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Water quality dynamics of Lake James in the Catawba River Basin of North Carolina

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WATER QUALITY DYNAMICS OF LAKE JAMES IN THE CATAWBA RIVER BASIN OF NORTH CAROLINA

A Dissertation
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy
Biological Sciences

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by
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Accepted by:
Dr. James Schindler, Committee Chair
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Dr. Gene Eidson
Dr. John Hains

ABSTRACT

Lake James is the uppermost hydropower reservoir in the Catawba River drainage in North Carolina. The Lake James Assessment (LJA) was a descriptive study initiated between Clemson University and Duke Energy Corporation to explore the physical, chemical and biological dynamics of this oligotrophic reservoir from spring 1997 through fall 1999 (Schindler 1997). The goals of this study were to ascertain the primary drivers for the chemical dynamics of Lake James, to assess the quantities of constituents entering and leaving the reservoir, where these chemicals were incorporated within the reservoir basins, and to evaluate the efficacy of the LJA chemical budget model (LJA-CB) against traditional calculations for measures of reservoir loading and yield. I hypothesized that meteorology and lithology would be the dominant factors regulating the chemical dynamics of Lake James (Gibbs 1979, 1992). I also hypothesized that assimilation of chemical constituents within Lake James would adhere to the heuristic model of longitudinal segmentation of reservoirs of Thornton et al. (1981). I further hypothesized that the LJA-CB model based on average daily flows and monthly chemical concentrations would be more reflective of the variability in constituent loading and yield for Lake James than the traditional methods generated using average annual flows and average annual chemical concentrations (Olem and Flock 1990).

The LJA water balance (LJA-WB) and LJA-CB models were developed in the STELLA modeling environment to quantify the hydrological and chemical dynamics of Lake James. Results of the energy budget (LJA-EB) and LJA-WB generated during the period of study indicated significant water losses (approaching 20% of the total volume)

from the reservoir each year with 7% attributed to evaporation and 13% to unmonitored losses. Post facto analysis of turbine losses conducted by Knight (2003) indicated losses of 1.56 m^3/s (55 ft^3/s) through the turbines in the Bridgewater Hydroelectric Facility (BHF), a value twice what was estimated at the time of our study (Knight 2003).

The LJA-CB was developed around the LJA-WB in STELLA as a Graphical User Interface (GUI) based modified Vollenweider (1969)/Chapra (1975 and 1979) style empirical mass balance model for an incompletely-mixed laterally-segmented reservoir with an embayment. Thornton et al. (1981) developed a heuristic model of longitudinal segmentation of reservoirs which stresses the importance of linear distance in the processing of watershed inputs into the reservoir (Thornton et al. 1981, Thornton 1990, Kennedy and Walker 1990). The LJA-CB allows for determination of lateral zones of constituent assimilation and assumes hydrology is the driving variable for the system. By summing the daily loading over a year, an annual loading estimate for each segment of the lake was calculated that was volume weighted and was used to make inferences about the spatial distribution of chemicals within the lake.

I ascertained that most of the constituent loading into the Lake James basin is derived from the Catawba River watershed (most notably the North Fork Catawba sub-watershed) and that most of the inflowing material is retained by the reservoir. I further discerned that relatively limited numbers of high flow events are responsible for providing the bulk of materials assimilated within the lake basins. I confirmed that the headwaters and upper transition zones of the Lake James reservoir have greater rates of sedimentation of most constituents relative to the lower transition and lacustrine zones and validates the model proposed by Thornton et al. (1981) and later work on spatial sedimentation of constituents and subsequent ecosystem production by Kennedy et al. (1982). However, the lacustrine station for the Linville basin is the receiving embayment for both basins and reflects the greater loading being brought in from the Catawba Basin.

I employed traditional loading calculations (Olem and Flock 1990) using monthly chemical concentrations and average daily discharge which were averaged for each year to provide a conservative estimate of loading and yield from the Lake James watershed. By comparing the LJA-CB with traditional loading and yield calculations I found that the traditional methods, in general, tended to be adequate for hydrologically driven constituents; however, biologically and redox regulated constituents do not appear to be sufficiently represented using traditional calculations of loading and yield.

DEDICATION

I dedicate this volume to my family and friends who have lovingly supported my efforts throughout my education. I thank my parents, Thames and Tootsie Lloyd, for their ongoing support and I credit them with my endless love of reading and passion for knowledge. To my in-laws, Al and Elouisa Stokes, I offer my deepest gratitude for their generous care of my family in the midst of this commitment. To my siblings and friends I offer my appreciation for the many phone calls and notes of support when the pressures of work kept me from returning the sentiment – they have always filled my cup. To my husband, Mark Stokes, I offer my love and thanks for his care and technical skills that have made the impossible become possible. And above all, I dedicate this work to my sons, Riley and Thames Stokes, in hopes that perhaps some day they will understand my passion for learning and the time it has required.

ACKNOWLEDGMENTS

I wish to acknowledge Duke Energy Corporation for their funding and for engaging Clemson University in this characterization of Lake James and the opportunity it provided me to learn about reservoir limnology. I would like to thank Bill Foris of Duke Energy and Dr. Jon Knight of Devine, Tarbell and Associates for their education, friendship and support during this study.

I thank Dr. Hap Wheeler, Department Chair of Biological Sciences, for believing in me even when the chips were down. I wish to recognize my officemate and colleague, Master Kate Elrod, for her insightful perceptions, her editorial assistance and helping to care for my children. I thank Dr. Howard Loring for many years of coffee and good counsel. I wish also to thank Chris Benson for his instruction in guitar and Mary Ellen LeFort for instruction in yoga - whose care and teaching have brought balance to my universe.

I thank my graduate committee, Dr. Jim Colacino, Dr. John Hains and Dr. Gene Eidson, for their collegiality, for supporting my first grant attempt, and for challenging me to grow. And I offer my deepest appreciation to my major professor, Dr. Jim Schindler, who has been patient and forgiving, but above all, for sharing his passion for the breadth of knowledge and being a mentor worthy of emulation. Arigato gozaimashita

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CHAPTER ONE

INTRODUCTION

Characterization of the geology and hydrology of the Lake James watershed

Brief Description of Lake James, NC

Lake James, the uppermost impoundment in the Catawba River drainage system, is a hydropower reservoir located at the transition between the Blue Ridge Escarpment and Inner Piedmont about 64 km east of Asheville, North Carolina between the towns of Marion and Morganton. Lake James is 365.76 m above mean sea level, lying in Burke and McDowell Counties of North Carolina. Lake James was formed by the impoundment of four headwater streams and their tributaries, including the Catawba River, the North Fork Catawba River, Paddy Creek and the Linville River (Figure 1). The lake was created by what is now Duke Energy Corporation between 1916 and 1919 with the construction of dams across the Catawba River and two tributaries, Paddy Creek and Linville River. These impoundments were connected by a broad canal to form a 27.01 km^2 body of water. Construction of Bridgewater Hydroelectric Station began on August 18, 1916. Commercial operation began on May 4, 1919 (Lyles and Lyles 2007).

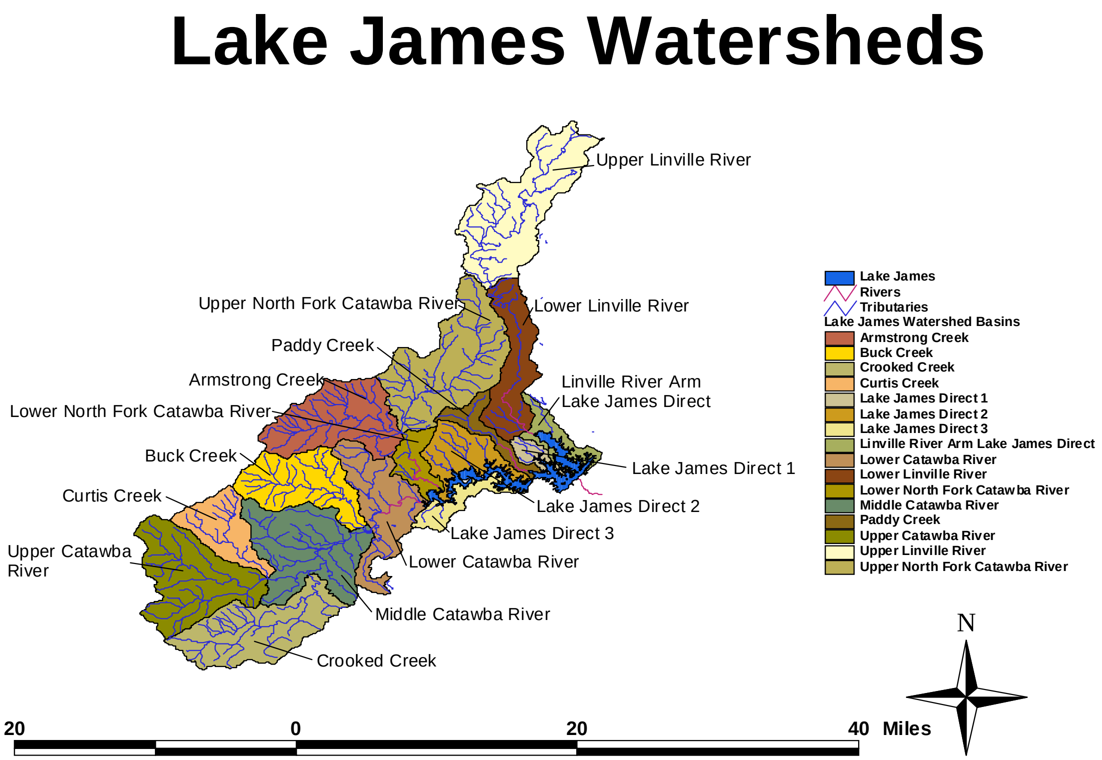


Figure 1 Watersheds of Lake James, NC

<u>Influence of geology on water quality</u>

Lake James takes its headwaters from the western edge of the Inner Piedmont and Blue Ridge Mountains of the Appalachians in a region known as the South Mountains (Stuckey and Steel 1953). The geochemical signatures within the reservoir and river basins reflect the geologic diversity of their derivation. The climate, lithology, soil type, land use and morphology of a watershed affect the physical, chemical and biological parameters of reservoir ecosystems (Kennedy and Walker 1990). Lithology, the physical characterization and classification of rock formations (Lithology 2007), provides the context for landscape development and therefore, geologic materials and processes, controls initial availability of nutrients, acidity and oxidation-reduction potential, and metal contents of soils and water, thereby controlling the initial chemical background parameters of ecosystems (Clark 1996).

Geologic Influence on the Headwaters of the Lake James Watershed

The Linville River descends from Grandfather Mountain in Avery County, NC. Grandfather Mountain's Calloway Peak is the highest point in the Blue Ridge Mountain range at 1817 m MSL (Grandfather 2007). The North Fork Catawba River takes its headwaters from Humpback Mountain which ascends to 1298.448 m in Avery County (Topozone 2007). This watershed is karstified and flows through an elongate formation of dolomitic limestone known as the shady dolomite (Conrad 1960), and is exemplified in the Linville Caverns. Paddy Creek descends from the toe slopes between Grandfather and Humpback mountains, whereas the Catawba River flows west to east along the Piedmont formation. This region is underlain by a complex geology (Stuckey and Steel 1953) which has evolved throughout geologic history, most notably influenced by the Appalachian (or Alleghenian) orogeny (Appalachian Orogeny 2007).

A more recent detailed coverage of the geology of the Blue Ridge and Inner-Piedmont can be found in the works of Hatcher and associates (2002 and 1993) and Stewart and associates (1997) from the publications of the Carolina Geologic Society field trips. Additional influences on geochemical weathering and chemical balances in the Upper Catawba Basin include the presence of karst regions within the Appalachians which have been recently mapped by Weary and associates (2005). A more detailed coverage of North Carolina limestone formations can be found in the work of Conrad (1960).

Regional climate and related issues

The state of North Carolina has a mean temperature of 15 °C, but ranges from 17.8 °C in the southeastern corner to 10 °C in the mountains near Highlands, NC. The frost-free season ranges from 180 days in the mountains to more than 220 days along the coast. The rainfall of the Mountains averages about 135 cm, that of the Piedmont about 122 cm, while that of the Coastal Plain is approximately 137 cm. The greatest rainfall of 152 to 254 cm occurs in the high mountains near Highlands in Macon County and the lowest of approximately 91 cm occurs along the French Broad River Valley from Asheville to Marshall. The average annual rainfall for the whole State is approximately 127 cm (Stuckey and Steel 1953).

Hydrologic Drought within the Upper Catawba River Basin

Invoking "typical" conditions to describe the climate of a lake system is often misleading. "Hydrological droughts" and floods are the most common hydrological hazards in the nation. Hydrological droughts are a period of below average water content in streams, reservoirs, ground-water aquifers, lakes and soils (Hanson 1987). Hydrologic droughts typically occur over larger areas and persist longer than floods. Furthermore, droughts do not occur suddenly but develop over months and years. Droughts in the East are typically shorter in duration than those that occur in the Midwest and West (Hanson 1987), but this pattern could change.

Changes in river flows associated with long-term droughts influence both quantity and quality of water supplied from a watershed to a lake or reservoir. Understanding the problem of interannual changes must be considered one of the important contemporary problems in assessing water balances of lakes and reservoirs (Schindler et al. 2007). The study period was influenced by both a prolonged el Niño event followed by five year la Niña cycle which brought drought to the Southeastern US from 1998 to 2002. This period is now recognized as the drought of record for the area (Weaver 2005) and its impacts were evident in both measures of water quantity and quality. This study coincided with the first year of the drought whose onset was the summer of 1998. The study ended in September 1999. The impacts of baseflow recessions on lake water levels were apparent even within the first year of the drought (Schindler et al. 2007).

The US Geological Survey (USGS) (Weaver 2005) released a study examining the impacts of the drought of 1998 to 2002. Precipitation deficits during the 1998 to 2002 drought for some locations in North Carolina were among the largest documented since the beginning of systematic collection of weather data, with the largest deficits, as much as 152.4 to 177.8 cm, occurring primarily in the western Piedmont during the four year period. Weaver (2005) found cumulative monthly precipitation departures for the period May 1998 through September 2002 at 13 selected precipitation sites across the State ranged from 13.46 cm below normal in Greenville, NC in the eastern Coastal Plain of the state to 169.42 cm below normal in Hickory, NC in the western Piedmont. A comparison of precipitation data for the period of record with precipitation deficits during the 1998 to 2002 drought revealed deficits at three of the eight sites examined, notably those in the western Piedmont (Hickory, Charlotte and Mocksville), with the average monthly deficit for the 1998 to 2002 drought exceeding the values computed for the other drought periods (Weaver 2005).

Weaver further noted that the 1998 to 2002 drought also resulted in record-low streamflow and ground-water levels in many areas. During this four year period the drought was continuous in areas of western North Carolina. Dry winters in 2001 and 2002 followed by a dry spring in 2002 caused substantial declines in streamflow and ground water levels during the summer of 2002 resulting in more than 200 municipalities in North Carolina operating under some form of water conservation measures. Reservoirs across North Carolina were also at record or near record low levels (Weaver 2005).

Flooding within the Upper Catawba River Basin

The region has also had been subjected three major flood events during the last century in 1916, 1940 and 2004. Both the floods of 1916 (Western North Carolina Heritage Project 2007) and 2004 (USGS 2004) were the result of double tropical systems which settled over the area in rapid succession. Each had a marked impact on regional rivers. The early floods influenced the development of flood control structures in the region (Wilkes 2007).

During flooding from hurricanes Frances and Ivan in September 2004, after the close of the drought of record, period-of-record peak river stages were recorded at more than 20 sites in western North Carolina (USGS 2004). Many of the USGS stream gages in the Catawba, French Broad and Pigeon River basins recorded period-of-record high stages after the passage of Frances, including those within the Lake James watersheds.

USGS gage sites in the Lake James watershed measured the following impacts from the floods of 2004 (USGS 2004). The Catawba River at Pleasant Gardens (HUC

02137727) recorded peak flows after Frances of 651 m^3/s with a river stage of 5.349 m. These flows were within the 200 to 500 year recurrence interval. Peak flows following Ivan, were 326 m^3/s, at a stage of 4.157 m and corresponded to the 10 year recurrence interval. The Linville River at Nebo, NC (HUC 02138500) recorded peak flows after Frances of 1210 m^3/s at a stage height of 4.176 m, again corresponding to the 200 to 500 year recurrence interval. Following Ivan, peak flows were recorded as 665 m^3/s at a stage of 3.432 m and corresponded to the 50 year recurrence interval. Below Lake James, the Catawba River at Calvin, NC (HUC 0213903612) recorded 1490 m^3/s at a stage height of 8.016 m, falling within the 200 to 500 year recurrence interval. Flows following Ivan reached a stage height of 4.529 m and discharges of 405 m^3/s, falling within the 50 year recurrence interval (USGS 2004).

El Niño Southern Oscillation Impacts on the Upper Catawba Basin

Recent developments in our understanding of the influence of the el Niño Southern Oscillation (ENSO) on global weather patterns contribute to our understanding of the weather patterns which influence water quality and quantity for the Lake James and the Catawba-Wateree River Drainage Basin. La Niña is characterized by unusually cold ocean temperatures in the Equatorial Pacific, compared to el Niño, which is characterized by unusually warm ocean temperatures in the Equatorial Pacific (NOAA 2007).

This study fell within the transition between ENSO neutral to el Niño to la Niña conditions and weather patterns. Although la Niña conditions generate drought patterns in the southeastern US, la Niña (also known as el Viejo) and ENSO neutral conditions are more conducive to generating US hurricanes (Bove et al. 1998) and resultant precipitation when these systems move inland. ENSO forecasting can, therefore, be used to help guide our water management decisions.

Lake James Basins Description

Four separate rivers in the headwaters of the Catawba River drainage system form Lake James (Figure 1). Waters from the Catawba River and the North Fork of the Catawba River are detained in the reservoir basin created by a dam on the original Catawba River. Surface water from this basin is routed through a canal into a larger reservoir basin formed by dams on Paddy Creek and the Linville River. Water from the receiving Linville Basin is removed from a depth of 25 m (337 to 341 m MSL) by the Bridgewater Hydroelectric Facility (BHF) at the Linville River dam.

The structure of the combined lake basins and the withdrawal regimes generate two distinctly different thermal regimes in the main body of the lake. The removal of epilimnetic water through the connection canal between the basins keeps the hypolimnion of the Catawba basin near winter minimum temperatures until fall mixing. In contrast, the hypolimnion of the Paddy Creek and Linville River basins warm during the stratified period as the hydroelectric station removes hypolimnetic water (Figure 2) (Foris and Knight p.c. 1998, Knight 2003).

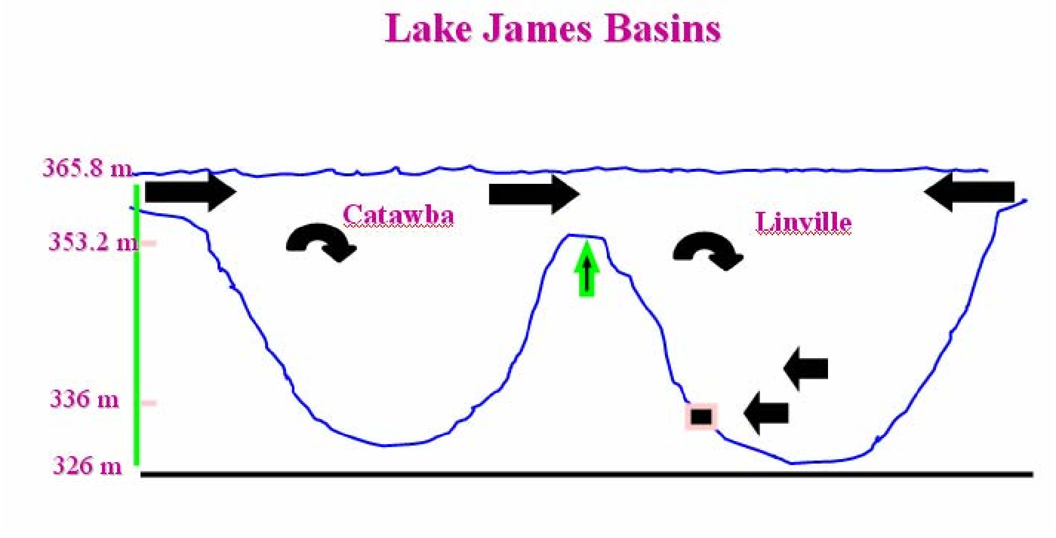


Figure 2 Generalized model of Lake James basin withdrawal

The Linville, Catawba and Paddy Creek drainage systems also produce different turbidity regimes in Lake James. The Linville and Paddy Creek drainage systems supply relatively clean mountain waters from drainage systems that are dominated by rocks of the Blue Ridge scarp. The larger Catawba River flows through Inner Piedmont soils and in river channels that are deeper and more easily eroded and supply greater concentrations of suspended material. The North Fork Catawba which joins the Catawba River just above Lake James passes through an elongate lens of shady dolomite along Humpback Mountain (Conrad 1960) which contributes a considerable portion of the cations and dissolved minerals entering the Lake James basins. As a consequence of greater loading of particulates, light penetration in the Catawba basin is relatively limited when compared to the Linville basin through much of the year (Schindler p.c. 2000 and Schindler et al 2001).

Only two of the in-flowing streams in the Lake James watershed are gauged by USGS: the Linville River at Nebo, NC (HUC 02138500, 1922 to present, Latitude: 35.79° N, Longitude: 81.89° W) and the Catawba River at Pleasant Gardens, NC (HUC 02137727, 1980 to present, Latitude: 35.69° N, Longitude: 82.06° W). Historic data for the Catawba River is available at the gage at Marion, NC (HUC 02138000, 1941 to 1981, Latitude: 35.71° N, Longitude: 82.03° W). Neither the North Fork Catawba River nor Paddy Creek drainage systems are gauged. Historical data for stream discharge were obtained from the USGS and stream chemistry was obtained from the North Carolina Department of Environmental Management (NCDENR) to assess short and long term trends in water quality within the watershed. Land use GIS (Geographic Information Systems) information for the watershed was obtained from the North Carolina Center for Geographic Information and Analysis (NCDENR-CGIA) was also gathered to facilitate our understanding of the external factors contributing to the biogeochemical dynamics within Lake James.

The hydrograph for the period of study (Figure 3) reflects, in general, greater flows in Catawba River, with the exception of the spring of 1999 where Linville flows during the drought conditions exceeded those of the Catawba. Note that most flows during the period of study are at or near baseflow, with a few exceptions, including moderate spring events in 1997, high flows in winter 1998 and are followed by the drought conditions in 1999.

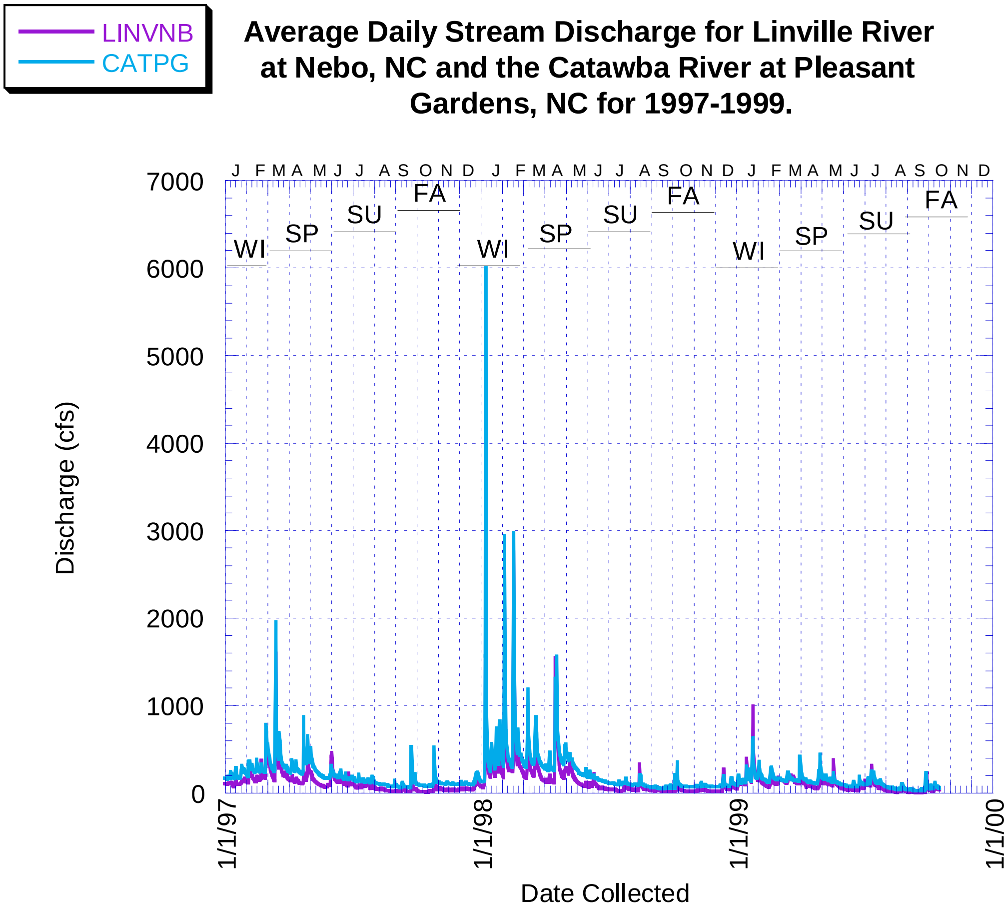


Figure 3 Average daily stream flow hydrograph from USGS gauged sites for the Linville River at Nebo, NC (HUC 02138500) and the Catawba River at Pleasant Gardens, NC (HUC 02137727)

Water leaving the reservoir through the Bridgewater Hydroelectric Facility is monitored indirectly by Duke Energy through a relationship developed for power production at the turbines (Figure 4). Water lost over the spillways is also assessed as lost power production (Foris and Knight p.c. 1998).

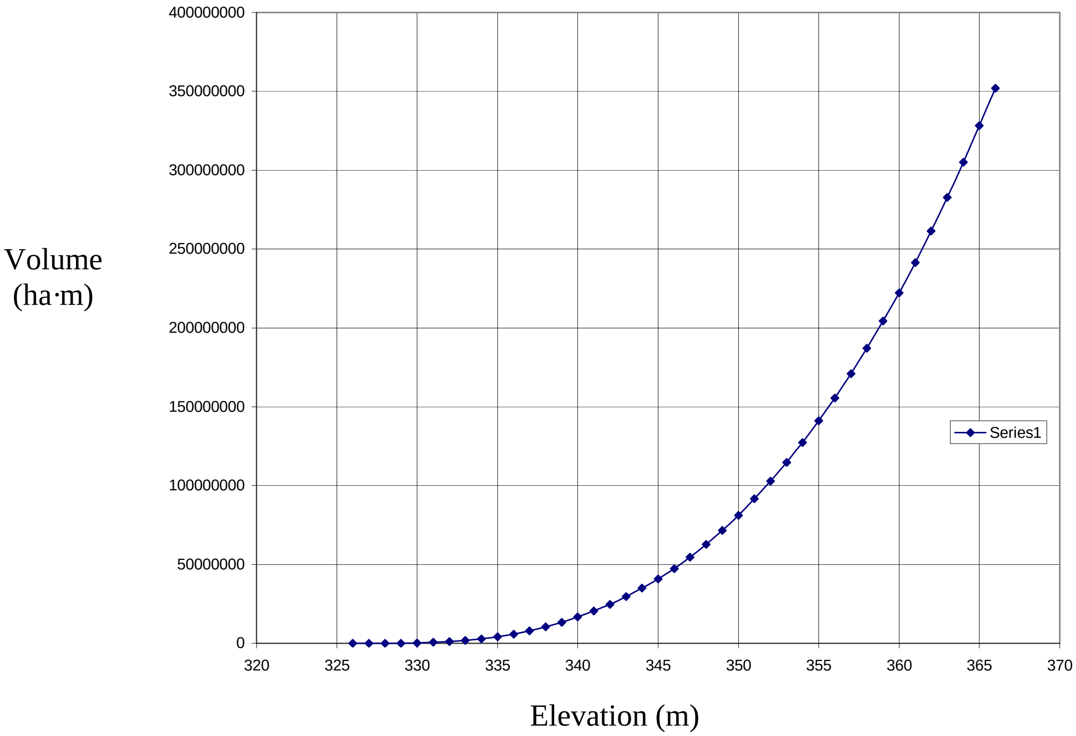


Figure 4 Lake James Storage Reference Curve: Elevation vs. Volume

Lake James is considered a primary water storage reservoir for the Catawba River basin, holding 336x10^6 m^3 of water volume with a retention time which spans 1/3 of the year (Figure 4). Retention time has been viewed as the amount of time it takes a molecule of water to pass through a reservoir, or the time water is held within a reservoir before it is released. Retention time is defined as the ratio between the lake volume and the water discharge (Håkanson and Peters 1995). There is 27.01 km^2 of surface area within the reservoir basin with 964.64 km^2 of watershed area contributing flow and materials to Lake James. The Catawba basin has a larger contributing watershed of 743.28 km^2 as compared to the Linville watershed with 221.36 km^2. The Linville basin, however, has a greater surface area of 14.26 km^2 and volume of 193x10^6 m^3 as compared to the Catawba basin with surface area of 12.75 km^2 and volume of 143x10^6 m^3. The Linville basin has a greater maximum depth and mean depth of 40 m and 13.6 m, respectively. The Catawba basin has a maximum depth of 34 m and a mean depth of 11.3 m. The average rate of inflow is greater into the Linville basin at 19.8 m^3/s, relative to the Catawba with inflows of 15.1 m^3/s. Retention time, as seen in Table 1, is similar among the basins with 110.4 days in the Catawba basin, compared to 113.1 days in the Linville basin (Foris and Knight, p.c. 1998, Knight 2003). Thermocline depth and hypolimnetic volume throughout the study varied among years and basins (Table 2), with the Catawba basin exhibiting a stronger thermocline and smaller hypolimnetic volume relative to the total basin volume as compared to the Linville basin.

Table 1 Morphometric properties of each basin in Lake James

	Catawba	Linville
Drainage Area (km^2)	743.28	221.36
Surface Area (km^2)	12.75	14.26
Volume (x10^6 m^3)	143	193
Maximum Depth (m)	34	40
Mean Depth (m)	11.3	13.6
Mean Inflow (m^3/s)	15.1	19.8
Retention Time (days)	110.4	113.1

Table 2 Thermocline depths and hypolimnetic volume comparisons for the Linville and Catawba basins of Lake James for August of 1997, 1998 and 1999

	Linville (3300)			Catawba Station (3310)		
Year	1997	1998	1999	1997	1998	1999
Thermocline (*d*Tmax/1 m depth) (ºC)	2.34	1.64	1.59	4.85	5.24	4.174
Thermocline Depth (m)	7	12	6	10	10	10
Metalimnion Top (m)	7	8	6	5	8	6
Hypolimnion Top (m)	10	12	12	13	13	12
Hypolimnetic Volume (m^3)	8.042E+07	6.110E+07	6.079E+07	2.894E+07	2.852E+07	3.428E+07
Total Volume (m^3)	1.872E+08	1.861E+08	1.855E+08	1.346E+08	1.336E+08	1.332E+08
Hypolimnion to total volume ratio	0.430	0.328	0.328	0.215	0.213	0.257
Elevation Water Surface (m MSL)	364.949	364.868	364.826	364.949	364.868	364.826
Elevation Hypolimnion Top (m MSL)	354.950	352.868	352.826	351.949	351.868	352.826
Canal Elevation (m MSL)	353.2	353.2	353.2	353.2	353.2	353.2
Hypolimnion Top - Canal Elevation (m)	1.749	-0.332	-0.374	-1.251	-1.332	-0.374

Lake James Assessment

LJA Study Objectives

This research was part of a larger descriptive study, the Lake James Assessment (LJA), examining physical, chemical and biological dynamics of Lake James, North Carolina. The unique structure of the reservoir, featuring the Catawba basin with epilimnetic withdrawal in contrast to the Linville basin with hypolimnetic withdrawal for power production lent itself naturally to a paired study. We hypothesized that the differing withdrawal regimes between the basins would impact the water quality dynamics of the two basins. We further hypothesized that these differences in water quality would be reflected in the chemical dynamics of the basins. Because Lake James and its watershed lie across a geological transition zone between the Blue Ridge escarpment and the Inner Piedmont, we also hypothesized that watershed differences would be reflected within the chemical dynamics of Lake James. In order to conduct an assessment of the chemical dynamics of Lake James, we first had to construct an energy budget (Schindler p.c. 2000) and water balance (Schindler et al. 2007) for the reservoir. An early assessment of land-use distribution (Figure 5) from NCDENR – CGIA GIS (NAD83) data revealed only nominal differences in gross land use designations. Point source contributions listed by Duke Energy and NC Department of Environment and Natural Resources (DENR) are listed in Table F- 1and Table F- 2.

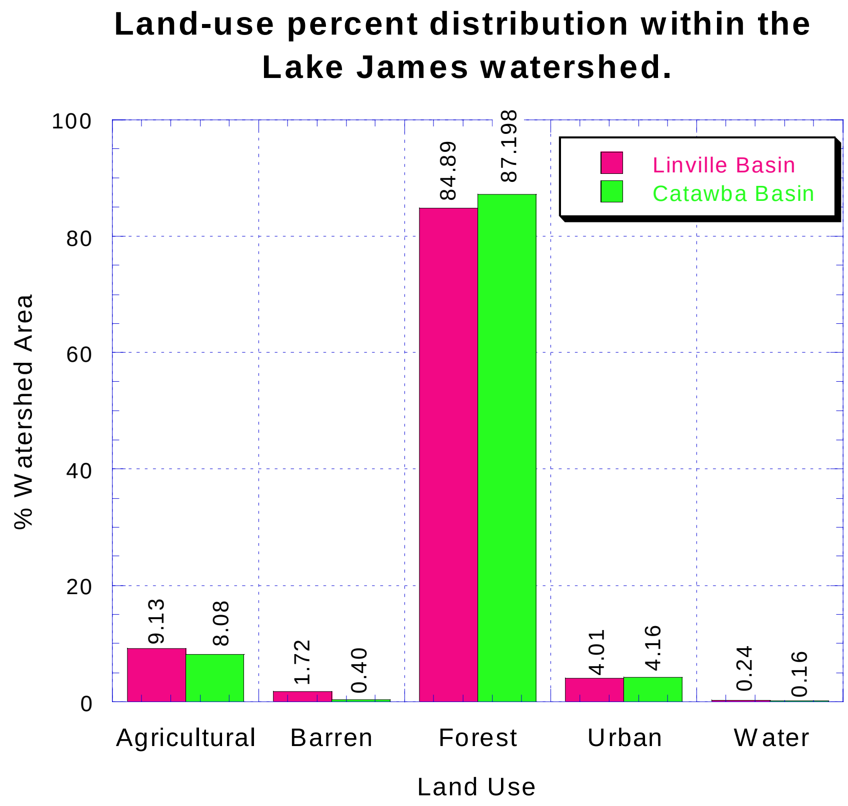


Figure 5 Gross land use designations for the Lake James watershed (adapted from NCDENR-CGIA GIS data (NAD83) in 1998)

<u>LJA Study Design</u>

Field sampling for this project was conducted between March 1997 and October 1999. This dissertation focuses on the water balance and the spatial and temporal chemical dynamics occurring in Lake James and its contributing watershed during the sampling period. Chemical, physical and biological parameters were assessed for each of the eight inlake sampling stations (Figure 6). The lake sampling stations for the Catawba basin included the lacustrine zone (3310), the lower transition zone (3311), the upper transition zone (3312) and the riverine zone (3313). The lake sampling stations for the Linville basin included the lacustrine zone (3300), the lower transition zone (3301), the riverine zone (3302) and the Paddy Creek embayment (3303). One should note, however, that these reservoir zones are used as a heuristic tool and that in reality this zonation is dynamic and depends on hydrodynamics.

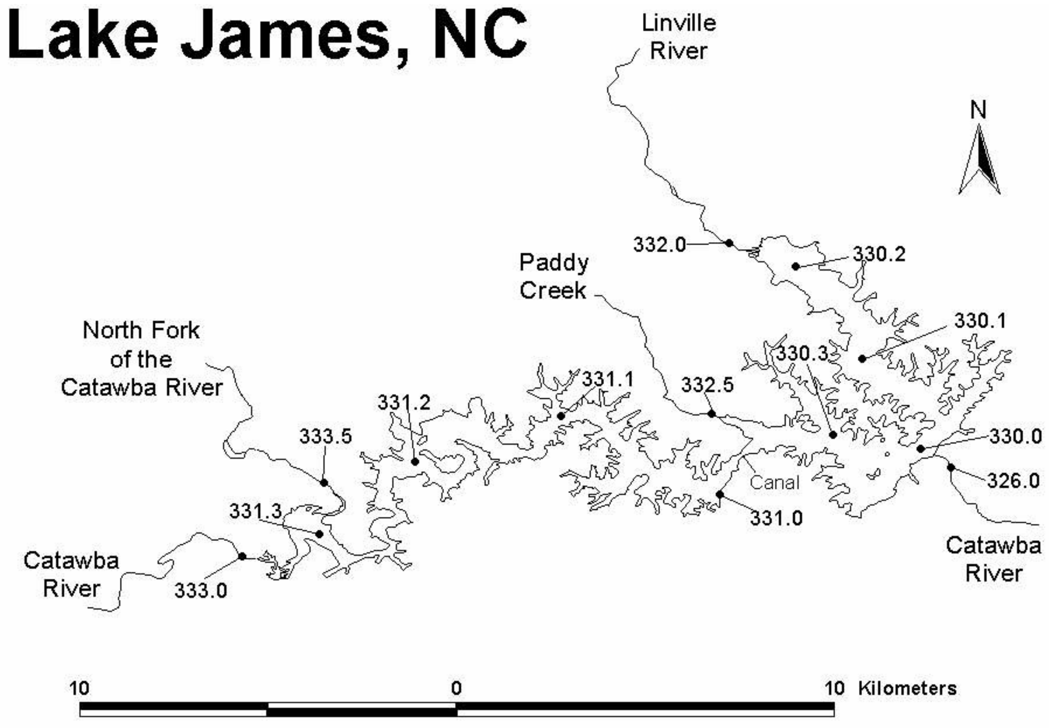


Figure 6 Map of Lake James, NC showing sampling sites

At each lake station the following in situ instruments were used to parameterize the hydrodynamics and water quality: Hydrolab ®Sonde, Horizontal Beam Transmissometer (HBT3/HBT2), Acoustic Doppler Current Profiler (ADCP), Solar collectors (spherical, upwelling and downwelling), and a Turner Fluorometer was used through 1998. These data were collected in one meter intervals during each monthly sampling event. Strings of in situ thermistors (®Hobo, ®Tidbit) were deployed to gather water temperature in five meter increments at the two lacustrine stations (330.0 and

331.0). Water temperature measurements were collected every two minutes throughout the three sampling years. Local meteorological information was gathered from a meteorological station on the Bridgewater dam control structure. These data were collected every five minutes throughout the three sampling years. A Hydrolab ®Sonde is a collection of electrodes that measure various water quality parameters. These parameters include depth, temperature, dissolved oxygen, percent oxygen saturation, conductivity, pH and oxidation-reduction potential. Chlorophyll was added September 1998.

Historical data for stream discharge and stream chemistry were obtained from the USGS and the NCDENR to assess short and long term trends in water quality within the watershed. Additional stream sampling stations were added to the study and included the inflowing Catawba River (3330), the North Fork Catawba River (3335), the Linville River (3320), Paddy Creek (3325) as well as the outflowing Catawba River (326) below the BHF. Land-use GIS information for the watershed from NCDENR-CGIA was also gathered to facilitate our understanding of the external factors contributing to the biogeochemical dynamics within Lake James.

Phytoplankton samples were gathered following the same sampling scheme as for water chemistry collections (below). Zooplankton tows were made each month at the two deep stations (330.0 and 331.0) from 15 and 30 meters. Phytoplankton and zooplankton data for Lake James were analyzed in the dissertation by Celik (2000).

LJA Water Balance Model

A water budget was developed for Lake James, NC (Schindler et al. 2007) using USGS discharge data coupled with power generation, spillway loss, water elevation records and meteorological data for a period from February 1997 to October 1999. The water budget is simply a balance sheet expressing the gains and losses of water in the reservoir during a particular time period. Base flow regression curves were generated to assess groundwater discharges to the system. River discharges decreased during summer to fall seasons each year. Discharges for the summer 1999 were the lowest recorded on the Linville River in over 80 years of data collection. Evaporative losses based on energy budgets range from over 100% of total measured precipitation in 1999 to a minimum 60% of measured precipitation in 1998 (Schindler p.c. 2000).

A water balance model was developed using the STELLA modeling environment. The water balance model attempts to express the simultaneous gains and losses of water over time. Results of dynamic modeling exercises indicate that water losses from Lake James exceed gains during prolonged hydrologic droughts. Estimated losses not accounted for are approximately 13% of full pool volume of this reservoir every year. Almost 20% of the total volume of the lake is lost to a combination of evaporation and the unmonitored losses each year.

LJA Chemical Mass Balance Model and Analysis

Surface water chemistry analysis provides a useful assessment of changes in the surface waters; however, it does not reflect the distribution of chemical species within the water column. For many chemical constituents, the effects of temperature/density stratification, the presence or absence of dissolved oxygen and the effects of seasonal changes in the lake are reflected in changes in monthly concentration. Failure to sample a reservoir across the dimensions of time and space can lead to misinterpretations of system dynamics and the factors which contribute to them.

Chemical Mass Balance

Calculation of average annual chemical loading and yield tend to oversimplify a complex system. The calculation of annual loading is sometimes chosen for simplicity. In lakes where the watershed area is small, relative to the lake surface area, and lake retention times are long, these calculations may be adequate. However, in reservoirs, where watersheds areas exceed lake surface area and turnovers are rapid, average annual loading oversimplifies a complex process. Additionally, because the majority of material loading occurs during a few episodic precipitation events, using annual averages diminishes the importance of these events. It can be misleading to make an assessment of concentration without considering the volume of the lake that the sample represents (Schindler p.c. 2000).

Because of these limitations, a segmented model was developed in the STELLA research modeling environment to examine the effects of flow, volume and surface water loading and to allow the user to assess the potential fate of constituents within the Lake James Basins. This exercise stresses the importance of linear distance in the processing of watershed inputs into the reservoir (Thornton et al. 1981, Thornton 1990, Kennedy and Walker 1990).

For the purpose of modeling in STELLA, Lake James was divided into eight segments using the bathymetry generated for Duke Energy using the W2-Grid preprocessor (available through Dr. Scott Wells at Portland State University, http://www.ce.pdx.edu/w2/). By examining the profile of the bathymetry, areas of morphometric restriction were used to assign segment limits and inlake sample locations were assumed to represent the segment wherein they fell.

The LJA mass balance is a simple model that assumes hydrology is the driving variable for the system. For each segment, daily hydrology and segment volume are used to compute loading for each constituent from concentration gathered at monthly sampling intervals. The calculated concentration is then compared to the measured concentration and any difference is assumed to have been “assimilated” within the water column. In the model this value is called sedimentation; however, the changes in concentration may be due to physical settling or biological assimilation, as well. By summing the daily loading over a year a volume weighted annual loading estimate for each segment of the lake is calculated that can be used to make inferences about the spatial distribution of chemicals within the lake.

Although 21 chemical constituents were sampled in this study, the findings in this volume will focus on surface water chemical dynamics of those which are hydrologically driven constituents. Alkalinity was chosen as a measure of the buffering or acid neutralizing capacity of the water. Chloride was chosen as a monovalent anion and calcium and potassium were chosen as bivalent and monovalent cations. Redox constituents, per say, will not be examined in detail due to the focus on surface water dynamics. Phosphorous is the limiting nutrient in many fresh waters, and the focus of most eutrophication studies. Ortho-phosphate and total phosphorous were chosen to represent biologically active constituents which are also hydrologically and redox regulated.

I ascertained that most of the constituent loading into the Lake James basin is derived from the Catawba River watershed (most notably the North Fork Catawba sub-watershed) and that most of the inflowing material is retained by the reservoir. I further discerned that relatively limited numbers of high flow events are responsible for providing the bulk of materials assimilated within the lake basins. I confirmed that the headwaters and upper transition zones of the Lake James reservoir have greater rates of sedimentation of most constituents relative to the lower transition and lacustrine zones and validates the model proposed by Thornton et al. (1981) and later work on spatial sedimentation of constituents and subsequent ecosystem production by Kennedy et al. (1982). However, the lacustrine station for the Linville basin is the receiving embayment for both basins and reflects the greater loading being brought in from the Catawba Basin.

I employed traditional loading calculations (Olem and Flock 1990) using monthly chemical concentrations and average daily discharge which were averaged for each year to provide a conservative estimate of loading and yield from the Lake James watershed. By comparing the LJA-CB with traditional loading and yield calculations I found that the traditional methods, in general, tended to be adequate for hydrologically driven constituents; however, biologically and redox regulated constituents are not sufficiently represented using traditional calculations of loading and yield.

CHAPTER TWO

WATER BALANCE: LAKE JAMES, NC

Lake James Assessment

Water Balance

The water balance of lakes is a critical part of developing loading models for eutrophication studies. A water balance is expressed by an equation that relates rate of change of volume to rates of inflow minus rates of water loss from all sources (Hutchinson 1957). Hence, a water balance is analogous to a simple budget that tracks all sources and sinks of a resource while monitoring accumulations in a residual pool. Although these instructions may appear to be quite simple, they are more daunting when applied to open lakes or reservoirs. In traditional limnological thinking lakes have been broadly considered open systems, lakes that have both inflows and outflows from the basin. This is contrasted with closed systems that have inflows only and no outflow (Hutchinson 1957). The flux of water into and out of an open system leads to dynamic volume changes over time. This complexity is compounded in reservoirs where outflows are regulated in response to demands for power generation. Indeed, most lake hydrology studies avoid tackling this complexity and use closed lakes as exemplars for describing the logic involved developing water budgets (Hostetler 1995). Unfortunately, the need to develop water balances for management and chemical loading calculations means that problems of describing water budgets cannot be confined to closed systems only. Indeed, many of the most vexing problems in lake management today are found in reservoirs that drain large watersheds. The complexity of a reservoir is increased by its multiple uses, such as flood protection, water supply, recreation and power generation. These multiple use demands place pressure on reservoir managers to develop an optimal mix of water management and nutrient control practices.

The development of loading models was initiated by the pioneering works of Piontelli and Tonolli (1964) who viewed lakes as a continuously stirred tank reactor (CSTR) (Brezonik 1996). These ideas were further extrapolated by Vollenweider (1969, 1975) and modified by Chapra (1975, 1979) to the formulation of a phosphorous budget in which (Gibson et al. 2000):

$$\mathbf{V}\ \boldsymbol{d}\mathbf{p}/\boldsymbol{d}\mathbf{t} = \mathbf{W} - \mathbf{Qp} - \mathbf{vAp}. \qquad \textbf{(1)}$$

Where:
V = volume (m^3)
p = TP concentration (mg/L)
t = time (s)
W = loading (g/s)
Q = outflow (m^3/s)
v = an apparent settling velocity (m/s)
A = surface area (m^2)

The beauty of the modified Vollenweider model was the simplistic characterization of phosphorous inputs and outputs, and its expression of sedimentation losses as a simple one-way settling of total phosphorous. Furthermore, it provided a framework in which temporal responses of a lake to loading changes could be examined facilitating a characterization of system dynamics (Gibson et al. 2000).

STELLA was developed by ISEE Systems, formerly High Performance Systems, founded in 1985 and focuses on ‘Systems Thinking’ software. Håkanson and Peters

(1995) demonstrated the utility of the STELLA platform for a variety of limnological modeling exercises, including a simple constituent mass balance model which we have modified for use as a water balance. Their model, here modified for the water balance, considered a lake as a simple "black-box" where Qin = Qout with a loss factor similar to the formulation given above.

$$\mathbf{V +/- \mathit{d}Q/\mathit{d}t = Qin - Qout - KET{*}A - KQT{*}V} \tag{2}$$

Change in lake volume   Inflow   Outflow   Flow losses to evaporation and seepage

Where:

Qin = the inflow to the lake (m^3/s)
Qout = the outflow (m^3/s)
KET = the rate of evaporative loss (cm/s)
A = the lake area (m^2)
KQT = the rate of flow loss (1/s), a rate constant
V = the lake volume (m^3)
*d*Q = the change in flow during the time interval *d*t

Methods

Lake James Inputs

The Catawba River system was monitored daily near Marion, NC from October 1941 to October 1981. Monitoring was moved upstream to Pleasant Gardens, NC in October 1980 and continues to the present. Since the Marion data include a larger component of the watershed than the Pleasant Garden data, the period of monitoring overlap from October 1980 to October 1981 was used to develop a regression equation for the discharge of the complete Catawba drainage system. The following regression equation accounts for the differences in the two discharges.

$$\textbf{Marion Discharge} = 3.0337 + (1.3222 * \textbf{Pleasant Garden Discharge}) \quad (3)$$

Discharge in cubic feet per second (ft^3/s)

Catawba discharges were converted to m^3/s and divided by the area of the watershed to obtain water yield ($m^3/km/s$) from watersheds throughout the monitoring period. Watershed and drainage areas were calculated from geographic information system maps provided by Duke Energy. The watershed area of the entire Lake James watershed Upper Catawba system is 465.691 km^2.

Linville River flows have been monitored daily at Nebo, NC since July 1922. Water yields from this watershed area were calculated by converting discharges to m^3/s and dividing by watershed area to obtain water yield ($m^3/km/s$). The watershed area of the Linville system is 172.079 km^2. Water yields from these two gauged systems were then used to calculate discharges from ungauged drainage systems including the North Fork of the Catawba River (220.008 km^2), Paddy Creek (20.673 km^2) and the local drainage systems of the lake (total 86.198 km^2).

