

Comparing Ecological Sensitivity with Stream Flow Rates in the Apalachicola-Chattahoochee-
Flint River Basin

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Introduction

For people in Georgia, the Apalachicola-Chattahoochee-Flint River Basin fuels a wealth of resources. Water in the ACF River Basin provides Atlanta residents with recreation opportunities and peanut farmers in Albany with crop irrigation. When the rivers reach the ocean, the headwaters create premium oyster habitat for fishermen. All along Western Georgia, people's drinking water comes from the ground and surface water belonging to the ACF River Basin. In addition to human uses, the ACF River Basin also supports a rich network of life. An ecological hotspot, hundreds of fish, insect and bird species call these three major Southeastern rivers home.

Literature Review

The challenge for Georgia has been to manage its water use of the ACF River Basin while sustaining the region's biological diversity. A U.S. Geological Survey reported that nearly one-third of all water withdrawn in Georgia in 1990 is taken from the ACF River Basin (Marella, Fanning, & Motty, 1993). The increasing trend in water use has grown immensely over the last 50 years, since irrigation innovations allowed farmers to grow on more land in Southwest Georgia. Along with the population centers of Atlanta, Albany, and Columbia, Georgians place heavy stress on the region's water supplies. From 1970 to 1990, agricultural water withdrawals from the Chattahoochee and Flint Rivers grew by 1,320 percent. During the same time period, surface-water withdrawals grew for public supply by 350 percent (Marella, Fanning, & Motty, 1993). Much of this water withdrawal occurs near the beginning of the ACF River Basin, where Lake Lanier and the Chattahoochee River provide 4 million Atlanta residents with potable water. However, a large proportion of this water is returned to the environment. Marella, Fanning, and Motty (1993) estimated that Georgians consume 21 percent of their total water use, while the

remaining 79 percent is returned for possible reuse. By 2000, Georgia withdrew 6,410 million gallons of freshwater every day to satisfy its agricultural, public and industrial demand.

Water withdrawals in Georgia are largely driven by farmers. All together, Georgia farmers irrigate 1,540,000 acres of land, using 1,140 million gallons of water per day. Agriculture is a \$9.9 billion industry in Georgia, and \$1.9 billion of the total comes from crops grown in Southwest Georgia (McKissick, 2004). In 1990, the Chattahoochee and Flint River Basin accounted for 38 percent of the total harvested cropland in Georgia. Here, farmers use irrigation to produce a variety of crops, including peanuts, cotton, pecans, wheat, hay and soybeans. In the Flint River Basin alone, farmers use 90% of total water withdrawn during April-September growing season (Georgia Department of Natural Resources, 2006). Many of these Southwest Georgia counties have access to cheap water, which is vital for them to maintain crop production at a high level.

Balancing human water use and maintaining the health of the ecosystem has become a major challenge. Richter, Mathews, Harrison, and Wigington (2003) identify the need for ecologically sustainable water management. Healthy freshwater systems provide people with an untold number of resources, but mismanagement causes environmental damages. Human changes to the rivers and streams can adversely affect the diversity and animal life in these ecosystems. According to Sparks (1995), alteration of a river's flow regime can affect wildlife in unknown manners, and proper ecosystem management needs to preserve the integrity of the entire ecosystem. Proper management of water in lakes and rivers is also necessary to preserve a sustainable amount of water for a region, ensuring that water never becomes too scarce (Dabrowski, Murray, Ashton, & Leaner, 2008).

In Georgia, policymakers have become particularly concerned about meeting the needs of farmers and maintaining ecological health in times of drought. During normal years, standard irrigation practices do not jeopardize the river's ecosystem by removing an excess of water (Congressional Research Service, 2008). However, this situation changes during drought years. Farmers use more water to irrigate crops during dry seasons, exacerbating the climatically dry conditions for wildlife due to the drought. Furthermore, Alabama and Florida also depend on rivers in the ACF River Basin to fuel economic growth (Stephenson, 2000). Alabama residents extensively use the Chattahoochee for agricultural and recreational purposes. Including thermo-electric power, Alabama withdraws about 185 million gallons of water per day from the Lower- and Middle-Chattahoochee watersheds (United State Geological Survey, 2005). In Florida, fisherman garner about \$134 million in economic benefit annually in Apalachicola Bay, most of it from the oyster harvest (Dixon, 2009). The harvest depends on healthy river flows to maintain the proper salinity content of the water. The competing water needs among the three states led to Alabama and Florida filing a lawsuit against U.S. Army Corps of Engineers in 1990 to prevent Atlanta from using more water and degrading the water quality in the ACF River Basin (Stephenson, 2000). The three-state water dispute demonstrates the difficulty in setting adequate water management when multiple stakeholders are involved with competing wants. Policymakers have to compromise between ensuring the health of the ecosystem and promoting economic production.

To help in these decisions and cut down on the consumptive use of water, environmental economists have previously employed spatial techniques to improve inefficient agricultural techniques (Crossman et al., 2010). Other economic scholars have looked at how trading water among regions can lead to more optimal outcomes for economic and environmental needs.

Qureshi, Connor, Kirby, and Mainuddin's (2007) analysis of an Australian river basin showed that free water trade results in an increase in irrigation benefits to farmers. However, some revenue gains can be offset by negative externalities related to the water's salinity. Water used for irrigation can further harm the environment when farmers use more water during naturally dry periods; the timing of water withdrawals is just as important as the quantity of water withdrawn. However, research has shown that compromises can be made to maximize economic benefit for farmers while minimizing environmental costs (Jones, Crean, Aluwihare, & Letcher, 2007). Virtual water trading across regions can also offset losses in water quality (Dabrowski, Murray, Ashton, & Leaner, 2008).

A compromise between economic needs and environmental conservation is essential in preventing harm to ecosystems. Severe drops in flow regimes have previously been shown to negatively affect ecological biodiversity. Fish species diversity and abundance is strongly related to year-round stream flows and river surface area (Oberdorff, Guégan, & Hugueny, 1995; Xenopoulos et al., 2005). Sharp drops in stream levels due to either climatic conditions or human use can drive species to extinction in certain areas. Other species will be confined to small tributaries after being driven out of main rivers, which isolates the surviving populations. According to Oberdorff, Guégan and Hugueny (1995), freshwater species are not able to adapt quickly enough to survive dramatic water withdrawals.

Large-scale anthropogenic changes on the environment can have immediate and dramatic effects on ecological biodiversity. A study by Bredenhand and Samways (2008) found that a newly built dam reduced benthic macroinvertebrate diversity by half in areas below the dam compared to untouched sections above. Benthic macroinvertebrates diversity relates strongly to stream size and the size of the surrounding catchment area (Heino, Mykrä, Hämäläinen, Aroviita,

Muotka, 2007). When people change the dynamic of a river's water, biodiversity levels can change quickly. However, anthropogenic changes to the environment can sometimes increase species diversity or abundance as well.

Research on Southwestern Georgia rivers often focuses on mussel species diversity. In the Flint River Basin, droughts have severely affected abundance and diversity levels of mussel species. More environmentally susceptible mussel species decline at a faster rate than common, tolerant mussel common species (Golladay, Gagnon, Kearns, Battle, & Hicks, 2003). Declines in mussel populations are thought to be associated both with droughts and increased demand for irrigation on streams and aquifers. Mussel species diversity is also highly susceptible to changes in the surrounding habitat and channel depth (Gagnon, Michener, Freeman, Brim Box, 2006). Mussels are one of the most monitored animals in the ACF River Basin since several endangered mussel species live in the region, along with one endangered sturgeon (Congressional Research Service, 2007).

Research Questions

Our project looks into how variation in stream flows and groundwater levels affects the ecological health of the ACF River Basin. We are studying how natural variation and human economic water needs change the integrity of the surrounding ecological system. We want to understand how ecological vulnerability changes throughout the year, both due to climatic conditions and human use.

RQ1: How do stream flows vary in the ACF River Basin?

RQ1: Are key indicator species most vulnerable during times of peak water use?

RQ2: Which species are most vulnerable to decreased stream flows from irrigation?

RQ3: If and when does agricultural water demand overlap with ecological sensitive periods of time within the ACF river basin?

ACF River Basin Background

The Chattahoochee River drainage covers an area of 8,770 square miles and is the most heavily used water resource in Georgia. Its headwaters begin at the southern edge of the Blue Ridge Mountains at an altitude above 3,000 feet and flow 430 miles to its confluence with the Flint River. The Chattahoochee River provides drinking water for more than half of all Georgians and recreation for more than 25 million people each year. The Chattahoochee and Flint Rivers are part of the larger Apalachicola-Chattahoochee-Flint River Basin, which flows through the states of Georgia, Alabama, and Florida. The Flint River is approximately 350 miles long and drains an area of 8,460 square miles. Most of the larger tributaries in the ACF River Basin are located in the lower reaches of the Flint River Basin.

The ACF river basin has greatly been affected by population growth, urbanization, an influx of industry's relocating to the state, increased water demands, and changes in the land cover. Populations within the metropolitan Atlanta area increased 97% from 1970 to 1995, and have continued to increase over the last two decades, growing 26% since 1990. Growth of industry and urban areas around the state has increased the overall population of Georgia 34% since 1990 to approximately 500,000 people.

Stream flow, or *discharge*, is the volume of water moving past a cross-section of a stream over a set period of time. It is usually measured in cubic feet per second (cfs). Stream flow in the

ACF is affected by the amount of water within a watershed, increasing with rainstorms, and decreasing due to drought, evaporation, and use. Flow is also important because it defines the shape, size and course of the stream. It is integral not only to water quality, but also to habitat. Food sources, spawning areas and migration paths of fish and other wildlife are all affected and defined by stream flow and velocity. Velocity and flow together determine the kinds of organisms that can live in the stream (USEPA, 1997).

Human impacts also affect stream flow, such as changes in land cover, especially impervious land cover, building dams, pollution and waste disposal, and demands on surface water and groundwater withdrawals.

Stream Flow

Stream flow data from USGS. Stream flow is measured in units of cubic feet per second (cfs) flowing past a point.

	Chattahoochee River (Columbus, GA)	Flint River (Newton, GA)
Drainage Area (square miles)	8,770	8,460
Min Daily Flow (cfs)	252	863
Mean Daily (cfs)	5,490	4,080
Max Daily (cfs)	150,000	100,000
Years of Collection	2002-2009	2002-2009

Impervious surface change in acres from 1991 to 2005

	1991	2001	2005
	455,621 acres	670,116 acres	824,250 acres
	Increase from 1991 to 2001: 214,495 acres		47.08% increase
	Increase from 2001 to 2005: 154,134 acres		23.00% increase
	Increase from 1991 to 2005: 368,629 acres		80.91% increase

2005 land cover statistics

ACF Watershed Totals

	ACF Total
Acres:	7,551,798
Hectares:	2141294
Square Miles:	9,742
Square Kilometers:	26,575
Beaches, Dunes, Mud	231
Open Water	204,218
Low Intensity Urban	836,027
High Intensity Urban	173,398
Clear-cut, Sparse	685,325
Quarries, Strip Mines, Rocks	8,165
Deciduous Forest	1,700,326
Evergreen Forest	2,123,684
Mixed Forest	426,467
Row Crops and Pasture	2,397,183
Forested Wetland	703,274
Non-forested Wetland-Salt	0
Non-forested Wetland-Fresh	10,209

Impoundments in the Apalachicola-Chattahoochee-Flint River Basin

Dams constructed by the U.S. Army Corps of Engineers have created large impoundments for flood control, water supply, power, and commercial navigation in the ACF River Basin. Thirteen of 16 mainstream dams in the ACF River basin are along on the Chattahoochee River (Congressional Research Service, 2007). Over most of its length, hydroelectric plants release water for production of hydropower and control the flow. Dam construction in the basin began in the early 1800s on the Chattahoochee River above the Fall Line at Columbus, Ga., to take advantage of natural elevation gradients for power production. During low flow periods, stored water is used to supplement the discharge of the river. There

have been marked decreases in the frequency of high and low flows since the start of operation of Buford Dam in 1956, and river flows fluctuate daily below the reservoirs along the Chattahoochee River. Lake Lanier provides 65 percent of the water storage to regulate flows, yet it drains only 5% of the ACF River basin.

Two hydropower dams located on the Flint River impound run-of-the-river reservoirs and do not appreciably influence the monthly flow of the Flint River. The Flint River is one of only 42 free-flowing river reaches longer than 125 miles remaining in the contiguous 48 states (Congressional Research Service, 2007). See Figure 1 for ACF dams and power plant locations.

Congress first authorized construction of federal facilities for water resources development of the ACF River basin in 1946. The Army Corps of Engineers operate five dams – four on the Chattahoochee River and one on the Apalachicola River at the confluence of the Chattahoochee and Flint Rivers. Four of these dams provide water storage. The most water is stored behind Buford Dam that forms Lake Lanier, providing 62% of the Army Corps’ of Engineers storage capacity in the ACF River Basin. The Army Corps of Engineers have contracts with local interests for municipal and industrial water supply storage space at Lake Lanier. Lake Lanier provides the ten heavily population counties around Atlanta with 72% of their water supply. The other dams that provide water storage include West Point, W. F. George and Woodruff. These facilities and other non-federal dams in the ACF River Basin also have hydroelectric capabilities. The fifth federal dam, Andrews Dam, is operated for navigation.

The four largest reservoirs along the Chattahoochee River:

	Area	Shoreline
Lake Lanier	38,000 acres	540 miles
West Point Lake	25,900 acres	525 miles
Lake Walter F. George	45,180 acres	640 miles
Seminole (Woodruff)	37,500 acres	500 miles



Figure 1: Location of power plants and dams in the ACF River Basin; adapted from a Army Corps of Engineers map from <http://www.sam.usace.army.mil/>.

