CREATION OF GEODATABASE AND GEOPROCESSING METHDOLOGIES FOR GEOLOGIC AND HYDROLOGIC APPRAISALS OF AGRICULTURAL WATER WITHDRAWAL PERMITS

by

AMBER ALFONSO

(Under the Direction of James E. Hook)

ABSTRACT

Water resources management in Georgia has become increasingly complex. Recent drought conditions as well as increased agricultural water withdrawals in the southwestern portion of the state have caused influent stream conditions. In order to mitigate further injurious environmental and economic effects, location-specific regulations and current geospatial datasets are manipulated in ArcGIS ® surface and groundwater geodatabases and process models. This research develops methodologies for joining and relating spatial and temporal data using the Arc Hydro data model for surface water evaluations and geodatabase functionality for groundwater evaluations. The hydrologic features contained within these hydrologic information systems are employed as inputs to the process models, which are in turn used to create appraisal forms.

INDEX WORDS: Geodatabase, Arc Hydro, agricultural water withdrawal, process model, hydrologic information systems, ArcGIS ®

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Chapter 1

INTRODUCTION

1.1 Background

Water management issues have become increasingly complex due to growing population size and resulting infrastructural demands. Competing consumptive uses and the compounding effects of recent droughts have diminished once abundant water resources. Effective water management strategies must therefore require examination from agricultural, industrial, governmental, domestic and natural perspectives.

Competing uses have amplified quantity and quality stresses on Georgia's water resources. Current and future water allocations among states, saltwater intrusion, assimilation of pollutants from non-point sources and wastewater, and drought have lead to a situation, where demand on water resources has exceeded supply. In recent years, Georgia officials have responded by implementing environmental policies and expanded resource planning to provide comprehensive strategies for water management.

Specifically, O.C.G.A. 12-5-31 (the Georgia Surface Water Use Act), O.C.G.A. 12-5-90 (the Georgia Groundwater Use Act), and the rules and regulations 391-3-6-.07 and 391-3-2-.03, established a water withdrawal permit system overseen by the Georgia Department of Natural Resources, Environmental Protection Division (EPD). These directives assert that "waters of the state" shall be utilized prudently and for the maximum benefit of the people. Environmental protections for aquatic species are also afforded in the state's water legislation; these include requirements on minimum instream flow.

1.1.1 Water management in Georgia: water sharing compacts and negotiation

States have the sovereign right to control water within their borders. However, when waters are shared with adjoining states, problems can and do arise. This has long been recognized as a problem in the arid west, but as population grows in the eastern states so does the tension over shared water resources. In Georgia, the efforts to resolve its supply issues raised concern among its neighbors. Florida and Alabama sought protection through the courts. That led to the tri-state water negotiations for the Apalachicola-Coosa-Tallapoosa (ACT)/ Apalachicola-Chattahoochee-Flint (ACF) Compacts. These negotiations have not yet led to an allocation formula that all parties can agree on, but they have brought about studies of water flow, use patterns, and models of future impacts.

These ACT/ACF studies delineated approximate watershed regions, 8 within Georgia. Although they were meant to approximate watersheds, little data on water use, demography, or land use was available. Most available data was collected by political areas, usually counties. As a result, subregions followed county borders. Those models and studies, summarized in the ACT/ACF Comprehensive Reports (USDA-SCS, 1994; USDA-NRCS, 1995) were the first to identify potential overdraft concerns. One study suggested that as much as 60% of the groundwater withdrawn from the Floridan aquifer in Subarea 4 of the lower ACF basin would have contributed flow to the Flint River. Models suggested that when coupled with direct surface water withdrawals, net flow from the Flint River could reach unacceptably low levels in drought years. Figure 1.1 illustrates the sub-area designations assigned to Georgia counties in the Comprehensive Studies.

After review of potential options, EPD proposed a moratorium on new agricultural water withdrawals in a 17 county area of southwest Georgia. After further consideration, they defined the affected area of groundwater to be the U.S. Geological Survey (USGS) delineated region known as Subarea 4. The Floridan aquifer in this region was believed to have direct hydrologic connection with surface streams. To achieve water management at that level, EPD needed a means to clearly determine if a new agricultural irrigation application fell within the Subarea 4 portion of the 17 counties.

In October 1999, EPD took formal action to suspend all agricultural groundwater withdrawal permitting in Subarea 4 and all agricultural surface water permitting in the entire Flint River basin (FRB) (Couch et al., 2006). Provisions within existing permitting laws (O.C.G.A 1205-31(h); O.C.G.A. 12-5-96(e)) allowed a suspension of permitting if the area was undergoing a water conservation and development planning process. The Flint River Basin Regional Water Development and Conservation Plan (FRBP) extended demands on EPD for site specific determinations for permitting decisions. The Plan also promised to document existing withdrawal locations (wells and pumps) and to quantify withdrawal quantities in specific streams.

The states of Georgia, Florida, and Alabama share the ACF River basin. Over the past 40 years, a number of water resource studies have been conducted by Federal and state agencies to develop a water management strategy for the basin. Conflicting information on water demands and the difficulty in determining adequate baseflows hindered settlement of tri-state water negotiations. The three states and the Army Corp of Engineers agreed to a comprehensive study to determine current and future water uses in the region.

Information gained from the comprehensive study was developed into an interstate water compact that would define allocation amounts, provide a means to monitoring water flow and use, and spell out procedures for handling grievances. Language was introduced into each of the states legislatures, then passed and signed by their governors.

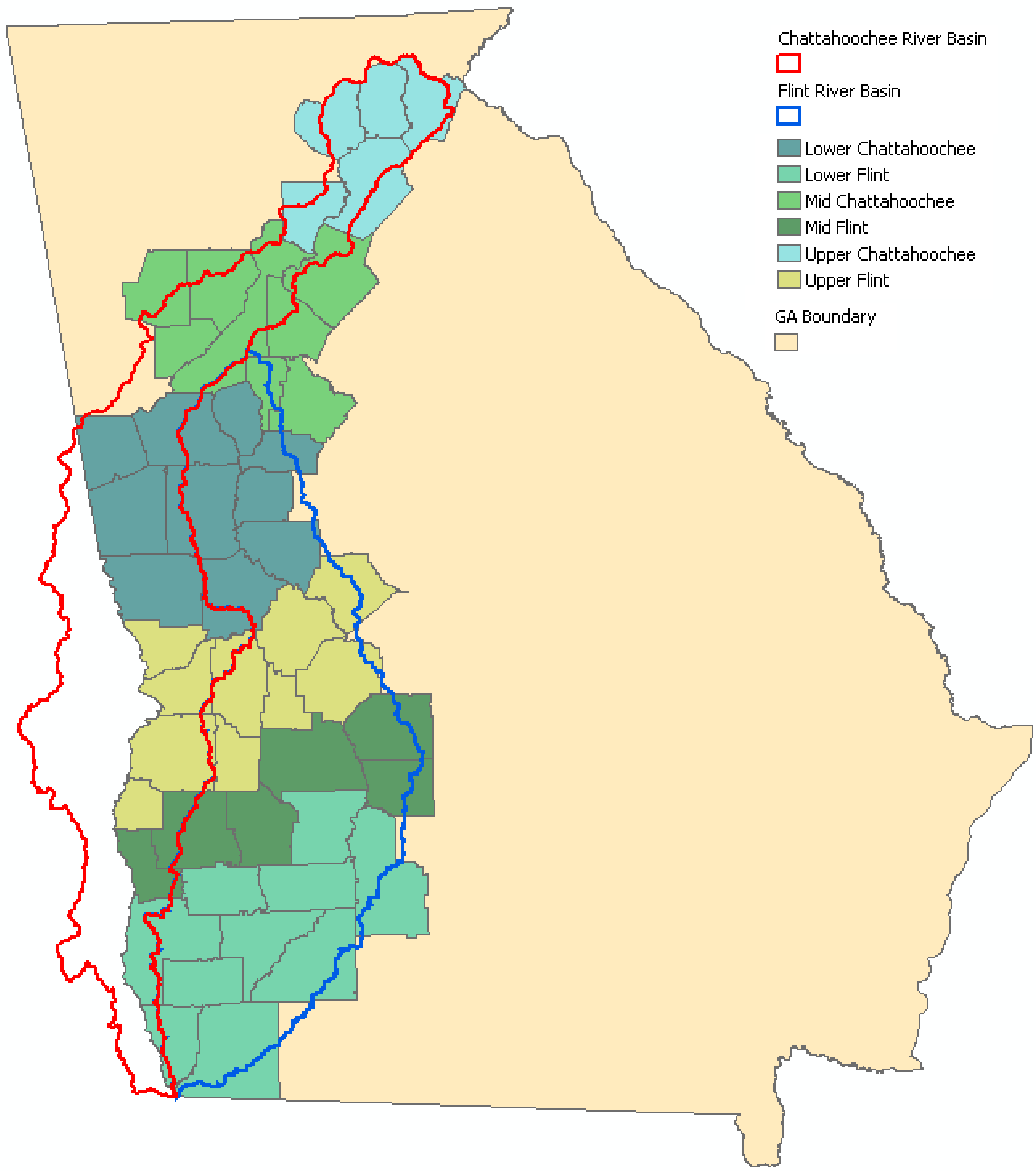


Figure 1.1 – Georgia counties split into sub-areas based on ACT/ACF Comprehensive Studies

The compact language demanded that allocation formulae be developed for equitable surface water appropriations in the ACF. However, the deadline for agreement on the formulas has been allowed to expire.

1.1.2 Regional water management

"FRBP was initiated in October 1999 in response to a prolonged drought, increased agricultural irrigation in southwest Georgia since the late 1970s, and scientific studies that predicted severe impacts on streamflow in the FRB due to withdrawals from area streams and the Floridan aquifer" (Couch et al., 2006). In response to these concerns, technical and stakeholder committees were formed to review prior research on the hydrography of the FRB and make suggestions on new permitting regulations to be implemented by EPD officials.

In 2006, the FRBP was ready for implementing. With it came water management and permitting decisions made on an 8-digit hydrologic unit, 10-digit hydrologic unit, and in some cases 12-digit hydrologic unit scale. Considerations for distance from protected streams, and protection of existing users increased demands for location specific decisions. The creation of a large backlog of applications increased the demand for an efficient and objective means to determine all rules applicable in thousands of application locations.

The Coastal Georgia Water & Wastewater Permitting Plan for Managing Salt Water Intrusion (Coastal Plan) describes the goals, policies, and actions EPD will undertake to manage the water resources of the 24-county area of coastal Georgia (GADNR, 2006). The Coastal Plan is based on the scientific findings of a seven-year study on groundwater use known as the Sound Science Initiative. It was done to address the concern that pumping of groundwater in the region is allowing salt water to seep into the Floridan aquifer.

Both Plans increased the demand for an accurate representation of water use, specifically irrigation, in the state. The backlog of applications created an urgency to make these changes in the most efficient and consistent manner possible. These Plans set the stage for a new set of improvements, a Geographical Information System (GIS)-based permit management system. This new system allows for the implementation of permitting regulations into the decision-making process.

1.2 Problem statement and motivation

In 1997, EPD entered into contract with the University of Georgia (UGA) to begin a random representative sampling of water use by farmers (Thomas et al., 1999). One facet of this effort was creation of a Microsoft Access ® database for managing agricultural permit ownership, physical condition, and location information. Permit locations were originally designated by an "x" on a small, low resolution county map remitted with permit applications.

The location was re-projected onto higher resolution paper maps where latitude and longitude information could be interpreted from overlying grids. While this location information was stored in the database, it was never provided on official permit documents for landowners. After several years and multiple applications, many permit holders had difficulty determining which permit was associated with which permitted source.

The inherent unreliability of the original 'x' map, and repeated translations in which new errors were introduced brought about no improvements to accuracy. The permit database and original GIS permit location layers became increasingly unreliable in representing the true water withdrawal sites or in managing permit issuance for new applications. EPD was left with incomplete and inaccurate information on withdrawals as it attempted to develop plans for future water use, and to protect instream flow and groundwater levels.

Prior research has illustrated the effectiveness of GIS in the management and analysis of water resources data. Spatial and temporal hydrologic data integrated into a Hydrologic Information System (HIS) has proved beneficial to water resource management efforts. This research uses the GIS technologies available to EPD permitting officials to construct a more efficient application process for evaluating and permitting agricultural water withdrawals in Georgia.

1.2.1 Development of a surface water hydrologic permit database

The ACF River basin is the case study area considered in the surface water portion of this research. The ACF basin is a one of the largest in Georgia, draining an area over 50,000 km^2, and spanning three states (Georgia, Alabama, and Florida). Research conducted by UGA Cooperative Extension Services and prior mapping efforts has indicated that Georgia counties in this basin contain a majority of the state's agricultural withdrawals. Therefore, the hydrologic modeling of this basin is fundamental to water management required to meet the state's mandate on protecting "waters of the state", and to comply with interstate obligations with Alabama and Florida.

The FRB was the site of a recent moratorium on new permitted agricultural withdrawals. This was due to the persistence of drought conditions, extensive development of irrigation and the resulting affects on instream flows. Georgia must provide priority in fulfilling its obligations under its ACF and ACT instream flow treaties. "Drought-year low flows in the FRB are reached sooner and are lower than before irrigation became widespread in the FRB" (Couch et al., 2006). Findings such as this make it difficult to negotiate downstream water availability calculations.

Regulatory permit data in the ACF are incomplete, inaccurate, and fragmented. Point data is mapped by several different agencies and rarely agrees with records in the EPD permit database and GIS. Erroneous data was left in the system to be processed at a later date. Incorrect records due to the implementation of 911address changes, wells mapped as surface withdrawals, surface withdrawals mapped as wells, false permit location coordinates, and land sales led to duplicate permits being issued and inaccurate analysis being performed. Therefore, the development of a geodatabase to store spatially corrected data, and its application in the ACF basin is one of the main motivations of this research.

Recent drought conditions in the FRB have increased tensions over this shared water source. The FRBP, by way of stakeholder and technical advisory committees, has identified areas of conflict and negotiated remedies. Development of the ACF geodatabase allows for the implementation of these recommendations into the permitting process. This geodatabase is generated using the Arc Hydro data model (Maidment, 2002); it is being applied to the Georgia portion of the ACF basin.

1.2.2 Development of a groundwater hydrologic permit database

Surface waters in Subarea 4 of the ACF River basin are in hydraulic connection with the underlying Floridan aquifer. This connection is evident in potentiometric maps of the lower FRB, where potentiometric contours bend strongly upstream when they cross the Flint River or its tributaries (Peck et al., 1999).

Agricultural groundwater withdrawals in Subarea 4 reduce baseflow for streams hydraulically connected to the Floridan aquifer (Couch et al., 2006). These streams are labeled “critical” and have a protected flow outlined by the FRBP. This decrease in streamflow can degrade aquatic habitats for endangered species, and exacerbate conflicts with ACF transboundary flow. In 1998, the U.S. Fish and Wildlife Service listed 3 of the 29 freshwater mussel species in the FRB as endangered, and one as threatened under the U.S. Endangered Species Act (U.S. Fish and Wildlife Service, 2004).

Since groundwater records are recorded in the same manner as surface water, the same errors and inconsistencies occur. Newly acquired transmissivity and aquifer thickness data is added to a geodatabase for agricultural withdrawals of groundwater. These preliminary data are available from USGS hydrologic engineers using Modular Finite Element (MODFE) to model the hydrogeology of the lower ACF River basin. The creation and implementation of this new data into a geodatabase is fundamental to appropriate adequate amounts of groundwater in Subarea 4.

The objective of the groundwater portion of this research is development of geospatial methodologies to aide in the process of permitting agricultural groundwater withdrawals. Information gained by these efforts consists of surface water and groundwater geodatabases containing geospatial hydrologic and withdrawal data for Georgia.

1.3 Objectives

The objective of this research is to create systems to improve the accuracy of application and permit maps. The utilization of joined HIS technology is necessary to facilitate surface water permitting decisions that protect existing downstream users and critical flows. Development of a model methodology for joining spatial and tabular data for groundwater is also essential to continue advancements in the precision, consistency and objectivity of permit decisions.

REFERENCES

(2006). "Coastal Georgia Water & Wastewater Permitting Plan for Managing Salt Water Intrusion." Georgia Department of Natural Resources, Environmental Protection Division.

Couch, C. A., McDowell, R. J. (2006). "Flint River Basin Regional Water Development and Conservation Plan." Georgia Department of Natural Resources, Environmental Protection Division.

Maidment, D. R. (2002). *Arc Hydro - GIS for Water Resources*, ESRI Press, Redlands, California, p. 7

Peck, M. F., Clarke, J.S., Ransom, C., Richards, C.J. (1999). "Potentiometric surface of the Upper Floridan aquifer in Georgia and adjacent parts of Alabama, Florida, and South Carolina, May 1998, and water-level trends in Georgia 1990-98." Georgia Department of Natural Resources Hydrologic Atlas 22.

Thomas, D. L., Myers-Roche, C., Harrison, K.A., Hook, J.E., Tyson, A.W., Hoogenboom, G., and Segars, W.I. (1999). "Ag Water Pumping: A New Program to Evaluate Agricultural Water Use in Georgia." *Proceedings of the 1999 Georgia Water Resources Conference*, University of Georgia, Athens, Georgia, 560-562.

USDA-NRCS. (1995). "ACT/ACF River Basins Comprehensive Study, Agricultural Water Demand Executive Summary." U.S. Department of Agriculture, Natural Resources Conservation Service.

USDA-SCS. (1994). "ACT/ACF River Basins Comprehensive Study, Agricultural Water Demand Technical Report." U.S. Department of Agriculture, Soil Conservation Service

U.S. Fish and Wildlife Survey (2004). "ACF Striped Bass Restoration and Evaluation 5 Year Plan."

Chapter 2

REVIEW OF LITERATURE

Water law is in a state of transition as governments try to reconcile disparities between riparian law and population growth. The relationship between water users and their environment, and the role of government in securing resources for future populations must be re-interpreted. In Georgia that has meant adoption of new laws placing responsibility of water protection in the hands of state agencies responsible for issuing permits on water use.

As discussed in the previous chapter, this research involves the implementation of current permitting statutes and recommendations using hydrologic data and GIS. Current legislation and rules must be brought to bear as each individual permitting decision is made. As Comprehensive Studies have shown, these decisions are increasingly location-specific. Agencies charged with issuing permits are challenged to track overlapping legislation affecting jurisdictions and watersheds. This chapter is primarily a review of this legislation, as well as an examination of past efforts to implement GIS into the permitting process.

2.1 Georgia's regional water supply issues

Georgia's 2,600 km^2 of inland water and 124 km^2 of coastal waters are coming under rising demand due to population increases and climatic conditions. Recent memory of 4 years of drought conditions has officials focusing more on protecting the water resources within their borders than at any time in our past.

As early as the 1970's, Georgia officials recognized a need for orderly access to waters shared by industries, commercial establishments, and municipalities. A series of groundwater and surface water bills were introduced in the Georgia General Assembly to protect water quality and quantity in what were defined as shared “waters of the state”. In part, the laws that were adopted in Georgia (discussed below) were patterned after similar federal water quality legislation. Among other things, they established a permitting system for water withdrawals.

In the 1970’s Georgia’s agricultural irrigation was limited to a large number of small withdrawals, mostly from ponds and streams. Legislators saw no advantage to including farm irrigation in the initial permitting laws. However, Georgia’s irrigation industry was on the verge of a rapid expansion that changed the face of agricultural field crop production. This was evidenced in triennial irrigation surveys conducted by Cooperative Extension Services staff.

By the late 1980’s many large agricultural withdrawals were in place, yet state water officials had only a vague notion of the number or impact of these withdrawals. By 1988, farmers were finally included in withdrawal permitting. Studies found that nearly 3,237 km^2 were under irrigation. While Georgians were just coming to grips with the extent of current and potential water use by its citizens, people in neighboring states were voicing their concerns over Georgia’s growth and accompanying water consumption.

Georgia, Florida, and Alabama began a continuing legal battle over the allocation of shared surface waters in 1990. Alabama filed a lawsuit against the U.S. Army Corps of Engineers with Georgia as codefendant. The suit clamed that proposed reallocations by the Corps infringed on Alabama’s sovereign interests in water of interstate rivers. Realizing that its concerns aligned with Alabama’s, Florida joined the lawsuit seeking to insure protection of its interests and rights to shared waters of the region. This litigation was stayed in 1990 pending a comprehensive study of current and future water use, and interstate negotiations for a compact for the ACT and ACF River basins. Compact legislation was passed by the affected states, ratified by congress, and signed by the president in 1997 (Public Law 105-105-Nov. 20, 1997 111 STAT. 2233). The compacts spelled out how negotiations over water allocations were to be handled, but they did not define those allocations.

From 1997 until talks broke off in August 2003, public meetings were held with representatives of affected state governments and Federal agencies. Water flow models, use projections, environmental impacts, and regulating statutes identified by the Comprehensive Studies (USDA-SCS 1994; USDA-NRCS 1995) were the subject of intense debate. In the end, negotiators failed to arrive at an equitable distribution of flows in the affected rivers. The jurisdiction returned to appropriate federal courts. As of this writing, the state governments have resumed negotiations, this time in closed sessions as ordered by the court.

With an uncertain future in court proceedings, Georgia found it prudent to proceed with statewide and regional water use planning and implementation of new rules regarding withdrawals. They understand that these rules may be modified for specific locales by the outcome of the interstate dispute, most notably in the Flint and Chattahoochee River basins of west and southwest Georgia and metropolitan Atlanta.

In the FRB of southwest Georgia, in an area that USGS has defined as Subarea 4, hydrologic connections between surface and groundwater were identified by USGS and ACT/ACF studies. The Flint and Apalachicola Rivers cut through the top of the Ocala limestone formation that makes up the upper part of the Floridan aquifer. In the affected area, groundwater withdrawals, principally for agricultural irrigation, reduce the flow of water in those rivers.

Increased groundwater withdrawals from coastal and inland wells caused water head declines in the Upper Floridan aquifer in southeast Georgia. Saltwater intrusion was detected in wells along the coasts of Georgia and southern South Carolina beginning in the 1990’s. This prompted EPD to issue a Coastal Zone Saltwater Management Plan in 1996. Although the Plan was quickly cancelled, it was replaced by the Interim Strategy for Managing Salt Water Intrusion in the Upper Floridan Aquifer of Southeast Georgia in 1997. The Plan placed caps on net withdrawals from the Upper Floridan aquifer in 24 coastal Georgia counties.

In some sections of the coastal zone, existing users were required to reduce their current groundwater withdrawals below permitted amounts. Most users were able to do so with a combination of conservation measures, leak repairs, and substitution of groundwater with more expensive surface or reused water. In addition to the withdrawal cap and conservation measures, the Plan called for sound science studies to refine the extent of saltwater intrusion and test alternatives that would minimize its impact. The interim strategy involves only groundwater, but its influence area was defined by political boundaries – counties. The affected area underlies parts of 6-digit hydrologic unit level river basins including the Suwannee, St Mary's, Altamaha, Satilla, and Savannah River Basins.

In the Atlanta metropolitan area, water planning is even more complex. Most of the region's water supply, including that found in the Flint and Chattahoochee Rivers of the AFC River basin and in the Coosa and Tallapoosa Rivers of the ACT River basin, is surface water. A number of water purveyors, both private and municipal, redistribute permitted withdrawals to their customers.

In 2000, state and local leaders recognized the need for a regional approach to water withdrawals and reuse. They formed the Metropolitan North Georgia Municipal Water Planning District (MNGMWPD) in 2001 (O.C.G.A 12-5-570). Although the district does not have authority over agricultural withdrawals within its boundaries, it can be impacted by decisions regarding those withdrawals. In the Chattahoochee River basin, withdrawals for golf course watering are handled as agriculture in lower reaches, but as municipal and industrial in upper reaches. In other MNGMWPD areas, including portions of the Flint, Ocmulgee, Oconee, and Coosa River basins, these withdrawals would be permitted as agricultural. MNGMWPD area is geopolitical – counties opted in or out – and as a result, decisions regarding individual withdrawal requests can only be made after carefully sorting out jurisdictional issues.

As each of these regional water issues suggests, separate legislation, rules and jurisdiction govern the issuance of water withdrawal permits. Some of these areas follow surface hydrologic boundaries, others subsurface delineations, and still others geopolitical boundaries. Cataloging the applicable rules requires careful sorting of overlapping rule areas.

In-state users of surface and groundwaters are not in consensus as to how Georgia's share of these waters should be allocated. Counties, municipalities, landowners, and utilities have clashed over proposed withdrawals and transfers. Regional initiatives have been employed by EPD to try and create upfront agreements to prevent litigation between the competing users. Ultimately Georgia elected officials and agencies have the responsibility to define how these water use disputes will be handled.

2.2 Riparian principles of surface water law

Common law forms a major part of the law of countries with a history as British territories or colonies, i.e. Georgia. The English common law riparian principles of the Reasonable Use Doctrine are the basis of surface water rights in Georgia. Common law riparianism has been modified by statue to provide increased state supervision on water withdrawals. This mixture of common law riparianism and state regulation is known as "regulated riparianism".

The riparian doctrine is based on the premise that the owner of the land bordering a stream or lake has the right to take water for use on their land. The right to use the water is solely because of the relation of the land to the water, and resides in the ownership of the land (Hirshleifer, et al., 1966). The water does not belong to anyone, it belongs to everyone. The first riparian user does not acquire priority over those who make use of the water at a later date; the rights upstream and downstream are viewed as equal (Hirshleifer, et al., 1966).

In 1848, the U.S. Supreme Court first considered riparian rights in Hendrick v. Cook. In this case, the court established the principle of riparian rights and the Reasonable Use Doctrine. The ruling stated that each riparian proprietor "has a natural and equal right to use of the waters which flow therein" without diminution or alteration. Also, "each riparian proprietor is entitled to a reasonable use of the water, for domestic, agricultural, and manufacturing purposes; provided that in making such use, he does not work a material injury to the other proprietors."

Surface water is deemed *public juris*, but riparian landowners have limited private property rights to withdraw "waters of the state". The riparian owner's right consists of the right to a "reasonable use" of the waters of the stream. The determination of "reasonable use" is primarily a judicial one, and is always related to the demands of adjacent landowners to the common supply (Hirshleifer, 1966). "Notwithstanding this right of reasonable use, it has been held that a riparian owner has no ownership of the water itself but has a simple usufruct (in the nature of the limited leasehold right) for the use of the water as it passes along." Goble v. Louisville & N.R.R., 187 Ga. 243, 200 S.E.2D 59 (1939).

"Riparian proprietors have no title to the water which flows over their land, but are entitled to a reasonable use thereof… the property, therefore, consists not in the water itself, but in the added value in which the stream gives to the land through which it flows. This is made up of the power which may be obtained from the flow of the stream, from the increased fertility of the adjoining fields because of the presence of the water, and the value of the water for the uses to which it may be put.” Price v. High Shoals Mfg. Co., 132 Ga. 246, 251, 64 S.E.2d 87, 89 (1909).

The riparian owner is entitled to “a reasonable use of the water, for domestic, agricultural, and manufacturing purposes; provided, that in making such use, he does not work a material injury” to other riparian proprietors. Pyle v. Gilbert, 245 Ga. 403, 405, 265 S.E.2d 584, 586 (1980). “Riparian proprietors have a common right in the water of the stream, and the necessities of the business of one can not be the standard of the rights of another.” 245 Ga. At 406-07, 265 S.E.2d at 587.

A riparian owner’s right of reasonable use is also subject to considerations of “public welfare.” 132 Ga. At 251, 64 S.E. at 89. An unreasonable use of water is one in which “others are deprived in whole or in part of the common benefit.” White v. East Lake Land Company, 96 Ga. 415, 417, 23 S.E.2d 393, 394 (1895).

Application of riparian law is difficult in that it requires definition of applicable waters, it has been recognized that some water that doesn’t normally leave that of a property owner can be used without regard to neighbors. Infiltrating soil water, local runoff, and percolating waters above a water table are included. Additionally, effectively implementing the sharing requires that withdrawers be aware of upstream and downstream users with whom they share rights to use the resource.

2.3 Reasonable use rules for groundwater law

The Rule of Absolute Ownership gives the overlying landowner the absolute right to use the groundwater without regard to quantity and effects of the pumping upon the water table in adjacent lands. In Georgia, the Reasonable Use Doctrine has surpassed the Rule of Absolute Ownership in that now a standard of "reasonable use" must be applied to groundwater withdrawals.

