THE FLINT RIVER BASIN:

TECHNICAL SUMMARY OF HYDROGEOLOGY, FARM WATER USE, AND ECOLOGY

The Flint River starts at Hartsfield-Jackson International Airport in Atlanta, GA. It flows southward approximately 349 miles to where it joins the Chattahoochee River to form the Apalachicola River. The Flint River drains an area of 8460 square miles, entirely within the boundaries of Georgia. The Flint has only two major impoundments on it: Lake Blackshear, near Warwick and Lake Worth, near Albany. Otherwise, the Flint River has one of the longest stretches of un-impounded flow of any river east of the Mississippi.

This report provides brief technical summaries of some of the major scientific aspects of the Flint River Basin: its hydrogeology, agricultural water use in the lower Flint River Basin, and fresh-water mussel ecology. These are the principal scientific areas that will be central to the Flint River Regional Water Development and Conservation Plan.

General basin description

The upper half of the Flint River, from Atlanta to Highway 137 between Crawford and Taylor Counties, is within the Piedmont Province of the Appalachian Mountains. Topography ranges from rolling to mountainous. Maximum relief in the FRB is approximately 1200 ft where the Flint River flows through the Pine Mountain trend in Meriwether County. Otherwise, relief is typically less than 500 feet.

The Piedmont section of the Flint River is characterized by straight segments reflecting the influence of crystalline bedrock structures such as faults, fractures and compositional trends. Furthermore, since bedrock structural trends are almost perpendicular to the river, there are numerous rocky shoals that are of great aesthetic and aquatic habitat value. In this part of the basin, the Flint River and its tributaries receive water from surface runoff, storage in saprolite, and bedrock fractures. The Flint River is almost always a gaining stream in this area.

Where Highway 137 crosses the Flint River, the river crosses the Fall Line, which separates the Piedmont from the Coastal Plain Province in Georgia. At the Fall Line, the gradient of the Flint River decreases abruptly and the river's floodplain widens as the Flint flows over coastal plain sediments instead of crystalline bedrock. South of the Fall Line, the channel pattern of the Flint switches from straight to meandering as its gradient drops and it flows over softer sediments of the Coastal Plain.

A few miles north of where Turkey Creek joins the Flint River in Dooly County, the Flint enters a physiographic sub-province known as the Dougherty Plain. The Dougherty Plain is underlain by the Ocala Limestone and a heavily weathered residuum. The Ocala Limestone comprises the Floridan aquifer in the Dougherty plain region, and the aquifer is unconfined to semi-confined from Turkey Creek to the confluence of the Flint and Chattahoochee rivers. In this area, the Flint River has incised into the limestone, and thus changes channel morphology significantly. Specifically, it again becomes characterized by straight segments and what appear to be entrenched meanders as it cuts down into the Ocala Limestone. Southward from Turkey Creek, the river receives hundreds of millions of gallons of groundwater discharge from the Floridan aquifer. This stream-aquifer relationship is unique in Georgia, and is the reason that the Flint River is of such concern to resource planners and southwest Georgia stakeholders.

At the common boundary of Sumter, Crisp, and Lee counties, the Flint River makes a broad curve to the west, and flows southwestward towards Lake Seminole. Below this point, the FRB begins to exhibit an interesting asymmetry in the length of its major tributaries. In the northern half of the basin, tributaries on either side of the Flint are of approximately equal length; i.e., the Flint River flows approximately down the middle of its basin. South of the westward curve, tributaries on the west or north side of the River are far longer than those on the southern or eastern side. The latter flow directly off of the Pelham Escarpment, which is a ridge of the more resistant Tampa Limestone that overlies the Ocala. The longer tributaries drain the rest of the Dougherty Plain and the adjacent parts of the Fall Line Hills that adjoin the Dougherty Plain on the north.

Hydrogeology

An aquifer is a geologic formation that can store and transmit significant quantities of water. Four major aquifers underlie the lower half of the Flint River Basin. Each aquifer is separated from the ones above and below by layers of clay or silt that impede the vertical flow of water from one aquifer to another. The aquifers are tilted to the southeast and overlie one another, such that the oldest and lowest layer is exposed farthest to the north along the Fall Line. The youngest and shallowest layer is exposed farthest to the south. The aquifers receive most of their water from the areas where they are exposed at or near land surface. These are called recharge areas. The aquifers also receive recharge as slow seepage through the clay and silt layers that confine them above and below. This process is called leakage, or leakance, by hydrogeologists.