Groundwater

The headwaters of the Chattahoochee and Flint Rivers occur north of the Fall Line in the Blue Ridge and Piedmont Provinces (Loeffler & Meyer). Water supplies in the headwater region derive primarily from surface waters. South of the Fall Line are several aquifers, including the Providence aquifers and upper Cretaceous strata. The Providence aquifers consist of sand and gravel that are separated by clay and silt beds. The lower reaches of both rivers are part of the Floridian aquifer system (Loeffler & Meyer). These groundwater sources are some of the most productive in the world.

On the other hand, the aquifers in the Piedmont and Blue Ridge Provinces have a much lower yield. Reported yields of wells in the rocks range from zero to 471 gallons per minute, although they are usually less than 50 gallons per minute (Environmental Protection Division, 1997).

Rivers and streams in the Coastal Plain Province commonly are deeply incised into underlying aquifers and receive substantial amounts of groundwater discharge. Rock layers associated with the Floridian aquifer system are exposed along sections of the Apalachicola River, Chattahoochee River, Flint River, and Spring Creek (Couch, Hopkins, & Hardy, 1996). Due to the hydraulic connection between the Floridian aquifer system and the Flint River, groundwater discharge contributes more significantly to stream flows in the Flint River than in the Chattahoochee River; aquifer discharge to the Chattahoochee River is one-fifth of the amount that discharges to the Flint River (Couch, Hopkins, & Hardy, 1996).

Groundwater depletion is a major issue associated with groundwater use. It occurs after long periods of sustained and excessive use of an aquifer, mainly for agricultural purposes (<http://ga.water.usgs.gov>). A few of the negative effects of groundwater depletion: drying up of

wells, reduction of water in streams and lakes, deterioration of water quality, increased pumping costs, and land subsidence (<http://ga.water.usgs.gov>). Negative effects of groundwater depletion are a lowering of the water table, increased costs of water, land subsistence, deterioration of water quality, and a reduction of water in streams and lakes (<http://ga.water.usgs.gov>).

The Hydrologic Interaction between Groundwater and Surface Water

While considering the future research of hydrological withdrawals in conjunction with agricultural sustainability and environmental health, it is important to note the relationship between groundwater and surface water. Aquifer withdrawals made north of the Apalachicola-Chattahoochee-Flint River basin, especially during years of low precipitation, can imply hardships not only for future farmers but also for continued ecological health and productivity in the ACF basin. Since groundwater withdrawals lag behind stream flows, data collected from USGS points in real time may not indicate simultaneous aquifer withdrawals. Therefore, low stream flows may not only reflect periods of low precipitation, but also former ground water withdrawals. Understanding the dynamic relationship between ground and surface water is vital to implementing effective water policy in Georgia.

In order to analyze the specific effect ground water has on stream flow, it may be necessary to update aquifers with new tracking systems. Several precipitation-runoff models have been created to gauge the effect of water usage, one of which was tested as a type of FORTRAN precipitation runoff model (STRMDPEL) to analyze flows in Massachusetts' Ipswich River. The program is successfully and easily collecting and storing real-time data specific to the Ipswich River and has, since its debut, been installed elsewhere in the country (Zarriello, 2001). These systems can monitor individual pumping wells and simultaneously monitor time variance affecting nearby channels. This program may be a valuable tool in

monitoring water use specific to ground withdrawals. This is important to future water management as a means of detailing where communities can effectively time aquifer withdrawals in respect to breeding patterns of key native species, reducing ecological damage.

Since the popularity of center pivot irrigation systems took hold of the Flint River Basin in 1975, this basin has seen a decrease in stream flows between 40 – 46%, with no significant change in rainfall (Rugel et al. 2009). Collecting data specific to ground water may bring attention to actual usage and help reduce withdrawals. With the installation of monitoring systems in Georgia's pumping wells and aquifers, hydrologists and policy makers may be well-informed to better manage our streams and river systems, allowing for prosperous crop yield in the future at no expense to local river basins and ecological systems.

Precipitation in Georgia

Average annual rainfall in the FRB ranges from 48-54 in/yr (Fig. 5). Most of this falls between early November and mid-April, although frontal rainfall, convective storms in late spring through fall, and tropical storms can add significantly to annual rainfall totals (Couch, McDowell, 2006). Droughts are also normal aspects of Georgia's climate. Droughts lasting more than two years in Georgia have occurred during the following years: 1708- 1709, 1714-1715, 1756-1760, 1762-1764, 1797-1802, 1844-1845, 1839-1840, 1855-1857, 1896-1899, 1925-1927, 1914-1915, 1954-1956, 1998-2002, 2006-2007 (Stooksbury, 2003). From 1952 to the late 1980's, southwest Georgia had an accumulating rainfall deficit of as much as 60 inches (GAEMN, 2005). Analysis of rainfall patterns over the last 50 years indicates that rainfall patterns have been changing slightly, and that from April to September, which corresponds to the main agricultural growing season, monthly rainfall totals have declined slightly (Couch, McDowell 2006).

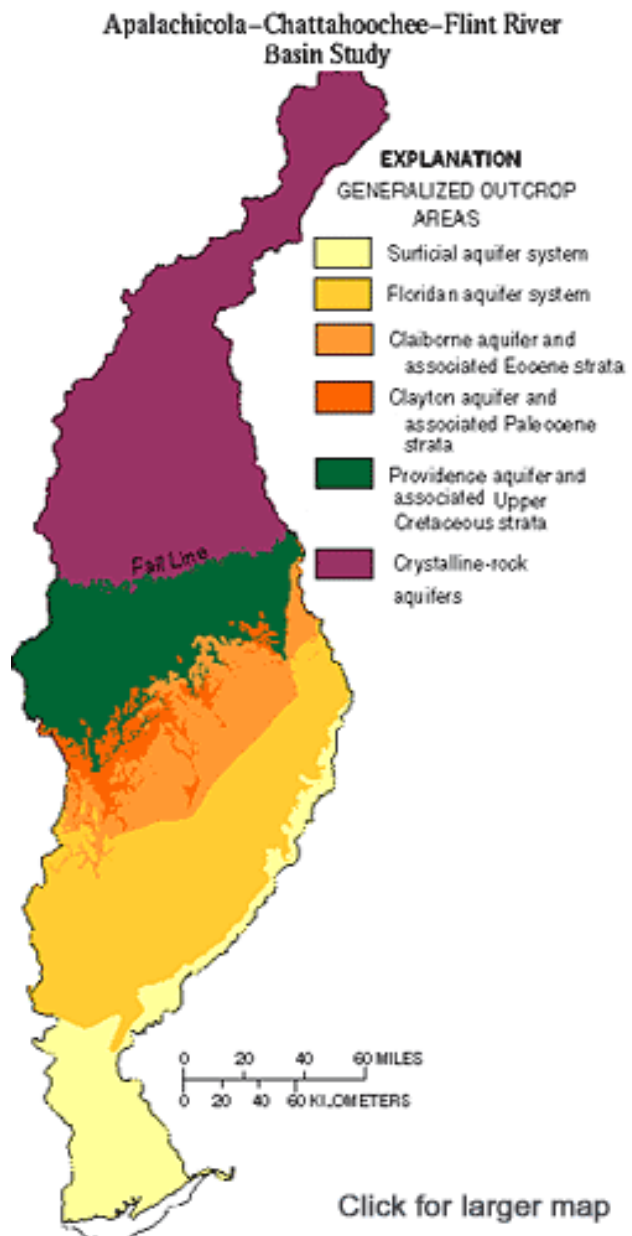


Figure 2: Aquifer regions in the ACF River Basin; Couch, C. A., Hopkins, E. H., Hardy, P. S. (1996). Influences of environmental settings on aquatic ecosystems in the Apalachicola-Chatthahoochee-Flint River Basin. Atlanta, GA: U.S. Geological Survey.

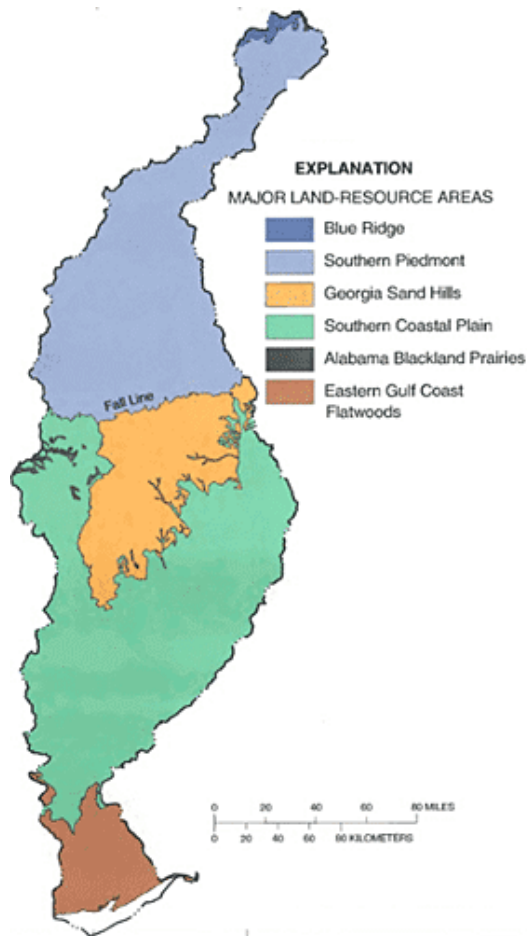


Figure 3: Land resource regions of the ACF River Basin; Couch, C. A., Hopkins, E. H., Hardy, P. S. (1996). Influences of environmental settings on aquatic ecosystems in the Apalachicola-Chattahoochee-Flint River Basin. Atlanta, GA: U.S. Geological Survey.

Physiography

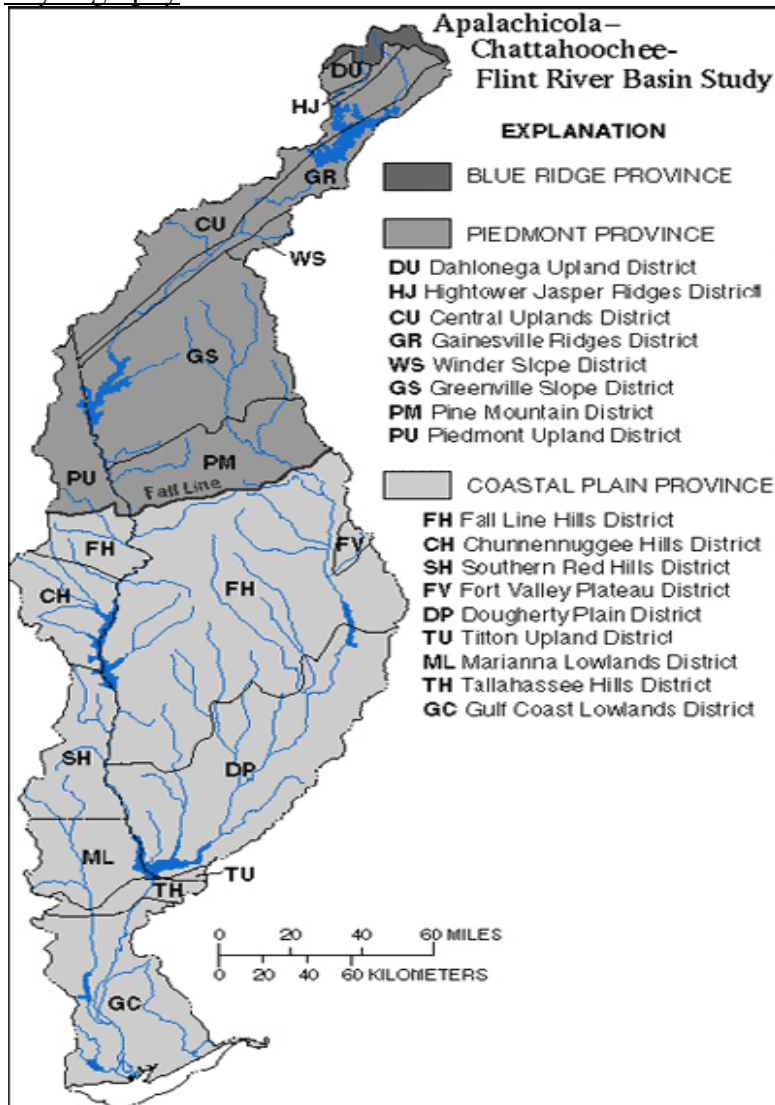


Figure 4: Physiography of the ACF River Basin; Couch, C. A., Hopkins, E. H., Hardy, P. S. (1996). Influences of environmental settings on aquatic ecosystems in the Apalachicola-Chattahoochee-Flint River Basin. Atlanta, GA: U.S. Geological Survey.