The average yield from the Linville system was approximately 1.3 times greater than the Catawba drainage system during this study period. Topography and shallower mountain soils may contribute to the greater yields observed. Local precipitation was monitored with a weather station mounted on the dam near the Bridgewater hydroelectric facility (Figure 1). Daily precipitation was partitioned between the Linville and Catawba basins based on surface areas. Precipitation input to each basin was added to discharges from the watersheds to calculate total inputs to both basins. Total Catawba inputs were calculated as the discharges from the Catawba River at Marion, the North Fork of the

Catawba, local drainage districts 2 and 3 and direct precipitation. Catawba River water yields were assigned to the ungauged North Fork Catawba River.

Linville River yields were used to calculate the local district discharges (regions of overland flow and direct input adjacent to the shores of Lake James) as well as to estimate flows for Paddy Creek. Total Linville inputs were calculated as the discharges of the Linville River, Paddy Creek and local drainage district 1 and the drainage area of the Linville River arm of Lake James (Figure 1).

Analysis of groundwater discharge in large and geologically complex and variable watersheds draining into reservoirs is difficult because of spatial variability and costs associated with deploying instrument arrays. However, since streams collect groundwater over large areas, measuring stream discharge under base flow conditions can be used as an approximation of groundwater discharges. The base flow recession curves used for this study were constructed following the methods of Riggs (1963). The first step in this analysis involves selection of 10 day linear base flow recession segments from all appropriate hydrographs during the observation period. Hanson (1987) used a database that spanned 16 years to develop a drought index for south central Oklahoma and noted that the assessment of the frequency of occurrence of droughts requires long-term stream flow databases. River discharges used in this analysis span almost 80 years of data for the Linville River and almost 60 years of data for the Catawba. Base flow recession segments for more than 300 recession events were used to prepare a logarithmic plot of the beginning day base flow discharges versus the base flow discharges 10 days later (Riggs 1963). These relations were then used to construct base flow regression equations that approximate the “assured” ground water discharges (Hanson 1987). Linville and Catawba River base flow regression equations were almost identical for every segment calculated and data from both rivers and all time periods were aggregated to generate a composite watershed curve. The similarities imply that both river systems draw water from the same or similar unconfined aquifers. However, this conclusion should not be accepted without more detailed studies. It is important to remember that base flow regressions are generated from a composite of many 10 day base flow segments taken from many years of data and inferences based on these curves must be made with care.

Since base flows from local drainage areas implicitly include ground water contributions to the system, we assume that ground water inputs are included in input calculations. However, a similar assumption cannot be drawn for losses from the reservoir system. While some of the outputs are monitored in power production and spillway losses, pressures generated by stored water influence water recharge of aquifers and loss through the earthen dams. Lake James was created between 1916 and 1919 with the construction of earthen dams across the Catawba River and two tributaries, Paddy Creek and Linville River. These impoundments were connected by a broad canal to form a 27.01 km^2 body of water. The dynamic interplay of surface and groundwater in the vicinity of reservoirs is poorly understood, but with recent technological developments it is an area ripe for much needed synthesis between the surface hydrologic disciplines and those focusing on geologic and subsurface hydrologic issues.

Water budget data are used to calculate advective flows from Lake James and to complete an analytical energy budget. Evaporation rates are calculated from energy budgets (Schindler 2000) using the method of Sturrock et al. (1995). Evaporation rates are also calculated using equations of Jensen-Haise and Stephens-Stewart (Winter et al. 1995).

Lake James Losses

Duke Power Company monitors Lake James water levels, discharges from the Bridgewater Power station and water released over the spillway at hourly intervals. Water discharged in power production is calculated from a turbine rating relationship between power production (MW·hr), head and water use. Spillway losses are also based on lost power production capacity. Water level in the reservoir is monitored directly. In addition, water quality parameters including water temperature, dissolved oxygen, pH, oxidation-reduction potential and conductivity in the direct tailrace waters are monitored with a data logging Hydrolab® sonde. Daily discharges through the power station and spillway losses are averaged and converted to m^3/s to compute daily water outputs from this system. Differences between total input and output are used to calculate net water balance.

Volume changes in the reservoir are computed by using a lake hyposograph for the Catawba and Linville basins. Volume changes are computed as a polynomial regression based on monitored height of the water in the forebay (Figure 4). Average volume during the study period was approximately 3.2×10^8 m^3 with a maximum of 3.8×10^8 m^3. Total volume at full pool is approximately 3.44×10^8 m^3. Differences in short-term storage volumes are added to the difference between the input and output. Volume differences that cannot be accounted for in inputs, outputs and storage volumes are assigned initially to evaporation losses for energy budget calculations. Calculated evaporation rates based on energy balances are then used to correct volume changes. When the total water balance is recomputed, differences between the known inputs and outputs and calculated evaporation rates are used to reassess volume changes. Residual differences in losses in water volume are then assumed to be associated with seepage through earthen dams and turbines and groundwater losses. This revision of the calculation of potential water losses cannot be verified with simple water balance computations. However, independent estimates of seepage losses from Lake James have likely been made in engineering surveys and these values can be used to assess the efficacy of this computational approach. In reality, the losses include errors associated with measurement, data logging and calculation as well as unmonitored water losses.

LJA Water Balance Modeling

The complexity of interactions in water balance calculations creates uncertainties of the quality of data used in the overall budget. These include variations in flows into and out of a reservoir combined with changes in volume due to rising and falling water levels. The combination of interactions makes the water budget an ideal topic for system modeling but few investigators are willing to invest the time it takes to develop and debug a water balance model. Fortunately, some new methods for computational assessment are quite user friendly. In this research, we developed a simple dynamic system model using STELLA® RESEARCH. The following pictorial model represents the major flows and stocks projected for Lake James (Figure 7). Linville and Catawba River discharges, evaporation rates, flow and waste rates are loaded directly as m^3/s using a dynamic data exchange between the model and a spreadsheet. Discharge and loss coefficients are treated as experimental variables to assess model output sensitivity to these terms. Volume changes calculated from water levels are used as “expected” values to compare with simulated volume changes based on input-output changes. A simple root mean square residual test was conducted on each experimental run to assess the outcome of variable modifications on overall model behaviors over 900 days of simulation. Graphical dynamics help to identify both episodic and gradual processes to optimize coefficients used to calculate the overall budget.

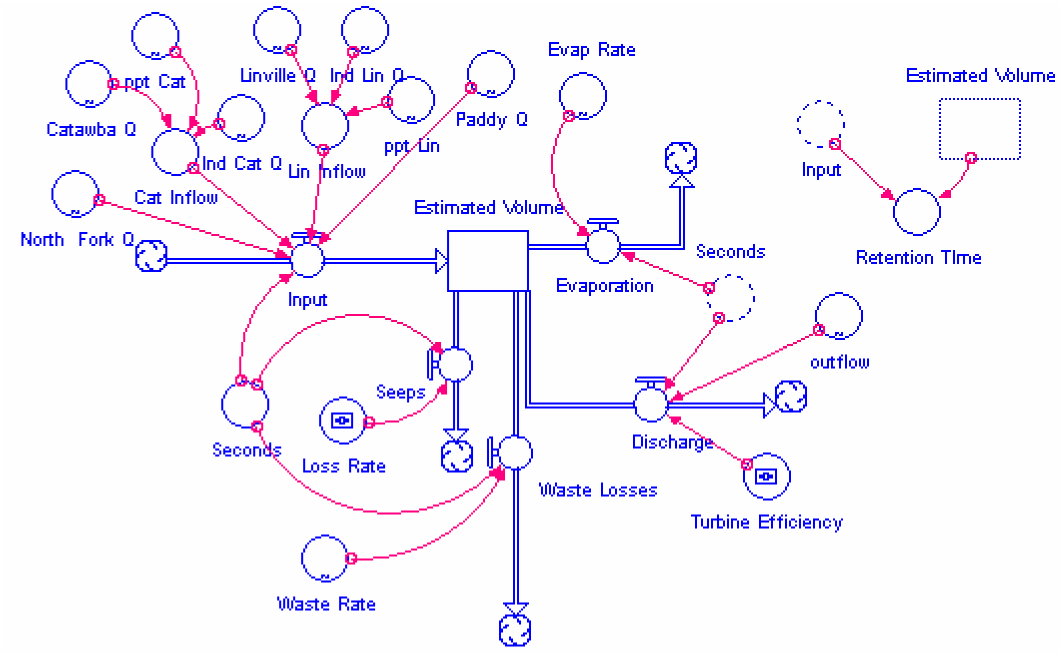


Figure 7 STELLA symbolic model used to simulate dynamic exchanges for water budget

Results and Discussion

Monthly evaporation rates calculated for Lake James range from 0.9 to 4.0 cm/mo in February, 2.9 to 6.9 cm/mo in March, 9.1 to 11 cm/mo in April, 11 to 16 cm/mo in May, 13 to 15 cm/mo in June, 14 to 16 cm/mo in July, 12 to 15 cm/mo in August and 7.0 to 9.0 cm/mo in September. These monthly rates are several centimeters greater than estimates for Williams Lake, Minnesota where evaporation rates ranged from 6.2 to 7.4 cm/mo in May, 6.5 to 11 cm/mo in June, 9.3 to 12 cm/mo in July, 8.3 to 12 cm/mo in August and 5.0 to 8.2 cm/mo in September (Winter et al.1995). Estimated seepage losses are approximately 13% of full pool volume of this reservoir every year. Almost 20% of the total volume of the lake is lost to a combination of evaporation and seepage each year.

Figure 8 illustrates the monthly balance between measured precipitation and calculated evaporation rates. Energy budget calculations yield negative evaporation rates when the total of outgoing energy exceeds incoming energy during the fall and winter periods. Negative results are obtained when lake surface temperatures exceed atmospheric temperatures and outgoing long-wave radiation and energy losses exceed combined incoming solar and atmospheric radiation. These results illustrate how fall and winter weather conditions influence lake dynamics. As illustrated in Figure 8, the relatively brief, warm 1998 to 1999 winter at Lake James is reflected in a short period of negative evaporation rates. In contrast, the longer and cooler 1997 to 1998 winter results a longer, more substantial negative evaporation period. While Figure 8 also shows that precipitation exceeds evaporation in 1997 and 1998, it is important to realize that the data are computed from May to December 1997. The important early spring rainfall period is not included in the figure. Since river discharges in this early period show significant flow, early 1997 precipitation would have added significantly to the annual total. Likewise, the study was terminated before the end of the 1999 calendar year and precipitation and evaporation totals do not include values for the fall period. However, the fact that evaporation exceeds precipitation during the first nine months of 1999 supports the conclusion that little, if any, water is available in soil storage pools in the watershed during this period. Hence, estimates of base flow conditions for river inputs are consistent with the interpretation of the local precipitation-evaporation calculations.

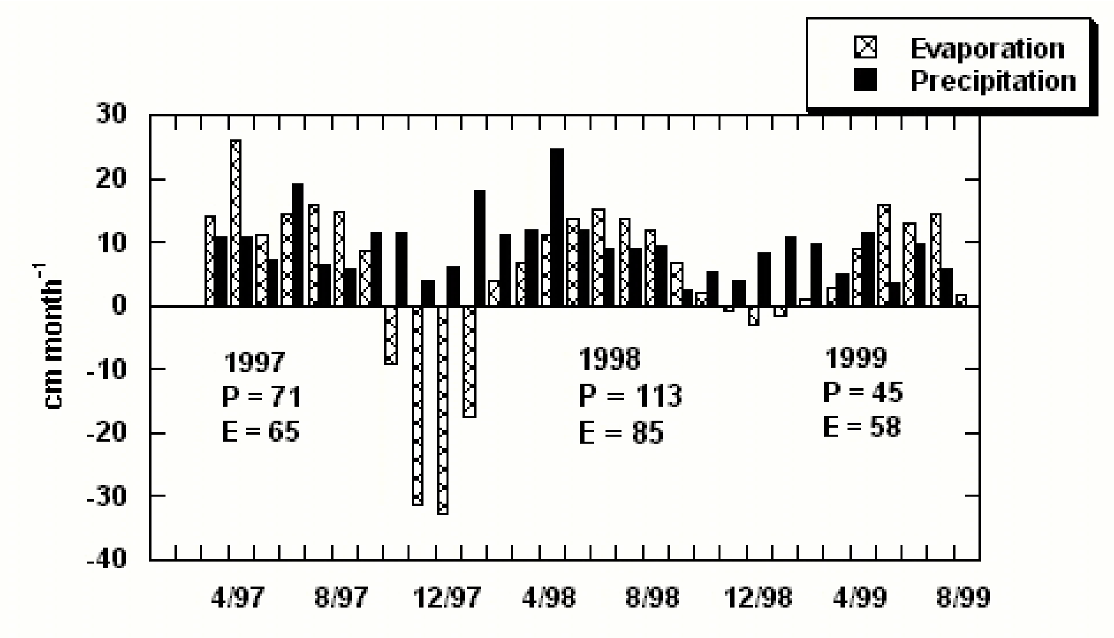


Figure 8 Volume changes (solid line) and balance between gains and losses for Lake James (+) during study period

In this water balance calculation, water released from the power station was calculated from an algorithm relating power generation to water use. Design engineers developed this algorithm for the turbine system when it was installed at beginning of the 20th century. The outcome of water balance simulations suggests that turbine efficiencies are approximately 98% of the original algorithm. Put another way, the turbines are still operating at 98% of their original design efficiency. Turbine efficiency refers to the mechanical efficiency of converting the power of water flowing through hydroelectric turbines into electricity (Wikipedia 2007). The model also suggests that the overall water balance is very sensitive to small changes in turbine efficiency since outflows from the reservoir are an important part of the overall water balance. Since turbine algorithms are also used to estimate water volumes available for power generation, a loss of efficiency can lead to unexpected changes in reservoir water levels. These simulations also reinforced our confidence in the seepage estimates since different approximations of seepage rates could be tested and compared against volume changes over time. Post facto analysis of turbine losses conducted by Knight (2003) indicated losses of 1.557 m^3/s (55 ft^3/s) through the turbines in the BHF, a value twice what was estimated at the time of our study. These losses coupled with the karst nature of the North Fork Catawba would impact the water balance as calculated and may account for some of the measured losses we detected.

Inflows from the Catawba and Linville arms are dominated by late winter and early spring discharges (Figure 9 and Figure 10) that occasionally exceed 100 m^3/s in both basins. In a comparison of discharges for the summer and fall periods of all three years of this study, the 1997 and 1999 discharges are less than the 1998 discharge for both basins. Discharges in 1999 summer and fall were the lowest ever recorded for both the Catawba and Linville River systems. Flows in the Catawba River in 1999 declined to the levels computed to be the "assured" base flow for that watershed. Linville River discharges declined to the calculated assured base flow conditions in late summer and fall in all three years. Declines to these low base flow conditions suggest that both drainage systems depend on aquifer discharges and that soil storage contributions to the total discharge are minimal during extended drought conditions.

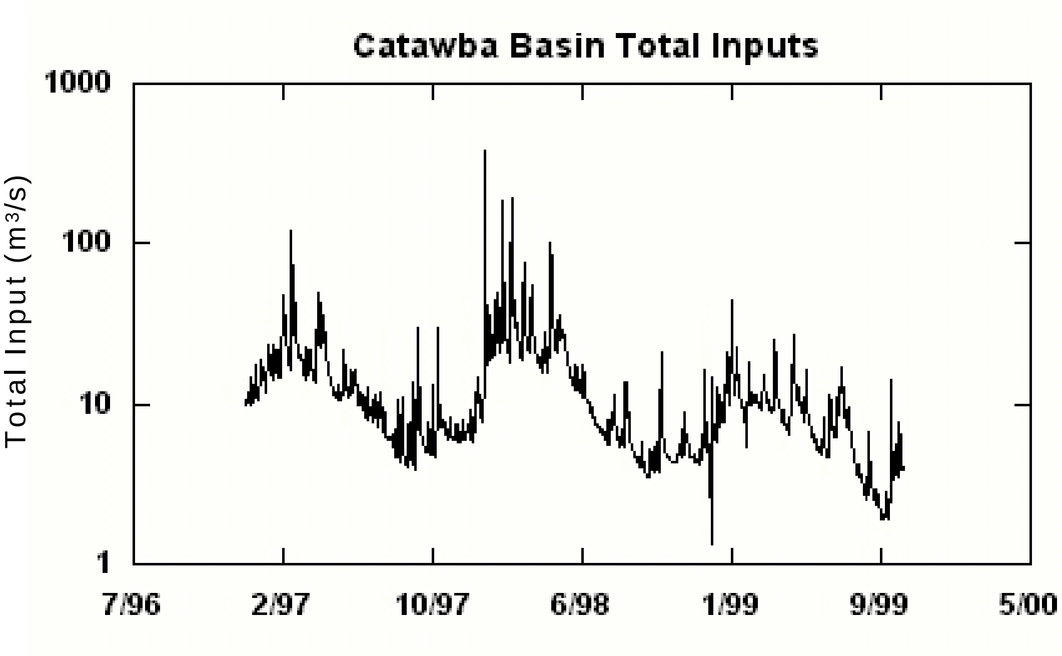


Figure 9 Catawba Basin total inputs to Lake James

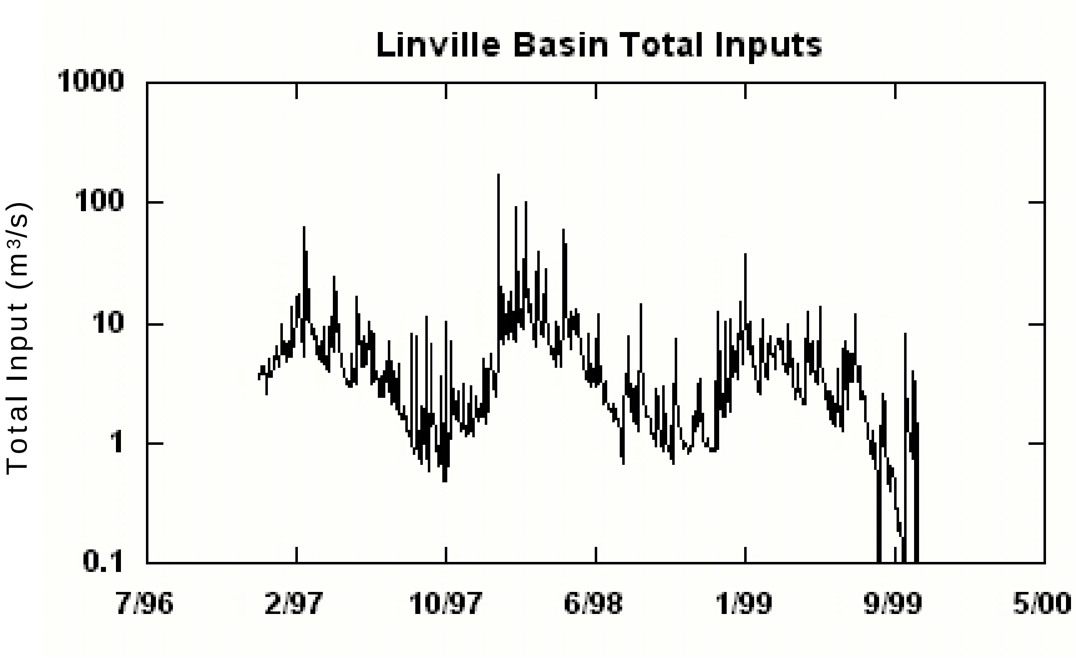


Figure 10 Linville Basin total inputs to Lake James

The gradual but continuing decline of discharges in the late summer and fall during the period from 1997 to 1999 indicate that the drainage system is undergoing a prolonged hydrological drought that has gradually drained all watershed storage pools in spite of the brief surplus in precipitation during 1998. Because the 1999 discharge levels are the lowest in the recorded history of these rivers, it also suggests that the current drought conditions are the worst that have been encountered since the 1920's, including the well known and widespread droughts of the 1930's and 1950's. This was confirmed by Weaver (2005) as the la Niña drought progressed from 1998 to 2002.

Inputs of water to the system occur in response to rainfall events on the watershed and usually occur faster than water losses. Close inspection of data used to construct the water balance show that net input peaks occur approximately three days before peaks in storage volume. Volume peaking responses and volume decreases depend on input rates and the rate that water is released through the dam for power generation combined with the continuous unmonitored losses. Water withdrawal is regulated to match power demands and to optimize revenues from the hydroelectric facility and water releases are not easily predicted from physical data. However, the continuously monitored flows through the hydroelectric facility permit an estimation of daily losses for power generation. Full pool volume for this reservoir is $3.44\text{x}10^8$ m^3. Water was spilled over the spillway from this system during two brief periods in 1998 when input volumes exceeded the storage capacity. Estimated spillway losses combined with power releases are used as the known total water losses from this system. Ouflow through BHF at the Linville Basin dam averaged nearly 17 m^3/s with a maximum of almost 127 m^3/s during the study period. Volume wasted over the spillway during this study period averaged 0.25 m^3/s with a maximum of almost 64 m^3/s during a relatively brief period when water levels exceeded reservoir capacities.

A perspective on the impact of unmonitored losses can be illustrated as estimates of the net balance between all inputs and losses for Lake James (m^3/s) combined with the change in storage volume (m^3) that accompany changes in net input-output balances (Figure 11). Storage volume data show a decline during the January to March 1999 period when atmospheric losses to evaporation are minimal. The difference between changes in storage volume and net balance between known surface discharges and losses during this period is 1.4 m^3/s ($1.2\text{x}10^5$ m^3/d). This is a considerable loss of water from this system, presumably due to seepage and groundwater. For comparison, the value is over an order of magnitude greater than the groundwater estimates based on base flow recession yields. The value also exceeds discharge from the Linville River and approaches the total input from all watersheds during severe drought conditions. Discharge data in the Catawba River below Lake James reservoir show minimum flows approaching 2.5 m^3/s during very dry conditions suggesting that these estimated seepage values are reasonable. Knight's (2003) analysis of turbine leakage at BHF revealed losses measuring 1.557 m^3/s (55 ft^3/s) and may account for the losses we found in our analysis.

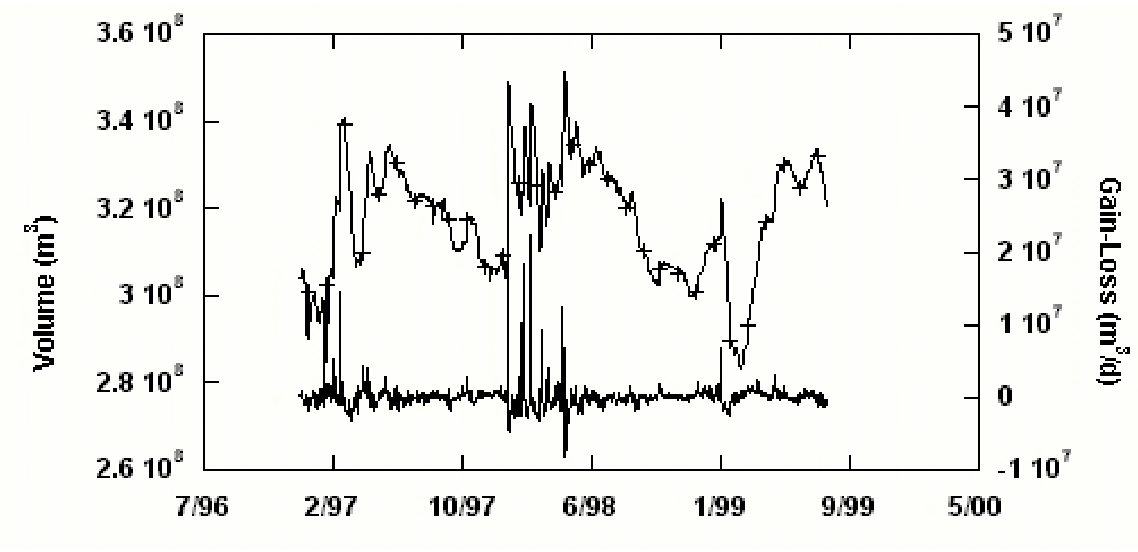


Figure 11 Evaporation and precipitation balances for study period (Negative evaporation rates (+) are generated in energy balance calculations when heat losses exceed gains.)

Results of LJA Water Balance Modeling

For the most part, the model faithfully represents the data including episodic rainfall events and seepage losses. However, what was not anticipated was the apparent effect of the discharge coefficient on the overall budget. In this water balance calculation, water released from the power station was calculated from an algorithm relating power generation to water use (Foris and Knight p.c. 1998). Large volumes of water are released with discrete bursts of power production. Episodic water releases are then followed by periods of zero discharge through the penstocks. These discrete bursts of water use are contrasted with the more continuous losses associated with evaporation and seepage. Water balance sensitivity analysis indicates that the lowest error residuals in calculated and measured volumes are generated by using a discharge value that is 98% of the original algorithm. The overall water balance is very sensitive to small changes in the discharge coefficient since outflows from the reservoir are an important part of the overall water balance.

Conclusions

The 1997 to 1999 study on Lake James provided an opportunity to calculate the water budget for a multi-use reservoir in the upper Catawba River watershed. The uncharacteristically dry period during 1999 provided an opportunity to use changes in storage volume to estimate unmonitored reservoir losses. The difference between measured volume changes and measured water inputs and losses is approximately 33.3 m^3/s (1.2×10^5 m^3/d), a rate that occasionally exceeds inputs from the entire watershed during this prolonged dry period. This rate applied to the entire year results in a loss of almost 13% of the total full pool every year. The calculated water balances are used to calculate evaporation from the lake using an analytical energy budget. Evaporation ranges from 65 to over 100% of measured precipitation during the 1997 to 1999 study period.

The results of the water balance analysis over this study period suggest that power generation and recreational uses of Lake James may be critically impaired during extremely prolonged hydrological droughts. Estimates of the assured base flows from the Catawba and Linville River watersheds do not supply sufficient volumes of water to make up differences in evaporation and seepage from the reservoir basin. Under normal climate regimes the excess of river discharge over water lost for power generation, evaporation and seepage maintains lake volumes. However, if climate changes result in continued hydrological drought conditions, Lake James may suffer critical water balance crises that could impair power generation and recreational uses. Post facto analysis of turbine losses (unmonitored seepage through turbines when not in use for power production) conducted by Knight (2003) indicated losses of 1.557 m^3/s (55 ft^3/s) through the turbines in the BHF, a value twice what was estimated at the time of our study. These losses coupled with the karst nature of the North Fork Catawba would impact the water balance as calculated and may account for some of the measured losses we detected. After the closing of this study the Upper Catawba River basin entered into the FERC Relicensing process. One of the outcomes of this process was the reworking of the three dams on Lake James, including revisions to the Bridgewater Hydroelectric Facility. As such, the system as we studied it, no longer exists; however, these data bear revisiting with further testing and validation of the models in reservoir systems with a strong existing water quality database or with future research. Furthermore, the models should be tested against existing established hydrologic and mass balance models. For the purposes of this exercise, the LJA water balance model was used as a descriptive model of the reservoir system, and should be tested as a predictive model and validated against a reliable database.

CHAPTER THREE

CHEMICAL DYNAMICS OF LAKE JAMES, NORTH CAROLINA

System Properties of Reservoirs

Reservoirs differ from lakes due to their structure and their response to hydrological inputs. Reservoirs are formed by the impoundment of one or more rivers. Watershed size is often greater in a reservoir than a natural lake, but it is the morphometry of the reservoir that makes it unique. Thornton et al. (1981) proposed a heuristic model to explain longitudinal zonation in a reservoir. The riverine zone is the shallowest part of the reservoir and is formed by direct inputs from the watershed. The lacustrine zone at the dam is most lake-like in its characteristics. The transition zone is in between the riverine and lacustrine zones and maintains features of both.

The riverine zone has properties of being well mixed and aerobic, with velocities sufficient to maintain fine particle suspension (Gordon and Behel 1985) such that light penetration is reduced and limits primary production (Thornton 1990). As depth increases through the transition zone, velocities slow and particles drop out of suspension, so this is a region of sedimentation resulting in an increase in light penetration (Kennedy et al. 1982) shifting the system from allochthonous to autochthonous production (Thornton 1990). By the time water reaches the lacustrine zone, sedimentation is low and light penetration is high relative to the other zones, promoting primary productivity which may or may not be nutrient limited (Thornton 1990), depending on the trophic status of the waterbody.

There are two further extrapolations of these zones that should be considered (Schindler 1997). The first is that surface layer mixing, particle suspension and nutrient entrainment are influenced by the declining kinetic energy (Kennedy et al. 1982) as flows proceed from the riverine to the lacustrine zone. This decrease in kinetic energy is generally associated with the increasing volume of the system associated with the impoundment of a valley. The second feature that should be noted is that the gradual sloping structure of bottom boundary layers in the riverine zone contrast directly with the steep slopes of the lacustrine zone.

Chemical dynamics of reservoirs

Biochemical cycles in reservoirs are not closed. They receive substances from the watershed and the atmosphere, export substances via the outflow and atmosphere and bury substances in the sediments. Depending on the balance of these processes, water passing through a reservoir can be either enriched or impoverished of constituents. Before entering a lake, water is chemically altered while passing its watershed; therefore, watershed geology and both the chemical composition and quantities of precipitation are extremely important (Lampert and Sommer 1997).

The Lake James water quality assessment included the monitoring of 21 chemical constituents. Table 3 lists these constituents examined as well as the abbreviation used in this text. A few constituents may need some clarification, however, to the reader. Nitrogen compounds measured include ammonia-N and nitrite+nitrate-N (inorganic fractions), total Kjeldahl-N (the organic fraction), and total N. Phosphorous compounds measured include total P and ortho-phosphate (bio-available fraction). Carbon compounds are divided into the dissolved and particulate fractions. Dissolved carbon includes total organic carbon (organic fraction) and alkalinity (inorganic fraction). Particulate carbon is measured as seston and is divided into seston dry weight (SDW) which includes both organic and inorganic particulates, and seston-ash free dry weight (SAFDW) which represents only the organic component of the particulate material.

Table 3 Constituents examined in LJA water chemistry analysis with abbreviations

Alkalinity	Alk
Aluminum	Al
Ammonia	NH_4
Calcium	Ca
Chloride	Cl
Iron	Fe
Magnesium	Mg
Manganese	Mn
Nitrite + Nitrate	NO2/NO3
Ortho-Phosphate	O-PO4
Potassium	K
Seston, Ash Free Dry Weight	SAFDW
Seston, Dry Weight	SDW
Silica	Si
Sodium	Na
Sulfate	SO4
Total Kjeldahl Nitrogen	TKN
Total Organic Carbon	TOC
Total Phosphorous	TP
Zinc	Zn

Regulating mechanisms of lake water chemistry

Different controlling mechanisms are responsible for the distribution of chemical constituents within the water column throughout the year. These include internal loading mechanisms, oxidation-reduction mechanisms, biological regulation, and hydrologically driven constituents.

Internal loading and boundary mixing phenomenon are often associated with seasonal thermal instabilities (MacIntyre et al. 1999, Wetzel 2001). In fall there is deterioration of the thermal structure as lake temperatures equilibrate with the atmosphere and in spring before a strong thermocline is established (Hutchinson 1957). Wind can generate basin rocking sufficient to mix hypolimnetic waters with surface waters mediated by basin morphometric differences (MacIntyre et al. 1999, Csanady 1978).

Oxidation-reduction potential also affects the ability of certain species to re-enter the water column or to become chemically active. Some chemical constituents such as iron and manganese are transition metals and are sensitive to redox state and require anoxic conditions to change their availability (Wetzel 2001). These species are often bound in the bottom sediments and become available under anoxic conditions under favorable redox potential. Pulses of these constituents would be expected at fall mixing. Other elements such as phosphorous may be tied to the redox state of other compounds such as clays (iron-alumino-silicates) and must be released in order to make them available to biota (Wetzel 2001; Hutchinson 1957; Mortimer 1941, 1942, 1971).

Biological regulation of water chemistry can be observed in the depletion of non-conservative elements (C, N and P), particularly during periods of high productivity such as spring and fall. There may also be remineralization in the vicinity of the metalimnion. Often, the dynamics of these elements are more dramatic near the thermocline where boundary mixing at the oxic-anoxic interface brings limited nutrients into contact with the biota (Wetzel 2001). Metalimnetic dissolved oxygen minimum is used as an indicator of respiration processes (Wetzel and Likens 1999). Biologically driven constituents include TP, O-PO_4, NH_4, TN, TKN, TOC and Si; although, TOC and Si also have a strong hydrologic component. Ortho-phosphate (O-PO_4), the biologically available form of phosphorous, and total phosphorous (TP) will be used as exemplars for biological regulation mechanisms.

Hydrologically driven constituents are associated with seasonal periodicity of rainfall. The timing, duration and severity of precipitation coupled with antecedent conditions and lithology serve to determine the amount of materials moved within the watershed (Schindler p.c. 2000). Depending on conditions, any precipitation event may increase concentration by mobilization of suspended solids from within the watershed into the lake or dilute the existing ionic concentration within the lake if rainfall amounts are insufficient to mobilize sediments and allochthonous materials into the reservoir. These effects may be coupled with the effects of evaporative concentration during years where insufficient rainfall fails to dilute ionic concentration. Hydrologically driven species include the major cations (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}) and major anions (CO_3^{-2}, SO_4^{-2}, Cl^{-}) as well as other hydrologically driven species (Al^{+3}, Zn^{+2}, SDW & SAFDW). I hypothesized that hydrology, mediated by the effects of local precipitation and antecedent conditions would have the most profound effect on water chemistry in Lake James.

Since my main focus is on the effects of hydrology on loading events into Lake James, I restricted the focus of this analysis to those constituents considered to be hydrologically driven. Chloride, considered a conservative tracer element in water quality studies (Canale 1976), will be used as an exemplar for a monovalent anion for the purposes of the discussion of hydrologically dominated constituent regulation. Alkalinity, a measure of the acid neutralizing capacity of the basin, will be examined. Calcium will be used as an exemplar for a hydrologically driven bivalent cation as well as integral to the reservoir’s carbonate buffering system. Potassium will be discussed as a monovalent cation. Phosphorous dynamics, as ortho-phosphate and total phosphorous, will also be explored as a constituent driven not only by watershed hydrology, but by biological regulation and redox processes, as well, to test the effectiveness of this modeling methodology with constituents of more complex behavior within reservoirs.

LJA Chemical Mass Balance Model and Analysis

It is acknowledged that calculating average annual loading and yield estimates using average daily flow, concentration and watershed area are suitable for running waters (Olem and Flock 1990) but their use in a lacustrine situation ignores the important effects of volume. Furthermore, these calculations are based on surface water concentrations and do not reflect changes inherent in the water column. Calculation of average annual loading and yield are traditional methods used in limnological analyses and tend to oversimplify a complex system, like a reservoir where the running waters are stored for relatively short periods of time, compared to lakes and other ‘standing water’ systems. Additionally, because the bulk of material incorporated into the water occurs during a few episodic precipitation events, using annual averages diminishes the effects of these events. It can be misleading to make an assessment of concentration without considering the volume of the lake that the sample represents.

A segmented model was developed in the STELLA research modeling environment to examine the effects of flow, volume and surface water loading on the behavior of Lake James and to allow the user to assess the fate of constituents due to changes in concentration between stations within the Lake James basins. This exercise stresses the importance of linear distance in the processing of watershed inputs into the reservoir (Thornton et al. 1981, Thornton 1990, Kennedy and Walker 1990). The LJA-CB model is a heuristic tool through which loading and sedimentation values can be generated in a sitting to facilitate study optimization. Other more rigorous models have been developed for management purposes, and range from such as the SIMPLI eutrophication model package (FLUX, BATHTUB, and PROFILE) (Walker 1996) to the complex hydrodynamic models such as CE-QUAL-W2 (Cole and Wells 2000) from the US Army Corps of Engineers (USACE).

> “The BATHTUB program applies empirical eutrophication models to morphometrically complex reservoirs or to collections of reservoirs. The program performs water and nutrient balance calculations in a steady-state, spatially segmented hydraulic network which accounts for advective transport, diffusive transport, and nutrient sedimentation. Eutrophication-related water quality conditions (expressed in terms of total phosphorus, total nitrogen, chlorophyll a, transparency, organic nitrogen, particulate phosphorus, and hypolimnetic oxygen depletion rate) are predicted using empirical relationships previously developed and tested for reservoir applications (Walker 1983, Walker 1996).”

> “CE-QUAL-W2 is a two-dimensional water quality and hydrodynamic code supported by the US Army Engineer Research and Development Center (Cole and Buchak 1995). The model has been widely applied to stratified surface water systems such as lakes, reservoirs, and estuaries and computes water levels, horizontal and vertical velocities, temperature, and 21 other water quality parameters (such as dissolved oxygen, nutrients, organic matter, algae, pH, the

> carbonate cycle, bacteria, and dissolved and suspended solids) (Cole and Wells 2000)."

For the purpose of modeling in STELLA, Lake James was divided into eight segments using the bathymetry generated for Duke Energy (Foris and Knight pc 1998) using the W2-Grid preprocessor. By examining the profile of the bathymetry, areas of morphometric restriction were used to assign segment limits, and inlake sample locations were assumed to represent the segment wherein they fell.

The LJA mass balance is a simple model and assumes hydrology is the driving variable for the system. For each segment, daily hydrology and segment volume are used to compute the loading for each constituent from concentration gathered at monthly sampling intervals. The calculated concentration is then compared to the measured concentration and any difference is then assumed to have been "assimilated" within the water column. In the model this value is called sedimentation; however, the changes in concentration may be due to particle settling or biological assimilation as well. By summing the daily loading over a year one can compute an annual loading estimate for each segment of the lake that is volume weighted and this value can be used to make inferences about the spatial distribution of chemicals within the lake.

LJA Chemical Balance Model

The Lake James Assessment chemical balance model for Lake James, NC was developed in the STELLA modeling environment as a GUI based modified Vollenweider (1969)/Chapra (1975, 1979) style empirical mass balance model for an incompletely-mixed vertically-segmented reservoir with an embayment. Vollenweider's (1969) model as modified by Chapra (1975, 1979) (Equation 1) was designed as a phosphorous budget. Håkanson and Peters (1995) demonstrated the utility of the STELLA platform for a variety of limnological modeling exercises, including a simple constituent mass balance model which considered a lake as a simple “black-box” where Qin = Qout with a consitutent sedimentation factor similar to the formulation given above.

The Lake James Assessment chemical mass balance model for Lake James has extended this conceptualization to consider the reservoir as compartmentalized or segmented. Bathymetry is used to identify areas of morphometric restriction/variation within the spatial array of in-lake water quality sampling sites to define the segment limits. Volume is computed based on segment limits and bathymetric mapping for Lake James conducted by Duke Energy using the W2-Grid Pre-processor and this data was used for our volumetric calculations for these segments (Foris and Knight p.c. 1998). Each segment within the reservoir basins is treated as a Continuously Stirred Tank Reactor (CSTR) (Piontelli and Tonolli 1964; Vollenweider 1969, 1975, Brezonik 1996). The difference between the volume weighted measured concentration and the calculated concentration as it passes from one segment to the next is computed and when the calculated exceeds the measured, the difference is sedimented.

$$\begin{aligned} \mathbf{V* \, \mathit{d}C/\mathit{d}t} &= \mathbf{Q*Cin_{Cat} + Q*Cin_{Lin} - Q*Cout} \\ &\quad \mathbf{- (V_{3313}*Ccalc - V_{3313}*Cmeas) - (V_{3312}*Ccalc - V_{3312}*Cmeas)} \\ &\quad \mathbf{- (V_{3311}*Ccalc - V_{3311}*Cmeas) - (V_{3310}*Ccalc - V_{3310}*Cmeas)} \\ &\quad \mathbf{- (V_{3303}*Ccalc - V_{3303}*Cmeas) - (V_{3302}*Ccalc - V_{3302}*Cmeas)} \\ &\quad \mathbf{- (V_{3301}*Ccalc - V_{3301}*Cmeas) - (V_{3300}*Ccalc - V_{3300}*Cmeas)} \end{aligned} \tag{4}$$

Change in lake = Inflow - Outflow - Sedimentation in each segment

Where:
V = lake volume (m^3) or for a given segment of the lake
*d*C = change in concentration (mg/L) during the time *d*t (s)
Q = discharge to the lake (m^3/s)
C = concentration (mg/L) of the constituent in the inflow (Cin) and in the outflow (Cout)
Ccalc = calculated concentration (mg/L) passed from the previous segment (or inflow)
Cmeas = measured concentration (mg/L) in the current segment

Methods

Chemical constituents analyzed

Water chemistry samples were collected monthly at each of the eight sampling stations within Lake James (Figure 6). For each sample, one liter of water was filtered for chlorophyll analysis. Of this liter, about 600 ml of filtered water was retained for further analysis. An additional two liters of unfiltered water were also collected for analysis. Water was collected in 5 m increments at the two lacustrine stations (3300 in the Linville and 3310 in the Catawba basin). Surface water samples were collected for the remaining stations (3301 and 3302 in the Linville basin, 3303 in Paddy Creek basin, and 3311, 3312, and 3313 in the Catawba basin). From these samples, 21 different chemical constituents were measured using the procedures listed in Table 4. Surface water was also collected and analyzed for the four inflowing streams and for the Catawba River outflow below the Bridgewater Hydroelectric Facility (station 326); however, no chlorophyll filtration was done on these samples. Water chemistry analysis (Table 4) conducted by Duke Power Company LLC DBA Duke Energy Analytical Laboratory (Huntersville, NC (704)875-4795) is certified by the National Environmental Laboratory Accreditation Conference (NELAC now TNI) for NP water, solids and chemistry analysis (http://www.nelac-institute.org/content.aspx?page_id=22&club_id=869462&module_id=17097).

Of note is the location of the downstream sampling station for the outflows. After this modeling effort was completed, water chemistry samples collected by Duke Energy directly at the BHF outflow above station 326 were made available to us. Upon examination, we found that the samples gathered at station 326 below the BHF were influenced by the confluence of the old Catawba River channel, also known as Muddy Creek. It would be a worthwhile effort to revisit our loading and yield calculations using this information to more accurately quantify the impacts of the reservoir on the water chemistry of the outflows without the confounding data from the confluence.

Table 4 Techniques for water chemistry analysis conducted by Duke Energy's analytical laboratory in Charlotte, NC

ALKALINITY	TOTAL INFLECTION POINT TITRATION
ALUMINUM	ICP
AMMONIA	COLORIMETRIC
CALCIUM	ICP
CHLORIDE	COLORIMETRIC
IRON	ICP
MAGNESIUM	ICP
MANGANESE	ICP
NITRITE + NITRATE	COLORIMETRIC
ORTHO-PHOSPHATE	COLORIMETRIC
POTASSIUM	ICP
SESTON, ASH FREE DRY WEIGHT	COMBUSTION
SESTON, DRY WEIGHT	COMBUSTION
SILICA	COLORIMETRIC
SODIUM	ICP
SULFATE	IC
TOTAL KJELDAHL NITROGEN	COLORIMETRIC
TOTAL ORGANIC CARBON	COMBUSTION
TOTAL PHOSPHORUS	COLORIMETRIC
ZINC	ICP

Derivation of Loading and Yield Calculations:

Traditional loading and yield estimates were calculated for the uplake stations of the Linville and Catawba basins in Lake James. Monthly chemical concentrations and average daily discharge were averaged for each year and multiplied to provide a conservative estimate of loading and yield to the Catawba River system. Loading refers to the amount of a given constituent which is carried by the streams into the waterbody. Yield calculations weight the loading into the basin by dividing the loading by the watershed area. Therefore, yields reflect the areal effects of the watershed to the lake basin. If yield values are similar, one can assume similar lithologies and land uses. These formulae generate a modest estimate of loading and yield for Lake James.

$$\textbf{Loading} = \textbf{average annual concentration} * \textbf{average annual flow} \tag{5}$$

$$\textbf{Yield} = (\textbf{average annual concentration} * \textbf{average annual flow}) / \textbf{watershed area} \tag{6}$$

Where:
Loading = g/yr
Concentration = g/L
Flow = m^3/s
Yield = $kg/km^2/yr$
Watershed Area = km^2

Flow weighted loading calculations, such as the ones used in the LJA-CB, take into consideration the variability in average daily flows, as opposed to average annual flows of the traditional calculations and use the daily flow regime to weight constituent loading from monthly measured concentrations, extrapolated across to each day until the next sampling period. Furthermore, the LJA-CB also considers segment volume in its derivation of constituent loading as material is passed through the Lake James basins to assess not only loading within the basins, but also assimilation of constituents.

Modeling methodology

Mass loading is calculated within STELLA (Figure 12) as a function of surface water chemical concentration gathered in monthly intervals from four inflowing and one outflowing stream below the BHF and eight in-lake stations and analyzed by Duke Energy analytical laboratory in Charlotte, NC according to NELAC certified standard methodologies for each constituent. Decreases in concentration and hence loading between reservoir segments are considered sedimentation, after Håkanson and Peters

(1995) and Chapra's (1975, 1979) modification of Vollenweider (1969), with the assumption that the sedimentation term is taken loosely to include the dimension of assimilation within the depth of the water column, the biota as well as the underlying sediments.

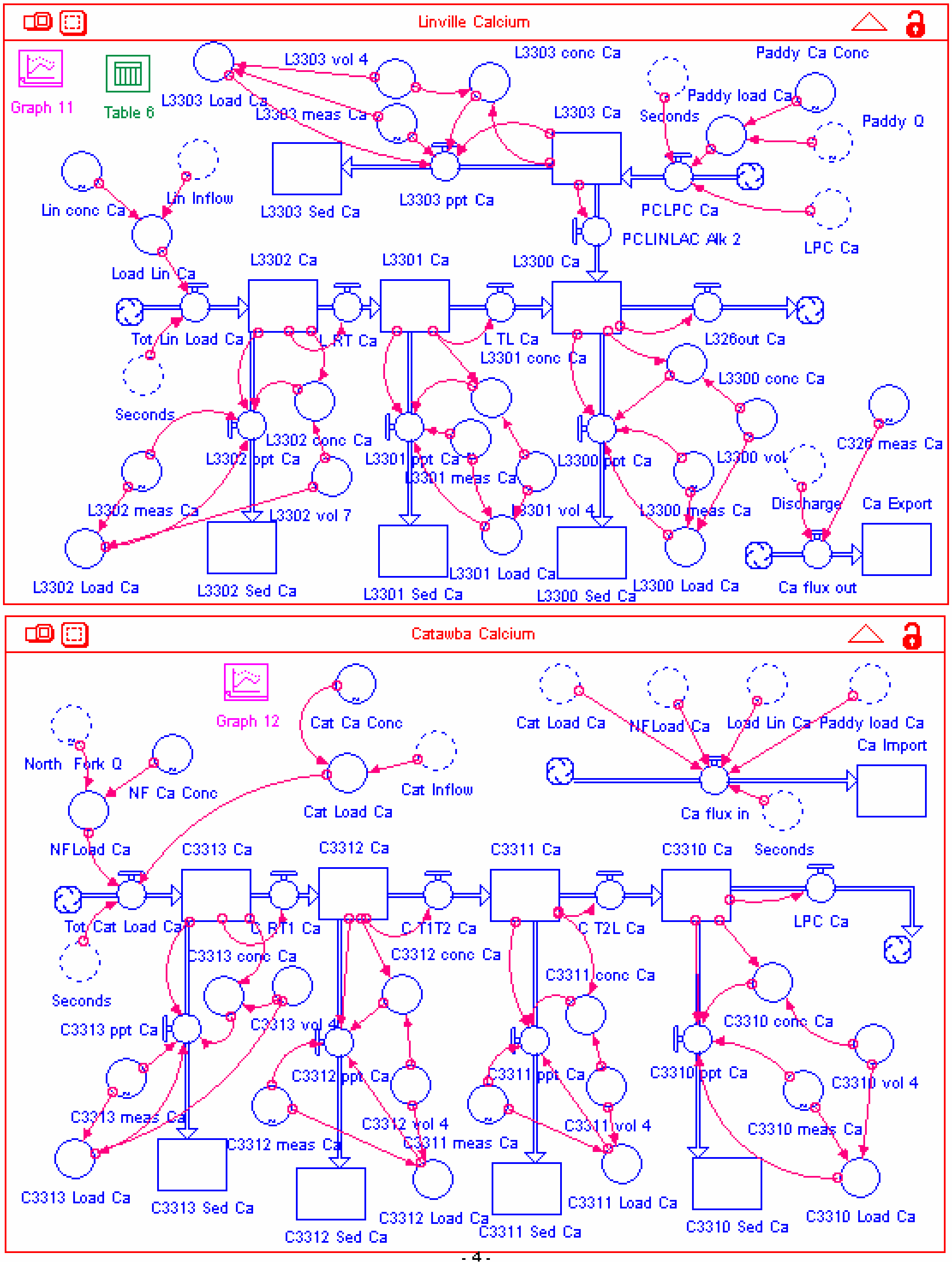


Figure 12 Lake James Assessment STELLA mass balance model for Calcium loading to Lake James, NC

Some data preparation was required in order to facilitate the coupling of hydrologic and chemical constituent data which were gathered at different time steps. Hydrologic outputs of the LJA water balance model, based on average daily stream flows, were imported into Microsoft® EXCEL and used as a template for the inputs for the chemical budget inputs. Monthly chemical concentration for each sampling station was then extrapolated across to each daily time step until a new concentration was gathered. These data for the 'daily' chemistry and hydrology were then exported as a CSV (comma delimited ASCII file) for import into STELLA. The data for the in-lake stations were gathered with regularity throughout the study; however, some of the stream chemistry stations were collected sporadically, especially at the onset of the study before their utility became apparent and the study design was adjusted. Those sites with limited numbers of samples should be viewed with some skepticism, as reliability and model accuracy improves with intensity of sampling (Olem and Flock 1990).

LJA-CB model generated loading and assimilation

The LJA-CB STELLA model (Figure 12) uses average daily flow rate, monthly measured concentration and segment volume to calculate a volume and flow weighted estimate of loading and constituent assimilation among segments within the basins of Lake James.