The deepest of these aquifers is the Cretaceous, or Providence, aquifer. It is composed of sand, shell, and gravel layers and some kaolin deposits of commercial and non-commercial value. The kaolin clays can be seen in small road cuts along Interstate 75 in Houston and Peach Counties. Sediments of the Cretaceous aquifer represent ancient shoreline deposits laid down approximately 80-100 million years ago when the Fall Line was the coastline of Georgia. The Cretaceous aquifer thus crops out along and near the Fall Line. It is a very productive aquifer providing abundant water supplies for agricultural and municipal users in the northern part of the Lower FRB.

Above the Cretaceous aquifer is the Clayton aquifer, which is a sandy formation towards the north but a limestone towards the south. The Clayton is a highly productive aquifer in the northwestern part of the lower FRB; however, unlike the other FRB aquifers it has a very small outcrop area and thus receives very little recharge from rainfall. The combination of the Clayton's high productivity and its small recharge area caused water levels in the Clayton to decline precipitously. In 1992, EPD imposed a permanent moratorium on new withdrawals from the Clayton.

Overlying the Clayton is the Claiborne aquifer. The Claiborne is typically a sandy aquifer like the Cretaceous aquifer, but it also contains more fine-grained sediment and consequently is not as productive as the Cretaceous in the northern part of the lower FRB. However, the Claiborne aquifer is very productive in parts of Sumter, Dooly, Lee, and Dougherty counties and is relied upon heavily in these areas for agricultural, industrial, and municipal water supply. The Claiborne has a much larger outcrop area than the Clayton, and thus recharges annually if rainfall is sufficient.

The Floridan aquifer lies above the Claiborne aquifer, and is one of the most productive aquifers in the world. It consists of a highly fossiliferous limestone that has developed an extremely high level of secondary porosity and permeability. In other words, groundwater seeping through the limestone has widened natural fractures, bedding planes, fossil moulds, etc., and created an extremely permeable layer. Furthermore, the Floridan aquifer is exposed over a very wide area…most of the Dougherty Plain…and thus receives complete recharge every year if there is sufficient rainfall.

Because the limestone is exposed at the surface, the streams and rivers in that area have cut down into the limestone. Therefore, the Floridan aquifer is in direct hydraulic connection with much of the surface water drainage network in the lower Flint River Basin. The Flint River and its tributaries receive hundreds of millions of gallons of water every day from the limestone. This is evident from the numerous springs along the stream channels in the Dougherty Plain. from Lake Blackshear to Lake Seminole, springs like Radium Springs and others provide the Flint River with large amounts of water. In fact, more than 20 major springs have been mapped by the Georgia DNR in the river section between Albany and Bainbridge. Furthermore, large volumes of groundwater seep directly through streambeds where bare limestone is exposed. The flow of water between the streams and the aquifer is referred to as “stream-aquifer flux”.

The amount of water that seeps or flows into the streams is controlled by the hydraulic pressure differential between the stream and the Floridan aquifer. As long as the head in the aquifer is higher than that of the streams, water will flow **from the aquifer** into the streams. This is called an effluent stream condition. However, if head in the aquifer drops below that of the stream, then water will seep or flow from the stream **into the aquifer**. This is called an influent stream condition. If a stream is an effluent stream, then the rate and volume of water entering the stream will depend on the head in the aquifer and the size of the spring opening. The greater the hydraulic differential, the more water will flow into the streams. It is like holding a water-filled funnel and siphon with your thumb over the end of the siphon tube. The higher the funnel is held, the greater the flow out of the tube when your thumb is released.

Not all the water that recharges the Floridan aquifer is released into the streams. The streams only cut into the upper few tens of feet of the aquifer (even though they receive most of the water that the aquifer discharges naturally). Under natural conditions (before irrigation pumping began), most of the water that fell as rain normally entered the Floridan regional flow system and flowed to down-gradient areas to the south and east. Thus, precipitation on the Dougherty Plain supplies the rest of the Floridan aquifer in Georgia with water. In warm weather, a significant amount of water is naturally drawn from the aquifer due to direct evaporation from the soil and sinkholes, and from plant transpiration (the pulling of water upwards by plants and release of it into the atmosphere). Once the groundwater infiltrates the earth below a depth of about 6 feet in southwest Georgia, plants no longer take up water from the aquifer. This is also a small drain on the aquifer compared to other types.