Precipitation

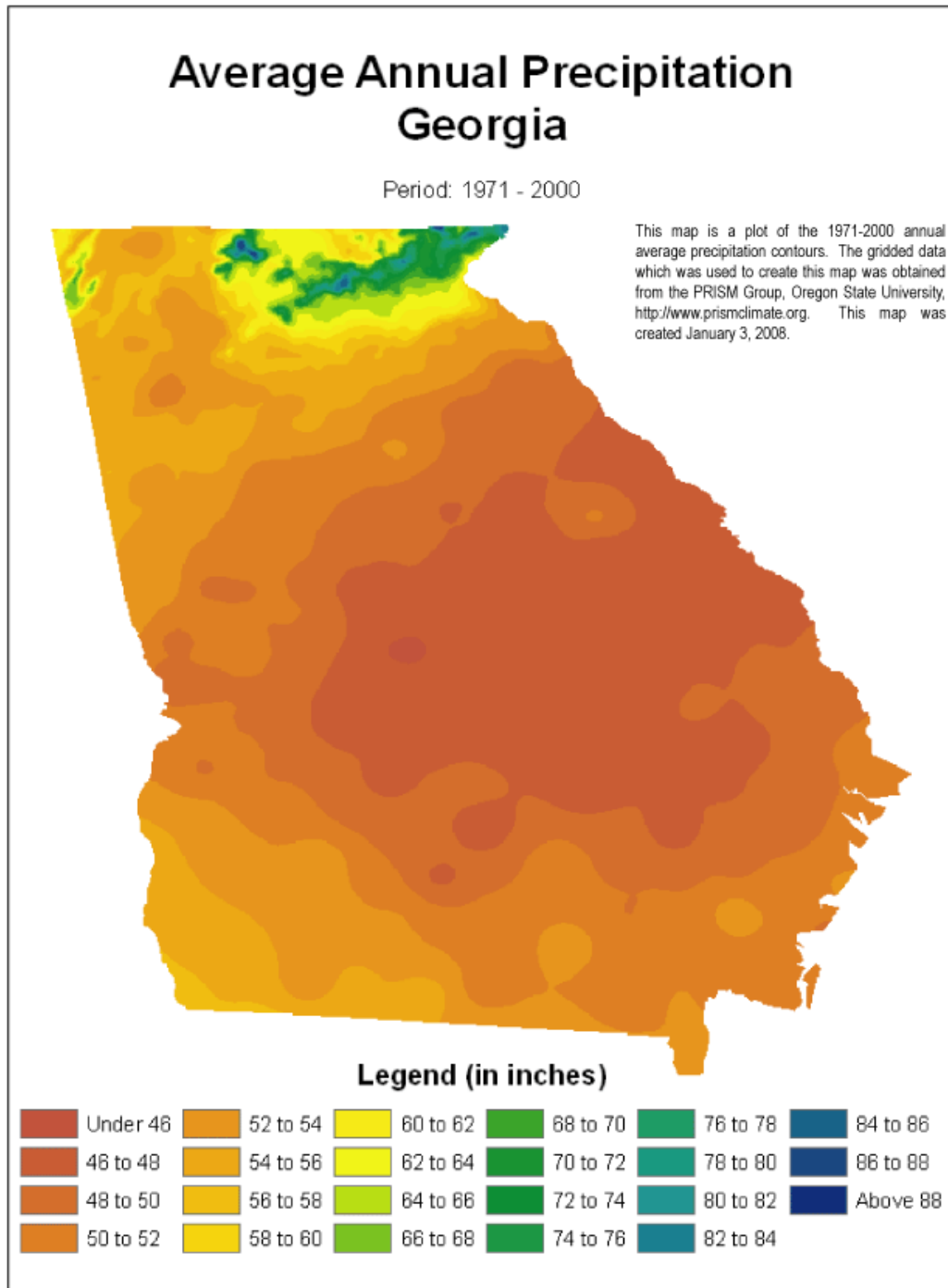


Figure 5: Average precipitation in Georgia.

Threats to Stream Ecological Health

Agricultural activities threaten fish populations, primarily through run-off of sediment, nutrients, and pesticides. According to the Georgia Department of Natural Resources, these impacts are most extreme in areas where agricultural practices occur next to stream banks and when livestock are given access to streams for watering. Sedimentation, which can also result from forestry practices and construction activities, is an almost ubiquitous problem in Georgia streams (<http://www.gadnr.org/>). Suspended sediment decreases water clarity and interferes with sight-feeding and other visually oriented aquatic animal behaviors (Blann, Anderson, Sands, & Vondracek, 2009). For example, fish display territorial messages and mussels use lures to attract their fish hosts. Sediment also fills in the spaces between larger rocks, eliminating habitats used for spawning, feeding, and shelter. The Georgia Department of Natural Resources warns that nutrient pollution from such sources as fertilizer runoff and animal waste can lead to algal blooms, which in turn may affect water clarity, oxygen levels, and also the health of aquatic plants that are beneficial to fishes. Cattle access points contribute to sedimentation and nutrient pollution as well. Healthy river ecosystems also require a forest buffer. Forests provide shade, filter runoff into the stream, give habitat to wildlife, and provide food sources of aquatic insects (<http://www.gadnr.org/>).

Depending upon the size of the operation and its location, forestry operations may negatively impact streams and its aquatic wildlife (Blann, Anderson, Sands, & Vondracek, 2009). Mechanisms of impact include sediment runoff associated with vegetation removal, soil disturbance from forestry equipment, and stream bank destabilization from poorly designed stream crossings (<http://www.gadnr.org/>). Additionally, the removal of trees from sensitive

habitats such as cypress swamps, floodplains, or other wetlands contributes to sedimentation and increases in water temperature (<http://www.gadnr.org/>).

In the Piedmont region, the health and diversity of fish communities are best in watersheds with adequate forests, followed by streams draining watersheds dominated by poultry and suburban areas (Frick et al., 1998). Urban areas can severely degrade streams and the ecological health of an entire watershed (Fitzhugh & Richter, 2004). The adverse effects on watershed health in urban areas include high storm flows, degraded habitat, and the presence of chemical contaminants such as insecticides (Frick et al., 1998).

Although urban and suburban land use accounts for only 5% of the ACF River Basin, it has the most important effect on stream-water quality (Frick et. al., 1998). The intensity of negative water quality varies in proportion to measures of urbanization, such as impervious area, population density, and industrial and transportation land use (Fitzhugh & Richter, 2004). Additionally, the use of nutrients and pesticides further degrade water quality of streams as urban land use increases within a watershed. Watersheds in the Piedmont with higher population densities generally are drained by streams dominated by a few species of pollution-tolerant, mostly non-native fishes (Frick et al., 1998). Invasions of non-native, pollution-tolerant fish species can indicate poor biological conditions and potentially poor water quality (Dick, Platvoet, & Kelly, 2002; MacNeil & Briffa, 2009).

In the Coastal Plain of the ACF River Basin, cropland in upland areas is separated from streams by relatively undisturbed riparian wetland habitats. This contrasts the extensively farmed areas of the United States where wetlands have been drained, channelized or filled, which leaves few riparian buffers between cropland and streams. Several water quality implications can partially be attributed to these wetland buffer areas. Firstly, these streams have fewer

pesticides present in the water and lower pesticide and nutrient concentrations than in other areas of the nation (Frick et. al., 1998). Secondly, there are lower nitrate concentrations in ground water underlying the forested flood plains than in ground water underlying cropland. Finally, fish communities are not as disturbed during large fluctuations in stream flows (Frick et. al., 1998).

Indicator Species

Several different species of insects, fish, and mussels were selected as biological indicators of ecological sensitivity to stream flows in the ACF River Basin. These organisms were selected for their interdependence on each other for survival and their sensitivity to changes in water quality and environmental habitat. Below are descriptions and reasoning behind each indicator species.

Fish

Two fish in the genus *Percina*, the Halloween Darter (*Percina crypta*) and Blackbanded Darter (*Percina nigrofasciata*), were chosen as indicators of the health of the ACF watershed aquatic ecosystem. They are endemic to the Chattahoochee and Flint River systems of the Apalachicola River drainage, and have a high sensitivity and response to chemical, physical, and biological changes within the stream environment. The health of fish communities can change with fluctuations in stream flows, increases in sedimentation, decreases in aquatic insects, and decreases in dissolved oxygen, among other factors. A brief description of habitat, life cycle, diet, and breeding requirements for each fish is detailed below.

Halloween Darter

The Halloween darter was discovered by Dr. Mary Freeman, an ecologist with the U.S. Geological Survey and the UGA Odum School of Ecology (Jimenez, 2009). The Halloween

darther grows between two to five inches. The fish received its common name because males and females develop a bright orange band on their front fins during breeding season in the late spring. The darther's other fins are banded with bright orange stripes.

Formally called *Percina crypta*, the Halloween, darther inhabits relatively swiftly flowing shoals over bedrock or a mixture of coarse (boulder to gravel) bed sediments (Hill, 1996; Marcinek, 2003). The Halloween darther consumes aquatic insect larvae, including mayflies and caddisflies. The darther has been observed to spawn during April and May. Juvenile darters less than one and one-half inches long live in stream shoals, but they grow to half of their adult size by October. The Halloween darther reaches sexual maturity after one year, and researchers have estimated the fish can live up to three years (Freeman, Freeman, Burkhead, & Straight, 2008).

The Halloween Darther is found in the ACF River Basin where it occurs in the Flint River system and the Chattahoochee River system (Jimenez, 2009). Within the Flint River system, the darther has been documented in the Flint River below and above the Fall Line, and in four tributary stream systems. In the Chattahoochee River system, *P. crypta* is known from two broadly separated areas, the first being the upper portion of the system in Georgia upstream from Lake Lanier, and from the Uchee Creek system, and the second being an Alabama tributary that enters the Chattahoochee River (Couch et al., 1996). The darther's fragmented habitat is believed to be due to pollutants from Atlanta, removal of shoal environments within the river, and the building of the 13 dams within the freshwater rivers of Georgia (Freeman, Freeman, Burkhead, & Straight, 2008).

Blackbanded Darther:

The blackbanded darters are another small fish similar in size to the Halloween darther. Unlike the Halloween darther, the blackbanded darther's appearance is extremely variable and

appears to be strongly influenced by the surrounding habitat (Mettee, 1996). Most individuals have up to 15 elliptical bars, crossing their light green, brown or tan sides. The darter's fins are normally transparent, but they change during the spawning season. Breeding males further undergo coloration changes by developing green or blue colors in their body (Mettee, 1996).

The blackbanded darter has a large range in the Southeast, occurring throughout the Mobile basin and coastal drainages in Alabama and the Piedmont region in Georgia. The darter lives in a variety of habitats, usually in the gravel or sand of rivers (Crawford, 1956). It spawns earlier than many fish species, as males begin the reproductive process beginning in late February or early March when the water temperature rises from 10 C to 12 C. The spawning season continues through July. On the other hand, most females prepare to spawn in late March into April. By the end of May, most females have fertilized their eggs. While pregnant, the female fish are highly susceptible to disturbances in their environments. By late June, all males and females have spawned (Mathur, 1973). The blackbanded darter feeds on small macroinvertebrate insects, including midges, blackflies, mayflies, and caddisfly larvae.

Insects

Mayflies and stoneflies were chosen because they are important insects to support fisheries in the ACF River Basin. Mayflies and stoneflies are also extensively used as indicators of pollution and environmental change. Adult insects and nymphs are a source of food for many freshwater fish, making both an important link in the food chain.

Stoneflies

Stoneflies, known as plecoptera, are a diverse group of insects that are primarily associated with clean, cold running waters. Stoneflies have been used for biological indicators for river quality in past studies (Krno & Holubec, 2009). They are rather primitive insects and

may have been among the first insects to develop flight (Marden & Kramer, 1994). Stonefly nymphs are found in a wide variety of habitats, from small to moderate-sized streams and rivers. Stonefly nymphs usually live in leaf packs and riffle areas of streams, where rocks, gravel, and woody debris provide hiding places and cover. Stonefly nymphs are predators that stalk their prey on the river bottom. However, young stonefly nymphs feed on organic detritus before gradually shifting to predation on other macroinvertebrates as they mature. Predatory nymphs commonly feed on other aquatic insects, such as midges, mayflies, caddisflies.

Stonefly diversity declines quickly from human disturbance (Krno & Holubec, 2009). Stoneflies emerge from the water as adults to mate, locating each other by drumming with their abdomens. The adults have been reported to emerge in May to July (Snellen & Stewart, 1979; Stark et al., 1998). In Florida, Stark & Gaufin (1978) reported the emergence from April to August (Pescador et al., 2000).

In our index, we have chosen the genus *perlesta banks*. This genus emerges from April through August throughout most of the Eastern United States (Stark & Gaufin 1978).

Mayflies

Mayflies are susceptible to changes in water quality such as temperature and pollution. Southeastern researchers have used mayflies, along with other benthic macroinvertebrates, to measure the health of river ecosystems (Barbour et al., 1996; Lenat, 1993). Belonging to the order ephemeroptera, mayflies are small- to medium-sized insects found near rivers and lakes found throughout the ACF River Basin (<http://www.sherpaguides.com>). Mayflies live most of their lives as nymphs in the stream. When they emerge as adults to mate, they live for only a few days before dying.

Mayfly nymphs are common in muddy river bottoms throughout North America (<http://www.sherpaguide.com>). Nymphs live in shallow burrows in muddy areas or near the river margin, although their habitats vary greatly depending on species (University of California Museum of Paleontology). They beat their feathery gills to circulate water and dissolved oxygen into their burrows. Nymphs feed by filtering silt or mud for organic matter and microbes. When the river's temperature rises to the proper level, nymphs swim to the surface to emerge as winged adult mayflies. Ten of thousands of mayflies can transform at one time to mate (Flecker, Allan, & McClintock, 1988). The new adults mate almost immediately in flight as they fly in large swarms. Swarming may take place over the water itself, over the shore area, or even away from the water. The time of swarming varies considerably, although dusk is the most common time of day in temperate regions.

After mating, females deposit eggs directly on the water surface, under rocks or in debris in the stream. The eggs sink to the river bottom where they will hatch and begin the next generation of burrowing mayflies (University of California Museum of Paleontology). The nymphal life span in mayflies varies, ranging for a few weeks to several years. Most nymphs hatch at temperatures in the range of 3 C to 21 C, although nymphs hatch at different temperatures by species (<http://www.sherpaguides.com>).

Mayflies will emerge at different times between spring and summer. Based on larval size distributions, there are three emergence periods: Cohort 1 – March through May; Cohort 2 – late June; and Cohort 3 – late September-early October (Johnson et. al., 2000). During the late summer months, larval growth slows compared to spring and fall. Larvae of the largest size class (10.5–10.9 mm) are most common during the first emergence period (Johnson et al., 2000).