Because of the difference in the time steps between the flow and measured concentration, an assumption is made that the concentration remains constant over the course of the month until the next sampling date when the concentrations are adjusted. Flows in the interim, however, vary with the daily time step. Therefore, rates and quantities of loading and assimilation are generated largely as a function of flow and do not truly reflect daily adjustments in constituent concentration. They should be viewed as representing a flow-weighted potential for constituent loading and assimilation within the basins as reflected in the daily variability of hydrology. Although a comparable study could be initiated to collect water samples on a daily time step, the costs of such an analysis would be prohibitive for such a long term study.

One of the limitations to this analysis is in the quality and limitations of the data inputs used in this modeling exercise. Although lacustrine sampling locations were used at the inception of this study in March 1997, transition stations were added in May 1997 and riverine stations were added in June 1997. Sparsity of measured data in 1997 limit the accuracy of the modeled measures generated for that year. Likewise, sampling for this study ended in October 1999, so calculations for loading and assimilation for 1999 do not reflect a full year's loading into Lake James. Such limitations impact the ability to use interannual comparisons and limit the discussion of annual loading and sedimentation to interbasin comparisons.

Results and Discussion

Impacts of withdrawal regime on physical properties of Lake James

Examination of thermocline depth for the Linville and Catawba basins in August of each year of the study reveals a stronger thermocline in the Catawba basin due to the hypolimnetic restriction from the connecting canal between the two basins (Table 2). The Catawba basin had a stronger thermal gradient as expressed in the maximum change in temperature per meter of depth with 4.85 º C, 5.25 º C, and 4.17 º C in 1997, 1998 and

1999, respectively. The Linville basin thermoclines were 2.34 ° C, 1.64 ° C, and 1.59 ° C, for the same time period. The proportion of volume in the hypolimnion in 1997 was approximately 43% for the Linville and 22% for the Catawba basin. In 1998, the proportion of volume in the hypolimnion was 33% for the Linville and 21% for the Catawba basin. In 1999, the proportion of volume in the hypolimnion was 33% for the Linville and 26% for the Catawba basin.

Constiuent behavior in aquatic ecosystems

Alkalinity

Carbonate is the principle anion of most fresh water systems (Cole 1994). Alkalinity refers to the buffering capacity of the carbonate system in water and is often used interchangeably with Acid Neutralizing Capacity (ANC), the capacity to neutralize strong inorganic acids. However other dissolved constituents contribute to alkalinity, such as weak acid ions which can accept and neutralize protons (Wetzel 2001).

The carbonate cycle is the principle buffering system in inland aquatic ecosystems. Carbon dioxide (CO_2) solubility exceeds that of oxygen (O_2) (Wetzel 2001). Dissolved CO_2 hydrates by slow reaction in water into carbonic acid (H_2CO_3) then bicarbonate (HCO_3^-) with a release of hydroxyl ions (OH^-), a reaction which predominates between pH of 4.5 and 8.3. Above pH of 8.3, carbonate (CO_3^{-2}) is favored in the reaction, and below pH 4.5 CO_2 is favored.

As water passes through the soils of a watershed it is enriched with CO_2 from plant and microbial respiration, forming carbonic acid which solubilizes limestone of calcium enriched rock formations generating calcium bicarbonate [$Ca(HCO_3^-)_2$], thereby increasing the quantities of ionized Ca^{2+} and HCO_3^- of the water and contributing to its buffering capacity (Wetzel 2001). We therefore tend to think of fresh waters as calcium carbonate ($CaCO_3$) solutions, which is crystallized either as calcite (hexagonal) or aragonite (orthorhombic) which is less common and precipitates in warm waters but is unstable at normal temperatures. Magnesite ($MgCO_3$) and dolomite ($CaMg(CO_3)_2$) are also common contributors to the alkalinity of watersheds (Cole 1994).

Chloride

Chlorine is the most abundant of the halogens (chlorine, bromine, iodine and fluorine) (Horne and Goldman 1994). Chlorine, as the chloride ion, is present in small quantities in fresh water but becomes a dominant ion in estuaries and the sea (Horne and Goldman 1994). Chloride usually ranks third among the anions. The sulfate ion (SO_4), is usually second to carbonate as the principal anion in fresh waters, although chloride occasionally surpasses it (Cole 1994).

Chloride functions in osmoregulation, cation uptake, photosynthesis and reactivity of enzymes (Wetzel 2001). The chloride ion is required by photosynthesizing cells for the photolysis of water to release oxygen, for adenosine tri-phosphate (ATP) formation, and for certain phosphorylation reactions (Horne and Goldman 1994). Chloride is a conservative element in aquatic ecosystems and is often used in modeling exercises as a conservative tracer as it tends to occur in excess of biological requirements for it (Canale 1976).

Calcium

Calcium, a bivalent cation, is essential for metabolic processes in all living organisms. It is a silvery white alkaline earth metal (Cole 1994). Calcium serves in structural and skeletal systems in many organisms (Horne and Goldman 1994). It also serves as a major skeletal strengthening material in all vertebrates, mollusks, and some invertebrates, and serves in cell wall structure of some algae and in coral (Horne and Goldman 1994).

Calcium serves a primary role in the carbonate buffering of aquatic ecosystems. It occurs in water in ionic form and as suspended particulates, mainly $CaCO_3$ (Horne and Goldman 1994). Although it is the predominant compound in many interior waters, $CaCO_3$, is also one of the least soluble (Cole 1994). Only a small amount can be dissolved in pure water, but in the presence of carbonic acid it is mobilized as the soluble $Ca(HCO_3^-)_2$ (Cole 1994). Therefore, carbonic acid formed in water as it passes through the watershed dissolves basic carbonate rocks such as limestone and contribute both Ca^{2+} and CO_3^{2-} to the receiving waters and their buffering capacity (Horne and Goldman 1994).

Calcium derived from the earth’s crust is found as a constituent of certain silicates (Cole 1994). Feldspars are the most abundant of all minerals and comprise about 60% of the earth’s coating. Anorthite ($CaAl_2Si_2O_8$) is a common member of the feldspar group of silicates (Cole 1994). Sedimentary deposits of $CaCO_3$ have been laid down by living things over time and these deposits contribute to calcium availability (Cole 1994).

Chemical weathering of calcium compounds can put them into solution, and they enter the aquatic environment through the watershed in the dissolved state or can be carried from afar by wind (Cole 1994). Calcium carbonate is the main constituent of chalk, limestone, and the metamorphosed rock, marble (Cole 1994). The mineral calcite is the common form and is the most stable type at normal temperatures and low pressures (Cole 1994). Aragonite is less common and is found in deposits from hot springs and geysers, cave stalactites, and in most molluscan shells (Cole 1994). Its crystalline structure differs from calcite, and it has a greater specific gravity (Cole 1994).

Potassium

Potassium, a monovalent cation is usually the fourth ranking cation in lake water (Cole 1994). Though similar to sodium it does not remain in solution so well as sodium (Cole 1994). Potassium is rarer in water than sodium, but more abundant to it in the world's rocks (Cole 1994). Potassium recombines easily with other products of weathering, being removed from solution by adsorption on clays (Cole 1994). It is weathered from various feldspars that have the formula $KAlSi_3O_8$; however, feldspathoids containing potassium do not weather so readily as the sodium minerals (Cole 1994). Leucite ($KAlSi_2O_6$) exists as crystals within volcanic rocks (Cole 1994). Potassium also tends to form micas, which are insoluble and unavailable to aquatic ecosystems (Cole 1994). Among the sources of potassium are potash K_2CO_3, KOH and potassium oxide, sylvite (KC1) and saltpeter (KNO_3). Sodium and potassium salts have been found to increase the solubility of $CaCO_3$ even in the absence of free CO_2 (Cole 1994).

Silicon, calcium, magnesium, sodium, potassium, sulfur, chlorine, iron and the minor metals are considered minor nutrients relative to carbon, nitrogen and phosphorous in aquatic systems (Horne and Goldman 1994). In plants, both extracellular and intracellular fluids contain an excess of K^+ over Na^+; whereas, in animals, extracellular Na^+ surpasses potassium (Cole 1994). Potassium is required for all cells and serves as an enzyme activator. Potassium occurs in larger quantities inside the cells of aquatic biota than in the surrounding medium (Horne and Goldman 1994). Lakes are much less concentrated solutions of potassium relative to the biota, so cell membranes must continually pump in potassium and pump out sodium using considerable amounts of energy (Horne and Goldman 1994).

Phosphorous (Ortho-phophate and Total Phosphorous)

Variation in the phosphorous content of natural waters, a function of the characteristics of regional geology, is generally lowest in mountainous regions of crystalline bedrock geomorphology and tends to increase in lowland waters derived from sedimentary rock deposits (Wetzel 2001). Total phosphorus concentrations range from <1 µg/L to more than 200 mg/L, but most waters are between 10 to 50 µg/L (Wetzel 2001). The phosphorus content of precipitation is low (approximately <30 µg/L) in unpopulated areas but can increase to over 100 µg/L around urban-industrial areas (Wetzel 2001). Ground water phosphorous is also typically low with average concentrations around 20 µg/L, due to the relatively insolubility of phosphate-containing minerals and the tendency of biota and soil particles to scavenge surface phosphate when available (Wetzel 2001).

In general, the soil characteristics of the drainage basins dictate the chemical dynamics of their surface waters as a function of regional geology and climate (Keup 1968, Vollenweider 1968, Lal 1998; Wetzel 2001). Surface drainage is often the primary source of phosphorus to streams and lakes (Wetzel 2001). Phosphorous weathers from rock fragments and is transported by dry deposition or by streams to be deposited in the sediments of lakes and the oceans. Phosphorous transport processes, therefore, are impacted by patterns of erosion and sediment transport. The lithology, topography and land use practices influence the amount of erosion; and, the transport of phosphorous is highly correlated with the average slope of the drainage basin (Horne and Goldman 1994). Within the watershed, soluble phosphorous tends to be retained by the soils and is much less mobile a nutrient than nitrate (Horne and Goldman 1994). This mobility is impacted by the soil water pH which regulates phosphorous exchange from complexes with iron, aluminum, manganese and calcium as well as organic complexes (Wetzel 2001). As overland flow and river discharges increase the quantity and rate of transport of particulate bound phosphorous increases. The bulk of the phosphorous transported in streams is inert and bound to sediment particles with as little as 5 to 10% of the phosphorous in natural waters carried in soluble form (Horne and Goldman 1994).

The most important measure of phosphorous is the total phosphorus content of unfiltered water consisting of the phosphorus in the particulate and in dissolved forms (Juday 1927, Ohle 1938; Wetzel 2001).

> ”Particulate phosphorus includes (1) phosphorus in organisms as (a) the relatively stable nucleic acids DNA, RNA, and phosphoproteins, which are not involved in

> rapid cycling of phosphorus; (b) low-molecular-weight esters of enzymes, vitamins, et cetera; and (c) nucleotide phosphates, such as adenosine diphosphate (ADP) and adenosine 5-triphosphate (ATP) used in biochemical pathways of respiration and C02 assimilation; (2) mineral phases of rock and soil, such as hydroxyapatite, in which phosphorus is adsorbed onto inorganic complexes such as clays, carbonates, and ferric hydroxides; (3) phosphorus adsorbed onto dead particulate organic matter or in macroorganic aggregations. In contrast to the phosphorus of particulate matter, dissolved phosphorus is composed of (1) orthophosphate (P043-), (2) polyphosphates, often originating from synthetic detergents, (3) organic colloids or phosphorus combined with adsorptive colloids, and (4) low-molecular-weight phosphate esters (Wetzel 2001)."

Froelich (1988) used the term phosphate buffer system to describe the relatively rapid adsorption and release of phosphorous in running waters. He described it as a two phase system in which phosphate ions (PO_4^{3-}) are adsorbed or desorbed from mineral particles as a function of external phosphate concentrations and salinity. First stage adsorption reactions occur between phosphate and suspended inorganic particles in a matter of minutes to hours, and are easily reversible. Second stage adsorption reactions are much slower, taking days to months, and involve solid-state diffusion of phosphate into the interior molecular spaces of the particle. The second stage adsorption reactions are not as easily reversed. Phosphate is released when the equilibrated particles flow into different external conditions which facilitate their release, largely by reversal of surface adsorption (Horne and Goldman 1994).

The result is that most of the phosphorous in lakes is inert and in the sediments or is present in organic form and bound within living or dead biomass (Horne and Goldman 1994). Vollenweider (1968) demonstrated that the amount of total phosphorus tends to increase with lake productivity (Wetzel 2001). Phytoplankton, however, can only use soluble phosphate (PO_4) for their growth. Under phosphorous-limitation, algal growth is determined by the levels of biologically available phosphate; however, the phytoplankton standing crop is proportional to total phosphorous levels under the assumption that most of it is recyclable (Horne and Goldman 1994). Zooplankton, fish and bacterioplankton excrete soluble and organic phosphorous. Decomposition of dead plants and animals release the dissolved organic phosphorous bound within the biota (Horne and Goldman 1994). Because phosphorous is the most limiting nutrient in fresh waters, the biota have developed mechanisms to exploit its availability. Luxury consumption is the process by which most phytoplankton store excess phosphorous within their cells as polyphosphorous granules which are rapidly formed when phosphate becomes available in phosphorous deficient waters. Some have the capacity to exploit phosphorous at extremely low levels; and, some use the enzyme alkaline phosphatase, an esterase which cleaves the bond between phosphate and the organic molecule to which it is attached. The production by algae of alkaline phosphatase is inhibited by elevated phosphate levels (Horne and Goldman 1994). Sediment bacteria also play a role in liberating phosphates by using organic acids to release sediment bound insoluble inorganic phosphates such as $FePO_4$ and $AlPO_4$ (Harrison et al. 1972; Horne and Goldman 1994).

Seasonality of precipitation and runoff restricts inputs of phosphorous into lakes (Horne and Goldman 1994). Thermal-density stratification further restricts the availability of sediment bound phosphorous to the euphotic zone of lakes (Horne and Goldman 1994). Seiches, wind-induced and seasonal mixing events, entrain phosphorous from the hypolimnion and transfer it to the epilimnion for biotic utilization (Horne and Goldman 1994). Phosphorous, therefore, becomes an internally loaded constituent regulated by redox conditions, physical mixing and biotic release (Horne and Goldman 1994).

There are two primary mechanisms for phosphorous losses to open waters. As biota senesce, they are sedimented to the lake bottom. The other mechanism is by precipitation of chemically bound phosphate adsorbed onto iron, calcium, aluminum and clays (Horne and Goldman 1994). The solid-liquid phase equilibria can reach completion in the time it takes for a particle to sink to the lake bottom (Horne and Goldman 1994). Anoxic conditions tend to favor the release of sedimented adsorbed phosphates at a rate of 1000 times faster than in oxygenated waters, as modified by pH, redox potential (Eh), and dissolved oxygen content (Horne and Goldman 1994). The clay content of the sediments is the most important determining factor of the phosphorous holding capacity. Clays are complexes of iron-alumino-silicates which sorb phosphates (PO_4^{3-}) with the aluminum (Al^{3+}) on the edges of the clay plates (Stumm and Leckie 1971; Horne and Goldman 1994). Phosphate also sorbs onto hydrous iron, aluminum oxides, calcite and apatite (Horne and Goldman 1994). Occlusion, or internal absorption, of phosphates occurs within iron oxides and some sediment functions in the phosphorous buffering system and is regulated by pH and Eh (Horne and Goldman 1994).

Hydrodynamic and biotic mechanisms regulate the internal phosphorus loading to a lake from the sediments (Wetzel 2001). There are steep concentration gradients between the phosphorus in interstitial water and the overlying water; therefore, molecular diffusion is the primary transport mechanism into the overlying anaerobic water (Wetzel 2001). Movement of phosphorous from the near-sediment region into the water column is facilitated by currents from wind induced water turbulence which disrupt gradients resuspending sediment particles, accelerated diffusion from ebullition of microbially generated gases (i.e. CO_2, CH_4 and N_2), as well as benthic biota which cause bioturbation of the sediments (Wetzel 2001). Metabolic processes of littoral plants can suppress or enhance the transport of phosphorus across the sediment-water interface (Wetzel 2001). Mortimer (1941, 1942, 1971) demonstrated the importance of the oxidized microzone to chemical exchanges, especially of phosphorus, from the sediments. His findings revealed that a difference of a few millimeters in oxygen penetration into the sediment surface is the critical factor regulating exchange between sediment and water (Wetzel 2001).

Lake Basin mean and standard deviation concentration

Alkalinity

Average alkalinity concentration among all Linville lake basin stations for 1997 is 0.213 meq/L, in 1998 it decreases to 0.197 meq/L and increases in 1999 to 0.250 meq/L as the drought progresses. Average concentration among all Catawba lake basin stations for 1997 is 0.296 meq/L, in 1998 they decrease to 0.276 meq/L and increase in 1999 to 0.339 meq/L as the drought progresses (Figure 13).

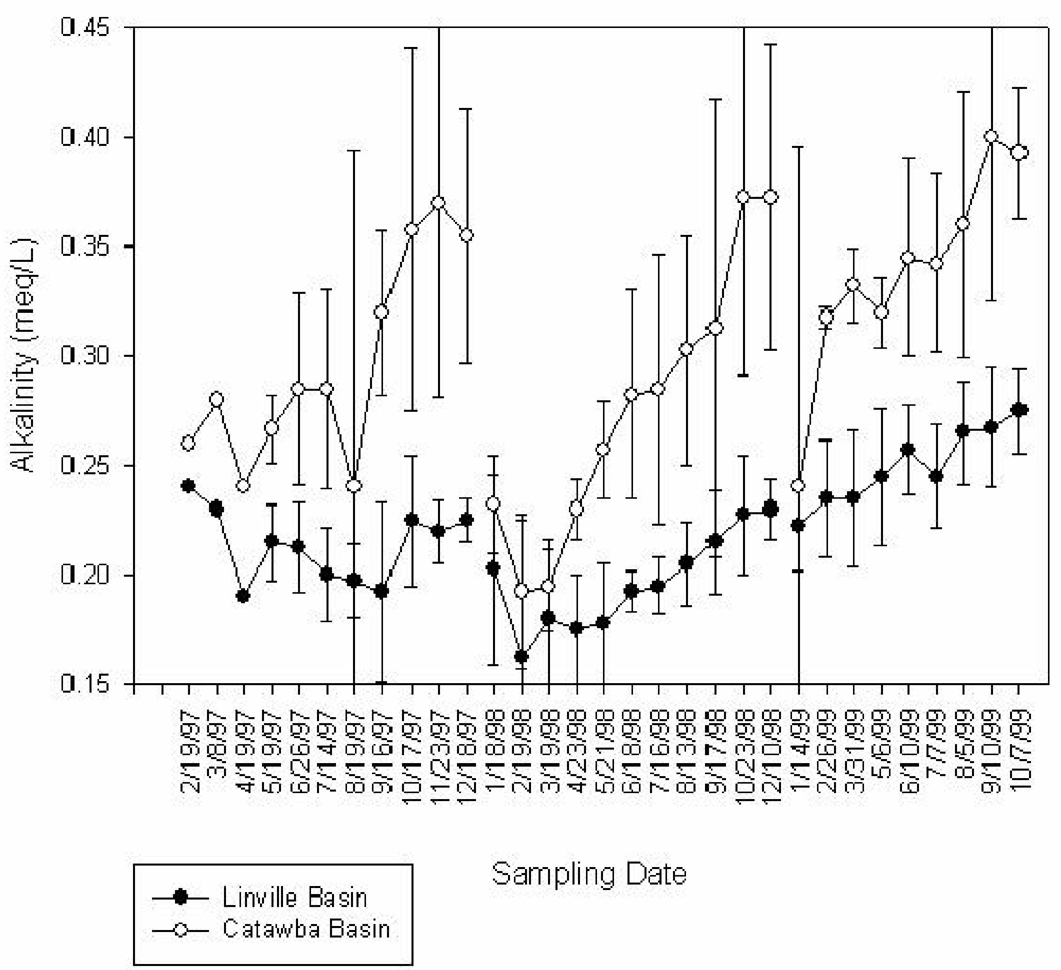


Figure 13 Mean and Standard Deviation of Alkalinity for All Stations in the Linville and Catawba Basins of Lake James, NC.

Chloride

Average chloride concentration among all Linville lake basin stations for 1997 is 2.952 mg/L, in 1998 it increases to 2.991 mg/L and increases in 1999 to 3.456 mg/L as the drought progresses. Average chloride concentration among all Catawba lake basin stations for 1997 is 3.911 mg/L, in 1998 they decrease to 3.357 mg/L and increase in 1999 to 5.081 mg/L as the drought progresses (Figure 14).

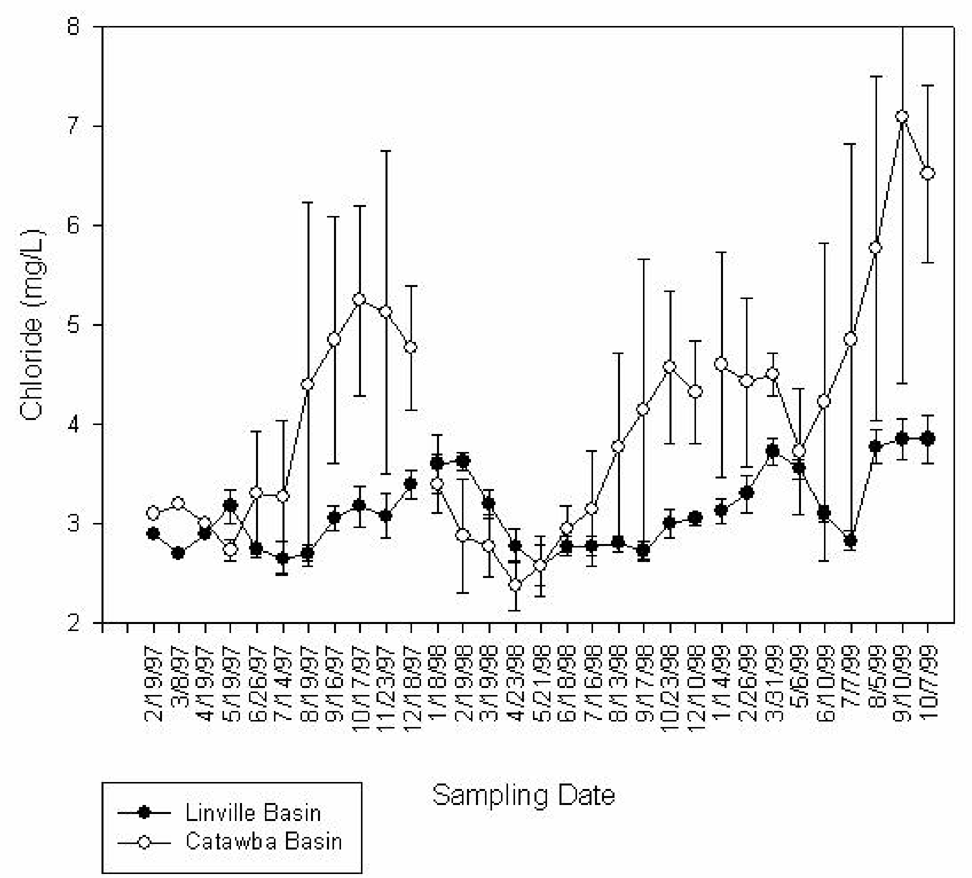


Figure 14 Mean and Standard Deviation of Chloride for All Stations in the Linville and Catawba Basins of Lake James, NC

Calcium

Average calcium concentration among all Linville lake basin stations for 1997 is 2.389 mg/L, in 1998 it decreases to 2.179 mg/L and increases in 1999 to 2.562 mg/L as the drought progresses. Average calcium concentration among all Catawba lake basin stations for 1997 is 3.039 mg/L, in 1998 they decrease to 2.804 mg/L and increase in 1999 to 3.418 mg/L as the drought progresses (Figure 15).

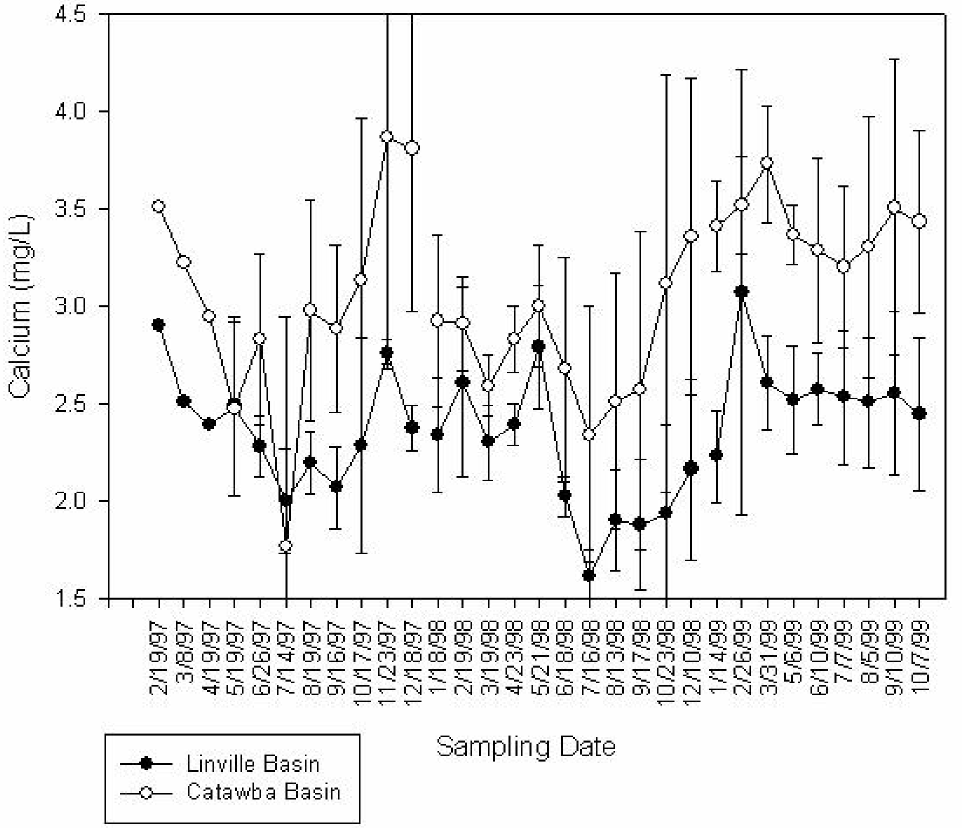


Figure 15 Mean and Standard Deviation of Calcium for All Stations in the Linville and Catawba Basins of Lake James, NC

Potassium

Average potassium concentration among all Linville lake basin stations for 1997 is 1.033 mg/L, in 1998 it decreases to 1.020 mg/L and increases in 1999 to 1.063 mg/L as the drought progresses. Average potassium concentration among all Catawba lake basin stations for 1997 is 1.152 mg/L, in 1998 they increase to 1.165 mg/L and increase in 1999 to 1.275 mg/L as the drought progresses (Figure 16).

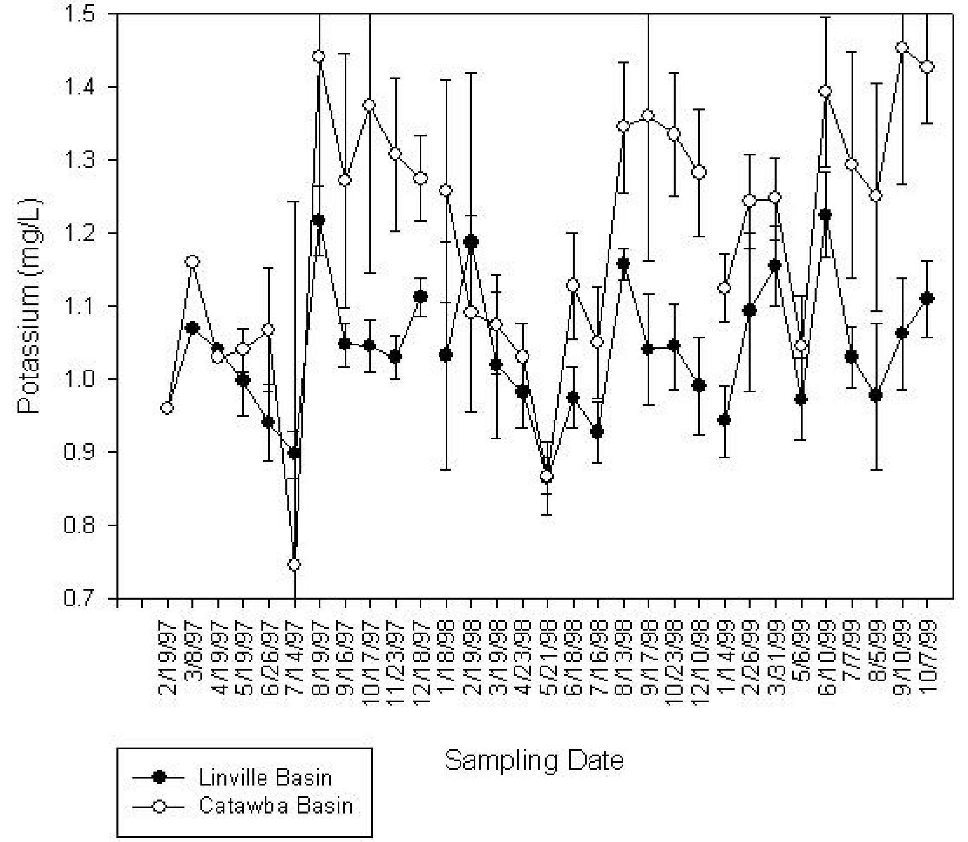


Figure 16 Mean and Standard Deviation of Potassium for All Stations in the Linville and Catawba Basins of Lake James, NC

Concentration of hydrologically driven constituents, including alkalinity, chloride, calcium and potassium within the Lake James basins seem to reflect the same pattern observed in the inflowing streams of an increase in concentration as the drought progresses from summer through fall and a dilution effect with winter and spring high flows. Because the averages calculated for the Linville basin do reflect the inflows as the embayment from the Catawba basin, they appear to increase as a function of the increase in concentration of the Catawba basin. A decrease in precipitation would imply greater reliance on baseflows and groundwater as source waters for Lake James. Slower movement of waters through the soils and sediments allow greater time for biogeochemical reactions and transformations to take place, relative to flushing flows of storm events. An increase in concentration would be expected from water which has time to react with the lithology of the watersheds (Figure 13, Figure 14, Figure 15 and Figure 16).

Ortho-phosphate

Average ortho-phosphate-P concentration among all Linville lake basin stations for 1997 is 0.005 mg/L, in 1998 it remains constant at 0.005 mg/L and increases in 1999 to 0.006 mg/L as the drought progresses. Average ortho-phosphate-P concentration among all Catawba lake basin stations for 1997 is 0.006 mg/L, in 1998 it increases to 0.007 mg/L and increases again in 1999 to 0.008 mg/L as the drought progresses (Figure 17).

Ortho-phosphate-P concentration within the surface waters of Lake James basins tend to remain close to the detectability limits in the Linville basin throughout the study, however, greater concentrations entering from the Catawba River watershed (especially the North Fork Catawba sub-basin) are reflected within the Catawba lake basin. The Linville lake basin shows little increase in ortho-phosphate-P although it is the receiving embayment from the Catawba basin. This implies greater nutrient loading and greater productivity potential within the Catawba basin of Lake James (Figure 17).

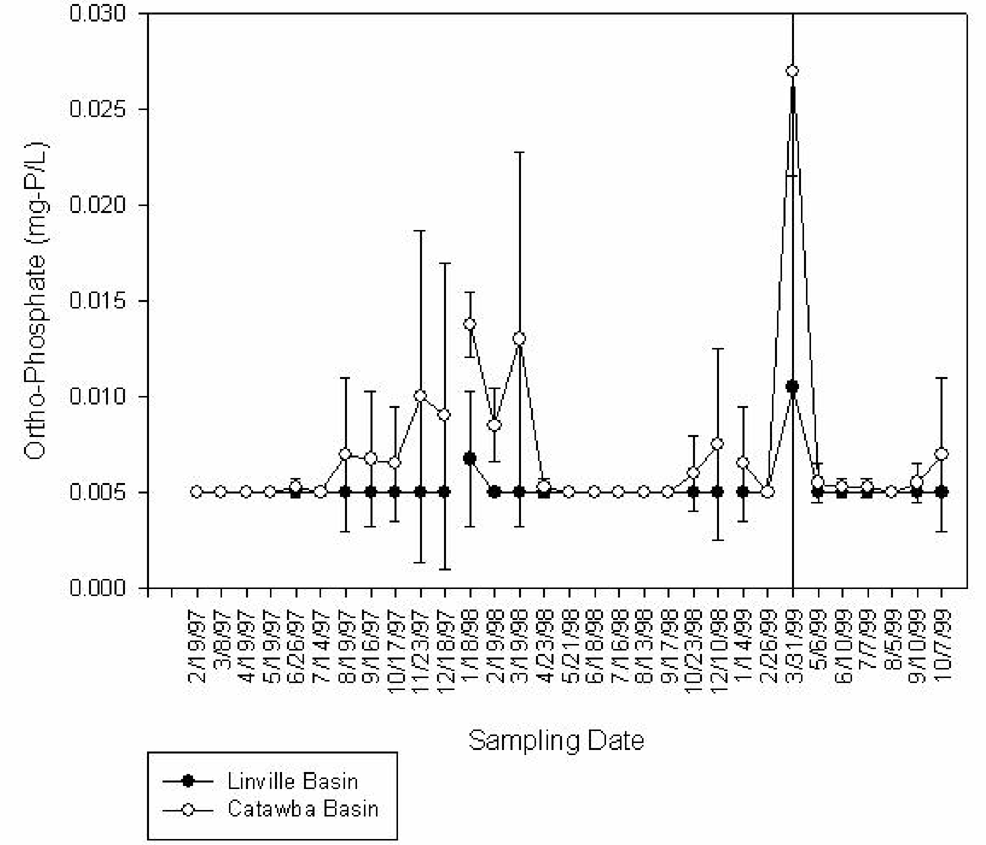


Figure 17 Mean and Standard Deviation of Ortho-Phosphate for All Stations in the Linville and Catawba Basins of Lake James, NC

Late summer and autumn lake basin increases in 1997 do not show concurrent increases in stream concentration and therefore imply internal loading from within the lake basin. Increases during the fall and winter mixed period are likely a function of a combination of inflows from the watershed and internal loading. However, the limited data for stream concentrations in 1997 are likely masking the actual concentrations entering the basin and these data should be taken with some skepticism. Once regular stream sampling was established in 1998 it revealed the amount of ortho-phosphate entering the Catawba lake basin from the North Fork Catawba River which shows an increase in ortho-phosphate-P concentration as the drought progresses from summer through fall and a dilution effect with winter and spring high flows. A decrease in precipitation would imply greater reliance on baseflows and ground water as source waters for Lake James. Slower movement of waters through the soils and sediments allow greater time for biogeochemical reactions and transformations to take place, relative to flushing flows of storm events. An increase in concentration is expected from water which has time to react with the lithology of the watersheds (Figure 17).

Total Phosphorous

Average total phosphorous concentration among all Linville lake basin stations for 1997 is 0.008 mg/L, in 1998 it decreases to 0.007 mg/L and remains constant in 1999 at 0.007 mg/L as the drought progresses. Average total phosphorous concentration among all Catawba lake basin stations for 1997 is 0.012 mg/L, in 1998 it increases to 0.017 mg/L and decreases in 1999 to 0.015 mg/L as the drought progresses (Figure 18).

Total phosphorous concentration within the surface waters of the Lake James basins show the greater concentrations entering the reservoir from the Catawba River watershed. The total phosphorous concentrations do not reflect the same pattern observed in the inflowing streams of an increase in total phosphorous concentration as the drought progresses from summer through fall and a dilution effect with winter and spring high flows. Peak concentration of total phosphorous was found in winter 1998 and is associated with the high flow events of that el Niño pattern and likely reflects the movement of particulate adsorbed phosphorous from the watershed into the Lake James basins. This is different from the behavior of the dissolved ortho-phosphate which seems to increase with increasing reliance on groundwater contributions to the lake basins. The variability seen in total phosphorous observed and general lack of trends aside from the winter 1998 high flows point to internal loading mechanisms and possible association with shifts in algal populations during the spring and summer, however, such conjectures would require substantiation with the biotic data from the study (Figure 18).

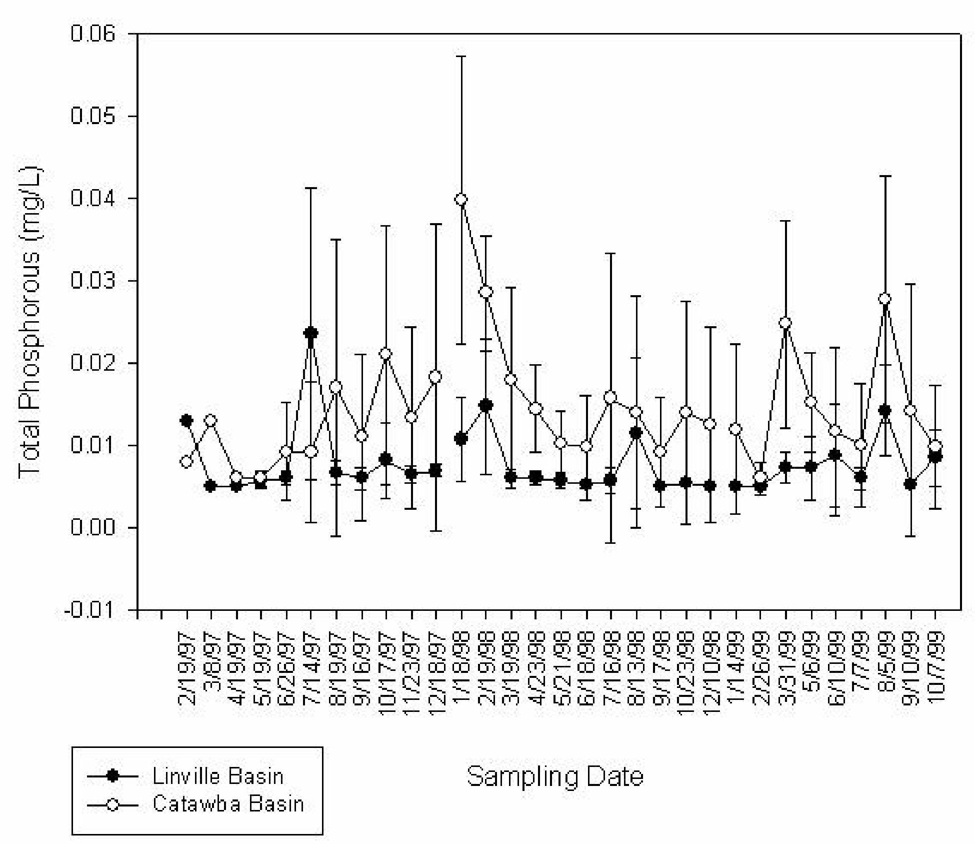


Figure 18 Mean and Standard Deviation of Total Phosphorous for All Stations in the Linville and Catawba Basins of Lake James, NC

Comparison of calculated vs. model loading and yield

Alkalinity

Catawba Loading: Calculated loading using traditional methods generated alkalinity loading estimates into the headwaters of the Catawba basin of Lake James of

143.281x10^3 keq/yr in 1997, 163.124x10^3 keq/yr in 1998 and 83.936x10^3 keq/yr in 1999. LJA-CB model estimates of alkalinity loading were 118.975x10^3 keq/yr in 1997, 178.418x10^3 keq/yr in 1998 and 98.075x10^3 keq/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of 24.305x10^3 keq/yr in 1997, with calculated values of 120% of those generated by the model. In 1998 there was a net of -15.294x10^3 keq/yr, with calculated values of 91.4% of those generated by the model. In 1999 there was a net of -14.139x10^3 keq/yr, with calculated values of 85.6% of those generated by the model (Figure 19, Table B- 4, Table B- 5 and Table B- 6).

Linville Loading: Calculated loading using traditional methods generated alkalinity loading estimates into the headwaters of the Linville basin of Lake James of 23.145x10^3 keq/yr in 1997, 28.611x10^3 keq/yr in 1998 and 21.200x10^3 keq/yr in 1999. LJA-CB model estimates of alkalinity loading were 20.056x10^3 keq/yr in 1997, 31.870x10^3 keq/yr in 1998 and 17.531x10^3 keq/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of 3.088x10^3 keq/yr in 1997, with calculated values of 115% of those generated by the model. In 1998 there was a net of -3.259x10^3 keq/yr, with calculated values of 89.8% of those generated by the model. In 1999 there was a net of 3.669x10^3 keq/yr, with calculated values of 121% of those generated by the model (Figure 19, Table B- 1, Table B- 2 and Table B- 3).

Catawba Yield: Calculated yield using traditional methods generated alkalinity yield estimates into the headwaters of the Catawba basin of Lake James of 192.789

keq/km^2/yr in 1997, 219.489 keq/km^2/yr in 1998 and 112.938 keq/km^2/yr in 1999. LJA-CB model estimates of alkalinity yield were 160.067 keq/km^2/yr in 1997, 240.040 keq/km^2/yr in 1998 and 131.948 keq/km^2/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of 32.722 keq/km^2/yr in 1997, with calculated values of 120% of those generated by the model. In 1998 there was a net of -20.551 keq/km^2/yr, with calculated values of 91.4% of those generated by the model. In 1999 there was a net of -19.009 keq/km^2/yr, with calculated values of 85.6% of those generated by the model (Figure 20, Table B- 10, Table B- 11 and Table B- 12).

Linville Yield: Calculated yield using traditional methods generated alkalinity yield estimates into the headwaters of the Linville basin of Lake James of 121.054 keq/km^2/yr in 1997, 149.643 keq/km^2/yr in 1998, and 110.881 keq/km^2/yr in 1999. LJA-CB model estimates of alkalinity yield were 104.900 keq/km^2/yr in 1997, 166.688 keq/km^2/yr in 1998 and 91.691 keq/km^2/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of 16.153 keq/km^2/yr in 1997, with calculated values of 115% of those generated by the model. In 1998 there was a net of -17.045 keq/km^2/yr, with calculated values of 89.8% of those generated by the model. In 1999 there was a net of 19.190 keq/km^2/yr, with calculated values of 121% of those generated by the model (Figure 20, Table B- 7, Table B- 8 and Table B- 9).

Traditional calculated loading of alkalinity is within approximately +/- 20% of the LJA-CB for both basins and is adequate for loading and yield determinations for this hydrologically driven constituent. Yield values reflect the watershed difference contributing to the chemical dynamics of the lake James basins. Conrad (1960) noted an elongate lens of the shady dolomite formation which extends within the North Fork Catawba River basin, as well as a lens of marble which crosses the Catawba River basin. These limestone formations contribute to the alkalinity of the Catawba basin of Lake James and may account for some of the variability seen between the two contributing watersheds in the constituent behavior of Lake James.

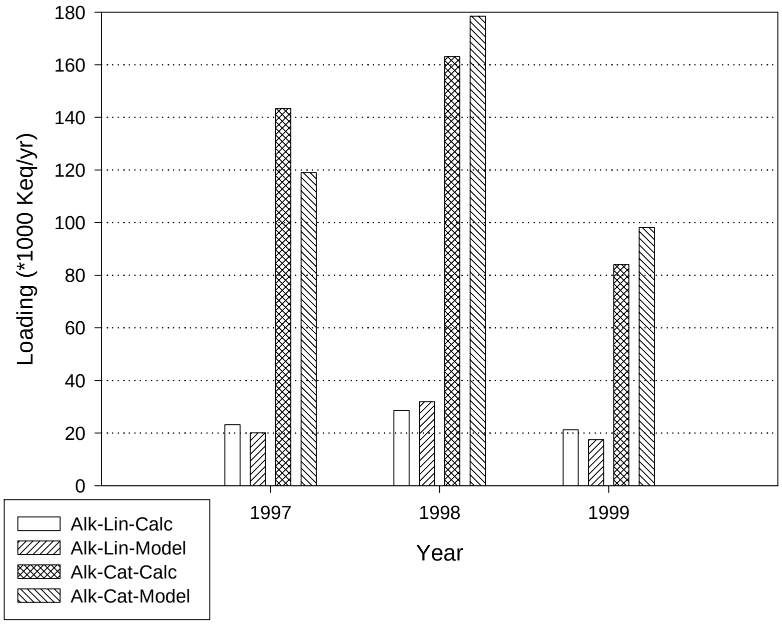


Figure 19 Average Annual Loading of Alkalinity for the Linville and Catawba Basins of Lake James, NC.

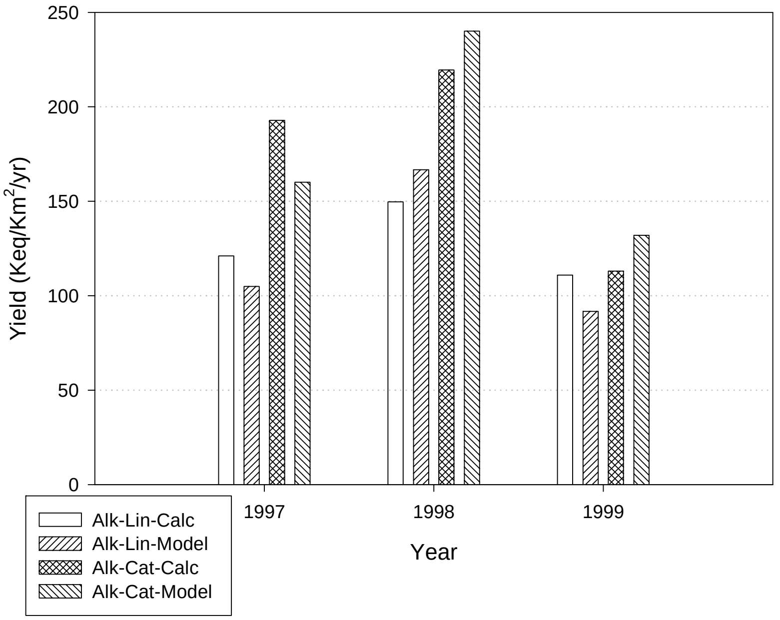


Figure 20 Average Annual Yield of Alkalinity for the Linville and Catawba Basins of Lake James, NC.

Chloride

Catawba Loading: Calculated loading using traditional methods generated chloride loading estimates into the headwaters of the Catawba basin of Lake James of 2,094.569x10^3 kg/yr in 1997, 1,875.704x10^3 kg/yr in 1998 and 1,599.031x10^3 kg/yr in 1999. LJA-CB model estimates of chloride loading were 2,069.444x10^3 kg/yr in 1997, 2,604.326x10^3 kg/yr in 1998 and 1,216.237x10^3 kg/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of 25.125x10^3 kg/yr in 1997, with calculated values of 101.2% of those generated by the model. In 1998 there was a net of -728.622x10^3 kg/yr, with calculated values of 72.0% of those generated by the model. In 1999 there was a net of 382.793x10^3 kg/yr, with calculated values of 131% of those generated by the model (Figure 21, Table B- 4, Table B- 5 and Table B- 6).

Linville Loading: Calculated loading using traditional methods generated chloride loading estimates into the headwaters of the Linville basin of Lake James of 339.166×10^3 kg/yr in 1997, 519.061×10^3 kg/yr in 1998 and 323.245×10^3 kg/yr in 1999. LJA-CB model estimates of chloride loading were 654.080×10^3 kg/yr in 1997, 657.978×10^3 kg/yr in 1998 and 336.332×10^3 kg/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of -314.914×10^3 kg/yr in 1997, with calculated values of 51.9% of those generated by the model. In 1998 there was a net of -138.917×10^3 kg/yr, with calculated values of 78.9% of those generated by the model. In 1999 there was a net of -13.086×10^3 kg/yr, with calculated values of 96.1% of those generated by the model (Figure 21, Table B- 1, Table B- 2 and Table B- 3).

Catawba Yield: Calculated yield using traditional methods generated chloride yield estimates into the headwaters of the Catawba basin of Lake James of 2,818.310 kg/km^2/yr in 1997, 2,523.820 kg/km^2/yr in 1998 and 2,151.547 kg/km^2/yr in 1999. LJA-CB model estimates of chloride yield were 2,784.181 kg/km^2/yr in 1997, 3,503.798 kg/km^2/yr in 1998 and 1,636.297 kg/km^2/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of 34.129 kg/km^2/yr in 1997, with calculated values of 101.2% of those generated by the model. In 1998 there was a net of -979.978 kg/km^2/yr, with calculated values of 72.0% of those generated by the model. In 1999 there was a net of 515.250 kg/km^2/yr, with calculated values of 131% of those generated by the model (Figure 22, Table B- 10, Table B- 11 and Table B- 12).

Linville Yield: Calculated yield using traditional methods generated chloride yield estimates into the headwaters of the Linville basin of Lake James of 1,773.931

kg/km^2/yr in 1997, 2,714.832 kg/km^2/yr in 1998 and 1,690.664 kg/km^2/yr in 1999. LJA-CB model estimates of chloride yield were 3,421.018 kg/km^2/yr in 1997, 3,441.406 kg/km^2/yr in 1998 and 1,759.108 kg/km^2/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of -1,647.087 kg/km^2/yr in 1997, with calculated values of 51.9% of those generated by the model. In 1998 there was a net of -726.574 kg/km^2/yr, with calculated values of 78.9% of those generated by the model. In 1999 there was a net of -68.445 kg/km^2/yr, with calculated values of 96.1% of those generated by the model (Figure 22, Table B- 7, Table B- 8 and Table B- 9).

Calculated loading of chloride is variable relative to the LJA-CB between basins and years ranging to +/- 50% in the Linville basin and +/- 30% in the Catawba basin and is not adequate for loading and yield determinations for this constituent which is typically viewed as a conservative tracer element in chemical mass balance studies. Potential point source loading or non-point source contributors (i.e. failed septic systems or farm feed lots) should be examined as possible contributors to the variability observed in the behavior of chloride within the Lake James basins. Hydrologic variability between years points to a reduction in chloride loading and yield during the drought of 1999.