The US Geological Survey developed a mathematical model to simulate groundwater flow between the streams and the aquifer. The model is of a type known as MODFE, which stands for Modular Finite Element. model. The model consists of a detailed mesh composed of thousands of triangular “elements”. Where element sides meet, the model calls “nodes”. Hydraulic properties such as aquifer hydraulic conductivity and head can be assigned to nodes such that groundwater flow from element to element (across element sides) can be simulated. A complex mathematical formula describes the flow of water through aquifers, and takes into account aquifer properties, heads, and flow directions. Stream flow is simulated in the model by element sides lined up along the length of a stream. Groundwater flow at the stream boundary is simulated by flow into or out of elements along their sides.

Groundwater flow has been modeled by hydrologists for decades. The MODFE model was developed in the 1980's, and is particularly well-suited for situations where aquifers are discharging to streams. Other groundwater flow models are not sufficient for this, but are commonly used to model groundwater flow through aquifers only.

The MODFE model was selected by the USGS and GA EPD to determine whether there is a measurable or significant impact to the stream-aquifer system caused by irrigation pumpage. During the growing season, the amount of water withdrawn from the aquifer exceeds that which naturally discharges to streams and to regional flow. Thus, irrigation is a major drain on the aquifer. The USGS MODFE model used different hydrologic conditions that reflected aquifer conditions in wet, normal, and dry years. All models must be 'calibrated" to see if they can recreate known, measured, natural conditions. The USGS model was calibrated to match conditions in October 1986, which was previously one of the driest times on record in Georgia. The model, when run, did indeed closely recreate conditions for October 1986.

In addition to using different hydrologic conditions, the model input different irrigation scenarios using assumptions of a particular irrigation use for October 1986. Subsequent model runs increased pumping rates by factors of 0.5, 2, 5, times October 1986 pumping rates. The original assumption was that October 1986 pumping rates were approximately 20% of peak season rates, or 475 million gallons per day (MGD).

The results of the various model runs showed a range of aquifer responses to the increased pumpage. The worst case scenario involved increasing October 1986 pumpage by a factor of 5, in dry conditions and extremely low stream stage. In this scenario there were several large cones of depression, (areas where groundwater levels were lowered) centered on areas where irrigation pumpage is high. Specifically, a large cone of depression was centered on Miller County, where drawdown in excess of 70 feet was simulated. Three other large cones formed in northern Lee County and adjacent Crisp County where pumpage is high and the aquifer is thinner. In contrast to areas of large simulated drawdown, the USGS model revealed areas of very low drawdown, even under extreme drought conditions and 5X multiplier of October 1986 pumpage. These areas were mostly on the east side of the Flint River in Worth, Mitchell, and Decatur Counties. Similarly, an area between Albany and Ichawaynochaway Creek in Baker County had small simulated drawdown.

In addition to simulated drawdown, the USGS model simulated changes in the stream-aquifer flux that would be caused by the aquifer drawdown. The model simulated that several stretches of the Flint River and its tributaries would become influent; i.e., water would seep or flow from the streams back into the aquifer. According to the model , this was most likely to occur on part of Muckalee Creek in Lee County, part of Kinchafoonee Creek, and part of the Flint River. Elsewhere, many other stream reaches would experience a fraction of their normal aquifer flow, or there would be zero flow. Combined with surface water withdrawals for irrigation, the net effect of drought and heavy irrigation could be severe. The colloquial expression of this was that "the Flint River could go dry". Although this didn't happen, the Flint River and its tributaries did experience record or near-record low flows during the droughts of 1998-2002, and parts of Spring Creek did stop flowing. Parts of other tributaries came close to being totally non-flowing, such as sections of Ichawaynochaway Creek. Also, several large blue hole springs stopped flowing, or even flowed backwards into the Floridan aquifer, judging by temperature measurements taken at the backs of the springs by the DNR Wildlife Resources Division..

