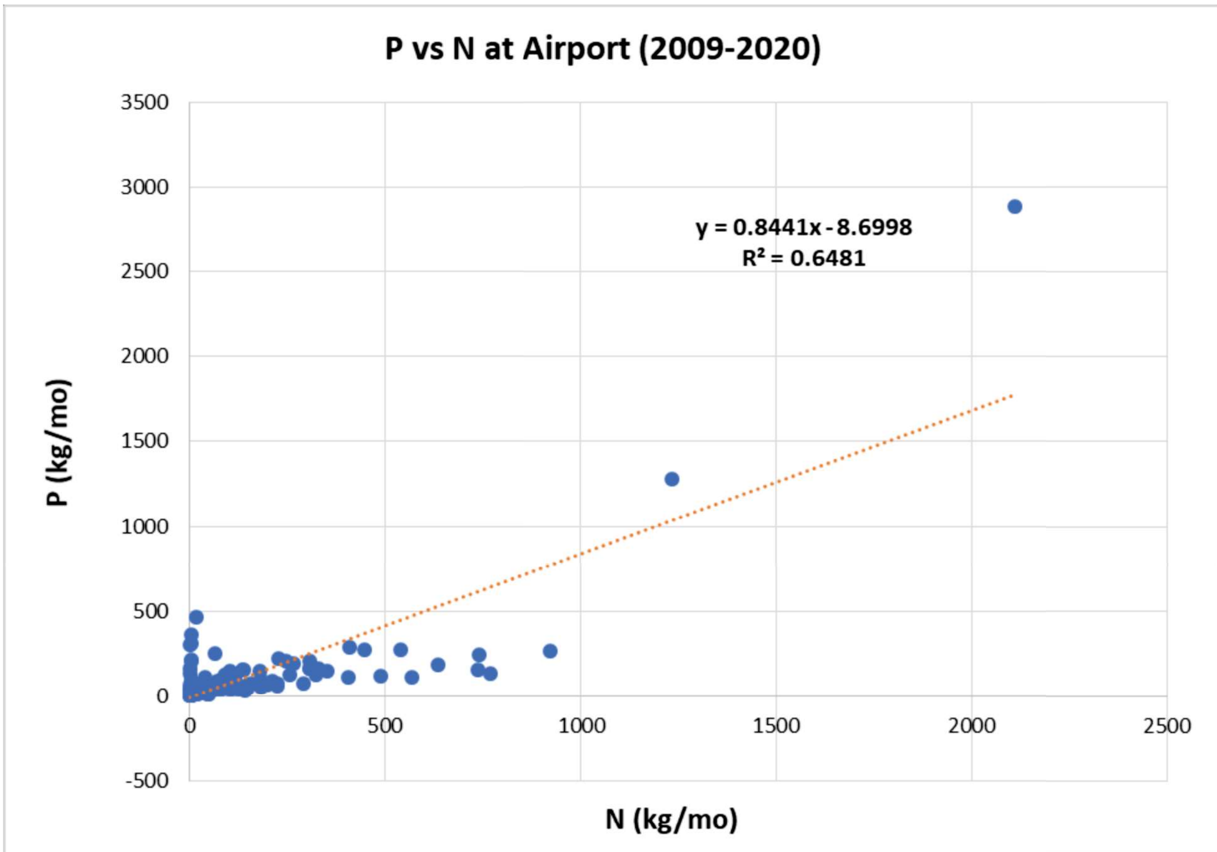



TKN vs N at Airport (1997-2008)
10000
1000
100
10
1
0.1
TKN (kg/mo)
0
200
400
600
800
1000
1200
N (kg/mo)
y = 1.9116x + 222.03
R² = 0.4035


TKN vs N at Airport (2009-2020)
100000
10000
1000
100
10
1
0.1
TKN (kg/mo)
0
500
1000
1500
2000
2500
N (kg/mo)
y = 4.5901x - 118.32
R² = 0.7094

Total Phosphorus (P) versus total Nitrogen (N)

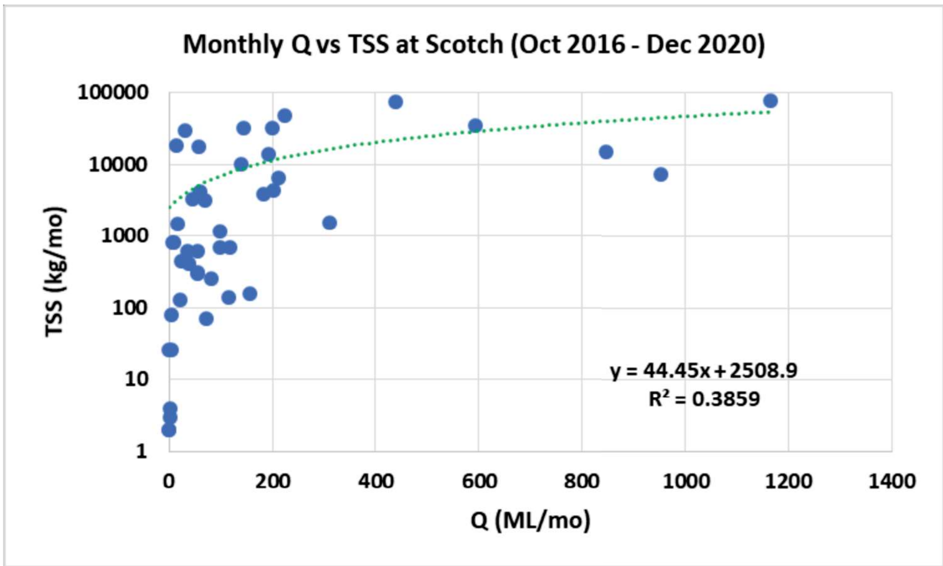




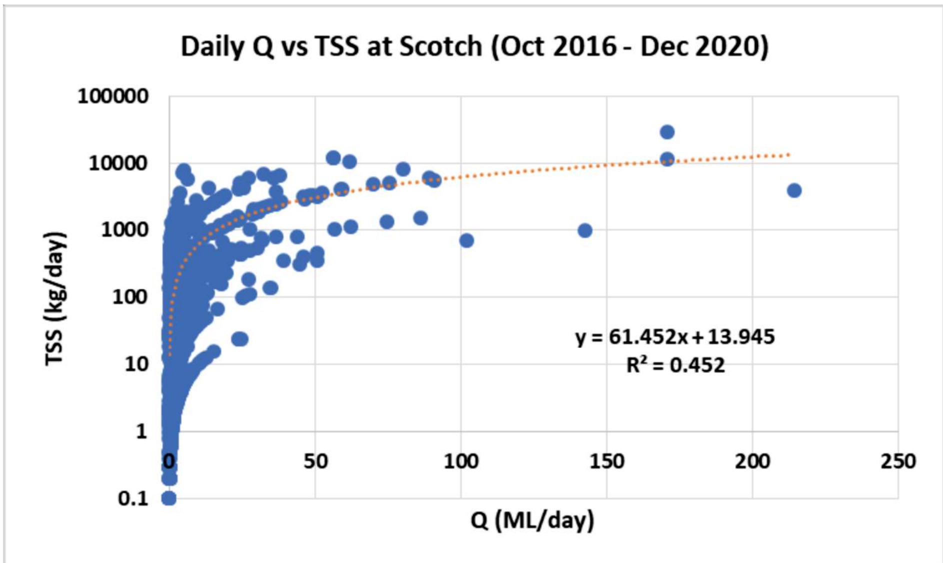
Appendices C

Monthly vs Daily variation and relationship in data at Scotch College gauging station

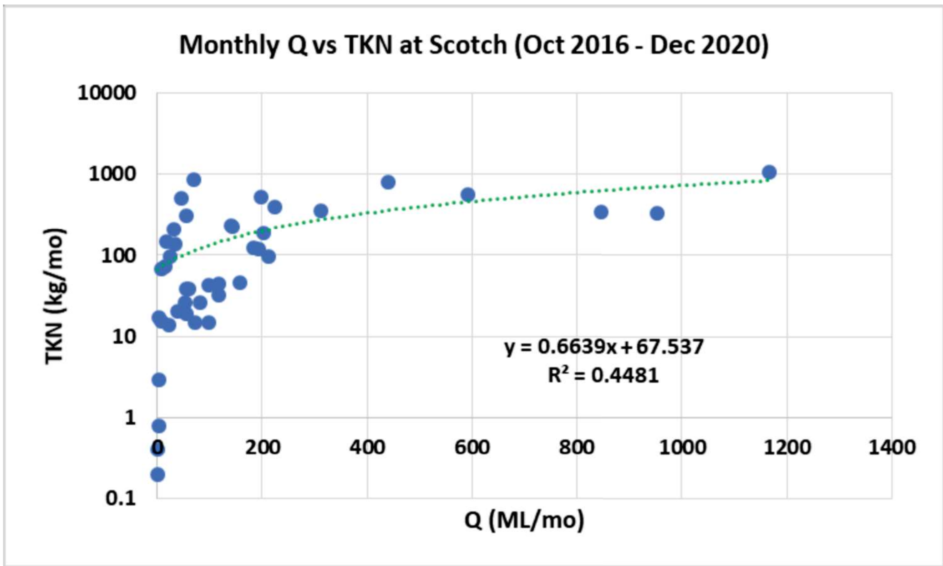
Monthly Discharge (Q) versus total Suspended Solids (N)