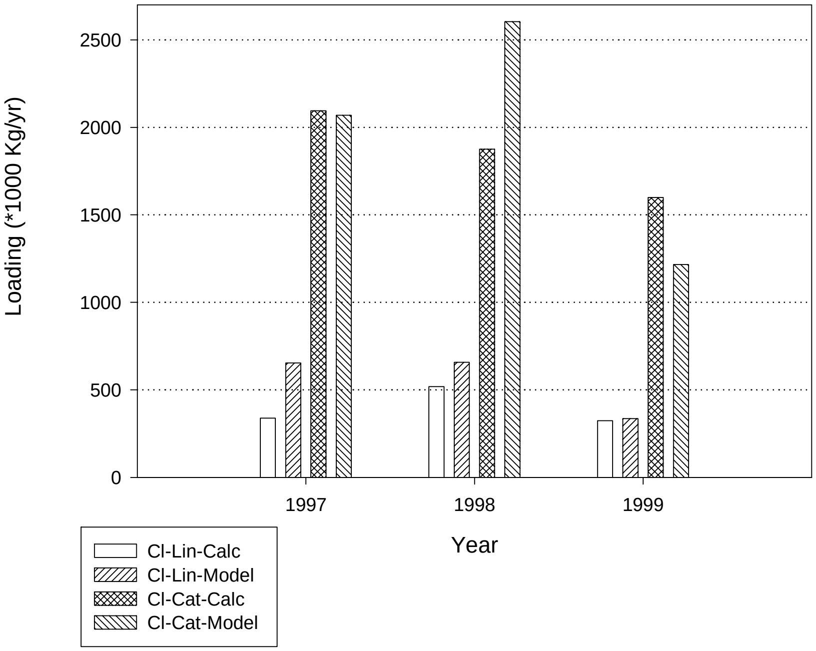


Figure 21 Average Annual Loading of Chloride for the Linville and Catawba Basins of Lake James, NC

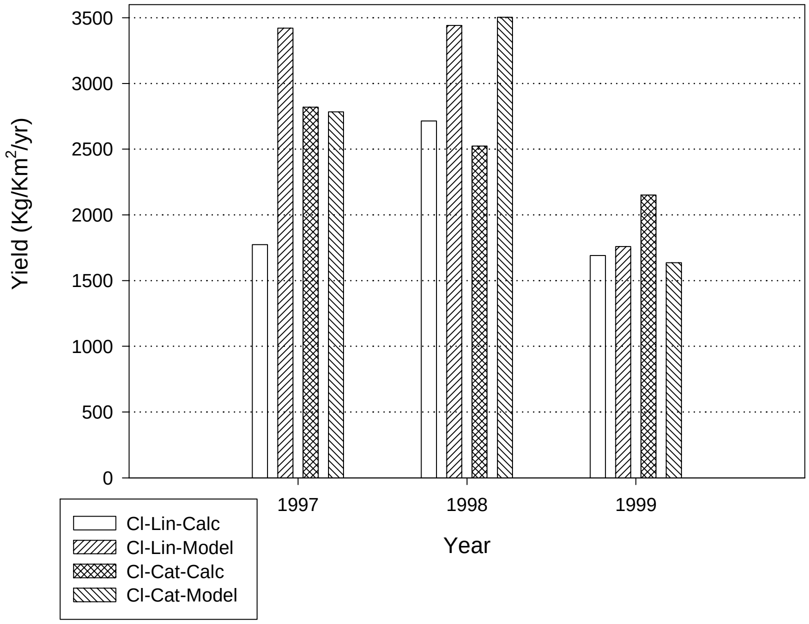


Figure 22 Average Annual Yield of Chloride for the Linville and Catawba Basins of Lake James, NC

Calcium

Catawba Loading: Calculated loading using traditional methods generated calcium loading estimates into the headwaters of the Catawba basin of Lake James of 1,226.446x10^3 kg/yr in 1997, 1,710.669x10^3 kg/yr in 1998 and 940.560x10^3 kg/yr in 1999. LJA-CB model estimates of calcium loading were 1,510.234x10^3 kg/yr in 1997, 2,113.106x10^3 kg/yr in 1998 and 1,056.060x10^3 kg/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of -283.787x10^3 kg/yr in 1997, with calculated values of 81.2% of those generated by the model. In 1998 there was a net of -402.437x10^3 kg/yr, with calculated values of 81.0% of those generated by the model. In 1999 there was a net of -115.501x10^3 kg/yr, with calculated values of 89.1% of those generated by the model (Figure 23, Table B- 4, Table B- 5 and Table B- 6).

Linville Loading: Calculated loading using traditional methods generated calcium loading estimates into the headwaters of the Linville basin of Lake James of 255.641x10^3 kg/yr in 1997, 351.617x10^3 kg/yr in 1998 and 207.664x10^3 kg/yr in 1999. LJA-CB model estimates of calcium loading were 331.715x10^3 kg/yr in 1997, 496.727x10^3 kg/yr in 1998 and 222.817x10^3 kg/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of -76.075x10^3 kg/yr in 1997, with calculated values of 77.1% of those generated by the model. In 1998 there was a net of -145.110x10^3 kg/yr, with calculated values of 70.8% of those generated by the model. In 1999 there was a net of -15.152x10^3 kg/yr, with calculated values of 93.2% of those generated by the model (Figure 23, Table B- 1, Table B- 2 and Table B- 3).

Catawba Yield: Calculated yield using traditional methods generated calcium yield estimates into the headwaters of the Catawba basin of Lake James of 1,650.223 kg/km^2/yr in 1997, 2,301.760 kg/km^2/yr in 1998 and 1,265.553 kg/km^2/yr in 1999. LJA-CB model estimates of calcium yield were 2,031.832 kg/km^2/yr in 1997, 2,842.922 kg/km^2/yr in 1998 and 1,420.799 kg/km^2/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of -381.610 kg/km^2/yr in 1997, with calculated values of 81.2% of those generated by the model. In 1998 there was a net of -541.162 kg/km^2/yr, with calculated values of 81.0% of those generated by the model. In 1999 there was a net of -155.245 kg/km^2/yr, with calculated values of 89.1% of those generated by the model (Figure 24, Table B- 10, Table B- 11 and Table B- 12).

Linville Yield: Calculated yield using traditional methods generated calcium yield estimates into the headwaters of the Linville basin of Lake James of 1,337.072 kg/km^2/yr in 1997, 1,839.053 kg/km^2/yr in 1998 and 1,086.142 kg/km^2/yr in 1999. LJA-CB model estimates of calcium yield were 1,734.963 kg/km^2/yr in 1997, 2,598.018 kg/km^2/yr in 1998 and 1,165.393 kg/km^2/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of -397.891 kg/km^2/yr in 1997, with calculated values of 77.1% of those generated by the model. In 1998 there was a net of -758.965 kg/km^2/yr, with calculated values of 70.8% of those generated by the model. In 1999 there was a net of -79.251 kg/km^2/yr, with calculated values of 93.2% of those generated by the model (Figure 24, Table B- 7, Table B- 8 and Table B- 9).

Calculated loading of calcium is within approximately +/- 30% of the LJA-CB for the Linville basin and +/- 20% for the Catawba basin and tends to underestimate both, but is likely adequate for loading and yield determinations for this hydrologically driven constituent. Differences in calcium loading and yield seem to be attributable to differences in watershed lithology. Dolomitic limestone is derived of magnesium-calcium-carbonate, and is found within the Shady dolomite formation in the North Fork Catawba River watershed. Marble is a metamorphosed calcium carbonate and is found within the Catawba River watershed (Conrad 1960). These watersheds contribute more calcium to the Catawba basin of Lake James than from the Linville River watershed.

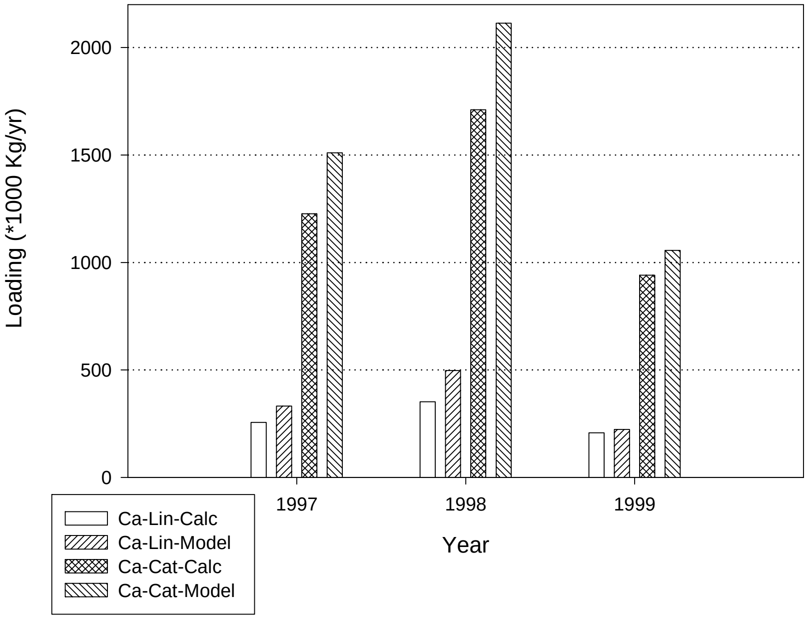


Figure 23 Average Annual Loading of Calcium for the Linville and Catawba Basins of Lake James, NC

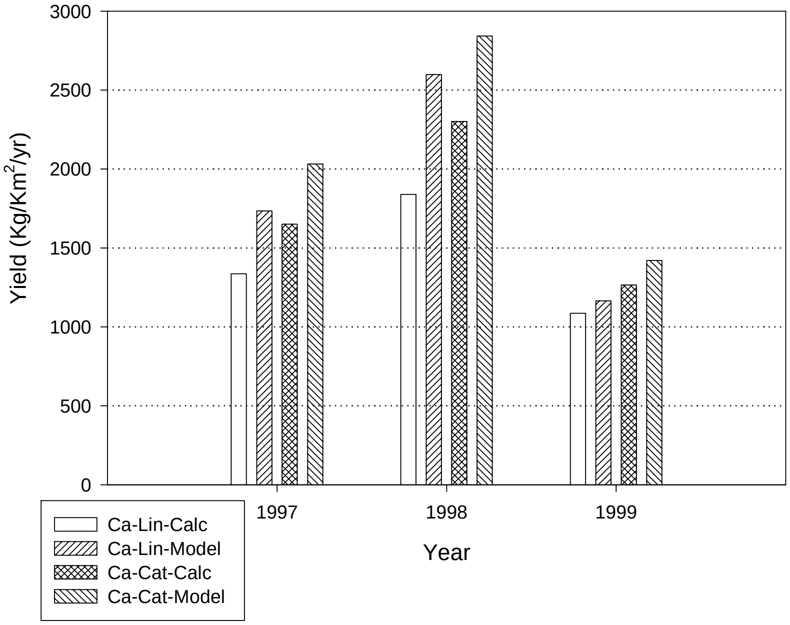


Figure 24 Average Annual Yield of Calcium for the Linville and Catawba Basins of Lake James, NC

Potassium

Catawba Loading: Calculated loading using traditional methods generated potassium loading estimates into the headwaters of the Catawba basin of Lake James of 438.342x10^3 kg/yr in 1997, 589.825x10^3 kg/yr in 1998 and 322.994x10^3 kg/yr in 1999. LJA-CB model estimates of potassium loading were 402.523x10^3 kg/yr in 1997, 661.387x10^3 kg/yr in 1998 and 321.543x10^3 kg/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of 35.819x10^3 kg/yr in 1997, with calculated values of 109% of those generated by the model. In 1998 there was a net of -71.563x10^3 kg/yr, with calculated values of 89.2% of those generated by the model. In 1999 there was a net of 1.451x10^3 kg/yr, with calculated values of 100.5% of those generated by the model (Figure 25, Table B- 4, Table B- 5 and Table B- 6).

Linville Loading: Calculated loading using traditional methods generated potassium loading estimates into the headwaters of the Linville basin of Lake James of 119.217x10^3 kg/yr in 1997, 170.415x10^3 kg/yr in 1998 and 97.393x10^3 kg/yr in 1999. LJA-CB model estimates of potassium loading were 91.762x10^3 kg/yr in 1997, 188.153x10^3 kg/yr in 1998 and 87.630x10^3 kg/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of 27.455x10^3 kg/yr in 1997, with calculated values of 130% of those generated by the model. In 1998 there was a net of -17.739x10^3 kg/yr, with calculated values of 90.6% of those generated by the model. In 1999 there was a net of 9.763x10^3 kg/yr, with calculated values of 111% of those generated by the model (Figure 25, Table B- 1, Table B- 2 and Table B- 3).

Catawba Yield: Calculated yield using traditional methods generated potassium yield estimates into the headwaters of the Catawba basin of Lake James of 589.803 kg/km^2/yr in 1997, 793.628 kg/km^2/yr in 1998 and 434.598 kg/km^2/yr in 1999. LJA-CB model estimates of potassium yield were 541.544 kg/km^2/yr in 1997, 889.815 kg/km^2/yr in 1998 and 432.596 kg/km^2/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of 48.258 kg/km^2/yr in 1997, with calculated values of 109% of those generated by the model. In 1998 there was a net of -96.187 kg/km^2/yr, with calculated values of 89.2% of those generated by the model. In 1999 there was a net of 2.002 kg/km^2/yr, with calculated values of 100.5% of those generated by the model (Figure 26, Table B- 10, Table B- 11 and Table B- 12).

Linville Yield: Calculated yield using traditional methods generated potassium yield estimates into the headwaters of the Linville basin of Lake James of 623.541 $kg/km^2/yr$ in 1997, 891.315 $kg/km^2/yr$ in 1998 and 509.395 $kg/km^2/yr$ in 1999. LJA-CB model estimates of potassium yield were 479.943 $kg/km^2/yr$ in 1997, 984.095 $kg/km^2/yr$ in 1998 and 458.330 $kg/km^2/yr$ in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of 143.597 $kg/km^2/yr$ in 1997, with calculated values of 130% of those generated by the model. In 1998 there was a net of -92.780 $kg/km^2/yr$, with calculated values of 90.6% of those generated by the model. In 1999 there was a net of 51.064 $kg/km^2/yr$, with calculated values of 111% of those generated by the model (Figure 26, Table B- 7, Table B- 8 and Table B- 9).

Calculated loading of potassium is within approximately +/- 30% of the LJA-CB for both basins and is adequate for loading and yield determinations for this hydrologically driven constituent. Whereas Catawba basin loadings tend to be greater for potassium, Linville basin yields surpass those of the Catawba. Much of the Blue Ridge escarpment in the South Mountain (Stuckey and Steel 1956) area is comprised of the Henderson Gneiss formation, of which feldspars are a common component. Much of the differences observed between years in this element are likely attributable to meteorological differences seen in the ENSO neutral, el Niño, and la Niña patterns of 1997, 1998 and 1999.

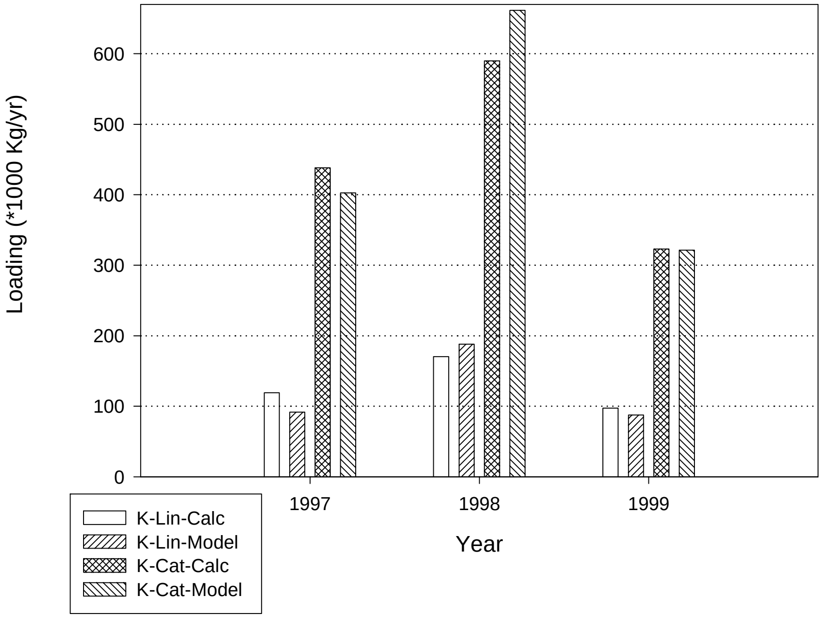


Figure 25 Average Annual Loading of Potassium for the Linville and Catawba Basins of Lake James, NC

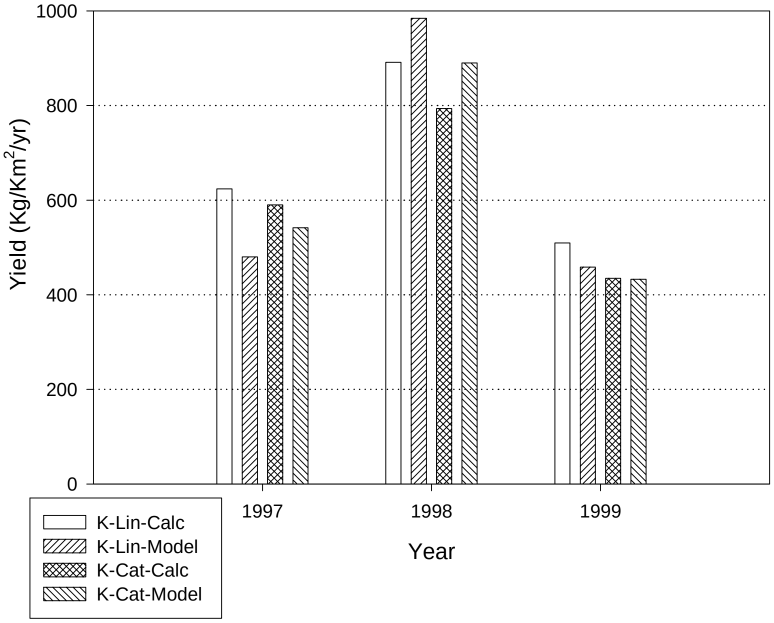


Figure 26 Average Annual Yield of Potassium for the Linville and Catawba Basins of Lake James, NC

Ortho-phosphate

Catawba Loading: Calculated loading using traditional methods generated ortho-phosphate loading estimates into the headwaters of the Catawba basin of Lake James of $4.128\text{x}10^3$ kg/yr in 1997, $4.356\text{x}10^3$ kg/yr in 1998 and $4.064\text{x}10^3$ kg/yr in 1999. LJA-CB model estimates of ortho-phosphate loading were $17.735\text{x}10^3$ kg/yr in 1997, $14.197\text{x}10^3$ kg/yr in 1998 and $9.240\text{x}10^3$ kg/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of $-13.607\text{x}10^3$ kg/yr in 1997, with calculated values of 23.3% of those generated by the model. In 1998 there was a net of $-9.841\text{x}10^3$ kg/yr, with calculated values of 30.7% of those generated by the model. In 1999 there was a net of $-5.176\text{x}10^3$ kg/yr, with calculated values of 44.0% of those generated by the model (Figure 27, Table B- 4, Table B- 5 and Table B- 6).

Linville Loading: Calculated loading using traditional methods generated ortho-phosphate loading estimates into the headwaters of the Linville basin of Lake James of $0.582\text{x}10^3$ kg/yr in 1997, $0.860\text{x}10^3$ kg/yr in 1998 and $0.472\text{x}10^3$ kg/yr in 1999. LJA-CB model estimates of ortho-phosphate loading were $1.161\text{x}10^3$ kg/yr in 1997, $1.171\text{x}10^3$ kg/yr in 1998 and $0.482\text{x}10^3$ kg/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of $-0.579\text{x}10^3$ kg/yr in 1997, with calculated values of 50.2% of those generated by the model. In 1998 there was a net of $-0.311\text{x}10^3$ kg/yr, with calculated values of 73.4% of those generated by the model. In 1999 there was a net of $-0.009\text{x}10^3$ kg/yr, with calculated values of 98.0% of those generated by the model (Figure 27, Table B- 1, Table B- 2 and Table B- 3).

Catawba Yield: Calculated yield using traditional methods generated ortho-phosphate yield estimates into the headwaters of the Catawba basin of Lake James of 5.555 kg/km^2/yr in 1997, 5.861 kg/km^2/yr in 1998 and 5.468 kg/km^2/yr in 1999. LJA-CB model estimates of ortho-phosphate yield were 23.860 kg/km^2/yr in 1997, 19.100 kg/km^2/yr in 1998 and 12.431 kg/km^2/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of -18.305 kg/km^2/yr in 1997, with calculated values of 23.3% of those generated by the model. In 1998 there was a net of -13.239 kg/km^2/yr, with calculated values of 30.7% of those generated by the model. In 1999 there was a net of -6.962 kg/km^2/yr, with calculated values of 44.0% of those generated by the model (Figure 28, Table B- 10, Table B- 11 and Table B- 12).

Linville Yield: Calculated yield using traditional methods generated ortho-phosphate yield estimates into the headwaters of the Linville basin of Lake James of 3.045 kg/km^2/yr in 1997, 4.497 kg/km^2/yr in 1998 and 2.470 kg/km^2/yr in 1999. LJA-CB model estimates of ortho-phosphate yield were 6.071 kg/km^2/yr in 1997, 6.125 kg/km^2/yr in 1998 and 2.519 kg/km^2/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of -3.026 kg/km^2/yr in 1997, with calculated values of 50.2% of those generated by the model. In 1998 there was a net of -1.627 kg/km^2/yr, with calculated values of 73.4% of those generated by the model. In 1999 there was a net of -0.049 kg/km^2/yr, with calculated values of 98.0% of those generated by the model (Figure 28, Table B- 7, Table B- 8 and Table B- 9).

Loading and yield of ortho-phosphate are poorly represented and are approximately - 80% using the traditional calculations, relative to the flow and volume-weighted loadings of the LJA-CB model with differences in basin lithology contributing to this variability, as well as redox complexes and biological reactivity. A prior examination of loading calculations for each of the inflowing streams revealed that most of the contribution of ortho-phosphate loading into the Lake James basins were derived from the North Fork Catawba River watershed. The variability in hydrology among years and meteorological conditions is expressed by the LJA model.

Hydrological variability in inflowing streams is expressed as a function of the intensity and periodicity of precipitation events modified by antecedent conditions and lithology and regulated by management releases. The frequency and duration of these events as recorded in recession curves reflects the time available for biogeochemical reactions to take place within the sediment-water interface and determines how much of the precipitation enters the soils as opposed to being carried as overland flow. Ortho-phosphate mobility within the sediments is regulated by redox reactions within the soil as phosphorous is readily bound to the iron-alumino-silicates within the clay soils, and becomes released under anoxic conditions.

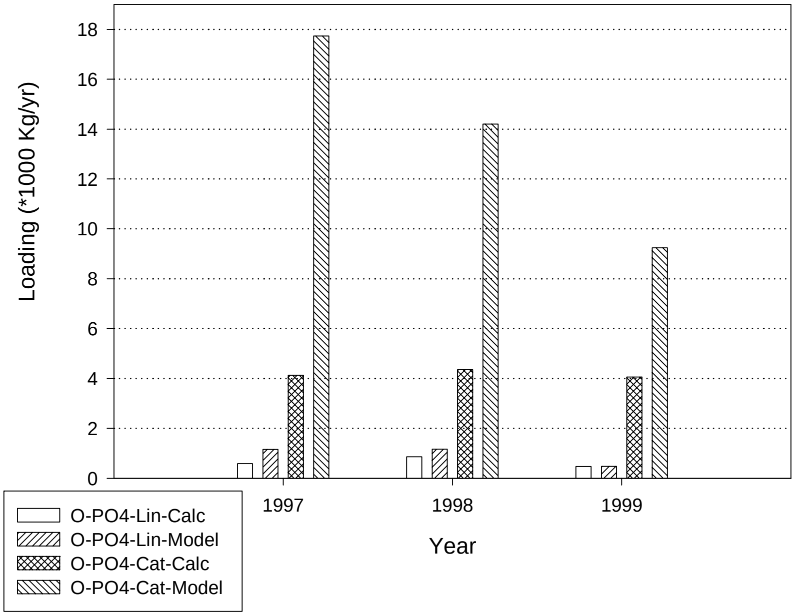


Figure 27 Average Annual Loading of Ortho-Phosphate for the Linville and Catawba Basins of Lake James, NC

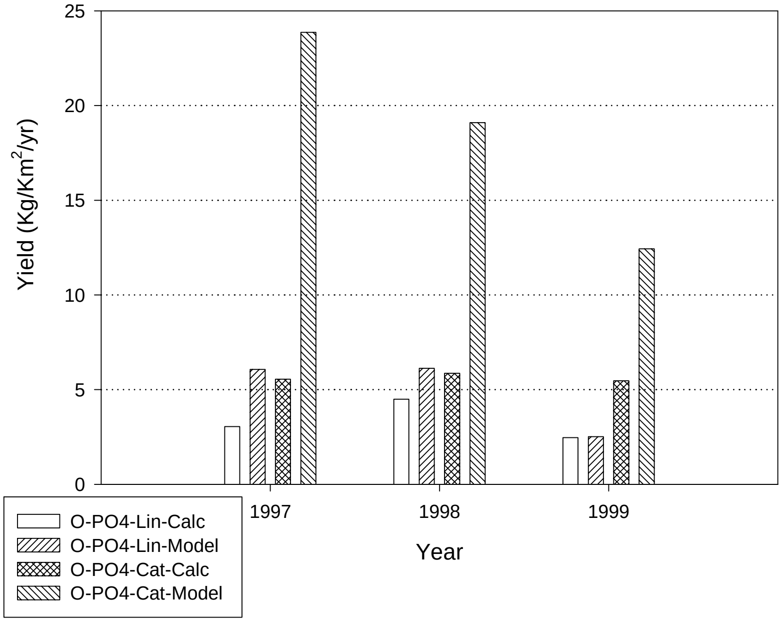


Figure 28 Average Annual Yield of Ortho-Phosphate for the Linville and Catawba Basins of Lake James, NC

Total Phosphorous

Catawba Loading: Calculated loading using traditional methods generated total phosphorous loading estimates into the headwaters of the Catawba basin of Lake James of 11.717x10^3 kg/yr in 1997, 13.734x10^3 kg/yr in 1998 and 6.216x10^3 kg/yr in 1999. LJA-CB model estimates of total phosphorous loading were 19.446x10^3 kg/yr in 1997, 23.497x10^3 kg/yr in 1998 and 11.949x10^3 kg/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of -7.728x10^3 kg/yr in 1997, with calculated values of 60.3% of those generated by the model. In 1998 there was a net of -9.763x10^3 kg/yr, with calculated values of 58.5% of those generated by the model. In 1999 there was a net of -5.733x10^3 kg/yr, with calculated values of 52.0% of those generated by the model (Figure 29, Table B- 4, Table B- 5 and Table B- 6).

Linville Loading: Calculated loading using traditional methods generated total phosphorous loading estimates into the headwaters of the Linville basin of Lake James of 1.383x10^3 kg/yr in 1997, 1.313x10^3 kg/yr in 1998 and 0.756x10^3 kg/yr in 1999. LJA-CB model estimates of total phosphorous loading were 1.539x10^3 kg/yr in 1997, 1.987x10^3 kg/yr in 1998 and 0.574x10^3 kg/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of -0.156x10^3 kg/yr in 1997, with calculated values of 89.9% of those generated by the model. In 1998 there was a net of -0.674x10^3 kg/yr, with calculated values of 66.1% of those generated by the model. In 1999 there was a net of 0.181x10^3 kg/yr, with calculated values of 132% of those generated by the model (Figure 29, Table B- 1, Table B- 2 and Table B- 3).

Catawba Yield: Calculated yield using traditional methods generated total phosphorous yield estimates into the headwaters of the Catawba basin of Lake James of 15.766 kg/km^2/yr in 1997, 18.480 kg/km^2/yr in 1998 and 8.363 kg/km^2/yr in 1999. LJA-CB model estimates of total phosphorous yield were 26.162 kg/km^2/yr in 1997, 31.613 kg/km^2/yr in 1998 and 16.075 kg/km^2/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of -10.395 kg/km^2/yr in 1997, with calculated values of 60.3% of those generated by the model. In 1998 there was a net of -13.133 kg/km^2/yr, with calculated values of 58.5% of those generated by the model. In 1999 there was a net of -7.712 kg/km^2/yr, with calculated values of 52.0% of those generated by the model (Figure 30, Table B- 10, Table B- 11 and Table B- 12).

Linville Yield: Calculated yield using traditional methods generated total phosphorous yield estimates into the headwaters of the Linville basin of Lake James of 7.233 kg/km^2/yr in 1997, 6.869 kg/km^2/yr in 1998 and 3.952 kg/km^2/yr in 1999. LJA-CB model estimates of total phosphorous yield were 8.049 kg/km^2/yr in 1997, 10.393 kg/km^2/yr in 1998 and 3.004 kg/km^2/yr in 1999. Comparison of values generated by taking the net of the calculated – model values found a difference of -0.816 kg/km^2/yr in 1997, with calculated values of 89.9% of those generated by the model. In 1998 there was a net of -3.524 kg/km^2/yr, with calculated values of 66.1% of those generated by the model. In 1999 there was a net of 0.948 kg/km^2/yr, with calculated values of 132% of those generated by the model (Figure 30, Table B- 7, Table B- 8 and Table B- 9).

Loading and yield are poorly represented using the traditional calculations, relative to the flow and volume-weighted loadings of the LJA-CB model with differences in basin lithology contributing to this variability, as well as redox complexes, and biological reactivity. Total phosphorous is better represented (- 50%) using the traditional calculations than is ortho-phosphate (- 80%). As with ortho-phosphate, total phosphorous loading and yield are closely tied to differences in basin lithology and the variability in hydrology under the three meteorological patterns observed of ENSO neutral in 1997, el Niño in 1998 and la Niña in 1999.

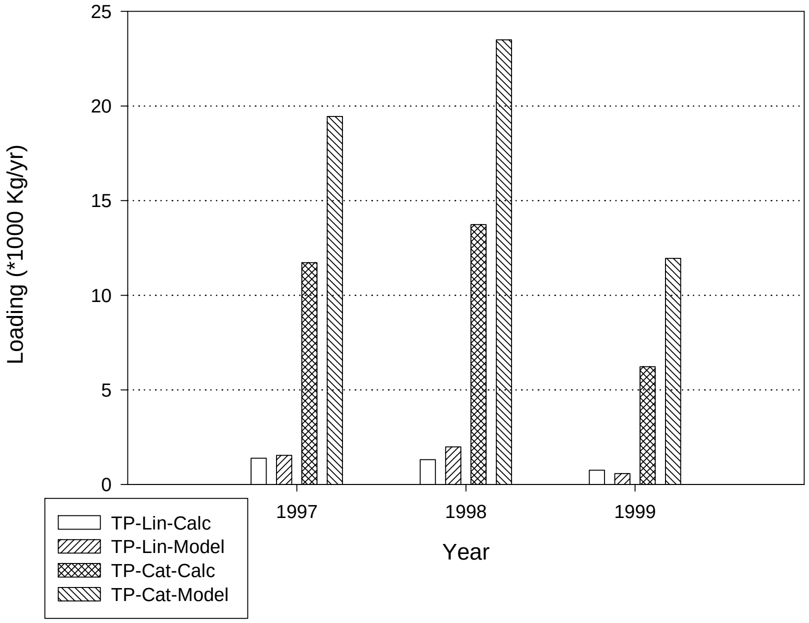


Figure 29 Average Annual Loading of Total Phosphorous for the Linville and Catawba Basins of Lake James, NC

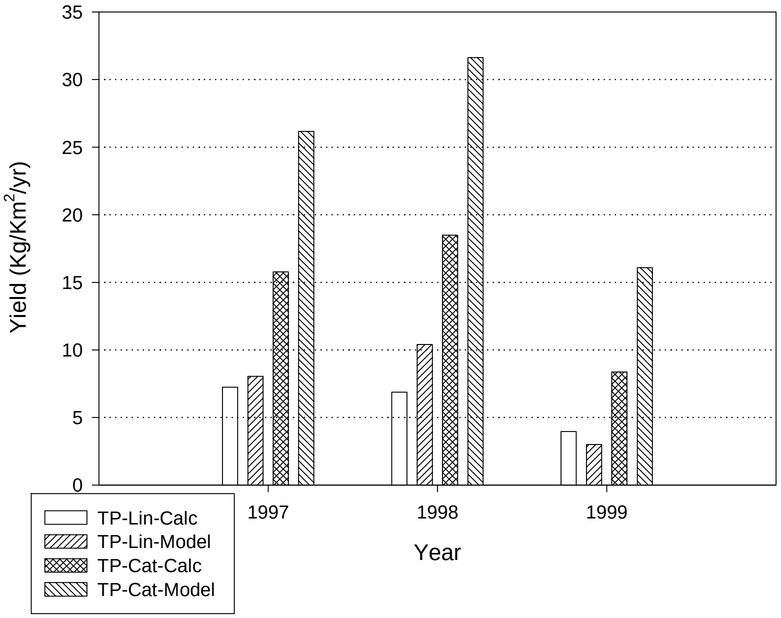


Figure 30 Average Annual Yield of Total Phosphorous for the Linville and Catawba Basins of Lake James, NC

Other constituent summary of comparison of calculated vs. model loading and yield

Aluminum

Calculated loading is variable relative to the LJA-CB between basins and years and is not adequate for loading and yield determinations for this constituent which is readily adhered to clay complexes. Mobility and transport of piedmont clays during precipitation events may contribute to these dynamics within the Catawba basin (Table A- 1, Appendix B, Figure C- 1 and Figure C- 2). The impacts of acid deposition and precipitation in this region of the Appalachians are poorly understood; however, the impacts have been noted in forest decline and impacts on the spruce and fir forests on the mountain tops of the Blue Ridge. Acid rain mobilizes metals in soils and this complex dynamic which contributes to changes in stream chemistry is a field ripe for research.

Iron

Calculated loading is variable relative to the LJA-CB between basins and years and is not adequate for loading and yield determinations for this constituent which is readily adhered to clay complexes and is involved in redox reactions. Mobility and transport of piedmont clays during precipitation events may contribute to these dynamics within the Catawba basin (Table A- 2, Appendix B, Figure C- 3 and Figure C- 4).

Magnesium

Calculated loading tends to overestimate within approximately +/- 50% of the LJA-CB for the Linville basin and underestimate approximately +/- 15% for the Catawba basin, but is likely adequate for loading and yield determinations for this hydrologically driven constituent. These differences are likely due to variability in lithology, some of which can be attributed to the dissolution of dolomitic limestone within the North Fork Catawba watershed (Table A- 3, Appendix B, Figure C- 5 and Figure C- 6).

Manganese

Calculated loading is variable relative to the LJA-CB between basins and years and is not adequate for loading and yield determinations for this constituent which is involved in redox reactions. The presence of manganese within the dolomitic limestone formations of the North Fork Catawba basin is evident in bands of grayish-black and may be one reason the formation was termed the “Shady Dolomite” (Table A- 4, Appendix B, Figure C- 7 and Figure C- 8).

Sodium

Calculated loading is within approximately +/- 20% of the LJA-CB for both basins and is adequate for loading and yield determinations for this hydrologically driven constituent (Table A- 5, Appendix B, Figure C- 9 and Figure C- 10).

Ammonia-N

Calculated loading is underestimated within both basins by approximately +/- 35% variable relative to the LJA-CB and is variable among years and is not adequate for loading and yield determinations for this constituent which is hydrologically, redox and biologically driven and displays interannual variability between basins (Table A- 6, Appendix B, Figure C- 11 and Figure C- 12).

Nitrite/Nitrate-N

Calculated loading tends to underestimate within approximately +/- 80% of the LJA-CB for both basins and is not adequate for loading and yield determinations for this biologically active and redox driven constituent. These differences are likely due to variability in lithology or non-point source loading within the watersheds. Atmospheric deposition may also be contributing to the deposition of nitrates into the Lake James watersheds as prevailing winds could potentially carry air pollution from within the watershed towards the Blue Ridge escarpment (Table A- 7, Appendix B, Figure C- 13 and Figure C- 14).

Seston Ash-Free Dry Weight

Calculated loading is up to +/- 50% variable relative to the LJA-CB between basins and years and is not adequate for loading and yield determinations for this constituent which is hydrologically driven and displays interannual variability between basins (Table A- 8, Appendix B, Figure C- 15 and Figure C- 16).

Seston Dry Weight

Calculated loading is +/- 75% variable relative to the LJA-CB between basins and years and is not adequate for loading and yield determinations for this constituent which is hydrologically driven and displays interannual variability between basins (Table A- 9, Appendix B, Figure C- 17 and Figure C- 18).

Silica

Calculated loading is within approximately +/- 36% of the LJA-CB for the Linville basin and +/- 15% for the Catawba basin and is likely adequate for loading and yield determinations for this hydrologically driven constituent (Table A- 10, Appendix B, Figure C- 19 and Figure C- 20).

Sulfate

Calculated loading tends to overestimate within approximately +/- 55% of the LJA-CB for the Linville basin and underestimate approximately +/- 20% for the Catawba basin and is not adequate for loading and yield determinations for this hydrologically driven constituent. These differences are likely due to variability in lithology, some of which can be attributed to the dissolution of dolomitic limestone within the North Fork Catawba watershed containing pyrites within the formation. Atmospheric deposition may also be contributing to the deposition of sulfates into the Lake James watersheds as prevailing winds could potentially carry air pollution from within the watershed towards the Blue Ridge escarpment (Table A- 11, Appendix B, Figure C- 21 and Figure C- 22).

Total Kjeldahl Nitrogen

Calculated loading is approximately +/- 60% variable relative to the LJA-CB between basins and years and is not adequate for loading and yield determinations for this constituent which is hydrologically and biologically driven and displays interannual variability between basins (Table A- 12, Appendix B, Figure C- 23 and Figure C- 24).

Total Nitrogen

Calculated loading is approximately +/- 65% variable relative to the LJA-CB between basins and years and is not adequate for loading and yield determinations for this constituent which is hydrologically, redox and biologically driven and displays interannual variability between basins (Table A- 13, Appendix B, Figure C- 25 and Figure C- 26).

Total Organic Carbon

Calculated loading is variable relative to the LJA-CB between basins and years and is not adequate for loading and yield determinations for this constituent which is biologically active and displays interannual variability between basins (Table A- 14, Appendix B, Figure C- 27 and Figure C- 28).

Zinc

Calculated loading tends to overestimate within approximately +/- 25% of the LJA-CB for the Linville basin and underestimate approximately +/- 50% for the Catawba basin. Traditional calculations are not adequate for loading and yield determinations for this hydrologically driven constituent. These differences are likely due to variability in lithology within the Lake James watersheds (Table A- 15, Appendix B, Figure C- 29 and Figure C- 30).

Model loading and export for whole lake and by basin

Alkalinity

In 1997, imports of alkalinity were 144% of exports, with 139.032×10^3 keq/yr loaded into Lake James and 96.252×10^3 keq/yr exported, with a net assimilation of alkalinity of 42.779×10^3 keq/yr. The Catawba basin loading was 593% of the Linville basin, with 118.975×10^3 keq/yr and 20.056×10^3 keq/yr, respectively. In 1998, imports of alkalinity were 140% of exports, with 210.288×10^3 keq/yr loaded into Lake James and 150.032×10^3 keq/yr exported, with a net assimilation of alkalinity of 60.256×10^3 keq/yr. The Catawba basin loading was 560% of the Linville basin, with 178.418×10^3 keq/yr and 31.870×10^3 keq/yr, respectively. In 1999, imports of alkalinity were 178% of exports, with 115.606×10^3 keq/yr loaded into Lake James and 64.809×10^3 keq/yr exported, with a net assimilation of alkalinity of 50.797×10^3 keq/yr. The Catawba basin loading was 559% of the Linville basin, with 98.075×10^3 keq/yr and 17.531×10^3 keq/yr, respectively (Table 5).

Table 5 LJA Model Mass Loading and Assimilation Summary for Alkalinity

Location / Calculation (*1000 keq/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed Alk	25.472	28.703	19.962
C3311 Sed Alk	8.046	16.674	4.766
C3312 Sed Alk	22.718	35.495	11.250
C3313 Sed Alk	12.044	45.800	19.523
Linville Basin			
L3300 Sed Alk	18.478	20.143	14.745
L3301 Sed Alk	0.046	1.683	0.143
L3302 Sed Alk	1.841	9.012	2.697
L3303 Sed Alk	5.259	6.908	3.732
Loading and Assimilation Summary			
Total Load Alk Exported	96.252	150.032	64.809
Total Load Alk Imported	139.032	210.288	115.606
import-export = total load assimilated	42.779	60.256	50.797
Sum Catawba Load	118.975	178.418	98.075
Sum Linville Load	20.056	31.870	17.531
Catawba/Linville = loading ratio	5.932	5.598	5.594
import/export = assimilation ratio	1.444	1.402	1.784

Chloride

In 1997, imports of chloride were 191% of exports, with 2,723.523x10^3 kg/yr loaded into Lake James and 1,424.657x10^3 kg/yr exported, with a net assimilation of chloride of 1,298.866x10^3 kg/yr. The Catawba basin loading was 316% of the Linville basin, with 2,069.444x10^3 kg/yr and 654.080x10^3 kg/yr, respectively. In 1998, imports of chloride were 130% of exports, with 3,262.304x10^3 kg/yr loaded into Lake James and 2,516.735x10^3 kg/yr exported, with a net assimilation of chloride of 745.569x10^3 kg/yr. The Catawba basin loading was 396% of the Linville basin, with 2,604.326x10^3 kg/yr and 657.978x10^3 kg/yr, respectively. In 1999, imports of calcium were 187% of exports, with 1,552.569x10^3 kg/yr loaded into Lake James and 829.863x10^3 kg/yr exported, with a net assimilation of calcium of 722.706x10^3 kg/yr. The Catawba basin loading was 362% of the Linville basin, with 1,216.237x10^3 kg/yr and 336.332x10^3 kg/yr, respectively (Table 6).

Table 6 LJA Model Mass Loading and Assimilation Summary for Chloride

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed Cl	375.976	386.210	284.354
C3311 Sed Cl	204.393	255.039	90.760
C3312 Sed Cl	455.710	520.441	188.288
C3313 Sed Cl	344.568	776.774	71.513
Linville Basin			
L3300 Sed Cl	345.454	328.032	234.596
L3301 Sed Cl	19.967	34.292	1.861
L3302 Sed Cl	189.417	197.059	61.485
L3303 Sed Cl	72.340	87.741	59.988
Loading and Assimilation Summary			
Total Load Cl Exported	1,424.657	2,516.735	829.863
Total Load Cl Imported	2,723.523	3,262.304	1,552.569
import-export = total load assimilated	1,298.866	745.569	722.706
Sum Catawba Load	2,069.444	2,604.326	1,216.237
Sum Linville Load	654.080	657.978	336.332
Catawba/Linville = loading ratio	3.164	3.958	3.616
import/export = assimilation ratio	1.912	1.296	1.871

Calcium

In 1997, imports of calcium were 135% of exports, with 1,841.949x10^3 kg/yr loaded into Lake James and 1,369.336x10^3 kg/yr exported, with a net assimilation of calcium of 472.613x10^3 kg/yr. The Catawba basin loading was 455% of the Linville basin, with 1,510.234x10^3 kg/yr and 331.715x10^3 kg/yr, respectively. In 1998, imports of calcium were 147% of exports, with 2,609.832x10^3 kg/yr loaded into Lake James and 1,772.513x10^3 kg/yr exported, with a net assimilation of calcium of 837.320x10^3 kg/yr. The Catawba basin loading was 425% of the Linville basin, with 2,113.106x10^3 kg/yr and 496.727x10^3 kg/yr, respectively. In 1999, imports of calcium were 199% of exports, with 1,278.877x10^3 kg/yr loaded into Lake James and 643.523x10^3 kg/yr exported, with a net assimilation of calcium of 635.354x10^3 kg/yr. The Catawba basin loading was 474% of the Linville basin, with 1,056.060x10^3 kg/yr and 222.817x10^3 kg/yr, respectively (Table 7).

Table 7 LJA Model Mass Loading and Assimilation Summary for Calcium

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed Ca	250.108	317.752	221.810
C3311 Sed Ca	165.399	225.795	75.275
C3312 Sed Ca	290.039	469.624	172.484
C3313 Sed Ca	280.349	556.430	142.815
Linville Basin			
L3300 Sed Ca	211.938	249.265	148.132
L3301 Sed Ca	4.482	34.241	1.875
L3302 Sed Ca	47.306	154.159	43.160
L3303 Sed Ca	63.625	74.081	45.934
Loading and Assimilation Summary			
Total Load Ca Exported	1369.336	1772.513	643.523
Total Load Ca Imported	1841.949	2609.832	1278.877
import-export = total load assimilated	472.613	837.320	635.354
Sum Catawba Load	1510.234	2113.106	1056.060
Sum Linville Load	331.715	496.727	222.817
Catawba/Linville = loading ratio	4.553	4.254	4.740
import/export = assimilation ratio	1.345	1.472	1.987

Potassium

In 1997, imports of potassium were 104% of exports, with 494.285x10^3 kg/yr loaded into Lake James and 477.505x10^3 kg/yr exported, with a net assimilation of potassium of 16.780x10^3 kg/yr. The Catawba basin loading was 439% of the Linville basin, with 402.523x10^3 kg/yr and 91.762x10^3 kg/yr, respectively. In 1998, imports of potassium were 108% of exports, with 849.541x10^3 kg/yr loaded into Lake James and 786.648x10^3 kg/yr exported, with a net assimilation of potassium of 62.893x10^3 kg/yr. The Catawba basin loading was 352% of the Linville basin, with 661.387x10^3 kg/yr and 188.153x10^3 kg/yr, respectively. In 1999, imports of potassium were 154% of exports, with 409.173x10^3 kg/yr loaded into Lake James and 266.133x10^3 kg/yr exported, with a net assimilation of potassium of 143.040x10^3 kg/yr. The Catawba basin loading was 367% of the Linville basin, with 321.543x10^3 kg/yr and 87.630x10^3 kg/yr, respectively (Table 8).

Table 8 LJA Model Mass Loading and Assimilation Summary for Potassium

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed K	83.448	108.003	69.821
C3311 Sed K	22.252	49.716	15.110
C3312 Sed K	57.350	114.927	44.364
C3313 Sed K	54.907	175.960	35.919
Linville Basin			
L3300 Sed K	64.630	98.913	63.662
L3301 Sed K	0.079	8.358	0.547
L3302 Sed K	6.518	50.117	11.542
L3303 Sed K	13.817	21.328	10.613
Loading and Assimilation Summary			
Total Load K Exported	477.505	786.648	266.133
Total Load K Imported	494.285	849.541	409.173
import-export = total load assimilated	16.780	62.893	143.040
Sum Catawba Load	402.523	661.387	321.543
Sum Linville Load	91.762	188.153	87.630
Catawba/Linville = loading ratio	4.387	3.515	3.669
import/export = assimilation ratio	1.035	1.080	1.537

Ortho-phosphate

In 1997, imports of ortho-phosphate were 775% of exports, with 18.896x10^3 kg/yr loaded into Lake James and 2.438x10^3 kg/yr exported, with a net assimilation of ortho-phosphate of 16.458x10^3 kg/yr. The Catawba basin loading was 1,528% of the Linville basin, with 17.735x10^3 kg/yr and 1.161x10^3 kg/yr, respectively. In 1998, imports of ortho-phosphate were 233% of exports, with 15.368x10^3 kg/yr loaded into Lake James and 6.599x10^3 kg/yr exported, with a net assimilation of ortho-phosphate of 8.769x10^3 kg/yr. The Catawba basin loading was 1,212% of the Linville basin, with 14.197x10^3 kg/yr and 1.171x10^3 kg/yr, respectively. In 1999, imports of ortho-phosphate were 770%

of exports, with 9.721x10^3 kg/yr loaded into Lake James and 1.262x10^3 kg/yr exported, with a net assimilation of ortho-phosphate of 8.459x10^3 kg/yr. The Catawba basin loading was 1,918% of the Linville basin, with 9.240x10^3 kg/yr and 0.482x10^3 kg/yr, respectively (Table 9).

Table 9 LJA Model Mass Loading and Assimilation Summary for Ortho-Phosphate

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed OPO4	1.457	1.423	0.957
C3311 Sed OPO4	2.134	1.854	1.266
C3312 Sed OPO4	4.399	3.390	2.642
C3313 Sed OPO4	7.782	5.578	3.066
Linville Basin			
L3300 Sed OPO4	0.779	0.764	0.498
L3301 Sed OPO4	0.028	0.049	0.002
L3302 Sed OPO4	0.290	0.330	0.070
L3303 Sed OPO4	0.622	0.604	0.259
Loading and Assimilation Summary			
Total Load OPO4 Exported	2.438	6.599	1.262
Total Load OPO4 Imported	18.896	15.368	9.721
import-export = total load assimilated	16.458	8.769	8.459
Sum Catawba Load	17.735	14.197	9.240
Sum Linville Load	1.161	1.171	0.482
Catawba/Linville = loading ratio	15.279	12.124	19.182
import/export = assimilation ratio	7.750	2.329	7.701

Total Phosphorous

In 1997, imports of total phosphorous were 598% of exports, with 20.984x10^3 kg/yr loaded into Lake James and 3.511x10^3 kg/yr exported, with a net assimilation of total phosphorous of 17.474x10^3 kg/yr. The Catawba basin loading was 1,264% of the Linville basin, with 19.446x10^3 kg/yr and 1.539x10^3 kg/yr, respectively. In 1998, imports of total phosphorous were 488% of exports, with 25.484x10^3 kg/yr loaded into Lake James and 5.227x10^3 kg/yr exported, with a net assimilation of total phosphorous of 20.258x10^3 kg/yr. The Catawba basin loading was 1,183% of the Linville basin, with 23.497x10^3 kg/yr and 1.987x10^3 kg/yr, respectively. In 1999, imports of total phosphorous were 736% of exports, with 12.523x10^3 kg/yr loaded into Lake James and 1.701x10^3 kg/yr exported, with a net assimilation of total phosphorous of 10.822x10^3 kg/yr. The Catawba basin loading was 2,080% of the Linville basin, with 11.949x10^3 kg/yr and 0.574x10^3 kg/yr, respectively (Table 10).