Because the Flint River didn't "dry up," the USGS was charged with re-evaluating their model. The original model was called a "steady state" model, because it simulated the aquifer and its water budget after a very long period of constant withdrawals and persistent conditions. At "steady state" conditions the aquifer is not receiving seepage from other sources like the overburden or other adjacent formations. (Steady state conditions could be pictured as measuring a car engine's performance after a long period of highway driving versus stop-and-start conditions: in the latter, the engine is always having to re-warm; fluids settle; etc.; whereas after highway conditions the engine performance is steady). The USGS model achieved "steady state" conditions after a period of more than 180 days. This is the approximate length of the growing season, during which conditions may change significantly and within which irrigation is extremely variable. The model did not consider seasonal fluctuations in irrigation that correspond to real-world planting and growing conditions. The new model being developed by USGS will be a "transient" model that will simulate aquifer behavior under real world, measured irrigation rates and schedules. It is assumed that the overall impact of irrigation will be somewhat less than that simulated for the steady-state model.

Another important hydrogeologic study conducted by USGS was the evaluation of Lake Seminole's effects on groundwater levels and flow directions. This study involved detailed evaluation of aquifer properties around Lake Seminole; measurement of groundwater levels; investigation of leakage under Woodruff Dam; evaluation of pre-Lake conditions; and a computer simulation of groundwater flows before and after construction of the dam. This study concluded that Lake Seminole has had a stabilizing effect on groundwater levels surrounding the Lake, and that groundwater levels have risen as much as 25 feet in some parts of Seminole and Decatur Counties. Furthermore, the presence of the lake as a zone of discharge has diverted groundwater away from being discharged into the Flint River from southeast of the lake to being diverted across the Florida state line into the Chattahoochee River for approximately 5 miles below Woodruff dam. An important result of the simulation is that groundwater discharge to Spring Creek is increased.

Agricultural Water Use

Agriculture uses the largest volume of water in the Flint River Basin. Total permitted municipal and industrial withdrawals are approximately 140 mgd. Agricultural permitted amounts total approximately 1200 mgd. Since 95% of irrigation occurs from April to September 30, that potential pumping rate could be as much 2400 mgd during peak irrigation times. Of that 1200 mgd permitted, approximately 337 mgd is permitted for withdrawals from surface water sources, and 874 mgd from groundwater wells. The predominance of groundwater usage reflects the easy availability of Floridan aquifer water in the Dougherty Plain.

Agricultural irrigation was rare in Georgia until the 1970's. Commodity pricing structures, crop loan rates and competition among farmers required more reliable annual crop yields achievable only by irrigation in Georgia where short-term droughts are a normal part of the climatic cycle. Beginning around 1978, irrigation systems started appearing all over Georgia. In 1954, by way of contrast, there were a total of 23,973 acres under irrigation in the entire state of Georgia (Thomson et al, 1954). This number has grown to 1.5 million acres (Harrison, 1991). In fact, the 1954 statewide figure represents only 3% of the irrigated acreage in the FRB alone.

As with the rest of Georgia, agricultural irrigation is concentrated south of the Fall Line in the FRB. Of the 714,000 acres under irrigation in the entire basin, more than 600,000 acres are south of the Fall Line. In the northern part of the FRB, irrigation is very sparse because of the lack of good soil and limited availability of groundwater. Aside from golf course and athletic field irrigation in metro Atlanta, most agricultural irrigation above the Fall Line is for sod farms and plant nurseries, with limited irrigation on hay and forage for cattle farms and horse pastures. Row crop irrigation is very sparse. Most irrigation is derived from surface water in the northern FRB.

Because agricultural withdrawal permits in Georgia have no reporting requirements, estimates of irrigation use have varied widely and have to be based on unreliable data. The least reliable estimate of irrigation water use has been to use permitted pump capacities in EPD's agricultural permit database. Each permit contains a permitted pump capacity submitted by the permit applicant or their drilling contractor. However, this only provides the total capacity of the pump motor, not a volume of water actually used. Totalling permitted pump capacities grossly overstates actually irrigation water use. It is estimated that farmers actually use only 5% of their total permitted water use based on permitted pump capacity. Basing estimates of irrigation water use is like basing a car's gasoline consumption on its motor's horsepower.

NRCS has provided estimates of crop water needs based on predicted rainfall and potential evapotranspiration calculated by the Blaney-Criddle model. For example, NRCS previously estimated that, in a drought year, farmers could use as much as 18 inches per acre.