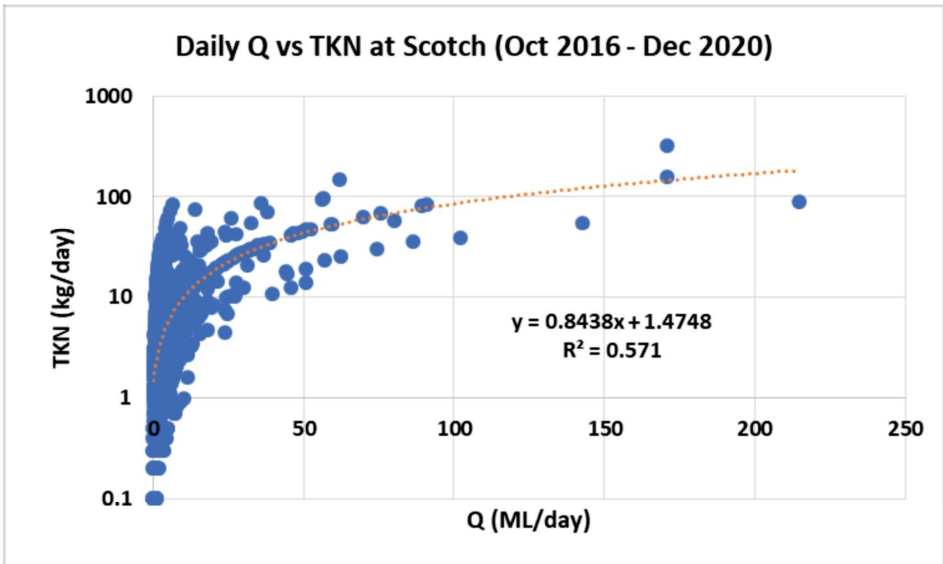
Monthly Discharge (Q) versus total Suspended Solids (N)



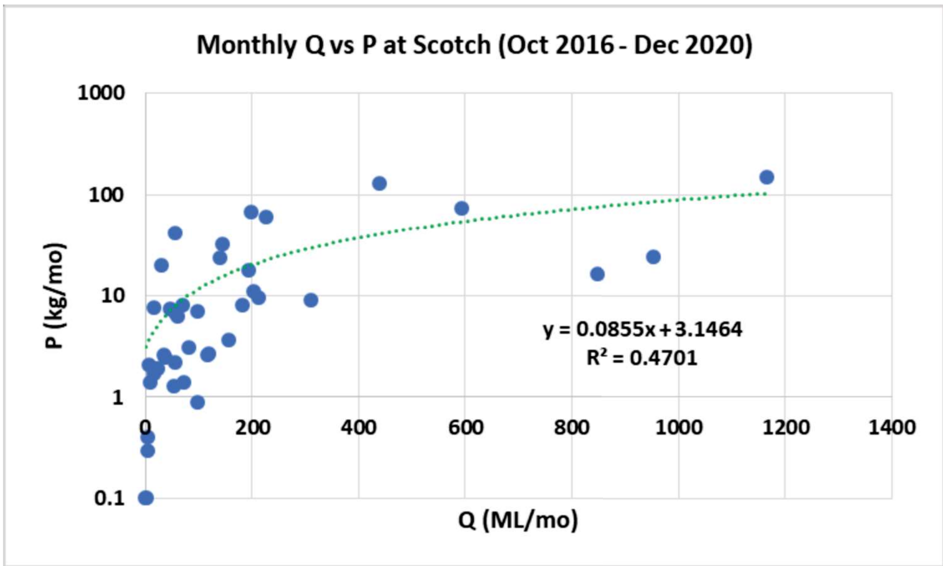
Monthly Discharge (Q) versus total Kjeldahl (TKN)



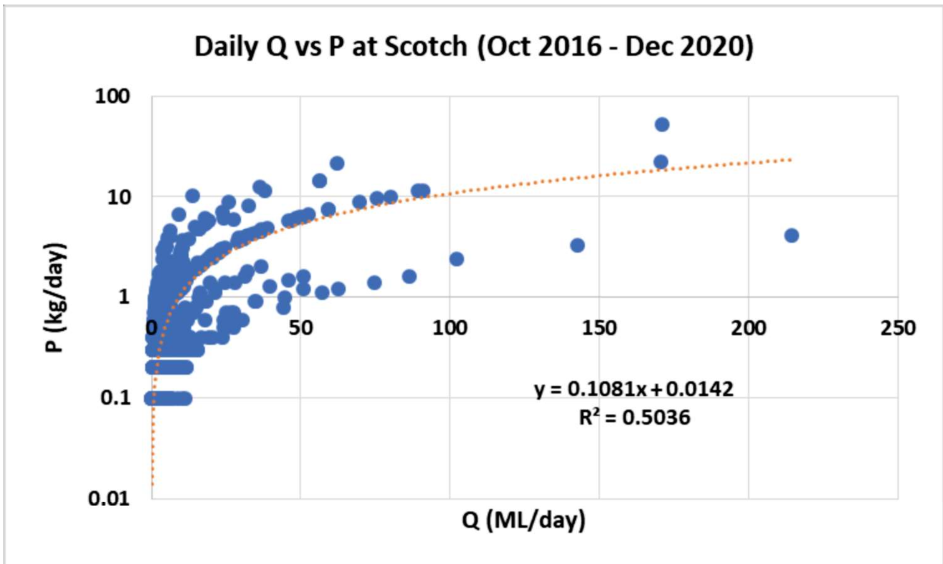
Daily Discharge (Q) versus total Kjeldahl (TKN)



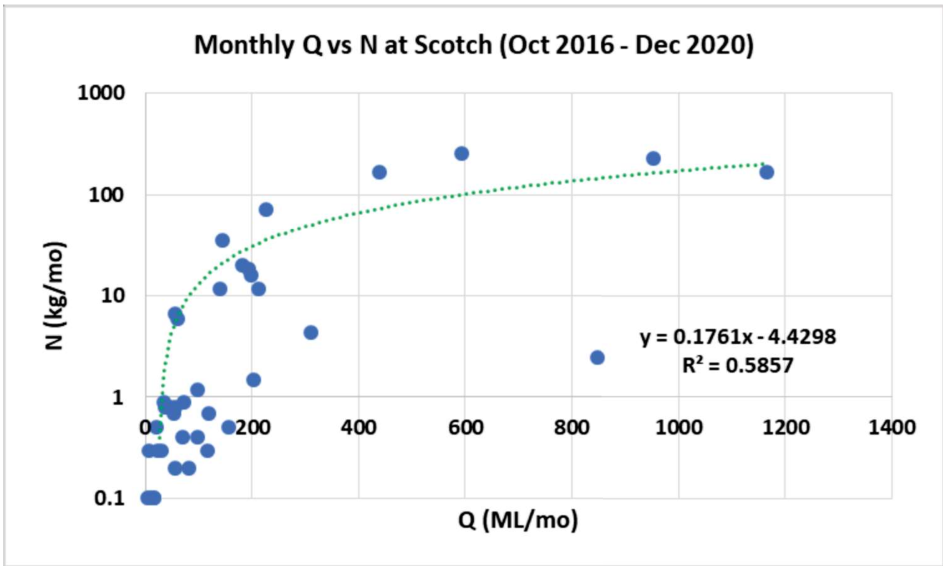
Monthly Discharge (Q) versus total Phosphorus (P)



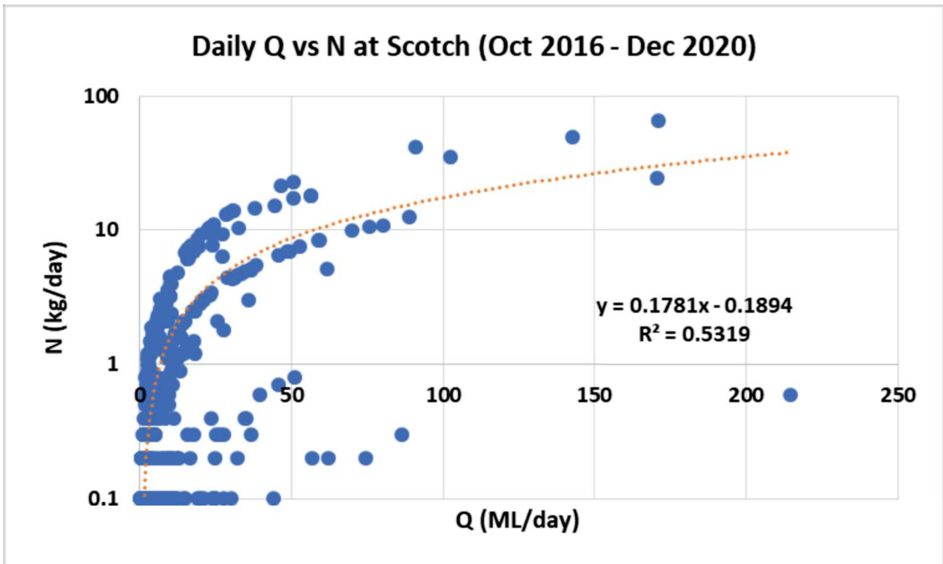
Daily Discharge (Q) versus total Phosphorus (P)