Groundwater cases in Georgia involving common law have distinguished between (a) "percolating water in the subsurface as to which the owner of the land overlying the water was held to have exclusive proprietorship", and (b) "subsurface water which had become a part of a well defined underground stream." Stoner v. Patten, 63 S.E.2d 897, 898 (1909). Stone v. Patten implied that the Reasonable Use Doctrine would apply to an underground stream by stating: "An underground stream of water differs from a surface stream only with respect to its location above or below the surface." 63, S.E.2d at 898.

Percolating water which "filters from the land of one proprietor to that of another, gives the latter no rights thereto which the law can recognize" Saddler v. Lee, 66 Ga. 45 (1880). "The malice of a neighbor in wasting or diverting underground water must be shown in order to enjoin the neighbor's well on an adjoining lot that might destroy the petitioner's mineral spring" St. Armand v. Lehman, 120 Ga. 253 (1904).

The case law for groundwater has resulted from a previous lack of knowledge of hydrogeology. Therefore, groundwater law is very similar to surface riparian common law. Also as in surface riparianism, withdrawers of groundwater must recognize those well owners who are close enough to affect or to be affected by the users pumping practices.

2.4 Permitting mandates for EPD

Georgia's statutory law provides EPD officials with certain powers with respect to water withdrawals, including powers to modify, suspend and revoke permits (O.C.G.A. §§ 12-5-31, 12-5-96, 12-5-105; Ga. Reg. 391-3-2-.05). Permitting allows EPD to control water use by imposing limits on withdrawals. It also provides better information as to the amount of water being used in any watershed. This information is used for modeling streamflows in water stressed areas.

The Groundwater Use Act of 1972, O.C.G.A. §§ 12-5-90, and Chapter 391-3-2 of the Georgia Administrative Rules and Regulations require that any Georgia landowner seeking to withdraw more than 379 m^3 of water per day from a well, apply to the EPD for a water withdrawal permit. In 1972 legislation, agricultural or “farm use” was exempted from this permitting. Permits were granted for no less than 10 and no more than 50 years. Withdrawers were required to periodically report use, develop and follow a water conservation plan, and submit and adhere to a drought management plan.

The purpose of the permitting system is to allow for full beneficial use of groundwater, while conserving the resource for sustainable future use and protecting against saltwater intrusion and adverse effects on other water users (O.C.G.A. §§ 12-5-91, 95(a)(2)). Permits are issued when they align with “the general welfare and public interest [which] requires that the water resources of the state be put to beneficial use to the fullest extent to which they are capable” (O.C.G.A. §§ 12-5-91). EPD can reject any permit application which is found to affect the public interest in a contrary way. EPD officials can also modify any permit if it is found to have an unreasonable effect on other water users in the area (Ga. Reg. 391-3-2-.05(5) (a)).

Existing permitted users must be considered during the decision-making process. “The granting of permits shall not have unreasonably adverse effects upon other water users in the area, including public use, and including potential as well as present use” (O.C.G.A. §§ 12-5-97(f)).

In 1977, the Georgia Water Quality Control Act O.C.G.A. §§ 12-5-20 and Chapter 391-3-6-.07 of the Georgia Administrative Rules and Regulations were passed. The Act and Rule required an EPD permit for any surface withdrawal, diversion or impoundment over 379 m^3 per day. The permits were granted for no less than 10 and no more than 50 years, and users were required to periodically report use. Again "farm use" was exempted from this type of permitting in the original legislation.

Permitting of surface water withdrawals is much the same as that of groundwater withdrawals. "Water resources of the state shall be utilized prudently for the maximum benefit of the people" (O.C.G.A. §§ 12-5-21(a)). When competing applicants or users qualify equally, "preference is given to an existing use over an initial application" (O.C.G.A. §§ 12-5-31(f)). Permits are revocable or modifiable providing they "would prevent other applicants from reasonable use of surface water… or for any other good cause consistent with the health and safety of the citizens of this state (O.C.G.A. §§ 12-5-31(k)).

2.4.1 Agricultural permitting process

Agricultural withdrawal permitting began in Georgia in 1988 when the Georgia Water Quality Control Act and the Groundwater Use Act were amended. Since then, "farm use" withdrawal permits have been required for surface and groundwater withdrawals averaging over 379 m^3 per day in any month. Unlike municipal and industrial (M&I) water use permits, early agricultural water withdrawal permits have no expiration, and cannot be revoked as a penalty for non-use. They were also exempt from the reporting, water conservation, and drought planning requirements associated with M&I permits. A full history of agricultural water withdrawal permitting is provided by Couch and McDowell in the FRBP.

Farm use is defined as:

"irrigation of any land used for general farming, forage, aquaculture, pasture, turf production, orchards, or tree and ornamental nurseries; provisions for water supply for farm animals, poultry farming, or any other activity conducted in the course of a farming operation. Farm use shall also include the processing of perishable agricultural products and the irrigation of recreational turf except in Chatham, Effingham, Bryan, and Glynn counties where irrigation of recreational turf shall not be considered a farm use" (O.C.G.A. §§ 12-5-92 (5.1)).

Any person who was withdrawing, started to withdraw, or is intending to withdraw water for agricultural uses, after July 1, 1988 is required to obtain a permit from EPD. Application information outlined in O.C.G.A. §§ 12-5-105 provides EPD data necessary to make permit decisions. During a grandfather period, July 1988 until June 1991, the application process served only to register users whose water withdrawal had begun before enabling legislation in 1988. During this period, more than 17,000 surface and groundwater withdrawals were issued permits. With the rush of applicants, EPD made no effort to verify the validity of claims or precise location of the pumps associated with the withdrawal. Applicants usually did mark a low resolution map to indicate which area of a county their withdrawal existed, but there was no way to infer specific streams, locations along a stream, or proximity of one well to another.

Ownership and pump capacity, along with certain well parameters usually accompanied the application. Farmers also estimated the land area associated with their water application system. Although irrigated acreage later became a condition of the permit, the interpretation and specificity of that acreage was never spelled out on the permit or in application information. Farmers saw the value as an approximation of their irrigated field areas, but they continued to reconfigure irrigation systems, expanding or decreasing the area as crop system, crop rotational requirements, or equipment changes dictated.

Initially permitting decisions for agricultural permits was designated to existing units in EPD who were already responsible for M&I surface withdrawal permitting or groundwater permitting. EPD units suffered under the flood of applicants created by the 1988 revision, but they worked to make a permitting system shaped by their experiences with M&I users. Unfortunately, some of the assumptions that worked for M&I permitting didn't for agriculture.

Whereas M&I wells were located in clearly defined locations that could usually be described by a street address, farm wells were usually located at some distance from rural routes that had no street addresses. M&I withdrawals had a seasonal variation in use, but water was pumped in every month so limits on withdrawals could be defined by maximum monthly and mean annual pumping rates. Irrigation pumps are designed to deliver a large quantity of water to cover a field as rapidly as possible. The capacities of pumps on individual farms thus rivaled total capacity of modest-sized cities.

Most irrigation pumps are turned on for short periods during the year, and for many months there is no water pumped. As a result, only full (maximum) pumping rate was specified as a limit on the permit. Lacking other limitations, the inference was that the pumps could potentially be used at that rate 24 hours a day, 365 days a year. While EPD understood that farmers had no intention to use water this way, this concession to simplicity is creating disputes as water permits have become limited in certain areas.

Another given for M&I pumps is their permanence in location at a reservoir or along a river. This is not so for farm pumps. Many pumps were built onto wheeled trailers to be moved from pond to pond or from one stream location to another. EPD took the approach of requiring a permit for each location of its use, but that meant that, for example, 5 permits could be issued for 1 portable pump.

In addition to mobility, farmers have found it prudent to utilize multiple sources and pumps with varying levels of interconnection to provide backup in the event of a single water source drying up or pump failing. While backup pumps would usually result in several separate permits, the associated irrigated area was sometimes duplicated for each; one class of backup that was unique to farms. Many farmers use runoff captured in ponds on their property to supply water. This source is relatively less expensive to pump, and large pumps needed for the irrigation system could usually be accommodated from this open water source. However, in periods of drought, precisely the periods for which irrigation was designed, runoff declines and ponds are drained by the pumps. As a backup, many farmers install wells adjacent to their ponds to refill them in times of low pond reserves. These wells often have a lower pumping rate than the surface pump that supply the irrigation system, but they can be run in anticipation of a drought to make sure the pond contains enough water. For these and only these combined systems, EPD created a dual permit known as a well-to-pond permit that specified both well pump rate and surface pump rate, using a single irrigated area for both.

Since EPD was in the habit of issuing multiple source permits for M&I water supplies, it was perhaps surprising that multiple source, or even combined farm permits were not used. Instead more than 20,000 permits have been issued for farm water withdrawals. That number alone explains EPD’s need for agricultural water permit data management system.

In 1998, UGA contracted with EPD to create their first comprehensive permitting data system to store and analyze information form these permits. Separate records for surface withdrawals, groundwater withdrawals, applicant contact, and EPD permit action, and conditions were combined in a Microsoft Access ® database. Engineering statistical data tests were conducted, and thousands of permits were identified as lacking information or having an unreasonable combination of pumping rate, irrigated area, and application depth. Paper records were scoured to correct those that could be accurate, but no follow-up with owners was possible at that time.

A glaring information gap in that record system was geospatial data. Often the streams on which surface withdrawals were made were lacking. In others, aquifers for wells or river basins were omitted. As discussed earlier, an attempt was made to specify coordinates of the withdrawal location, but these were unreliable. Without these geographic references, protection of aquifers, of stream flow, or of existing users is not possible, even though the processes used to permit groundwater and surface withdrawals require them.

2.4.1.1 Groundwater withdrawal application evaluation process

Groundwater withdrawal applications are evaluated by a geologist to determine which aquifer will be used for the proposed withdrawal. EPD takes into consideration the best available information on the geologic and hydrologic characteristics of other withdrawals in the area. Mitigation procedures to protect against or abate adverse effects are given in Chapter 391-3-2-.11 of the Georgia Administrative Rules and Regulations.

The procedure involves the determination of the surface elevation of a proposed well, the proposed well depth, and the known depths of aquifer tops and bottoms as shown in Arora, 1984 and other published reports. If the proposed withdrawal is for a well in an EPD sanctioned aquifer, a “Letter of Concurrence to Drill an Irrigation Well” (Ga. Reg. 391-3-2-.04) is sent to the applicant. The Letter may stipulate restrictions on depth and pump capacity of the installation. The applicant has one year in which to install the new well after the Letter is received.

Subsequent to the well installation, the Letter along with well completion data forms expressing well depth, casing depth and other well data must be returned to EPD. A withdrawal permit is then issued to the applicant along with a map of the well location.

2.4.1.2 Surface water withdrawal application evaluation process

Surface water withdrawal applications are evaluated by a hydrologist to determine the capacity of the water source to allocate another withdrawal. Applications received before July, 1 1991 for surface water uses occurring before July 1, 1988 were issued for the original pump capacity, and did not require a low-flow protection plan.

Applications for surface water withdrawals received after July 1, 1991 must incorporate a low-flow protection plan. Any new permit application needs to accommodate one of 3 minimum instream flow criteria: 1. monthly 7Q10, which is the average streamflow that occurs over seven consecutive days and has a ten-year recurrence interval period, or a one in ten chance of occurring in any one year (Carter et al., 1978); 2. 30% of average annual flow in summer months, 40% of average annual flow in spring and fall months, and 60% of the average annual flow in winter or; 3. a stream-specific study of minimally acceptable flows that protect instream flow needs (Pendergrast, 2001).

If prior permitted withdrawals exist downstream, the new permit applicant must develop a drought contingency plan to protect the “non-depletable” flow or the natural stream flow, whichever is less (Ga. Reg. 391-2-3-.04). Non-depletable flow is the “instream flow consisting of the 7Q10 flow plus an additional flow needed to ensure the availability of water to downstream users” (Ga. Reg. 391-3-6-.07(2)(k). “For withdrawals south of the Fall Line, where stream channels are not well defined, EPD has determined that it is necessary to protect only non-depleatable flows of 0.03 m^3 per second or greater" (Couch et al., 2006).

Local 7Q10 values for surface water permit applications are gathered from http://ga2.er.usgs.gov/lowflow. This site presents selected low-flow frequency data for USGS partial and continuous stream gauge records collected up to 1974. The information on this site is from "Low-Flow Frequency of Georgia Streams" (Carter et al., 1978). When an application location is not near enough to a monitoring station for definitive analysis, methodologies described in "Effect of a Severe Drought (1954) on Streamflow in Georgia" (Carter et al., 1963) is used. A proportional area method is employed to determine the 7Q10 in locations without any data.

2.4.1.3 "Grandfathered" withdrawal permits

Applications submitted prior to July 1, 1991 providing reasonable proof that the applicant's "farm use" of water occurred prior to July 1, 1988 are considered "grandfathered". Under these circumstances, the withdrawal permit must be granted at a rate equal to the greater of the operating capacity in place for withdrawal on July 1, 1988, or, when measured in gallons per day on a monthly average for a calendar year, the greatest withdrawal capacity during the 5-year period immediately preceding July 1, 1988 (O.C.G.A. §§ 12-5-96; O.C.G.A. §§ 12-5-97).

2.4.1.4 Transfer, modification, and enforcement of permit regulations

Prior to 2003 and 2006 legislation revisions, permits issued for "farm use" had no annual reporting requirements, no term limits, and could be transferred with the sale of the adjoining land. Also, the permit cannot be revoked or modified for nonuse, although it may be suspended or modified if the usage prevents other applicants from reasonable use of the water resource (O.C.G.A. §§ 12-5-105(b)(3); Ga. Reg. 391-3-2-.11). A permit can however be denied if the well or pump is not installed within a year of receiving a Letter of Concurrence or if the installation is not consistent with that specified in the Letter. Other than responding to occasional complaints, EPD has rarely inspected installations or tested pumping rate or field area for compliance with permit conditions. The lack of inspection and reporting that typically accompanies M&I permits left Georgia with little information about actual usages of its permitted agricultural withdrawals.

2.4.2 Agricultural irrigation metering and reporting

Although initial legislation brought “farm use” withdrawals into the permitting system, it exempted them from withdrawals. This was changed by House Bill 579 passed by the General Assembly in 2003. The Bill dictates that the State Soil and Water Conservation Commission “shall develop a priority system for installation of water-measuring devices for ‘farm uses’ that have permits as of July 1, 2003” (HB 579 §§ 2(2)(c)). The metering devices are to be installed by July 1, 2009, the cost of which is charged to the permittee if the permit is issued after July 1, 2003. The Bill also states that any agricultural withdrawal permit issued, modified, or amended after July 1, 2003 is to have annual reporting requirements (HB 579 §§ 3(1)). These irrigation records as well as the information gained from the metering project are to be used in the implementation of water resources management in the state.

Any person found violating or intentionally or negligently failing or refusing to comply with any final order shall be liable for a civil penalty not to exceed $1000 for such violation, and an additional civil penalty not to exceed $500 for each day during which such violation continues (O.C.G.A. §§ 12-5-106). A hearing will be requested before an officer appointed by the Board of Natural Resources to determine penalties. Any person found violating their permit limits shall be guilty of a misdemeanor.

Although metering and reporting was handed to a separate agency, both agencies needed improved accuracy in location of permitted withdrawals. In areas where EPD had contracted mapping of permits, primarily the lower FRB, and the coastal zone, GIS-based mapping provided a starting point for meter installers. GPS measurements obtained during pre-installation site visits by the Georgia Soil and Water Conservation Commission (GaSWCC), led to verification of or corrections to GIS records in EPD's permit management system. However, there are still sizeable areas of the state where no mapping of permits has occurred and neither agency has the location information it needs to aid permit decision making or meter installation. It was primarily problems in the FRB and the coastal zones that led to the initial implementation of GIS tools in permitting

2.5 FRB water management

Hydrogeologic studies suggested that under conditions of extreme drought and increased agricultural irrigation, the Flint River would "dry up". USGS indicated that groundwater baseflow to the Flint River and several major tributaries could become negative, which coupled with already low surface water flows, could lead to brief periods of actual drying of some stream segments (Torak et al., 1996). The decrease in flow would threaten endangered species in the lower FRB, and could cause contamination of the Floridan aquifer by polluted surface water.

Georgia's waterways shrank during the drought that began in May 1998 as a result of the impact of landowners trying to keep crops viable through irrigation. This decrease in flow affected downstream water supplies as well as the instream flow that protects aquatic species. This also led to an increase in the number of permit applications received by EPD for agricultural water withdrawals in the FRB. In order to accommodate the flow reduction the state resorted to

2 measures: a moratorium on water withdrawal permits in the FRB; and the Flint River Drought Protection Act.

In 1998, EPD commenced with the Regional Water Development and Conservation Planning for the Lower Flint River and Upper Floridan Aquifer. EPD was allowed a 5-year period in which to suspend withdrawal permit activity in the region. This time was used for a scientific review of the challenges to the water supply. A grace period was given to allow irrigators to come into compliance before the moratorium was put into effect in December of 1999. This moratorium suspended the permitting of irrigation wells drawing from the Floridan aquifer in the lower FRB. Agricultural groundwater permits were available for other aquifers in the lower FRB such as the Claiborne and Cretaceous. No new surface water permits were being issued for the entire FRB from Atlanta to Lake Seminole.

The suspension on new permitted irrigation became the Flint River Drought Protection Act of 2000. The Act maintains instream flow in times of drought by providing incentives for farmers to take acres out of irrigation. It allows EPD to pay irrigators to stop irrigating their crops when a drought is predicted. EPD can hold auctions in which farmers offer prices per acre at which they would stop irrigating. This policy was spurned by critics whom argued that it was not productive to pay individuals not to do something.

"The large number of permit applications (1134) held in abeyance since December 1999, (i.e., the 'backlog')" (Couch et al., 2006) as well as the Act emphasized the need for more effective hydrologic calculations for allocation formulas.

2.5.1 Flint River Basin Regional Water Development and Conservation Plan

The impetus behind the FRBP, especially the moratorium, was the USGS hydrogeological modeling of stream-aquifer flux. It predicted influent stream conditions in the

FRB (McDowell, 2005). Two hydrologic modeling studies were conducted to evaluate the effects of groundwater and surface water withdrawals on streamflow in the FRB using the updated number of irrigated acreage from the "Agricultural Water Pumping" project. These studies simulated flow between the Flint River and the Floridan aquifer, as well as the effects future surface water irrigation will have on baseflow. Models were also used to show that maintaining instream flow will prevent further harm being done to endangered aquatic species.

The FRBP sets forth how EPD will conduct management of agricultural water use and permitting in the FRB. It lifts the moratorium on new agricultural water use permits from the Floridan aquifer in Subarea 4. "The goals of the FRBP are to promote conservation and reuse of water, guard against a shortage of water, promote the efficient use of the water resource, manage the water resources of the FRB such that they are used sustainability, and to be consistent with the public welfare" (Couch et al., 2006).

Three categories of sub-watersheds are identified as areas of further conservation measures: 1. Capacity Use Areas, in which irrigation use from the Floridan aquifer is at the maximum permitted capacity; 2. Restricted Use Areas, in which additional irrigation must be restricted in order to prevent the watershed from becoming a Capacity Use Area; and 3. Conservation Use Areas, in which hydrologic models indicate decreased baseflow of less than 0.5 m^3 per second in any month of a drought year, and less than 1.4 m^3 per second in the lower Flint River sub-basin (Couch et al., 2006). These designations are based on hydrologic modeling done during the course of the FRBP and will change as further investigations progress into the hydraulic connectivity of the lower Flint River and the Floridan aquifer.

The FRBP sets forth a process for evaluating the backlog of permits associated with the permit moratorium. Surface and groundwater withdrawal applications in Conservation and

Restricted Use Areas received before October 23, 1999 will be evaluated ahead of applications received after this date. New and pending applications must provide proof of land ownership or lease before receiving a Letter of Concurrence. An accurate latitude/longitude location is also required of all surface and groundwater sites to determine whether the proposed installation will have an adverse impact on existing users. Applicants must also provide documentation demonstrating that the permit is for a "farm use" as defined by O.C.G.A. §§ 12-5-31(b)(3) and O.C.G.A. §§ 12-5-92(5.1).

EPD's new permitting strategies will evaluate the effect of a proposed water withdrawal on existing users and streamflow, issuing the new permit in such a way that it will not adversely impact water availability. "All Floridan aquifer irrigation well permits will be evaluated to determine the calculated radius of influence of a proposed well and its relationship to the radii of influence of nearby Floridan aquifer wells on adjacent property. EPD will no longer issue permits for proposed Floridan aquifer irrigation wells that are in within 0.4 km of another user's well, or within 0.8 km of an in-channel spring or stream which exhibits a demonstrable connection with the Floridan aquifer, unless hydrogeologic evaluation indicates that the proposed well would not cause or contribute to excessive drawdown in the other user's well" (Couch et al., 2006).

Permittees are encouraged to adopt low-flow plans to allow for the continuance of irrigation under drought conditions. Permits issued in Spring Creek and the Ichawaynochaway sub-basins must include low-flow protection plans as part of standard permit conditions. "These plans will require a complete cessation of irrigation from the newly permitted source when discharge at the withdrawal location falls below 25% of the average annual discharge as calculated at that point based on the period of record for the nearest downstream continuous flow gauge, plus a prorated portion of the permitted amount of downstream users" (Couch et al., 2006).

Duplicate permits as well as permits for which no initial use of water has commenced will be revoked. Permit status was obtained through a survey conducted by UGA researchers and EPD.

The FRBP will be reevaluated every 3 years based on new scientific information on surface and groundwater interactions in the lower FRB as well as how instream flow is affecting sensitive aquatic species.

2.6 Coastal zone water management

Since the early 1960's, the problem of saltwater intrusion into coastal Georgia aquifers has been recognized (Counts et al., 1963). Groundwater monitoring by USGS indicated the presence of elevated chloride levels in Upper Floridan aquifer wells at Brunswick (Wait, 1965). Hydrogeological studies conducted since the 1970s have illustrated the need for efforts to conserve water and utilize alternative water supply sources.

A series of events involving declining aquifer head levels and increasing chloride concentrations between 1985 and 1995 demonstrated the need for a plan to address salt water intrusion in coastal Georgia. The "Interim Strategy for Managing Salt Water Intrusion in the Upper Floridan Aquifer of Southeast Georgia" described how Georgia would address groundwater withdrawal permitting in a 24-county area of coastal Georgia from 1997-2005. The Strategy introduced a moratorium on groundwater withdrawals from the Upper Floridan aquifer by municipal, industrial, and agricultural users.

The Coastal Sound Science Initiative was implemented with the Interim Strategy. The Initiative included definition and execution of an array of scientific and engineering investigations. These investigations were intended to generate data and information required to guide development of a plan for managing saltwater intrusion.

The goals of the Interim Strategy were: 1. to stop the encroachment of saltwater before municipal groundwater supplies at Hilton Head Island and Savannah/Chatham County were contaminated; and 2. to prevent the existing saltwater intrusion at Brunswick from worsening (Coastal Plan, 2006).

2.6.1 Coastal Georgia Water & Wastewater Permitting Plan for Managing Salt Water Intrusion

The Coastal Plan replaces the "Interim Strategy for Managing Salt Water Intrusion in the Upper Floridan Aquifer of Southeast Georgia", dictating how EPD will conduct surface and groundwater withdrawal permitting in the 24-coastal counties. The goal of the Coastal Plan is to stabilize saltwater intrusion into the Upper Floridan aquifer through the use of sub-regional management areas.

The Coastal Plan establishes 3 sub-regions for the purpose of implementing region-specific policies and permit requirements. This strategy is meant to stop saltwater intrusion, manage wastewater and apply water conservation and reuse practices. Sub-regions are based on the susceptibility to saltwater intrusion as based on the Coastal Sound Science Initiative.

All sub-regions must employ measures that will ensure efficient and effective use of the water resource. Each gallon of water sought under any permit application must be justified. Reactions of the Upper Floridan aquifer must be monitored as management actions are implemented.

Sub-region 1 consists of Chatham, Bryan, and Liberty Counties as well as a portion of Effingham County south of Georgia Highway 119. "This region overlays the cone of depression that extends into South Carolina; the Gulf bisects Effingham County roughly in a line defined by the location of Highway 119. The Gulf Trough is a feature of the aquifer whose low permeability acts as a barrier to the development of the cone of depression towards the northwest. Groundwater pumping on the northern side of the Gulf Trough has insignificant influence on the cone of depression" (GADNR, 2006).

No net increases in Upper Floridan aquifer withdrawals above amounts withdrawn in 2004, approximately 242,266 m^3 per day, are allowed in Chatham County and Effingham County south of Georgia Highway 119. Step increases in use of the Upper Floridan aquifer with monitoring of impacts on the potentiometric surface is allowed in Bryan and Liberty Counties.

Sub-region 2 consists of Glynn County where "saltwater intrusion is caused by very localized pumping that does not contribute significantly to the development or extent of the cone of depression underlying Sub-region 1" (GADNR, 2006).

The management goal in Sub-region 2 is to withdraw from the Upper Floridan aquifer in such a manner as to not change the current configuration of the "t-shaped" saltwater intrusion plume. No new wells will be permitted within the area of the plume, or within a setback of the plume.

Sub-region 3 consists of the remaining 19 counties within the 24-county coastal area, and the portion of Effingham County north of Highway 119. "The remaining 19 counties do not contribute significantly to the development or extent of saltwater intrusion at Savannah-Hilton Head or Brunswick" (GADNR, 2006).

There are no specific restrictions in Sub-region 3, only the general regulations governing permitting in the remaining 24-coastal counties.

2.7 Implementation of GIS-based permit mapping

The earliest geographic permit data came from a 1993 effort by EPD to interpret small, low resolution, Department of Transportation county maps mailed in with permit applications. The 'x-marks-the-spot' information was manually translated onto large county road maps. In turn, latitude and longitude were read from the overlying grids on the road maps. The coordinates derived from these maps were typed into the database, and became known as the '93 G' points. The highway maps with stick markers became known as the 'dot maps'. 'Dot' could refer to the Department of Transportation whose paper maps formed the base or the red and blue stick-on dots that routinely came unstuck as the maps aged. The '93G' points have been added to and removed from the GIS several times because of their known error rate. However, for many permits, they remain the only source of geographic information. They remain in current layers only when no newer data exists.

Earlier attempts at comprehensive permit mapping began as a result of shortcomings identified in studies of the ACF and subsequent negotiations. Conflicting acreage estimates were hindering negotiations on allocation formulas, and preventing EPD from calculating withdrawals from ground and surface water.

Permitting of new agricultural withdrawals in Subarea 4 was suspended while EPD conducted the Regional Water Development and Conservation Plan for the Lower Flint River and Upper Floridan Aquifer. The Plan required an accurate determination of irrigated acreage in the region; EPD entered into contract with the UGA to this end. The effort was designed to quickly provide estimates of area for use in negotiations, but these GIS maps did not contain information on permits, and no withdrawal points were identified.

During 1998, researchers from the J.W. Jones Ecological Research Center in Ichauway used USGS 1993, and later 1999, digital orthophoto quarter-quadrangles (DOQQ) of the lower FRB to begin mapping center pivot irrigation near ecologically sensitive streams. In that same year, researchers at the UGA's National Environmentally Sound Production Agriculture Laboratory (NESPAL) used high resolution images as well as statistical techniques to express pivot circles and semi-circles of fields that had distinct pivot wheel treads. This project was called "Agricultural Water Pumping", and consisted of several nested projects: selection of suitable irrigation systems to meter; determination of irrigated acreage; and metering of irrigation systems. These studies provided the first real measure of irrigated acreage for the region.

The second contract was designed to determine what sources were being used by permitted agricultural users, their location, and which field areas were irrigated by them. This mapping became the basis of the current GIS-based permit management system.

Farmers and other permit holders identified which of their permits were associated with previously mapped fields. EPD and UGA specialists drew associated wells, surface pumps, and other irrigated fields and collected information on the permits associated with those points. The resulting permit maps and all data for the permit management were stored in a Microsoft Access ® 2000 database. More than 90% of the permits in counties of the FRB were accounted for through this multi-year effort. The linkage of this geospatial data and permits has proved invaluable for computing potential withdrawals for specific sources and locations as well as for protecting the existing permitees as subsequent permitting has progressed. The success of those efforts in mapping demonstrated to EPD how a GIS could greatly assist their management of agricultural withdrawal permits and determine accurate irrigated area (Hook et al., 2001).