Approximately every three years since 1970, the Cooperative Extension service has conducted a county-by-county survey of irrigated area, crops irrigated, and irrigation amounts based on those crops' irrigation in the survey year (Harrison, 2001). County agricultural agents determine those amounts for their county, and Extension Irrigation Engineering Specialists compile the information into the survey. In the most recent years of the survey, 1998 and 2000, area-weighted mean irrigation in 26 southwest Georgia counties below the fall line was 11.3 and 10.1 in., respectively. Irrigated area for these 26 counties, which made up the ACF lower Flint planning area, were 803,000 ac in 2000, according to the survey.

To refine the irrigation data with actual measurements on farmers' fields, in 1998, EPD requested that the Georgia Cooperative Extension Service (CES) establish a statewide system for measurement of water use by farmers and conduct a multi-year study of those water withdrawals . Engineers, researchers and statisticians of the University of Georgia (UGA) designed a statewide irrigation monitoring program that met the dual needs of rapid startup and modest budget. The basic design included monthly visits to selected irrigation sites by UGA personnel. Water use was calculated from equipment use time and calibrated flow rates for most irrigation systems. Electric timers were installed on irrigation application equipment when possible or on pumps or generators that supplied unique irrigation systems and had uniform flow rates. When flow rates varied over time, flow meters were used. At each monthly visit, crops that were in the irrigated fields were noted, and the proportion of water that was used on each was estimated.

Flow rates were measured with the pumps and application system operating under normal conditions and under control of the farmer. Portable “strap-on” digital flow meters provided flow rates. These did not require modification of the irrigation system for the measurement and follow-up flow checks could easily be made. A systematic follow-up of flow rates was made during the 2001 to evaluate changes in farmers systems over time.

A random sampling was used to identify potential participants for a voluntary monitoring program. A statewide 2% random sample was taken of the Agricultural Water Withdrawal Permits issued by EPD between 1988 and 1998. The state was divided into four reporting areas based on special water planning needs. The 26-county area in Southwest Georgia that had been described because of agriculture's unique role in water use in the tri-state water planning talks was designated as the monitoring area for the lower Flint basin. Setup and monitoring of AWP sites was initiated during 1999; 221irrigation systems were monitored in Southwest Georgia. Monthly monitoring was continued through 2004

Basin-wide mean annual application depths were 10.3, 8.1, 9.1, and 4.6 in. for 2000, 2001, 2002, and 2003, respectively. These irrigation depths were weighted by field sizes to minimize the influence of small fields of specialty crops that received high irrigation depths. The 2000 through 2002 data reflects water use during a period of drought considered one of the worst in Georgia's history. During 2003 significant periods of recharge occurred, and normal in-season rainfall returned. This was reflected in decrease in irrigation depths.

In each year, farmers at some of the metered systems made the decision not to irrigate. These varied from 5 to 7% during the drought years and increased to 11% during 2003. At times the decision to withhold irrigation was based upon limited water supplies; at others it reflected rotation of more valuable crops among a farmer's irrigation systems.

Farmers who used ground-water sources for irrigation used more water than those who relied upon surface water sources. Basin-wide mean application was 11.8 in. when irrigation was from ground-water sources, and 8.0 when it was from surface water sources in 2000. Similarly comparisons for 2001 through 2003 were 9.2 vs. 5.3, 9.4 vs. 6.8, and 5.2 vs. 2.7 in., respectively. Explaining these differences presents a "chicken vs. egg" dilemma. Farmers who produce higher value, more water intensive crops might drill wells to obtain a reliable water source; farmers with wells might choose to grow higher value crops. During the 1998 through 2002 drought, farmers often found that their surface water supplies had dried up. While they might have planned to use more water, dry ponds and streams prevented that. In still other explanations from farmers in our study, surface water supplies were often connected to irrigation systems like travelers that are used less frequently because of increased labor requirements. Thus for a variety of reasons, surface water users applied less irrigation during our study.

Faced with inadequate runoff to refill ponds just when it was needed for irrigation, many farmers drilled wells adjacent to the ponds to supplement them during peak use periods. In some cases, the choice of a well-to-pond system was made because wells of sufficient pumping capacity to directly supply the irrigation system were too expensive or impossible given the local geology. Wells of smaller capacity could be drilled and run longer, while water would be pumped out at higher rates with separate pumps while the irrigation system was used. In other cases the choice of well to refill the pond was only to provide insurance in times of inadequate runoff and stream flow to maintain pond water levels. The higher costs associated with pumping from ground-water and again from the pond made this a less desired option than using surface water whenever it was available.