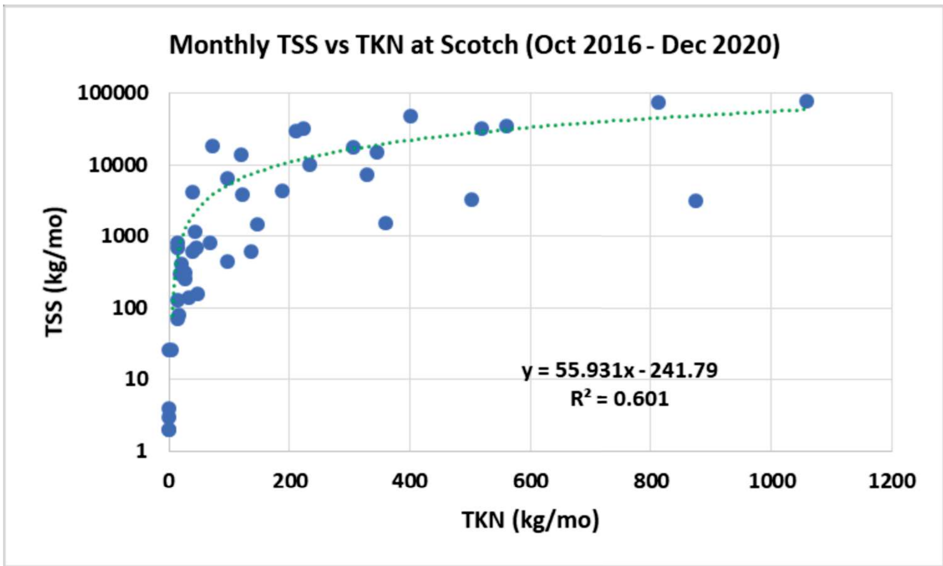
Monthly Discharge (Q) versus total Nitrogen (N)



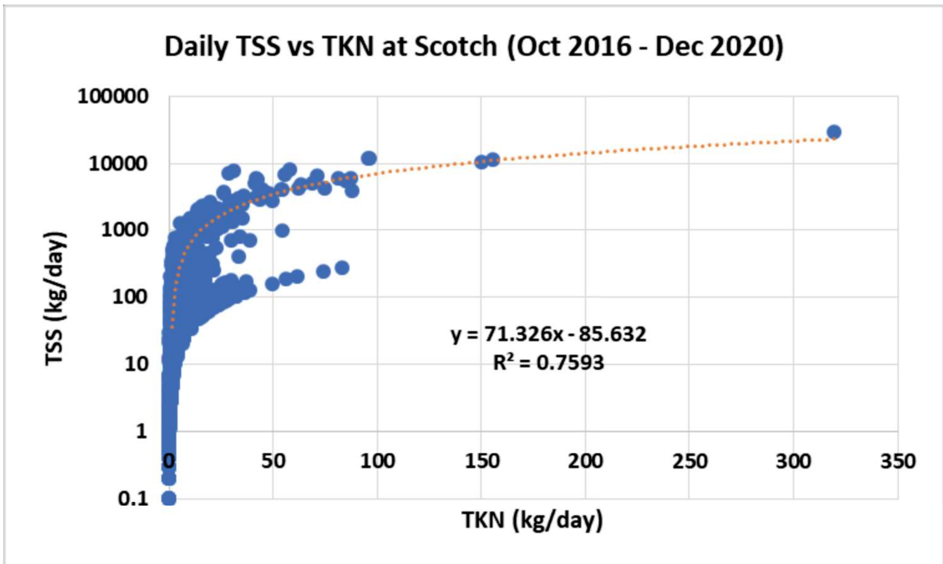
Daily Discharge (Q) versus total Nitrogen (N)



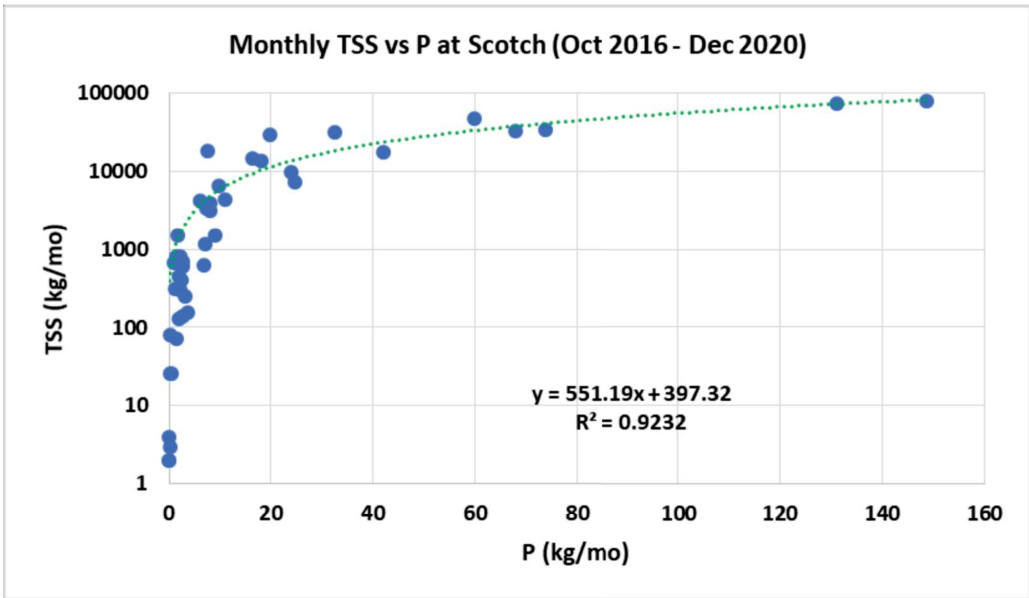
Monthly total Suspended Solids (TSS) versus total Kjeldahl (TKN)



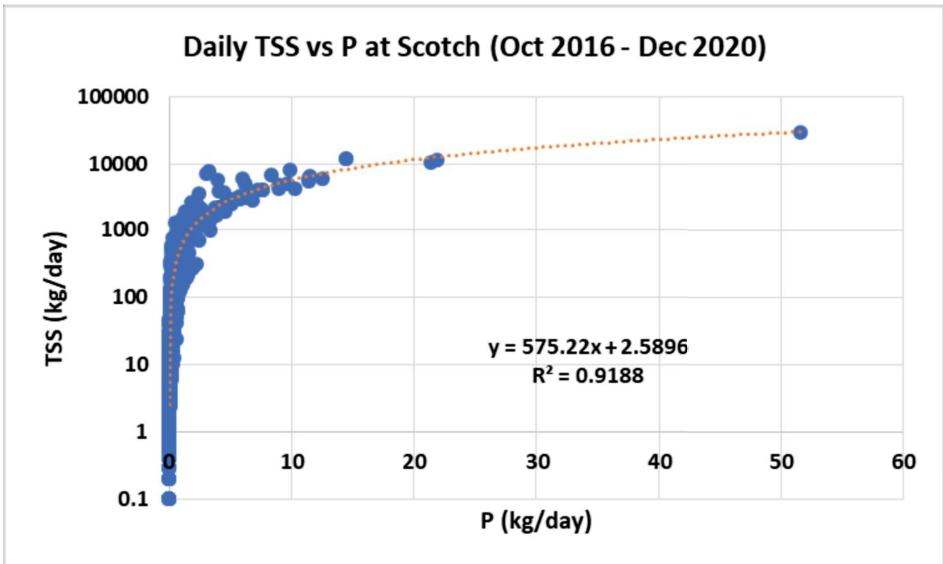
Daily total Suspended Solids (TSS) versus total Kjeldahl (TKN)



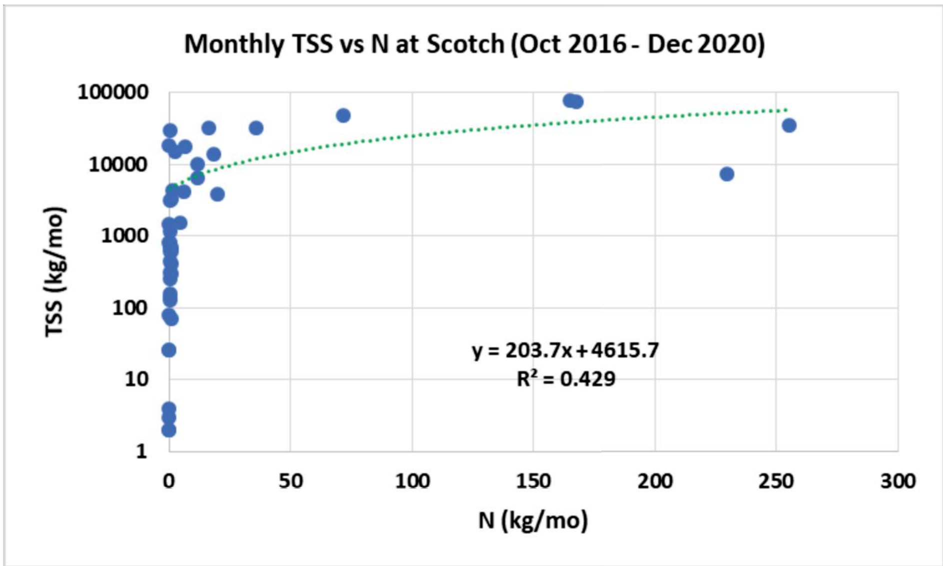
Monthly total Suspended Solids (TSS) versus total Phosphorus (P)