Field visits were not conducted to verify locations reported in GIS-based permit mapping of the FRB. Additionally, permit holders were required to report locations of inactive pumps and fields. This was done so that permittees rights to restart the permitted withdrawal could be protected. Both of these factors left a disconnect between current and permitted pump locations.

In the coastal zone, EPD's GIS unit used a different approach to mapping of irrigation and pumps. For the most part, site visits were made when pumps and visible systems were installed. These withdrawal locations were drawn on DOQQs, and then digitized by EPD personnel to create GIS data layers. The field site investigators made reasonable attempts to locate every irrigation system and pump in use in the coastal counties. However, they were not able to find a location for every permit.

The most recent permit mapping endeavor occurred during September of 2006, and included data from the GaSWCC. GaSWCC location coordinates were obtained from GPS-units, computed during the site characterization for flow meters, as per House Bill 579. Ideally, this kind of site measurement would be the last stage of permitting with pump installation verified by an on-site visit by EPD. With too few personnel to complete this permit stage, GaSWCC's measurements provide the first concrete evidence that these permits have been activated and pumps installed. While the GaSWCC coordinates note surface pump and well location, others note center pivot points; some precautions were taken to be sure point which was which.

2.8 Proposed contributions

House Bill 237 provides legislation for EPD officials in developing a comprehensive state-wide water management plan. The Bill states that effective water resources management requires efforts based on a sound scientific foundation that provide sustainable supplies of quality water supporting both human and natural needs. “A comprehensive and accessible database must be developed to provide scientific information” (HB 237 §§ (2)(6)) for effective water resource management decisions. “Water resources management encourages local and regional innovation, implementation, adaptability, and responsibility for watershed and river basin management and accommodation of new scientific and policy insights as well as changing social, economic, cultural, and environmental factors” (HB 237 §§ (2)(7);HB 237 §§ (2)(9)).

The research proposed in this thesis meet the needs of effective water management as outlined by House Bill 237. A Microsoft Access ® database houses all permit records on agricultural water withdrawals in the state. The entries are constantly updated with information on scientific permit specifications such as pumping rates and installation locations. The geodatabase adds spatial information on transmissivity, distance to permitted source as well as distance between existing permitted sites. These allow for more accurate representations of water use conditions in Georgia.

The permit geodatabase is a dynamic product that should continue to improve in accuracy as new geospatial data becomes available, and old, deactivated permits are removed. It should never be viewed as a static map of irrigation permits. Regional restrictions as well as localized mapping efforts have increased the precision demanded by new permitting statutes. New spatial data provided by USGS and EPD on basin hydrography as well as hydrogeology are implemented in the geodatabases, and will be updated as new data become available.

REFERENCES

(2006). "Coastal Georgia Water & Wastewater Permitting Plan for Managing Salt Water Intrusion." Georgia Department of Natural Resources, Environmental Protection Division.

Arora, R. (1984). "Hydrogeologic evaluation for underground injection control in the coastal plain of Georgia ", Hydrologic Atlas 10, Georgia Department of Natural Resources Atlanta, Georgia.

Carter, R.F. and Thomson, M.T. (1963). Effect of Severe Drought (1954) on Streamflow in Georgia. Georgia Geologic Survey Bulletin B-73, p. 97.

Carter, R.F. and Putnam, S.A. (1978). Low Flow Frequency of Georgia Streams. U.S. Geological Survey Water-Resources Investigations Report 77-127, p. 104.

Couch, C. A., McDowell, R. J. (2006). "Flint River Basin Regional Water Development and Conservation Plan." Georgia Department of Natural Resources, Environmental Protection Division.

Counts, H. B., and Donsky, E. (1963). "Salt-water encroachment, geology, and groundwater resources of Savannah area, Georgia and South Carolina." U.S. Geological Survey Water Supply Paper 1611.

Hirshleifer, J., Haven, J.C. and Millimand, J.M. (1966). *Water Supply Economics, Technology, and policy*, University of Chicago Press, Chicago, IL.

Hook, J. E., Blood, E.R. (2001). "Mapping agricultural withdrawal permits and irrigated area in the Lower Flint Basin." *Proceedings of the 2001 Georgia Water Resources Conference* University of Georgia Institute of Ecology, Athens, Georgia.

Mack, D. M., Karp, H.C., Jr. . (1984). *Structure-Contour Map of the Top of the Miocene Aquifer, in Arora, Ram, ed. Hydrogeologic Evaluation for Underground Injection Control in the Coastal plain of Georgia*, Georgia Geologic Survey Hydrologic Atlas 10, plate 5.

McDowell, R. J. (2003). "Status of the Flint River Regional Water Development and Conservation Plan " *Georgia Water Resources Conference*, The University of Georgia, Athens Georgia.

Pendergrast, C. K. (2001). "Whose Water is it Anyway? A Brief Survey of Geological Law on Water Supply Rights." Paul, Hastings, Janofsky & Walker LLP, Atlanta, Georgia.

Torak, L. J., and MacDowell, R.J. (1996). "Ground-water Resources of the Lower Apalachicola-Chattahoochee-Flint River Basins in Parts of Alabama and Georgia - Subarea 4 of the Apalachicola-Chattahoochee-Flint and Alabama-Coosa-Tallapoosa River Basins." U.S. Geological Survey Open File Report 95-321.

USDA-NRCS. (1995). "ACT/ACF River Basins Comprehensive Study, Agricultural Water Demand Executive Summary." U.S. Department of Agriculture, Natural Resources Conservation Service.

USDA-SCS. (1994). "ACT/ACF River Basins Comprehensive Study, Agricultural Water Demand Technical Report." U.S. Department of Agriculture, Soil Conservation Service

Wait, R. L. (1965). "Geology and occurrence of fresh and brackish water in Glynn County, Georgia." U.S. Geological Survey Water-Supply Paper 1613-E.

Chapter 3

GIS ANALYSIS OF SURFACE WATER PERMIT DECISIONS

3.1 Relational database management for the ACF River basin

The University of Georgia's National Environmentally Sound Production Agriculture Laboratory and EPD have cooperated to build a hydrologic information system to support hydrologic analysis of water withdrawal permit applications in Georgia. A prototype of this system includes an Arc Hydro-based GIS and relational database containing geographic, hydrologic and related data for the ACF River basin. This system supplies accurate, objective and reliable data necessary for analysis and resolution of water resources issues while incorporating EPD permit regulations. Datasets procured for this research have been processed and re-projected so each data feature has the same characteristics. These data features representing the surface water hydrography of the ACF River basin are contained in a geographically referenced relational database (geodatabase).

3.2 Geographic and temporal data collection

Four important datasets were incorporated into the surface water geodatabase. All four datasets are available from the U.S. Geological Survey (USGS): National Elevation Dataset (NED); National Hydrography Dataset (NHDPlus); the "USGS streamgages linked to the medium resolution NHD"; and the "Georgia Hydrologic Unit Boundaries, 8-, 10-, and 12-digit".

The NED is a high-resolution, seamless, raster elevation dataset produced by the USGS National Center for Earth Resources Observation and Science for the conterminous United States. The dataset was created by joining USGS digital elevation model (DEM) 7.5 minute tiles of data at 30 m resolution for the United States. These are updated bimonthly. Bilinear interpolation, mean profile filtering, and edge-matching algorithms were used to resample, transform, correct artifacts, and merge multiple DEMs (USGS, 2005). These processes were necessary in order to smooth the joins between the 7.5 minute DEMs. The raster dataset is available in Geographic projection, North American Datum 1983, in units of decimal degrees, with Z (elevation) units in meters.

DEMs and other grids are available at various spatial resolutions for download from http://seamless.usgs.gov/website/seamless/viewer.php. Watershed delineations produced from higher resolution grids are more accurate, but require more memory and processing time. To acquire a precise representation of waterways in the ACF River Basin, 10, 30-meter resolution, 1-arc second DEMs are processed.

NHDPlus is a comprehensive dataset that stores geospatial and temporal information about naturally occurring and constructed bodies of water. The dataset is compiled from the Environmental Protection Agency's reach files, and the USGS Digital Line Graph for the United States at a scale of 1:100,000. It incorporates features of the 2002 version NHD stream network, the NED, and National Watershed Boundary Dataset (WBD). NHDPlus utilizes the "New-England Method" to perform elevation and catchment analysis by modifying NED and WBD data to the medium resolution (1:100,000) scale. Network accuracy and performance is improved due to the implementation of these additional datasets.

The geospatial datasets included in NHDPlus have been used to develop estimates of mean annual streamflow and velocity for each NHD flow line in the conterminous United States. Value-added attribute-based routing techniques were used to produce the NHDPlus cumulative drainage areas and land cover, temperature, and precipitation distributions (Dewald, 2006).

These cumulative attributes are used in flow calculations using the Vogel and Unit Runoff Methods (UROM).

NHDPlus data are available, by region, for download from http://www.horizon-systems.com/nhdplus/. Data for the South-Atlantic Gulf (Hydrologic Region 03) became available September 1, 2006, and are loaded into the "ACFBasin ArcHydro" geodatabase feature classes. Production unit 03b contained data on the ACF specifically, but most of it could not be used due to errors in the datasets and incompatibilities with Arc Hydro.

The flow line and water body data from the hydrography dataset, available with the NHDPlus download, were employed in this research. It was the intent to use all the dataset s provided with this dataset, but upon further analysis, it was found that the "cat" grid and "catchment" shapefile could not be processed using Arc Hydro tools. Error messages stating inaccuracies in the datasets arose each time the data was processed; troubleshooting methods were performed to no avail. This could be due to ArcMap's ® tendency to round grid cell values to six significant digits. Therefore, the original DEMs were downloaded and manipulated to create these features.

"USGS streamgages linked to the medium resolution NHD" contain the physical locations of the USGS stream gauges, as well as their location on the NHD version 2002 medium resolution (1:100,000 scale) flow lines. The streamflow data used to compute the historical flow characteristics are from the National Water Information Systems (NWIS) website, http://waterdata.usgs.gov/nwis. The information provided in this data layer are both spatial and temporal including baseflow indices, drainage areas, daily flow percentiles, and stream gauge names and numbers, among others.

The USGS stream gauge data geodatabase is available for download at http://water.usgs.gov/GIS/metadata/usgswrd/XML/streamgages.xml. The gauges used for the surface water portion of this research were clipped to the ACF River basin boundary, resulting in 142 streamflow gauges. Future releases of NHDPlus will update this data for each hydrologic region.

The “Georgia Hydrologic Unit Boundaries, 8-, 10-, and 12-digit” dataset contains 8-, 10-, and 12-digit hydrologic unit boundaries for Georgia, Alabama, North Carolina, South Carolina, and Tennessee. The boundaries are delineated on 1:24,000 scale, 7.5 minute USGS topographic quadrangles, and labeled with the appropriate 8-, 10-, or 12-digit hydrologic unit. “The purpose of the hydrologic unit coverage is to provide accurate, standardized GIS of watershed boundaries through the fifth and sixth (10- and 12-digit) hydrologic unit scale using a nationally accepted, consistent method” (McFadden, 2000).

The hydrologic unit data is available for download at http://www.gis.state.ga.us/. The watershed approach to investigation and water resources management used in this research employed 536 hydrologic units at the sixth hydrologic unit scale (12-digit), clipped to the outline of Georgia.

The data collected from these sources came in several formats, so it had to be manipulated and transformed to generate the feature data classes that are part of the geodatabase. The vector data in the NHDPlus, Hydrologic Unit Boundaries, USGS stream gauge, and raster data in the NED datasets used the Geographic Coordinate System to create their geographic information. The Universal Transverse Mercator (UTM) projection for zone 16N is used for this project in order to coincide with existing EPD permit data. The North American Datum (NAD)

1983 was chosen as it is a standard datum accepted around the world, and the Geodetic Reference System 1980 was used as the spheroid.

3.3 Study area

The ACF River basin drains an area of 51,282 km^2. This area is comprised of the Chattahoochee and Flint Rivers, which merge at Lake Seminole to form the Apalachicola River. The Apalachicola River flows through the panhandle of Florida into the Apalachicola Bay, and discharges into the Gulf of Mexico (Figure 3.1). Three-quarters of the ACF is located in Georgia, extending over 62 of its 159 counties.

The ACF River basin is the study area for the surface water portion of this research. This is due to recent legislation that has created zones within the basin with differing rules for permitting. Streamflow protection rules have been enhanced in the basin, and it is already under higher pressure from existing surface water withdrawals and for new withdrawals.

Population of the ACF River basin in 1990 was estimated at 2.6 million, 90% of this population lived in Georgia, principally in the metro-Atlanta area (Couch, 1993). This number is expected to increase by 30% to 3.4 million by 2010 (Couch, 1993). The southern coastal plain regions of the basin are used predominantly as agricultural lands. By 1990 estimates, Georgia withdrew 6,245,930 m^3 (82 percent) of the 7,646,532 m^3 of freshwater flowing through the river system each day.

Total water use within the ACF River basin has increased by 37% since 1970. The rise is attributed to an increase in public-supply water use, mainly in the metropolitan Atlanta area, and an increase in agricultural water use, mostly in the Dougherty Plain area of southwest Georgia (Couch, 1993). Georgia accounted for 92% of irrigated area in the basin, with most of the irrigation occurring in the Dougherty Plain (Marella et al., 1999), Agricultural water withdrawals are one of the largest uses of water in the basin.

The Flint River flows north to south for 341 km, most of that free flowing, making it one of the least controlled rivers in the country. Its basin (FRB) drains an area 21,911 km^2, extending from Hartsfield-Jackson International Airport to the southwestern corner of Georgia, where it joins the Chattahoochee (Figure 3.2). Agricultural irrigation uses the largest volumes of water in the FRB, a total of 648 km^2 are irrigated from surface water (Couch, 2006). As a result, a majority of the agricultural water use applications and permits in the state are from the FRB. The FRB contains a disproportionate number of permits, but its large farms account for 40% of all of the state's agricultural withdrawals.

The surface streams in the Flint River basin (FRB) and interconnected groundwater in the lower Flint were under a moratorium on new agricultural withdrawal permits beginning in November, 1999. The moratorium was initiated by Harold Reheis (then Director of EPD) in response to several factors: 1. a drought that began in May of 1998; 2. an increasing number of "farm use" permit applications from southwest Georgia; and 3. USGS hydrogeologic studies that predicted a severe impact on the Flint River and some of its tributaries under conditions of drought and increased irrigation withdrawals from the Floridan aquifer (Torak et al., 1996).

Following a scientific study and stakeholder process, the Flint River Basin Regional Water Development and Conservation Plan (FRBP) was created. With adoption of the Plan, the moratorium was lifted in March, 2006. In the FRBP, the FRB was divided into "Capacity Use Areas", "Restricted Use Areas" and "Conservation Use Areas", each with differing new permit conditions. The zones are represented in the Arc Hydro geodatabase a polygonal feature class that followed 12-digit hydrologic unit (sub-watershed) boundaries, furthering the accuracy of permit decisions. These designations are based on the best available data and analysis of the hydrogeology and irrigation practices in the lower FRB. A 'backlog' of several hundred permit requests has to be evaluated under these new Plan rules.

Figure 3.1 – The ACF River basin drainage area spans Georgia, Alabama, and Florida before reaching the Gulf of Mexico

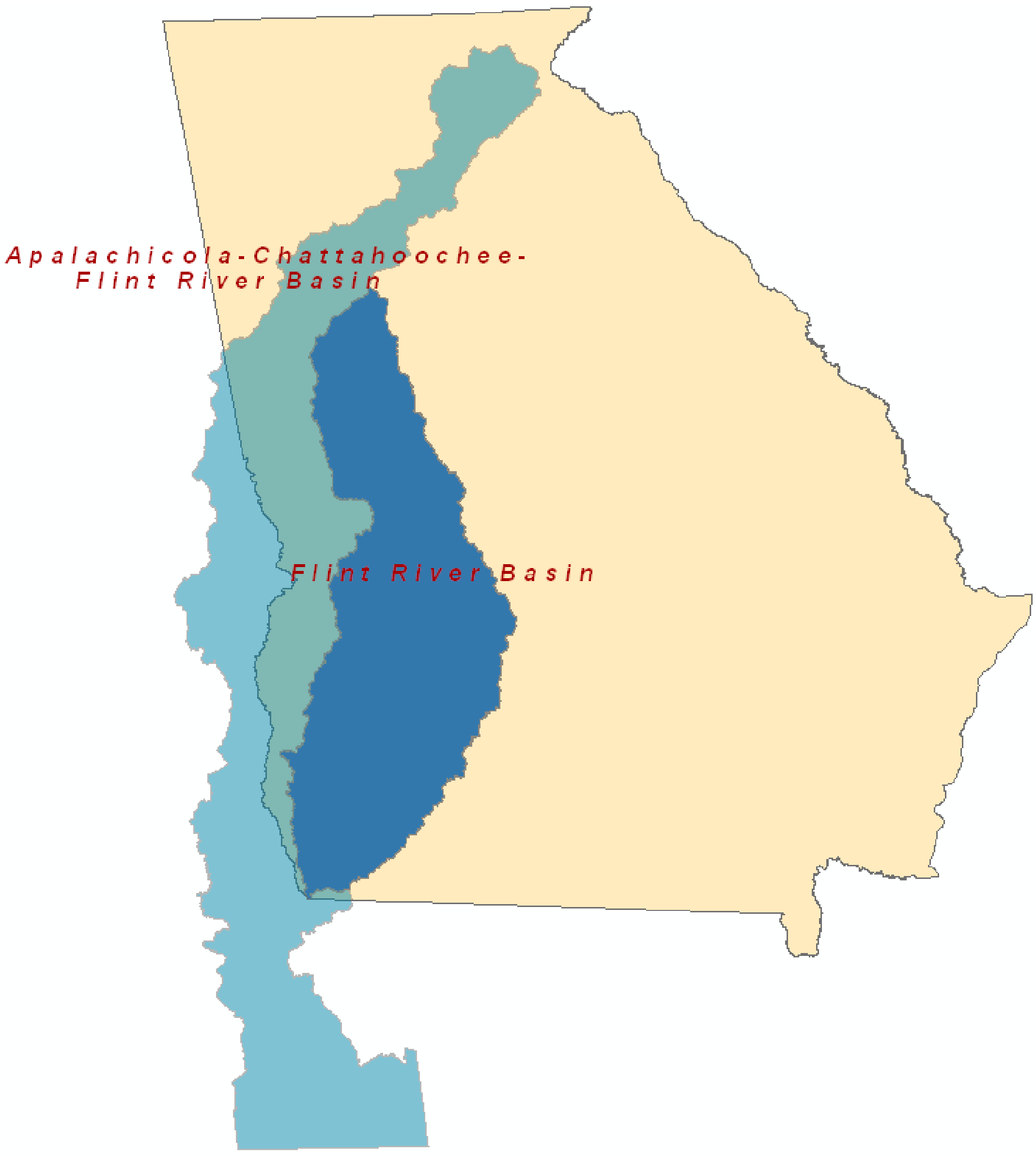


Figure 3.2 – The FRB in relation to the ACF River basin

3.3.1 ACF physiography

The ACF River basin spans both the Piedmont, and Southeast Coastal Plain physiographic provinces (Figure 3.3). These provinces are separated by a sharp drop in elevation known as the Fall Line, as such; there is a wide variance in landscape relief.

The Blue Ridge physiographic province has mountains and ridges ranging in elevation from 914 to 1067 m. The boundary between the Blue Ridge and Piedmont Plateau physiographic province is a sharp drop of 518 m.

The Piedmont Plateau elevation ranges between 457 m and 305 m from northeast to southeast, respectively. The Fall Line is a sharp drop in elevation from the Piedmont Plateau to the Coastal Plain physiographic province.

The Coastal Plain region is split into 3 districts with highly varied relief. The hilly region directly below the Fall Line has elevations ranging from 15m to 76 m. The karst topography of the Dougherty Plain has altitudes of 91 m in the northeast to less than 31 m near Lake Seminole. The low-lying coastal region has elevations of 99 m in the northeast, and less than 31 m southward toward the Gulf Coast Lowlands. ACF River basin physiography is discussed in greater detail by Leitman and others (1983).

The physiography affects the nature of withdrawal requests for surface water. In the Blue Ridge and Piedmont, agricultural withdrawals are almost always made directly from streams. Downstream regional reservoirs and permitted municipal and industrial (M&I) surface withdrawals require protection in the flow analysis. In the Upper Coastal Plain, most of the requests are for withdrawals from ponds created to retain runoff. Depending on their connectivity with flowing streams, some of these will require permits while others will not. In the karst regions of the lower Flint, few ponds exist and surface withdrawal requests are again for direct stream as well as springs and wetland ponds.

3.4 Hydrologic information systems

Water resource managers require information on the characteristics of watersheds that drain “waters of the state”. Geographic Information Systems (GIS) technology coupled with increased geospatial data availability allow managers to obtain this information. A GIS provides a platform for analyzing spatial data. Hydrology is the study of the movement, distribution, and quality of water throughout the Earth. Hydrologic data can be symbolized accurately in GIS due to its inherent spatial nature.

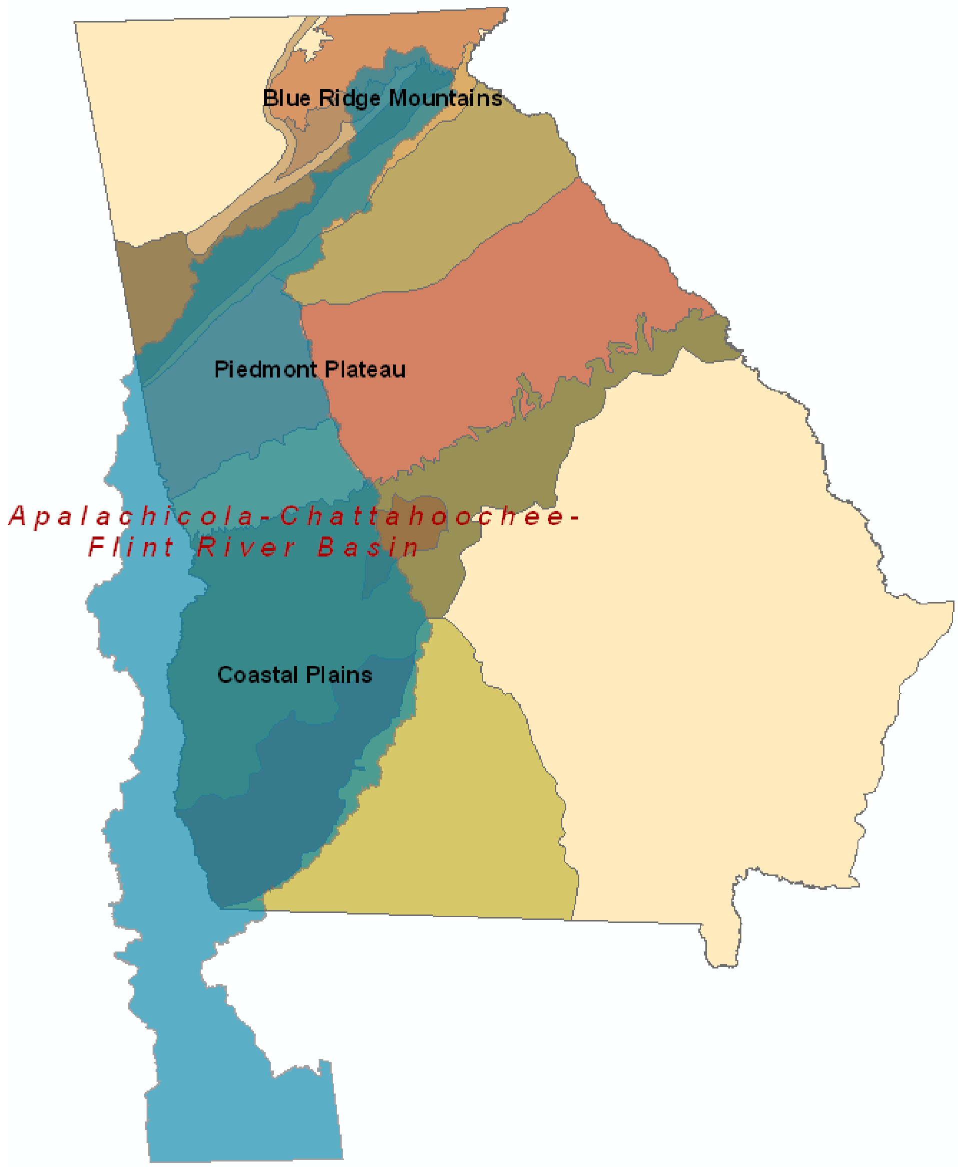


Figure 3.3 – ACF physiographic provinces: Blue Ridge Mountains; Piedmont Plateau; and Coastal Plain

Vector and raster are the two most common forms of geospatial data. Vector data consists of points, lines and polygons with their associated attributes. Vector data has proven ideal for the representation of hydrologic data; stream paths are represented by lines, stream and watershed areas are represented by polygons, and gauging stations are represented by points.

Rasters are grid data, where each grid cell contains a unique value representing elevation, precipitation or stream flow. Rasters can be processed in GIS to produce vector data, which can be used to convey a third dimension in hydrologic data. For instance, this would allow for analysis on the length, depth and width of a stream channel at different locations.

Hydrologic Information Systems (HIS) is a concept that combines GIS technologies and geospatial hydrologic data. An HIS results from the synthesis of temporal and spatial data; flow rate is an example of temporal data; stream segments are an example of spatial data. HIS is used to perform hydrologic modeling and analysis of a river basin (Maidment, 2002). The use of HIS technology facilitates the creation of objective analysis methodologies for water resource management issues. “Although watershed area is easy to conceptualize and delineate on a paper map, GIS delineations are less labor intensive, more reproducible, and less dependent on subjective judgment” (Chinnayakakahalli, 2006).

Successful management of water resources, “requires HISs, which are used for many purposes such as risk assessment and possible mitigation of droughts and floods, manage water rights, assess water quality, and to understand the hydrology of a river basin” (Patiño-Gomez et al., 2005). Spatial and temporal data stored in a HIS relational database can be accessed by hydrologic simulation models in order to replicate basin-wide conditions.

The application of any hydrologic simulation model requires efficient management of large spatial and temporal datasets. GIS is used increasingly in the form of geospatial databases (geodatabases) to manage these data. This is done by integrating watershed simulation models, the input and output datasets associated with them, and GIS, creating the ability to manage large volumes of data in a readily understood spatial structure (Al-Sabhan et al., 2003).

The Environmental Research System Institute's (ESRI) ArcGIS ® uses an object-oriented data model known as a geodatabase, gives the features in GIS datasets custom behaviors. The geodatabase data model provides a common data and management framework into which geospatial data is imported. Geodatabase extensions for storing, querying, and manipulating geospatial data are employed to facilitate the management of ACF River basin datasets. ArcGIS ® personal geodatabases can hold up to 2-gigabytes of information; our geodatabase holds 365 MB of data related to EPD proposed and permitted locations. One advantage of the geodatabase is that it can be examined in both the ArcGIS ® platform and Microsoft Access ® database format, both of which EPD officials are familiar.

ArcGIS ® Hydro (Arc Hydro), developed by the Center for Research in Water Resources at the University of Texas in Austin and ESRI, is a surface water data model for storing geospatial and temporal hydrologic data. Arc Hydro consists of a geodatabase, managed using ArcGIS ® software, which is used in the facilitation of hydrologic analysis of geospatial and temporal data associated with the ACF River basin. Geodatabases manage the vector data as well as relationship and topology rules describing the behavior of and physical environment through which water flows. Historical information gathered from gauging stations is included in the geodatabase. This allows for integration of temporal and geographic information in the same structure.

Tri-state allocations, drought year management, and improved protection of permit holders demand a system of permit mapping for the management of agricultural withdrawal permits (Hook et al., 2001). Adapting the Arc Hydro data model for the ACF River basin represents the first attempt to utilize a HIS in the facilitation of surface water permitting. This System allows for the protection of existing downstream users and critical flow through the implementation of EPD permitting regulations. The geodatabase makes it possible to obtain information about water availability, water use, and drainage in the basin. These data permit EPD officials to calculate the state of water availability under current and future water resource management scenarios.