Emergence is a critical period for mayflies, since this is when they breed. However, mayfly nymphs can be adversely affected by pesticides, polluted water, and non-native predators (Palmquist, Jepson, & Jenkins, 2008; Love, Taylor, & Warren, 2005). Some research even suggests that reproductive success for mayflies may depend on the size of mayfly nymphs (Love, Taylor, & Warren, 2005). Water regulation, such as dams, for water supply and power can have profound effects on mayfly communities. In reservoirs, still water conditions can reduce mayfly diversity (Crankshaft). Furthermore, loss of habitat and reduction in connectivity between freshwaters is becoming a more pressing threat to mayflies.

Mollusks

According to the Georgia Department of Natural Resources, the freshwater mollusks in Georgia are one of the most diverse and abundant found anywhere in the world. However, freshwater mollusks are an imperiled group of animals and many efforts have been taken to confront mussels dying off (Butler & Hartfield, 2006). Researchers think the primary cause for species loss could be increased water demands by people and alterations to natural river habitats (Gollady, Gagnon, Kearns, Battle, & Hicks, 2003). Mussels are important because they are one of the most sensitive indicator species occurring in the ACF River Basin. Furthermore, the ACF River Basin has several endangered species of mussels (Golladay, Gagnon, Kearns, Battle, & Hicks, 2003). While many fish can move away from polluted stretches of rivers and streams, mussels will remain until they can no longer survive. However, mussels have complex life cycles, making re-colonization difficult in restored waters. In Georgia, mussel species richness has been found to vary with average channel depth, forest cover and drainage network position (Gagnon, Michener, Freeman, & Box, 2006). They are also a vital food source for certain fishes and mammals, including otters, muskrats, and raccoons (<http://www.gadnr.org/>).

The majority of mussel species live in streams or rivers, although a few species live in lakes as well. Mussels can survive in a variety of streambeds, but most species prefer a mixture of sand, gravel and cobble. Adult freshwater mussels feed by filtering food particles – including algae and bacteria – from the water (<http://www.georgiaencyclopedia.org>). They collect the food particles by siphoning them through their entire body cavity.

Many mussel species release sperm into the water, which is carried by water currents to female mussels (Storer, 1951). Female mussels then can capture the free-floating sperm in a similar manner to their feeding behavior. The mussel's eggs are fertilized in its body cavity, where the mussel larvae can safely grow (<http://www.georgiaencyclopedia.org>).

The U.S. Fish and Wildlife Service recognizes 14 distinct threatened or endangered mussel species in Georgia. Several of these species live in the ACF River Basin, including the oval pigtoe and the shiny-rayed pocketbook.

The oval pigtoe's reproductive season goes from May to late July (Baker, 1928). Likewise, shiny-rayed pocketbooks release their mussel larvae from late May through mid-July when water temperatures fluctuate from 20 C to 23.5 C.

Mussels have an odd parasitic relationship with during their beginning stages of life. Mussel larvae, called glochidia, require a period of parasitism on the gills or fins of a fish. Glochidia reach the host species in two manners. The first option is for the female mussel to release the larvae into the water column (<http://www.georgiaencyclopedia.org>). Once the glochidia reach a potential host fish, they latch onto the fish's gills or fins. The second method is for the female mussel to trick a fish by displaying a lure. These displays mimic a specific type of food eaten by the target fish to ensure the mussel larvae will develop into a juvenile mussel. For several weeks or months, the mussel larvae draw nutrients from their fish host.

After progressing to a more mature state, the juvenile mussels free themselves from the fish to live on the river bottom (<http://www.georgiaencyclopedia.org>).

Freshwater mussels are sensitive to pollution, sedimentation, and other human-induced habitat alterations (U.S. Fish & Wildlife, 2006). Historically, the primary factors leading to the decline of mussels and snails in Georgia were the construction of dams; dredging; in-stream sand and gravel mining; deforestation; and pollution. Sedimentation, further dam construction, and urbanization continue to degrade or eliminate mussel habitat (U.S. Fish & Wildlife, 2006). Decreased water flow caused by drought and withdrawal of water from streams and rivers poses a threat to the survival of many species of mussels.

Data Analysis and Results

ACF watershed data for groundwater, surface water, and water quality was collected from, USGS water resources for the United States web resource pages.

Agricultural water use data was obtained from the ground water and surface water supplied systems from the U.S. Geological Survey. We also obtained data on typical year irrigation application depths (inches) expected for monthly irrigation across all crop types for sub-basins of the Lower Flint. Data were derived from observations of the Ag Water Pumping program from 1999 through 2004 (Hook & Harrison, 2005).

Average monthly irrigation applications are influenced by the proportion of wet and dry years. Based on the data collected over the six years of observations, there was variation in the precipitation amounts that affected agricultural irrigation withdrawal amounts. The years 1999, 2000, and 2002 had dry summers, whereas 2003 was a wet summer. Both 2001 and 2004 were more normal summers in terms of precipitation. These monthly averages are offered as the typical irrigation scenario for each sub-basin.

Our indicator species ecological sensitivity index was based on the biological reproduction periods of each species. Our index assumes species are at their ecologically sensitive peak during primary reproductive months when species are spawning or during the emergence of reproductive adults. Sensitivity is arbitrarily denoted by 0 = No sensitivity; 100= Sensitivity (Peak breeding time). These periods are critical for the chosen species to successfully complete their life cycle. As noted previously, the species were chosen due to their being good indicators of water quality and overall watershed health. Since water withdrawals from surface and ground water throughout the ACF River Basin have effects on the entire watershed and its health, it is important to document during which months high water demand and water use overlaps with the high ecological needs of the watershed flows and its inhabitants.

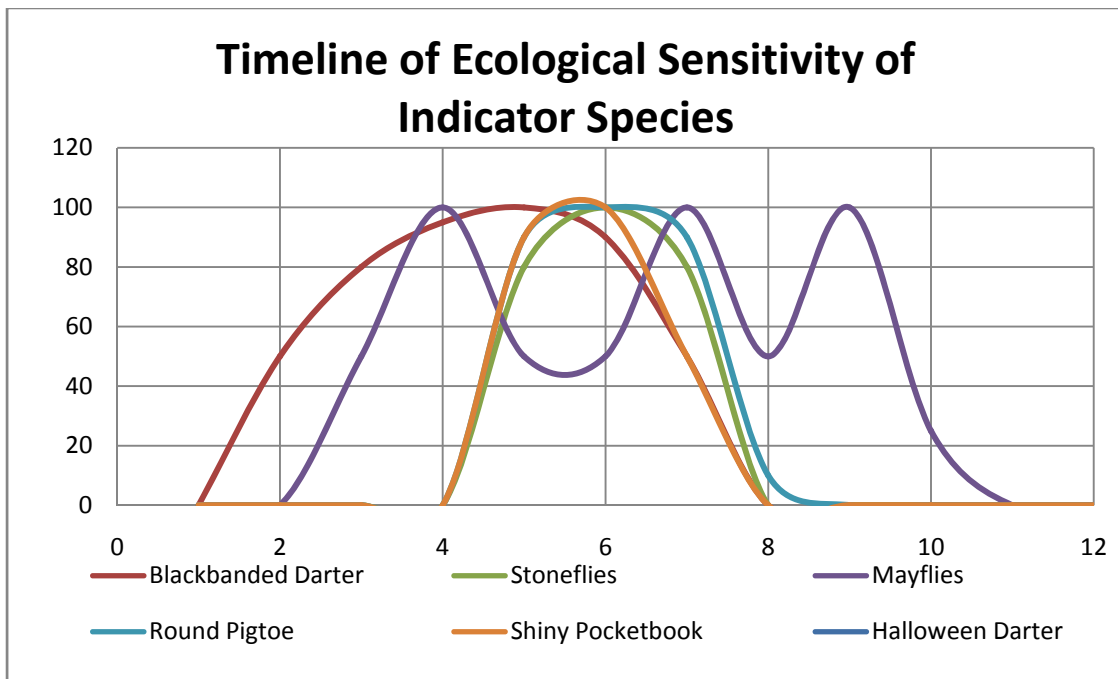


Figure 6: Timeline of Ecological Sensitivity of Indicator Species; X-axis denotes months 0-12, (January-December). Y-axis; Ecological sensitivity is based on a (0 -100) index.

The following stations were included in the stream flow analysis:

Station Descriptions

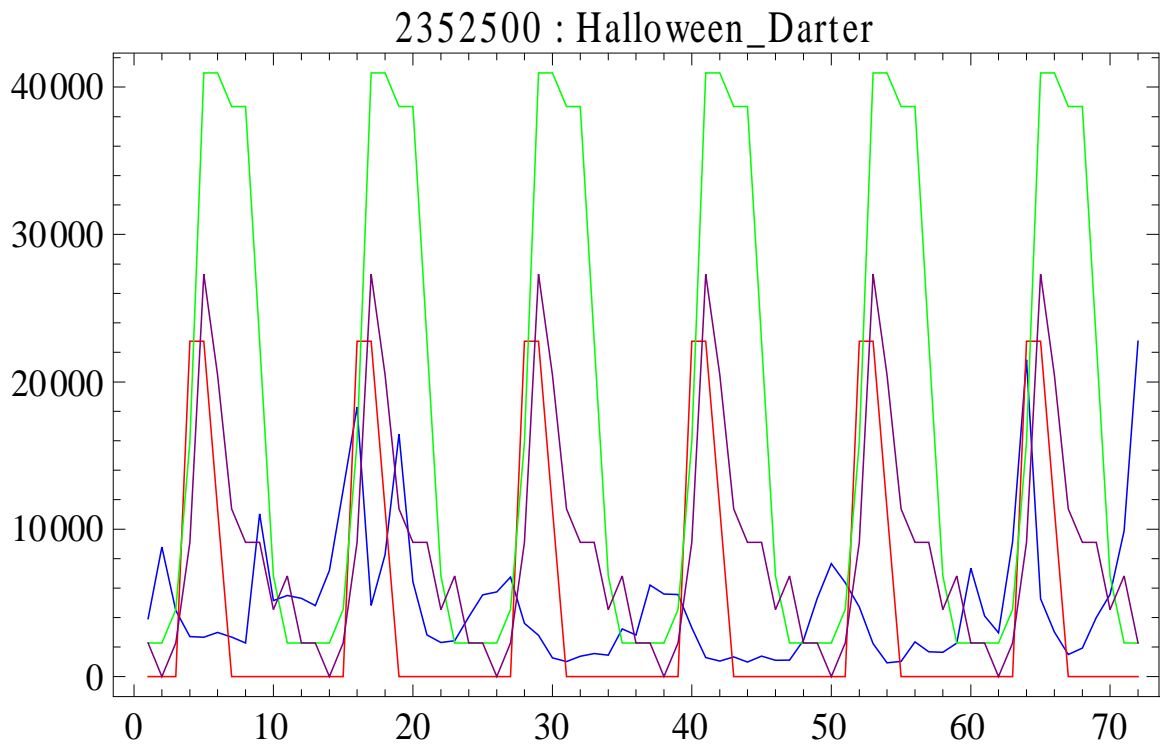
02334430 Chattahoochee River at Buford Dam near Buford, GA
02334480 Richland Creek at Suwanee Dam Road Near Buford, GA
02334578 Level Creek at Suwanee Dam Road near Suwanee, GA
02335000 Chattahoochee River near Norcorss, GA
02335350 Crooked Creek near Norcross, GA
02335815 Chattahoochee River below Morgan Falls Dam, GA
02336030 N.F. Peachtree Creek at Graves Road near Doraville, GA
02336120 N.F. Peachtree Creek Buford Highway near Atlanta, GA
02336490 Chattahoochee River at GA 280, near Atlanta, GA
02336635 Nickajack Creek at US 78/278, near Mableton, GA
02336968 Noses Creek at Powder Springs Road, Powder Springs, GA
02337170 Chattahoochee River near Fairburn, GA
02338000 Chattahoochee River near Whitesburg, GA
02338523 Hillabahatchee Creek at Thadton Road, near Franklin, GA
02338660 New River at GA 100, near Corinth, GA
02346310 Potato Creek at County Line Road, near Orchard Hill, GA
02347500 Flint River at US 19 near Carsonville, GA
02351500 Muckalee Creek near Americus, GA
02352500 Flint River at Albany, GA
02354800 IchawayNochaway Creek near Elmodel, GA
02355662 Flint River at Riverview Plantation, near Hopeful, GA
02358000 Apalachicola Rier at Chattahoochee, FL

Station graphs are listed by ID number, x-axis is month, Y-axis is cubic feet of water

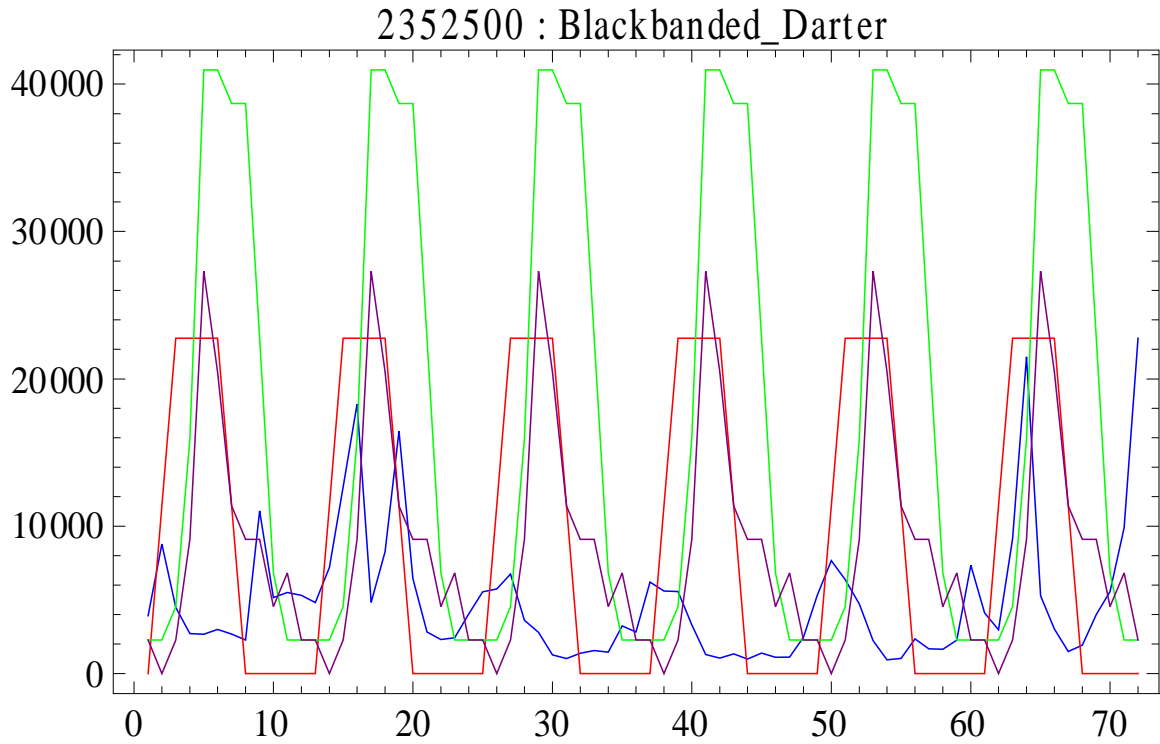
Mathmatica software package was used to create the ecological sensitivity, surface flow, agricultural withdrawal, and overlay graphs. Station (2352500) and (2355662) use lower-flint Ag-use data, and (2354800) uses Ichaway-Nochaway Ag-use data. X-axis data is consecutive months for 6 years, (1-72): January-December, Y-axis flow scale. (Derivatives were calculated using the central difference formula in Mathematica. Central difference is $f'(x)$ approximately equals $(f(x+h) - f(x-h))/2h$, and has an error bound of $O(h^2)$... which means on order of h^2 ...