Table 10 LJA Model Mass Loading and Assimilation Summary for Total Phosphorous

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed TP	1.873	2.696	1.734
C3311 Sed TP	3.024	3.782	1.967
C3312 Sed TP	5.893	5.984	3.295
C3313 Sed TP	5.893	7.449	2.723
Linville Basin			
L3300 Sed TP	0.929	1.393	0.673
L3301 Sed TP	0.024	0.155	0.002
L3302 Sed TP	0.427	0.608	0.079
L3303 Sed TP	0.883	1.207	0.645
Loading and Assimilation Summary			
Total Load TP Exported	3.511	5.227	1.701
Total Load TP Imported	20.984	25.484	12.523
import-export = total load assimilated	17.474	20.258	10.822
Sum Catawba Load	19.446	23.497	11.949
Sum Linville Load	1.539	1.987	0.574
Catawba/Linville = loading ratio	12.636	11.825	20.805
import/export = assimilation ratio	5.977	4.876	7.362

Model assimilation by basin

Alkalinity

In 1997, the greatest amount of alkalinity was assimilated in the lacustrine zone of the Catawba basin at station 3310 with 25,472 keq/yr, followed by the upper transition zone, station 3312, with 22,718 keq/yr. Deposition was greater this yr in the lacustrine zone of the Linville basin, station 3300, with 18,478 keq/yr than the riverine zone of the Catawba basin, station 3313, which assimilated 12,044 keq/yr. It is worthy of noting that the Linville lacustrine station is the receiving embayment for both river basins and likely reflects the inflows from the Catawba lake basin. The least amount of deposition was found in the transition station 3301 of the Linville basin with 46 keq/yr sedimented (Table 5 and Figure D- 2).

In 1998, the greatest amount of alkalinity assimilated was in the riverine zone of the Catawba basin, station 3313, with 45,800 keq/yr assimilated. The upper transition zone of the Catawba basin, station 3312, followed with 35,495 keq/yr assimilated. The lacustrine zone of the Catawba basin, station 3310, exceeded the lacustrine zone of the Linville basin, station 3300, sedimenting 28,703 keq/yr and 20,143 keq/yr, respectively. Again, the transition zone of the Linville basin, station 3301, assimilated the least alkalinity with 1,683 keq/yr (Table 5 and Figure D- 2).

In 1999, the greatest amount of alkalinity was assimilated by the lacustrine zone of the Catawba basin, station 3310, with 19,962 keq/yr and was followed with a close second by the riverine zone of the Catawba basin, station 3313, with 19,523 keq/yr. The lacustrine zone of the Linville basin, station 3300, was third in assimilation with 14,745 keq/yr assimilated. Again, the transition zone of the Linville basin, station 3301, assimilated the least alkalinity with 143 keq/yr (Table 5 and Figure D- 2).

Chloride

In 1997, the greatest amount of chloride was assimilated in the upper transition zone of the Catawba basin at station 3312 with 455,710 keq/yr, followed by the lacustrine zone of the Catawba basin, station 3310, with 375,976 keq/yr. Next highest assimilation was the lacustrine zone of the Linville basin, station 3310, which assimilated 345,454 keq/yr, followed closely by the riverine zone of the Catawba basin, station 3313, with 344,568 keq/yr. The least amount of deposition was found in the transition station 3301 of the Linville basin with 4,482 keq/yr sedimented (Table 6 and Figure D- 4).

In 1998, the greatest amount of chloride assimilated was in the riverine zone of the Catawba basin, station 3313, with 776,774 keq/yr assimilated. The upper transition zone of the Catawba basin, station 3312, followed with 520,441 keq/yr assimilated. Third highest assimilation was in the lacustrine zone of the Catawba basin, station 3310, sedimenting 386,210 keq/yr. Again, the transition zone of the Linville basin, station 3301, assimilated the least chloride with 34,292 keq/yr (Table 6 and Figure D- 4).

In 1999, the greatest amount of chloride was assimilated by the lacustrine zone of the Catawba basin, station 3310, with 284,354 keq/yr and was followed by the upper transition zone of the Catawba basin, station 3312, with 234,596 keq/yr. The lacustrine zone of the Linville basin, station 3300, was third in assimilation with 188,288 keq/yr assimilated. Again, the transition zone of the Linville basin, station 3301, assimilated the least chloride with 1,861 keq/yr (Table 6 and Figure D- 4).

Calcium

In 1997, the greatest amount of calcium was assimilated in the upper transition zone of the Catawba basin at station 3312 with 290,039 keq/yr, followed by the riverine zone of the Catawba basin, station 3313, with 280,349 keq/yr. Next highest assimilation was the lacustrine zone of the Catawba basin, station 3310, which assimilated 250,108 keq/yr. The least amount of deposition was found in the transition station 3301 of the Linville basin with 4,482 keq/yr sedimented (Table 7 and Figure D- 3).

In 1998, the greatest amount of calcium assimilated was in the riverine zone of the Catawba basin, station 3313, with 556,430 keq/yr assimilated. The upper transition zone of the Catawba basin, station 3312, followed with 469,624 keq/yr assimilated. Third highest assimilation was in the lacustrine zone of the Catawba basin, station 3310, sedimenting 317,752 keq/yr. Again, the transition zone of the Linville basin, station 3301, assimilated the least calcium with 1,875 keq/yr (Table 7 and Figure D- 3).

In 1999, the greatest amount of calcium was assimilated by the lacustrine zone of the Catawba basin, station 3310, with 221,810 keq/yr and was followed by the upper transition zone of the Catawba basin, station 3312, with 172,484 keq/yr. The lacustrine zone of the Linville basin, station 3300, was third in assimilation with 148,132 keq/yr assimilated. Again, the transition zone of the Linville basin, station 3301, assimilated the least calcium with 1,875 keq/yr (Table 7 and Figure D- 3).

Potassium

In 1997, the greatest amount of potassium was assimilated in the lacustrine zone of the Catawba basin at station 3310 with 83448 keq/yr, followed by the lacustrine zone of the Linville basin, station 3300, with 64630 keq/yr. Next highest assimilation was the upper transition zone of the Catawba basin, station 3312, which assimilated 57349 keq/yr. The least amount of deposition was found in the transition station 3301 of the Linville basin with 78 keq/yr sedimented (Table 8 and Figure D- 6).

In 1998, the greatest amount of potassium assimilated was in the riverine zone of the Catawba basin, station 3313, with 175960 keq/yr assimilated. The upper transition zone of the Catawba basin, station 3312, followed with 114927 keq/yr assimilated. Third highest assimilation was in the lacustrine zone of the Catawba basin, station 3310, sedimenting 108003 keq/yr. Again, the transition zone of the Linville basin, station 3301, assimilated the least potassium with 8358 keq/yr (Table 8 and Figure D- 6).

In 1999, the greatest amount of potassium was assimilated by the lacustrine zone of the Catawba basin, station 3310, with 69821 keq/yr and was followed by the lacustrine zone of the Linville basin, station 3300, with 63662 keq/yr. The upper transition zone of the Catawba basin, station 3312, was third in assimilation with 44364 keq/yr assimilated. Again, the transition zone of the Linville basin, station 3301, assimilated the least potassium with 547 keq/yr (Table 8 and Figure D- 6).

Ortho-phosphate

In 1997, the greatest amount of ortho-phosphate-P assimilated was in the riverine zone of the Catawba basin, station 3313, with 7782 kg/yr assimilated. The upper transition zone of the Catawba basin, station 3312, followed with 4399 kg/yr assimilated. Third highest assimilation was in the lower transition zone of the Catawba basin, station

3311, sedimenting 2134 kg/yr. Again, the transition zone of the Linville basin, station 3301, assimilated the least ortho-phosphate-P with 28 kg/yr (Table 9 and Figure D- 12).

In 1998, the greatest amount of ortho-phosphate-P assimilated was in the riverine zone of the Catawba basin, station 3313, with 5578 kg/yr assimilated. The upper transition zone of the Catawba basin, station 3312, followed with 3390 kg/yr assimilated. Third highest assimilation was in the lower transition zone of the Catawba basin, station 3311, sedimenting 1854 kg/yr. Again, the transition zone of the Linville basin, station 3301, assimilated the least ortho-phosphate-P with 49 kg/yr (Table 9 and Figure D- 12).

In 1999, the greatest amount of ortho-phosphate-P assimilated was in the riverine zone of the Catawba basin, station 3313, with 3066 kg/yr assimilated. The upper transition zone of the Catawba basin, station 3312, followed with 2642 kg/yr assimilated. Third highest assimilation was in the lower transition zone of the Catawba basin, station 3311, sedimenting 1266 kg/yr. Again, the transition zone of the Linville basin, station 3301, assimilated the least ortho-phosphate-P with 2 kg/yr (Table 9 and Figure D- 12).

Total Phosphorous

In 1997, the greatest amount of total phosphorous assimilated was in the riverine zone of the Catawba basin, station 3313, with 5893 kg/yr assimilated. The upper transition zone of the Catawba basin, station 3312, followed closely with 5893 kg/yr assimilated. Third highest assimilation was in the lower transition zone of the Catawba basin, station 3311, sedimenting 3024 kg/yr. Again, the transition zone of the Linville basin, station 3301, assimilated the least total phosphorous with 24 kg/yr (Table 10 and Figure D- 20).

In 1998, the greatest amount of total phosphorous assimilated was in the riverine zone of the Catawba basin, station 3313, with 7449 kg/yr assimilated. The upper transition zone of the Catawba basin, station 3312, followed with 5984 kg/yr assimilated. Third highest assimilation was in the lower transition zone of the Catawba basin, station 3311, sedimenting 3782 kg/yr. Again, the transition zone of the Linville basin, station 3301, assimilated the least total phosphorous with 155 kg/yr (Table 10 and Figure D- 20).

In 1999, the greatest amount of total phosphorous assimilated was in the upper transition zone of the Catawba basin, station 3312, with 3295 kg/yr assimilated. The riverine zone of the Catawba basin, station 3313, followed with 2723 kg/yr assimilated. Third highest assimilation was in the lower transition zone of the Catawba basin, station 3311, sedimenting 1967 kg/yr. Again, the transition zone of the Linville basin, station 3301, assimilated the least total phosphorous with 2 kg/yr (Table 10 and Figure D- 20).

Interannual comparisons are inadvisable due to the sparsity of samples in early 1997 and the ending of sampling in October 1999. However, interbasin and comparisons among zones can be enlightening when one considers the variability in hydrology among the years. Early 1997 ENSO neutral conditions brought intermediate flows to the upper Catawba basin, relative to the el Niño high flows of 1998 or the la Niña drought flows of 1999 (Table G- 1, Table G- 2, Table G- 3 and Table G- 4). Variability in the seasonal expression of these flows impacts material transport from the watersheds. The quantity and quality of sediments and allochthonous materials transported are relative to the intensity and periodicity of precipitation events. Particle transport is a function of particle size, transport velocities, basin morphometry and residence time (a function of management releases). Constituent distribution within the reservoir can therefore primarily be attributed to the hydrologically driven physical dynamics and secondarily to the chemical and biological transformation processes within the lake basins.

Cumulative plots of assimilation (Appendix D) display the variability in sedimentation of different constituents within the Lake James basins and the importance of individual precipitation events in mobilizing materials into the lake basins. Examination of these plots reveals different depositional patterns through time and classes of constituents within these patterns. Within the hydrologically driven constituents of alkalinity (Figure D- 2), potassium (Figure D- 6), magnesium (Figure D- 7), sodium (Figure D- 9), silica (Figure D- 15) and sulfate (Figure D- 16), cumulative sedimentation by the end of the study was highest in the riverine zone (3313), followed by the lacustrine station (3310), then the upper transition zone (3312), then the lower transition zone (3311) of the Catawba basin. In the Linville basin, however, the lacustrine zone (3300) sedimented the greatest amount of materials over time, followed by either the riverine zone (3302) or Paddy Creek (3303), then by the transition zone (3301). Sulfate cumulative assimilation was different from the above pattern for the Linville basin with the riverine zone (3302) sedimenting the highest amount by the end of the study (Appendix D).

The assimilation behavior of chloride (Figure D- 4) and calcium (Figure D- 3) were slightly different in their depositional pattern in which the greatest amount of these constituents were assimilated over time in the riverine zone (3313), followed by the upper transition zone (3312), then the lacustrine zone (3310) and the least sedimented was in the lower transition zone (3311). The behavior of these constituents, however, within the Linville basin was consistent with the other hydrologically driven constituents listed above (Appendix D).

Relative quantities of assimilation alkalinity, chloride, calcium and potassium were variable among locations and years and seem to be driven by hydrologic processes rather than internal loading phenomena. Phosphorous dynamics, however, imply a more complex behavior due to its biological and redox reactivity. Sedimentation patterns among the redox constituents were similar for ortho-phosphate (Figure D- 12), total phosphorous (Figure D- 20), iron (Figure D- 5), manganese (Figure D- 8) as well as for aluminum (Figure D- 1). Typically aluminum is not viewed as a redox constituent, however, in its function within clay complexes it may become sedimented and released with the redox behavior of iron and phosphorous; however, this is conjecture and merits further examination. For these constituents, sedimentation is highest in the riverine zone (3313), then the upper transition zone (3312), then the lower transition (3311), followed by the lacustrine station (3310) of the Catawba basin. In the Linville basin, however, the lacustrine zone (3300) sedimented the greatest amount of materials over time, followed by Paddy Creek (3303), then the riverine zone (3302), followed by the transition zone (3301) (Appendix D).

There was variability in the nuances among the nitrogen constituents in their depositional patterns. Total nitrogen (Figure D- 18), total Kjeldahl nitrogen (Figure D-17) and nitrite/nitrate-N (Figure D- 11) cumulative sedimentation was highest in the riverine zone (3313), then the upper transition zone (3312), followed by the lacustrine station (3310), then the lower transition (3311) of the Catawba basin. Zinc (Figure D- 21) cumulative deposition was similar to that of the nitrogen constituents above. Ammonia-N (Figure D- 10) followed the same general pattern, however, deposition in the lacustrine zone (3310) approached that of the upper transition zone (3312) by the end of the study. In the Linville basin for all nitrogen constituents, cumulative deposition was highest in the lacustrine zone (3300), then the riverine zone (3302), then Paddy Creek (3303), followed by the transition zone (3301) (Appendix D).

There was variability among the other carbon constituents which differed from that of alkalinity. Of the particulate fraction, seston ash-free dry weight (Figure D- 13) and seston dry weight (Figure D- 14) followed the same cumulative assimilation pattern with highest deposition in the Catawba basin in the riverine zone (3313), followed by the upper transition zone (3312), then the lower transition zone (3311) and the least sedimented was in the lacustrine zone (3310). Cumulative sedimentation within the Linville basin was highest in the lacustrine zone (3300), followed by Paddy Creek (3303), then the riverine zone (3302), followed by the transition zone (3301). Of the dissolved fraction, total organic carbon (Figure D- 19), cumulative sedimentation was highest in the lacustrine zone (3310), then the riverine zone (3313), then the upper transition zone (3312), followed by the lower transition (3311). In the Linville basin, cumulative deposition was highest in the lacustrine zone (3300), then the riverine zone (3302), then Paddy Creek (3303), followed by the transition zone (3301). Particle size may be a determining factor in the depositional patterns of the carbon constituents within Lake James (Appendix D).

Conclusions

Differences between the Linville and Catawba basins with respect to hypolimnetic volume and thermocline magnitude and depth supports the hypothesis that differences generated by the two withdrawal regimes created by epilimnetic release from the Catawba basin and hypolimnetic release from the Linville basin have an impact on the physical and chemical behavior within Lake James (Table 2).

I ascertained that most of the constituent loading into the Lake James basin is derived from the Catawba River watershed (most notably the North Fork Catawba sub-watershed) and that most of the inflowing material is retained by the reservoir. I further discerned that relatively limited numbers of high flow events are responsible for providing the bulk of materials assimilated within the lake basins. I confirmed that the headwaters and upper transition zones of the Lake James reservoir have greater rates of sedimentation of most constituents relative to the lower transition and lacustrine zones and validates the model proposed by Thornton et al. (1981) and later work on spatial sedimentation of constituents and subsequent ecosystem production by Kennedy et al. (1982). However, the lacustrine station for the Linville basin is the receiving embayment for both basins and reflects the greater loading being brought in from the Catawba Basin.

I employed traditional loading calculations (Olem and Flock 1990) using monthly chemical concentrations and average daily discharge, both of which were averaged for each year, to provide a conservative estimate of loading and yield from the Lake James watershed. By comparing the LJA-CB with traditional loading and yield calculations I found that the traditional methods, in general, tended to be adequate for hydrologically driven constituents; however, biologically and redox regulated constituents do not appear to be sufficiently represented using traditional calculations of loading and yield.

One of the model limitations is that it does not consider the vertical distribution of chemical constituents within the water column or the role of dissolved oxygen in defining hypolimnetic concentrations. Although such considerations could potentially be modeled in concert with vertical chemical concentration profiles if data were available, the level of hydrodynamic modeling that would be required would extend beyond the capabilities of the software and intentions of the model.

The LJA-CB model has utility as a descriptive model (as per Walker 1996). It calculates flow and volume weighted loading into the Lake James basins and allows the conceptualization of regions of assimilation of materials within the longitudinal zones of the reservoir and can help to target potential ecosystem “hot spots” within the reservoir due to sedimentation. Due to the different time steps of USGS average daily flows and the monthly chemistry sampling regime, caution should be exercised in interpretation of model outputs. The number of high flow events, and therefore, antecedent conditions within the watershed will likely affect the amount of material moved from the watershed into the lake basin.

How "flashy" a watershed is would affect the amount of precipitation retained by or shed by the soil surface. Faster rises and drops as reflected in the hydrograph would indicate movement of water through the watershed faster and that would affect the monthly average more than a gradual rise and fall of the same volume. The traditional calculation method averages the daily flows for the year as well as the concentrations of elements; whereas, the LJA-CB model uses average daily flows and monthly concentrations to determine loading and yield. Therefore, the hydrologic responses of the watersheds become critical for defining system behavior and for determining the adequacy of the calculated method. Since this is likely to vary as a function of a prolonged hydrologic drought, the model may be a useful tool for examining systems undergoing large-scale climatic change. In such systems, the base flow response curves are likely to change as the system wets and dries over time.

The LJA-CB, as a flow and volume weighted model of the chemical dynamics of the reservoir, is more reflective of the variability in the chemical dynamics of many of the constituents within the Lake James reservoir than traditional calculations of loading and yield. The primary difference between generating loading and yield estimates with the model versus the traditional calculations using annual averages of flow and concentration is due to the hydrologic responses of the streams. If the streams display a rapid rise and fall in the storm hydrograph then the amount of water represented by a rainfall event is quickly lost in time. However, if stream rise and fall is relatively slow then the discharge over the hydrograph contributes more to the monthly averages and the flow-weighted loading, assuming monthly average chemistry. Therefore, the effect of precipitation events will have different loading effects if the system is undergoing a prolonged hydrologic drought as opposed to "normal" fairly evenly distributed rainfall over time. Because of lithological and topographic variability, each sub-watershed within the Lake James basin is likely to have different hydrologic response curves in response to prolonged droughts. Calculations of the base flows for the inflowing streams to Lake

James were generated to estimate minimum flows for the water budget, however, the regressions themselves provide information on the responsiveness of the watershed during periods of drought and rainfall.

Further exploration of this hydrologic variability by an examination of baseflow recessions for each inflowing stream for the period of study and extending throughout the la Niña drought period would provide additional insights to the utility of the LJA-CB model. Comparison of this data with systems under different hydrological regimes would test its applicability and its relevance to examining processes of global change in lake and reservoir ecosystems.

APPENDICES

APPENDIX A

LJA Model Mass Loading and assimilation summary tables for all Constituents

Table A- 1 LJA Model Mass Loading and Assimilation Summary for Aluminum

LJA Model Mass Loading and Assimilation Summary for Aluminum

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed Al	6.669	42.487	6.105
C3311 Sed Al	10.608	56.454	6.335
C3312 Sed Al	18.428	84.712	12.151
C3313 Sed Al	24.948	181.277	18.014
Linville Basin			
L3300 Sed Al	4.914	19.376	3.560
L3301 Sed Al	0.921	0.838	0.094
L3302 Sed Al	3.150	4.297	1.390
L3303 Sed Al	3.388	20.591	1.779
Loading and Assimilation Summary			
Total Load Al Exported	36.007	109.626	17.388
Total Load Al Imported	86.610	442.559	59.127
import-export = total load assimilated	50.603	332.933	41.739
Sum Catawba Load	75.426	424.890	52.580
Sum Linville Load	11.184	17.669	6.547
Catawba/Linville = loading ratio	6.744	24.047	8.032
import/export = assimilation ratio	2.405	4.037	3.401

Table A- 2 LJA Model Mass Loading and Assimilation Summary for Iron

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed Fe	9.808	30.881	8.337
C3311 Sed Fe	17.655	42.539	10.154
C3312 Sed Fe	25.210	72.073	17.105
C3313 Sed Fe	11.973	134.168	10.302
Linville Basin			
L3300 Sed Fe	7.620	14.395	4.212
L3301 Sed Fe	1.627	1.433	0.477
L3302 Sed Fe	2.212	5.560	1.990
L3303 Sed Fe	3.992	15.635	3.906
Loading and Assimilation Summary			
Total Load Fe Exported	18.426	74.079	5.362
Total Load Fe Imported	93.217	336.466	63.646
import-export = total load assimilated	74.791	262.387	58.285
Sum Catawba Load	81.471	319.142	57.313
Sum Linville Load	11.745	17.325	6.333
Catawba/Linville = loading ratio	6.936	18.421	9.050
import/export = assimilation ratio	5.059	4.542	11.870

Table A- 3 LJA Model Mass Loading and Assimilation Summary for Magnesium

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed Mg	113.441	158.825	106.262
C3311 Sed Mg	51.525	84.081	25.875
C3312 Sed Mg	85.162	185.537	68.246
C3313 Sed Mg	87.493	238.334	80.110
Linville Basin			
L3300 Sed Mg	82.159	109.022	75.962
L3301 Sed Mg	0.351	8.099	0.145
L3302 Sed Mg	6.392	41.255	7.102
L3303 Sed Mg	27.931	37.650	17.221
Loading and Assimilation Summary			
Total Load Mg Exported	603.241	866.400	352.386
Total Load Mg Imported	692.135	1,114.957	583.620
import-export = total load assimilated	88.894	248.558	231.233
Sum Catawba Load	586.675	953.614	505.294
Sum Linville Load	105.460	161.343	78.325
Catawba/Linville = loading ratio	5.563	5.910	6.451
import/export = assimilation ratio	1.147	1.287	1.656

Table A- 4 LJA Model Mass Loading and Assimilation Summary for Manganese

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed Mn	0.902	0.987	0.216
C3311 Sed Mn	1.101	1.189	0.039
C3312 Sed Mn	2.516	2.239	0.083
C3313 Sed Mn	4.098	4.160	0.036
Linville Basin			
L3300 Sed Mn	0.614	0.621	0.276
L3301 Sed Mn	0.006	0.055	0.002
L3302 Sed Mn	0.143	0.309	0.067
L3303 Sed Mn	0.439	0.403	0.097
Loading and Assimilation Summary			
Total Load Mn Exported	10.334	8.215	1.698
Total Load Mn Imported	11.162	11.205	1.603
import-export = total load assimilated	0.828	2.991	-0.095
Sum Catawba Load	10.311	10.098	1.129
Sum Linville Load	0.851	1.107	0.474
Catawba/Linville = loading ratio	12.119	9.118	2.382
import/export = assimilation ratio	1.080	1.364	0.944

Table A- 5 LJA Model Mass Loading and Assimilation Summary for Sodium

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed Na	359.116	429.415	354.903
C3311 Sed Na	173.678	223.759	95.731
C3312 Sed Na	342.302	505.908	214.215
C3313 Sed Na	393.449	653.407	115.154
Linville Basin			
L3300 Sed Na	284.618	315.020	251.620
L3301 Sed Na	3.417	24.238	0.870
L3302 Sed Na	59.778	147.459	40.531
L3303 Sed Na	98.158	107.317	68.828
Loading and Assimilation Summary			
Total Load Na Exported	1,482.850	2,413.980	1,064.933
Total Load Na Imported	2,420.410	3,128.668	1,790.792
import-export = total load assimilated	937.560	714.688	725.859
Sum Catawba Load	2,010.545	2,581.771	1,497.551
Sum Linville Load	409.866	546.897	293.241
Catawba/Linville = loading ratio	4.905	4.721	5.107
import/export = assimilation ratio	1.632	1.296	1.682

Table A- 6 LJA Model Mass Loading and Assimilation Summary for Ammonia

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed NH4	4.236	4.393	1.678
C3311 Sed NH4	1.135	2.609	0.937
C3312 Sed NH4	3.289	6.000	1.253
C3313 Sed NH4	3.286	9.354	1.625
Linville Basin			
L3300 Sed NH4	4.251	4.626	1.502
L3301 Sed NH4	0.057	0.543	0.097
L3302 Sed NH4	1.388	3.092	0.660
L3303 Sed NH4	0.585	1.193	0.355
Loading and Assimilation Summary			
Total Load NH4 Exported	24.381	35.546	6.522
Total Load NH4 Imported	28.634	42.278	11.496
import-export = total load assimilated	4.253	6.732	4.974
Sum Catawba Load	20.967	31.184	8.624
Sum Linville Load	7.668	11.093	2.872
Catawba/Linville = loading ratio	2.734	2.811	3.003
import/export = assimilation ratio	1.174	1.189	1.763

Table A- 7 LJA Model Mass Loading and Assimilation Summary for Nitrite-Nitrate-N

Location / Calculation (*1000 kg/yr)	1997	1998	1999
Catawba Basin			
C3310 Sed NO2NO3	9.367	17.566	7.787
C3311 Sed NO2NO3	12.914	18.163	4.026
C3312 Sed NO2NO3	28.221	37.288	11.606
C3313 Sed NO2NO3	53.281	58.269	13.159
Linville Basin			
L3300 Sed NO2NO3	14.461	16.771	7.787
L3301 Sed NO2NO3	1.639	2.642	0.524
L3302 Sed NO2NO3	13.891	13.652	5.090
L3303 Sed NO2NO3	2.495	5.471	2.793
Loading and Assimilation Summary			
Total Load NO2NO3 Exported	97.778	134.126	34.202
Total Load NO2NO3 Imported	165.363	198.606	66.934
import-export = total load assimilated	67.585	64.480	32.732
Sum Catawba Load	125.154	158.045	50.834
Sum Linville Load	40.208	40.561	16.100
Catawba/Linville = loading ratio	3.113	3.896	3.157
import/export = assimilation ratio	1.691	1.481	1.957

Table A- 8 LJA Model Mass Loading and Assimilation Summary for Seston-Ash Free Dry Weight

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed SAFDW	100.098	332.924	105.732
C3311 Sed SAFDW	114.767	408.755	68.232
C3312 Sed SAFDW	142.633	598.559	98.688
C3313 Sed SAFDW	118.232	976.333	50.887
Linville Basin			
L3300 Sed SAFDW	86.379	183.808	71.592
L3301 Sed SAFDW	1.357	41.664	3.035
L3302 Sed SAFDW	11.573	118.113	18.055
L3303 Sed SAFDW	12.337	155.223	45.119
Loading and Assimilation Summary			
Total Load SAFDW Exported	200.510	1,224.121	601.358
Total Load SAFDW Imported	740.141	3,123.799	619.775
import-export = total load assimilated	539.631	1,899.678	18.417
Sum Catawba Load	635.936	2,767.415	520.205
Sum Linville Load	104.204	356.384	99.571
Catawba/Linville = loading ratio	6.103	7.765	5.224
import/export = assimilation ratio	3.691	2.552	1.031

Table A- 9 LJA Model Mass Loading and Assimilation Summary for Seston-Dry Weight

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed SDW	294.531	1,520.633	198.488
C3311 Sed SDW	373.883	2,510.211	194.572
C3312 Sed SDW	496.236	3,626.275	258.876
C3313 Sed SDW	489.926	6,866.466	104.139
Linville Basin			
L3300 Sed SDW	222.880	684.363	97.539
L3301 Sed SDW	9.962	161.971	4.061
L3302 Sed SDW	32.278	403.045	17.409
L3303 Sed SDW	40.829	739.230	91.258
Loading and Assimilation Summary			
Total Load SDW Exported	406.909	1,504.773	718.375
Total Load SDW Imported	2,282.575	17,347.840	1,158.109
import-export = total load assimilated	1,875.667	15,843.068	439.735
Sum Catawba Load	2,061.379	16,305.079	1,052.537
Sum Linville Load	221.196	1,042.761	105.572
Catawba/Linville = loading ratio	9.319	15.636	9.970
import/export = assimilation ratio	5.610	11.529	1.612

Table A- 10 LJA Model Mass Loading and Assimilation Summary for Silica

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed Si	450.867	471.690	279.966
C3311 Sed Si	166.197	243.277	59.382
C3312 Sed Si	422.212	558.740	168.394
C3313 Sed Si	325.252	796.583	73.153
Linville Basin			
L3300 Sed Si	347.656	359.402	199.590
L3301 Sed Si	2.920	20.607	0.000
L3302 Sed Si	81.285	147.957	20.439
L3303 Sed Si	104.427	128.489	48.409
Loading and Assimilation Summary			
Total Load Si Exported	2,036.701	2,806.310	1,022.075
Total Load Si Imported	2,723.370	3,525.523	1,409.579
import-export = total load assimilated	686.669	719.214	387.504
Sum Catawba Load	2,246.088	2,942.849	1,174.597
Sum Linville Load	477.282	582.674	234.982
Catawba/Linville = loading ratio	4.706	5.051	4.999
import/export = assimilation ratio	1.337	1.256	1.379

Table A- 11 LJA Model Mass Loading and Assimilation Summary for Sulfate

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed SO4	374.075	423.530	299.157
C3311 Sed SO4	128.089	216.973	81.712
C3312 Sed SO4	380.018	509.674	184.541
C3313 Sed SO4	387.086	640.774	177.135
Linville Basin			
L3300 Sed SO4	20.809	53.584	3.172
L3301 Sed SO4	0.613	13.621	0.000
L3302 Sed SO4	22.090	111.733	9.734
L3303 Sed SO4	0.000	0.000	0.000
Loading and Assimilation Summary			
Total Load SO4 Exported	1,721.760	2,653.784	901.122
Total Load SO4 Imported	2,326.804	3,032.726	1,527.186
import-export = total load assimilated	605.044	378.942	626.064
Sum Catawba Load	2,029.111	2,559.580	1,334.397
Sum Linville Load	297.692	473.146	192.789
Catawba/Linville = loading ratio	6.816	5.410	6.922
import/export = assimilation ratio	1.351	1.143	1.695

Table A- 12 LJA Model Mass Loading and Assimilation Summary for Total Kjeldahl Nitrogen

Location / Calculation (*1000 kg/yr)	1997	1998	1999
Catawba Basin			
C3310 Sed TKN	19.410	13.901	7.312
C3311 Sed TKN	17.539	7.097	2.883
C3312 Sed TKN	37.121	17.378	4.821
C3313 Sed TKN	62.427	27.610	4.211
Linville Basin			
L3300 Sed TKN	15.840	13.548	6.729
L3301 Sed TKN	0.170	1.750	0.113
L3302 Sed TKN	4.387	9.665	1.975
L3303 Sed TKN	6.244	3.391	1.262
Loading and Assimilation Summary			
Total Load TKN Exported	74.281	162.867	30.586
Total Load TKN Imported	197.427	127.031	45.696
import-export = total load assimilated	123.146	-35.835	15.111
Sum Catawba Load	173.768	93.351	34.600
Sum Linville Load	23.659	33.681	11.096
Catawba/Linville = loading ratio	7.345	2.772	3.118
import/export = assimilation ratio	2.658	0.780	1.494

Table A- 13 LJA Model Mass Loading and Assimilation Summary for Total Nitrogen

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed TN	30.610	33.658	17.417
C3311 Sed TN	31.516	24.354	8.833
C3312 Sed TN	64.337	54.399	17.209
C3313 Sed TN	111.981	82.748	10.017
Linville Basin			
L3300 Sed TN	31.166	31.152	15.713
L3301 Sed TN	1.463	4.034	0.263
L3302 Sed TN	18.047	22.817	6.752
L3303 Sed TN	9.422	8.695	4.620
Loading and Assimilation Summary			
Total Load TN Exported	171.142	296.993	64.788
Total Load TN Imported	362.789	325.776	112.631
import-export = total load assimilated	191.647	28.784	47.843
Sum Catawba Load	298.922	251.535	85.434
Sum Linville Load	63.867	74.242	27.196
Catawba/Linville = loading ratio	4.680	3.388	3.141
import/export = assimilation ratio	2.120	1.097	1.738

Table A- 14 LJA Model Mass Loading and Assimilation Summary for Total Organic Carbon

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed TOC	105.463	134.053	80.675
C3311 Sed TOC	37.536	66.210	27.386
C3312 Sed TOC	66.070	136.030	58.286
C3313 Sed TOC	28.287	206.698	75.290
Linville Basin			
L3300 Sed TOC	93.421	129.252	71.567
L3301 Sed TOC	0.672	14.948	0.670
L3302 Sed TOC	21.146	87.333	19.816
L3303 Sed TOC	9.907	22.335	10.710
Loading and Assimilation Summary			
Total Load TOC Exported	493.762	989.836	304.862
Total Load TOC Imported	626.295	1,120.339	542.464
import-export = total load assimilated	132.533	130.503	237.602
Sum Catawba Load	467.290	810.048	418.635
Sum Linville Load	159.006	310.291	123.829
Catawba/Linville = loading ratio	2.939	2.611	3.381
import/export = assimilation ratio	1.268	1.132	1.779

Table A- 15 LJA Model Mass Loading and Assimilation Summary for Zinc

Location / Calculation (*1000 kg/yr)	**1997**	**1998**	**1999**
Catawba Basin			
C3310 Sed Zn	0.488	0.554	0.248
C3311 Sed Zn	0.214	0.486	0.031
C3312 Sed Zn	0.557	1.009	0.120
C3313 Sed Zn	0.747	1.789	0.063
Linville Basin			
L3300 Sed Zn	0.416	0.471	0.250
L3301 Sed Zn	0.006	0.057	0.002
L3302 Sed Zn	0.135	0.315	0.067
L3303 Sed Zn	0.081	0.164	0.022
Loading and Assimilation Summary			
Total Load Zn Exported	2.438	3.522	1.262
Total Load Zn Imported	3.704	5.934	1.533
import-export = total load assimilated	1.266	2.412	0.271
Sum Catawba Load	2.965	4.838	1.059
Sum Linville Load	0.739	1.097	0.474
Catawba/Linville = loading ratio	4.011	4.410	2.235
import/export = assimilation ratio	1.519	1.685	1.214

APPENDIX B

Comparison of Calculated and Model Generated Loading and Yields

Table B- 1 Comparison of calculated and model generated loadings for the Linville basin of Lake James for 1997-1999

Linville Loading (*1000 kg/yr)	3302 97 Calc	3302 98 Calc	3302 99 Calc	3302 97 Model	3302 98 Model	3302 99 Model
Alk	23.145	28.611	21.200	20.056	31.870	17.531
Al	5.808	16.916	4.723	11.184	17.669	6.547
NH_4-N	5.823	8.599	1.889	7.668	11.093	2.872
Ca	255.641	351.617	207.664	331.715	496.727	222.817
Cl	339.166	519.061	323.245	654.080	657.978	336.332
Fe	4.061	9.631	2.960	11.745	17.325	6.333
Mg	142.566	180.718	118.205	105.460	161.343	78.325
Mn	0.597	1.001	0.472	0.851	1.107	0.474
NO_2/NO_3-N	8.879	22.201	6.192	40.208	40.561	16.100
O-PO_4-P	0.582	0.860	0.472	1.161	1.171	0.482
K	119.217	170.415	97.393	91.762	188.153	87.630
SAFDW	100.731	207.312	121.007	104.204	356.384	99.571
SDW	186.032	389.296	135.910	221.196	1042.761	105.572
Si	385.746	548.766	320.097	477.282	582.674	234.982
Na	377.158	515.465	346.020	409.866	546.897	293.241
SO_4	395.790	545.952	298.058	297.692	473.146	192.789
TKN	18.487	26.735	9.445	23.659	33.681	11.096
TN	27.366	48.936	15.638	63.867	74.242	27.196
TOC	206.411	286.734	137.694	159.006	310.291	123.829
TP	1.383	1.313	0.756	1.539	1.987	0.574
Zn	0.582	0.860	0.472	0.739	1.097	0.474

Table B- 2 Difference and ratio comparison of calculated and model generated loadings for the Linville basin of Lake James for 1997-1999

Linville Loading (*1000 kg/yr)	3302 97 Diff C-M	3302 98 Diff C-M	3302 99 Diff C-M	3302 97 Ratio C:M	3302 98 Ratio C:M	3302 99 Ratio C:M
Alk	3.088	-3.259	3.669	1.154	0.898	1.209
Al	-5.376	-0.752	-1.824	0.519	0.957	0.721
NH_4-N	-1.845	-2.495	-0.983	0.759	0.775	0.658
Ca	-76.075	-145.110	-15.152	0.771	0.708	0.932
Cl	-314.914	-138.917	-13.086	0.519	0.789	0.961
Fe	-7.684	-7.694	-3.373	0.346	0.556	0.467
Mg	37.106	19.374	39.880	1.352	1.120	1.509
Mn	-0.254	-0.107	-0.002	0.701	0.904	0.997
NO_2/NO_3-N	-31.329	-18.360	-9.908	0.221	0.547	0.385
O-PO_4-P	-0.579	-0.311	-0.009	0.502	0.734	0.980
K	27.455	-17.739	9.763	1.299	0.906	1.111
SAFDW	-3.474	-149.072	21.436	0.967	0.582	1.215
SDW	-35.164	-653.466	30.338	0.841	0.373	1.287
Si	-91.535	-33.908	85.115	0.808	0.942	1.362
Na	-32.707	-31.432	52.779	0.920	0.943	1.180
SO_4	98.098	72.806	105.268	1.330	1.154	1.546
TKN	-5.172	-6.946	-1.651	0.781	0.794	0.851
TN	-36.501	-25.306	-11.559	0.428	0.659	0.575
TOC	47.405	-23.557	13.865	1.298	0.924	1.112
TP	-0.156	-0.674	0.181	0.899	0.661	1.316
Zn	-0.157	-0.237	-0.002	0.788	0.784	0.997

Table B- 3 Percentage comparison and evaluation of calculated and model generated loadings for the Linville basin of Lake James for 1997-1999

Year	1997	1998	1999	1997	1998	1999
	O:E:U	O:E:U	O:E:U	100(C:M)	100(C:M)	100(C:M)
Alk	O	U	O	115.4	89.8	120.9
Al	U	E	U	51.9	95.7	72.1
NH4	U	U	U	75.9	77.5	65.8
Ca	U	U	E	77.1	70.8	93.2
Cl	U	U	E	51.9	78.9	96.1
Fe	U	U	U	34.6	55.6	46.7
Mg	O	O	O	135.2	112.0	150.9
Mn	U	E	E	70.1	90.4	99.7
NO2/NO3	U	U	U	22.1	54.7	38.5
O-PO4	U	U	E	50.2	73.4	98.0
K	O	E	O	129.9	90.6	111.1
SAFDW	E	U	O	96.7	58.2	121.5
SDW	U	U	O	84.1	37.3	128.7
Si	U	E	O	80.8	94.2	136.2
Na	E	E	O	92.0	94.3	118.0
SO4	O	O	O	133.0	115.4	154.6
TKN	U	U	U	78.1	79.4	85.1
TN	U	U	U	42.8	65.9	57.5
TOC	O	E	O	129.8	92.4	111.2
TP	U	U	O	89.9	66.1	131.6
Zn	U	U	E	78.8	78.4	99.7

O= >110% Traditional annual average calculated values overestimate the model yield
E= 90-110% Traditional annual average calculated values are equivalent to the model yield
U= <90% Traditional annual average calculated values underestimate the model yield

Table B- 4 Comparison of calculated and model generated loadings for the Catawba basin of Lake James for 1997-1999

Catawba Loading (*1000 kg/yr)	3313 97 Calc	3313 98 Calc	3313 99 Calc	3313 97 Model	3313 98 Model	3313 99 Model
Alk	143.281	163.124	83.936	118.975	178.418	98.075
Al	29.749	97.963	17.318	75.426	424.890	52.580
NH_4-N	18.214	24.891	5.312	20.967	31.184	8.624
Ca	1226.446	1710.669	940.560	1510.234	2113.106	1056.060
Cl	2094.569	1875.704	1599.031	2069.444	2604.326	1216.237
Fe	63.748	80.140	37.001	81.471	319.142	57.313
Mg	572.819	830.332	437.369	586.675	953.614	505.294
Mn	2.489	4.356	1.912	10.311	10.098	1.129
NO_2/NO_3-N	26.106	63.561	22.578	125.154	158.045	50.834
O-PO_4-P	4.128	4.356	4.064	17.735	14.197	9.240
K	438.342	589.825	322.994	402.523	661.387	321.543
SAFDW	666.012	1594.793	619.160	635.936	2767.415	520.205
SDW	1351.452	4465.687	1026.620	2061.379	16305.079	1052.537
Si	2021.715	2613.540	1229.819	2246.088	2942.849	1174.597
Na	2013.215	2321.962	1803.824	2010.545	2581.771	1497.551
SO_4	1900.897	2147.726	1179.352	2029.111	2559.580	1334.397
TKN	77.712	75.117	53.124	173.768	93.351	34.600
TN	103.818	138.678	75.702	298.922	251.535	85.434
TOC	750.402	787.618	384.352	467.290	810.048	418.635
TP	11.717	13.734	6.216	19.446	23.497	11.949
Zn	1.518	2.445	1.195	2.965	4.838	1.059

Table B- 5 Difference and ratio comparison of calculated and model generated loadings for the Catawba basin of Lake James for 1997-1999

Catawba Loading (*1000 kg/yr)	3313 97 Diff C-M	3313 98 Diff C-M	3313 99 Diff C-M	3313 97 Ratio C:M	3313 98 Ratio C:M	3313 99 Ratio C:M
Alk	24.305	-15.294	-14.139	1.204	0.914	0.856
Al	-45.677	-326.927	-35.262	0.394	0.231	0.329
NH_4-N	-2.753	-6.294	-3.312	0.869	0.798	0.616
Ca	-283.787	-402.437	-115.501	0.812	0.810	0.891
Cl	25.125	-728.622	382.793	1.012	0.720	1.315
Fe	-17.724	-239.002	-20.313	0.782	0.251	0.646
Mg	-13.856	-123.281	-67.925	0.976	0.871	0.866
Mn	-7.822	-5.742	0.784	0.241	0.431	1.694
NO_2/NO_3-N	-99.048	-94.485	-28.256	0.209	0.402	0.444
O-PO_4-P	-13.607	-9.841	-5.176	0.233	0.307	0.440
K	35.819	-71.563	1.451	1.089	0.892	1.005
SAFDW	30.076	-1172.622	98.955	1.047	0.576	1.190
SDW	-709.927	-11839.392	-25.917	0.656	0.274	0.975
Si	-224.374	-329.308	55.222	0.900	0.888	1.047
Na	2.670	-259.809	306.273	1.001	0.899	1.205
SO_4	-128.214	-411.854	-155.045	0.937	0.839	0.884
TKN	-96.056	-18.234	18.524	0.447	0.805	1.535
TN	-195.104	-112.857	-9.733	0.347	0.551	0.886
TOC	283.112	-22.430	-34.283	1.606	0.972	0.918
TP	-7.728	-9.763	-5.733	0.603	0.585	0.520
Zn	-1.447	-2.393	0.136	0.512	0.505	1.128

Table B- 6 Percentage comparison and evaluation of calculated and model generated loadings for the Catawba basin of Lake James for 1997-1999

Year	1997	1998	1999	1997	1998	1999
	O:E:U	O:E:U	O:E:U	100(C:M)	100(C:M)	100(C:M)
Alk	O	E	U	120.4	91.4	85.6
Al	U	U	U	39.4	23.1	32.9
NH4	U	U	U	86.9	79.8	61.6
Ca	U	U	U	81.2	81.0	89.1
Cl	E	U	O	101.2	72.0	131.5
Fe	U	U	U	78.2	25.1	64.6
Mg	E	U	U	97.6	87.1	86.6
Mn	U	U	O	24.1	43.1	169.4
NO2/NO3	U	U	U	20.9	40.2	44.4
O-PO4	U	U	U	23.3	30.7	44.0
K	E	U	E	108.9	89.2	100.5
SAFDW	E	U	O	104.7	57.6	119.0
SDW	U	U	E	65.6	27.4	97.5
Si	E	U	E	90.0	88.8	104.7
Na	E	U	O	100.1	89.9	120.5
SO4	E	U	U	93.7	83.9	88.4
TKN	U	U	O	44.7	80.5	153.5
TN	U	U	U	34.7	55.1	88.6
TOC	O	E	E	160.6	97.2	91.8
TP	U	U	U	60.3	58.5	52.0
Zn	U	U	O	51.2	50.5	112.8

O= >110% Traditional annual average calculated values overestimate the model yield
E= 90-110% Traditional annual average calculated values are equivalent to the model yield
U= <90% Traditional annual average calculated values underestimate the model yield

Table B- 7 Comparison of calculated and model generated yields for the Linville basin of Lake James for 1997-1999

Linville Yield (kg/km^2/yr)	3302 97 Calc	3302 98 Calc	3302 99 Calc	3302 97 Model	3302 98 Model	3302 99 Model
Alk	121.054	149.643	110.881	104.900	166.688	91.691
Al	30.378	88.477	24.701	58.496	92.413	34.240
NH_4-N	30.454	44.975	9.881	40.105	58.022	15.023
Ca	1337.072	1839.053	1086.142	1734.963	2598.018	1165.393
Cl	1773.931	2714.832	1690.664	3421.018	3441.406	1759.108
Fe	21.241	50.372	15.479	61.432	90.612	33.123
Mg	745.660	945.203	618.245	551.583	843.870	409.664
Mn	3.122	5.233	2.470	4.450	5.792	2.479
NO_2/NO_3-N	46.442	116.116	32.386	210.301	212.146	84.209
O-PO_4-P	3.045	4.497	2.470	6.071	6.125	2.519
K	623.541	891.315	509.395	479.943	984.095	458.330
SAFDW	526.850	1084.297	632.901	545.018	1863.986	520.782
SDW	972.997	2036.124	710.847	1156.916	5453.931	552.172
Si	2017.561	2870.199	1674.196	2496.316	3047.548	1229.021
Na	1972.642	2696.025	1809.779	2143.710	2860.424	1533.730
SO_4	2070.094	2855.480	1558.924	1557.014	2474.686	1008.341
TKN	96.691	139.830	49.403	123.743	176.159	58.036
TN	143.133	255.947	81.789	334.044	388.305	142.245
TOC	1079.585	1499.699	720.179	831.644	1622.907	647.660
TP	7.233	6.869	3.952	8.049	10.393	3.004
Zn	3.045	4.497	2.470	3.866	5.737	2.479

Table B- 8 Difference and ratio comparison of calculated and model generated yields for the Linville basin of Lake James for 1997-1999

Linville Yield (kg/km^2/yr)	3302 97 Diff C-M	3302 98 Diff C-M	3302 99 Diff C-M	3302 97 Ratio C:M	3302 98 Ratio C:M	3302 99 Ratio C:M
Alk	16.153	-17.045	19.190	1.154	0.898	1.209
Al	-28.118	-3.936	-9.539	0.519	0.957	0.721
NH_4-N	-9.651	-13.047	-5.142	0.759	0.775	0.658
Ca	-397.891	-758.965	-79.251	0.771	0.708	0.932
Cl	-1647.087	-726.574	-68.445	0.519	0.789	0.961
Fe	-40.191	-40.240	-17.644	0.346	0.556	0.467
Mg	194.077	101.333	208.581	1.352	1.120	1.509
Mn	-1.328	-0.559	-0.008	0.701	0.904	0.997
NO_2/NO_3-N	-163.859	-96.030	-51.823	0.221	0.547	0.385
O-PO_4-P	-3.026	-1.627	-0.049	0.502	0.734	0.980
K	143.597	-92.780	51.064	1.299	0.906	1.111
SAFDW	-18.169	-779.689	112.119	0.967	0.582	1.215
SDW	-183.918	-3417.807	158.675	0.841	0.373	1.287
Si	-478.756	-177.349	445.176	0.808	0.942	1.362
Na	-171.069	-164.399	276.049	0.920	0.943	1.180
SO_4	513.079	380.794	550.583	1.330	1.154	1.546
TKN	-27.053	-36.328	-8.633	0.781	0.794	0.851
TN	-190.911	-132.358	-60.456	0.428	0.659	0.575
TOC	247.942	-123.208	72.519	1.298	0.924	1.112
TP	-0.816	-3.524	0.948	0.899	0.661	1.316
Zn	-0.820	-1.240	-0.008	0.788	0.784	0.997

Table B- 9 Percentage comparison and evaluation of calculated and model generated yields for the Linville basin of Lake James for 1997-1999

Year	1997	1998	1999	1997	1998	1999
	O:E:U	O:E:U	O:E:U	100(C:M)	100(C:M)	100(C:M)
Alk	O	U	O	115.4	89.8	120.9
Al	U	E	U	51.9	95.7	72.1
NH4	U	U	U	75.9	77.5	65.8
Ca	U	U	E	77.1	70.8	93.2
Cl	U	U	E	51.9	78.9	96.1
Fe	U	U	U	34.6	55.6	46.7
Mg	O	O	O	135.2	112.0	150.9
Mn	U	E	E	70.1	90.4	99.7
NO2/NO3	U	U	U	22.1	54.7	38.5
O-PO4	U	U	E	50.2	73.4	98.0
K	O	E	O	129.9	90.6	111.1
SAFDW	E	U	O	96.7	58.2	121.5
SDW	U	U	O	84.1	37.3	128.7
Si	U	E	O	80.8	94.2	136.2
Na	E	E	O	92.0	94.3	118.0
SO4	O	O	O	133.0	115.4	154.6
TKN	U	U	U	78.1	79.4	85.1
TN	U	U	U	42.8	65.9	57.5
TOC	O	E	O	129.8	92.4	111.2
TP	U	U	O	89.9	66.1	131.6
Zn	U	U	E	78.8	78.4	99.7