3.5 Arc Hydro data model and tools

Arc Hydro creates a basis for modeling surface water systems through the representation of various hydrologic datasets in a standardized geodatabase structure. The data model incorporates a combination of GIS objects enhanced with the capabilities of a relational database to allow for relationships, topologies, and geometric networks (Maidment, 2002). Arc Hydro consists of two components: the Arc Hydro data model framework and the Arc Hydro tools implemented in GIS.

The data model framework “provides the initial functionality that can be extended by adding to it database structures and functions required by a specific task or application” (Patiño-Gomez et al., 2005). The framework contains information organized in 5 levels based on ArcGIS ® network, object class, and object modeling capabilities (Maidment, 2002):

1. Geodatabase – a Microsoft Access ® database file;
2. Feature dataset – a folder that stores feature classes within the geodatabase, its has a defined map projection, coordinate system, and spatial extent;
3. Geometric network – stores information that topologically connects hydrologic features;

4. Feature Class, Object Class – stores information on individual geographic features;
5. Relationship Class– where features from one feature class are related to another.

Figure 3.4 illustrates the geodatabase structure of the Arc Hydro data model framework. There are 5 main feature classes that store geospatial data related to water resource systems (Maidment, 2002):

1. HydroEdge – a network of lines describing map streams and water body centerlines;
2. HydroJunction – a set of junctions located at the ends of flow segments and other strategic locations on the flow network;
3. Waterbody – ponds, lakes, and reservoirs in the water system;
4. Watershed – the drainage areas contributing flow from the land surface to the water system;
5. MonitoringPoint – a set of points representing gauge locations where water is measured

Arc Hydro also provides a set of tools to "be used for a number of hydrologic processing routines including raster processing and the assignment of feature attributes" (Obenour et al., 2004). Tools from ESRI's Spatial Analyst extension for ArcGIS ® are employed to process large DEM raster datasets into catchment and watershed areas. Unique feature identifiers known as HydroID are assigned to create relationships between point and polygon data. The Utility Network Analyst toolbar is used to set flow direction for streams in the geometric network created within the geodatabase.

Vector and raster data are utilized by the Arc Hydro data model for the representation of hydrologic 'object' and 'feature' classes. Vector data depicting streams, water bodies, and watersheds can be imported to the data model from NHDPlus or generated using raster DEMs.

"Much of the Arc Hydro toolset focuses on using land surface elevation rasters to generate streams and catchments for the data model" (Obenour et al., 2004).

The data model structure is not rigid; it can be modified to fit the needs of individual research projects. This research involves the operation of the "Arc Hydro Framework" data model. This framework "contains the feature classes necessary to create a useable Arc Hydro flow network (watersheds, rivers, junctions, water bodies, and monitoring points)" (Obenour, 2004).

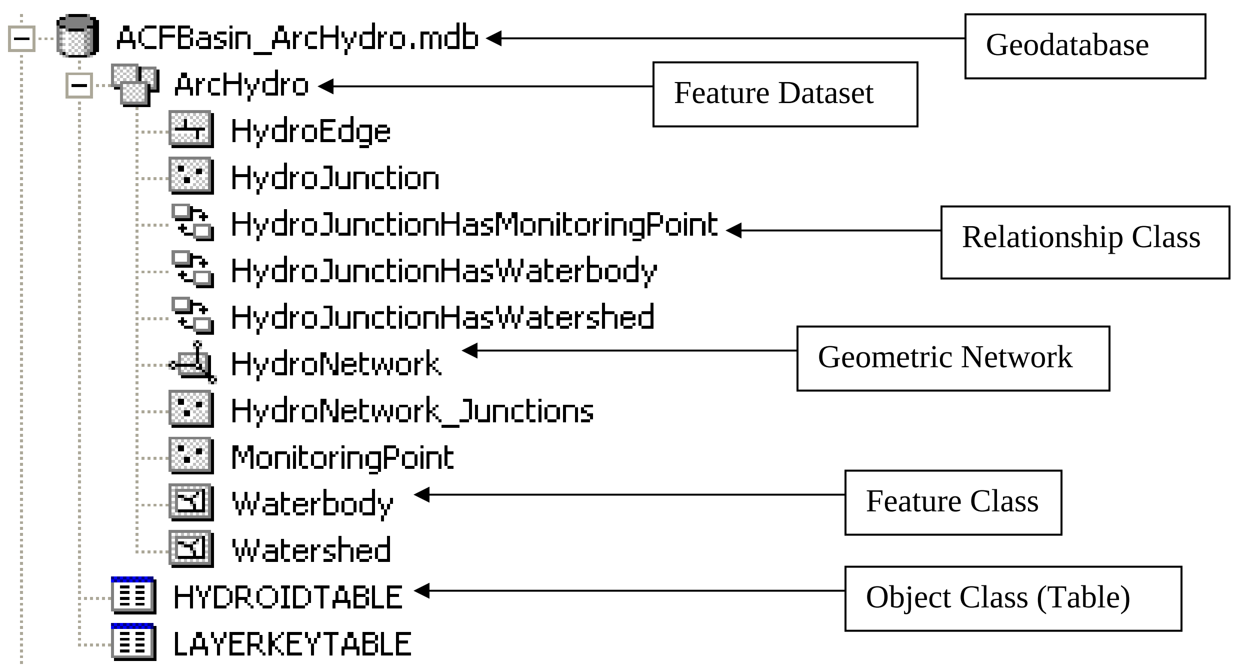


Figure 3.4 – The Arc Hydro geodatabase structure used in the evaluation of surface permitting

3.6 Raster processing

Data distributed on a national or state level is clipped to the ACF River basin boundary; raster and vector data distributed on a county or grid level are merged. The spatial extent of the basin and the processing abilities of the computer determine the number and size of the hydrologic units processed.

The raster and vector data representing flow direction, pit-filled DEM, flow accumulation, stream delineation, catchments, and stream segmentation available with NHDPlus are not used in this research. As mentioned before, when processing was attempted on this data using Arc Hydro tools, several errors were encountered. Therefore, the raster datasets used to create vector data for this research were calculated using original USGS NED DEM data.

DEMs are available from the NED seamless data download website at various spatial resolutions (10-meter, 30-meter, and 90-meter). Delineations generated by finer resolution grids are more accurate, but require more storage space and processing time. "30-meter resolution grids are recommended for watersheds $<10{,}000\ km^2$ (about the size of an 8-digit hydrologic unit), but 90-meter resolution for larger basins" (Chinnyakanahalli, 2006).

"Analysis of features found on the earth's curved surface with models that treat the surface as flat requires projecting geographic features from the curved to flat surface in a way that minimizes distortion" (Chinnyakanahalli, 2006). The UTM coordinate system is a grid-based method of specifying locations on the earth's surface. The system is not a map projection; rather it employs a series of 60 Transverse Mercator projection zones capable of mapping a region of large north-south extent with a low amount of distortion. The ACF River basin is of a large north-south extent.

The theory behind the raster development process has been well documented in a number of past reports (Stone, 2001). Hydrologic analysis tools needed to accomplish watershed delineation from grid data are available through the Arc Hydro toolset, the hydrology toolset in

ArcToolbox ®, or TauDEM. The Tools start with an existing raster, perform an algorithm on the raster, and generate a new raster containing the algorithm results (Obenour, 2004).

For this research, Arc Hydro raster processing tools are combined with preprocessing procedures provided with the **“**The Multi-Watershed Delineation (MWD) Tool” to develop vector data for surface water permitting analysis. The MWD Tool was developed by researchers from the Department of Civil and Environmental Engineering and The Western Center for Monitoring and Assessment of Freshwater Ecosystems Department of Aquatic, Watershed, and Earth Resources at Utah State University in 2006.

The MWD Tool is a standalone windows program that uses ArcObjects and TauDEM functionalities to derive watershed attributes for multiple sites across large geographic areas (Chinnayakanahalli et al., 2006). This Tool is ideal for this research because the ACF River basin covers such a large area. The processing starts with grid representations of topography (DEMs), from which a series of additional grids are produced signifying hydrologic characteristics of a selected basin (Figure 3.5).

Once the basin boundary of is defined, 10 seamless 30-meter resolution DEMs are clipped to a 10 km buffer of the basin, and processed using the MWD Tool data preprocessing functionality. The grid datasets, delineating a large geographic area, require a memory capacity too large for most computers. The MWD preprocessing tools clip large hydrologic grids to a more manageable size using a polygon shapefile (10 km buffer) that approximates the hydrologic boundary of the basin. This is much the same as is done in preprocessing with Arc Hydro tools. However, unlike Arc Hydro, the MWD preprocessing tools allow for the creation of multiple hydrologic grids in one step.

An Arc Macro Language (AML) script, run in ArcInfo ®, creates the hydrologic grids necessary for analysis and watershed delineation. The “hydrogrid” and “agree” AML text scripts available with the MWD Tool combine sequential commands into a single process to produce hydrologic grids.

The MWD Tool AMLs complete six functions (Chinnayakanahalli et al., 2006):

1. The AMLs clip and merge several DEM tiles to create a single DEM that covers the extent of the ACF River basin;
2. DEM elevation values are then multiplied by 10 and the DEM is converted to an integer grid;
3. The DEM is projected to the UTM projection (the projection chosen for this research);
4. A trench is “burned” into the DEM with the stream coverage;
5. The hydrologic grids are created with the output from the first four steps. The final grids are: a pit-filled DEM; a flow-direction grid; a flow-accumulation grid; and a modeled stream grid. The AMLs produce the hydrologic grids at both 30-meter and at a re-sampled resolution of 90 meters;
6. The AML cleans the working directory of temporary files created during the process.

The AML text scripts are edited to specify different values and naming conventions. In the original script, the raw DEMs are re-projected during the AML data preprocessing. To save time, the 10 raw DEMs for this research were re-projected before they were processed. Therefore, it was necessary to edit AML text pertaining to the re-projection of preprocessed data.

The resulting 30-meter and re-sampled 90-meter resolution preprocessed hydrologic grids, and the 10 “raw” DEM rasters are illustrated in Figure 3.6. The “raw_dem” folder contains all the original seamless DEM grids required to cover the extent of the ACF River basin. The "ArcHydro" folder contains the 90-meter resolution grids clipped to a 10 km buffer of the ACF River basin created with the MWD Tool AMLs and Arc Hydro toolset. The 90-meter resolution grids are further processed instead of the finer resolution 30-meter grids due to the large extent of the basin's drainage area (>50,000 km^2).

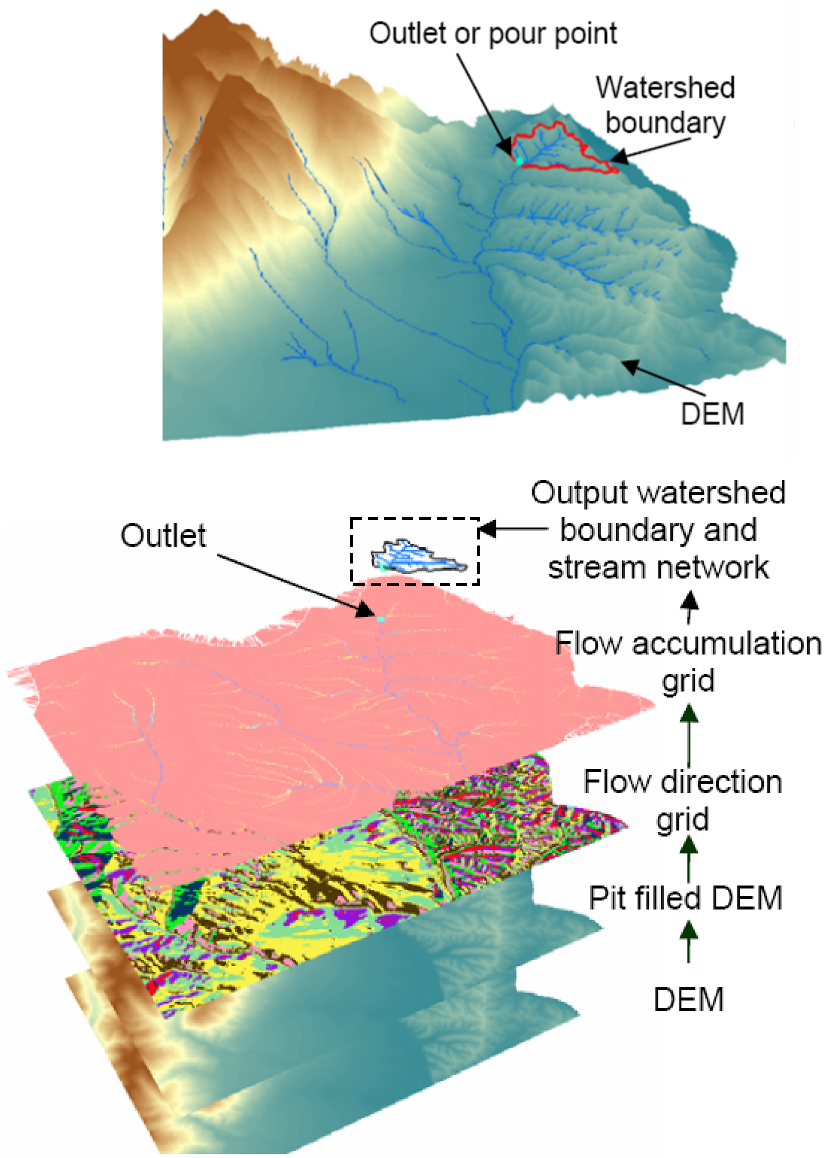


Figure 3.5 - Representation of a DEM and hydrologic grids needed for watershed delineation (Chinnayakanahalli, 2006).

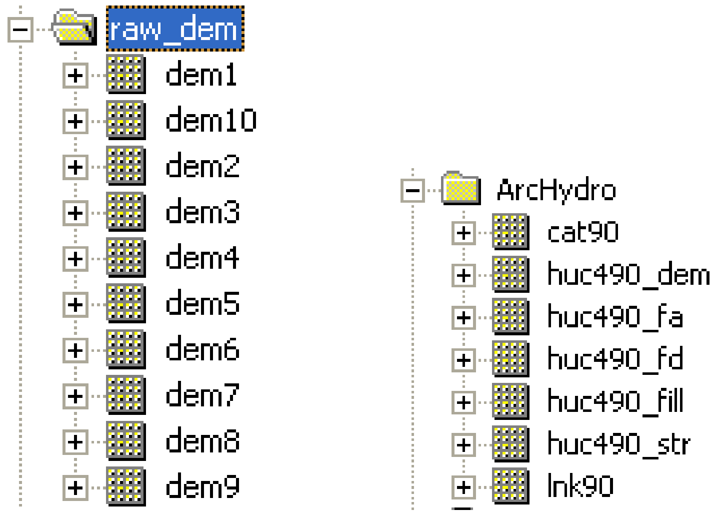


Figure 3.6 - Raster grids processed using Arc Hydro and MWD Tools

The “huc490_dem” in Figure 3.6 is the reconditioned 90-meter resolution grid representing the ACF River basin clipped to a 10 km buffer, and projected in UTM NAD83 zone 16N. The merged DEM is modified by imposing linear features onto it during the implementation of the “AGREE” method performed by the MWD Tool “agree” AML.

Watershed analyses conducted with DEMs require surfaces to be hydrologically connected. Each cell comprising the DEM must flow into the next downstream cell from source to sink until the water flows off the grid. The connectivity of cells can be disrupted when low elevation areas are surrounded by areas of higher elevation, essentially stopping flow. These low-elevation cells are known as pits and must be filled in order for meaningful hydrologic analysis to occur. “The ‘fill’ is accomplished by raising the value of a cell identified as a pit to match the elevation of its downhill neighbor” (Chinnayakanahalli, 2006). The pit-filled DEM is represented as “huc490_fill” in Figure 3.6.

The pit-filled DEM is processed to determine the direction of flow from each grid cell to the next downhill neighbor. “The flow direction is calculated by examining the 8 neighbors of a cell and determining the neighbor with the steepest downhill slope" (Chinnayakanahalli, 2006). The flow can go in one of 8 directions, which are coded by number: northwest is 32; north is 64; northeast is 128; east is 1; southeast is 2; south is 4; southwest is 8; and west is 16. The calculation process is repeated until each cell in the DEM has a coded value, the resulting grid is represented as "huc490_fd" in Figure 3.6.

The cell values assessed in the flow direction grid can be summed to determine the number of uphill cells that drain to them. This process creates a flow-accumulation grid, represented as "huc490_fa" in Figure 3.6. Each cell in this DEM is coded with the number of cells which flow into it. For example, if the value of the cell is 1 and it has flow coming from the northeast (128), then the flow accumulation value for that cell is 129. This number is multiplied by 8100 m^2 (the value of each cell in a 90-meter resolution grid) to delineate a drainage area.

A stream grid can be generated based on the flow accumulation grid based on a tolerance value. The flow accumulation grid is queried by the stream grid process to determine the base number of cells that are receiving flow, which can be considered as a stream segment. The "huc490_str" grid represents this stream network for the ACF River basin in Figure 3.6.

The Stream Segmentation function, available through Arc Hydro, creates a grid of stream segments with unique identification. This function tags a stream segment as either a source or as lying between two segment junctions. It links each cell value along a segment by assigning it the same grid code as other cells along the same segment. This grid is represented as "lnk90" in Figure 3.6.

The Catchment Grid Delineation function, also available through Arc Hydro, creates a grid in which each cell carries a grid code indicating which catchment the cell belongs. This value is based on the values assigned to each cell in the stream segmentation DEM ("lnk90"). The grid is represented as "cat90" in Figure 3.6.

3.7 "ACFBasin ArcHydro" data model schema

"Building an Arc Hydro data model requires gathering, compiling, and modifying of significant amounts of data, often from unrelated sources" (Obenour et al., 2004). This data is stored in a geodatabase schema consisting of objects such as feature datasets, feature classes and tables, and the relationships between them. The Arc Hydro data model schema is applied to an empty geodatabase providing a framework stored in the schema document. This framework is then loaded with hydrologic information from the various datasets.

A new empty geodatabase is created in ArcCatalog ®; feature datasets are created within the geodatabase that include feature and object classes related to each type of information in the Arc Hydro schema. A particular application of the Arc Hydro data model called "Arc Hydro Framework" is employed for the ACF River basin prototype. This framework creates the necessary functionality required by water withdrawal permit managers.

The feature classes and attribute fields required for this research are retained; those that are not are removed, still others that do not exist in the framework are added. Relationships between the geodatabase features are stored within the project file, editable in the ArcMap ® platform. Most relationships are based on the geometric network connectivity between the application points and the stream segments. Figure 3.7 shows the Arc Hydro data model structure for the ACF River basin. Compared to Figure 3.4, this data model structure is significantly more elaborate and better-suited for the purposes of this research.

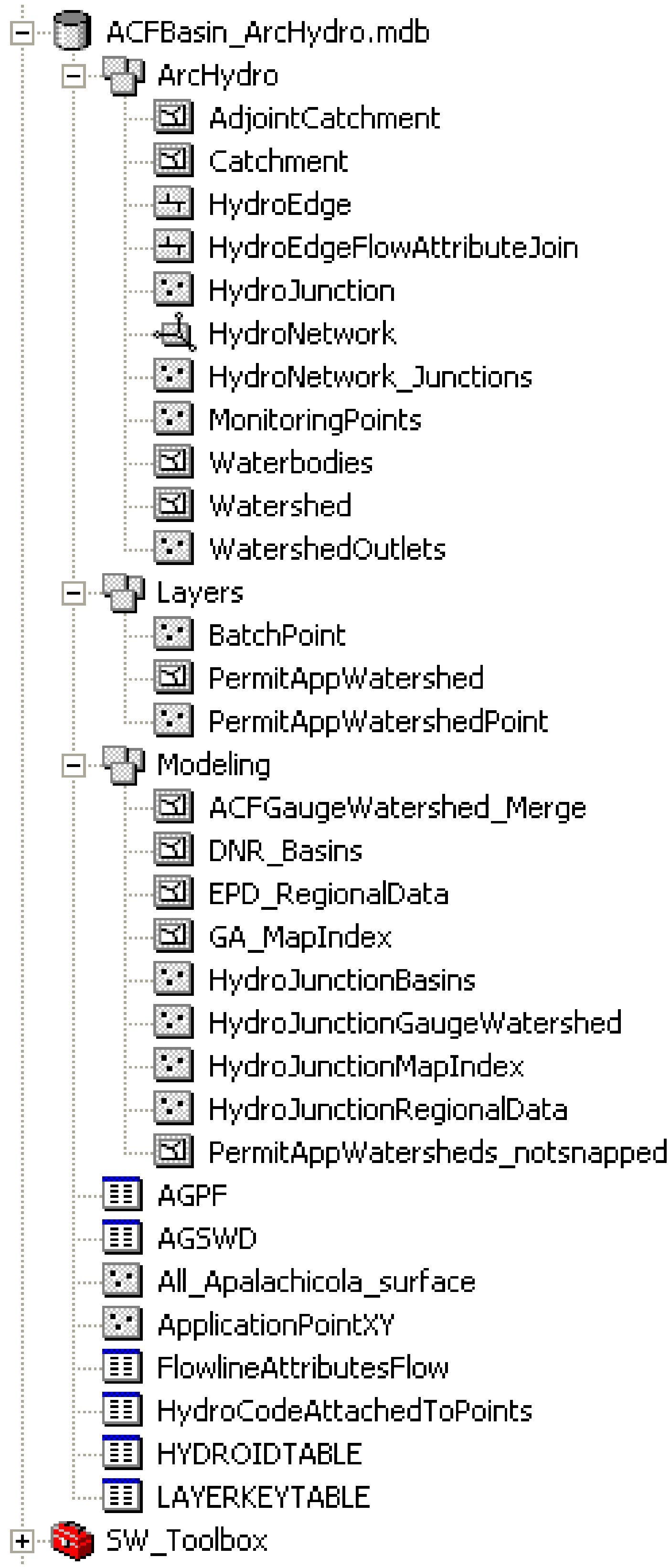


Figure 3.7 – Arc Hydro geodatabase structure after ACF River basin alterations

Each component of the "ACFBasin ArcHydro" data model is described below:

- The "ACFBasin ArcHydro" geodatabase contains all the feature datasets, classes and objects used in conjunction with grid processing outputs to perform hydrologic analysis for agricultural water withdrawal applications.
    - ArcHydro. This feature dataset contains a majority of the geospatial data that has been processed using Arc Hydro functionality. This data is edited, checked for inconsistencies, and assigned flow direction. "HydroEdgeFlowAttributeJoin" is a line feature class containing stream segments connected by junctions in the "HydroNetwork". This feature class is built with complex edges so "HydroJunctions" can be added to the interior of the flow line segments without necessarily splitting the segments. "HydroJunction" is a point feature class that includes junctions between stream segments and other points vital to network analysis, such as outlet points for drainage areas and locations of stream gauges. The "HydroNetwork" element is a complex geometric network composed of "HydroEdgeFlowAttributeJoin" and "HydroJunction" feature classes. The Network stores the connectivity between geometric features; this is required to assign flow directions for each stream segment and delineate watersheds. "HydroNetwork_Junctions" is a point feature class generated by the "HydroNetwork"; these points represent the intersections of stream segments in the Network. "MonitoringPoints" is a point feature class that stores the locations and station numbers of gauges measuring water quantity and quality. "Waterbodies" is a polygonal feature class providing generalized representations of lakes, reservoir, ponds, and estuaries. "Watershed" is a polygonal feature class that contains a

landscape subdivision of drainage areas, which drain to outlets along the Network. "WatershedOutlets" is the point feature class representing the points of drainage for the watersheds in the "Watershed" feature class.

- Layers. This feature dataset contains all the data for which parameters have been generated using the ACF basin hydrologic grids created through MWD Tool and Arc Hydro processing. The "AdjointCatchment" polygon feature class is the aggregated upstream catchment areas generated from the "Catchment" feature class. It is used to speed up the point delineation process. The "BatchPoint" point feature class represents the permit and application points for water withdrawals from "waters of the state". The "Catchment" polygonal feature class is generated from "cat90", it combines adjacent cells in the DEM that have the same grid code into a single area with a vectorized boundary. It delineates a drainage area for each stream segment in the "HydroEdgeFlowAttributeJoin" feature class. "PermitAppWatershedPoint" is a point feature class containing the "BatchPoint" permit and application points used to generate the "PermitAppWatersheds" feature class. This feature class is combined with the flow accumulation hydrologic grid through the Batch Watershed Delineation function in Arc Hydro to generate "PermitAppWatersheds."
- Modeling. This feature dataset contains vector features representing information used in the surface water evaluation process model. The "ACFGaugeWatershed_Merge" polygonal feature class holds all vectorized watersheds associated with each USGS stream gauge station in the ACF River basin. This feature class allows the process model to capture all of the proposed and permitted points within the station's drainage area, generating the "HydroJunctionGaugeWatershed" point feature class.

The “DNR_Basins” polygonal feature class provides EPD groupings of USGS designated hydrologic units and their related naming conventions. This data is added to “HydroJunction” to create the “HydroJunctionBasins” point feature class. The “EPD_RegionalData” polygonal feature class is a union of spatial information required by the FRBP. It is attached to a withdrawal location to create the “HydroJunctionRegionalData” point feature class. This provides data on whether the point is in Subarea 4, any of the 24-coastal counties, the 8-digit hydrologic unit, the county name, and if it is in a “Capacity Use Area”, a “Restricted Use Area”, or a “Conservation Use Area”. The “GA_MapIndex” polygonal feature class contains the index grid tag reference maps of the state. This information is added to the withdrawal locations to determine the county index grid map associated with each point, thus creating the “HydroJunctionMapIndex” point feature class. “PermitAppWatersheds-notsnapped” is a feature class used to compare the watersheds generated by Arc Hydro for withdrawal points in the locations in which they were mapped (i.e. before they were “snapped” to “HydroEdgeFlowAttributeJoin”). The “All_Apalachicola_surface” and “ApplicationPointXY” feature classes are not added to the feature dataset during the modeling process. They represent the proposed and permitted points for surface water withdrawals and those same points, but with latitude and longitude coordinates added.

- Object Classes. These tables contain data from the EPD permit database, NHDPlus UROM and Vogel method flow calculations, and the linear referenced permit and application points. The “AGPF” object class contains permit and application information provided in the EPD permit database; the records in this table provide the contact information supplied by the applicant in their withdrawal application. The “AGSWD” table provides the pump rate and water source for each location, which is used during statistical analyses performed in the permitting process. The “FlowlineAttributesFlow” object class contains records on flow rates determined by USGS in NHDPlus using the UROM and Vogel methods. These records are joined with the “HydroEdge” feature class to create “HydroEdgeFlowAttributeJoin”. The “HydroCodeAttachedToPoints” object class contains the linear referenced (“snapped”) locations of the permit and application points in the Network. This table provides a unique identifier for each stream segment the withdrawal point is “snapped” to; the unique identifier is established by USGS and is available in the NHDPlus download. The “HYDROIDTABLE” and “LAYERKEYTABLE” are generic object classes created by Arc Hydro; they contain information on the assignment of unique identifiers to the feature classes in the geodatabase.

3.8 Populating the geodatabase

Considerable data preparation is required for geospatial data to be effectively imported into the Arc Hydro data model framework. Geospatial data from the aforementioned datasets are imported the empty feature classes provided in the framework.

Georgia is split between 2 zones of the UTM coordinate system. The UTM NAD83 zone 16N map projection covers the western half of the state, and the UTM NAD83 zone 17N projection covers the eastern half. Since a majority of the ACF River basin is in zone 16, the UTM NAD83 zone 16N projection is employed (Figure 3.8). The details of this projection and the relevant geographic coordinate system are included below:

Projection: Transverse_Mercator	Geographic Coordinate System:
Parameters:	Name: GCS_North_American_1983
False_Easting: 500000.000000	Angular Unit: Degree (0.01745329252)
False_Northing: 0.000000	Prime Meridian: Greenwich (0.0000000)
Central_Meridian: -87.000000	Datum: D_North_American_1983
Scale_Factor: 0.999600	Spheroid: GRS_1980
Latitude_Of_Origin: 0.000000	Semimajor Axis: 6378137.00000000000
Linear Unit: Meter (1.000000)	Semiminor Axis: 5.356752.3141403560
	Inverse Flattening: 298.25722210100002

An empty geometric network ("HydroNetwork") exists in the Arc Hydro data model schema. A geometric Network locks the feature classes used to create it, disallowing any importing or exporting of geospatial data to or from the feature classes. The Network must be deleted to allow importing of features to the "HydroEdgeAttributeJoin" and "HydroJunction" feature classes.