EPD who issued permits by water source recognized well-to-pond systems as a separate category in its permitting. It was included among our random selections in proportion to those permits and counties. On a basin-wide basis, mean annual application depths were 9.8, 7.9, 7.5, and 4.6 .in. for 2000 to 2003, respectively. These values were in between amounts used with ground-water and surface supplies.

Irrigation systems in the Flint Basin include center pivots, traveler systems like hose reel and cable tow, solid set sprinklers, and micro-irrigation including surface drip, drip under plastic and subsurface drip. Irrigation depths for center pivot systems were very close to overall statewide means. This was expected since 90% of the region's systems were center pivots. Of these 54% were supplied by ground-water. Almost 97% of these were in use in each year. In contrast, only

6% of systems were travelers, and of those only 7% were used ground-water. Even during drought only 40 to 75% were in use. Irrigation depths with travelers were generally less than 4 in./y.

Farmers used solid set systems primarily for pecan and other orchards, nurseries, and athletic fields. These uses resulted in mean annual application depths of 8 to 25 in./y between 2000 and 2003. Drip systems were also in use on specialty crops including pecan orchards and vegetables. All of these were supplied with ground-water. Annual application depths varied from 5 to 22 in./y in this period. The systems were used each year.

Means for irrigation depths are useful in planning for water withdrawals, but it is important to recognize that means were computed from fields whose individual application depths varied from 0 to over 100 in./y. In drought years, these application depths were normally distributed over much of the range of observed irrigations. However, irrigation application depths that exceeded 20 in./y occurred with a greater frequency than would be expected for a normally distributed population.

When the full range of observations were ranked, application depths associated with the 50th (median), 75th,, 90th and 95th percentiles were determined. Median irrigation application depth was 8.3, 6.2, 6.7, and 2.8 in. for 2000, 2001, 2002, and 2003, respectively. About 75% of farmers used less than 10 to 13 in./y in drought years, while the 90th percentile was 14 to 18 in./y and 95th percentile was 19 to 21 in./y between 2000 and 2002.

Surface water withdrawal volumes were calculated for the entire basin area of the Flint using data from all sites in the basin and CES estimates of irrigated land lying in the basin. Surface withdrawal volumes varied from a high of 28 billion gal/y during both 2000 and 2002 drought years and a low of 9 billion gal/y in 2003. Additionally, 9 billion gal/y in 2000 to 2002 and 5 billion gal/y in 2003 were taken from ponds that were at least partially refilled by wells.

Ground-water withdrawals within boundaries of the Flint basin were 112 to 150 billion gal/y in 2000 to 2002 and 65 billion gal/y in 2003. Depending upon the degree of interconnection between ground water and surface water in the basin, part of those groundwater withdrawals may be removing flow that would normally flow into the Flint River and its tributaries.

Irrigation does not occur uniformly throughout the year. Farmers apply water in response to plant needs, and those plants have different growing periods. Irrigation demand is also related to net difference between evapotranspiration and effective rainfall. Patterns of monthly withdrawals were prepared for each region and source, but common to all were peak use periods of May through September. In the Southwest region, little water was applied outside of this peak use period.

Three other EPD sponsored studies shed additional light on agricultural water use. Irrigated areas that were visible in aerial photographs were mapped in GIS by the UGA Center for Remote Sensing and Mapping Science (Litts et al., 2001). They also estimated areas not visible in photographs from discussions with CES agents as well as NRCS and FSA personnel. They estimated a total of 545,000 acres under irrigation in the Georgia portion of Sub-area 4, most of which lies within the boundaries of the Flint basin. Simultaneously, personnel with UGA, EPD, and the Jones Center worked directly with farmers to map irrigated area that had been or were still under irrigation in the Flint basin, and a GIS-based permit management system was created to track specific irrigated areas as well as pump and well locations for all EPD issued permits in the basin. More than 95% of EPD issued permits have now been mapped in the Flint Basin.

In the lower Flint sub-basins south of the Fall-Line, a real-time irrigation monitoring system was installed during 2001 to 2003. It was based upon the 1999 to 2004 statewide Ag Water Pumping monitoring effort, but only ground-water sites were monitored. The effort added 1 92 irrigated fields to those already being monitored in the basin, bringing the monitoring to a level of about 6% of all systems in the basin. Both daily and monthly water use was collected with this equipment.