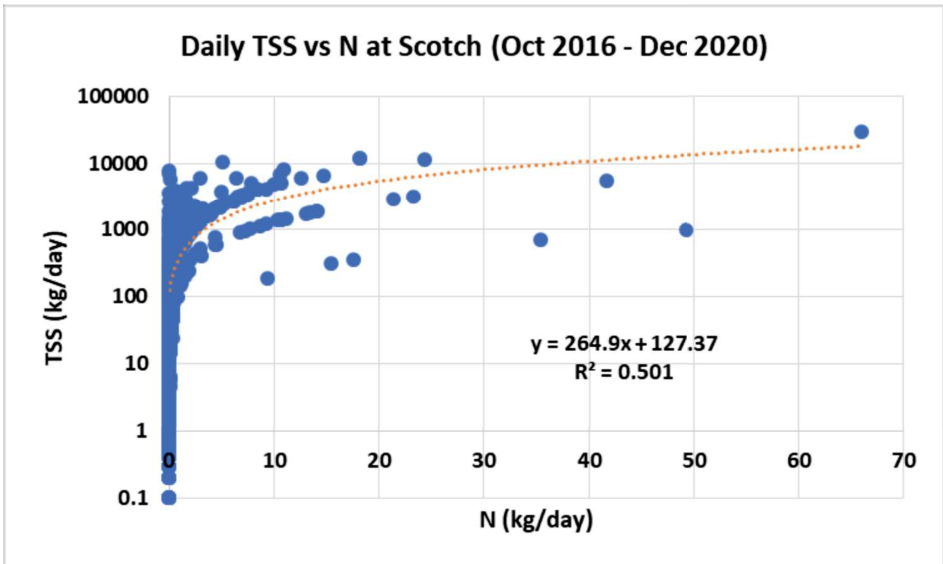
Daily total Suspended Solids (TSS) versus total Phosphorus (P)



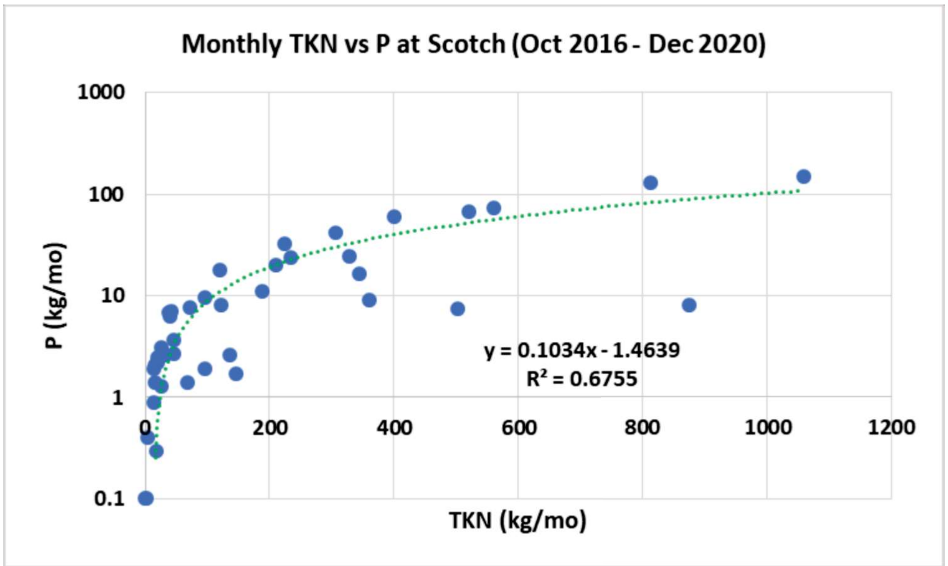
Monthly total Suspended Solids (TSS) versus total Nitrogen (N)



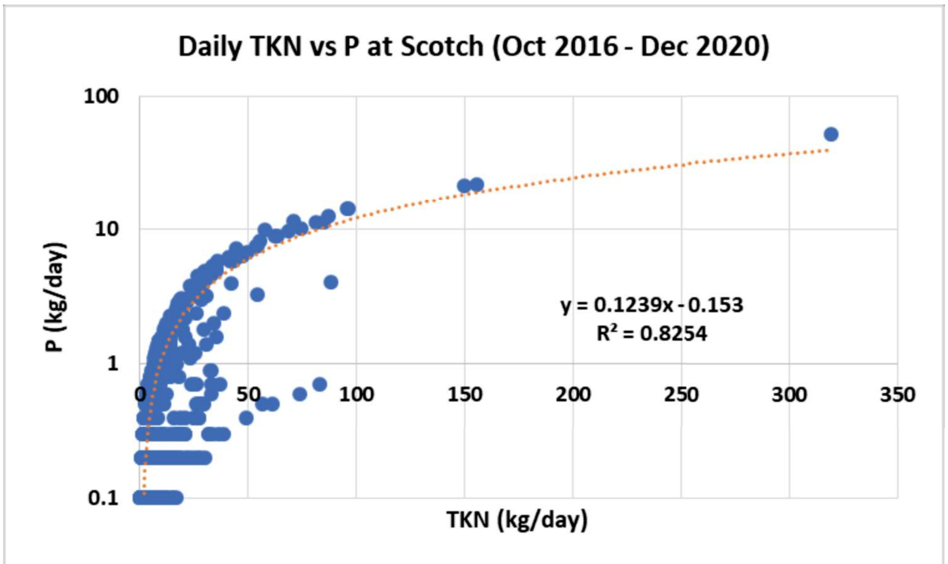
Daily total Suspended Solids (TSS) versus total Nitrogen (N)



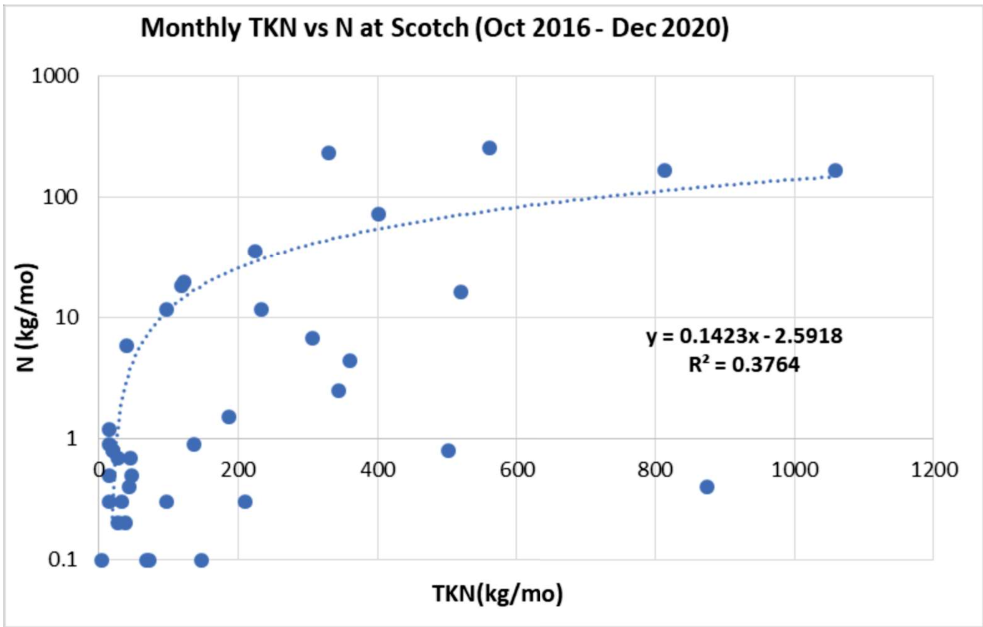
Monthly total Kjeldahl (TKN) versus total Phosphorus (P)



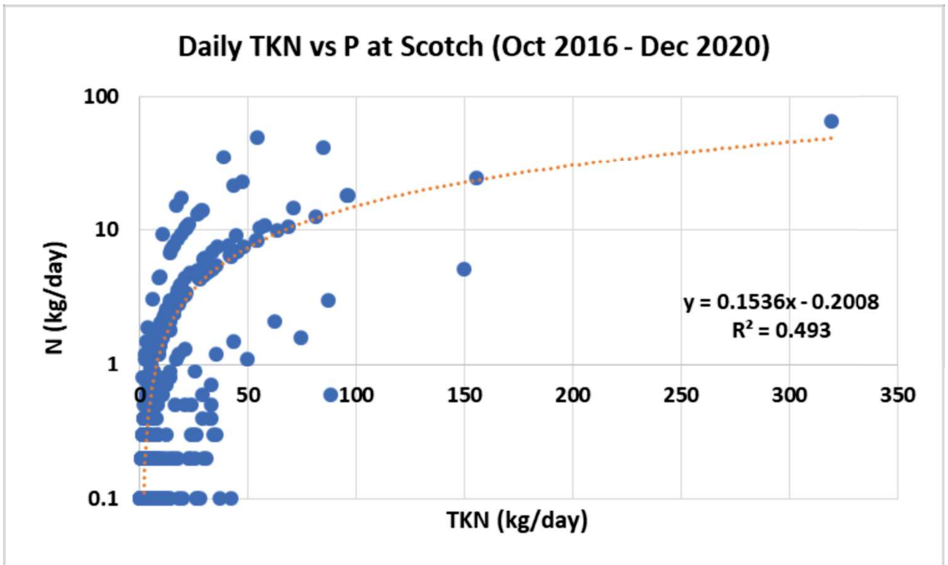
Daily total Kjeldahl (TKN) versus total Phosphorus (P)



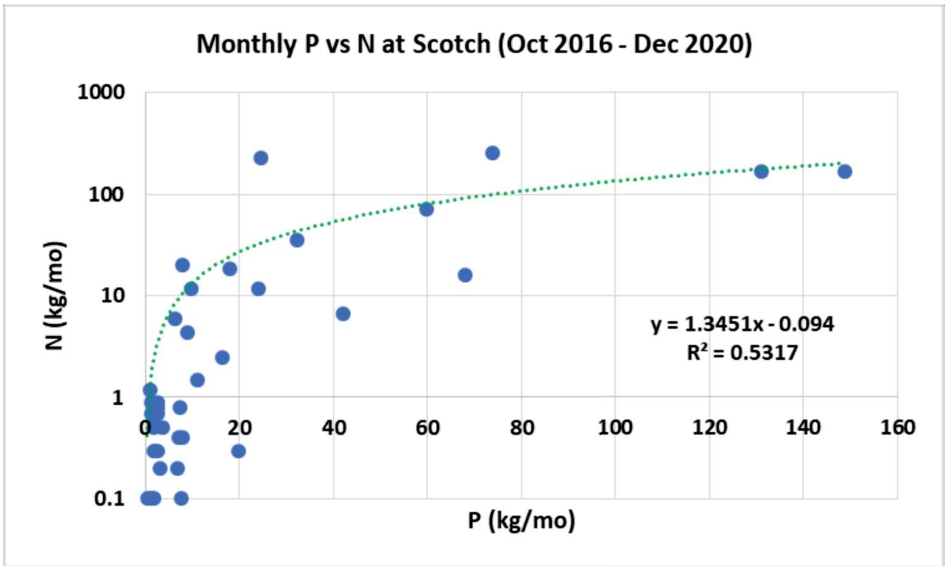
Monthly total Kjeldahl (TKN) versus total Nitrogen (N)