The 4-digit hydrologic unit shapefile containing the ACF River basin is downloaded from the USGS 2002 version of NHD data. Sub-watershed polygons that lie within the basin, obtained from the Georgia GIS Data Clearinghouse, are selected and exported to the "Watershed" feature class. Since this feature class has the biggest spatial extent, it must be imported into the geodatabase first. "This is because the spatial extent of a feature dataset cannot be changed once it is assigned, thus the spatial extent must be large enough to contain all the thematic feature classes that will be inside a given feature dataset" (Maidment, 2002).

Once the spatial extent of the feature dataset is established, all remaining geospatial data imported into the geodatabase will conform to the established projection (UTM NAD83 zone

16N). The NHDPlus region 03 “NHDFlowline” stream segment and “NHDWaterbody” feature classes that lie within the basin boundary are selected and exported to create the “HydroEdgeFlowAttributeJoin” and “Waterbody” feature classes, respectively. The “USGS streamgages linked to the medium resolution NHD” station locations within the basin are selected and exported to the “MonitoringPoints” feature class.

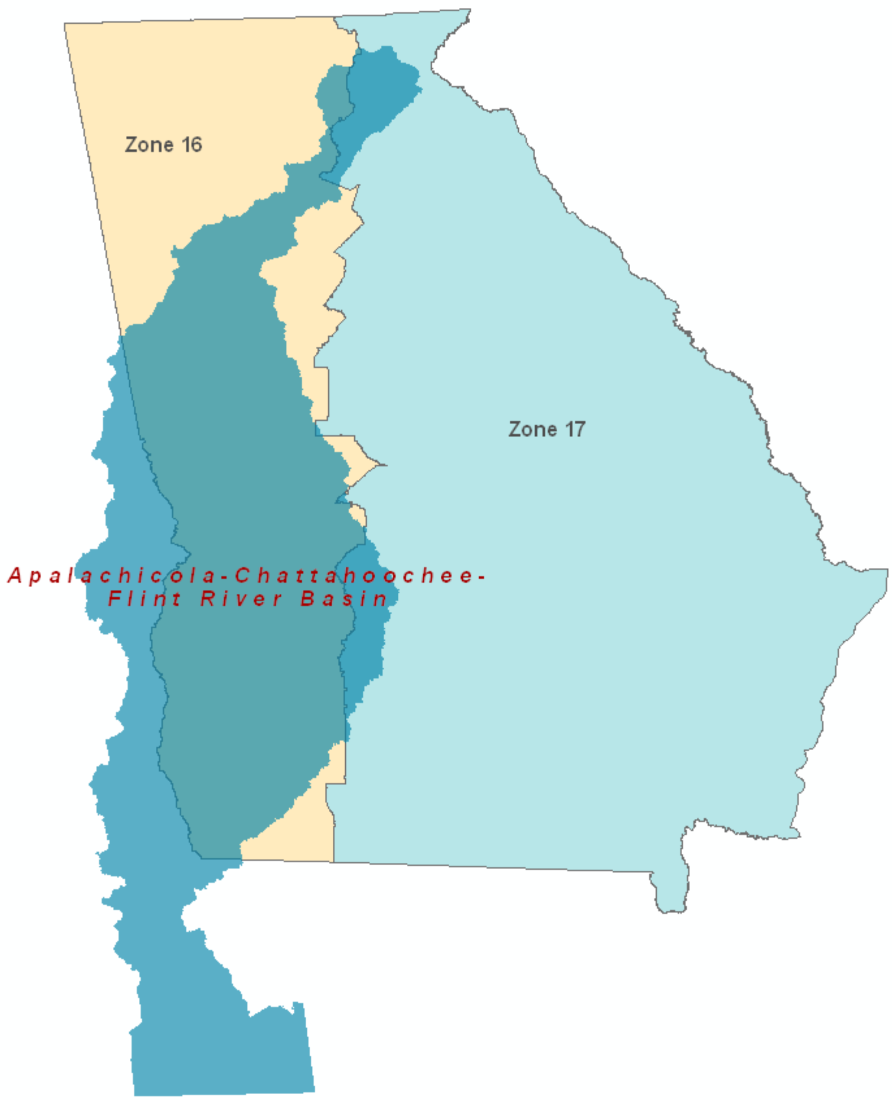


Figure 3.8 – Zone 16 is the majority zone for the ACF River basin

3.9 Importing points into the "HydroJunction" feature class

The USGS gauging stations do not lie exactly on the "HydroEdgeFlowAttributeJoin" stream segments; this may be due to the representation of the Network in GIS, the map projection, or the type of station. For this reason, gauging stations are dually represented in both "MonitoringPoints" and "HydroJunction" feature classes. The original gauging stations recorded in "MonitoringPoints" are exported to the "HydroJunction" feature class. The USGS gauaging stations in "MonitoringPoints" represent the exact Global Positioning System coordinates of said stations as gathered by USGS officials. The locations of gauging stations included in "HydroJunction" are corrected so they lie directly on the stream segment they have been "snapped" to (Figure 3.9). Any station location within 10,000 map unit of a stream segment is spatially-corrected, "snapped" to the nearest "HydroEdgeFlowAttributeJoin" line.

Permit and application point locations may be a considerable distance from stream segments. This is due to the previous mapping methodology discussed in Chapter 2. In order to perform hydrologic analyses on these existing and proposed sites, point locations are spatially-corrected using ArcGIS ® "linear referencing" geoprocessing functionality. Each location is assigned a unique identifier consisting of the permit or application number followed by an underscore and the pump number (i.e. A90-119-0653_1). The "linear referencing" tools allowed for any withdrawal location within 1 km of the stream to be snapped to the nearest reach. These points are then exported to the "HydroJunction" feature class.

Watershed outlets for the ACF River basin sub-watersheds were added manually in the "WatershedOutlets" feature class. These drainage points are then exported to the "HydroJunction" feature class where they are assigned an ancillary role pertaining to Network flow.

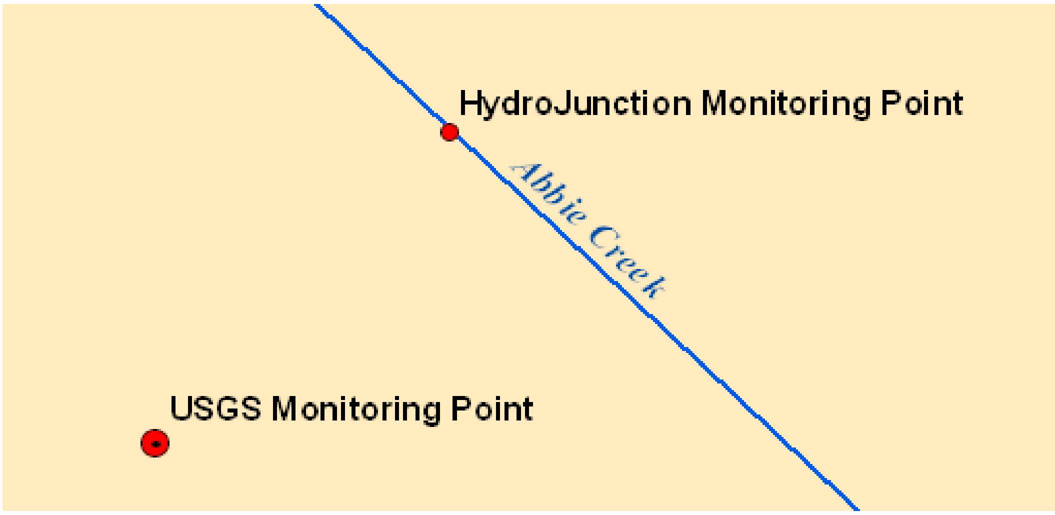


Figure 3.9 – The original USGS monitoring points are snapped to the closest stream segment

3.10 Building the geometric network

Once the "HydroEdgeFlowAttributeJoin" and "HydroJunction" feature classes contain spatially-corrected data, the creation of a Network to store feature connectivity ("HydroNetwork") can begin. This process is fairly simple, involving the construction of a complex geometric network in the geodatabase. The Network stream segments are given complex edges; this allows segments to be attached to each other without splitting their multi-part geometry. Sources (where flow originates) and sinks (where flow ends) are established to determine flow direction for network streams. After this routine has completed, new "HydroNetwork" and "HydroNetwork_Junctions" features are present in the geodatabase.

The topological connections of the "HydroEdgeFlowAttributeJoin" and "HydroJunction" features in a geometric network enables tracing of water movement upstream and downstream through streams, rivers, and water bodies (Patiño-Gomez et al., 2005). The network allows calculations of parameters necessary to complete hydrologic analyses.

HydroIDs are assigned for every element in every feature class to provide a unique integer identifier to each. The HydroID assists in the management of information within the “ACFBasin ArcHydro” geodatabase.

3.10.1 Setting flow direction

Sources and sinks drive flow through a geometric network; sources are junction features that push flow away, whereas sinks are junction features that pull flow toward themselves through the streams in a network. A well withdrawing groundwater to fill an irrigation pond is an example of the source-sink relationship. Water flows away from sources to sinks, therefore in order to understand the behavior of water in a geometric network, flow direction must be assigned.

All “NHDFlowline” stream segments have a pre-defined flow direction based on flow direction grids generated by USGS in NHDPlus. The flow drains from all upstream catchment sources to a single sink point, in this case the Atlantic Ocean (Figure 3.10). This directionality of flow allows for linkages to be established, which are used to trace water movement from one feature to the next. Network flow connectivity also allows for an association between hydrologic geospatial data entities.

3.11 Arc Hydro parameters for hydrologic analyses

Hydrologic analyses performed in this research require connectivity of water movement through the landscape. This association of network flow allows for the calculation of watershed parameters using Arc Hydro tools. The functions performed by these tools also validate the location of junctions on the network by assigning null values to disconnected feature elements. Watershed parameters calculated through geometric network functionality are:

- Next downstream gauging station and withdrawal site

- Distance of each point in the "HydroJunction" feature class to the basin outlet
- Watershed areas for each "HydroJunction" point

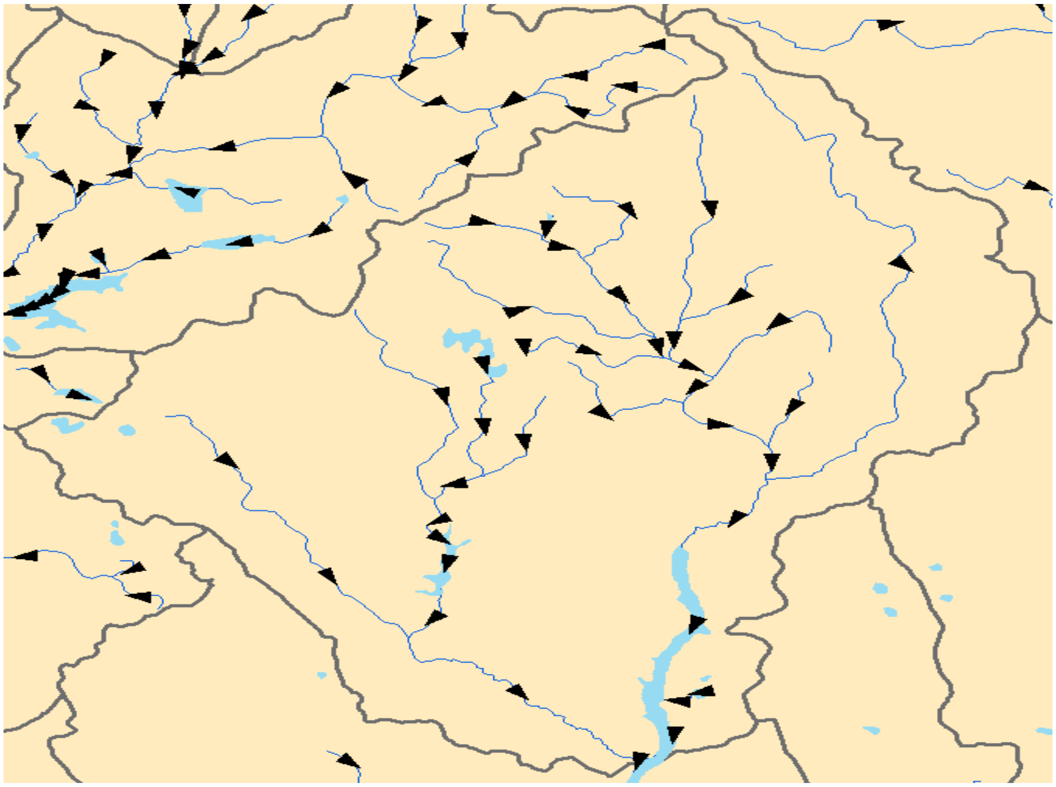


Figure 3.10 – "HydroEdgeFlowAttributeJoin" streams with assigned flow directions, arrows indicate direction

3.11.1 Finding the next downstream junction (NextDownID)

This parameter uses the flow direction set in the complex geometric network to find the next downstream junction in the "HydroJunction" feature class. For each junction in the network, the "Find Next Downstream Junction" function selects an adjacent stream segment that carries flow away from that junction (Maidment, 2002). The closest downstream junction's HydroID, based on the defined flow direction of the stream segment, and is assigned to the

NextDownID attribute field (Figure 3.11). If no downstream junction is found (i.e. basin outlet or junction not participating in the network), a value of -1 is added in its corresponding NextDownID attribute.

Downstream junctions can also be determined by performing a downstream trace using the “Utility Network Analyst Trace Task”. The “Trace Downstream” task helps to identify all the downstream reaches and junctions whose flow is affected by the withdrawals at a given location along the stream network. A flag is placed on a network junction thereby defining the starting point for the trace. The trace function is performed using “selection” as the analysis option; in doing so all downstream features are selected.

When stream segments in the “HydroEdgeFlowAttributeJoin” feature class are deselected, distance and travel time between network junctions can be determined. The “Find Path” trace task helps find connections between any 2 points along a stream network. The accumulated distances (determined through relates in the ArcMap ® project) can be established by performing summary statistics on the “LengthDown” attributes of the selected junctions.

3.11.2 Calculate length downstream for junctions (LengthDown)

The length of every stream feature in the “HydroEdgeFlowAttributeJoin” feature class is predetermined in the NHDPlus “NHDFlowline” feature class. Based on this length, the “Calculate Length Downstream for Junctions” function calculates the length from a network junction to the sink the junction flows to. This is done by summing the lengths of all streams located downstream of the junction. The resulting value specified in kilometers populates the “LengthDown” attribute field in the “HydroJunction” feature class (Figure 3.12). The value starts a zero at the basin outlet and increases the further upstream a junction is located

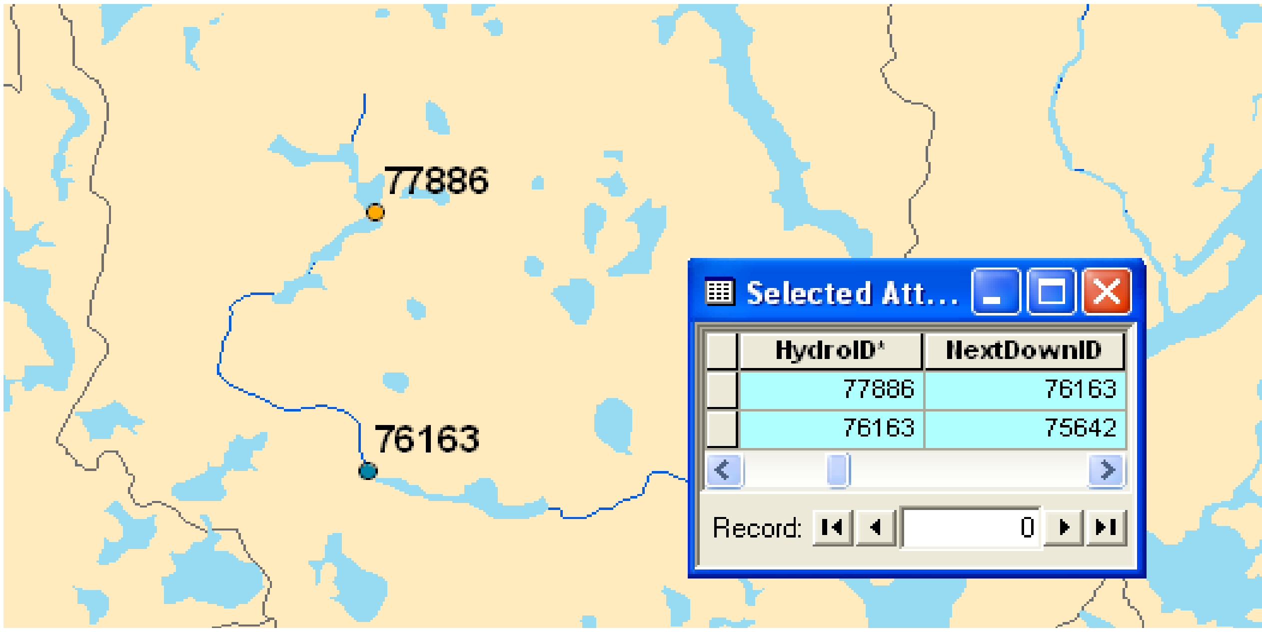


Figure 3.11 – Finding next downstream junciton, location 76163 is downstream of 77886

The values contained in the “LengthDown” field can also be used to determine the distance between points (Figure 3.13). The value associated with the lower junction can be subtracted from that of the upper junction to compute this distance.

3.11.3 Batch watershed delineation

In order to find the total drainage area for each permit and application withdrawal location, it is necessary to delineate the incremental watersheds that contribute to each junction. The first step in the delineation process is to establish catchment areas for all streams in the network. This is done using the “Catchment Polygon Processing” function, which takes the input catchment grid (“cat90”) and coverts it into a catchment polygon feature class (“Catchment”). Adjacent grid cells with similar grid code values are combined into a single area with a vectorized boundary. The “Catchment” feature class is added to the “Layers” feature dataset in the “ACFBasin ArcHydro” geodatabase.

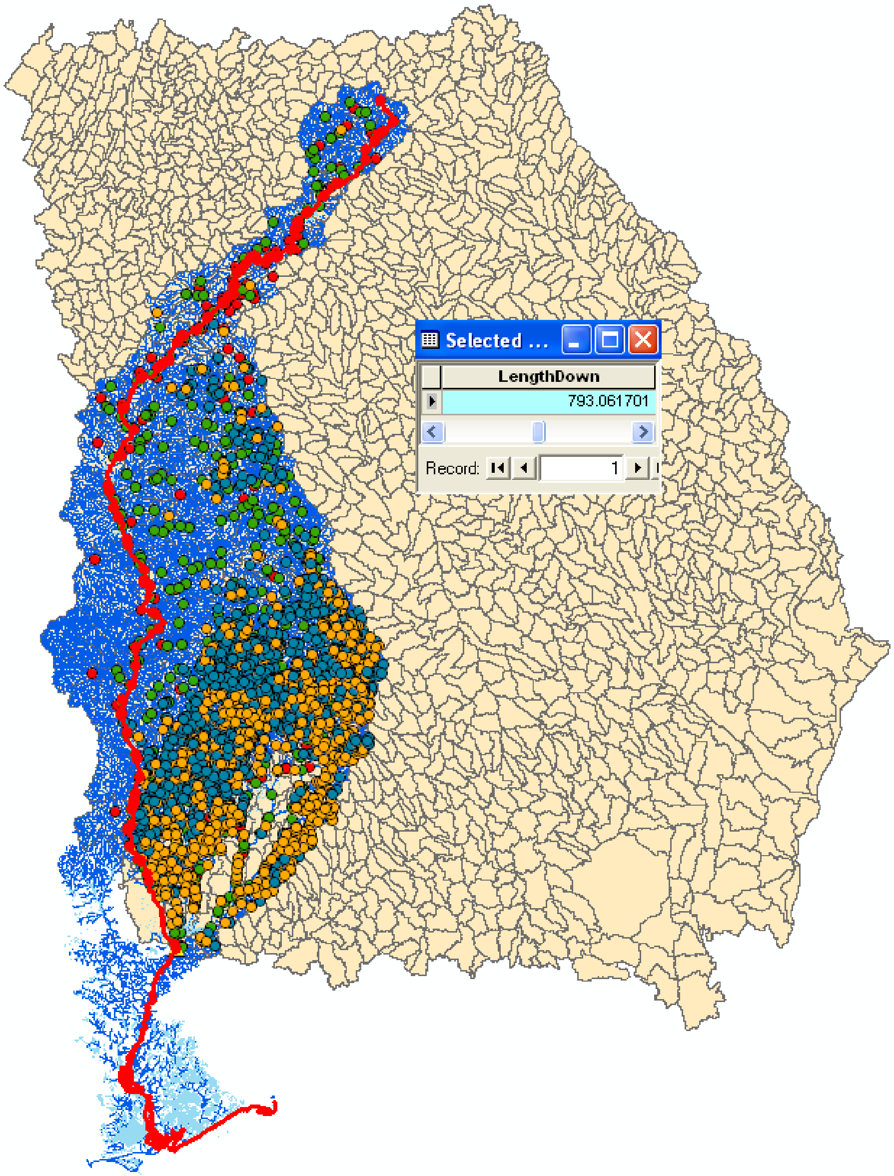


Figure 3.12 – Length downstream for a monitoring point junction 793 km from the basin outlet

The next step is the identification of upstream-downstream relationships between streams in the network. The "Drainage Line Processing" function combines the stream segmentation grid ("lnk90") and flow direction grid ("huc490_fd") converting the streams to lines of network drainage ("Drainage Line" feature class). The "AdjointCatchment Processing" function combines the "Catchment" and "Drainage Line" feature classes. This union generates the aggregated upstream drainage areas for each drainage outlet on the network, creating the "AdjointCatchment" feature class in the "Layers" feature dataset.

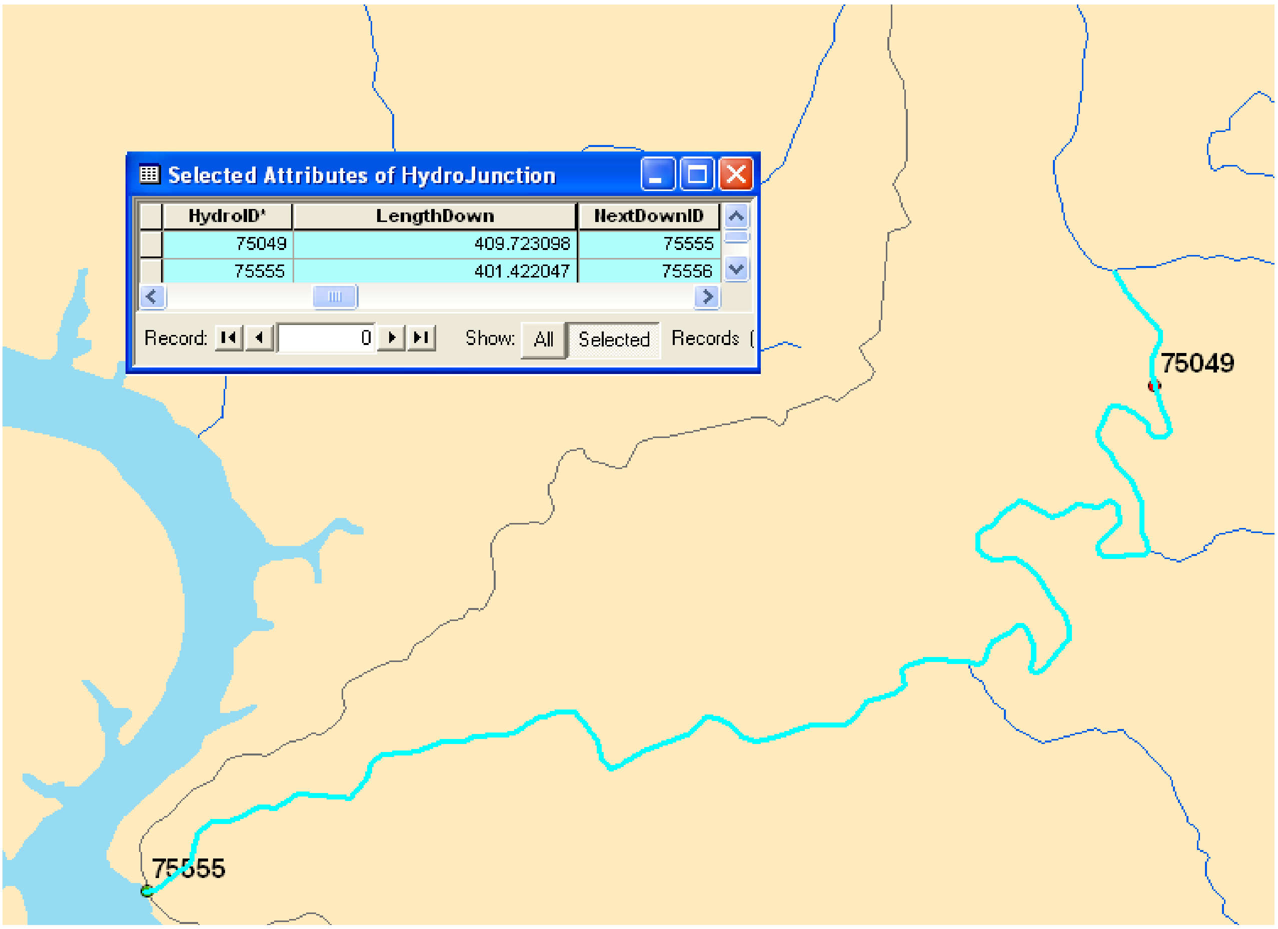


Figure 3.13 – The segment length between junctions 75049 and 7555 is 8.3 km

The watershed delineation process for each withdrawal point is performed using the "Batch Point Generation" and "Batch Watershed Delineation" functions available with the Arc Hydro toolset. A "BatchPoint" feature class containing a generic outlet for the basin is created using the "Batch Point Generation". The surface water permit and application points are then "snapped" to the stream edges. These points are imported to the "BatchPoint" feature class in the "Layers" feature dataset where they are used as input for the "Batch Watershed Delineation" function.

The "Batch Watershed Delineation" function allows for the delineation of watersheds for points defined in the "BatchPoint" feature class. This function creates two new feature classes in the "Layers" feature dataset known as "PermitAppWatershedPoint" and "PermitAppWatersheds". The "PermitAppWatershedPoint" feature class stores the locations of the batch points processed; the "PermitAppWatersheds" feature class stores the delineated watersheds for the batch points. This function requires the "AdjointCatchment", "Catchment" and "BatchPoint" feature classes as well as the flow direction and stream delineation grids ("huc490_fd" and "huc490_str") to compute the drainage areas.

The watershed drainage areas computed in the "PermitAppWatersheds" feature class are tagged with the permit or application and pump numbers of the withdrawal points they are delineated from (Figure 3.12). These overlapping cumulative areas are employed by EPD permit managers in the calculation of proportional flow for proposed sites.

3.12 Mean annual flow calculations

The flow volume and velocity estimates contained in the "FlowlineAttributesFlow.dbf" are integrated from the NHDPlus "NHDFlowlineVAA.dbf", "CatchmentAttribute.dbf" and elevation data. The information in these tables is cumulative for all stream segments, associating upstream catchments using hydrologic routing information available with the NHDPlus dataset. Quality assurance/ quality control measures were taken by USGS to ensure that the estimates were accurate.

The NHDPlus datasets estimate mean annual flow for each flow line using two methods: UROM and Vogel. Values for mean annual flow using UROM were developed for the National

Water Pollution Control Assessment Model (Research Triangle Institute, 2001). Vogel values are determined using methods outlined in "Regional Regression Models of Annual Streamflow for the United States" (Vogel et al., 1999).

Figure 3.14 – Vectorized watershed (blue mass) for pump number 1 of permit A89-004-0044

Both estimation procedures were developed using the HydroClimatic Data Network (HCDN) of gauges. These gauges were used because they are not affected by human impacts on water systems. Therefore, they are more representative of "natural flow"; this gauge network was also chosen because it is compatible with large-scale areas.

The UROM flow values use flow line catchment area estimates and unit runoff data from associated 8-digit hydrologic units. HCDN gauges within 322 km of the center of the hydrologic units were selected, and their runoff estimates were calculated using a weighted-average technique based on the squares of these distances. This provided an incremental flow measurement at the base of every stream segment in the hydrologic units.