Beginning in 2004, irrigation flow totalizing meters have been installed at about 10% of the permitted irrigation withdrawal sites in the Itchawaynochaway Sub-basin of the Flint. Eventually all systems will have water use meters in place, a monitoring expected to be completed by 2009.

Determining water use by farmers has evolved from the time when only generalities could be drawn from estimates to the time when specific use patterns can be determined. Monitoring studies conducted in the interim have provided solid water use data under several years of drought in the basin and this data can be used in planning for future use during droughts as well. Likewise the location and area of irrigation has been identified closely in the Flint and impacts on specific sub-watersheds can be estimated closely to identify areas that may require special attention as well as others with only minimal irrigation.

Mussel ecology

Historically, the rivers of southwestern Georgia were home to 29 species of fresh-water mussels. Recent surveys indicate that this number has fallen to 22 species, and of those remaining species, 5 are listed as endangered or threatened by the State of Georgia or the Federal Government. Throughout North America all mussel species have experienced drastic declines in the past century as a result of dam construction, siltation, water pollution, and the harvesting of mussels for pearl buttons. Today, formerly large populations of freshwater mussels have dwindled to small remnant populations that, in some cases, are functionally extinct; i.e., the populations are not capable of replacing themselves through reproduction.

Freshwater mussels belong to the family *Unionidae* and are commonly referred to as “Unionids” (yoo-nee-on-ids). They are closely related to saltwater mussels, oysters, and clams. Unionids are widespread throughout much of North America in numerous rivers, lakes, and ponds. Internally they consist of a soft-bodied animal enclosed by two shells. The shells are composed of calcium carbonate, and are secreted in successive layers by the animal. Mussels are filter feeders, which means that they pump water into their bodies with a siphon and strain food particles such as algae, bacteria, and other organic particles. In this way, they actually act as small water filters and can remove large amounts of particulate matter from streams. Before their decline, freshwater mussels were important in the natural cleansing ability of rivers.

Unionids generally live partly burrowed into the sand and gravel of a streambed, leaving only their siphons and a small part of their shell exposed (Figure 1). This position leaves them susceptible to siltation and low levels of dissolved oxygen (DO). However, they are able to move very slowly by extending and contracting their muscular foot. They may burrow deeper, move to deeper water, or climb a bank depending on the situation. However, they have only a limited ability to migrate longer distances.

Figure 1. A freshwater mussel in a natural habitat, partially burrowed in a stream bottom. Note the presence of a lure, designed to attract a fish

The reproductive cycle of Unionids is unique, and includes a short phase in which the juvenile mussel is a parasite, attached to a fish's gills. The cycle starts when a male mussel releases sperm into the water. Female mussels receive the sperm in their siphons and it fertilizes their eggs. Reproduction may be triggered by increasing day length and water temperature. The female retains the fertilized larvae called "glochidia" (glow-kid-ee-uh) until they are released in spring and early summer.

Some larvae are released into the water current and seek a suitable fish host on which they can attach themselves (Figure 2). Other mussel species have enlarged mantle tissue that extends from the main body of the animal and looks like a worm, insect, or small fish. The larvae are attached to this tissue in a mass known as a lure, and when a fish bites at it, the larvae are released into the fish's mouth. Some of the larvae will then attach themselves to the fish's gills. Larval mussels do not harm the fish. However, they must locate the proper fish host quickly; they cannot survive long without a host. After a few weeks, larvae drop off the host fish as juvenile mussels and begin their life on the stream bottom.