<http://math.fullerton.edu/mathews/n2003/differentiation/NumericalDiffProof.pdf>

Graphs below are identified by the site Id, and the indicator species used for comparison.



Figures 7: Flint River at Albany GA. X-axis is months, Y-axis is surface flow scale. Green is agriculture groundwater use (application depths in inches); Purple agricultural surface water use; Red is ecological sensitivity; Blue is stream flow (cfs); All data is multiplied by max flow to scale.



Figures 8-24: 2352500- Flint River at Albany, GA. 02354800-IchawayNochaway Creek near Elmodel, GA. 02355662- Flint River at Riverview Plantation, near Hopeful, GA
 Green is agriculture groundwater use (application depths in inches); Purple agricultural surface water use; Red is ecological sensitivity; Blue is stream flow (cfs); All data is multiplied by max flow to scale.

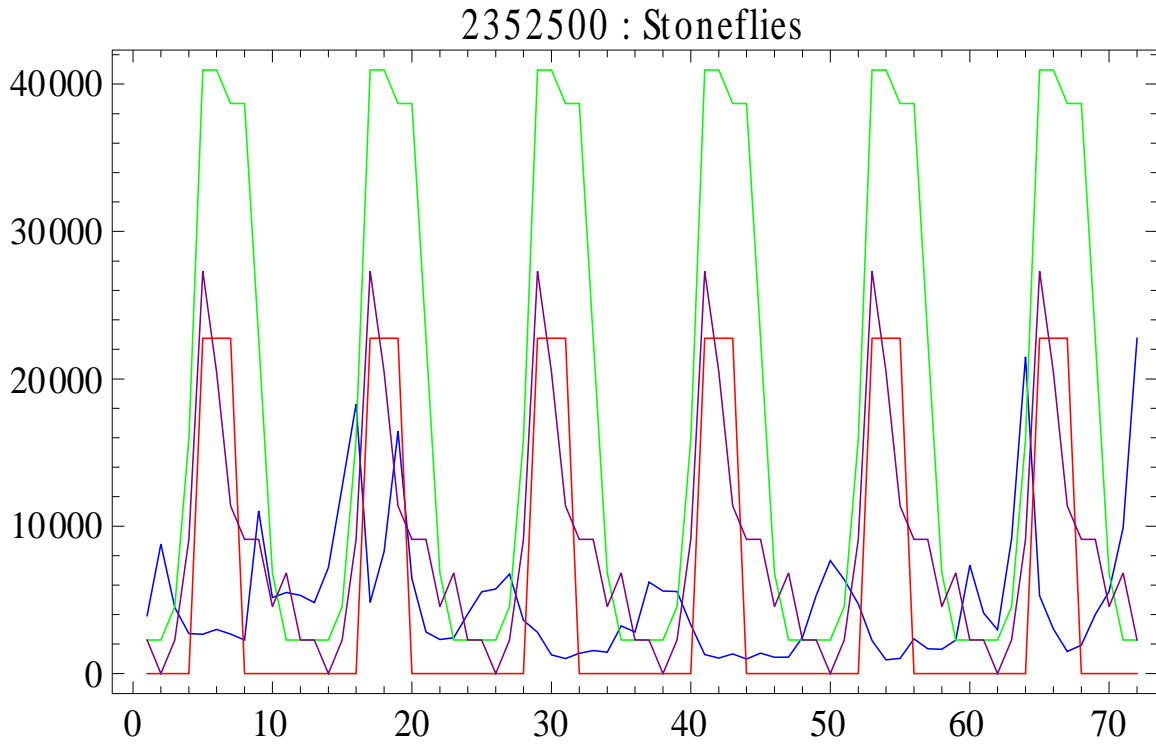


Figure 9:

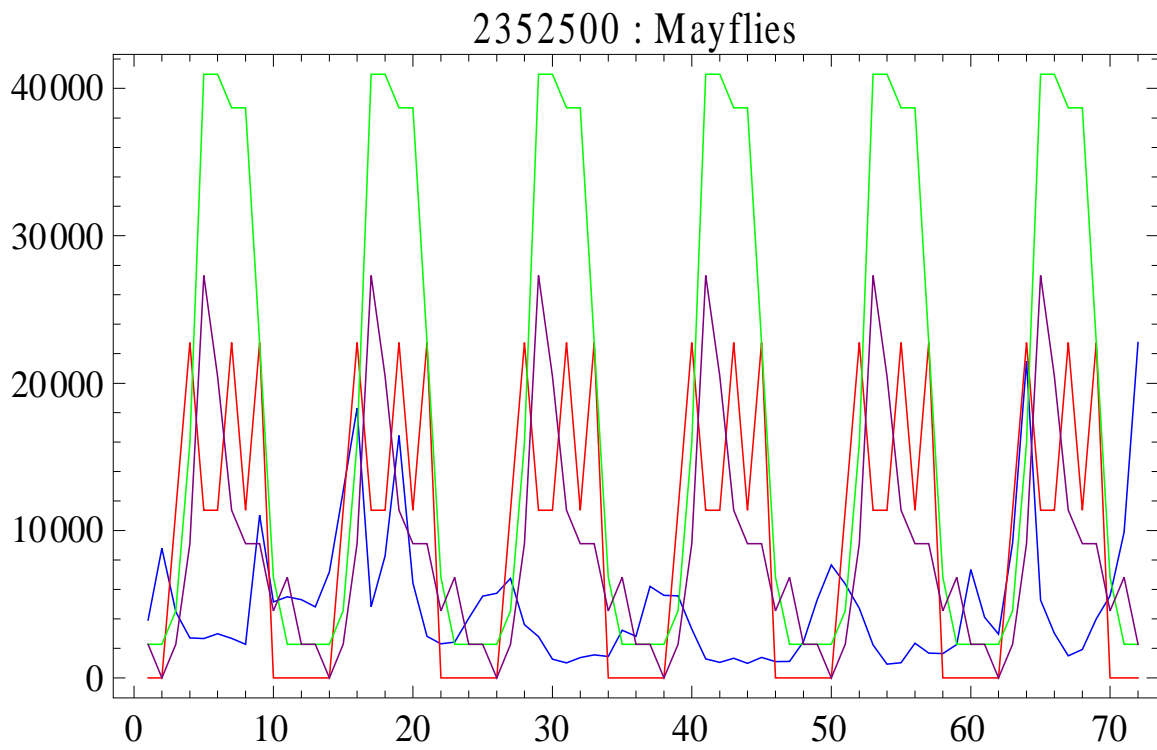


Figure 10:

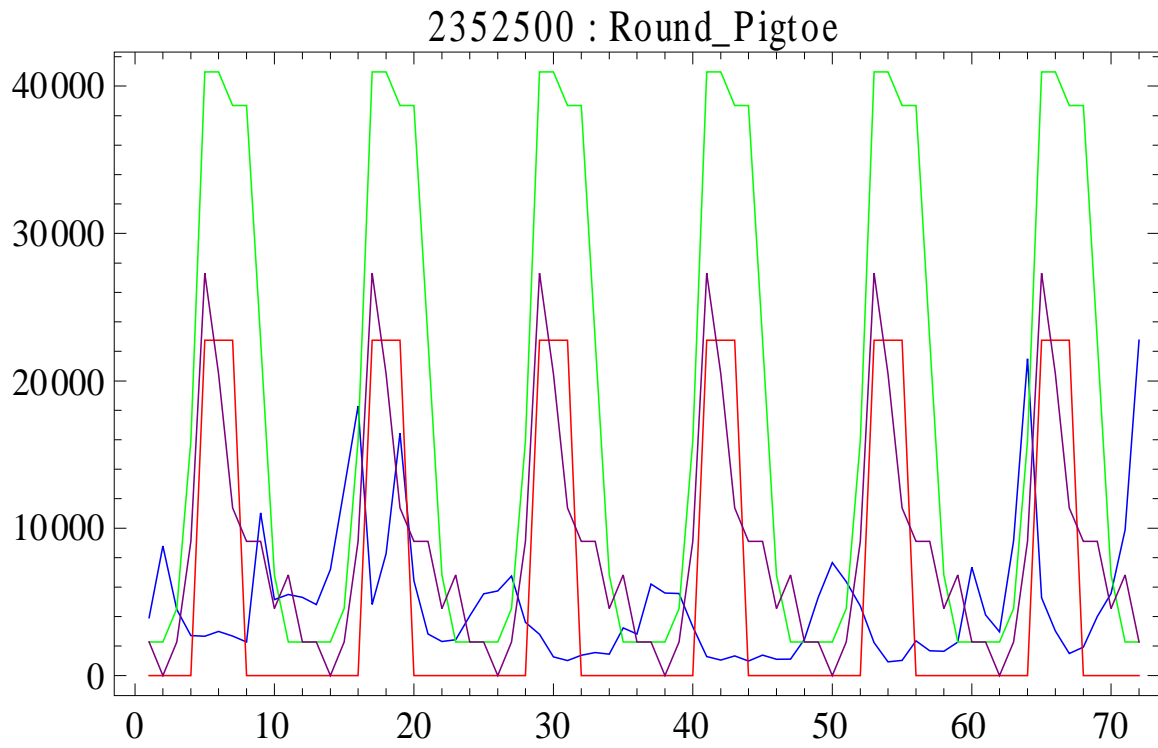


Figure 11:

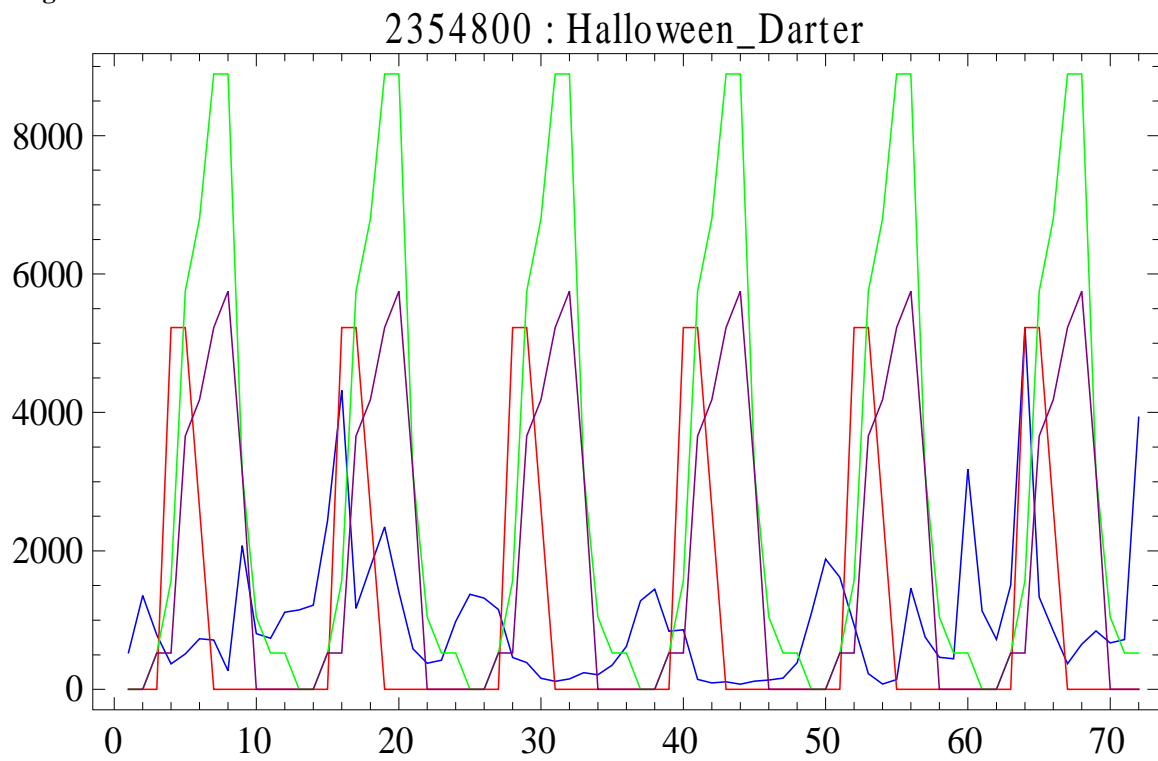


Figure 12:

2354800 : Blackbanded_Darter

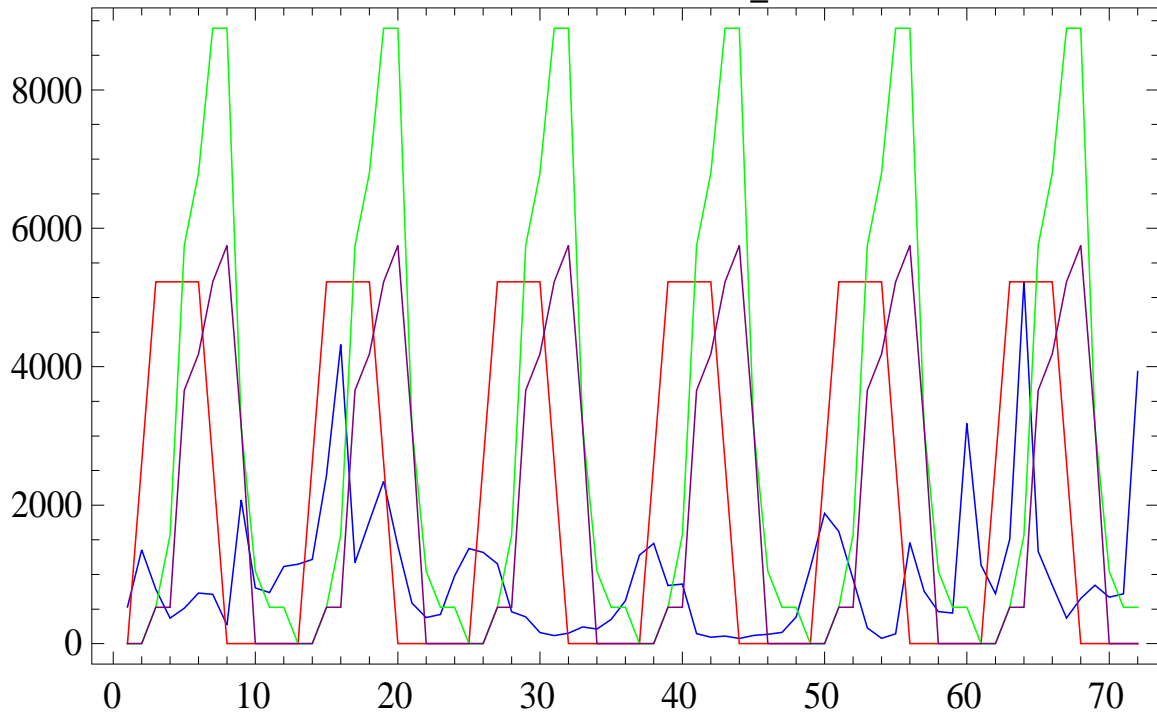


Figure 13:

2352500 : Shiny_Pocketbook

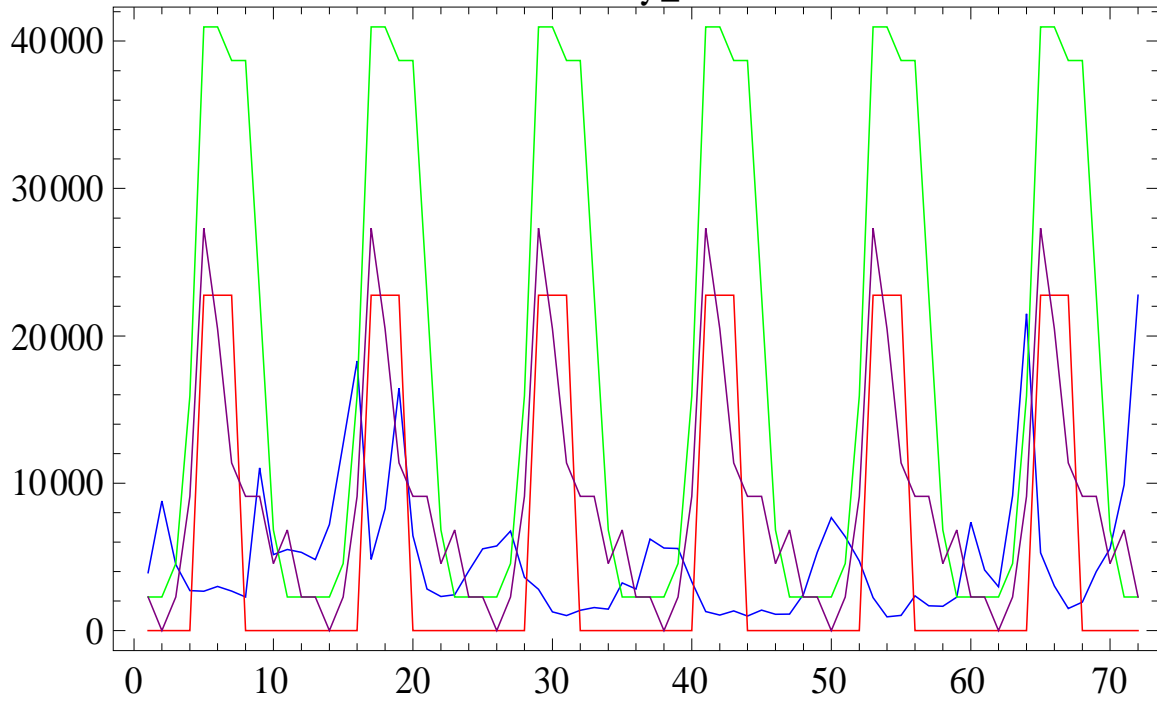


Figure 14:

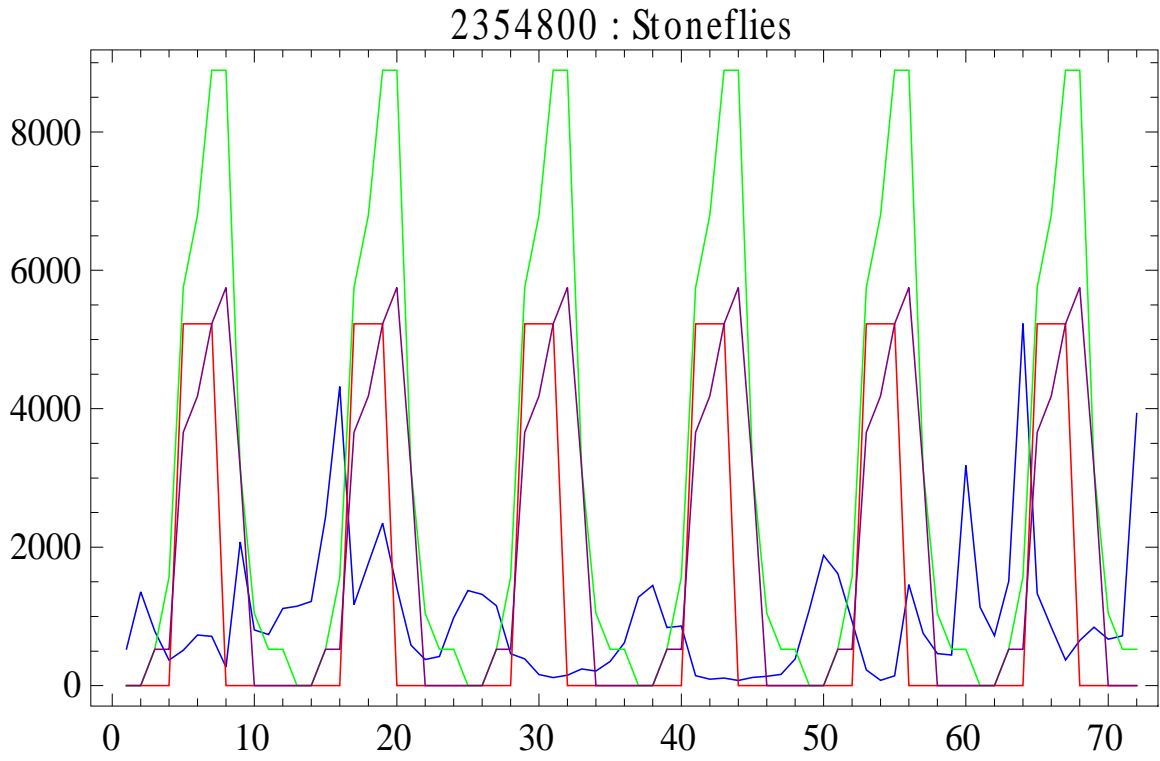


Figure 15:

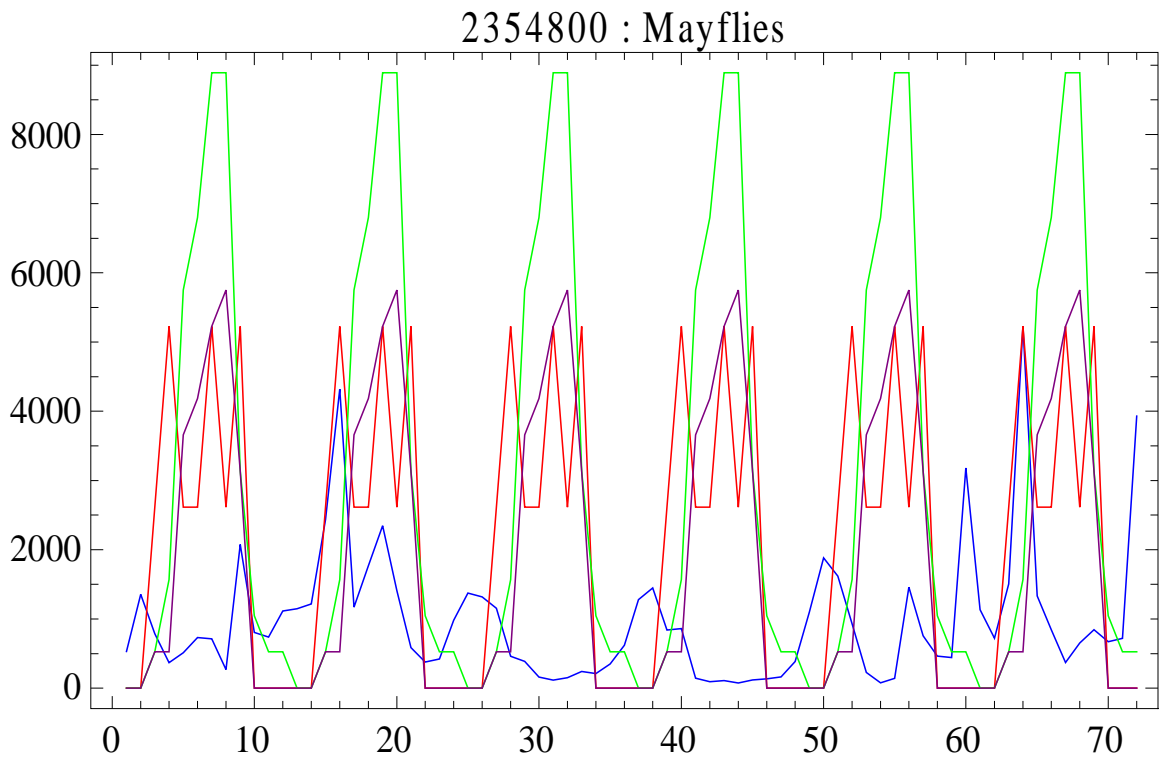


Figure 16:

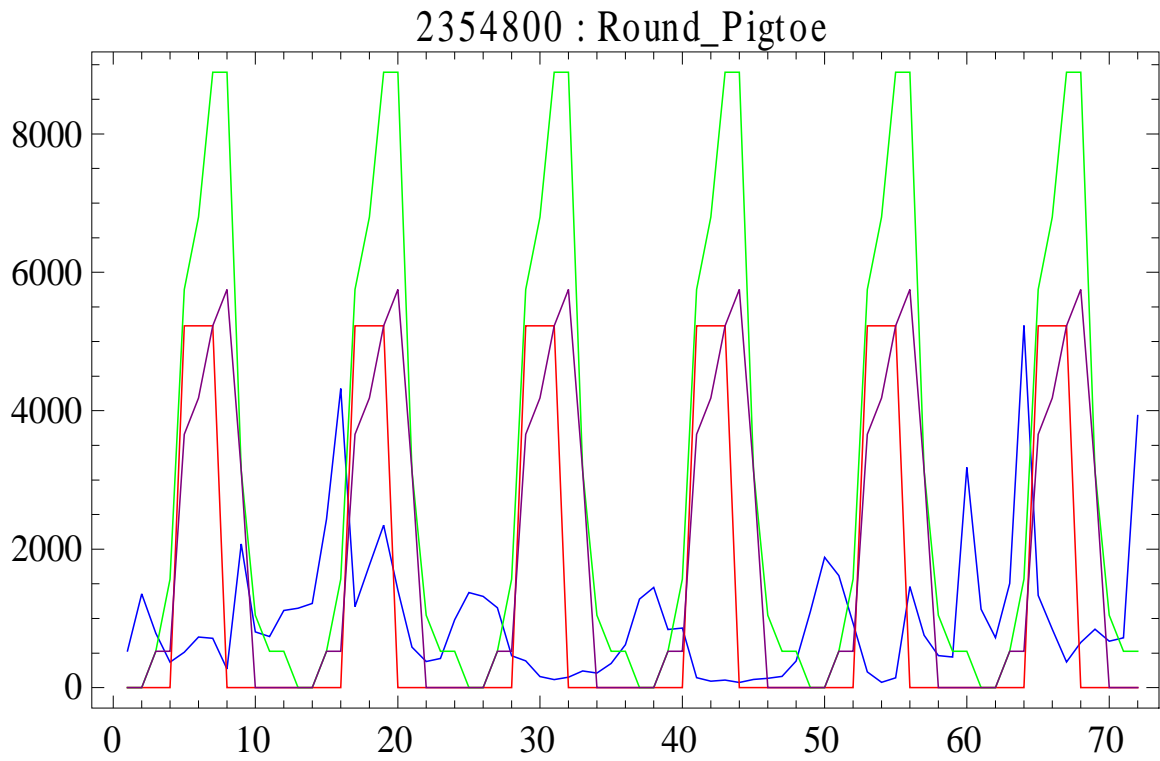


Figure 17:

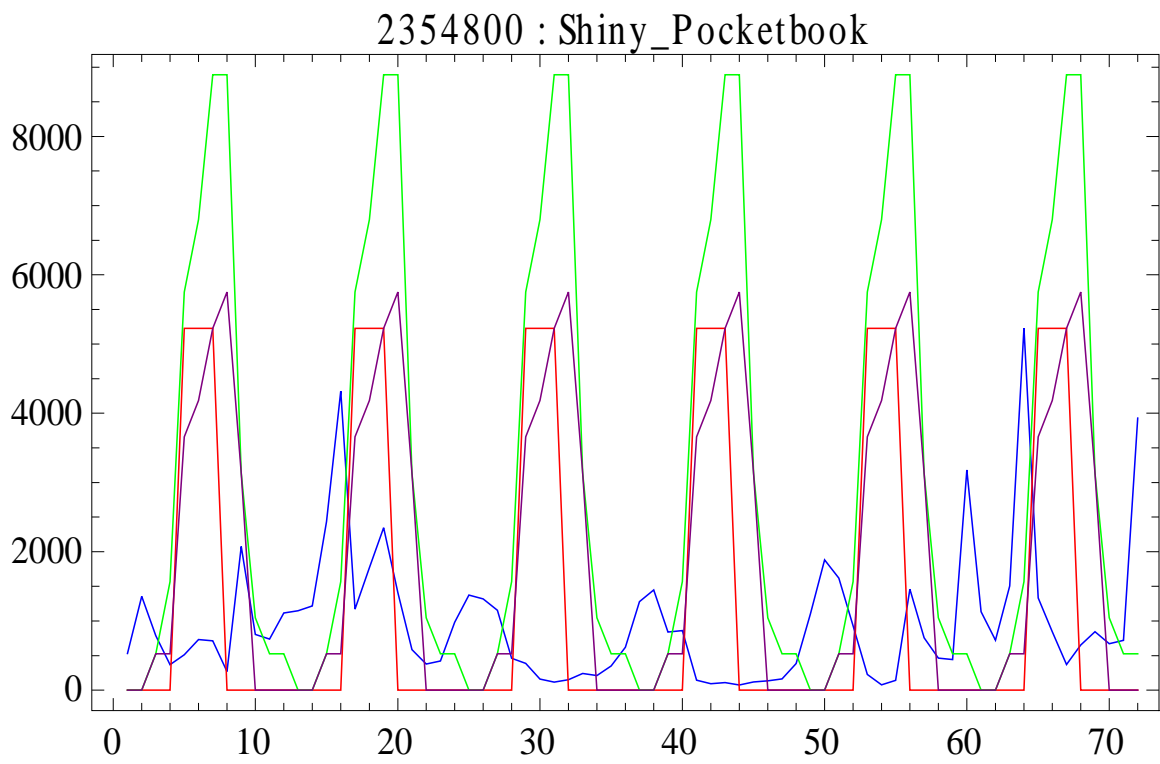


Figure 18.

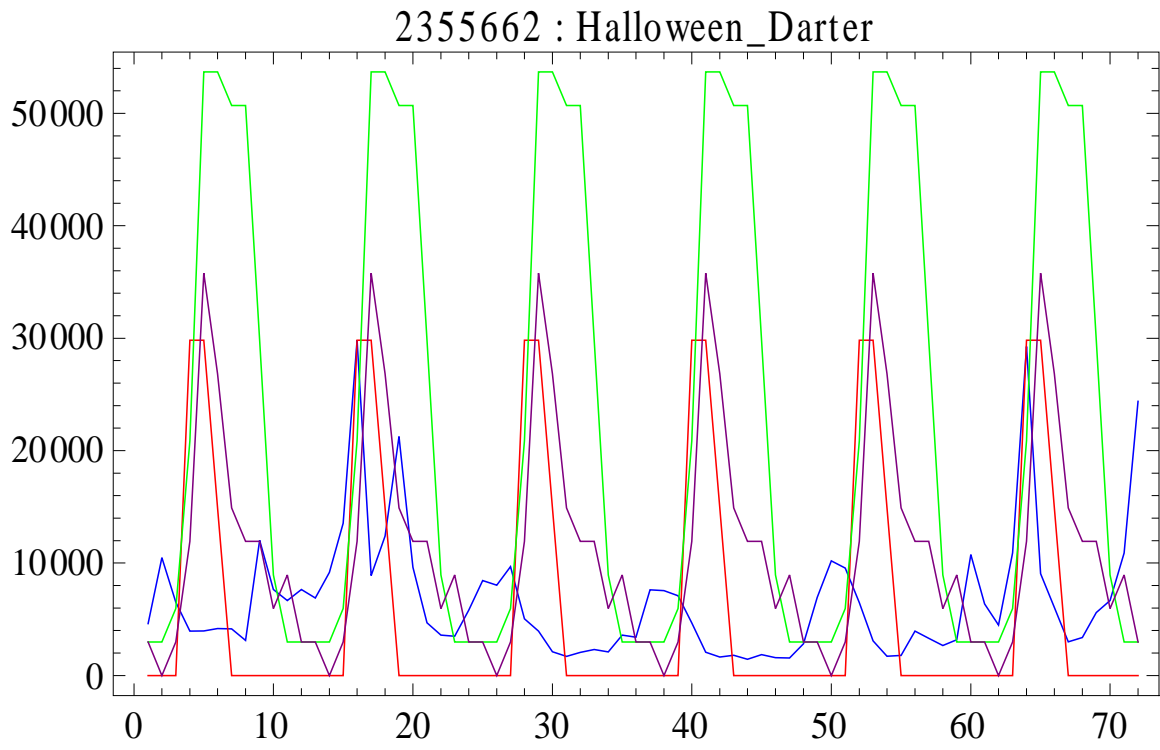


Figure 19:

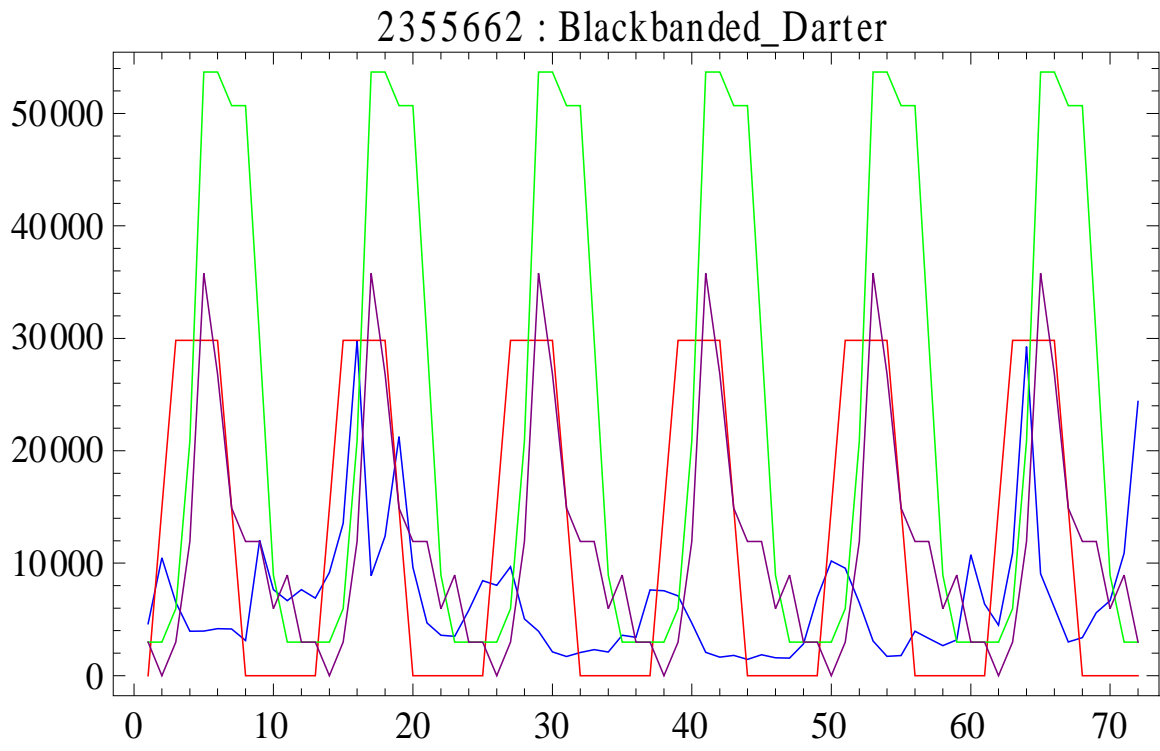


Figure 20:

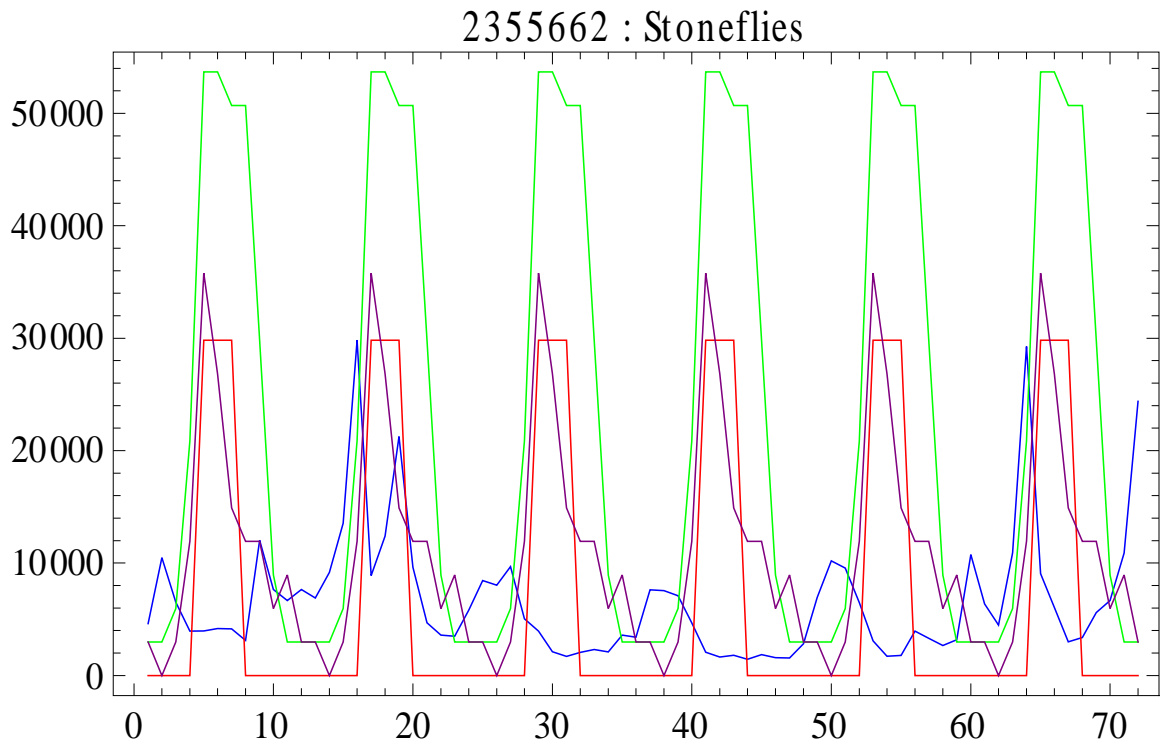


Figure 21.