O= >110% Traditional annual average calculated values overestimate the model yield
E= 90-110% Traditional annual average calculated values are equivalent to the model yield
U= <90% Traditional annual average calculated values underestimate the model yield

Table B- 10 Comparison of calculated and model generated yields for the Catawba basin of Lake James for 1997-1999

Catawba Yield (kg/km^2/yr)	3313 97 Calc	3313 98 Calc	3313 99 Calc	3313 97 Model	3313 98 Model	3313 99 Model
Alk	192.789	219.489	112.938	160.067	240.040	131.948
Al	40.028	131.813	23.302	101.476	571.637	70.740
NH_4-N	24.507	33.491	7.148	28.208	41.955	11.603
Ca	1650.223	2301.760	1265.553	2031.832	2842.922	1420.799
Cl	2818.310	2523.820	2151.547	2784.181	3503.798	1636.297
Fe	85.775	107.831	49.786	109.610	429.366	77.108
Mg	770.747	1117.239	588.495	789.298	1282.969	679.811
Mn	3.349	5.861	2.573	13.872	13.586	1.519
NO_2/NO_3-N	35.127	85.523	30.379	168.380	212.630	68.391
O-PO_4-P	5.555	5.861	5.468	23.860	19.100	12.431
K	589.803	793.628	434.598	541.544	889.815	432.596
SAFDW	896.141	2145.845	833.099	855.574	3723.214	699.871
SDW	1818.423	6008.726	1381.351	2773.331	21936.467	1416.058
Si	2720.282	3516.603	1654.761	3021.834	3959.239	1580.275
Na	2708.845	3124.274	2427.103	2704.939	3473.454	2014.770
SO_4	2557.718	2889.834	1586.856	2729.918	3443.598	1795.266
TKN	104.563	101.072	71.480	233.783	125.592	46.550
TN	139.690	186.595	101.859	402.162	338.409	114.941
TOC	1009.690	1059.765	517.158	628.680	1089.819	563.222
TP	15.766	18.480	8.363	26.162	31.613	16.075
Zn	2.042	3.289	1.608	3.988	6.508	1.425

Table B- 11 Difference and ratio comparison of calculated and model generated yields for the Catawba basin of Lake James for 1997-1999

Catawba Yield (kg/km^2/yr)	3313 97 Diff C-M	3313 98 Diff C-M	3313 99 Diff C-M	3313 97 Ratio C:M	3313 98 Ratio C:M	3313 99 Ratio C:M
Alk	32.722	-20.551	-19.009	1.204	0.914	0.856
Al	-61.448	-439.824	-47.438	0.394	0.231	0.329
NH_4-N	-3.701	-8.463	-4.455	0.869	0.798	0.616
Ca	-381.610	-541.162	-155.245	0.812	0.810	0.891
Cl	34.129	-979.978	515.250	1.012	0.720	1.315
Fe	-23.835	-321.535	-27.322	0.783	0.251	0.646
Mg	-18.552	-165.731	-91.316	0.976	0.871	0.866
Mn	-10.523	-7.725	1.055	0.241	0.431	1.695
NO_2/NO_3-N	-133.253	-127.107	-38.012	0.209	0.402	0.444
O-PO_4-P	-18.305	-13.239	-6.962	0.233	0.307	0.440
K	48.258	-96.187	2.002	1.089	0.892	1.005
SAFDW	40.567	-1577.369	133.228	1.047	0.576	1.190
SDW	-954.908	-15927.741	-34.708	0.656	0.274	0.975
Si	-301.552	-442.637	74.487	0.900	0.888	1.047
Na	3.906	-349.180	412.333	1.001	0.899	1.205
SO_4	-172.199	-553.764	-208.410	0.937	0.839	0.884
TKN	-129.219	-24.520	24.930	0.447	0.805	1.536
TN	-262.472	-151.813	-13.082	0.347	0.551	0.886
TOC	381.010	-30.054	-46.064	1.606	0.972	0.918
TP	-10.395	-13.133	-7.712	0.603	0.585	0.520
Zn	-1.946	-3.219	0.183	0.512	0.505	1.129

Table B- 12 Percentage comparison and evaluation of calculated and model generated yields for the Catawba basin of Lake James for 1997-1999

Year	1997	1998	1999	1997	1998	1999
	O:E:U	O:E:U	O:E:U	100(C:M)	100(C:M)	100(C:M)
Alk	O	E	U	120.4	91.4	85.6
Al	U	U	U	39.4	23.1	32.9
NH4	U	U	U	86.9	79.8	61.6
Ca	U	U	U	81.2	81.0	89.1
Cl	E	U	O	101.2	72.0	131.5
Fe	U	U	U	78.3	25.1	64.6
Mg	E	U	U	97.6	87.1	86.6
Mn	U	U	O	24.1	43.1	169.5
NO2/NO3	U	U	U	20.9	40.2	44.4
O-PO4	U	U	U	23.3	30.7	44.0
K	E	U	E	108.9	89.2	100.5
SAFDW	E	U	O	104.7	57.6	119.0
SDW	U	U	E	65.6	27.4	97.5
Si	E	U	E	90.0	88.8	104.7
Na	E	U	O	100.1	89.9	120.5
SO4	E	U	U	93.7	83.9	88.4
TKN	U	U	O	44.7	80.5	153.6
TN	U	U	U	34.7	55.1	88.6
TOC	O	E	E	160.6	97.2	91.8
TP	U	U	U	60.3	58.5	52.0
Zn	U	U	O	51.2	50.5	112.9

O= >110% Traditional annual average calculated values overestimate the model yield
E= 90-110% Traditional annual average calculated values are equivalent to the model yield
U= <90% Traditional annual average calculated values underestimate the model yield

APPENDIX C

Average Annual Loading and Yield for the Linville and Catawba Basins of Lake James, NC

(Other constituents are located within chapter 3)

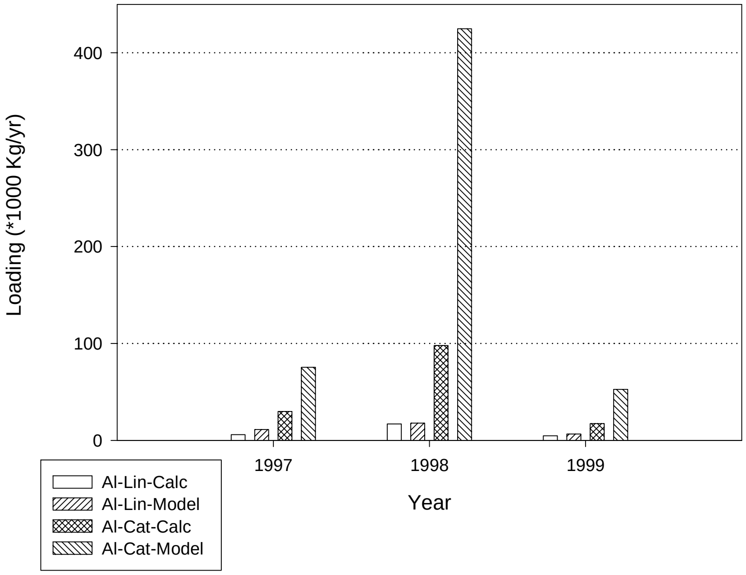


Figure C- 1 Average Annual Loading of Aluminum for the Linville and Catawba Basins of Lake James, NC

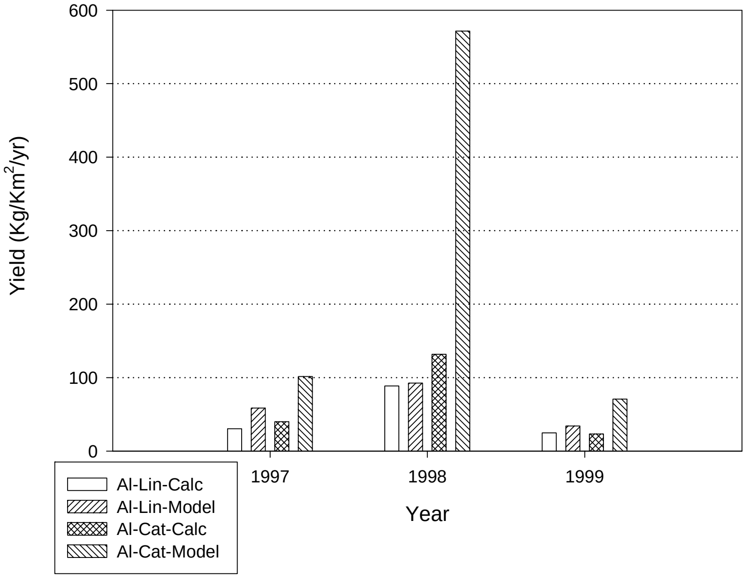


Figure C- 2 Average Annual Yield of Aluminum for the Linville and Catawba Basins of Lake James, NC

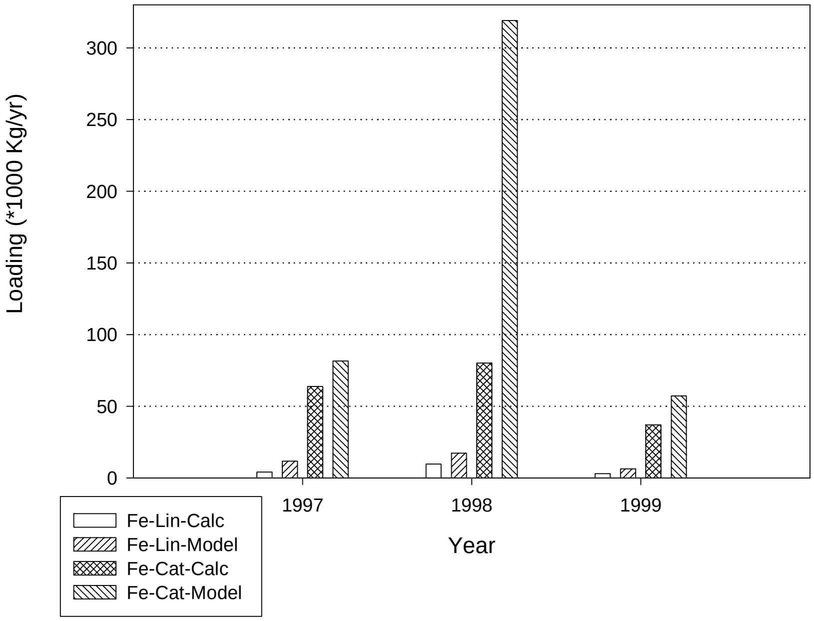


Figure C- 3 Average Annual Loading of Iron for the Linville and Catawba Basins of Lake James, NC

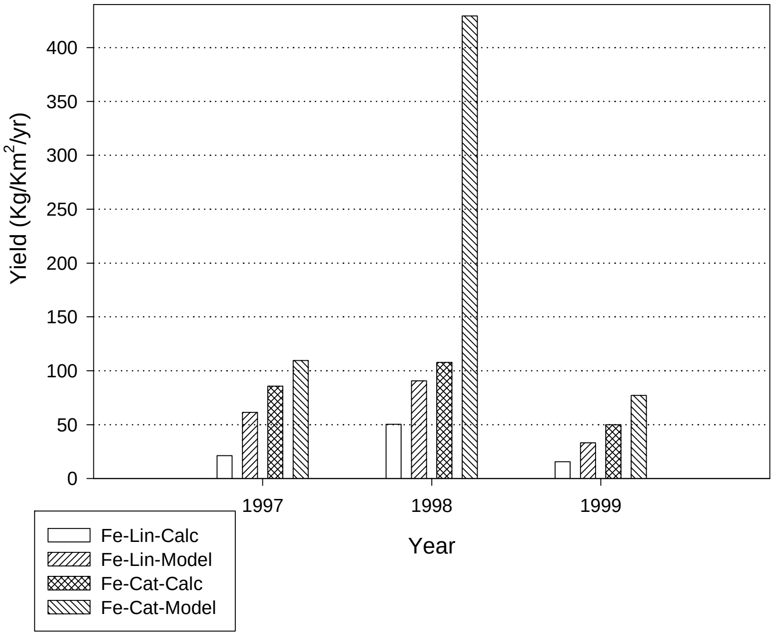


Figure C- 4 Average Annual Yield of Iron for the Linville and Catawba Basins of Lake James, NC

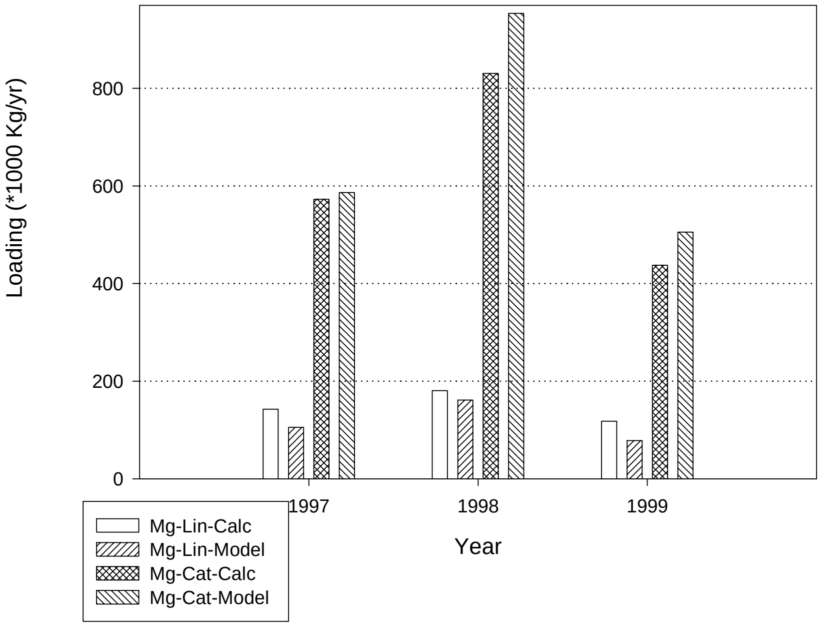


Figure C- 5 Average Annual Loading of Magnesium for the Linville and Catawba Basins of Lake James, NC

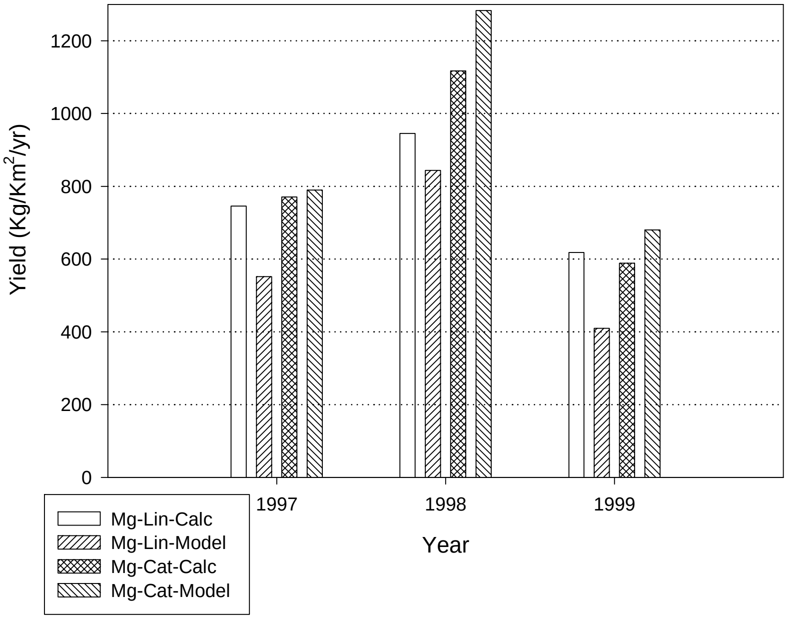


Figure C- 6 Average Annual Yield of Magnesium for the Linville and Catawba Basins of Lake James, NC

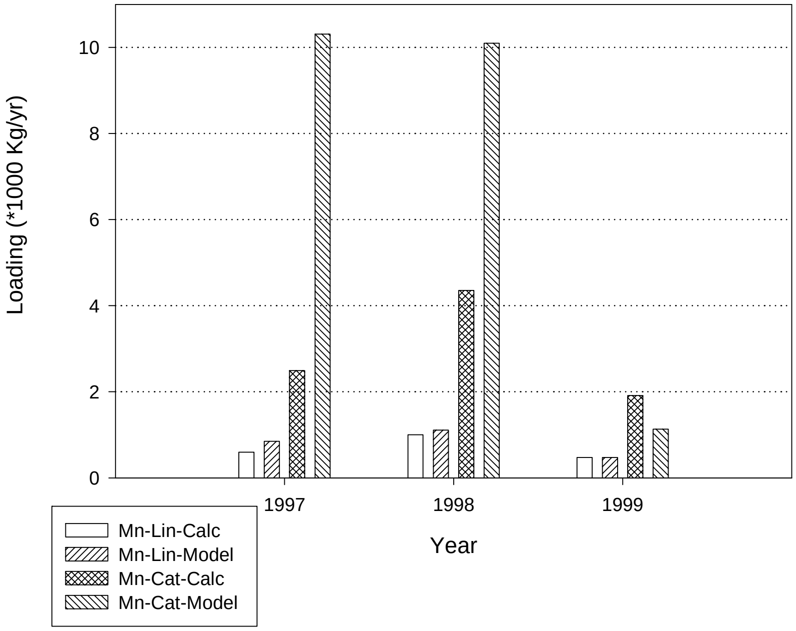


Figure C- 7 Average Annual Loading of Manganese for the Linville and Catawba Basins of Lake James, NC

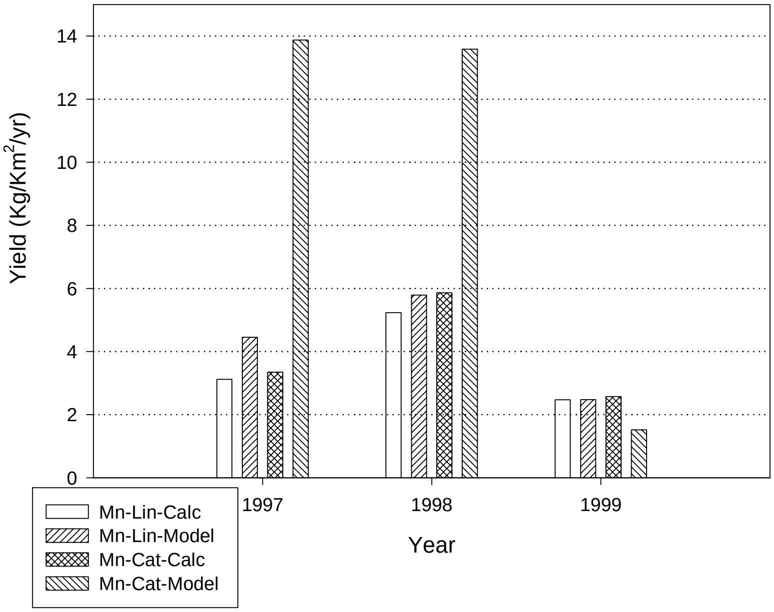


Figure C- 8 Average Annual Yield of Manganese for the Linville and Catawba Basins of Lake James, NC

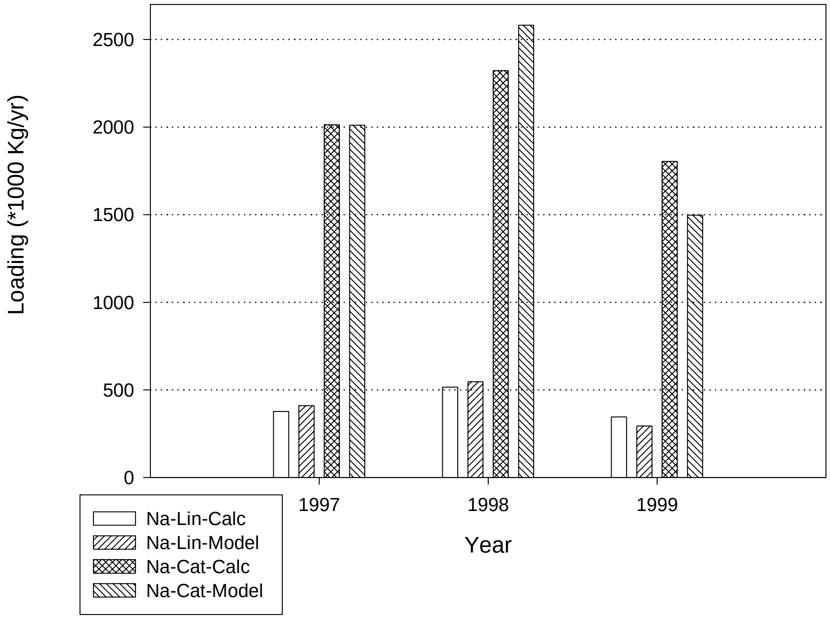


Figure C- 9 Average Annual Loading of Sodium for the Linville and Catawba Basins of Lake James, NC

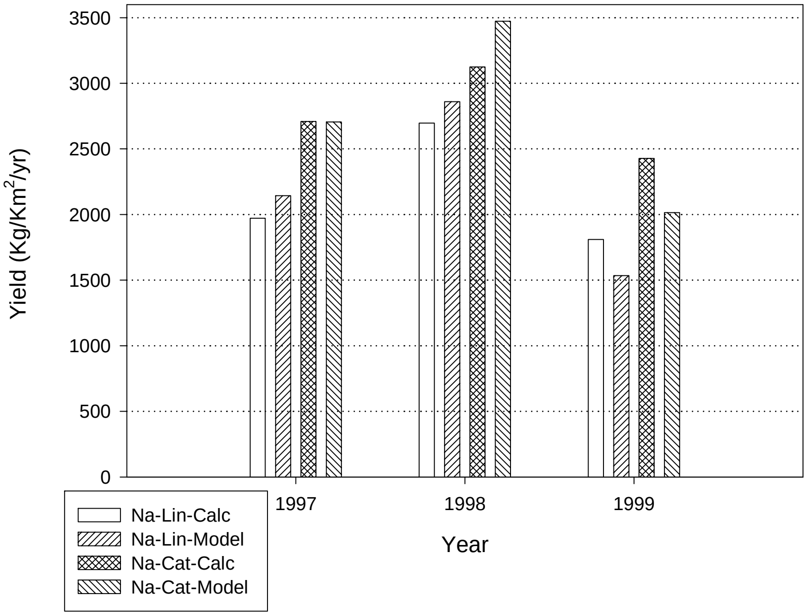


Figure C- 10 Average Annual Yield of Sodium for the Linville and Catawba Basins of Lake James, NC

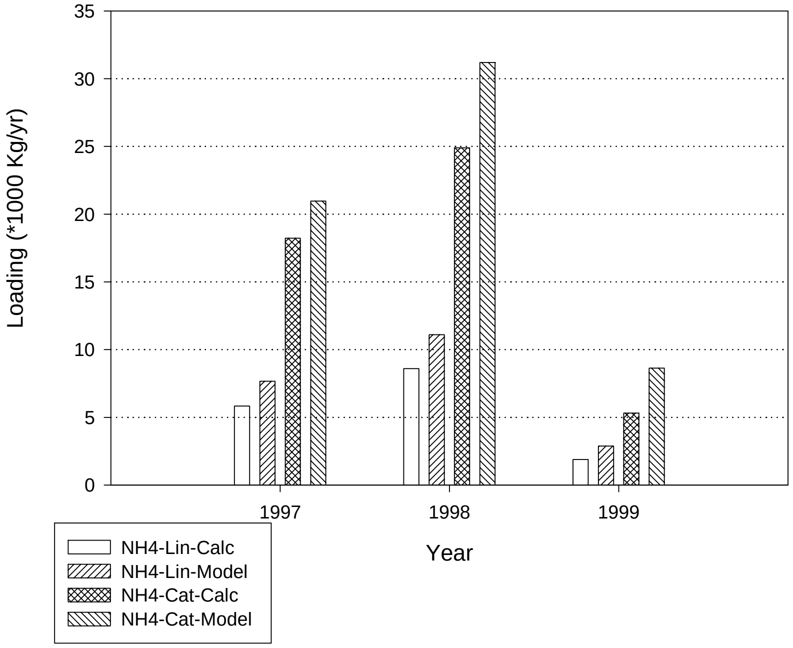


Figure C- 11 Average Annual Loading of Ammonia-N for the Linville and Catawba Basins of Lake James, NC

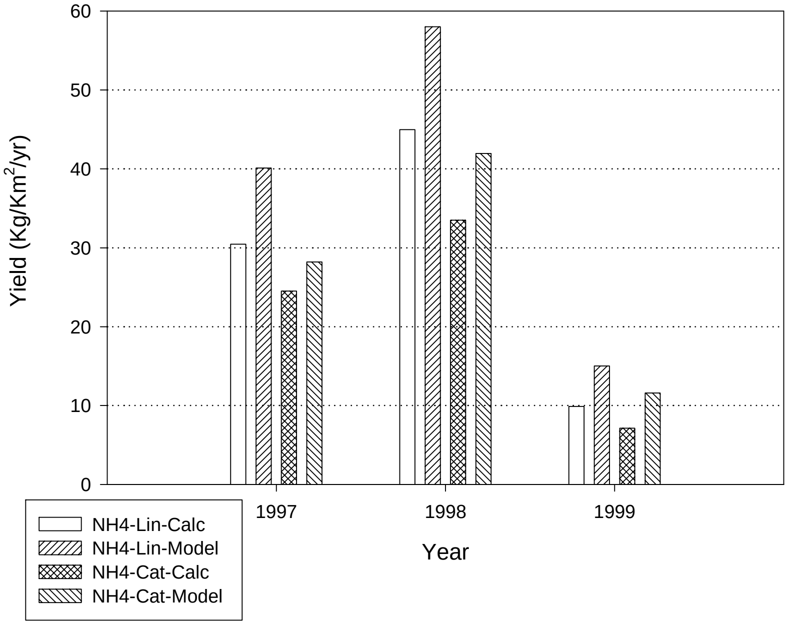


Figure C- 12 Average Annual Yield of Ammonia-N for the Linville and Catawba Basins of Lake James, NC

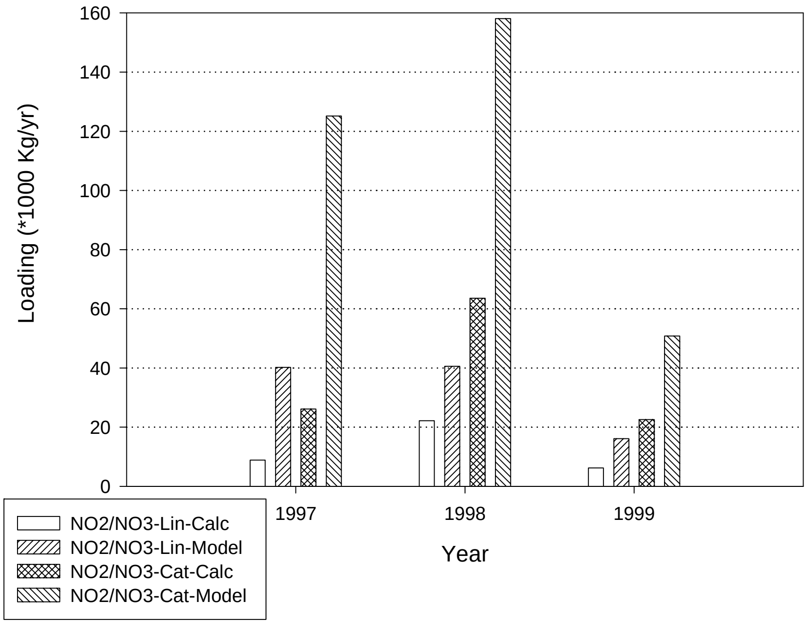


Figure C- 13 Average Annual Loading of Nitrate and nitrite-N for the Linville and Catawba Basins of Lake James, NC

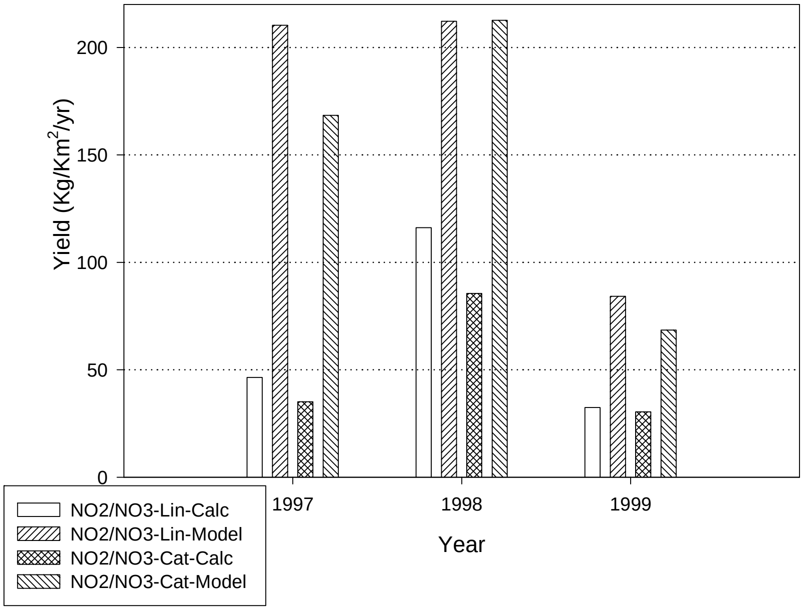


Figure C- 14 Average Annual Yield of Nitrate and nitrite-N for the Linville and Catawba Basins of Lake James, NC

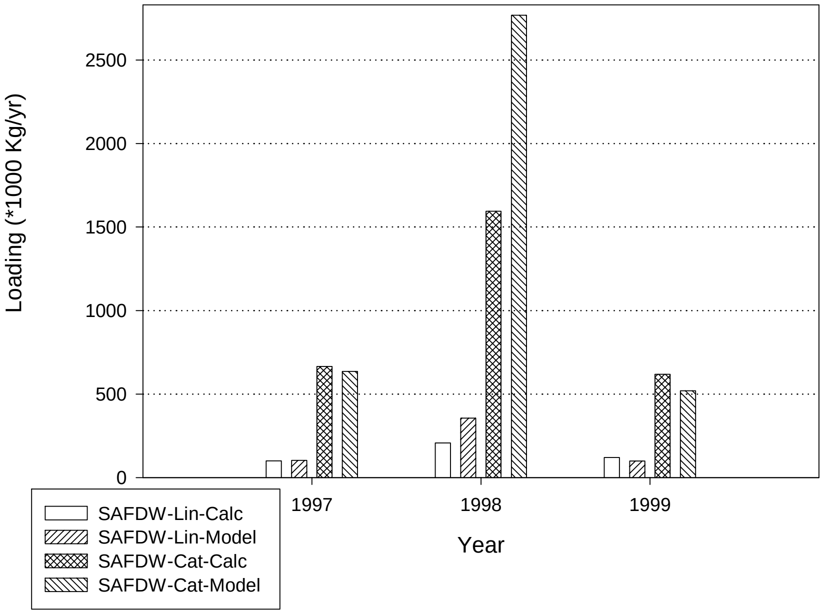


Figure C- 15 Average Annual Loading of Seston-ash free dry weight for the Linville and Catawba Basins of Lake James, NC

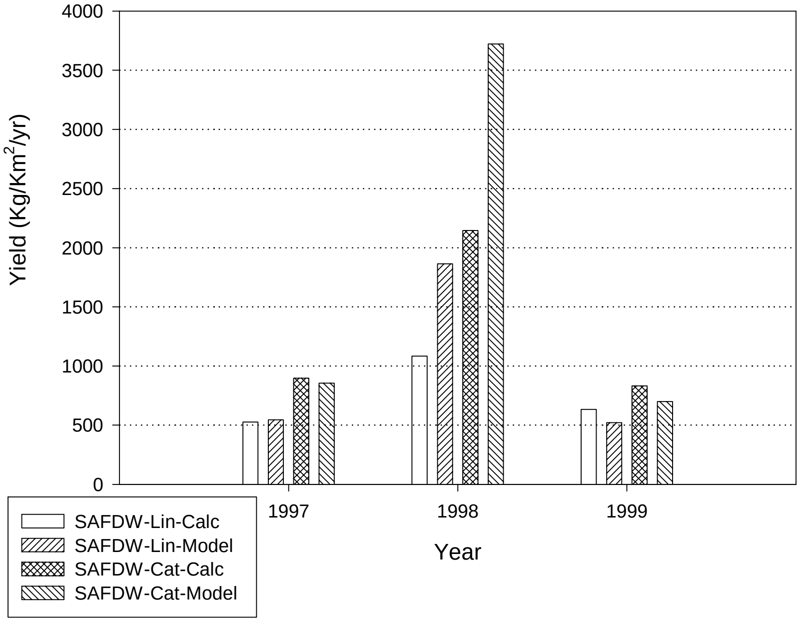


Figure C- 16 Average Annual Yield of Seston-ash free dry weight for the Linville and Catawba Basins of Lake James, NC

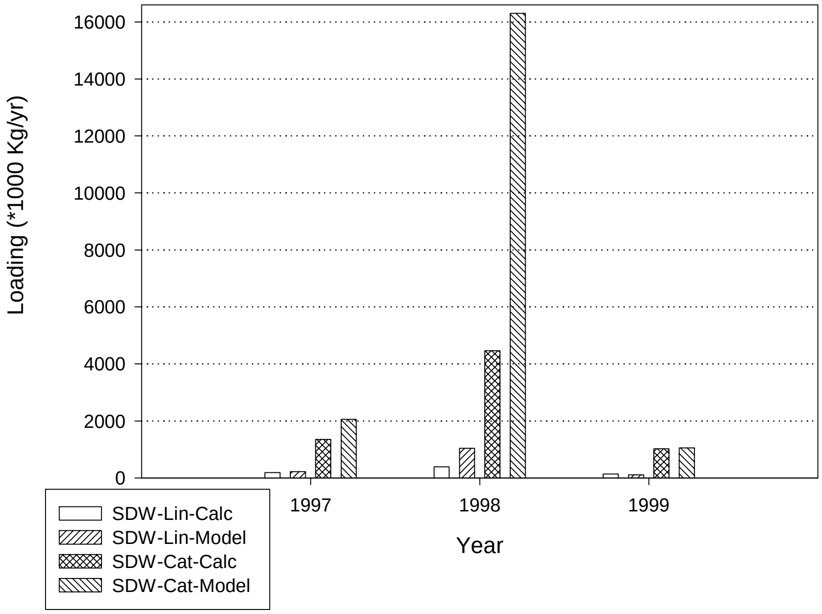


Figure C- 17 Average Annual Loading of Seston dry weight for the Linville and Catawba Basins of Lake James, NC

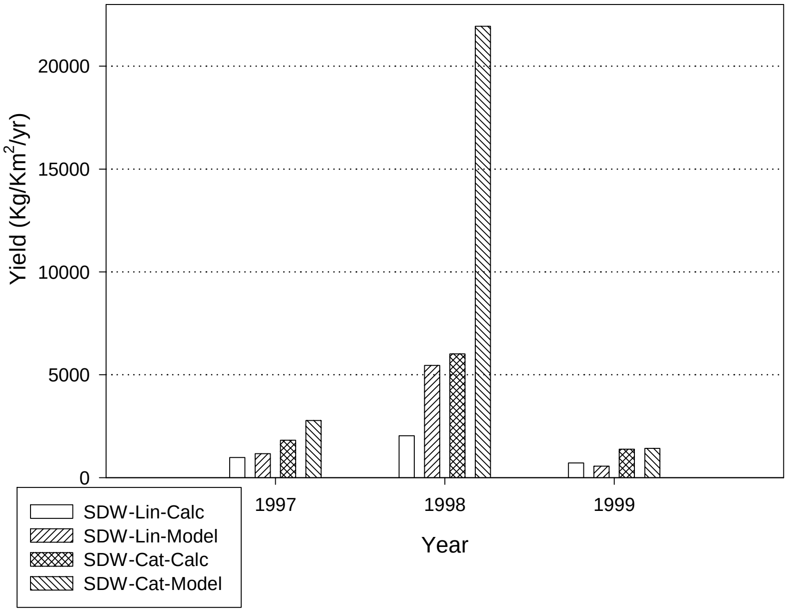


Figure C- 18 Average Annual Yield of Seston dry weight for the Linville and Catawba Basins of Lake James, NC

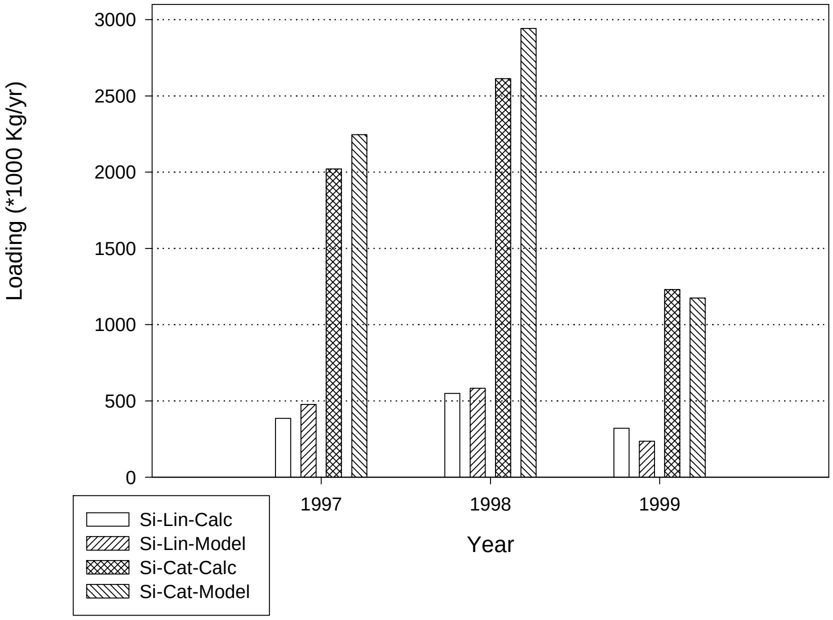


Figure C- 19 Average Annual Loading of Silica for the Linville and Catawba Basins of Lake James, NC

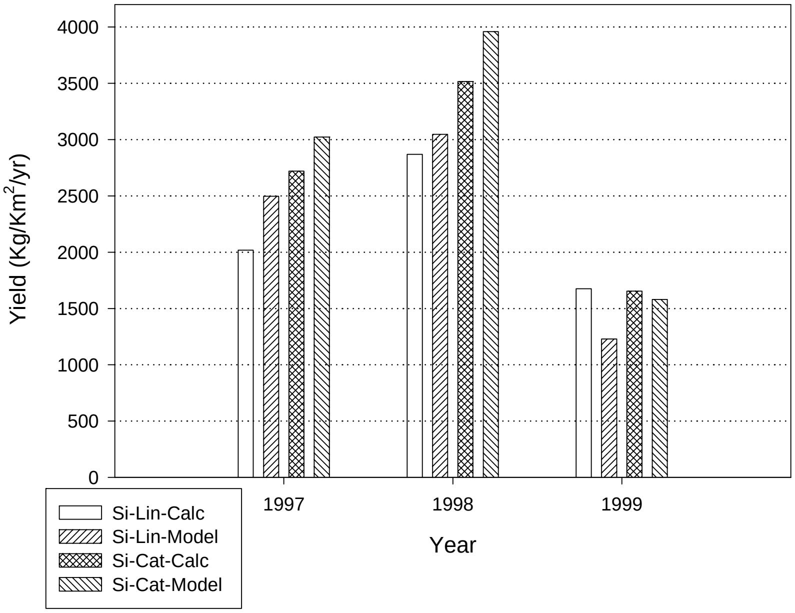


Figure C- 20 Average Annual Yield of Silica for the Linville and Catawba Basins of Lake James, NC

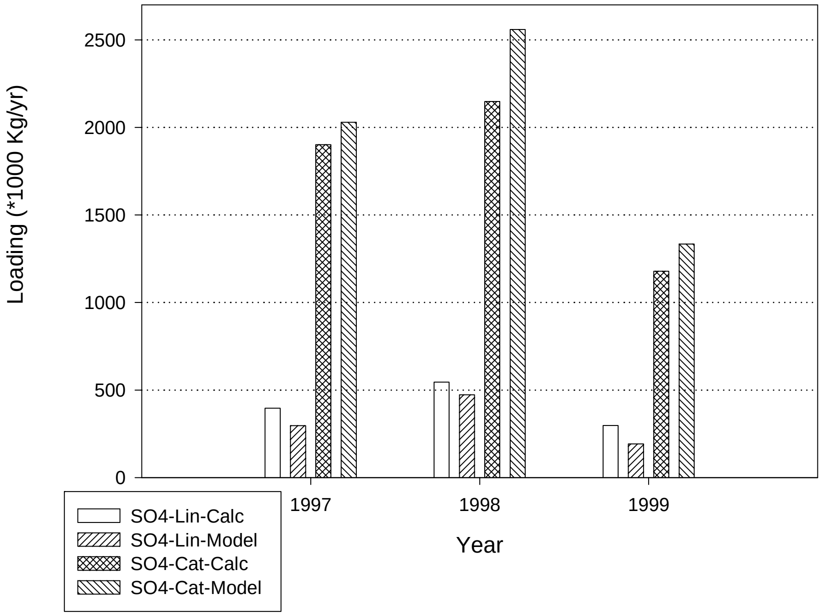


Figure C- 21 Average Annual Loading of Sulfate for the Linville and Catawba Basins of Lake James, NC

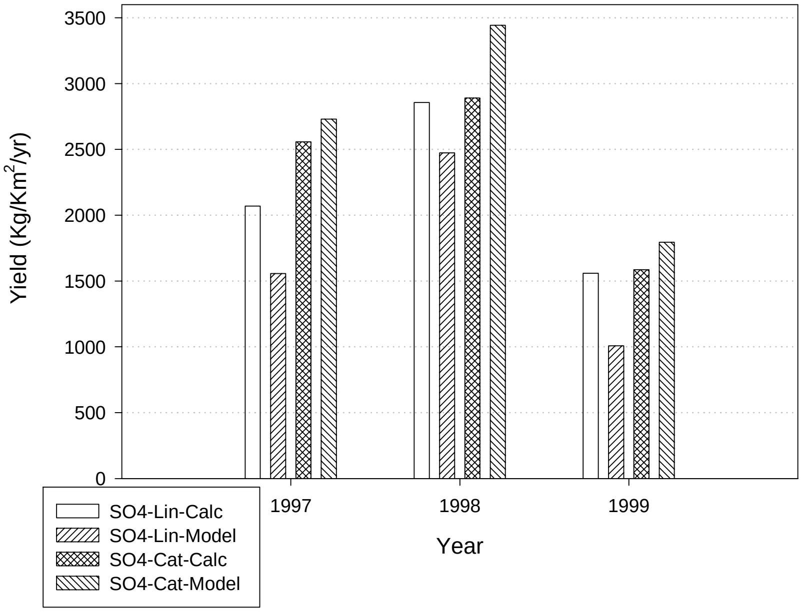


Figure C- 22 Average Annual Yield of Sulfate for the Linville and Catawba Basins of Lake James, NC

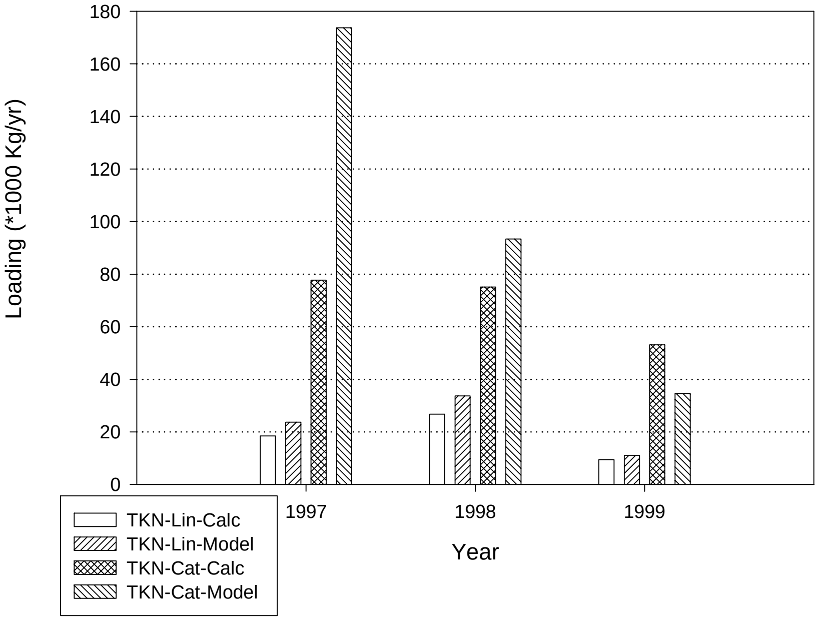


Figure C- 23 Average Annual Loading of Total Kjeldahl nitrogen for the Linville and Catawba Basins of Lake James, NC

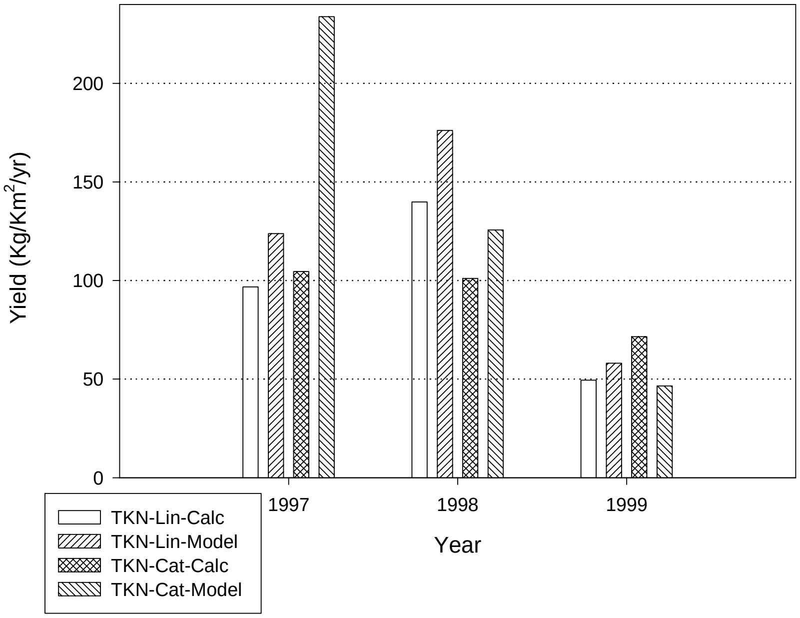


Figure C- 24 Average Annual Yield of Total Kjeldahl nitrogen for the Linville and Catawba Basins of Lake James, NC

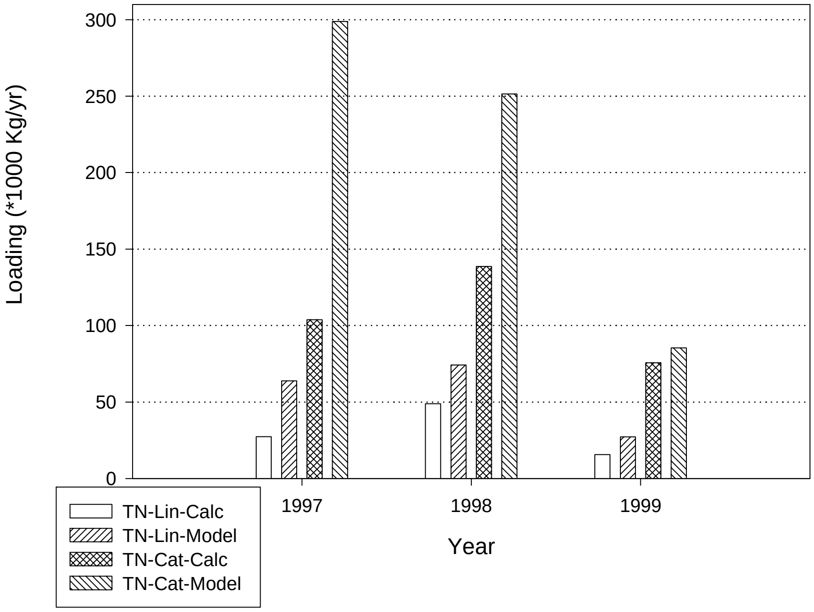


Figure C- 25 Average Annual Loading of Total nitrogen for the Linville and Catawba Basins of Lake James, NC

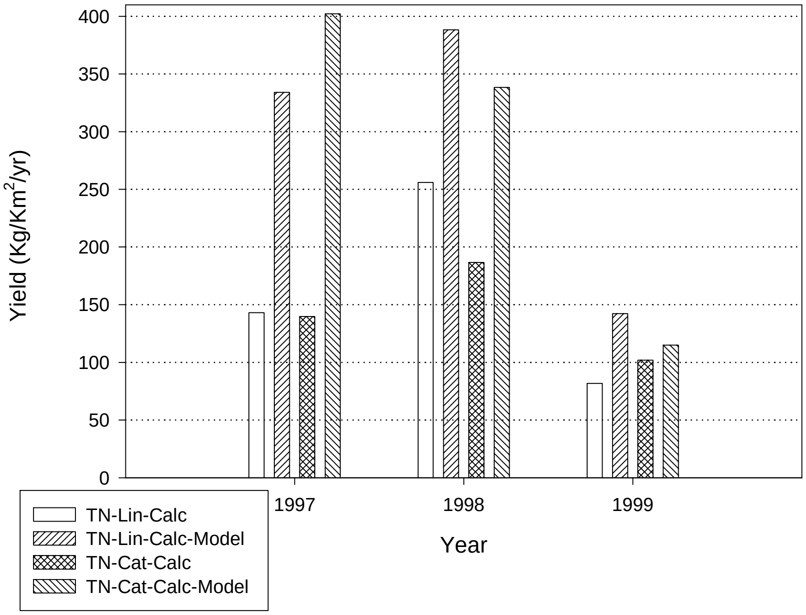


Figure C- 26 Average Annual Yield of Total nitrogen for the Linville and Catawba Basins of Lake James, NC