Log-log regression based on drainage area, precipitation, and temperature gathered from the HCDN gauges are used in the Vogel method. This method estimates mean annual flow for a drainage point using a bias correction factor (due to the log-log scale); cumulative drainage areas outside the calculated ranges are given null values.

Each hydrologic region contains a quality assurance Microsoft ® Excel spreadsheet discussing specific issues encountered during the data preparation. For the ACF River basin area, hydrologic region 03, no significant problems were met when determining drainage area or any other value-added attribute parameter for watershed analysis.

3.13 Process modeling for surface water permit evaluations

Complex GIS models represent quantitative and qualitative information used to manage and automate geoprocessing procedures. There are two types of complex models: representation models; and process models. Each attempts to simplify the inherent complexity of the world into a manageable view of reality.

Representation models such as Arc Hydro portray features of the landscape. The model represents spatial data layers in raster and vector form, capturing the relationships within and between objects in the landscape. Attributes of drainage areas, withdrawal locations, and stream networks are described in this data model, allowing process models to refine the interactions between the features.

In ArcGIS ®, process models are built using ModelBuilder ® software technology. This software assists in the creation of spatial models of geographic areas utilizing both quantitative and qualitative information. The model is displayed as a diagram stringing together spatial processes that will execute in sequence when the model is run; the processes convert input data into an output feature or object class using specific functions such as append or extract.

For this research ModelBuilder ® process models are used to combine individual feature and object classes for the surface evaluation report. The report is created in Microsoft Access ®; it relies on queries of the spatial data in the geodatabase to fill-in pre-determined data fields. Figure 3.15 illustrates the procedures in a flow chart diagram representing the geoprocessing techniques used to create the output data. The data inputs and outputs are stored in the Modeling feature dataset and geodatabase object classes. These geoprocessing tools are incorporated into a process model because they must be performed each time new data is added to the evaluation form.

The “Identity” geoprocessing tool calculates a geometric juncture of the input features and the identity features. It assigns the attributes of identity features to the overlying input features. In the first process, the input feature is “HydroJunction” in the “ArcHydro” feature dataset. They are given the attributes of the “DNR_Basins” to which they are spatially coincident. This tool is used 3 more times to apply subsequent attributes to the “HydroJunction” feature class. The “Project” geoprocessing tool alters the coordinate system of the input dataset to a new output dataset with a defined coordinate system. This tool is combined with the “Add XY Coordinates” process to add latitude and longitude coordinates to the points in the input feature class. These processes assign the UTM NAD83 zone16N coordinate system to the surface withdrawal locations and add x and y coordinates to each point in the dataset.

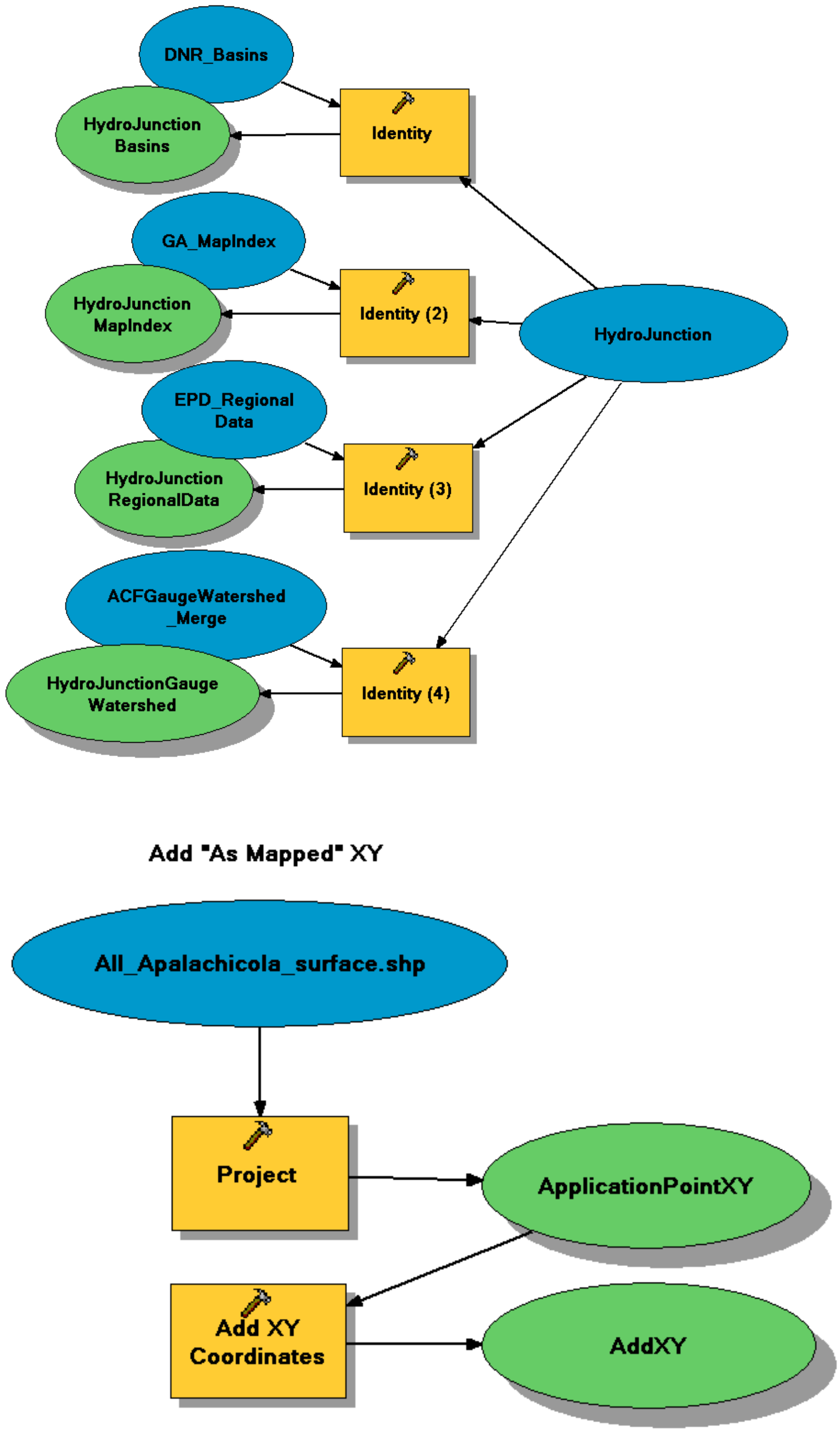
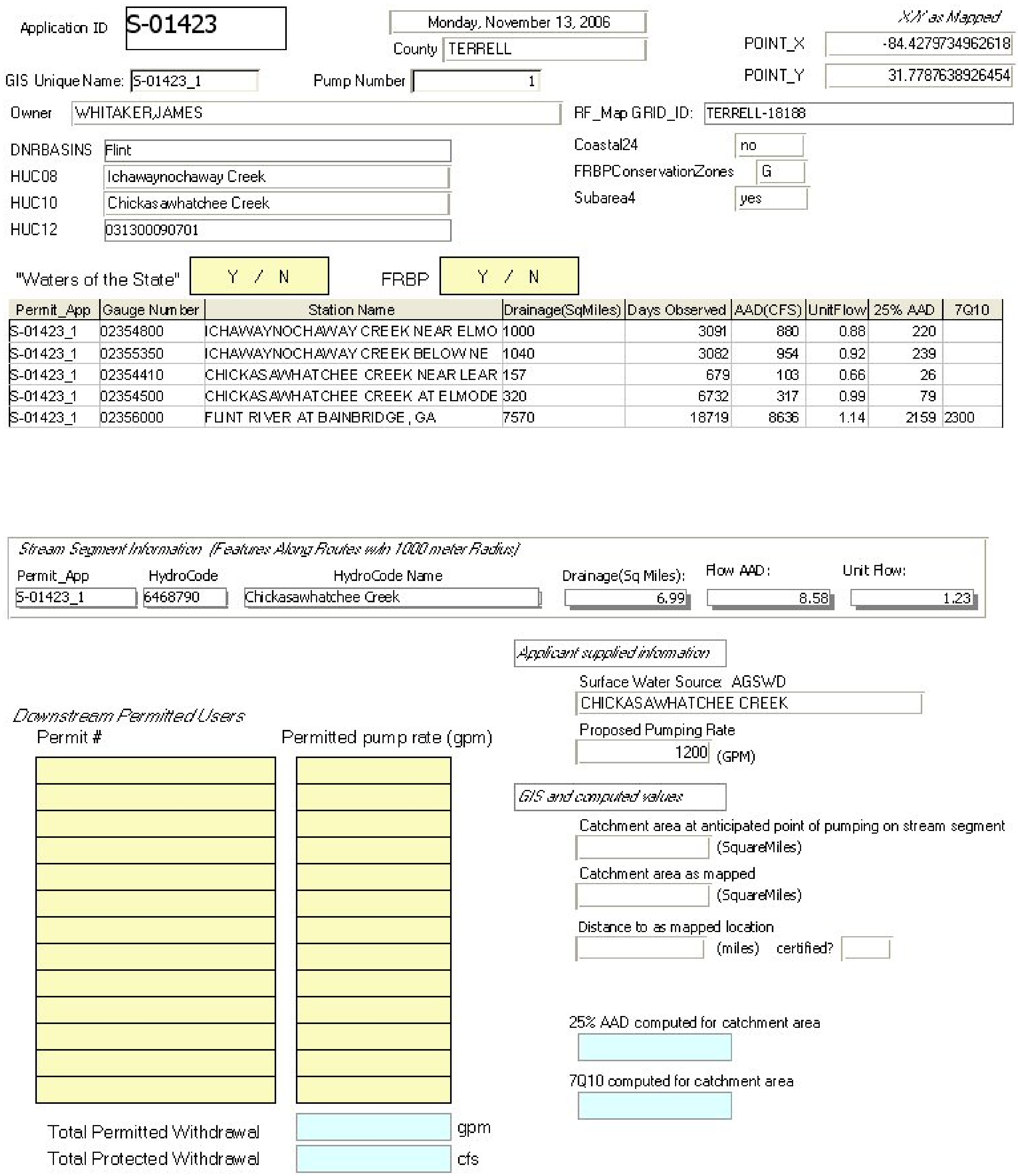


Figure 3.15 – Process model of used in surface water evaluations

3.14 Agricultural surface water withdrawal evaluation report

All information relevant to the decision-making process contained in the "ACFBasin ArcHydro" geodatabase are linked to create a single query. This query is used to create a report document in Microsoft Access ®. The report function generates a document for every application point in the geodatabase (Figure 3.16). It displays all applicable records in the underlying query.

Figure 3.17 illustrates the tables and queries used to generate a surface water evaluation report. Arrows show the attributes that are in the tables used to fill the data fields. The "GRID_ID" from the "HydroJunctionMapIndex" feature class provides the reference map identifier for the application location. The owner name is suplied by the "AGPF" object class. The naming conventions for watersheds, sub-watersheds, and basins are provided by the "HydroJunctionBasins" feature class. The pump number, pump rate, water source, and unique application identifier are provided by the "AGSWD" object class. The coordinates of the withdrawal location are provided by the "ApplicationPointXY" feature class. The location-specific restriction information is provided by the "HydroJunctionRegionalData" feature class. The gauge number, station name, days UROM and Vogel estimates were calculated for, the "UnitFlow" (avareage annual discharge (AAD)/ drainage area (DA) of each gauge location), the DA for each gauge station, the AAD, 25% of the AAD, and 7Q10 values are from the "Q_App_Pts_Gauge" query. This query pulls information from the "USGS streamgages linked to the medium resolution NHD" and low-flow estimates from http://ga2.er.usgs.gov/lowflow/. Data for this website are published in "Low Flow Frequency of Georgia Streams" (Carter et al., 1978). The "Q_AppPts_HydroEdge_CumDrainage" query provides information specific to each stream segment in the "HydroEdgeFlowAttributeJoin" feature class as calculated in NHDPlus.



Application ID S-01423

Monday, November 13, 2006

County TERRELL

X/Y as Mapped

POINT_X -84.4279734962618

POINT_Y 31.7787638926454

GIS Unique Name: S-01423_1

Pump Number 1

Owner WHITAKER,JAMES

RF_Map GRID_ID: TERRELL-18188

DNRBASINS Flint

HUC08 Ichawaynochaway Creek

HUC10 Chickasawhatchee Creek

HUC12 031300090701

Coastal24 no

FRBPConservationZones G

Subarea4 yes

"Waters of the State" Y / N

FRBP Y / N

Permit_App	Gauge Number	Station Name	Drainage(SqMiles)	Days Observed	AAD(CFS)	UnitFlow	25% AAD	7Q10
S-01423_1	02354800	ICHAWAYNOCHAWAY CREEK NEAR ELMO	1000	3091	880	0.88	220	
S-01423_1	02355350	ICHAWAYNOCHAWAY CREEK BELOW NE	1040	3082	954	0.92	239	
S-01423_1	02354410	CHICKASAWHATCHEE CREEK NEAR LEAR	157	679	103	0.66	26	
S-01423_1	02354500	CHICKASAWHATCHEE CREEK AT ELMODE	320	6732	317	0.99	79	
S-01423_1	02356000	FLINT RIVER AT BAINBRIDGE, GA	7570	18719	8636	1.14	2159	2300

Stream Segment Information (Features Along Routes w/in 1000 meter Radius)

Permit_App	HydroCode	HydroCode Name	Drainage(Sq Miles):	Flow AAD:	Unit Flow:
S-01423_1	6468790	Chickasawhatchee Creek	6.99	8.58	1.23

Applicant supplied information

Surface Water Source: AGSWD

CHICKASAWHATCHEE CREEK

Proposed Pumping Rate

1200 (GPM)

Downstream Permitted Users

Permit # Permitted pump rate (gpm)

Total Permitted Withdrawal gpm

Total Protected Withdrawal cfs

GIS and computed values

Catchment area at anticipated point of pumping on stream segment

(SquareMiles)

Catchment area as mapped

(SquareMiles)

Distance to as mapped location

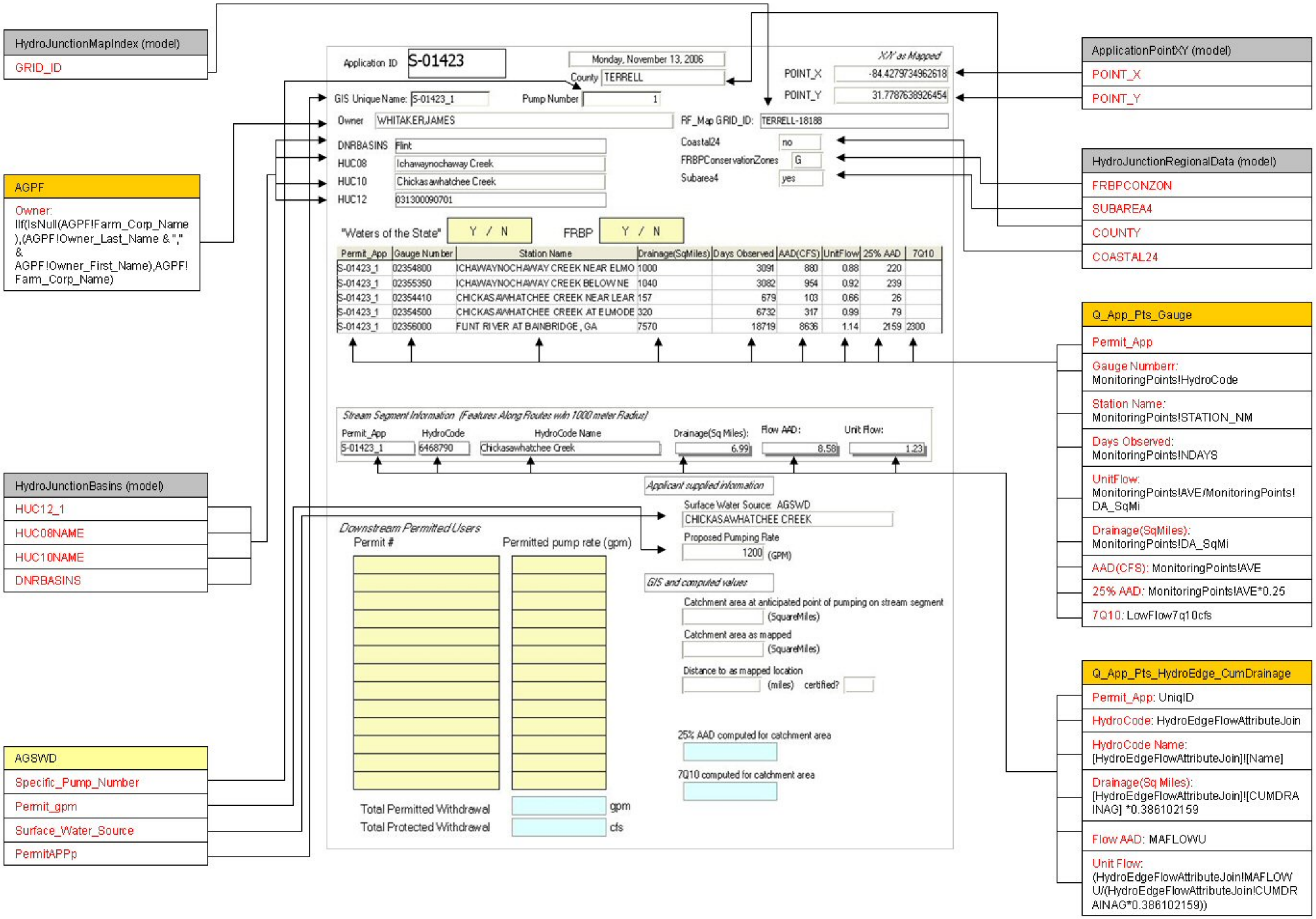
(miles) certified?

25% AAD computed for catchment area

7Q10 computed for catchment area

Figure 3.16 – Agricultural surface water withdrawal evaluation form

Figure 3.17 – The report plus the information sources used to fill the data fields



3.15 Results

Upon further inspection, it appears that some of the watershed delineations created for permit and application points, using Arc Hydro functionality, are incorrect. In some cases, the Arc hydro delineated drainage area is much larger than that reported by USGS in the NHDPlus dataset. It seems that when a watershed is delineated, it accumulates the areas of surrounding permit and application drainage areas. In these cases, either sub-watersheds are generated (do not overlap areas), or the USGS area is used instead.

The FRBP set up an order in which the permit "backlog" in the FRB is to be handled. Surface water permit applications for the FRB held in abeyance during the moratorium are to be evaluated before applications in other areas. Since the "ACFBasin ArcHydro" geodatabase will not be available to EPD until November of 2006, they have not been able to permit any new agricultural surface water withdrawals.

Tables 3.1 illustrates the number of Letters of Concurrence issued and permit stages in the FRB as of October 27, 2006. 20 Letters of Concurrence have been issued in the basin using old permitting methodologies. 161 applications have been cancelled; cancellations occur when an applicant is no longer interested in perusing a permit, if the applicant is deceased, or if the application is a duplicate. 1 application has been denied. 588 applicants are awaiting Letters of Concurrence so they can proceed with the installation of irrigation pumps. This brings the total number of applicants in the database to 769.

A HIS has been successfully constructed implementing datasets from USGS, as well as new and existing permitting regulations. The permit geodatabase is a dynamic product that should continue to improve in accuracy as new hydrologic datasets become available, and as new permits are issued, and old, deactivated permits are removed. The System, consisting of a surface water permit geodatabase (“ACFBasin ArcHydro), process model, and report will be employed by EPD officials in their pursuit of objective water resource management strategies.

Table 3.1 – FRBP implementation updates as of October 27, 2006

Letters of Concurrence issued to date in the FRB and Dougherty Plain	19 old & 1 this year
Letters of Concurrence issued and all forms returned (ready to permit)	0
FRB applications appraised but not yet approved or denied	0
FRB applications cancelled	161
FRB application denied	1
FRB applications awaiting action	588
Current total size of FRB and Dougherty Plain applicant pool	*769*

REFERENCES

Al-Sabhan, W., Mulligan, M., Blackburn, G.A. . (2003). "A real-time hydrological model for flood prediction using GIS and the WWW." *Computers, Environment and Urban Systems*, 27, 9-32.

Carter, R. F., Putnam, S.A. (1978). "Low Flow Frequency of Georgia Streams ", U.S. Geological Survey Water-Resources Investigations Report 77-127, p. 104.

Chinnayakanahalli, K. (2006). "The Multi-Watershed Delineation Tool: GIS Software in Support of Regional Watershed Analyses." Utah State University.

Couch, C. A. (1993). "Environmental Setting of the Apalachicola-Chattahoochee-Flint River Basin." *1993 Georgia Water Resources Conference*, The University of Georgia, Athens, GA.

Couch, C. A., McDowell, R. J. (2006). "Flint River Basin Regional Water Development and Conservation Plan." Georgia Department of Natural Resources, Environmental Protection Division.

Hook, J. E., Blood, E.R. (Year). "Mapping agricultural withdrawal permits and irrigated area in the Lower Flint Basin." *Proceedings of the 2001 Georgia Water Resources Conference* University of Georgia Institute of Ecology, Athens, Georgia.

Leitman, H. M., Sohn, J.E. and Franklin, M.A. (1983). "Wetland Hydrology and Tree Distribution of the Apalachicola River Flood Plain, Florida." U.S. Geological Survey Water-Supply Paper 2196, Chapter A, p. 52

Maidment, D. R. (2002). *Arc Hydro - GIS for Water Resources*, ESRI Press, Redlands, California, p. 7

Marella, R. L., Fanning, J.L., and Mooty, W.S. (1993). "Estimated use of water in the Apalachicola-Chattahoochee-Flint River Basin during 1990 with State summaries for 1970 to 1990: U.S. Geological Survey Water-Resources Investigations Report."

McFadden, K. W. (2000). "Georgia Hydrologic Unit Boundaries, 8-, 10-, and 12-digit." U.S. Geological Survey.

Obenour, D. R., Miadment, D. R. (2004). "Arc Hydro Developments for the Lower Colorado River Basin." *CRWR Online Report 04-06*, Center for Research in Water Resources, Bureau of Research, The University of Texas at Austin, Austin, Texas.

Patiño-Gomez, C., McKinney, D.C. (2005). "GIS for Large-Scale Watershed Observational Data Model," Dissertation, The University of Texas at Austin, Austin, Texas.

Stone, S., Maidment, D. (2001). "Geospatial Database and Preliminary Flood Hydrology Model for the Lower Colorado River Basin." CRWR Online Publication 01-4.

Research Triangle Institute (2001). "The National Water Pollution Control Assessment Model (NWPCAM) Verion 2 Draft Report." Research Triangle Park, NC: Research Triangle Institute.
U.S. Geological Survey (2005). "National Elevation Dataset Methodology." <http://ned.usgs.gov/Ned/methodology.asp> (August 29, 2006, 2006).

Vogel, R. M., Wilson, I.W., Daly, C. (1999). "Regional Regression Models of Annual Streamflow for the United States." *Journal of Irrigation and Drainage Engineering*, 125(3), 148-157.

Chapter 4

GIS ANALYSIS OF GROUNDWATER PERMIT DECSIONS

4.1 Relational database management for groundwater resources

Geospatial data on physiography, hydrogeology and groundwater resources of Georgia are employed in the agricultural water withdrawal permitting process. This data is collected from different sources in a variety of formats leading to challenges in effective organization and consistent management of water resources. This research creates a relational database supporting comprehensive analysis of groundwater to access and query this data during the decision-making process. This database combines hydrogeologic and geographic information for the study area to form a Hydrologic Information System (HIS).

A prototype of the HIS includes a GIS-based data model framework for describing standardized representations of groundwater features. The system provides a methodology for sharing, documenting, and analyzing groundwater datasets for resolution of water resource issues while incorporating EPD permit regulations. The data is structured into a geographically referenced relational database (geodatabase); a design centered on geospatial data structures provides a platform for data assimilation, integration, and communication of hydrogeologic information (Strassberg, 2005).

4.2 Permit decision rules for agricultural wells

Groundwater permit decisions utilize several criteria. Locations of proposed wells must be defined on reference imagery. If limitations are found on additional evaluations, the imagery will be used to locate alternative withdrawal sites. If a permit is approved, the location may become part of the Letter of Concurrence, and eventually the permit.

New applications must be located further than 0.4 km from existing agricultural wells, and 0.8 km from springs, and critical stream reaches to minimize interference. Alternately, calculated drawdown in nearby wells can be compiled from well design specifications (i.e., casing and screen depth, static pump rate, well diameter) and aquifer properties (i.e., transmissivity, specific capacity, aquifer thickness). If the computed drawdown would lower static head in nearby wells by more than 5% of the length of the intake section of the well, a permit request may be rejected.

In the Upper Floridan aquifer, transmissivities are high enough that few wells would be seriously impacted by individual withdrawals at distances greater than 0.4 km. However, to provide an extra measure of safety for M&I supplies, the distance was expanded to 0.8 km.

Once the hydrologic evaluation of proposed wells is computed and found suitable for permitting, EPD determines its location within a certain "Capacity Use Area", "Restricted Use Area", or "Conservation Use Area" (FRBP). These areas are tied to political or surface hydrology boundaries, and will be used to stipulate other conditions of groundwater withdrawal permits.

All of the criteria are determined in the geodatabase. A report is prepared within the geodatabase, using Microsoft Access ®, for the state geologist to use in permit evaluations.

4.3 Geographic and temporal data collection

Several studies on hydrogeologic properties of the ACF River basin have been carried out since the late nineteenth century (Wait, 1963; Hayes, 1983; Torak et al., 1993, 1996). The datasets created from these efforts are incorporated into the groundwater geodatabase. Seven are from U.S. Geological Survey (USGS): transmissivity, specific capacity, the top and bottom of the Upper Floridan aquifer, USGS monitoring wells, National Hydrography Dataset (NHDPlus) and National Elevation Dataset (NED); the remaining ten datasets are derived from EPD records: Public Water System (PWS) groundwater sources, PWS and non-PWS surface water sources, permitted, active industrial groundwater withdrawal wells, “natural springs”, verified permit points, and “DNR Basins”.

The top and bottom of the Upper Floridan aquifer, specific capacity and transmissivity datasets are from USGS MODFE estimates in the lower ACF basin. These data were generated as part of an effort to represent the hydrogeologic characteristics of the aquifer in Subarea 4 (Torak et al., 2006). Each of the top and bottom aquifer datasets contains a point file representing well locations, well and casing depths, and limited hydraulic conductivity and transmissivity data. Each dataset also includes an elevation contour file interpolated into a raster grid using ESRI’s Spatial Analyst ® extension. Spline with tension weight interpolation methodology was performed, creating a polyline surface with contour values closely constrained by the point data range. Both datasets employ the Albers Conical Equal Area map projection due to its minimal distortion factor. This data was as yet unpublished when it was received by EPD, therefore small changes in depth exist in the 2006 published report by Torak and others.

Regional estimates of transmissivity for the Upper Floridan aquifer are contained in the transmissivity dataset. The dataset contains estimates for Subarea 4 transmissivity obtained from field tests by combining the spatial distribution of hydraulic conductivity, derived log-log kriging interpolation, with aquifer thickness. Point and polyline contour shapefiles contain the interpolated estimates based on information from the bottom and top of the Upper Floridan aquifer datasets. “Geostatistics provided unbiased estimates for the spatial distribution and variation in hydraulic conductivity and transmissivity, and was well suited for making inferences about these hydraulic-property distributions from 'incomplete', or sparse, spatial information provided by aquifer-performance-test results" (Torak et al., 2006).

The USGS monitoring wells dataset is a subset of the NWIS Ground-water Site Inventory database containing the physical locations of wells. Attributes for the entire state are selected for this research; they represent a small subset of what is available from the database. The database provides access to inventory information about sites at stream reaches, wells, test holes, springs, tunnels, drains, lakes, reservoirs, ponds, excavations, and water-use facilities (USGS, 1998). The data were downloaded in tabular form and digitized in ArcInfo ® to create a stream gauge coverage. Similar information can be found in June 0f 2006 through the NWISWeb website at: http://waterdata.usgs.gov/ga/nwis/gwsi?search_criteria=lat_long_bounding_box&submitted_form=introduction.

NHDPlus is a comprehensive dataset that stores geospatial and temporal information about naturally occurring and constructed bodies of water. The dataset is compiled from the Environmental Protection Agency's reach files, and the USGS Digital Line Graph for the United States at a scale of 1:100,000. It incorporates features of the 2002 version NHD stream network, the NED, and National Watershed Boundary Dataset. NHDPlus utilizes the "New-England Method" to perform elevation and catchment analysis by modifying NED and WBD data to the medium resolution (1:100,000) scale. Network accuracy and performance is improved due to the implementation of these additional datasets.