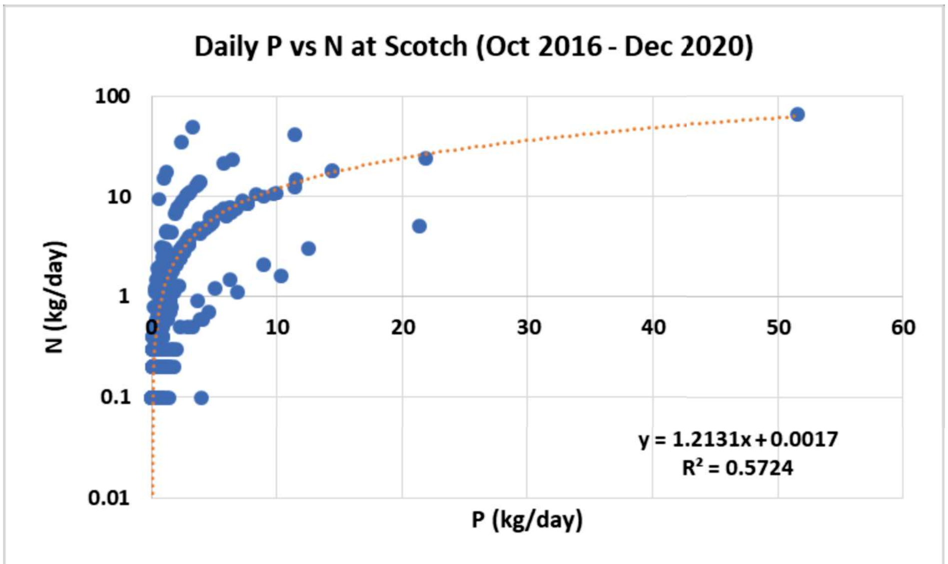
Daily total Kjeldahl (TKN) versus total Nitrogen (N)



Monthly total Phosphorus (P) versus total Nitrogen (N)



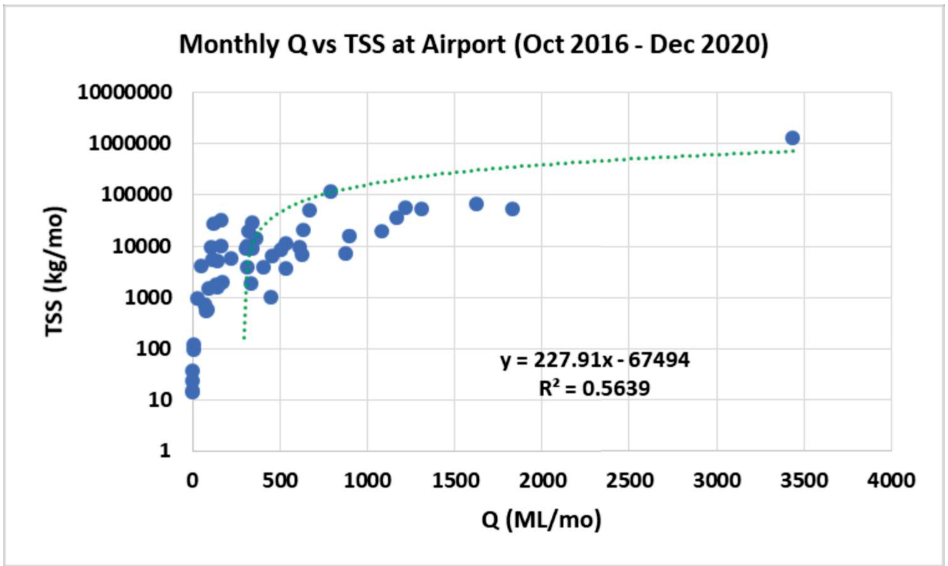
Daily total Phosphorus (P) versus total Nitrogen (N)



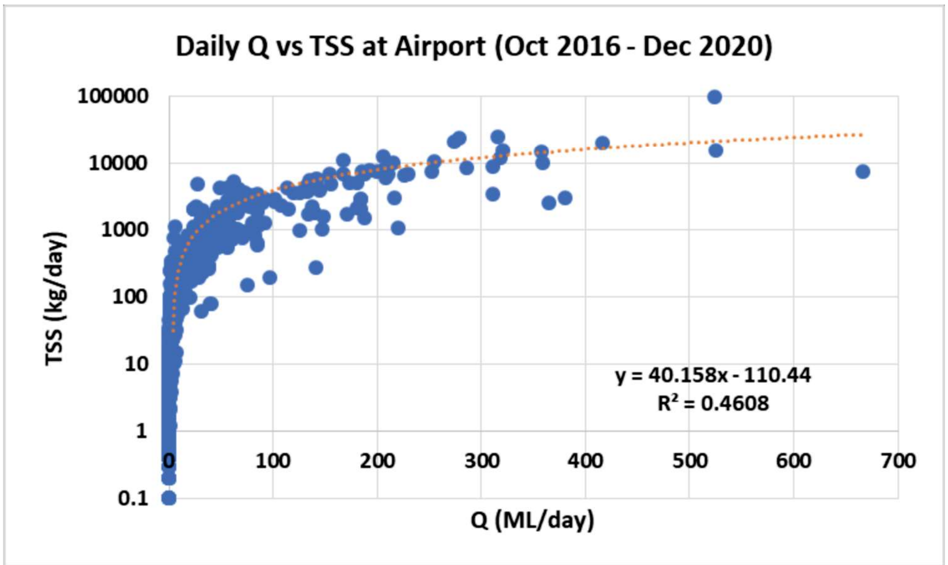
Appendix D

Daily vs Monthly variation and relationship in data at Adelaide Airport gauging station

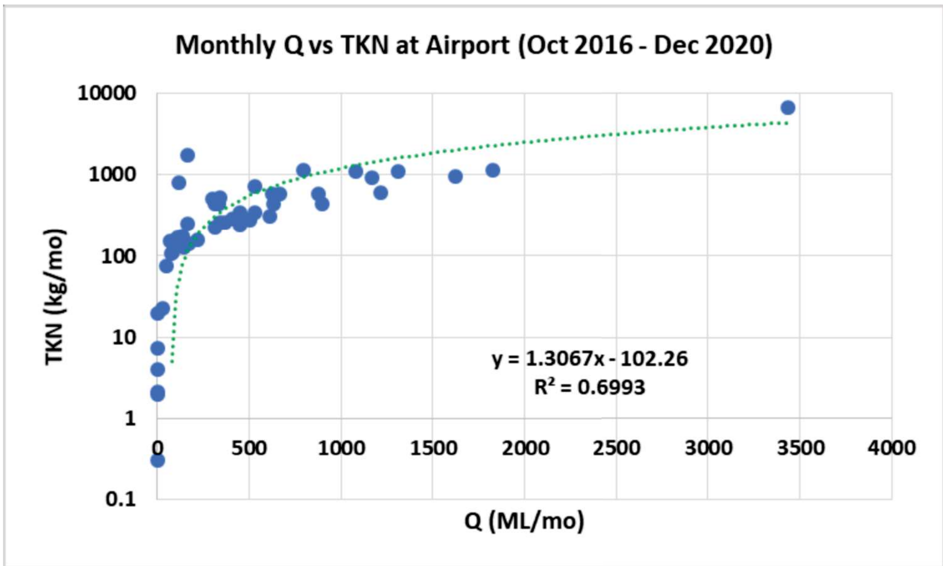
Monthly total Discharge (Q) versus total Suspended Solids (TSS)



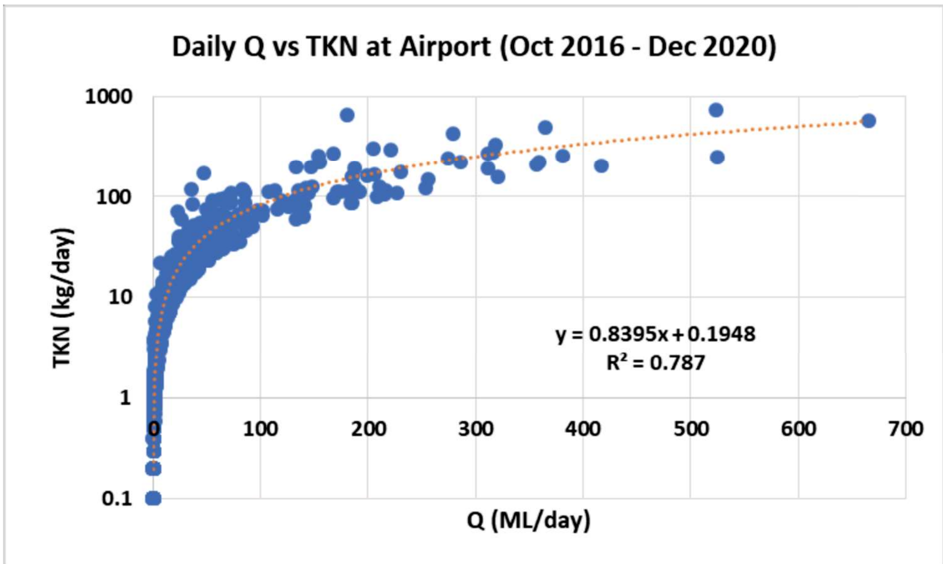
Daily total Discharge (Q) versus total Suspended Solids (TSS)