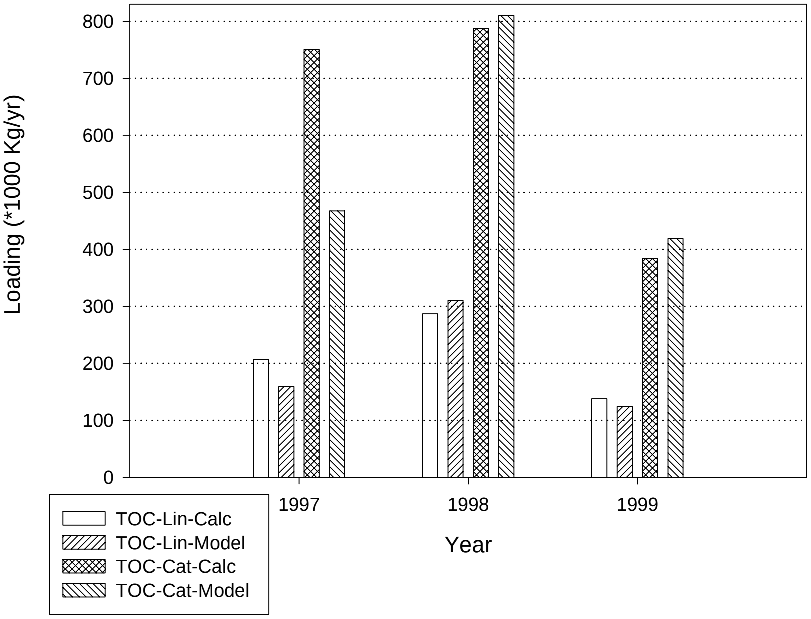


Figure C- 27 Average Annual Loading of Total organic carbon for the Linville and Catawba Basins of Lake James, NC

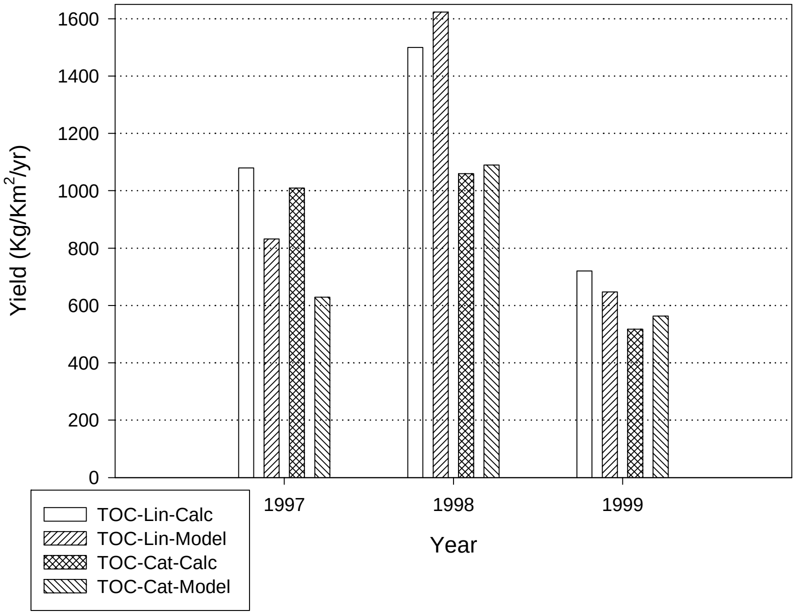


Figure C- 28 Average Annual Yield of Total organic carbon for the Linville and Catawba Basins of Lake James, NC

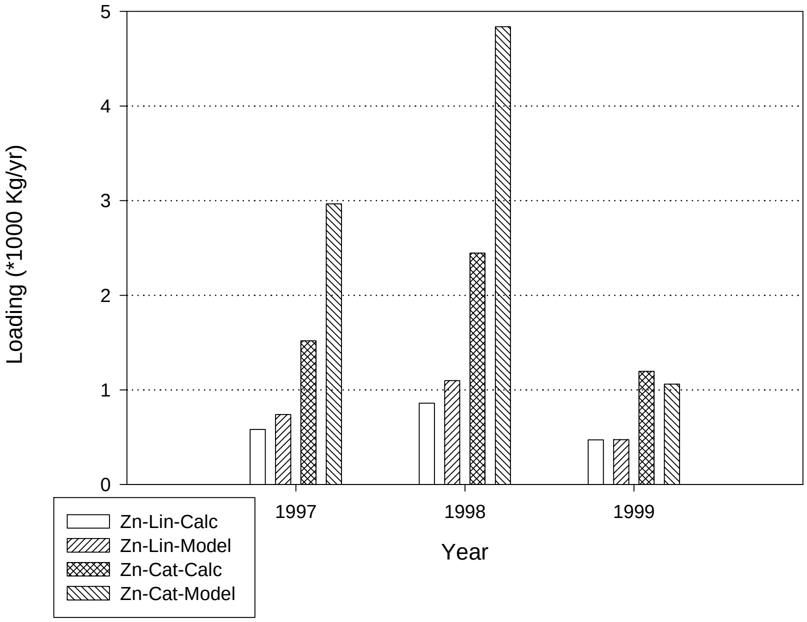


Figure C- 29 Average Annual Loading of Zinc for the Linville and Catawba Basins of Lake James, NC

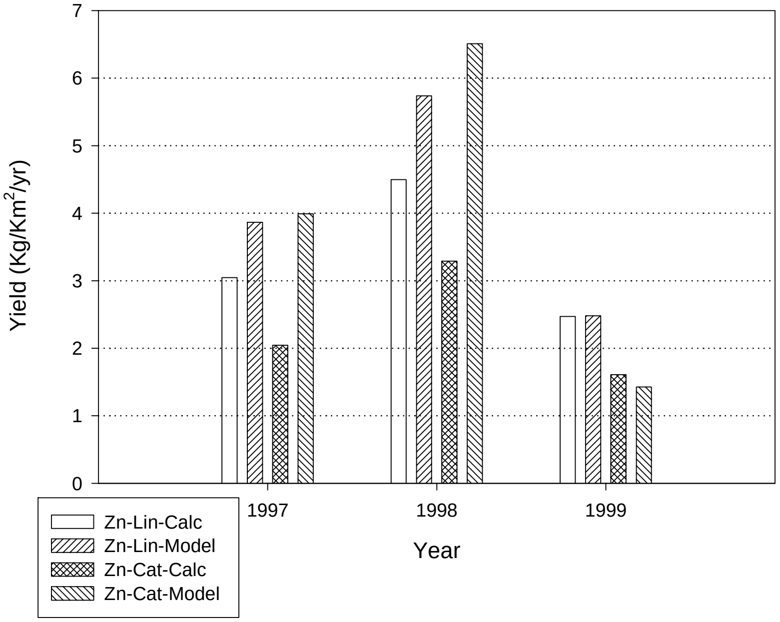
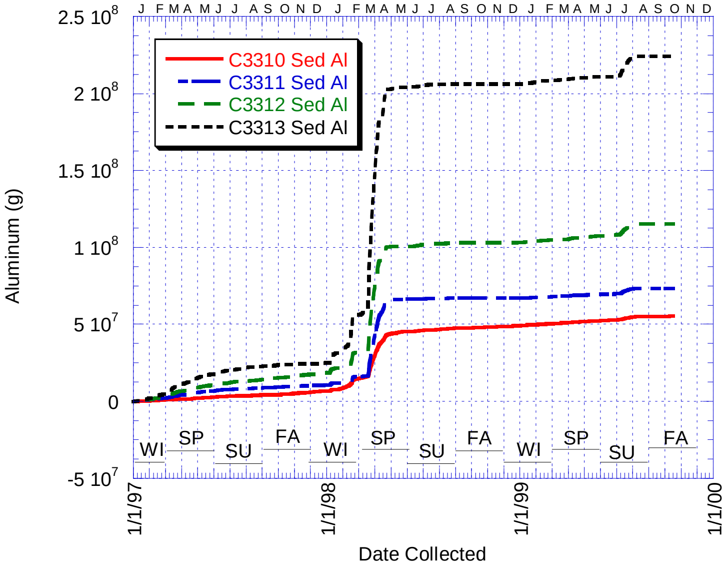


Figure C- 30 Average Annual Yield of Zinc for the Linville and Catawba Basins of Lake James, NC

APPENDIX D

LJA Model basin Sedimentation

Lake James 1997-1999
Catawba Basin
Aluminum assimilation derived from LJA Model



Lake James 1997-1999
Linville Basin
Aluminum assimilation derived from LJA Model

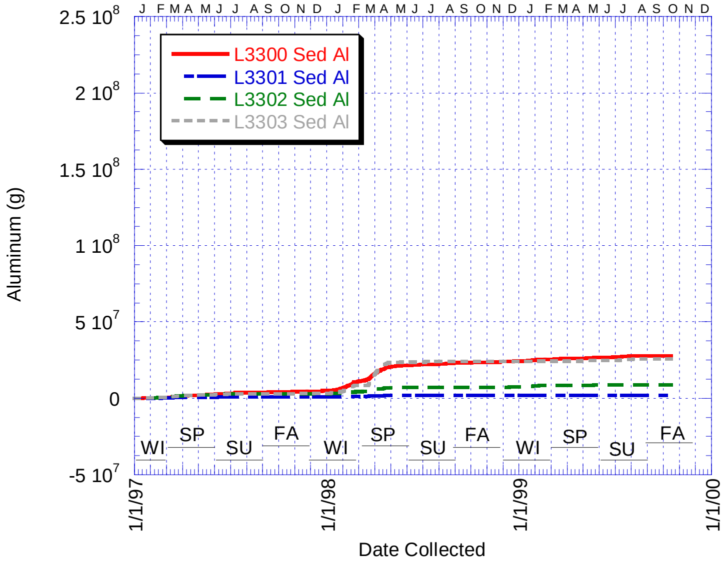


Figure D- 1 LJA Model assimilation/sedimentation of aluminum loading by longitudinal station for the Linville basin within Lake James.

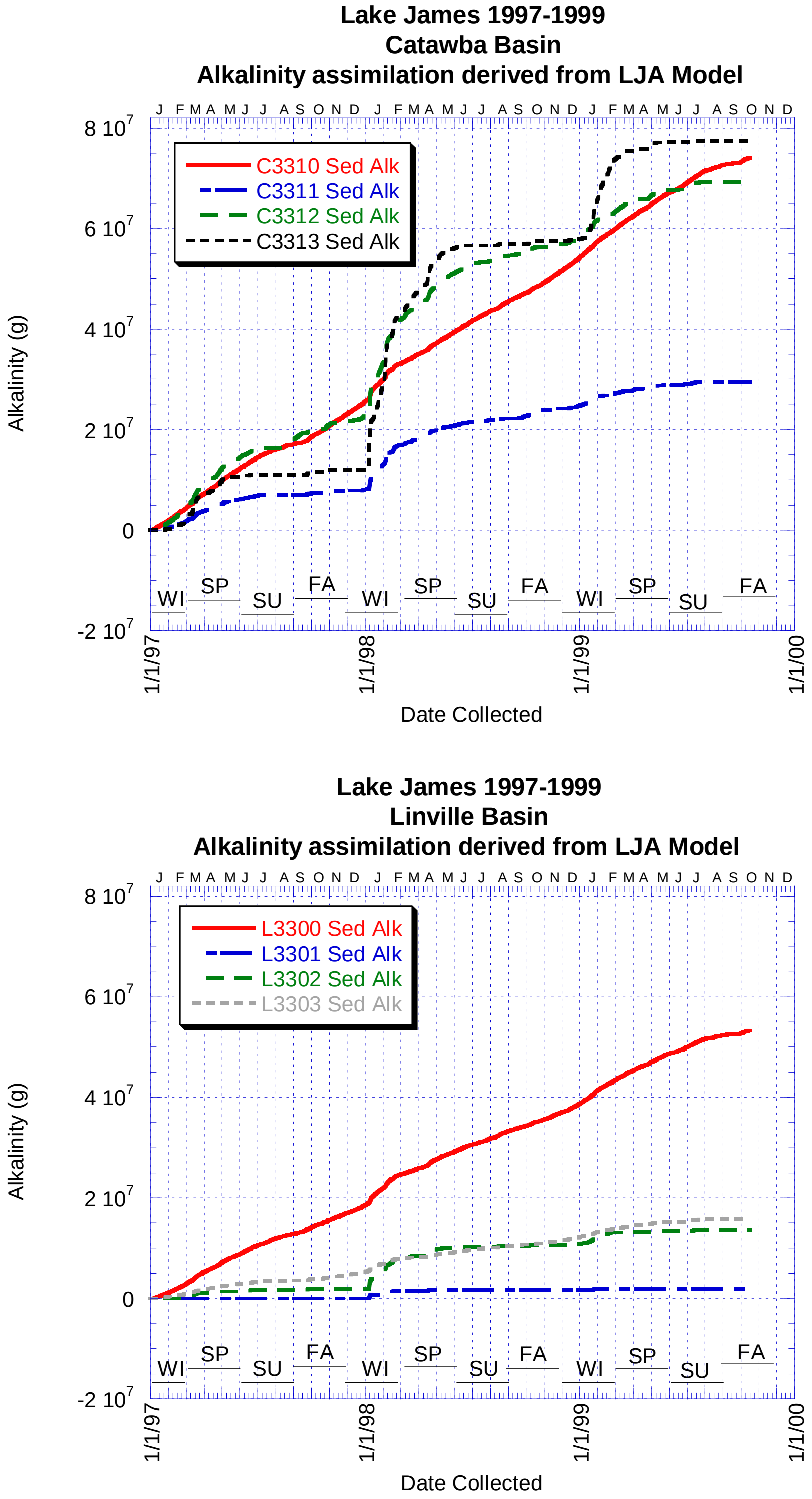
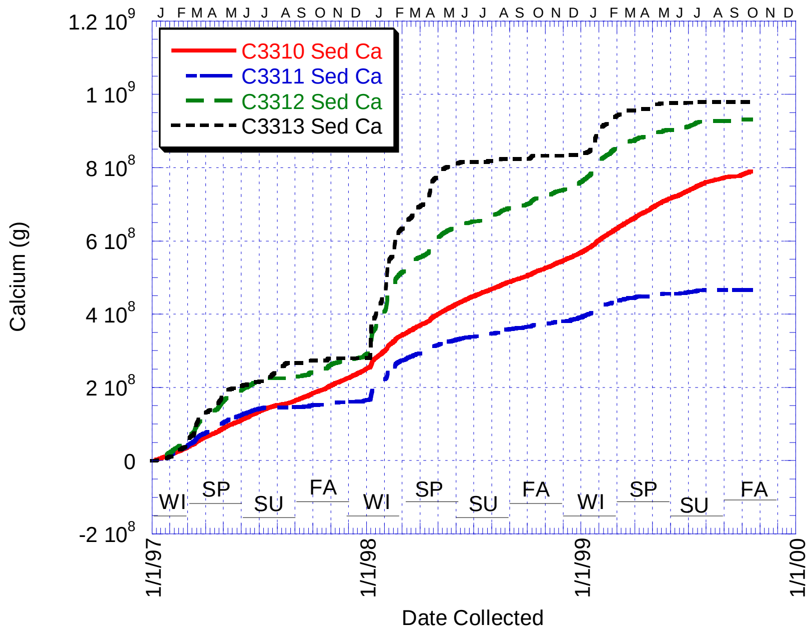


Figure D- 2 LJA Model assimilation/sedimentation of alkalinity loading by longitudinal station for the Linville and Catawba basins within Lake James.

Lake James 1997-1999
Catawba Basin
Calcium assimilation derived from LJA Model



Lake James 1997-1999
Linville Basin
Calcium assimilation derived from LJA Model

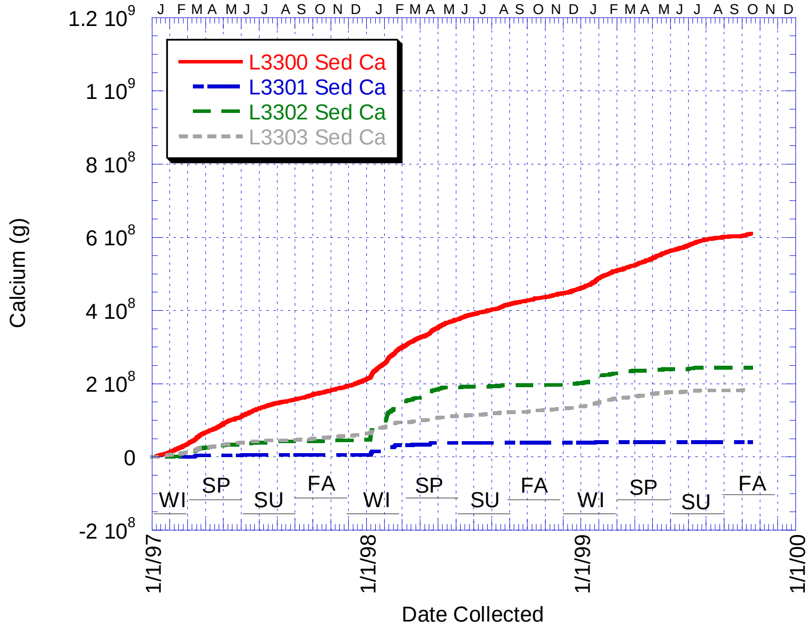
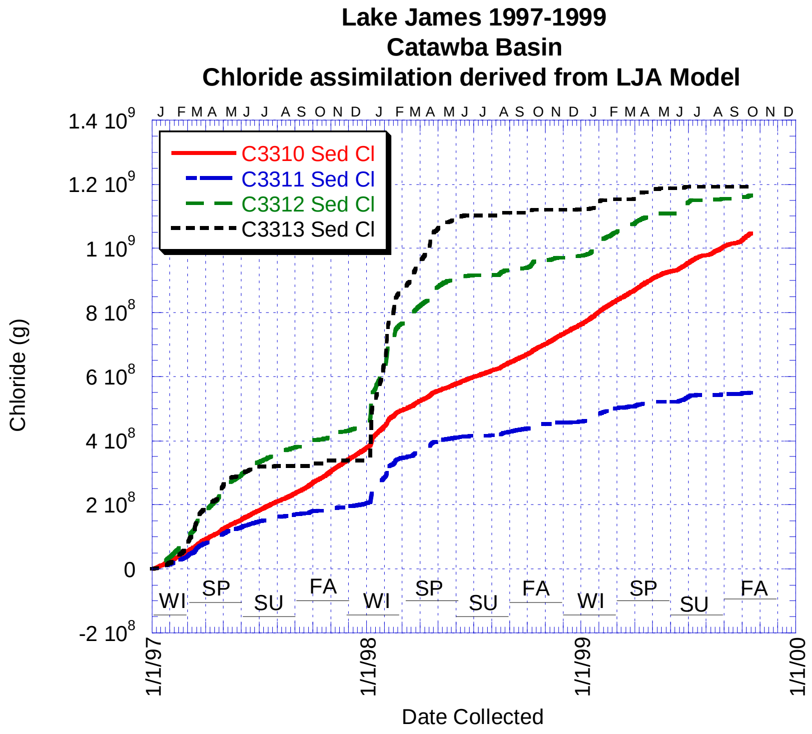
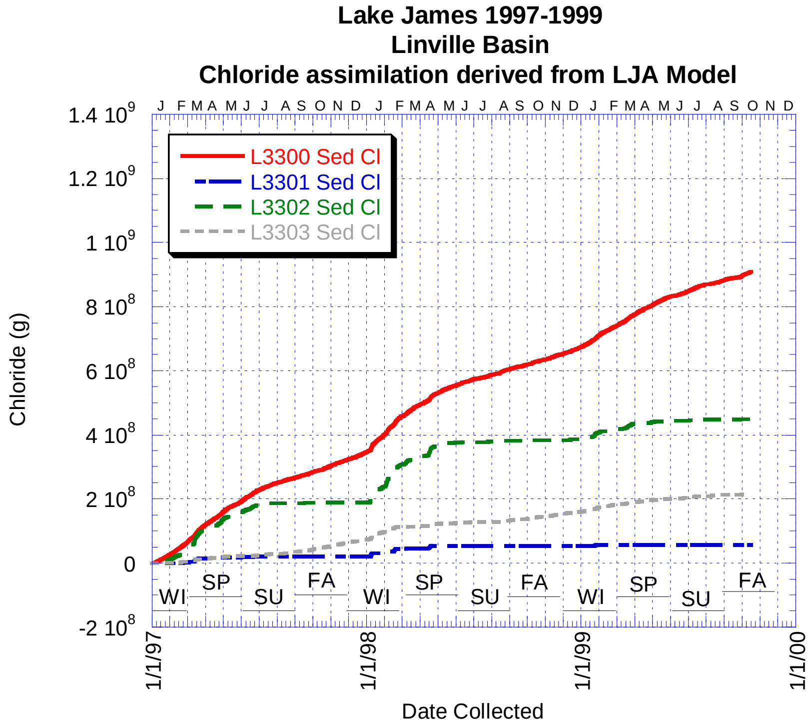


Figure D- 3 LJA Model assimilation/sedimentation of calcium loading by longitudinal station for the Linville and Catawba basins within Lake James.

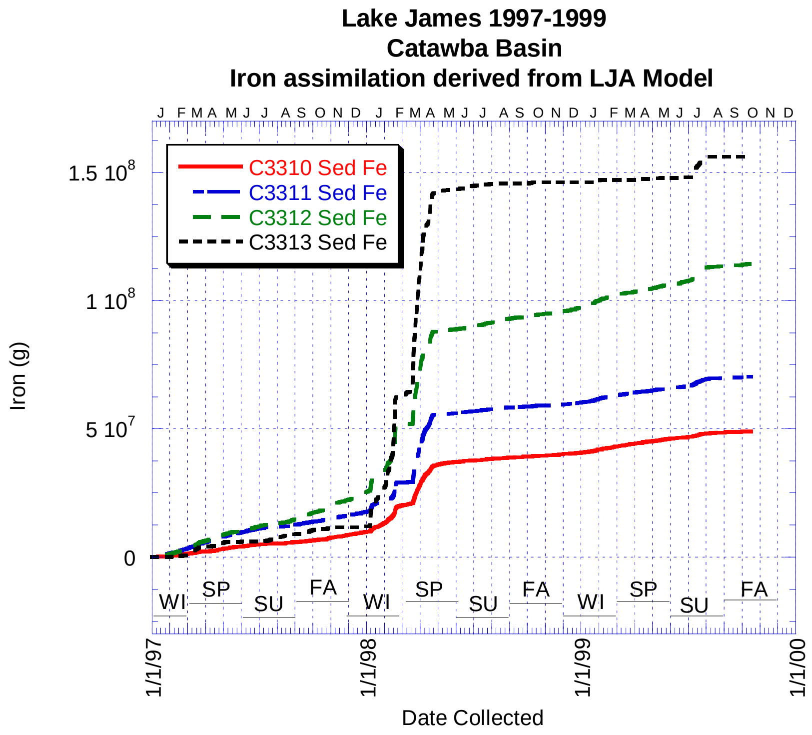


Lake James 1997-1999
Catawba Basin
Chloride assimilation derived from LJA Model



Lake James 1997-1999
Linville Basin
Chloride assimilation derived from LJA Model

Figure D- 4 LJA Model assimilation/sedimentation of chloride loading by longitudinal station for the Linville and Catawba basins within Lake James.



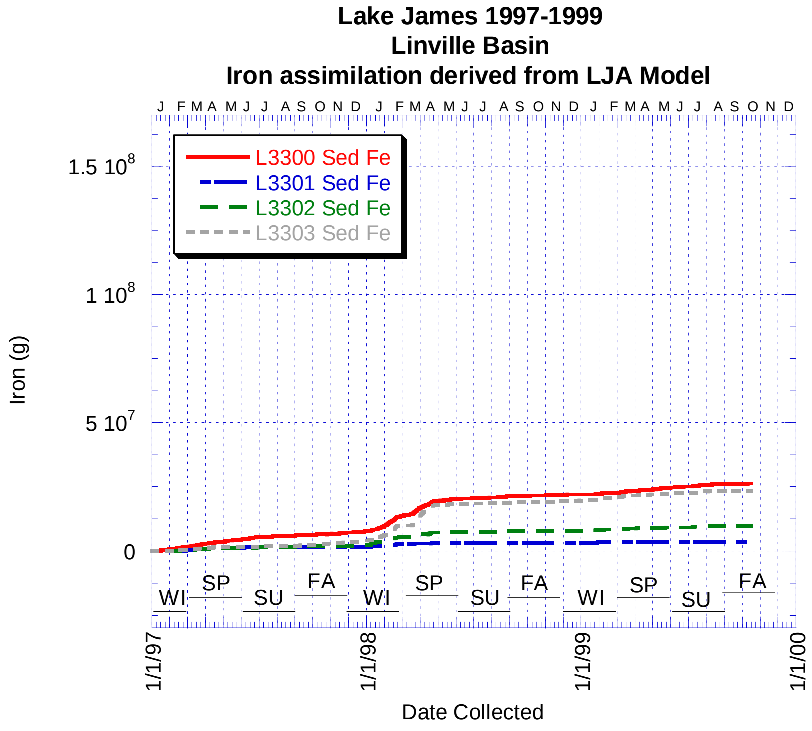


Figure D- 5 LJA Model assimilation/sedimentation of iron loading by longitudinal station for the Linville and Catawba basins within Lake James.

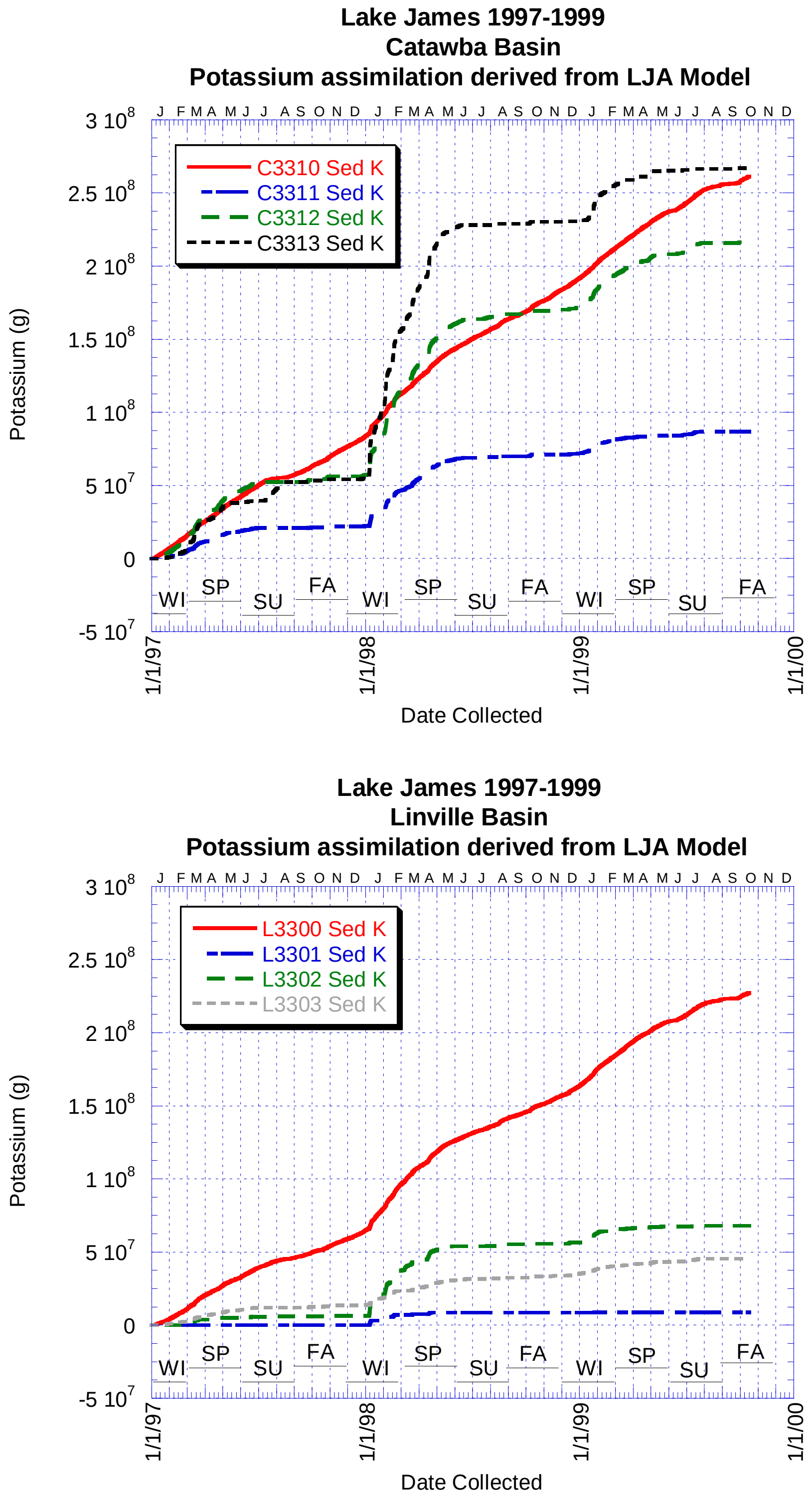
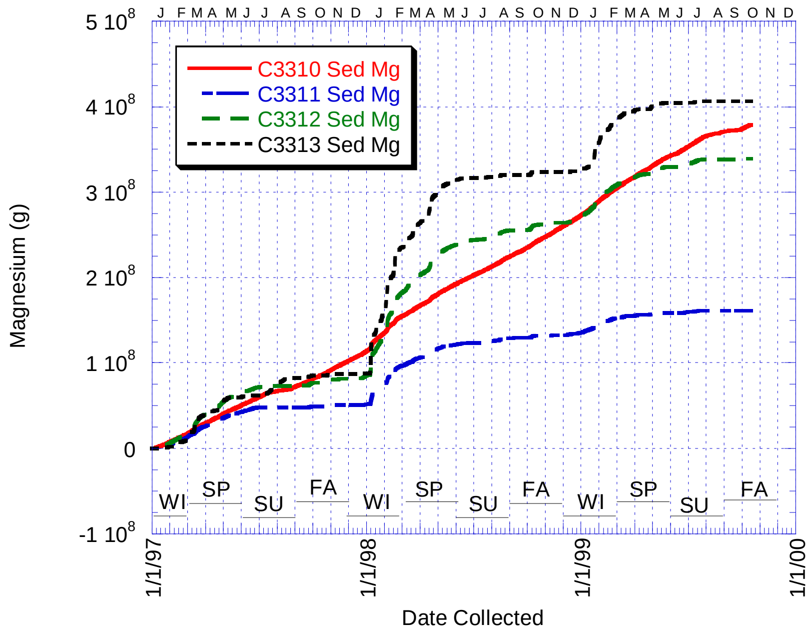


Figure D- 6 LJA Model assimilation/sedimentation of potassium loading by longitudinal station for the Linville and Catawba basins within Lake James.

Lake James 1997-1999
Catawba Basin
Magnesium assimilation derived from LJA Model



Lake James 1997-1999
Linville Basin
Magnesium assimilation derived from LJA Model

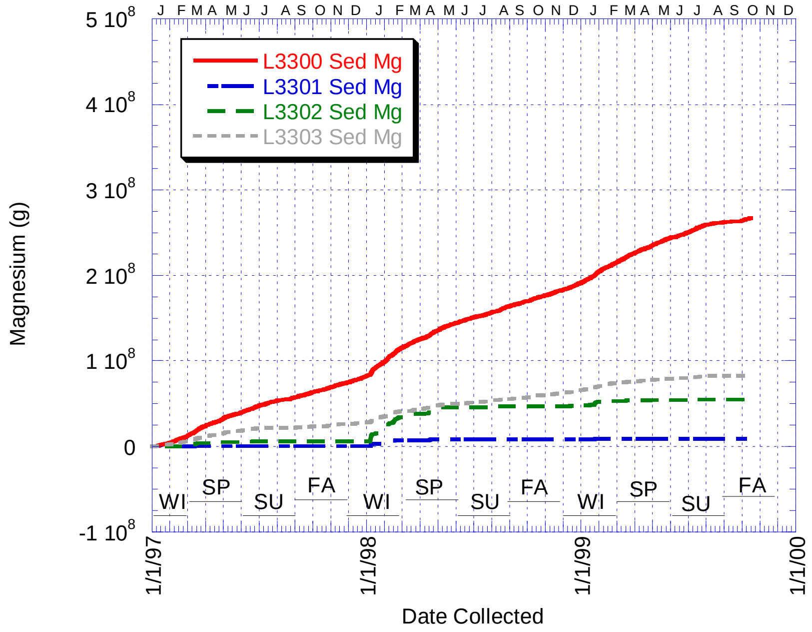
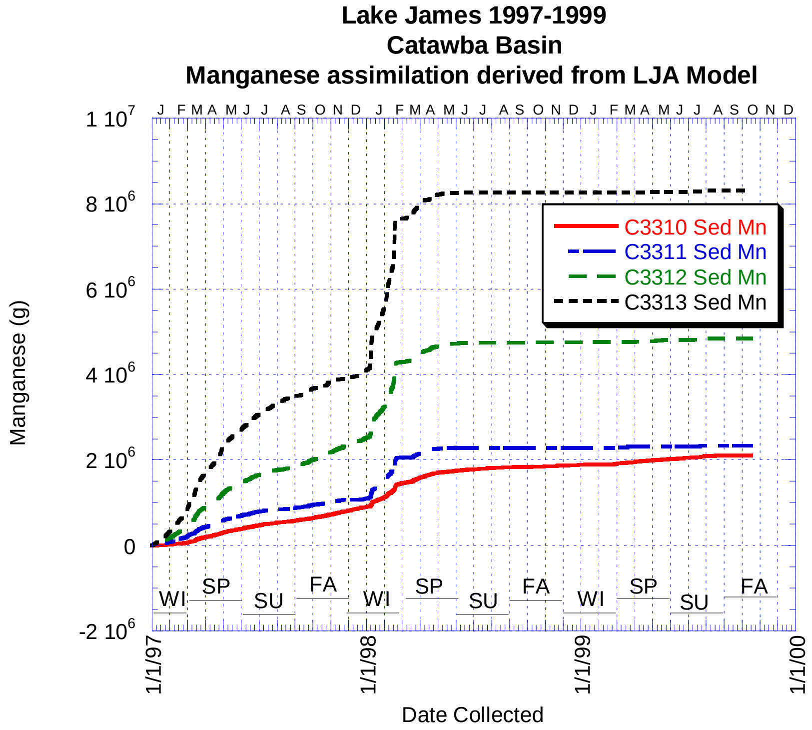
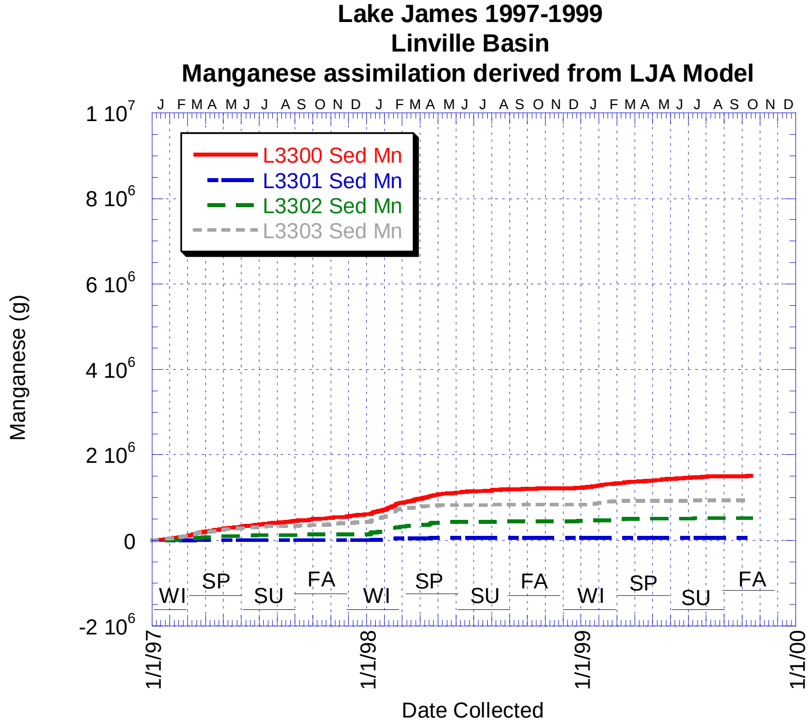


Figure D- 7 LJA Model assimilation/sedimentation of magnesium loading by longitudinal station for the Linville and Catawba basins within Lake James.



Lake James 1997-1999
Catawba Basin
Manganese assimilation derived from LJA Model



Lake James 1997-1999
Linville Basin
Manganese assimilation derived from LJA Model

Figure D- 8 LJA Model assimilation/sedimentation of manganese loading by longitudinal station for the Linville and Catawba basins within Lake James.

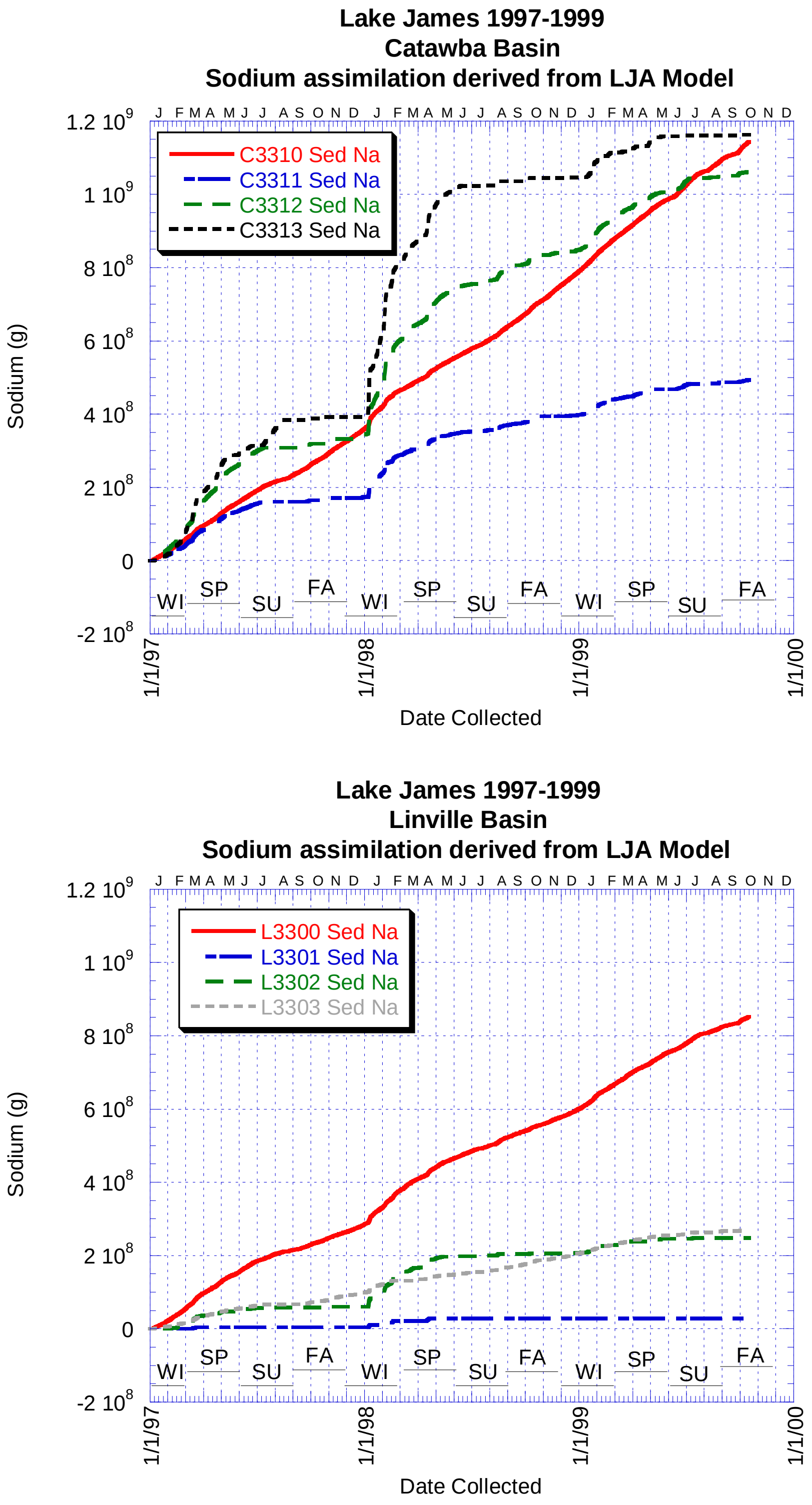
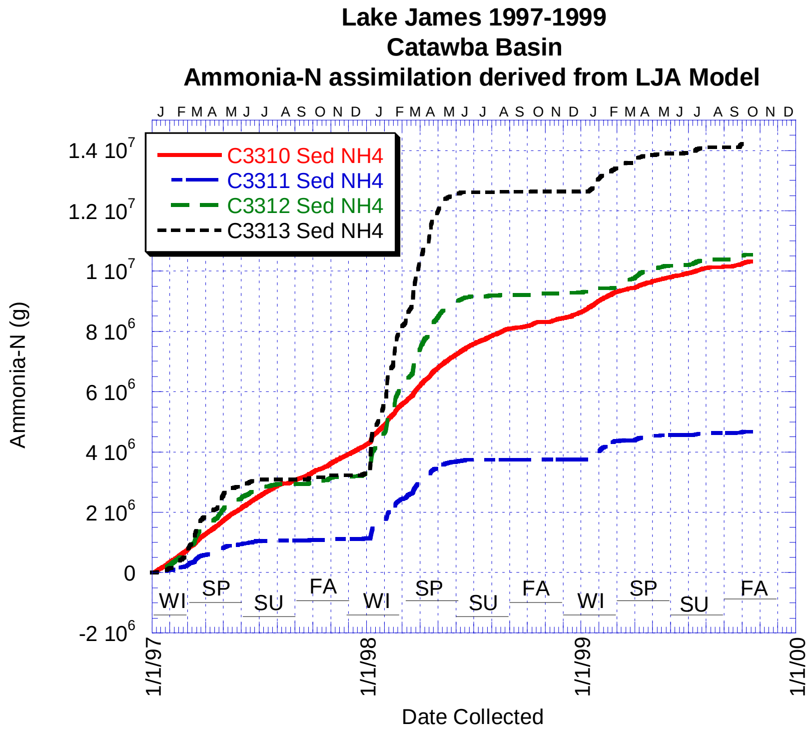


Figure D- 9 LJA Model assimilation/sedimentation of sodium loading by longitudinal station for the Linville and Catawba basins within Lake James.



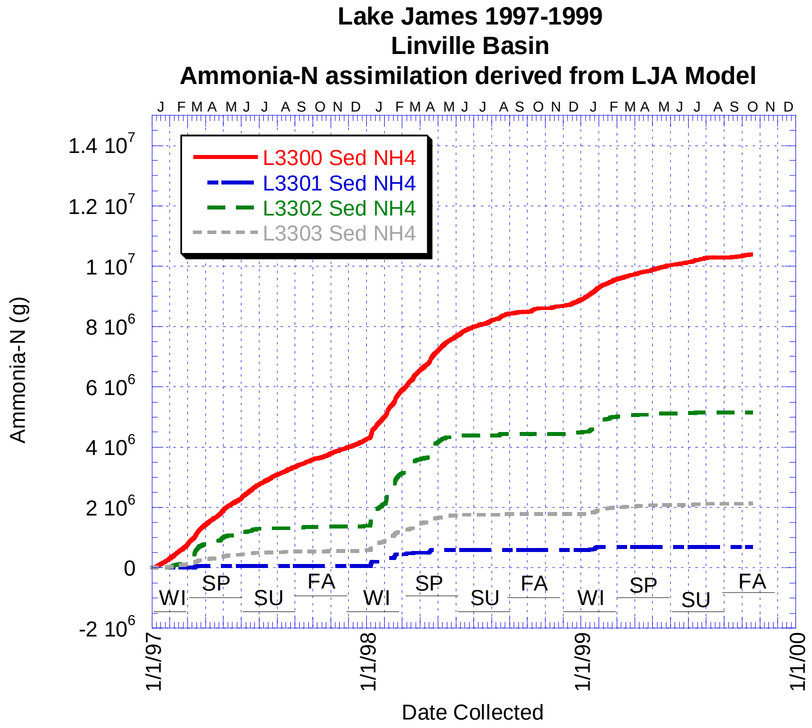
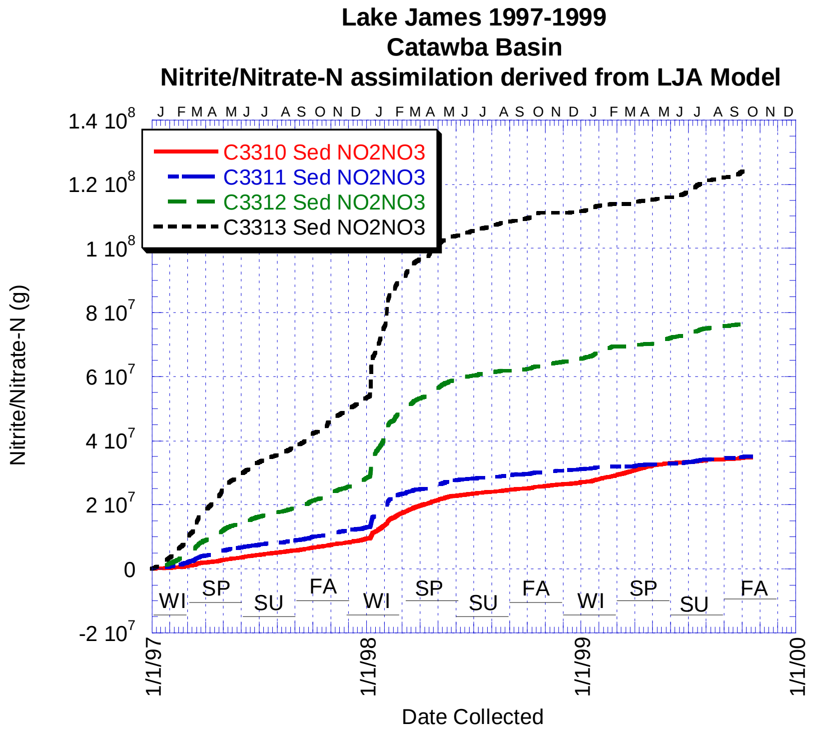


Figure D- 10 LJA Model assimilation/sedimentation of ammonia-N loading by longitudinal station for the Linville and Catawba basins within Lake James.



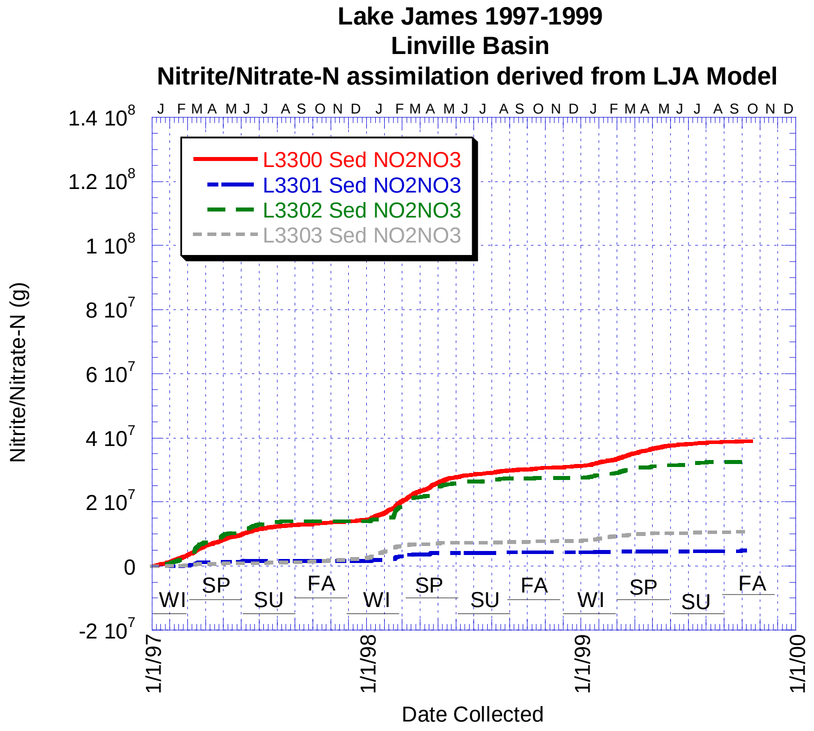


Figure D- 11 LJA Model assimilation/sedimentation of nitrate and nitrite-N loading by longitudinal station for the Linville and Catawba basins within Lake James.