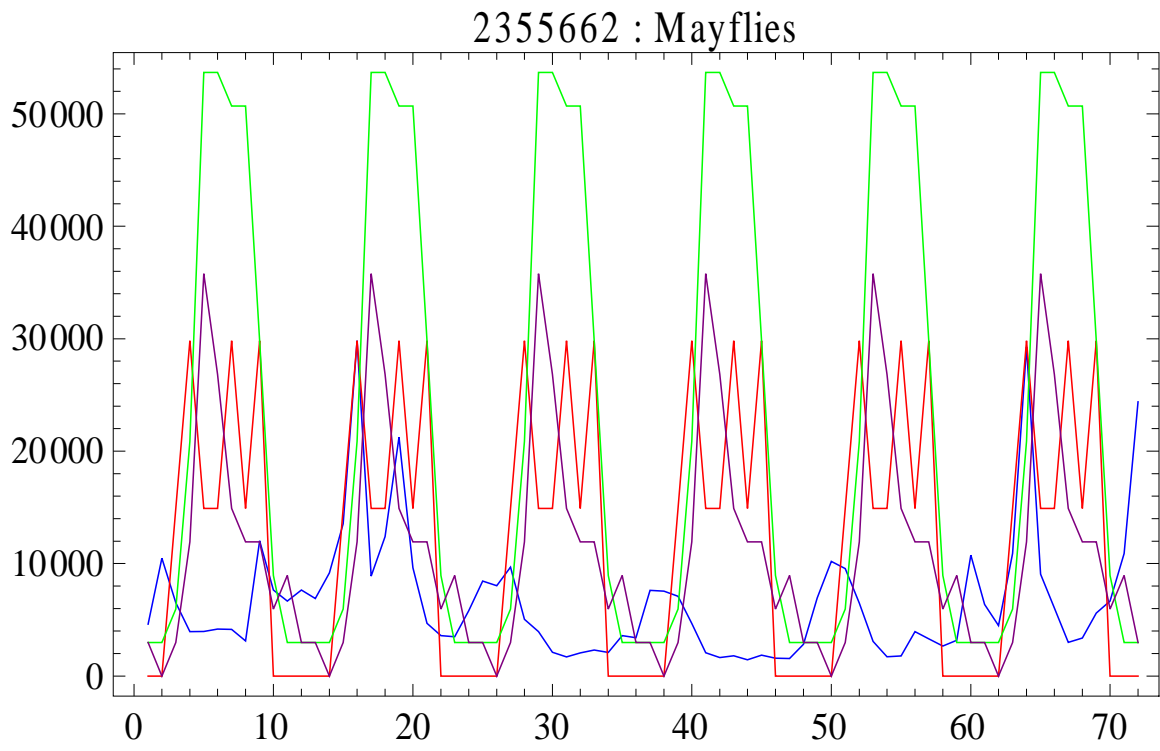


Figure 22:

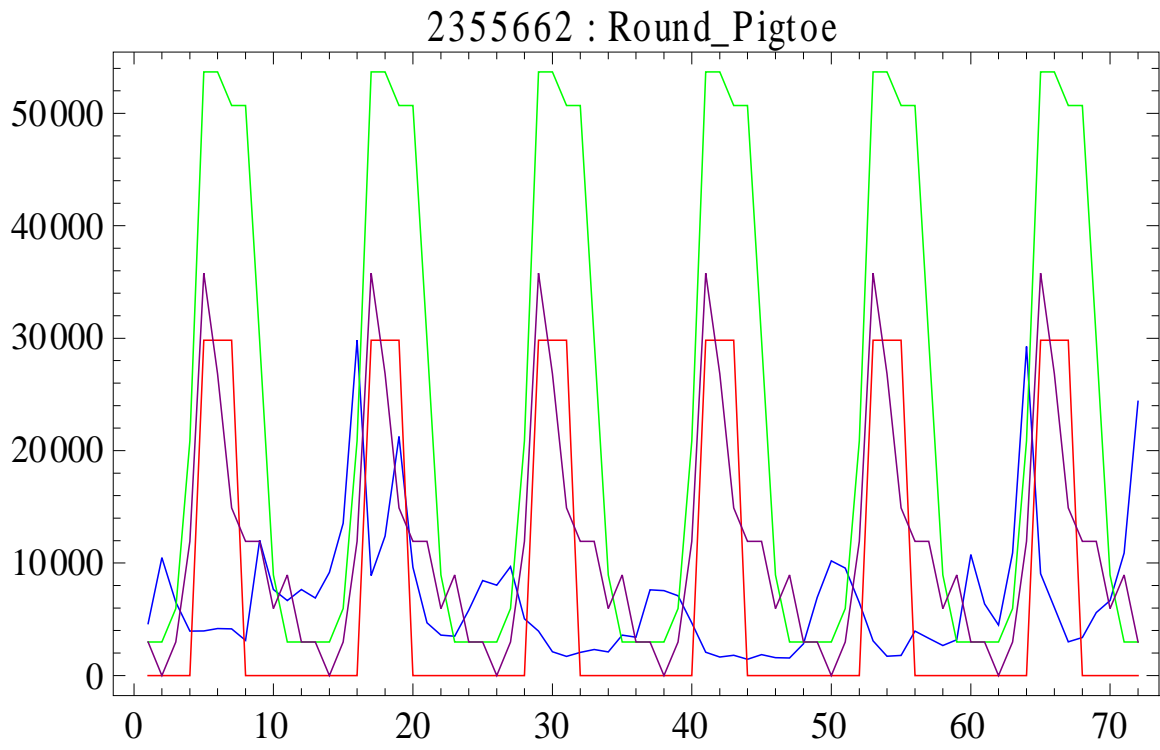


Figure 23:

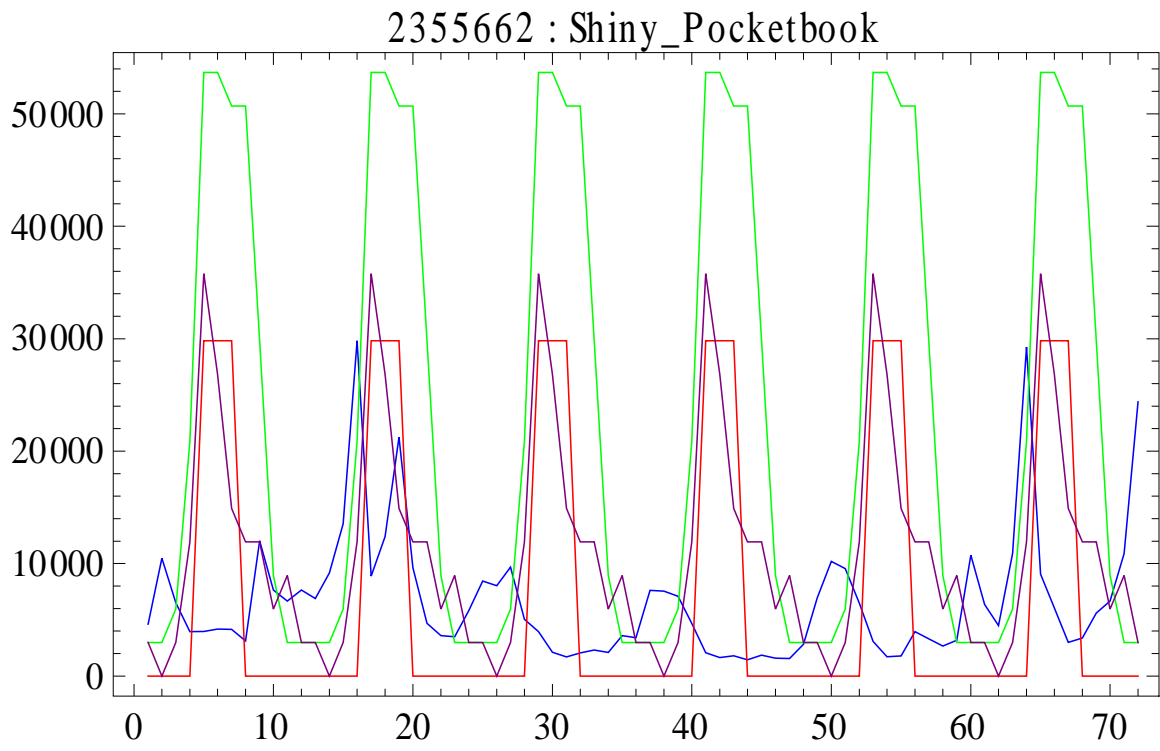


Figure 24:

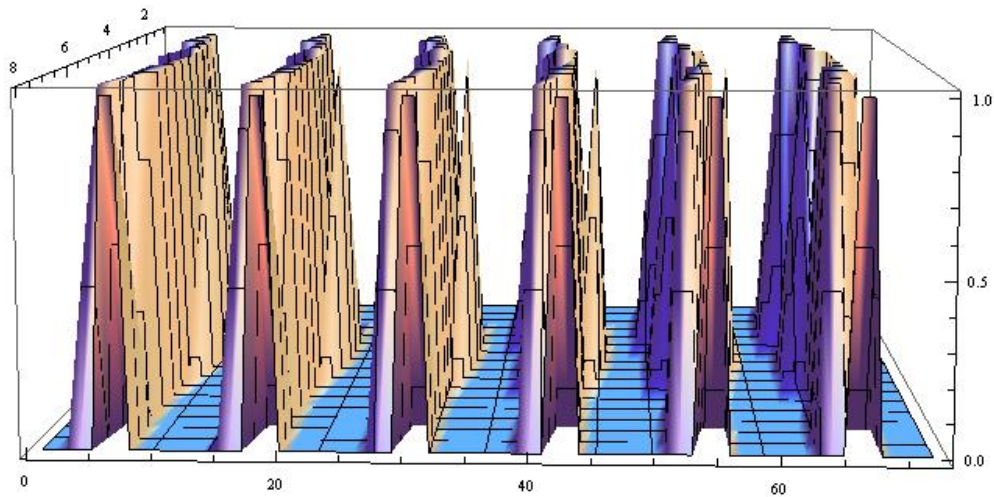


Figure 25: 3-D Species sensitivity index. X-axis is 6 year monthly span, Jan-Dec; Y-axis is scale (0-1) 0=No sensitivity, 1=Sensitivity; Z-axis are the species numbered (1-6).

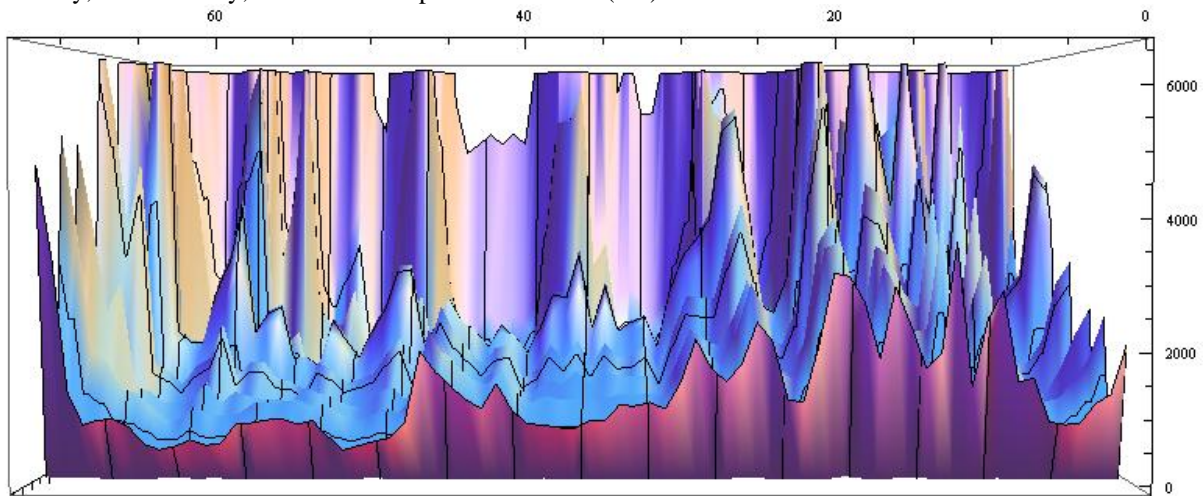


Figure 26: 3-D Surface water flows for each of the 22 stations selected.

As can be seen in figures 7-24, there is a very high correlation between ecological sensitivity and water demand during the late spring into summer. Each species has different environmental requirements for reproduction that vary depending on location, and some species have multiple periods of sensitivity where others have only a short window of sensitivity. Using GIS software to plot the position of specific species and corresponding stream flow statistics at particular stations throughout the ACF river basin will enable us to get much better ecological impact results compared to water use needs at each location. This will help us pinpoint ecological “hot

spots” where water demands have the greatest negative effects on the stream ecosystems, and identify other areas where water demand has little affect on stream ecosystems. Analysis of the 3 stations in the lower Flint river basin provide a good “enough” picture of the type of agricultural water demand in these areas, and its high correlation to reproductive time frames for many river basin inhabitants. Agriculture groundwater withdrawals are much greater than Ag surface water withdrawals, and since groundwater withdrawals have a delayed effect on stream flow, they most likely have the greatest impact in the late summer months, rather than the spring and early summer. This project needs to establish an accurate groundwater lag period for affects on stream flow to make a conclusive determination about overlap of water use and ecological needs.

Conclusions

Our project looks into how variation in stream flows and groundwater levels affects the ecological health of the ACF River Basin, focusing this portion of the project on agricultural withdrawals. We were able to look at natural variation in surface water flows, and agricultural water use for surface and groundwater, to compare with a select group of indicator species and determine overlap of peak ecological sensitivity and agricultural water use needs. We addressed each of our research questions:

RQ1: How do stream flows vary in the ACF River Basin?

RQ1: Are key indicator species most vulnerable during times of peak water use?

RQ2: Which species are most vulnerable to decreased stream flows from irrigation?

RQ3: If and when does agricultural water demand overlap with ecological sensitive periods of time within the ACF river basin?

Stream and groundwater flows throughout the region were identified to vary greatly depending on the surrounding land cover, population, water demands, rainfall, impoundments, and river source waters. Indicator species were identified, and their reproductive time periods were used to indicate ecological sensitivity. Most indicator species reproductive time periods begin in the spring and continue into summer. Depending on specific biological needs some begin reproducing earlier and other continue to reproduce late into the summer. The group was able to create an overlaying graph of indicator species ecological sensitivity, surface flows, agricultural surface and groundwater use in the lower Flint River area. Overall, the project shows that agricultural water demands are greatest during the spring and summer months, and have a high correlation to the reproductive timeframes for many of the river basins inhabitants, which are most sensitive during the spring and summer months.

Further Research on the Project

This is a working project and further research, data collection, and analysis will be continued in the future. Areas of extension on the project include:

- Using drought year data from the Lower Flint Watersheds, and comparing to the typical year applications.
- Use recent data, collected as part of the State Water Management Plan, and use monthly surface and groundwater demands for agricultural use by local drainage areas (LDAs).
- Further documentation of the hydrologic interaction between groundwater withdrawals and surface water flows. Need to establish a lag timeframe between groundwater withdrawal and stream flow affects.

- Use of GIS to identify specific areas within the ACF river basin affected highly by stream flow changes.
- Closer analysis of water quality data and the interaction with ecological sensitivity at particular station sites within the ACF river basin.

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