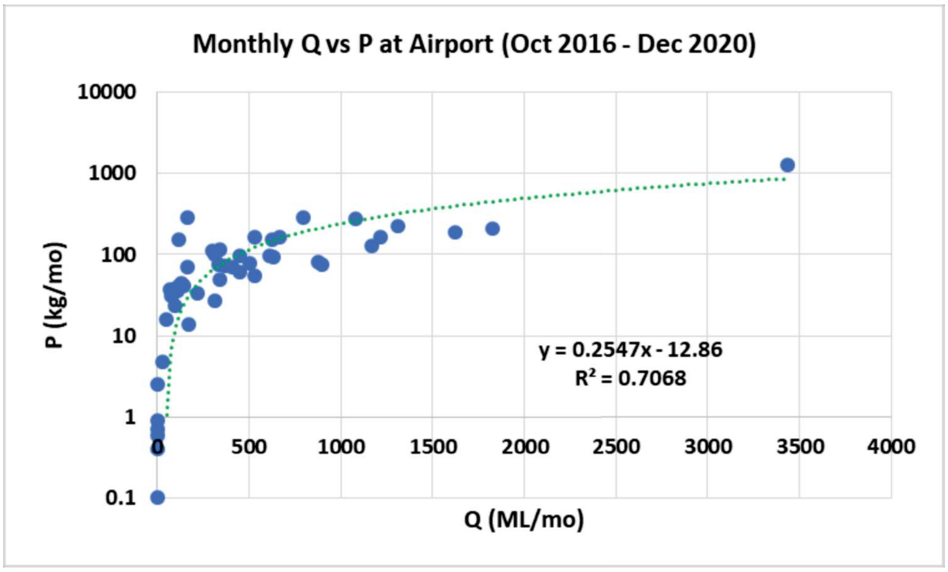
Monthly total Discharge (Q) versus total Kjeldahl (TKN)



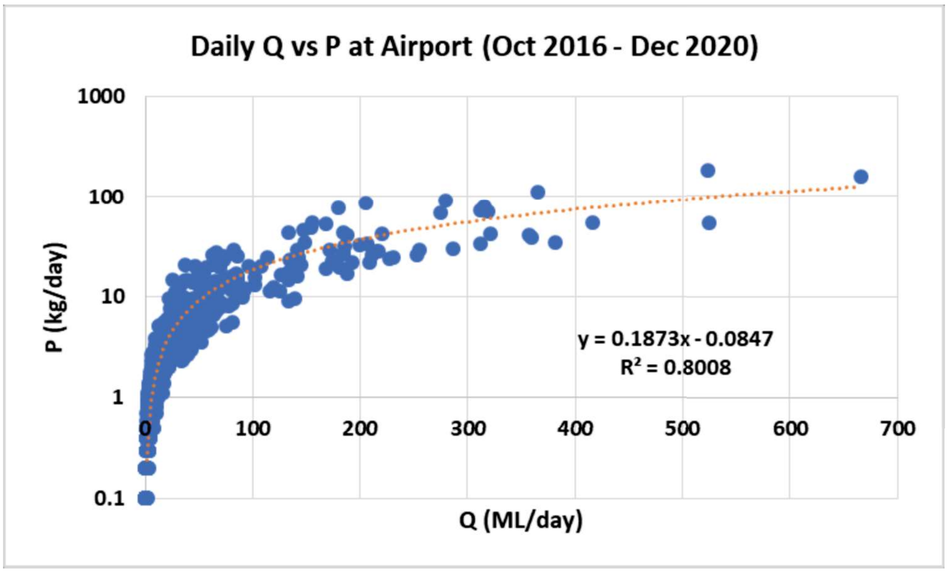
Daily total Discharge (Q) versus total Kjeldahl (TKN)



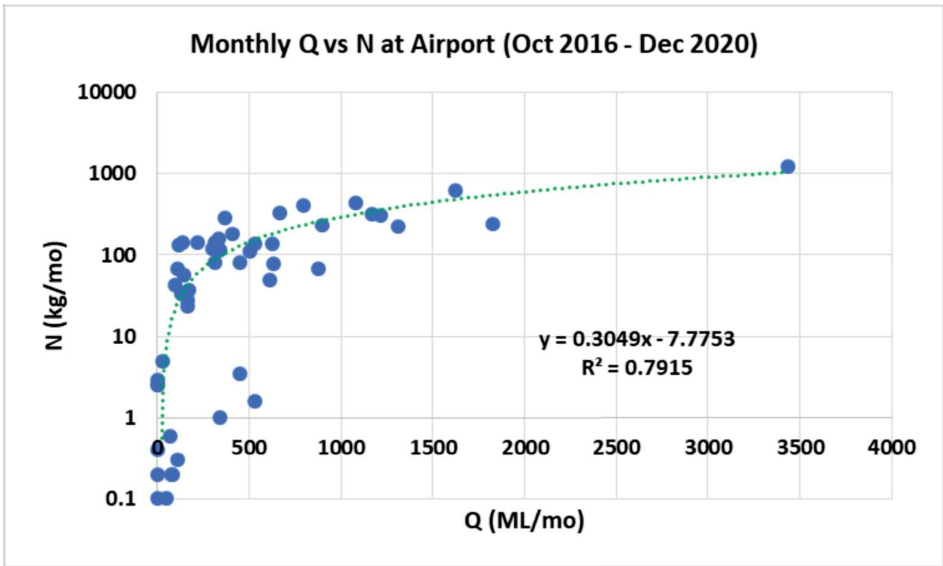
Monthly total Discharge (Q) versus total Phosphorus (P)



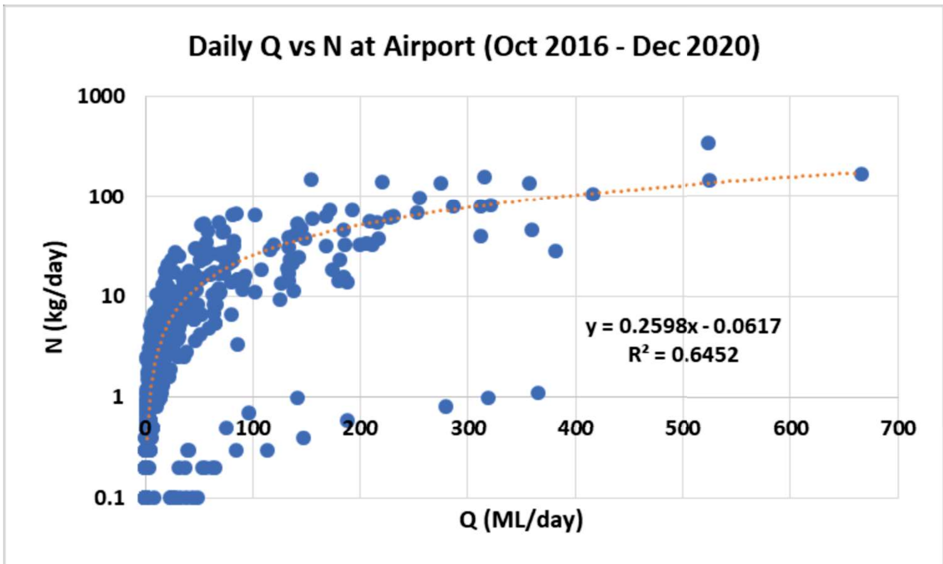
Daily total Discharge (Q) versus total Phosphorus (P)



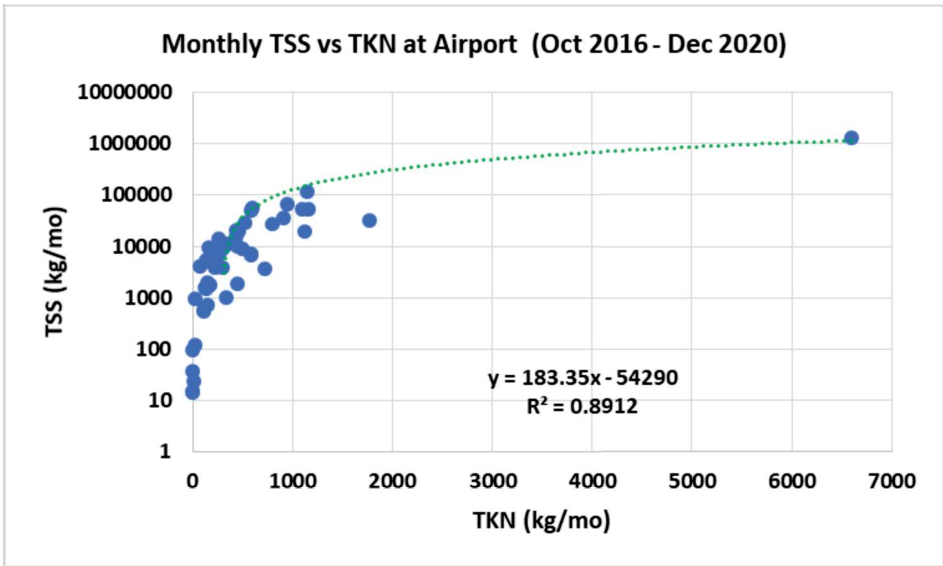
Monthly total Discharge (Q) versus total Nitrogen (N)