NHDPlus data are available, by region, for download from http://www.horizon-systems.com/nhdplus/. Data for the South-Atlantic Gulf (Hydrologic Region 03) became available September 1, 2006, and are loaded into the "Geological Evaluation gdb" feature classes. Production unit 03b contained data on the ACF specifically, but most of it could not be used due to errors in the datasets and incompatibilities with Arc Hydro.

The NED is a high-resolution, seamless, raster elevation dataset produced by the USGS National Center for Earth Resources Observation and Science for the conterminous United States. The dataset was created by joining USGS digital elevation model (DEM) 7.5 minute tiles of data at 30 m resolution for the United States, which are updated bimonthly. Bilinear interpolation, mean profile filtering, and edge-matching algorithms were used to resample, transform, correct artifacts, and merge multiple DEMs (USGS, 2005). These processes were necessary in order to smooth the joins between the 7.5 minute DEMs. The raster dataset is available in Geographic projection, North American Datum 1983, in units of decimal degrees, with Z (elevation) units in meters.

DEMs and other grids are available at various spatial resolutions for download from http://seamless.usgs.gov/website/seamless/viewer.php. They were downloaded in July of 2006. To acquire an accurate representation of surface elevation, 2-arc second DEMs (60-meter resolution) were projected, merged and clipped to the boundary of the state.

The Watershed Protection Branch of EPD monitors the locations of public and non-public water systems in the state in the “Regulated_Withdrawals” personal geodatabase. This geodatabase contains data related to public water systems and EPD-permitted water withdrawals of over 379 m^3 per day as per the Georgia Groundwater Use and Water Quality Control Acts. The feature datasets within the geodatabase represent all permitted non-agricultural water withdrawals within the state as of November 20, 2003. The geodatabase employs the Albers Conical Equal Area map projection due to its minimal distortion factor.

Active and inactive municipal well locations are represented in the PWS groundwater sources dataset. The active and inactive feature classes contain municipal well locations, directly associated with groundwater sources, collected over a 10-year period. These data are used in planning and regulatory operations within the state. Withdrawals are considered active if the permit has not been revoked or terminated.

Active, inactive, and dormant PWS and non-PWS surface water intakes are represented in the PWS surface water sources dataset. These intakes are located along flowing streams and reservoir pools or substantial impoundments. Facilities are considered to be “active” id the intake is “on-line”, or has the potential for pumping raw water to the water system within a 48-hour period. Each location represents an intake facility where raw water is or was withdrawn from surface water features and subsequently used for municipal or industrial (non-PWS) purposes. A permit is considered dormant when there is currently no water being withdrawn but the permit is still active.

The permitted, active industrial groundwater withdrawal wells dataset contains the locations of 675 EPD-permitted, active industrial wells in the state. The information is current as of December 21, 1999; it was collected by Georgia Geologic Survey personnel utilizing a global positioning satellite receiver for each well head site or nearby point at the facility. Positional data are corrected using Trimble’s differential correction software and digitized to an ArcInfo ® coverage file. Attribute information are acquired from EPD’s Water Resources Management Branch. The data is published at a scale of 1:24,000 and projected with Albers Conical Equal Area.

The PWS and non-PWS surface and groundwater datasets also contain locations of groundwater springs regulated by EPD. The spring locations are collected north of the Fall Line.

The "natural springs" dataset acquired from Georgia Department of Natural Resources Wildlife Resources Division. Spring locations are south of the Fall Line; they were collected as part of a Fisheries study to determine aquatic species living in the spring.

The permit points dataset was compiled from EPD and Georgia Soil and Water Conservation Commission (GaSWCC) efforts to gain spatially-verified locations on permitted agricultural water withdrawals. The points were gathered by GaSWCC staff using Trimble Global Positioning System receivers during their duties of installing permit meters on all new withdrawal devices as per House Bill 579. The data was spatially-corrected and compiled into a shapefile.

"DNR Basins" consists of sixteen polygons representing river basin boundaries that intersect the state. These polygons represent the fourteen river basin boundaries defined by EPD for the planning purposes. The boundaries are compiled using the 1:24,000 hydrologic unit boundaries provided by USGS Water Resources Division. These data are merged with 8-digit, 10-digit, and 12-digit HUC boundaries to provide spatial information for each hydrologic feature the dataset traverses.

Reference grid maps were created in order to facilitate the mapping of new surface and groundwater withdrawal points. This was deemed necessary by the FRBP, Senate Bill 191, and the Coastal Plan. Grid maps were generated using the DS Map Book a developer sample code for creating map series in ArcGIS ®. A fishnet grid of the state was produced using ArcInfo ®, this was converted to a polygon shapefile. The shapefile was laid over digital county mosaics of orthoimagery available from the U.S. Department of Agriculture; the images are 2005 true-color collected by the Department's Farm Service Agency. Each map covers a 10 km^2 area, and map identifiers were tagged with the county in which the center of the image resides. Georgia

Department of Transportation 1997 DLG-F Roads and Highways and NHD2004 flow line geospatial data were added in order to aide as a reference of location when navigating the maps. The roads dataset was obtained through the Georgia Geographic Information Systems Clearinghouse. The NHD streams layer was obtained through the USGS and Environmental Protection Agency NHD website.

4.4 Study area

The study area is located in the lower ACF River basin of the Coastal Plain physiographic province in southwest Georgia. Subarea 4 encompasses most of the lower Flint River, a sub-basin of the ACF basin and a small part of the Ochlocknee and Suwannee River basins. The area includes all or parts of the following counties: Baker, Calhoun, Colquitt, Crisp, Decatur, Dooly, Dougherty, Early, Grady, Lee, Miller, Mitchell, Seminole, Sumter, Terrell, Turner, and Worth (Figure 4.1).

Subarea 4 is chosen for the groundwater portion of the research due to the increased availability of hydrogeologic data for the region. It is located in an area of conservation restrictions on surface and groundwater withdrawals for agricultural use. Increased withdrawal rates in this area have caused influent stream conditions in the lower ACF basin.

4.4.1 Subarea 4 physiography

Subarea 4 contains two distinctive regions: a low-lying karstic region; and a region of dissected remnant hills and sand-hill ridges (Torak et al., 2006). The karstic region includes the Dougherty Plain and Tifton Upland physiographic districts. The boundary between the Dougherty Plain and Tifton Upland districts is a regionally prominent, northwest facing escarpment called the Solution Escarpment (MacNeil, 1947). This solution escarpment continues to the northeast, forming a surface water divide between the FRB and the Ochlocknee River basin.

The Fall Line is the boundary between the Piedmont Plateau and Coastal Plain Provinces. This boundary approximately follows the contact between crystalline rocks of the Piedmont Province and the unconsolidated Cretaceous and Tertiary sediments of the Coastal Plain Province (Couch, 1993). Below this boundary is the Fall Line Hills physiographic district, a highly dissected series of ridges and valleys that diminish in relief to the south and east into lowlands of the Dougherty Plain (Wagner et al., 1984).

The Dougherty Plain district is characterized by lowland outcrops of limestone that result in a karst topography; relief within the Plain rarely exceeds 6 meters. The karst topography has numerous sinkholes and depressions that fill with water to form marshes. The sinkholes collect runoff from rainfall providing recharge to the Upper Floridan aquifer. Small streams in the Dougherty Plain District are frequently intermittent during the summer (Couch, 1993).

The Tifton Upland contains gently rolling hills with broad rounded summits sloping to the southeast. The Upland district has distinct ridges formed by gently tilted hard rock layers with escarpments 46 meters high overlooking the Flint River (Fenneman, 1938). Solution features such as valleys and ravines dissect these hills.

4.4.2 Subarea 4 hydrogeology

The unique geologic and hydrologic settings of the Upper Floridan aquifer, overlying and underlying hydrologic units, and surface water features in Subarea 4 control the movement of groundwater in the stream-lake-aquifer flow system (Torak et al., 2006). Karst topography, hydraulic properties, and stratigraphic relations limit the groundwater and surface water interaction in the regions flow system. Hydrologic units underlying Subarea 4 are: the surficial aquifer system, upper semi-confining unit, Upper Floridan aquifer, and lower confining unit (Torak et al., 2006). Other aquifers within Subarea 4 may also enter into permitting considerations. These include the Claiborne and Clayton aquifers.

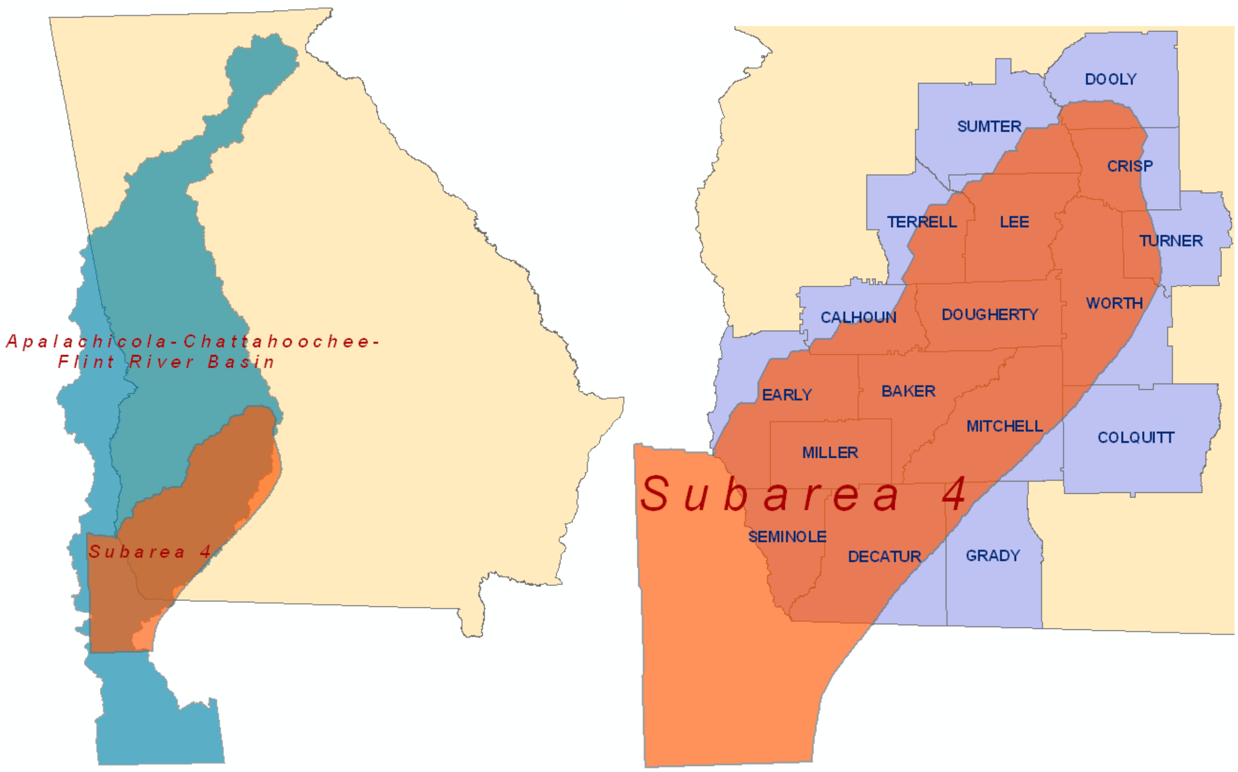


Figure 4.1 – Subarea 4 in relation to the ACF River basin and encompassing Georgia counties

"The Southeast Coastal Plain region consists of thick layers of sand and clay over consolidated carbonate rock" (Fetter, 2001). Surficial deposits of this region are composed of loose gravel, shell beds, and unconsolidated clays and sands; the surficial aquifer system is a shallow, mostly unconfined water-table aquifer. Deeper layers are comprised of semi-consolidated and consolidated limestone and dolomite. The confined Floridan aquifer located in these deeper deposits, is known for its high-yield wells. It is therefore highly depended upon by irrigators to supply water for agricultural crops. Hydraulic connection between surface water and the surficial aquifer and Upper Floridan aquifer is direct where sandy deposits overlie the limestone, or indirect where fluvial deposits overly clayey limestone residuum (Torak et al., 2006). Water in Coastal Plain aquifers is located in intergranular pore spaces, as well as in carbonate solution. Lower yield withdrawals can also be made from the surficial unconsolidated materials of the Hawthorn Formation, where it is composed of sandy deposits.

The surficial aquifer system in the study area, consisting of a series of marine and fluvial terrace deposits, has a thickness ranging from 9 to 15 meters (Scott, 1992). The upper semi-confining unit has a thickness ranging from less than 15 to 122 meters to the south and east of Lake Seminole in the Tifton Upland district (Torak et al., 2006). Thickness of the Upper Floridan aquifer ranges from a few meters along the northwestern boundary of the study area to more than 244 meters along the southeastern boundary (Torak et al., 2006). The lower confining unit, composed of hard sandy, clayey limestone, has a low water –transmitting rate and acts as a nearly impermeable base to the aquifer (Hayes, et al., 1983).

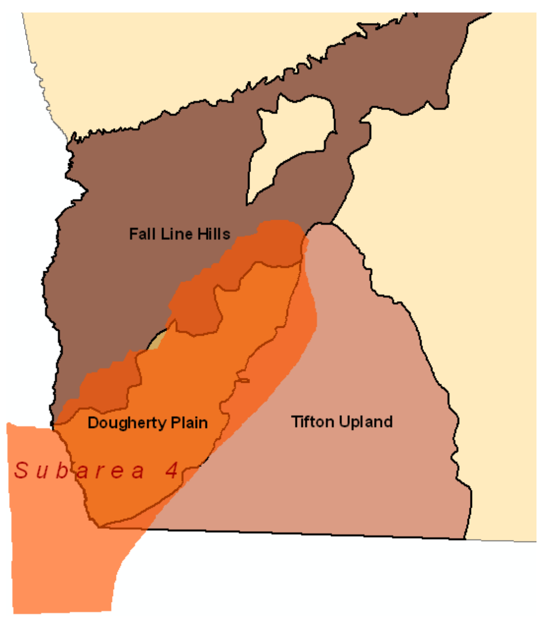


Figure 4.2 – Subarea 4 Coastal Plain physiographic districts

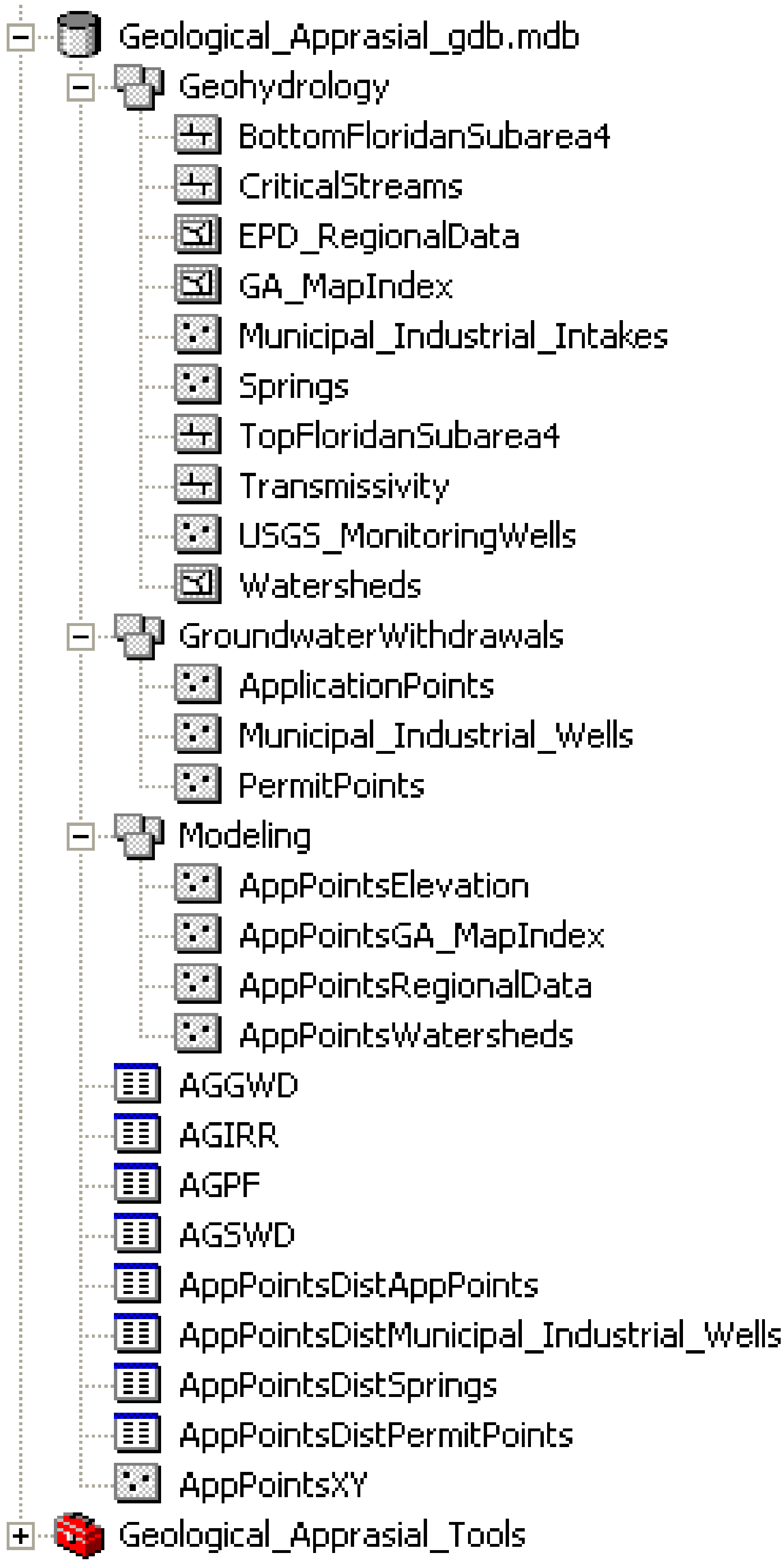


Figure 4.3 – “Geological Appraisal gdb” geodatabase structure

4.5 "Geological Appraisal gdb" geodatabase structure

Design of a groundwater geodatabase structure for storing and analyzing geospatial groundwater information is the primary objective of this research. The groundwater geodatabase structure allows EPD permitting officials to develop strategies for effective water resources management by implementing geospatial data in a productive, standardized manner. Significant amounts of data on primary features in a hydrgeologic system are compiled, modified, and stored in feature datasets, and feature and object classes. Figure 4.3 outlines three feature datasets containing spatial information necessary for permitting decisions in Subarea 4. In addition to the spatial features, temporal information derived from the transmissivity contours is represented.

Each component of the "Geological Evaluation" geodatabase is described below:

- The "Geological Evaluation gdb" geodatabase contains all the feature datasets, feature and object classes used in conjunction with permit data from the EPD database to perform hydrologic analysis for groundwater withdrawal applications.
- Geohydrology. This feature dataset holds vector classes that describe the hydrogeology of the Upper Floridan aquifer system in Subarea 4. The dataset includes representations of two-dimensional features that have been edited and checked for inconsistencies. "BottomFloridanSubarea4" is a polyline feature class containing splined elevation contours for the bottom of the Upper Floridan aquifer in Subarea 4. The data are obtained from the 2006 geohydrologic study on the lower ACF basin performed by Torak and others. "CriticalStreams" is a line feature class representing NHDPlus flow line data given the designation "critical" based on studies performed as part of the FRBP. They are labeled such due to their hydrologic connection with groundwater, a condition prevalent in the karst topography of lower ACF basin. The "EPD_RegionalData"

polygonal feature class is a union of spatial information on HUCs, FRB conservation zones, 24 coastal counties, and county names. This feature class is combined with hydrologic features to assign them the data attributes of the polygon they intersect. “GA_MapIndex” is a polygonal feature class representing the county name and grid identifier of reference maps generated to increase the accuracy of withdrawal locations. This feature class is applied in the same manner as the “EPD_RegionalData” feature class; it assigns the county name and grid identifier of the reference map the hydrologic feature intersects. The “Municipal_Industrial_Intakes” point feature class contains all the PWS and non-PWS surface water sources merged into one feature class with all active, inactive, and dormant EPD-permitted withdrawals except agricultural. “Springs” is a point feature class containing the merged locations of PWS, non-PWS, and “natural springs” spring locations; it encompasses both north and south of the Fall Line. “TopFloridanSubarea4” is a polyline feature class containing the splined elevation contours for the Upper Floridan aquifer in Subarea 4. The data are obtained from the 2006 Torak and others study. The “Transmissivity” feature class contains the log-log kriging contour interpolation of transmissivity estimates from the 2006 Torak and others study. “USGS_MonitoringWells” is a point feature class representing nearly 6700 groundwater monitoring station locations throughout the state. “Watersheds” is a polygonal feature class holding the “DNR Basins” designations of river basins in the state.

- GroundwaterWithdrawals. This feature dataset holds all the vector features representing proposed and permitted withdrawal locations for agricultural, PWS, and non-PWS use. “ApplicationPoints” is a point feature class representing all the proposed agricultural withdrawals of groundwater in the state. "Municipal_Industrial_Wells" is a point feature class representing all the PWS, non-PWS, and active industrial groundwater withdrawals in the state. The two datasets are merged to create the master feature class. "PermitPoints" is a point feature class representing all the permitted agricultural withdrawals of groundwater in the state.

- Modeling. This feature dataset is a set of vector features that represent outputs from the "Geo_Evaluation" process model. The features within this dataset are recreated every time the model is run. The "AppPointsElevation" point feature class is the "ApplicationPoints" feature class assigned surface elevations from a 60-meter resolution DEM of the state. The "AppPointsGA_MapIndex" point feature class is the "ApplicationPoints" feature class assigned the county name and grid identifier of the reference map it intersects. The "AppPointsRegionalData" point feature class is the "ApplicationPoints" feature class with attributes assigned by their location within the "EPD_RegionalData" feature class. The "AppPointsWatersheds" point feature class is the "ApplicationPoints" feature class assigned information from the "Watersheds" feature class.
- Object Classes. These tables contain data from the EPD permit database as well as model outputs from the "Geo_Evaluation" process model. The "AGGWD" is a database file containing well installation specifications for each proposed and permitted groundwater withdrawal in the state. "AGIRR" is a database file containing the irrigated acreage of proposed and permitted withdrawals. "AGPF" is a database file containing pump rates for all withdrawal locations. "AGSWD" is a database table containing all the contact information submitted by applicants for surface water withdrawals. The next five object

classes and one feature class are recreated every time the process model is run. "AppPointsDistAppPoints" is a table listing the distances between adjacent applications. "AppPointsDistMunicipal_Industrial_Wells" is a table listing the distances between features in the "ApplicationPoints" and "Municipal_Industrial_Wells" feature classes. The "AppPointsDistSprings" database table lists the distances between the features in "ApplicationPoints" and the "Springs" feature classes. "AppPointsDistPermitPoints" is a database table listing the distances between features in the "ApplicationPoints" and "PermitPoints" feature classes. "AppPointsXY" is a feature class representing "ApplicationPoints" after being assigned latitude and longitude coordinates.

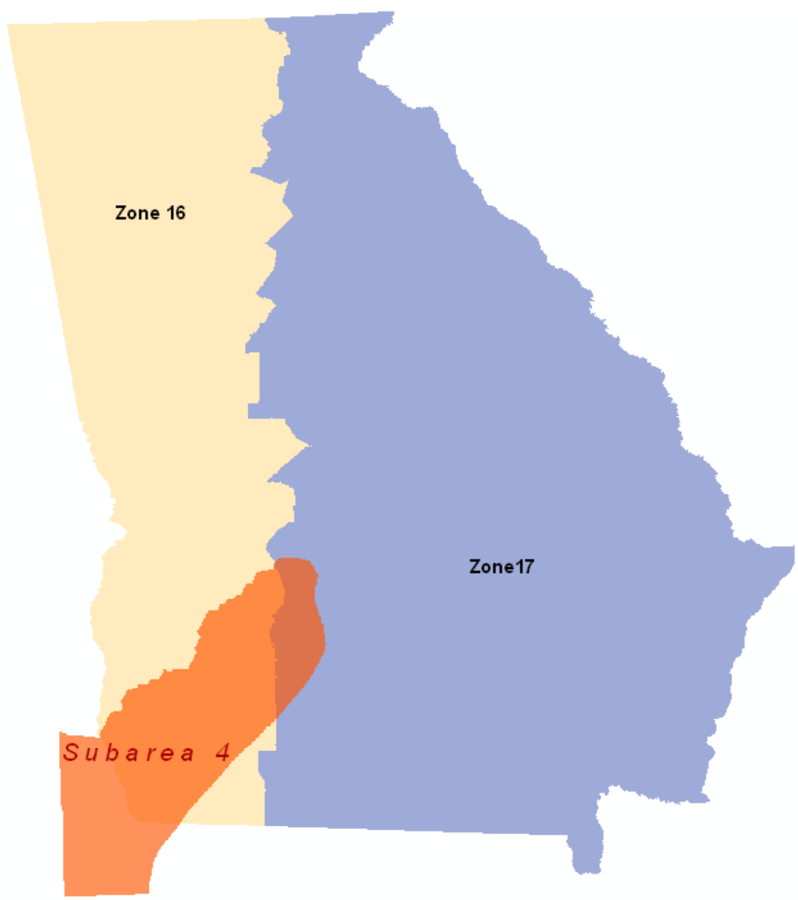


Figure 4.4 – Zone 16 is the majority zone for Subarea 4

4.6 Geospatial data manipulation

Considerable data preparation is required for geospatial data to be effectively loaded into the “Geological Appraisal gdb” geodatabase structure. Geospatial data from the aforementioned datasets are imported into the feature datasets. Georgia is split between two zones of the UTM coordinate system. The UTM NAD83 zone 16N map projection covers the western half of the state, and the UTM NAD83 zone 17N projection cover the eastern half. A majority of Subarea 4 is in zone 16, therefore the UTM NAD83 zone 16N map projection is employed for the data (Figure 4.4). Details of the projection and relevant geographic coordinate system are included below:

Projection: Transverse_Mercator
Parameters:
False_Easting: 500000.000000
False_Northing: 0.000000
Central_Meridian: -87.000000
Scale_Factor: 0.999600
Latitude_Of_Origin: 0.000000
Linear Unit: Meter (1.000000)

Geographic Coordinate System:
Name: GCS_North_American_1983
Angular Unit: Degree (0.01745329252)
Prime Meridian: Greenwich (0.0000000)
Datum: D_North_American_1983
Spheroid: GRS_1980
Semimajor Axis: 6378137.00000000000
Semiminor Axis: 5.356752.3141403560
Inverse Flattening: 298.25722210100002

After creating the three feature datasets, the “DNR Basins” shapefile is the first feature class to be imported into the geodatabase. This is ordering is necessary because the “Watersheds” feature class has the largest spatial extent, thus assigning the spatial extent of the geodatabase feature datasets. Once the spatial extent is established, all remaining geospatial and tabular data are imported into the Geohydrology, GroundwaterWithdrawals, and Modeling feature datasets. These imported feature classes will automatically conform to the established coordinate system and spatial extent. Relationships between the geodatabase features are stored within the project file, editable in the ArcMap ® platform.

4.7 Process modeling for groundwater permit evaluations

The theory behind process modeling has been discussed in chapter 3; ModelBuilder ® software technology is again employed to create a process model that generates outputs for the geological appraisal form. Figure 4.5 illustrates the modeling procedures in a flow chart diagram representing geoprocessing techniques used to generate the output data. The data inputs and outputs are stored in the Modeling feature dataset and geodatabase object classes. The geoprocessing tools are incorporated into a process model because they must be performed each time new data is added to the evaluation form.

The “ApplicationPoints” feature class is the model parameter that is processed in the model. This results in output data containing the original information in the feature class plus data from the other input feature classes it is linked to.

The “identity” geoprocessing tool calculates the geometric juncture of the input features to the identity features. It assigns the attributes of the identity feature to the overlying input feature. In the first “identity” process, the “ApplicationPoints” feature class is assigned the attributes of the “EPD_RegionalData” that it is spatially coincident with. This results in the “AppPointsRegionalData” feature class to be generated and imported into the Modeling feature dataset. This process is repeated, assigning data from “Watersheds” and “GA_MapIndex” feature classes to “ApplicationPoints” generating the “AppPointsWatersheds” and “AppPointsGA_MapIndex” feature classes, respectively.