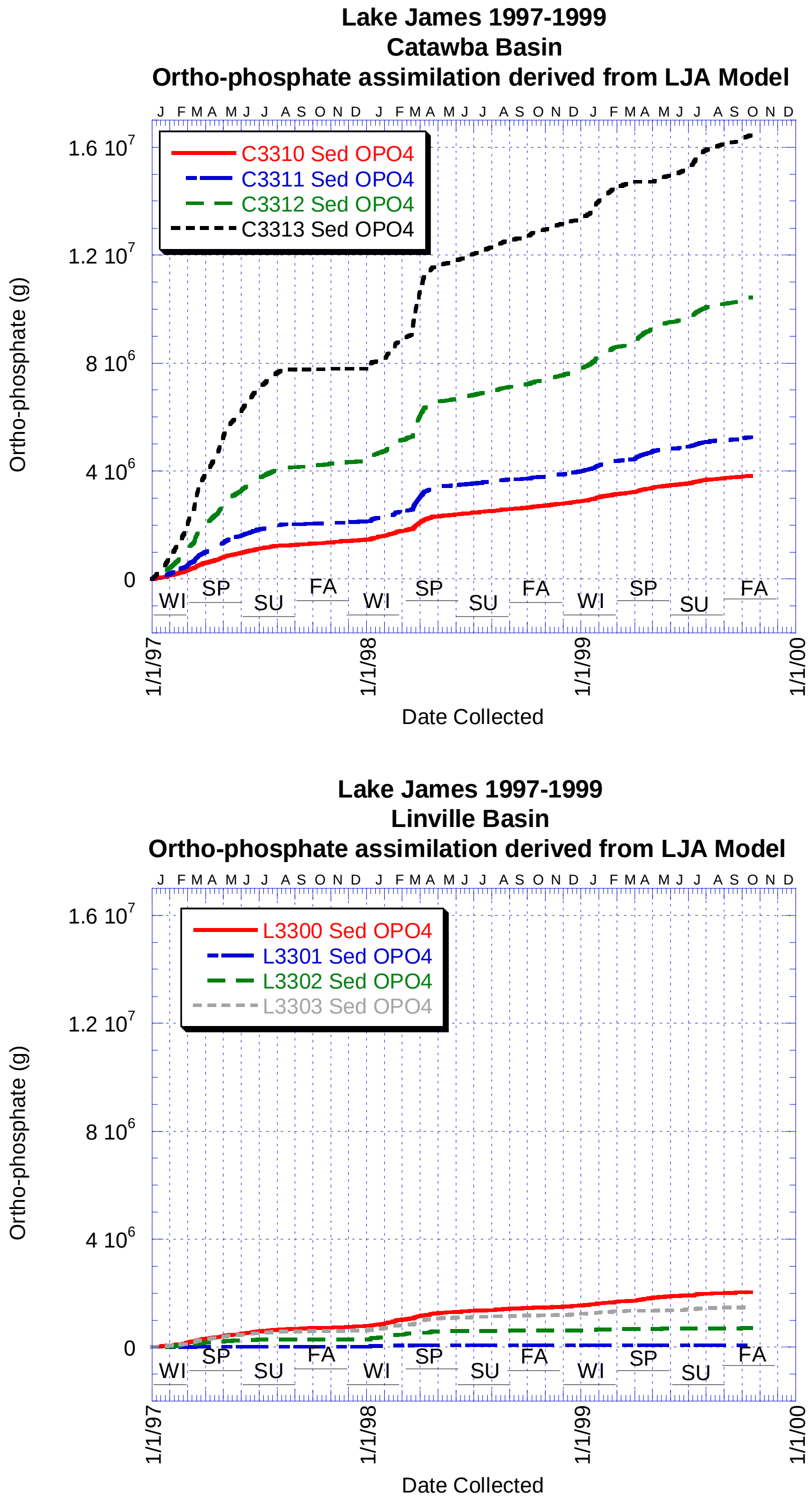
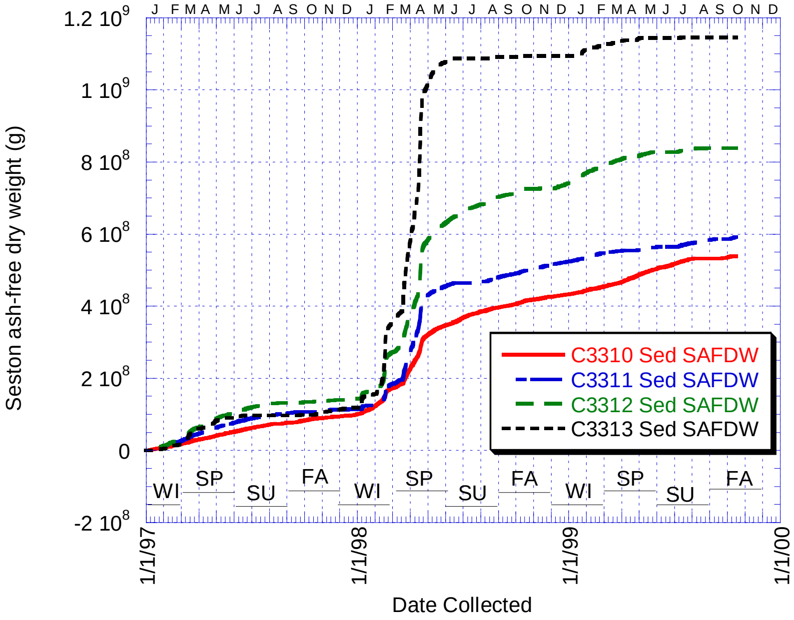
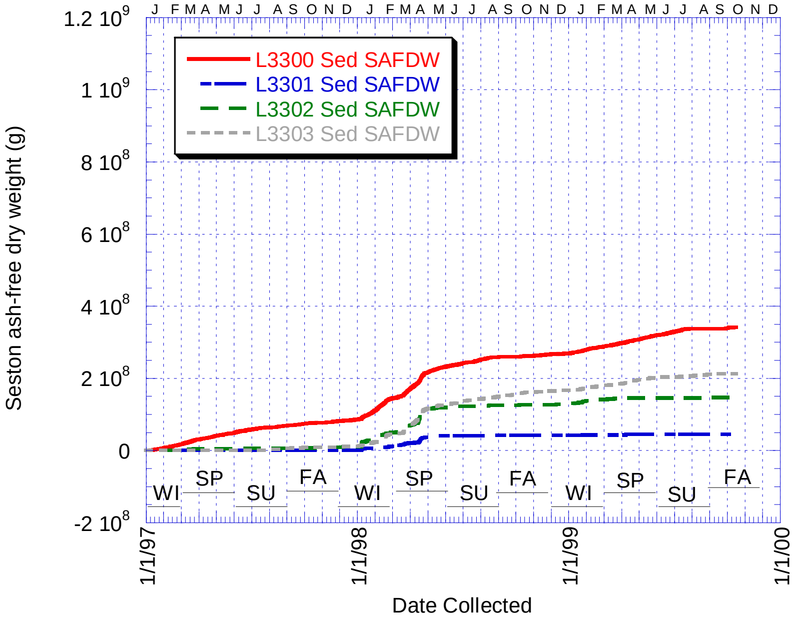


Figure D- 12 LJA Model assimilation/sedimentation of ortho-phosphate loading by longitudinal station for the Linville and Catawba basins within Lake James.

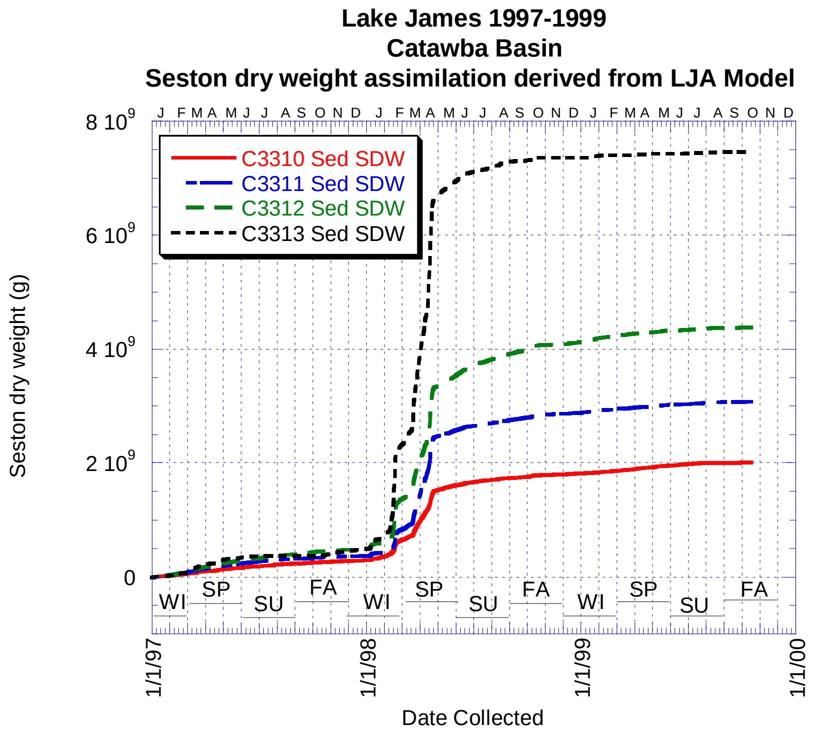


Lake James 1997-1999
Catawba Basin
Seston ash-free dry weight assimilation
derived from LJA Model



Lake James 1997-1999
Linville Basin
Seston ash-free dry weight assimilation
derived from LJA Model

Figure D- 13 LJA Model assimilation/sedimentation of seston-ash free dry weight loading by longitudinal station for the Linville and Catawba basins within Lake James.



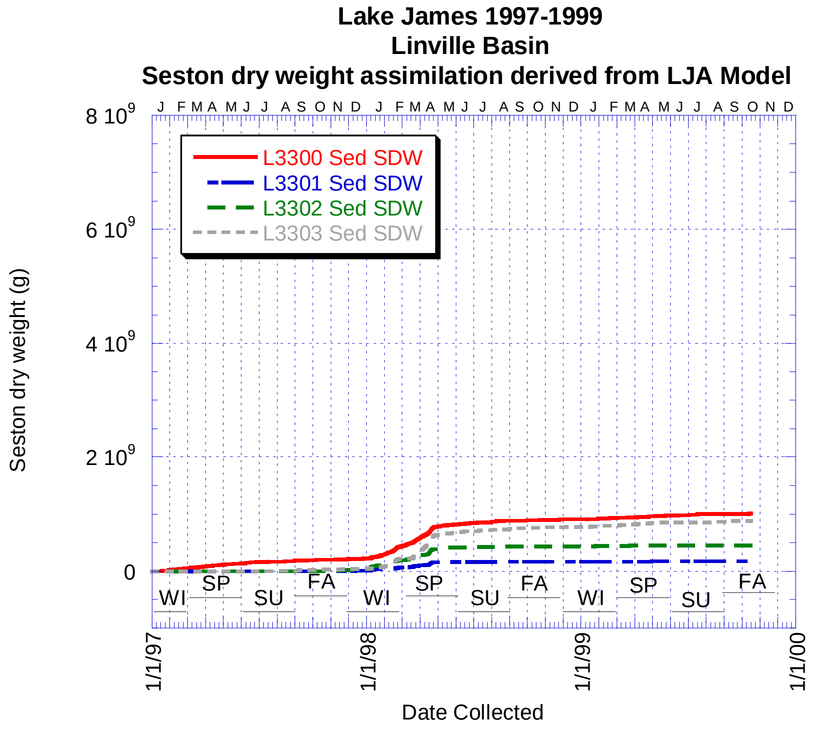
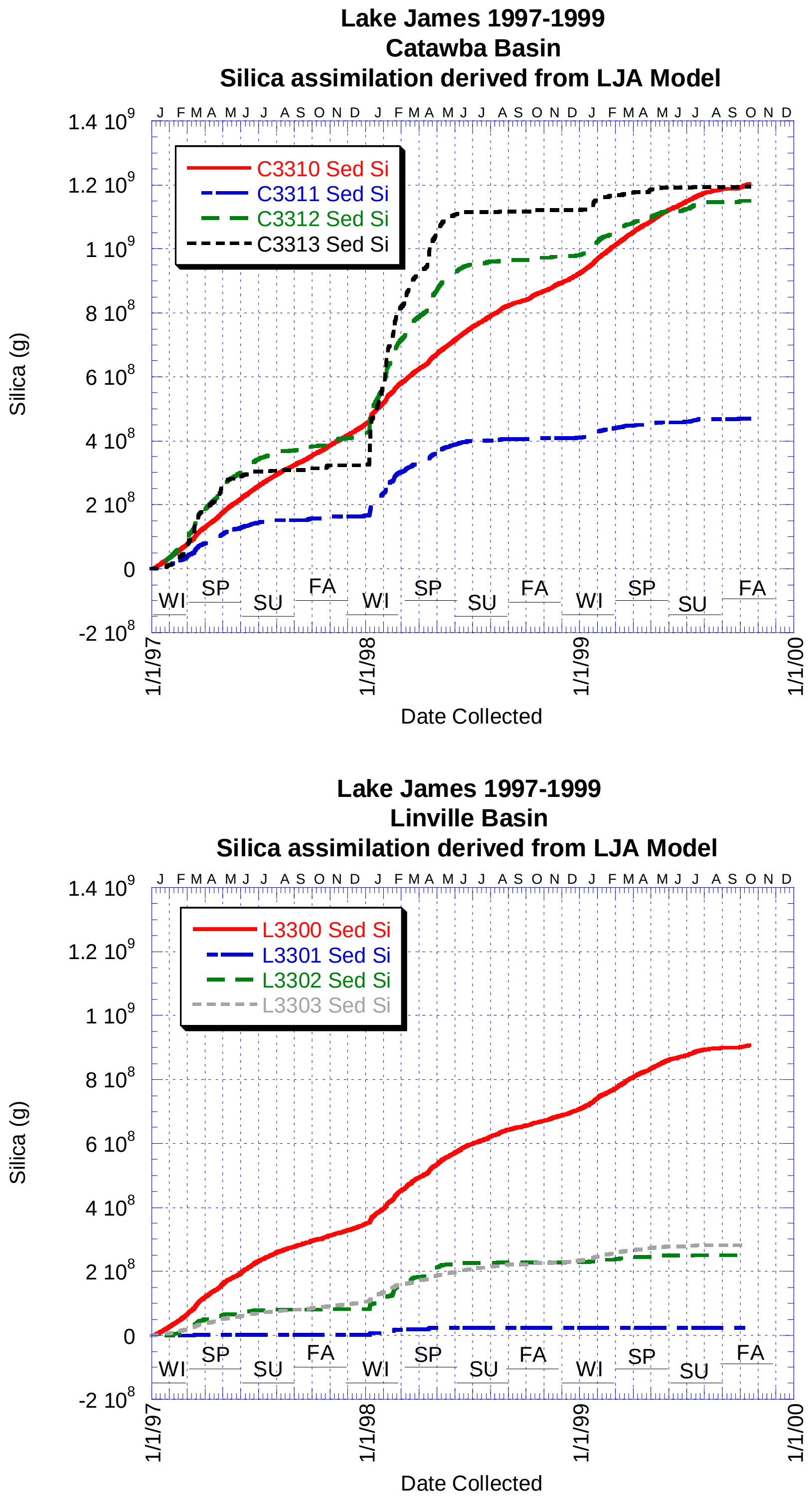


Figure D- 14 LJA Model assimilation/sedimentation of seston-dry weight loading by longitudinal station for the Linville and Catawba basins within Lake James.


Lake James 1997-1999
Catawba Basin
Silica assimilation derived from LJA Model

Lake James 1997-1999
Linville Basin
Silica assimilation derived from LJA Model

Figure D- 15 LJA Model assimilation/sedimentation of silica loading by longitudinal station for the Linville and Catawba basins within Lake James.

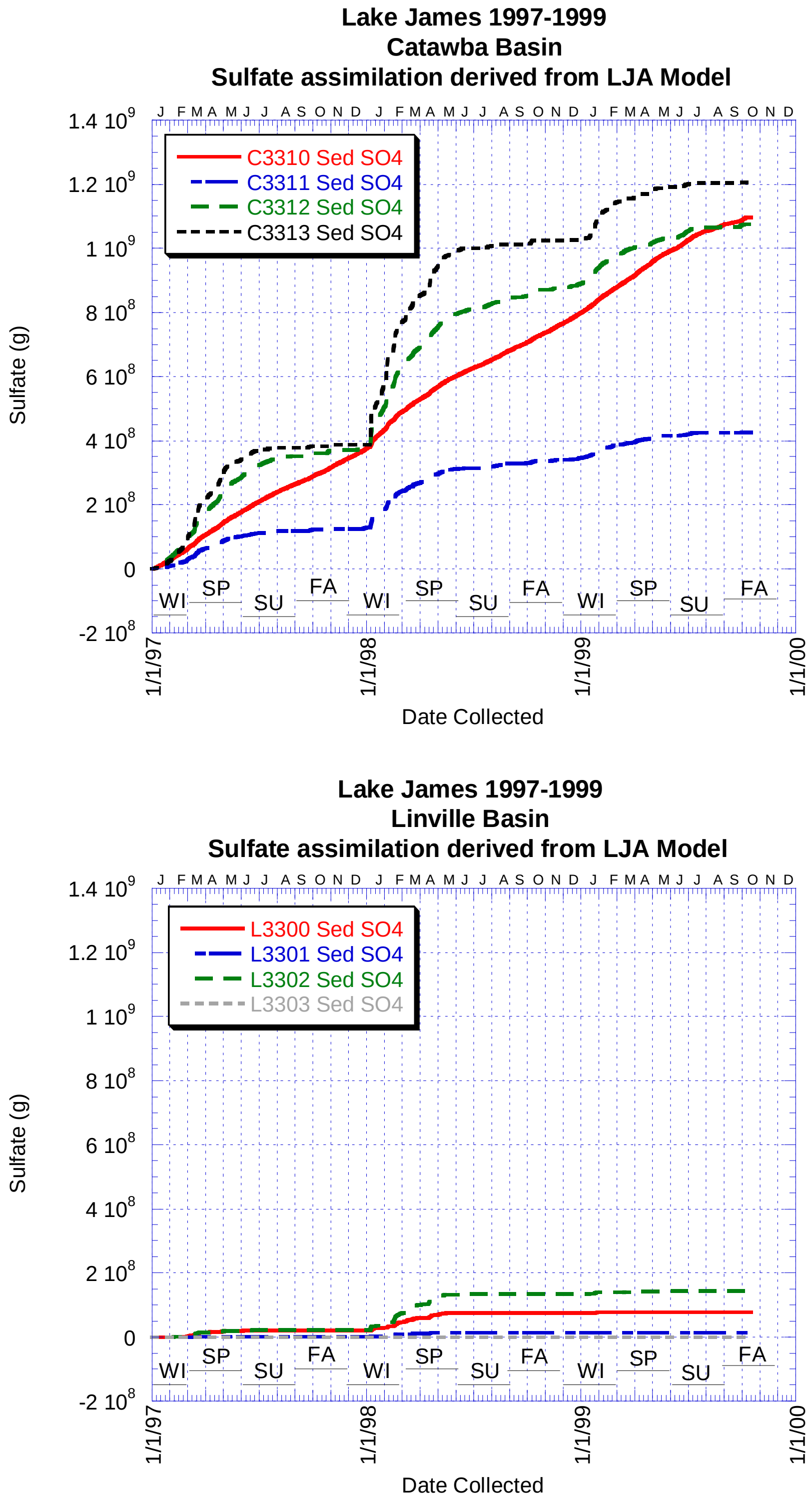


Figure D- 16 LJA Model assimilation/sedimentation of sulfate loading by longitudinal station for the Linville and Catawba basins within Lake James.

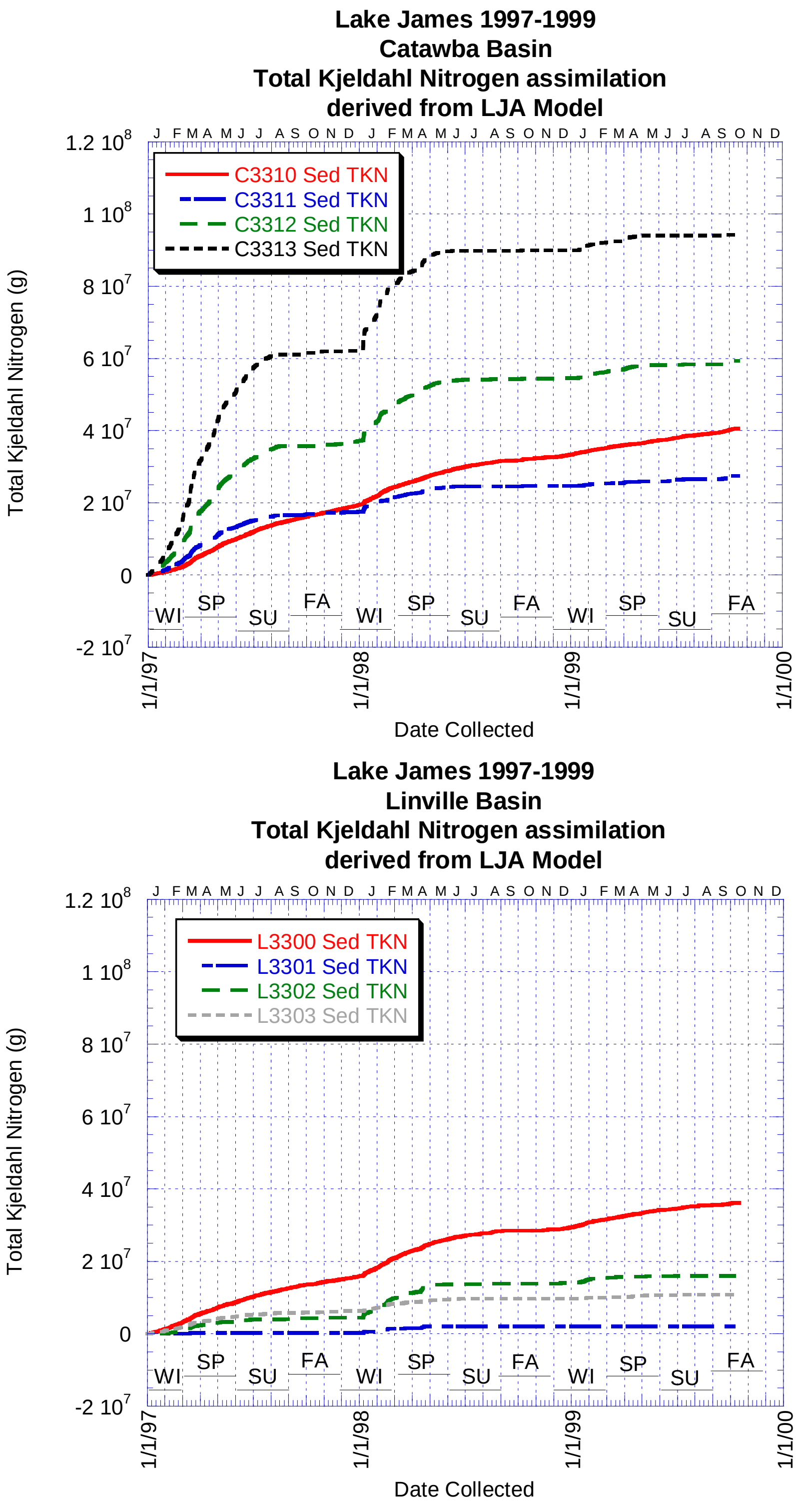


Figure D- 17 LJA Model assimilation/sedimentation of total Kjeldahl nitrogen loading by longitudinal station for the Linville and Catawba basins within Lake James.

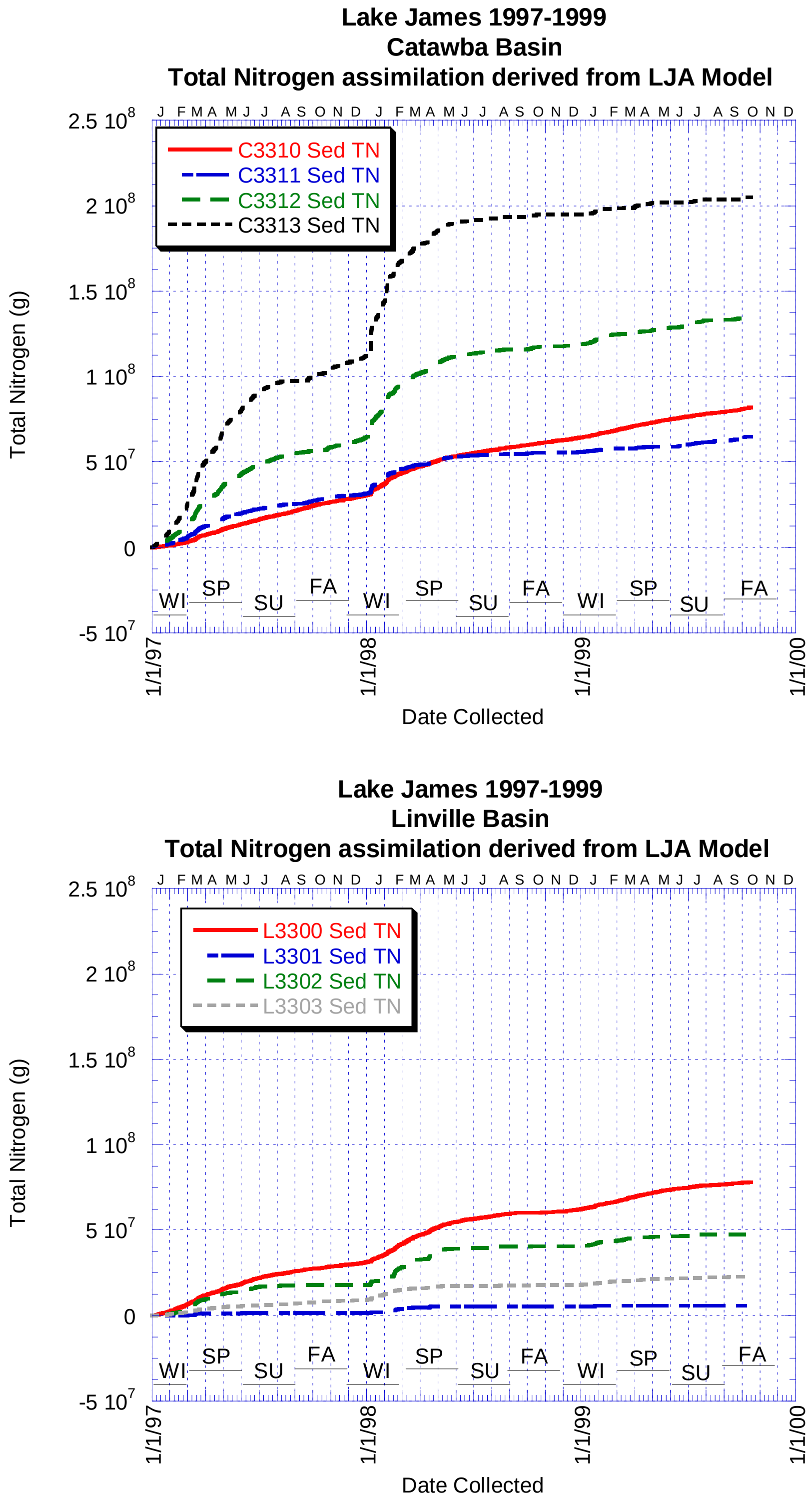
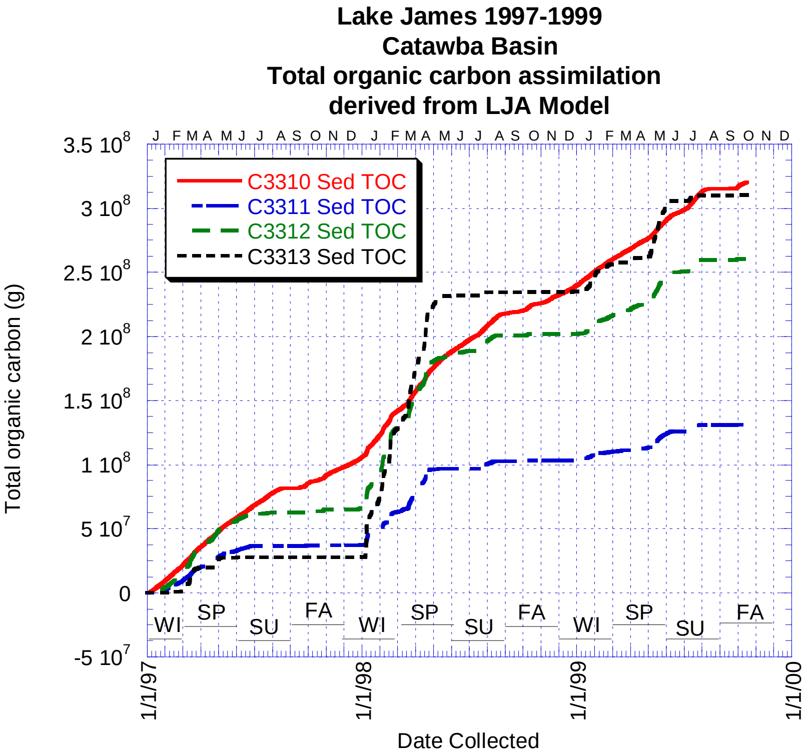


Figure D- 18 LJA Model assimilation/sedimentation of total nitrogen loading by longitudinal station for the Linville and Catawba basins within Lake James.



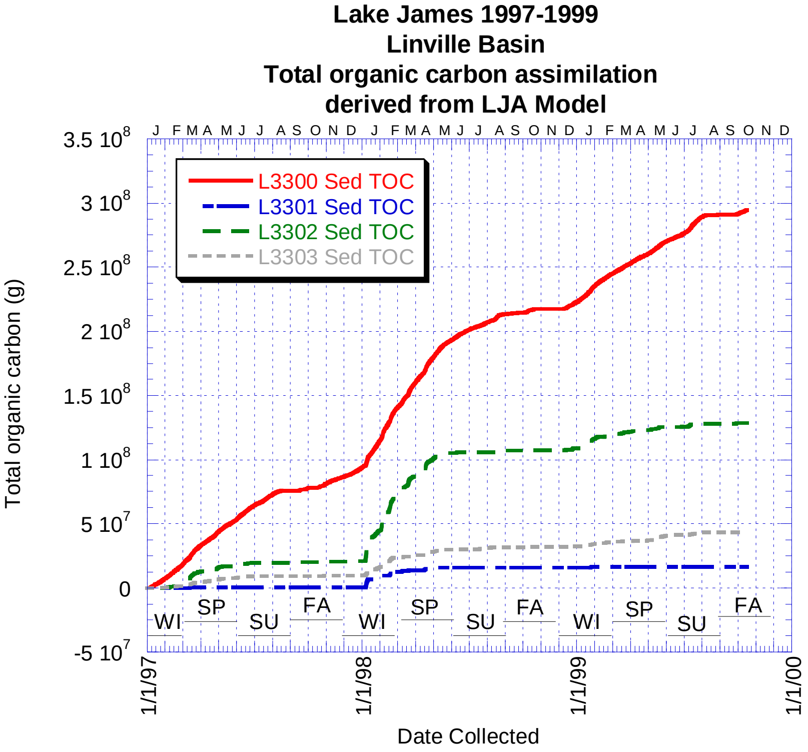
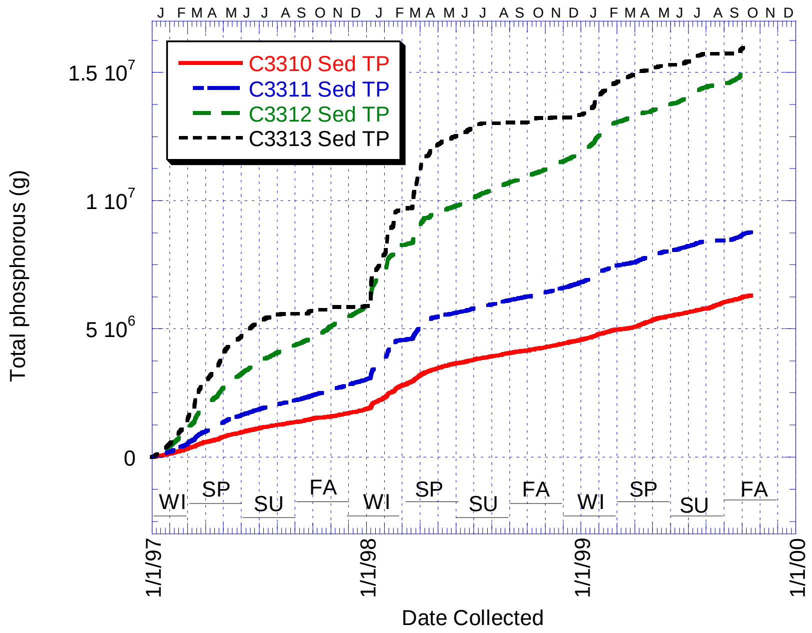


Figure D- 19 LJA Model assimilation/sedimentation of total organic carbon loading by longitudinal station for the Linville and Catawba basins within Lake James.

Lake James 1997-1999
Catawba Basin
Total phosphorous assimilation derived from LJA Model



Lake James 1997-1999
Linville Basin
Total phosphorous assimilation derived from LJA Model

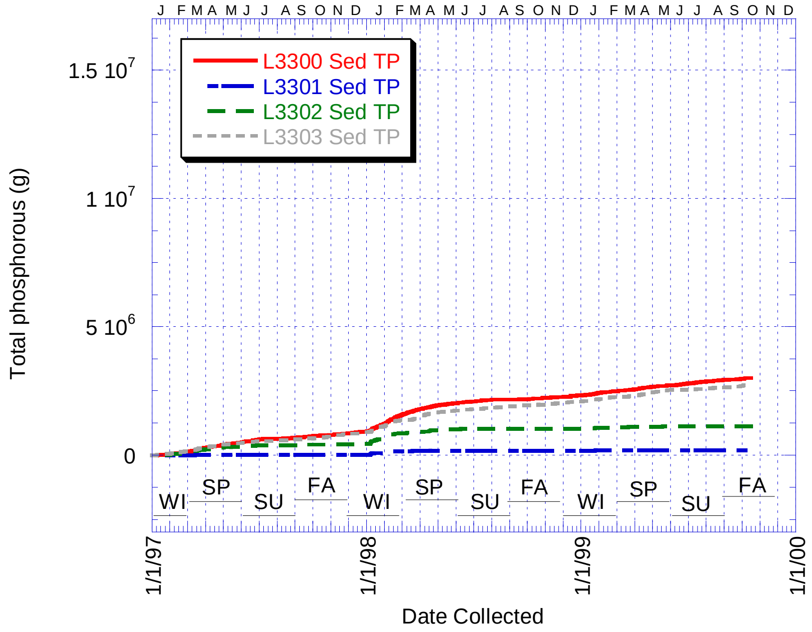
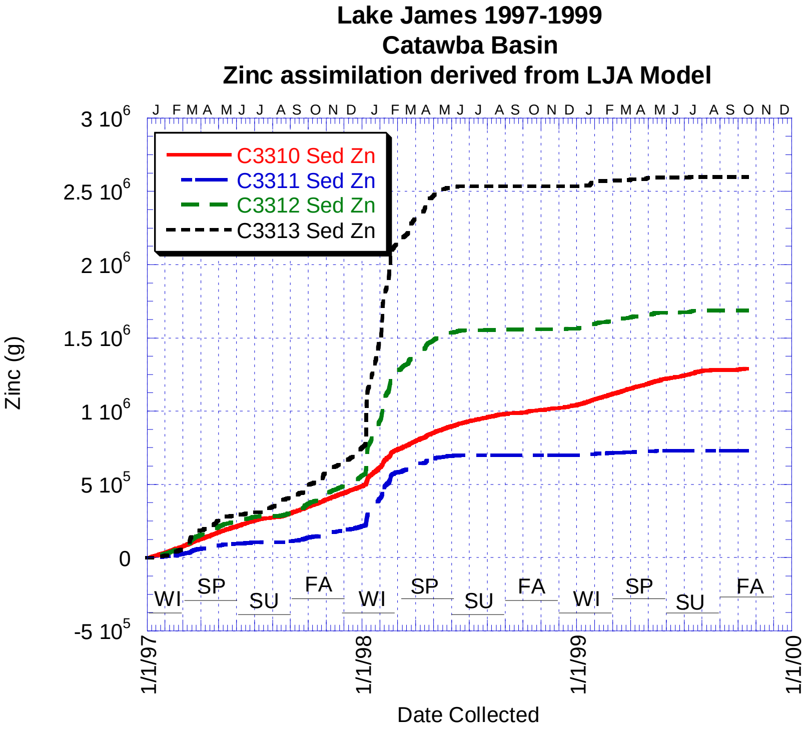


Figure D- 20 LJA Model assimilation/sedimentation of total phosphorous loading by longitudinal station for the Linville and Catawba basins within Lake James.



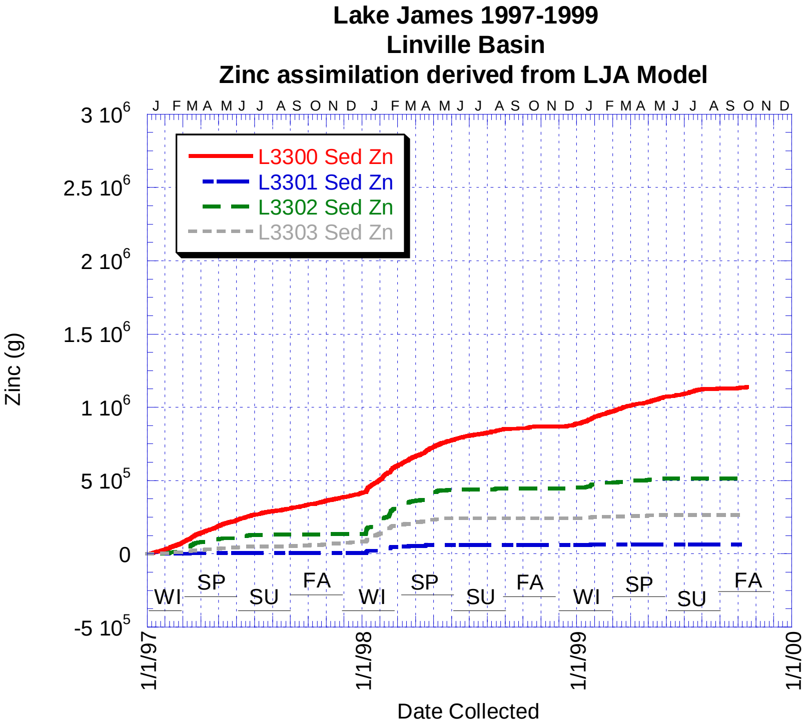


Figure D- 21 LJA Model assimilation/sedimentation of zinc loading by longitudinal station for the Linville and Catawba basins within Lake James.

APPENDIX E

Publications and Presentations by Clemson University Personnel for Lake James Assessment

Schindler, J. E., J. Hudgens, W. J. Foris, J. C. Knight, K. Celik, and S. L. Stokes (Submitted and Revising). 2001. Optical Properties of Lake James, NC. North American Lake Management Society. Lake and Reservoir Management.

Schindler, J. E., S. L. Stokes, K. Celik, W. J. Foris, J. C. Knight, and D. A. Braatz. 2001. River storm flow phosphorus loading to Lake James, North Carolina, USA. Societas Internationalis Limnologiae Proceedings, Melbourne, Australia 4-10, 2000. Published February 2001.

Schindler, J. E., W. J. Foris, J. C. Knight, K. Celik, and S. L. Stokes (Submitted and Revising). 2001. Energy Budget: Lake James, NC. North American Lake Management Society. Lake and Reservoir Management.

Schindler, J. E., W. J. Foris, J. C. Knight, K. Celik, and S. L. Stokes (Submitted and Revising). 2001. Upwelling Responses of a Stratified Reservoir to Wind Stresses: Lake James, NC. North American Lake Management Society. Lake and Reservoir Management.

Schindler, J. E., W. J. Foris, J. C. Knight, K. Celik, and S. L. Stokes (Submitted, revision this volume). 2001. Water Balance: Lake James, NC. North American Lake Management Society. Lake and Reservoir Management.

Stokes, S. L., K. Celik, T. J. Flynn and J. E. Schindler. 1998. Watershed effects on water quality of Lake James, North Carolina. Presentation to the Ecology and Biological Resource Management Symposium Clemson University, October 1998.

Stokes S. L., J. E. Schindler, K. Celik, W. L. Foris and J. C. Knight. 2000. Surface water chemical dynamics of Lake James, NC. NALMS: Presentation to the 9th Annual Southeastern Lakes Management Conference, March 2000.

Stokes, S. L., J. E. Schindler, K. Celik, W. J. Foris and J. C. Knight. 2001. Loading and yield estimates for Lake James, NC. Presentation to the 10th Annual Southeastern Lakes Management Conference, March 2001.

APPENDIX F

National Pollutant Discharge Elimination System (NPDES) Point-source dischargers

Table F- 1 NPDES Point-source dischargers in Lake James watershed, from Duke Energy 1998

Facility	NPDES No.	County	Receiving Stream	Sub basin	Permitted Q (MGD)	Av. Q (MGD)	TP (mg/L)	TN (mg/L)
Baxter Healthcare Corp.	NC0006564	McDowell	NF Catawba River	UNF	1.2	0.8422	1.52	5.94
Chalet Motor Lodge	NC0030996	McDowell	UT Buchanan Creek	AC	0.01	0.0063	No Data	No Data
City of Marion WTP	NC0055221	McDowell	Nicks Creek	LC	No Data	0.2478	No Data	No Data
City of Marion, Catawba R. WWTP	NC0071200	McDowell	Catawba River	LC	0.25	0.0731	1.428	4.928
Coats American	NC0004243	McDowell	NF Catawba River	UNF	2	1.2178	2.0533	3.185
Crane Resistoflex	NC0039934	McDowell	UT Catawba River	UC	0.016	0.0102	No Data	No Data
Gibbs Motel & Restaurant	NC0077801	McDowell	UT Catawba River	BC	0.009	0.0054	No Data	No Data
Hillside Mobile Village MHP	NC0069965	McDowell	UT Catawba River	LC	0.01	0.0066	No Data	No Data
Jeld-Wen Fiber	NC0076180	McDowell	Catawba River	UC	0.012	0.0025	No Data	No Data
Metal Industries	NC0057819	McDowell	Mackey Creek	UC	0.01	0.004	No Data	No Data
Old Fort WWTP	NC0021229	McDowell	Curtis Creek	CUC	0.8	0.5376	3.23	21.33
Brigam Medical, Inc.	NC0045543	Avery	Stacey Creek	UL	0.0081	0.0027	No Data	No Data
Crossnore WWTP	NC0026654	Avery	Mill Timber Creek	UL	0.07	0.0441	1.0075	4.907
EHNR - Corpening Training Ctr	NC0040339	Avery	Linville River	UL	0.018	0.018	No Data	No Data
GGCC Utility, Inc.	NC0023124	Avery	Linville River	UL	0.07	0.0472	0.5633	2.03
Linville Land Harbor - POA	NC0022756	Avery	Linville River	UL	0.225	0.1021	1.8	17.4
Linville Resorts	NC0039446	Avery	Linville River	UL	0.1	0.0365	4.5233	9.11
Jonas Ridge Nursing Home	NC0060224	Burke	UT Camp Creek	UL	0.0075	0.0048	No Data	No Data

Table F- 2 NPDES Dischargers for Upper Catawba River Basin in 1999 (Basin wide Planning Program: 1999 Catawba River Basin wide Water Quality Plan - Catawba River Sub basin 03-08-30 - Includes Catawba River Headwaters)

Permit	Facility	Type	Municipal	Expires	Receiving Stream
NC0006564	BAXTER HEALTHCARE CORP.	Major	Non	4/30/2000	NORTH FORK CATAWBA R
NC0080098	BLUE RIDGE COUNTRY CLUB LTD.	Minor	Non	4/30/2000	NORTH FORK CATAWBA R
NC0045543	BRIGAM MEDICAL, INC.	Minor	Non	4/30/2000	STACEY CREEK
NC0004243	COATS AMERICAN INC-MARION	Major	Non	4/30/2000	NORTH FORK CATAWBA R
NC0039934	CRANE RESISTOFLEX	Minor	Non	4/30/2000	UT CATAWBA RIVER
NC0026654	CROSSNORE WWTP, TOWN OF	Minor	Municipal	4/30/2000	MILL TIMBER CREEK
NC0040339	EHNR - CORPENING TRAINING CNTR	Minor	Non	4/30/2000	LINVILLE RIVER
NC0079481	ELLEDGE (R.D.) HARMONY ESTATE	Minor	Non	4/30/2000	UT NORTH MUDDY CREEK
NC0023124	GGCC UTILITY INC	Minor	Non	4/30/2000	LINVILLE RIVER
NC0077801	GIBBS MOTEL AND RESTAURANT	Minor	Non	4/30/2000	UT CATAWBA RIVER
NC0069965	HILLSIDE MOBILE VILLAGE MHP	Minor	Non	4/30/2000	UT CATAWBA RIVER
NC0076180	JELD-WEN FIBER OF N.CAROLINA	Minor	Non	5/31/2000	CATAWBA RIVER
NC0060224	JONAS RIDGE NURSING HOME	Minor	Non	4/30/2000	UT LINVILLE RIVER
NC0022756	LINVILLE LAND HARBOR- POA	Minor	Non	4/30/2000	LINVILLE RIVER
NC0039446	LINVILLE RESORTS	Minor	Non	4/30/2000	LINVILLE RIVER
NC0062413	LINVILLE RIDGE DEVELOPMENT	Minor	Non	4/30/2000	UT WEST FORK LINVILLE R
NC0055221	MARION WTP, CITY OF	Minor	Non	4/30/2000	NICKS CREEK
NC0031879	MARION, CITY-CORPENING CREEK	Major	Municipal	4/30/2000	CORPENING CREEK
NC0071200	MARION, TOWN-CATAWBA RIVER WWT	Minor	Municipal	4/30/2000	CATAWBA RIVER
NC0067130	MCDOWELL CO SCH.-GLENWOOD ELEM	Minor	Non	4/30/2000	GOOSE CREEK
NC0067148	MCDOWELL CO SCH.-NEBO ELEM.	Minor	Non	4/30/2000	UT SHADRICK CREEK
NC0057819	METAL INDUSTRIES, INC.	Minor	Non	4/30/2000	MACKEY CREEK

Continued

Table F- 2 (continued) NPDES Dischargers for Upper Catawba River Basin in 1999 (Basin wide Planning Program: 1999 Catawba River Basin wide Water Quality Plan - Catawba River Sub basin 03-08-30 - Includes Catawba River Headwaters

Permit	Facility	Type	Ownership	Expires	Receiving Stream
NC0021229	OLD FORT, TOWN - WWTP	Minor	Municipal	4/30/2000	CURTIS CREEK
NC0040291	PARK INN INTERNATIONAL	Minor	Non	4/30/2000	HICKS BRANCH
NC0035157	PINNACLE REST HOME	Minor	Non	4/30/2000	UT SOUTH MUDDY CREEK
NC0075353	ROCKY PASS ADULT CARE, LLC	Minor	Non	4/30/2000	NORTH MUDDY CREEK
NC0060208	SCENIC INN	Minor	Non	5/31/2000	HICKS BRANCH
NC0029831	SUGAR HILL TRUCK STOP	Minor	Non	4/30/2000	UT NORTH MUDDY CREEK
NC0030996	THE CHALET MOTOR LODGE	Minor	Non	4/30/2000	UT BUCHANAN CREEK
NC0077623	UNITED MERCHANTS & MANUFACTURING	Minor	Non	4/30/2000	CATAWBA RIVER

APPENDIX G

Hydrology of Lake James Watershed 1997-1999

Table G- 1 Hydrologic intensity summary for inflowing gauged streams to Lake James for 1997-1999

flows > (ft^3/s)	Linville 1997	Catawba 1997	Linville 1998	Catawba 1998	Linville 1999	Catawba 1999
500	2	14	10	27	1	2
1000	1	1	5	8		
2000			2	2		
3000						
4000			1			
5000						
6000				1		

Table G- 2 Mean Seasonal Flows (Q)

Season	Months	Year	Mean Q (ft^3/s)	(m^3/s)	(m^3/d)
Winter	Jan-Feb	1997	19.495	0.552	47696
Spring	Mar-May	1997	27.392	0.776	67016
Summer	Jun-Aug	1997	12.161	0.344	29752
Fall	Sep-Nov	1997	7.599	0.215	18591
Winter	Dec-Feb	1998	40.178	1.138	98299
Spring	Mar-May	1998	32.740	0.927	80100
Summer	Jun-Aug	1998	9.364	0.265	22910
Fall	Sep-Nov	1998	5.787	0.164	14157
Winter	Dec-Feb	1999	14.021	0.397	34304
Spring	Mar-May	1999	13.782	0.390	33719
Summer	Jun-Aug	1999	7.724	0.219	18897
Fall	Sep-Oct 17	1999	4.341	0.123	10620

Table G- 3 Minimum Seasonal Flows (Q)

Season	Months	Year	Minimum Date	Minimum Q (ft^3/s)	(m^3/s)	(m^3/d)
Winter	Jan-Feb	1997	1/1/1997	11.420	0.323	27941
Spring	Mar-May	1997	5/24/1997	11.989	0.339	29332
Summer	Jun-Aug	1997	8/30/1997	4.801	0.136	11745
Fall	Sep-Nov	1997	9/21/1997	4.169	0.118	10201
Winter	Dec-Feb	1998	12/20/1997	6.658	0.189	16289
Spring	Mar-May	1998	5/29/1998	14.171	0.401	34670
Summer	Jun-Aug	1998	8/31/1998	5.347	0.151	13081
Fall	Sep-Nov	1998	9/20/1998	4.033	0.114	9868
Winter	Dec-Feb	1999	12/23/1998	2.152	0.061	5264
Spring	Mar-May	1999	5/31/1999	7.383	0.209	18062
Summer	Jun-Aug	1999	8/19/1999	2.271	0.064	5556
Fall	Sep-Oct 17	1999	9/26/1999	1.712	0.048	4189

Table G- 4 Maximum Seasonal Flows (Q)

Season	Months	Year	Maximum Date	Maximum Q (ft^3/s)	(m^3/s)	(m^3/d)
Winter	Jan-Feb	1997	2/28/1997	56.344	1.595	137851
Spring	Mar-May	1997	3/14/1997	173.135	4.903	423588
Summer	Jun-Aug	1997	6/1/1997	35.439	1.004	86703
Fall	Sep-Nov	1997	10/26/1997	31.687	0.897	77525
Winter	Dec-Feb	1998	1/8/1998	514.364	14.565	1258431
Spring	Mar-May	1998	4/17/1998	137.808	3.902	337158
Summer	Jun-Aug	1998	8/15/1998	22.767	0.645	55700
Fall	Sep-Nov	1998	10/8/1998	24.236	0.686	59296
Winter	Dec-Feb	1999	1/24/1999	77.836	2.204	190431
Spring	Mar-May	1999	4/30/1999	34.401	0.974	84163
Summer	Jun-Aug	1999	7/13/1999	27.429	0.777	67106
Fall	Sep-Oct 17	1999	9/28/1999	17.899	0.507	43791

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