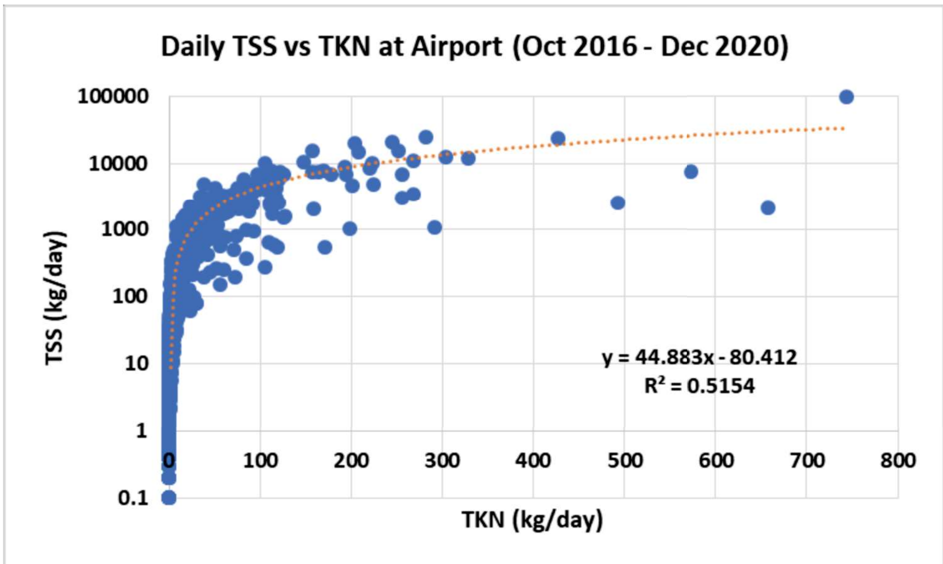
Daily total Discharge (Q) versus total Nitrogen (N)



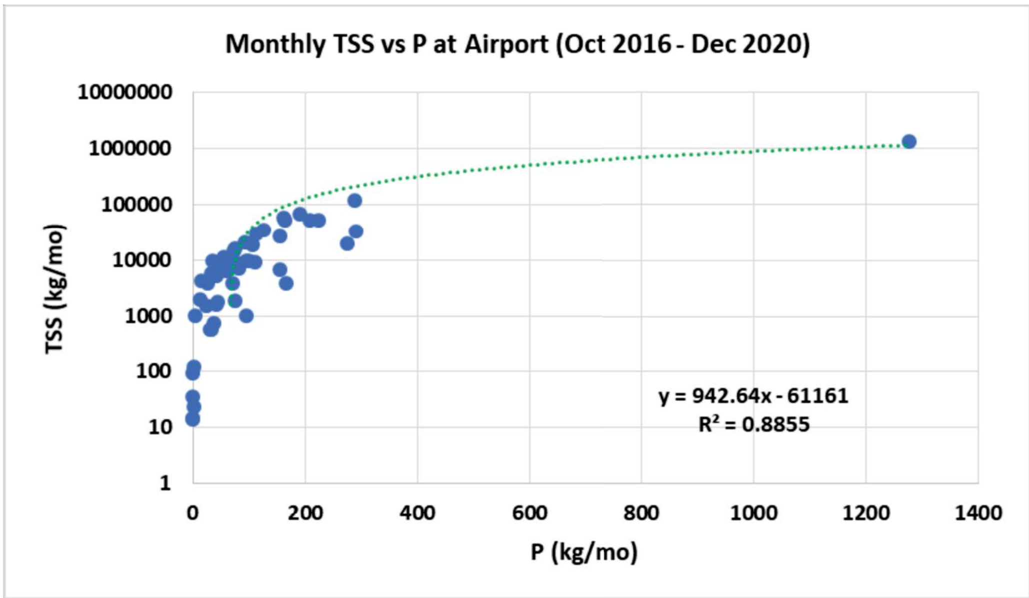
Monthly total Suspended Solids (TSS) versus total Kjeldahl (TKN)



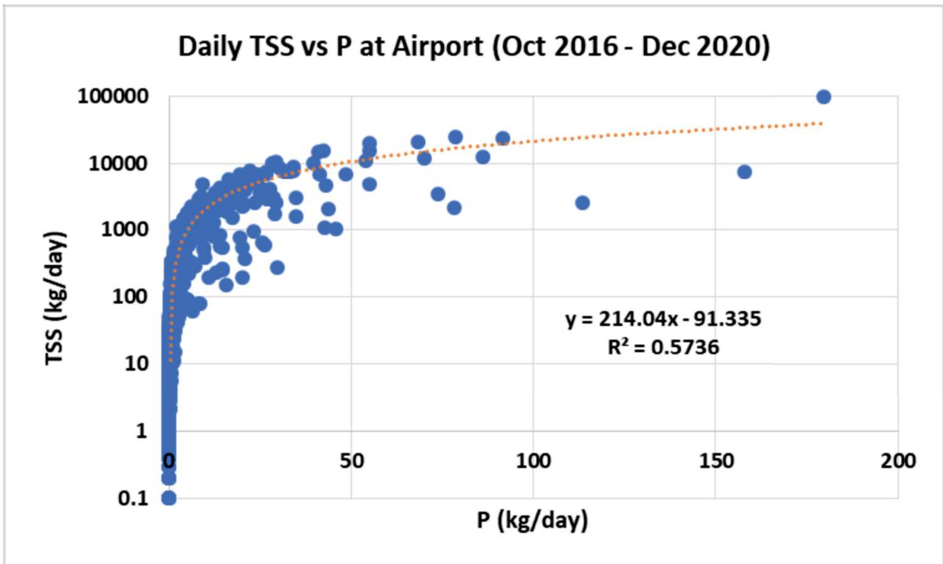
Daily total Suspended Solids (TSS) versus total Kjeldahl (TKN)



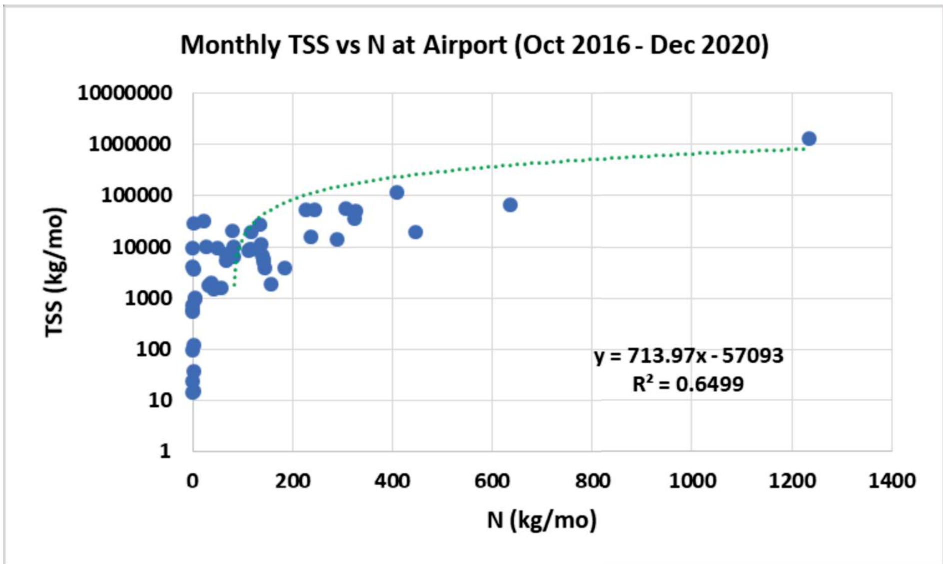
Monthly total Suspended Solids (TSS) versus total Phosphorus (P)



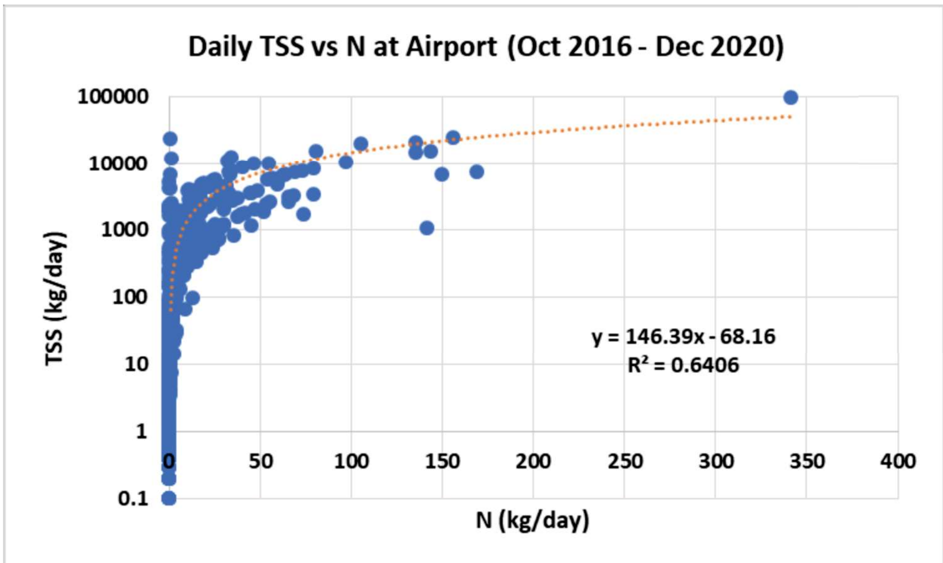
Daily total Suspended Solids (TSS) versus total Phosphorus (P)