The "extract values to points" geoprocessing tool extracts the cell values of a raster, in this case elevation, on a set of points. The 60-meter resolution DEM "ga_ned_utm16" has its elevation values extracted and assigned to the overlying "ApplicationPoints" feature class. This adds surface elevation data to each application point in the "ApplicationPoints" feature class. The "project" geoprocessing tool alters the coordinate system of the input dataset to a new output dataset with a defined coordinate system. This tool is combined with the "Add XY Coordinates" process to assign latitude and longitude coordinate fields to the "ApplicationPoints" feature class. These processes assign the UTM NAD83 zone 16N coordinate system to the groundwater withdrawal locations, and adds X and Y coordinates to each feature in the attribute table. This generates the "AppPointsXY" feature class to the geodatabase.

The "point distance" geoprocessing tool calculates the distance between point features in the input feature to all points in the near feature within a specified search radius. The process determines the "PermitPoints", "Springs", "ApplicationPoints", and "Municipal_Indutrial_Wells" feature class points within a distance of 1600 meters (FRBP) of the "ApplicationPoints" feature class points. The resulting object classes are: "AppPointsDistPermitPoints", "AppPointsDistSprings", "AppPointsDistAppPoints", and "AppPointsDistMunicipal_Industrial_Wells". Wells within this 1600 meter radius are assigned distances in the groundwater withdrawal evaluation form.

The "near" geoprocessing tool calculates the distance from each point in the input feature to the nearest point or polyline in the near feature within a defined search radius. The tool is used to determine if there are any streams from the "CriticalStreams" polyline feature class within a distance of 1600 meters (FRBP) of the points in the "ApplicationPoints" feature class.

The resulting distances are recorded in the "ApplicationPoints" feature class. The distance of points within this search radius are also provided on the evaluation report.

4.8 Agricultural groundwater withdrawal evaluation report

All information relevant to the decision-making process contained in the "geological Appriasal gdb" geodatabase are linked to create a single query. This query is used to create a report document in Microsoft Access ®. The report function generates a document for every application point in the geodatabase (Figure 4.6). It displays all applicable records in the underlying query.

Figure 4.7 illustrates the tables and queries necessary for generating an agricultural groundwater withdrawal evaluation report. The owner name and "App_ID" (application number) attached to each groundwater withdrawal location are from the "AGPF" table in the geodatabase. The "GRID_ID" from the "AppPointsGA_MapIndex" feature class, provides the reference map identifier for the application location. The latitude and longitude coordinates are provided by the "AppPointsXY" feature class. The distances between features in the "ApplicationPoints" feature class and "PermitPoints" (AppPointsDistPermitPoints), "Municipal_Industrial_Wells" (AppPointsDistMunicipal_Industrial_Wells), "Springs" (AppPointsDistSprings), and other application points (AppPointsDistAppPoints) provide exct distance between these features for the report. The "ApplicationPoints" feature class provides the distance between application points and critical streams, the name of the stream reach an application is located on, and the surface elevation of each application point. The location-specific restriction information is provided by the "AppPointsRegionalData" feature class. The naming convensions for basins, watersheds, and sub-watersheds are provided by the "AppPointsWatersheds" feature class. "AGGWD" provides installation specifics.

Figure 4.5 – “Geological Evaluation” process model

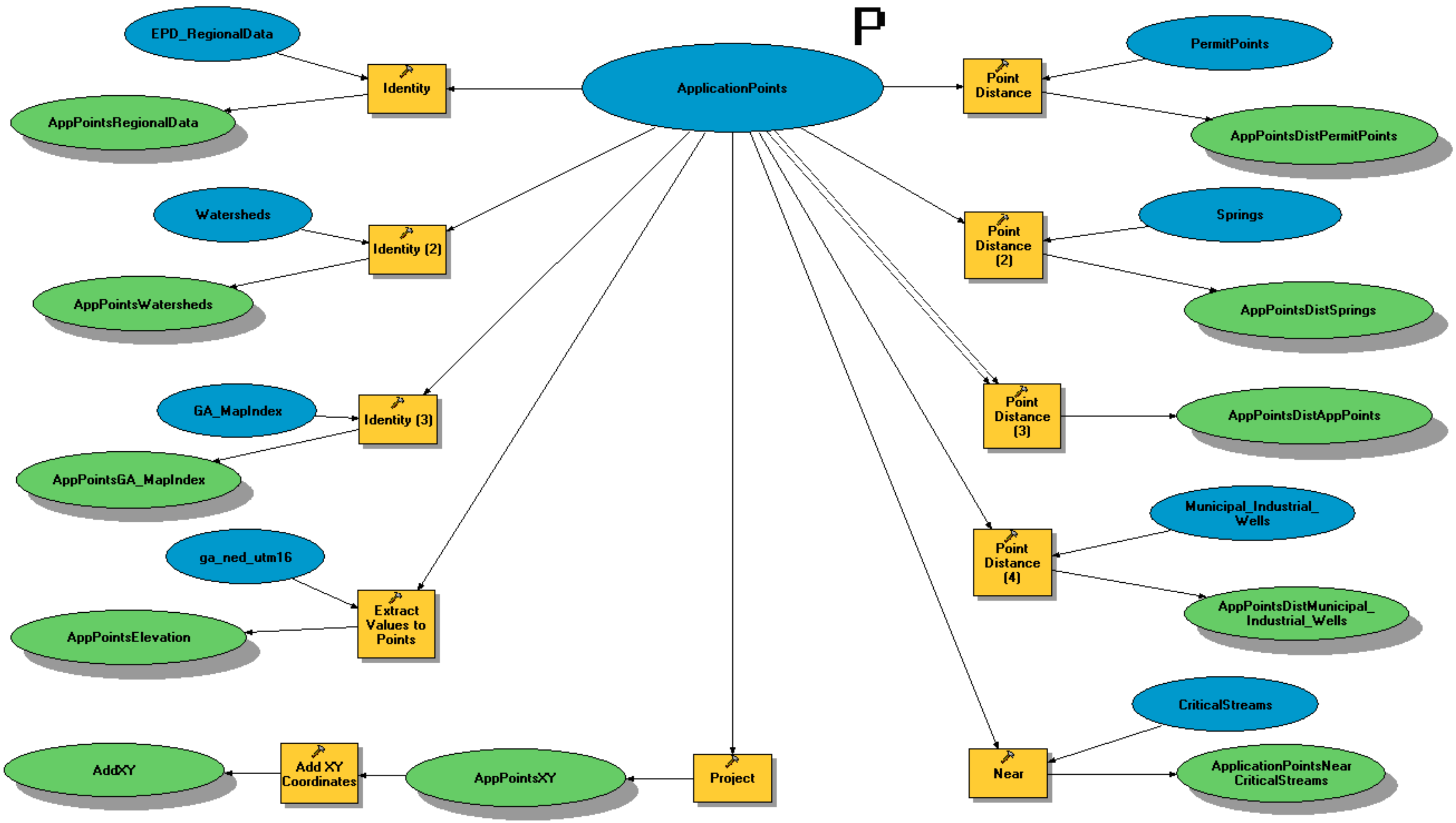


Figure 4.6 – Agricultural groundwater withdrawal application evaluation report

APP_ID G-04825

Owner NEWBERRY ANGUS FARMS, INC.

POINT_X -84.50696

POINT_Y 31.09330

SurElev(ft): 115

RF_Map GRID_ID: BAKER-22074

Subarea4 yes

County BAKER

Coastal24 no

FRBPConZon R

DNRBASINS Flint

HUC08 Lower Flint

HUC10 Flint River-lower-

HUC12 031300080701

Thursday, November 16, 2006

App Point Distance

APP_ID	AppPtsDist(ft)	neighbor APP_ID
G-04825	2523	G-02446
G-04825	3758	G-02478

Well Depth: 200

Casing Depth: 80

Intake Depth: 70

Diameter: 12

GPM: 70

Permitted Well Distance

APP_ID	AgWell_Dist(ft)	PERMIT_NO
G-04825	4771	A97-101-0657

M-I Distance

PubDrk Distance

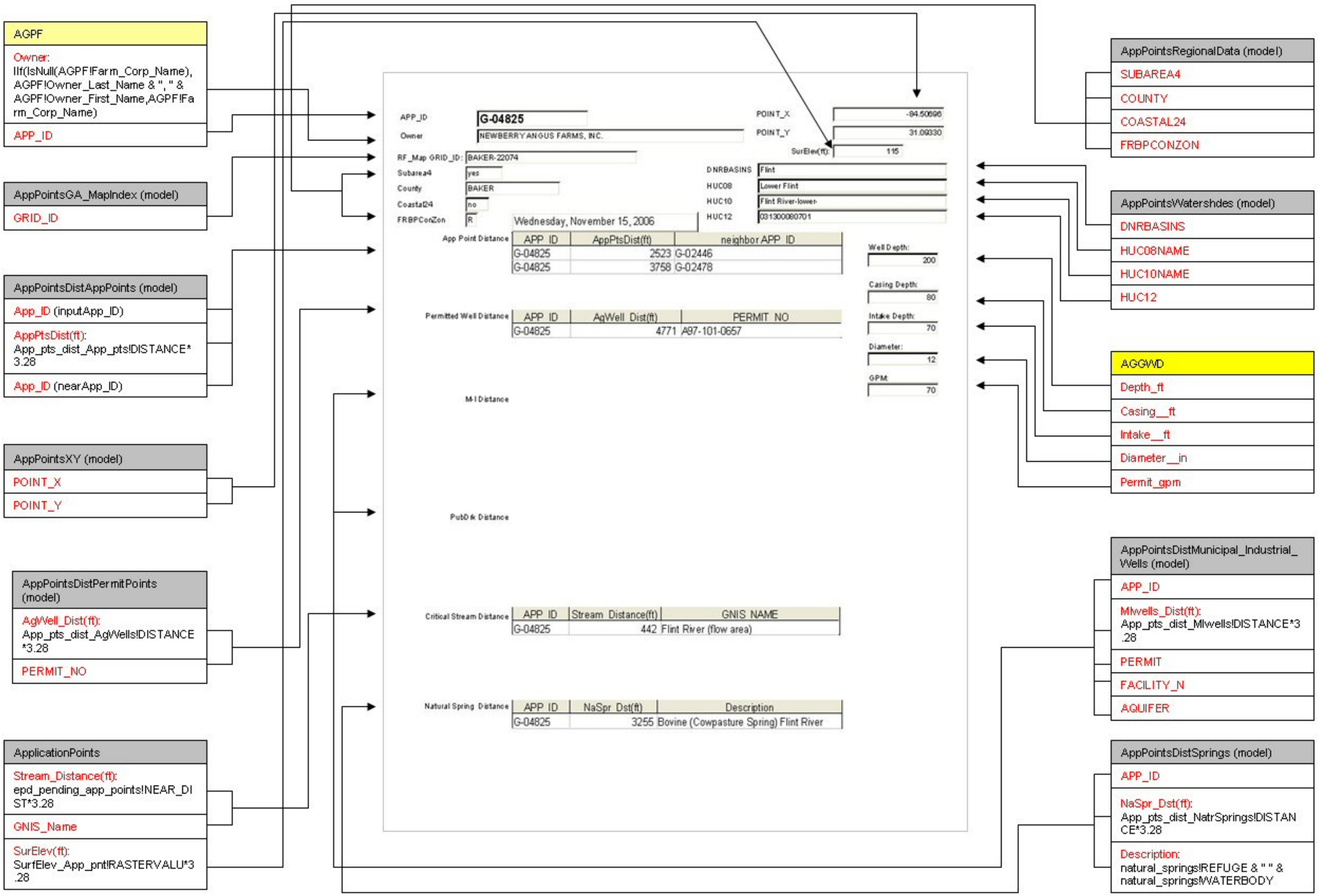
Critical Stream Distance

APP_ID	Stream_Distance(ft)	GNIS_NAME
G-04825	442	Flint River (flow area)

Natural Spring Distance

APP_ID	NaSpr_Dst(ft)	Description
G-04825	3255	Bovine (Cowpasture Spring) Flint River

Figure 4.7 – The report including the sources of information used to fill the data fields



4.8 Results

The preliminary USGS datasets representing transmissivity, bottom and top of the Upper Floridan aquifer and specific capacity were not implemented by EPD permitting officials. Instead, the permitting unit's geologist relies on paper maps from prior USGS research reports (Brooks et al., 1985; Clarke et al., 1985; Mack et al., 1984).

Since the groundwater geodatabases enception within EPD, amny Letters of Concurrence have been issued in the FRB and Dougherty Plain. Table 4.1 illustrates the number of Letters of Concurrence issued and permit stages for the FRB as of October 27, 2006. 563 Letters of Concurrence have been issued in the basin using the new permitting methodologies. 325 applications have been appraised but not yet approved or denied. If the application point appears to be closer than the prescribed distance limits as per the FRBP, the permit is put on "hold" (Table 4.2). 4 of the 325 well applications were too close to Public Drinking Water wells; 100 are too close to permitted agricultural wells; 24 are too close to other application sites; 34 are too close to critical streams; 6 are for withdrawals from the Clayton Aquifer (no permit are to be issued for this aquifer at this time); 103 are not present in the GIS or are awaiting location verification from applicants; and 54 applications have incorrect contact information or some other issue impeding action. 261 applications have been cancelled; cancellations occur when an applicant is no longer interested in persuing a permit, if the applicant is deceased, or if the application is a duplicate. 36 applications have been denied. 181 applications are awaiting Letters of Concurrence so they proceed with the installation of wells.

A HIS incorporating hydrogeologic geospatial datasets, verified permit locations, and proposed water withdrawal applications has been succesfully implemented by the EPD managers. The permit geodatabase is a dynamic product that should continue to improve in accuracy as new hydrogeologic datasets become available, and as new permits are issued, and old, deactivated permits are removed. Improved datasets on the hydrogeologic conditions of the Upper Floridan aquifer in Subarea 4 have recently be published by Torak and others, 2006. These new data will be imported into the geodatabase to reduce the use of older information in permitting decsisions. The System, consisting of a groundwater permit geodatabase ("Geological Appraisal gdb"), process model, and report are employed by EPD officials in their pursuit of objective water resource management strategies.

Table 4.1 – FRBP implementation updataes as of October 27, 2006

Letters of Concurrence issued to date in the FRB & Dougherty Plain	563
FRB applications appraised but not yet approved or denied (see Table 4.2)	325
FRB applications cancelled	261
FRB applications denied	36
FRB applications awaiting action	181
Current total size of FRB & Dougherty Plain applicant pool	1395

Table 4.2 – Well applications too close to other landscape features

Public Drinking Water Well	4
Existing Agricultural Withdrawal Well	100
Proposed Agricultural Withdrawal	24
Critical Stream	34
Restricted Aquifer (Clayton aquifer)	6
Not Mapped or Awaiting Location Verification	103
Other	54
Current total applications appraised but not yet approved or denied	*325*

REFRERENCES

(1998). "National Water Information System (NWIS): U.S. Geological Survey, Fact Sheet FS-027-98." <http://water.usgs.gov/pubs/FS/FS-027-98/>.

Brooks, R., Clarke, J.S., and Faye, R.E. . (1985). "Hydrogeology of the Gordon aquifer system of east-central Georgia." Georgia Geologic Survey Information Circular 75, 41 p.

Clarke, J. S., Brooks, Rebekah, and Faye, R.E. (1985). "Hydrology of the Dublin and Midville aquifer system of east-central Georgia." Georgia Geologic Survey Information Circular 74, 62 p.

Couch, C. A. (1993). "Environmental Setting of the Apalachicola-Chattahoochee-Flint River Basin." *1993 Georgia Water Resources Conference*, The University of Georgia, Athens, GA.

Fenneman, N. M. (1938). *Physiography of the eastern United States* Mcgraw-Hill, Inc., New York, New York.

Fetter, C. W. (2001). *Applied Hydrogeology*, 4th Ed., Prentice-Hall, Inc., Upper Saddle River, New Jersey, p. 343-344.

Hayes, L. R., Maslia, M.L., Meeks, W.C. (1983). "Hydrology and model evaluation of the principal artesian aquifer, Dougherty Plain, southwest Georgia." Georgia Geologic Survey Bulletin 70.

Mack, D. M., Karp, H.C., Jr. . (1984). *Structure-Contour Map of the Top of the Miocene Aquifer, in Arora, Ram, ed. Hydrogeologic Evaluation for Underground Injection Control in the Coastal plain of Georgia*, Georgia Geologic Survey Hydrologic Atlas 10, plate 5.

MacNeil, F. S. (1947). "Geologic Map of the Tertiary and Quarternary Formations of Georgia: U.S. Geological Survey Oil and Gas Inventory (Preliminary) Map 72, 1 sheet, scale 1:500,000." U.S. Geological Survey.

Scott, T. M. (1992). "A geological overview of Florida." Florida Geological Survey Open-File Report 50.

Strassberg, G. (2005). "A Geographic Data Model for Groundwater Systems," The University of Texas at Austin, Austin, Texas.

Torak, L. J., Davis, G.S., Strain, G.A., Herndon, J.G. (1993). "Geohydrology and evaluation of water-resource potential of the Upper Floridan aquifer in the Albany area, southwestern Georgia." U.S. Geological Survey Water Supply Paper 2391.

Torak, L. J., and McDowell, R.J. (1996). "Ground-water Resources of the Lower Apalachicola-Chattahoochee-Flint River Basins in Parts of Alabama and Gerogia - Subarea 4 of the Apalachicola-Chattahoochee-Flint and Alabama-Coosa-Tallapoosa River Basins." U.S. Geological Survey Open File Report 95-321.

Torak, L. J., and Painter, J.A. (2006). "Geohydrology of the Lower Apalachicola-Chattahoochee-Flint River Basin, Southwestern Georgia, Northwestern Florida, and Southeastern Alabama: U.S. Geological Survey Scientific Investigations Report 2006-5070." U.S. Geological Survey, Reston, Virginia.

U.S. Geological Survey (2005). "National Elevation Dataset Methodology." <http://ned.usgs.gov/Ned/methodology.asp> (August 29, 2006, 2006).

Wagner, J. R., Allen, T.W. (1984). "Ground-water section, in 1984 water assessment for the Apalachicola-Chattahoochee-Flint River basin water management study: U.S. Army Corps of Engineers, and States of Alabama, Florida, and Georgia." volume 3(appendix III, section 3), 129.

Wait, R. L. (1965). "Geology and occurrence of fresh and brackish water in Glynn County, Georgia." U.S. Geological Survey Water-Supply Paper 1613-E.

Chapter 5

CONCLUSIONS

5.1 Contributions to EPD data management strategies

Relational database methodologies using combined hydrologic and geologic geospatial and temporal data were created in this research. We used the Arc Hydro data model framework and tools, ArcGIS ® geodatabase and Microsoft Access ® functionality. The geodatabases were developed in response to new location-specific regulations in the FRBP and Coastal Plan.

Implementation of HIS technology in the form of relational databases has been applied to provide objective, consistent water resource management strategies. This technology took the form of two geodatabases, process models, and evaluation reports, all of which employ geoprocessing techniques that have not before been used to advance permitting management in Georgia.

The groundwater data model pulls together USGS and EPD datasets on the hydrogeologic conditions and water withdrawals in Subarea 4. A GIS toolset is developed and implemented in the ArcGIS ® platform employing these datasets. The tools calculate distances between agricultural and M&I wells, transmissivity at proposed sites, and identify withdrawals that would impact "critical streams" as per the FRBP.

The surface evaluation tools include parameters necessary for delineation of watersheds. The Arc Hydro data model presents a standard spatial structure for the connectivity between data, allowing for spatial analysis of applications. The geodatabase makes obtaining geospatial data from the database about water uses, withdrawal amounts, and irrigated acreage possible.

This relational database and its analogs for other basins and rule areas allow EPD and other regulatory agencies to calculate pond catchment areas, watershed drainage areas, and protected flow at proposed and permitted surface withdrawal locations.

Data management strategies proposed by this research meet the standards of effective water resource management as stated in Georgia House Bill 237. As adopted, these methodologies are improving the accuracy of EPD permit decision making. Already several hundred permit applications have been evaluated and decisions made based upon these techniques.

5.2 Future Research

While many challenges in the geographic analyses of permit applications were addressed in this research, others were uncovered. As a guide to those who may wish to improve or expand implementation of these procedures, we point out these specific problems.

Groundwater geoprocessing, as developed in this research, is limited by data. For most of the state's high-yield aquifers, only paper maps exist for elevation of upper layers and lower confining beds. Additionally, only Subarea 4 has enough transmissivity and specific capacity data georeferrenced for processing into suitable data layers. Efforts should be undertaken to create georeferenced layers for each of the states major aquifers.

Landscape relief in the Coastal Plain physiographic province is so slight that watershed delineation using raster datasets is very difficult. The 90-meter resolution DEMs processed in this research occasionally provided incorrect vectorized drainage areas in this province. Incorporating finer resolution DEMs in watershed delineations is complicated; while we would like to use 10-meter DEMs to delineate watersheds, this would require processing raster datasets 81 times larger than datasets based on 90-meter DEMs. The Raster-Network Regionalization technique for large basins utilizing raster-based analysis at the sub-regional scale, perfected by Patiño-Gomez and others in 2005, could be used for future processing. This technique allows large regions to be divided into hydrologically distinct sub-regions, allowing for higher resolution datasets to be processed generating more spatially-correct parameterized watersheds. The method uses a combination of both raster and vector data to find these parameters. It reduces dramatically the problems found by the traditional methods for watershed parameterization in GIS when processing large regions (Patiño-Gomez et al., 2005).

Current flow data used in setting low flow protection in streams was derived for FRB streams from NHDPlus average annual discharge using UROM and Vogel methods. Current Georgia laws, however, protect only 7Q10 in most streams. Two challenges were identified. The 7Q10 values have only been derived for long-term stream gauging stations for pre-irrigation flows. That is, they were derived for 7Q10 values at gauges monitored prior to 1970, while NHDPlus values have been computed for all stream gauges through 2004. In computing the 7Q10 at points upstream from the gauge stations, we assumed that the ration of 7Q10 to land area followed the same pattern as annual average discharge to land area. This is an untested assumption. Thus there are uncertain changes in flow patterns that may be affected by withdrawals since irrigation began and there is an uncertain relationship of average flows to drought flow relative to land area.

In the lower ACF River basin, rivers have cut downward into the limestone exchanging water with the Floridan aquifer. Many of the FRB tributaries are also in contact with the limestone and exchange groundwater discharge with it (Torak et al., 1996). Water in surficial streams dips underground through sinkholes along fracture trace lineaments in the karst topography, and arises again to the surface. Fracture-trace analysis has led to the location of high-yield wells; therefore a dataset delineating these linear features would be beneficial to the accuracy of determinations as to whether an application is for “waters of the state”. A dataset providing stream gauge data for sinkholes would also be advantageous in determining the stream-aquifer flux in these regions.

REFERENCES

Patiño-Gomez, C., McKinney, D.C. (2005). "GIS for Large-Scale Watershed Observational Data Model," Dissertation, The University of Texas at Austin, Austin, Texas.

Torak, L. J., and McDowell, R.J. (1996). "Ground-water Resources of the Lower Apalachicola-Chattahoochee-Flint River Basins in Parts of Alabama and Gerogia - Subarea 4 of the Apalachicola-Chattahoochee-Flint and Alabama-Coosa-Tallapoosa River Basins." U.S. Geological Survey Open File Report 95-321.

APPENDIX

Reference grid maps (Figure A1) were created by UGA staff in order to facilitate the accuracy of mapping new surface and groundwater withdrawal points (Figure A2). This was deemed necessary by the Flint River Basin Regional Water Development and Conservation Plan, Senate Bill 191, and the Coastal Georgia Water and Wastewater Management Plan for Managing Saltwater Intrusions. Grid maps were generated using the DS Map Book a developer sample code for creating map series. This code acts as a software extension for ArcGIS ®. A fishnet grid of the state was produced using ArcInfo ®, this was converted to a polygon shapefile. The shapefile was laid over digital county mosaics of orthoimagery available from the USDA Geospatial Data Gateway. Each map covers a 4 mi^2 area, and map identifiers were tagged with the county in which the center of the image resides. Georgia DOT 1997 DLG-F Roads and Highways and NHD2004 flow line layers were added in order to aide as a reference of location when navigating the maps. The roads dataset was obtained through the Georgia GIS Clearinghouse. The NHD streams layer was obtained through the USGS and EPA NHD Data website.

Figure A1- Reference grid map for Appling County

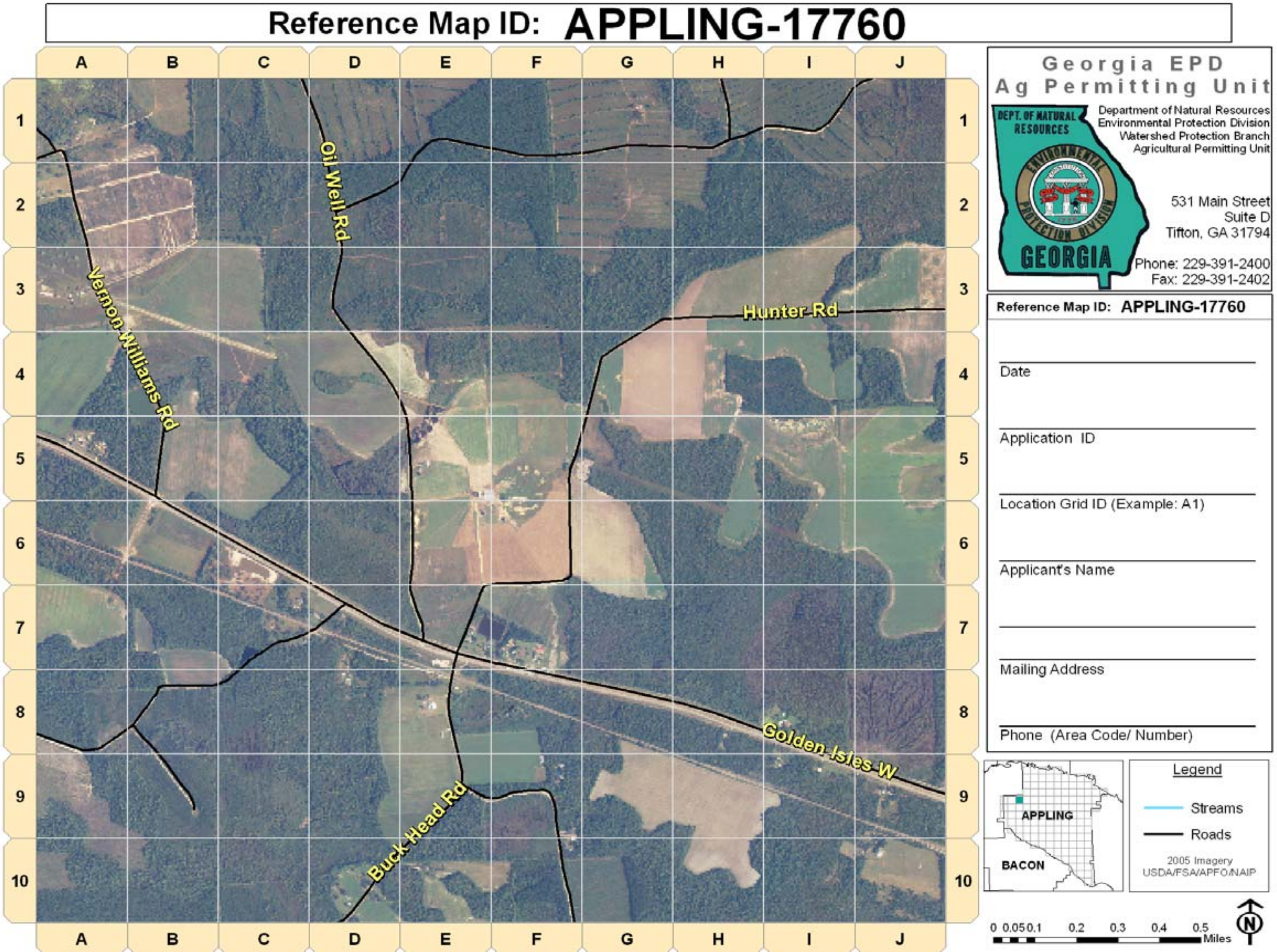


Figure A2 – Groundwater application site map