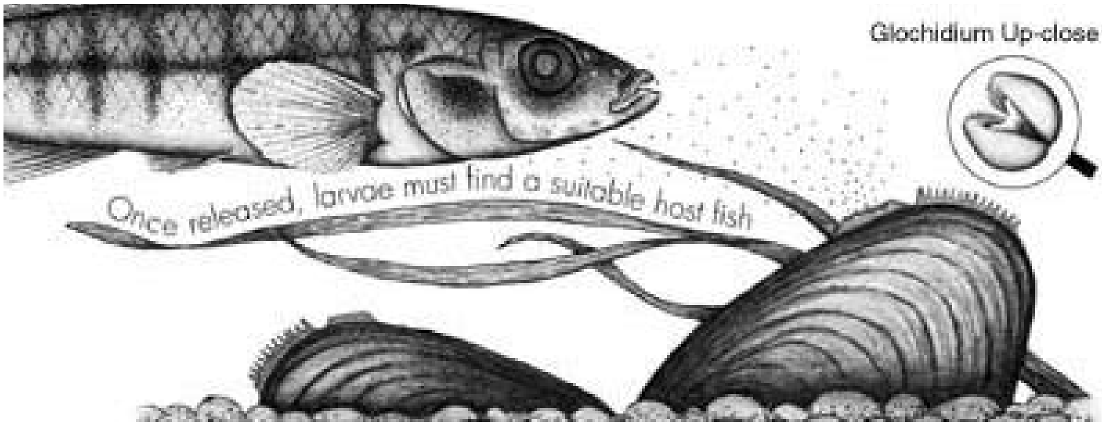

Figure 2. To reproduce, freshwater mussels require a fish host.

Because Unionids live burrowed in a stream bed, are filter feeders, and have a life cycle that depends on adequate fish populations and water flow, they are susceptible to the types of environmental stressors that commonly occur in the lower Flint River Basin. Specifically, soil erosion from human development, pollution, river impoundments, declines in native fish populations, and natural or human-caused low flows have led to large declines in mussel populations (in addition to pre-World War II mussel harvesting). Mussels can move, but they cannot migrate far and consequently must be able to tolerate the physical and chemical conditions of their immediate environment. Thus, they are strongly affected by changes in local conditions. For example, droughts reduce the delivery of food and dissolved oxygen (DO) required for respiration and impair the ability of the glochidia to be dispersed. Since droughts are typically prolonged, mussels may ultimately experience complete emersion (being stranded out of water) or anoxia (lack of oxygen in stagnant water). Even if extreme conditions do not occur, increased water temperature caused by droughts may severely impair the reproductive cycle of the mussels; increase their oxygen needs; and decrease their burrowing ability. Low DO levels in drought-impacted streams slows growth, impairs respiration, and may inhibit reproduction.

Droughts are a normal part of the climate of southwestern Georgia; consequently, Unionids have evolved a range of mechanisms to survive most droughts. These include hibernating in response to temporary temperature and DO changes, deep burrowing to more favorable conditions, altering metabolism to reduce their dependence on environmental oxygen, and “mantle exposure behavior”, where the mussel actually opens slightly to expose its mantle (the internal membrane that surrounds the soft animal tissue), through which oxygen can be absorbed and carbon dioxide released. The ability to survive droughts varies among mussels and unfortunately not all species found in the lower FRB can tolerate prolonged drought. Several of the endangered and threatened species appear to lack some or all of these drought survival tactics. While it is normal for some mussel populations to decline during droughts in a natural setting they would recover when flows returned to normal. However, droughts when combined with other stresses on mussel populations threaten the long-term survival of many mussel species in southwestern Georgia.

Researchers were able to examine the impacts of the 2000 drought on mussel populations. In 2001, 21 stream reaches that contained recently surveyed populations of Unionids were resurveyed to determine the impact of the drought on the mussels. Some sites were non-flowing; i.e. the stream bed was dry or had isolated pools of slack water during the drought; other sites maintained flow. The most severely impacted populations (those with the greatest population declines) were those at non-flowing sites, and most of the non-flowing sites were in the Dougherty Plain. Non-flowing sites with high amounts of woody debris had lower mortality rates than non-flowing sites without woody debris.

Clearly, the 2000 drought greatly impacted Unionids in the Dougherty Plain. Although the drought severely affected the whole southwest Georgia region, groundwater withdrawals on the Dougherty Plain may have compounded drought stresses, and thus played a major role in mussel mortality. In the Dougherty Plain, there is a direct connection between the streams and the Floridan aquifer. During summer, when streams are at seasonal low flows, almost all stream flow is derived from groundwater seepage. This condition is called baseflow. During the 2000 drought researchers noted that many streams showed declining flows downstream across the Dougherty Plain. This provided additional evidence that the connection between the aquifer and streams was greatly reduced during the drought. Irrigation in the Dougherty Plain decreases aquifer discharge, and thus exacerbates drought-related low stream flows. While mussel survival was higher in streams with abundant wood debris, this is not a long term aide to declining mussel populations. To ensure the survival of the unique mussel fauna in southwestern Georgia, conservation measures must ensure adequate stream flows. Preserving adequate stream flow will not only benefit freshwater mussels, but all aquatic life. The preservation of healthy streams and rivers provides many benefits to the citizens of southwestern Georgia including abundant fisheries, wildlife habitat, recreation, and clean water.

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