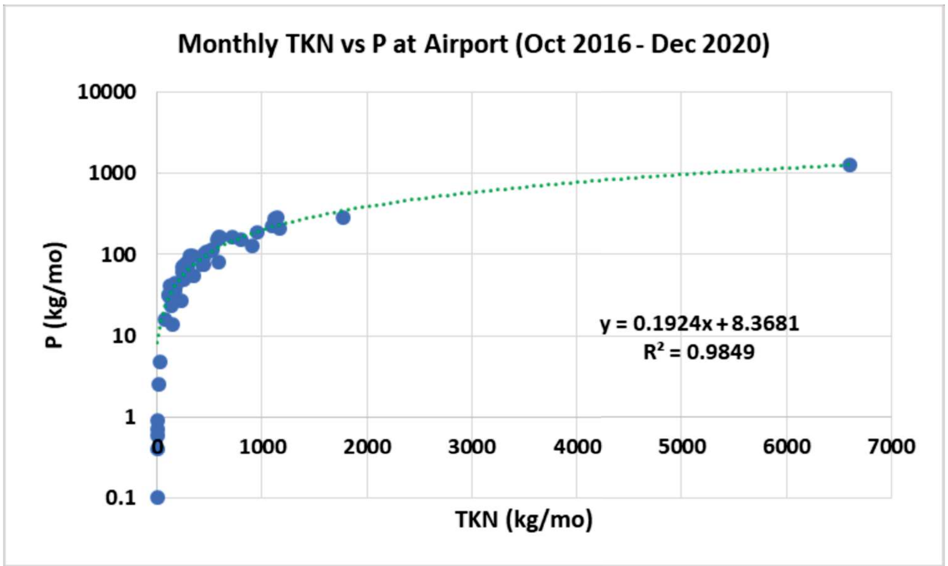
Monthly total Suspended Solids (TSS) versus total Nitrogen (N)



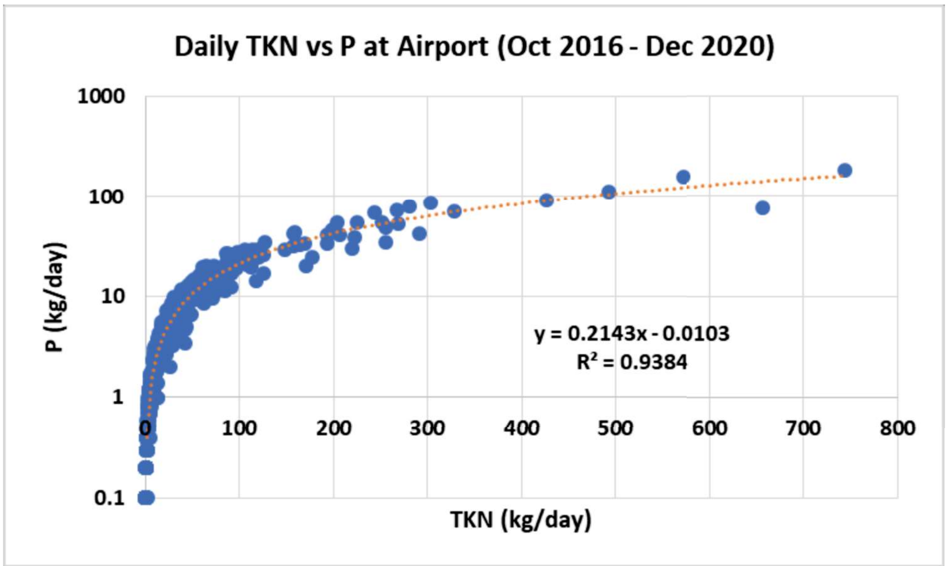
Daily total Suspended Solids (TSS) versus total Nitrogen (N)



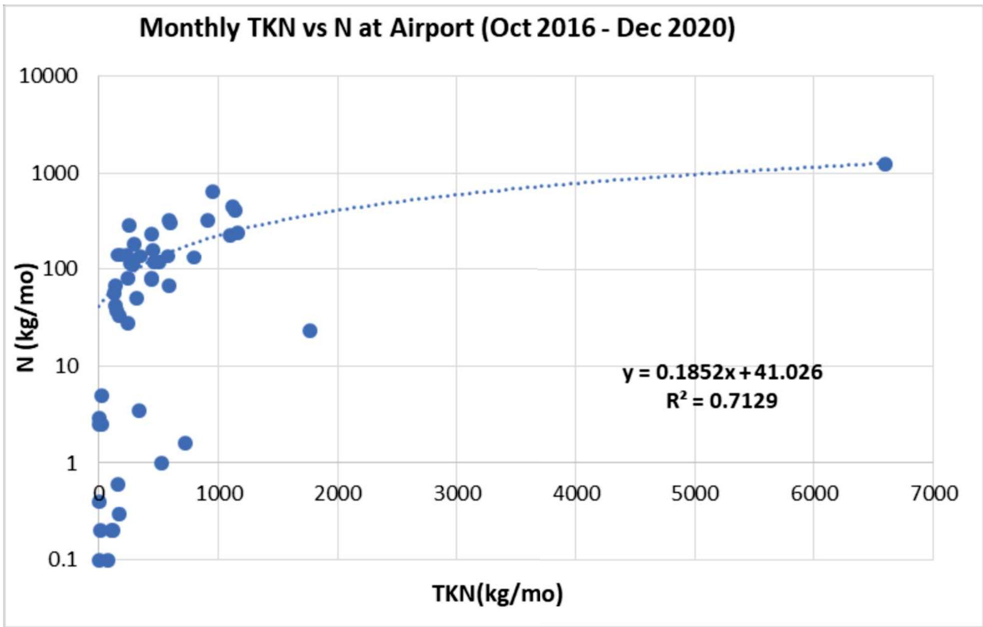
Monthly total Kjeldahl (TKN) versus total Phosphorus (P)



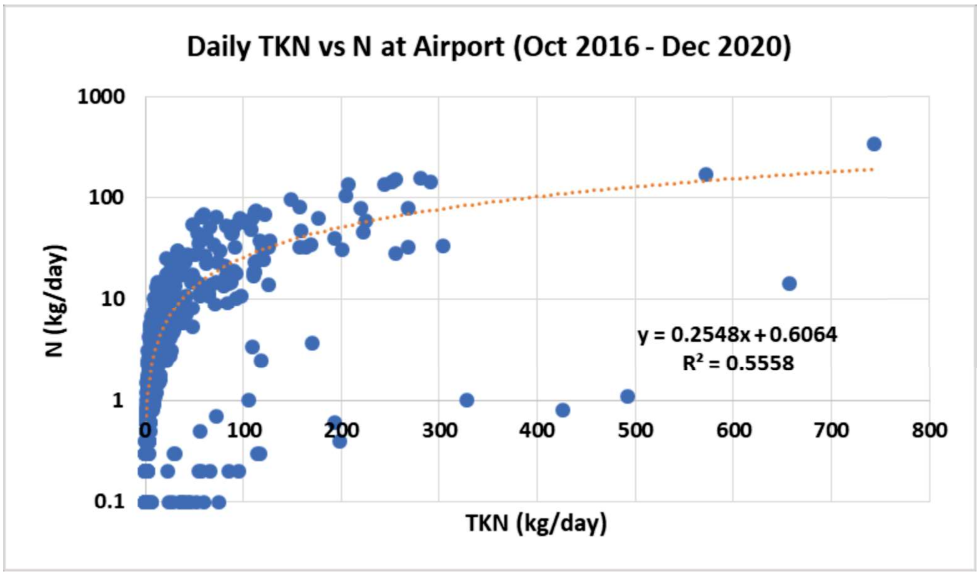
Daily total Kjeldahl (TKN) versus total Phosphorus (P)



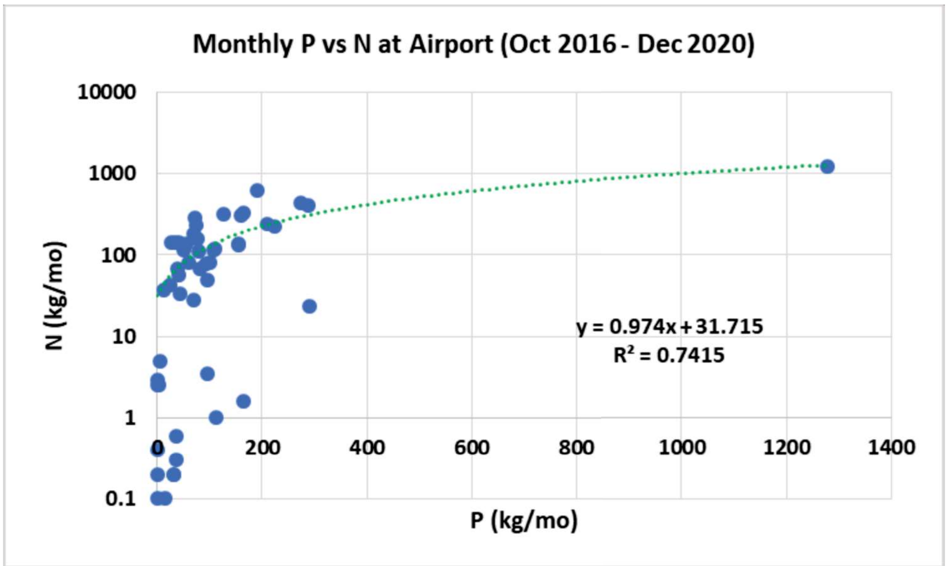
Monthly total Kjeldahl (TKN) versus total Nitrogen (N)



Daily total Kjeldahl (TKN) versus total Nitrogen (N)



Monthly total Phosphorus (P) versus total Nitrogen (N)



Daily total Phosphorus (P) versus total Nitrogen (N)