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EFFECTS OF GROUNDWATER WITHDRAWALS IN GEORGIA ON BASE FLOW IN A FLORIDA RIVER SYSTEM

The Apalachicola River is Florida's largest river in terms of flow, and it is significant component of Florida's marine- and recreation-based economic sectors. Base flow in the river is important for the provision of a federally authorized navigation channel and for the ecological functioning of the river's estuary along of the Gulf of Mexico. Apalachicola estuary provided about 90% of the state's and 10% of the nation's oyster harvest, as well as sizeable shrimp, blue crab, and fin fish yields.

In the paper there are investigated the impacts of irrigation activities in the Flint River in the state of Georgia on base flow in the Apalachicola River, which is formed by the confluence of the Flint and Chattahoochee Rivers at the Florida border with Georgia and Alabama. Statistical analysis of monthly data on groundwater withdrawals for agricultural irrigation and river base flow over a period of more than twenty years shows a significant negative correlation. The analysis leads us to conclude that agricultural withdrawals of groundwater have substantial negative effects on base flow in the river and estuarine system, especially during periods of low flow.

1. INTRODUCTION

Base flow in the Apalachicola River constitutes the largest volume of the river water in terms of flow, and it is important component of Florida's marine- and recreation-based economic sectors. Thus, it is essential that the river's flow regime be maintained with relatively little human disturbance. Base flow in the river is important for the provision of a federally authorized navigation channel and for ecological functioning of the river's estuary along of the Gulf of Mexico. This paper investigates the impacts of irrigation activities in the Flint River in the state of Georgia on base flow in Florida's Apalachicola River.

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2. BACKGROUND

2.1. DOWNSTREAM USES

The Apalachicola River is formed by the confluence of the Flint and Chattahoochee Rivers at the Florida border with Georgia and Alabama (figure 1). Throughout the early 1980s, the Apalachicola estuary provided about 90 percent of the state's and 10 percent of the nation's oyster harvest, as well as sizeable shrimp, blue

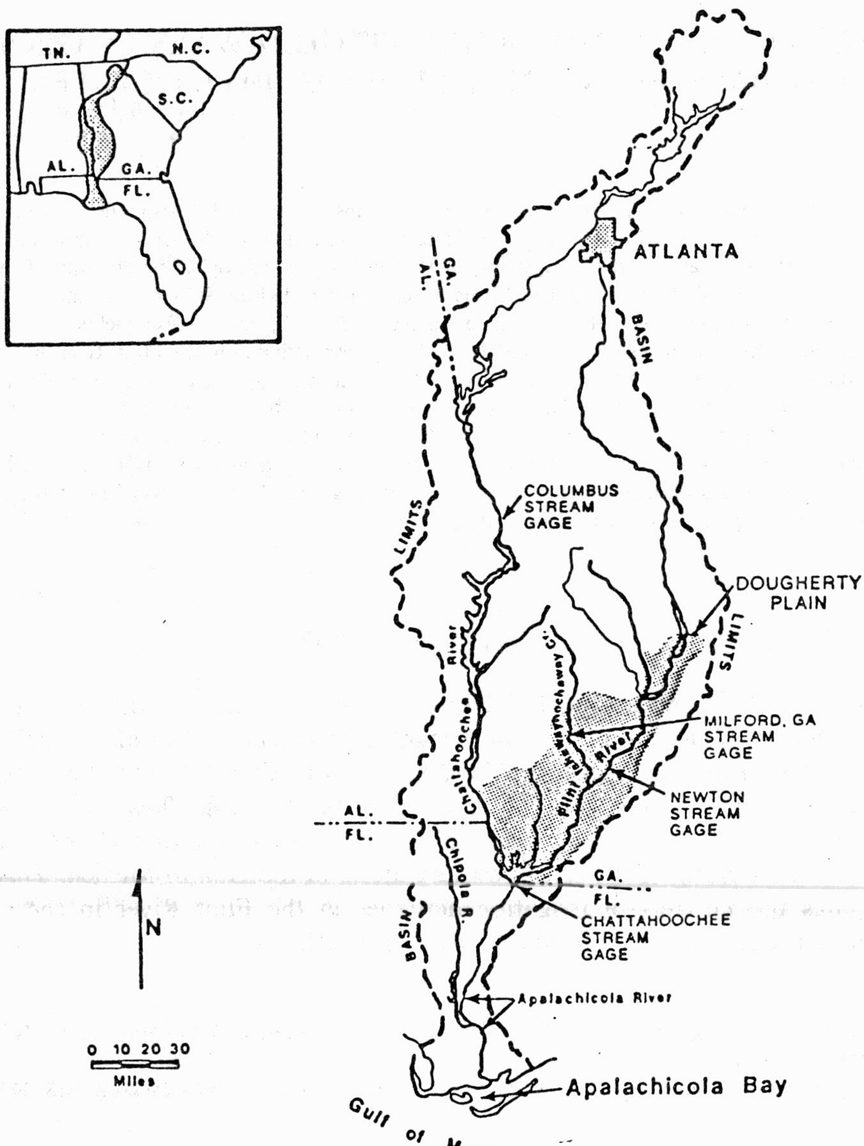

Fig. 1. Geographic features of the ACF basin

crab and fin fish yields. Although annual seafood landings are valued in the tens of millions of dollars, the real value of the estuary is in its role as a nursery. Over 95 percent of the commercial species harvested in the Gulf spend some critical portion of their life-cycle in an estuary [12]. Its high productivity is the result of good water quality, the estuary's physical form, its salinity regime and energy subsidies in the form of nutrient/detrital transport from the river's floodplain. It is tied to a diurnal tidal cycle and a salinity regime defined by an annual cycle of spring floods and winter low flows and cyclical long-term fluctuations in river flow [5].

As a commercial navigation project, the Apalachicola River is federally authorized to be maintained at a nine by one-hundred foot dimension. Availability of this depth is dependent on flow in the river. Channel dimensions may be provided by 1) dredging, cutoffs, training works and other open-river methods; 2) a series of locks and dams; and 3) flow regulation from upstream storage projects [10]. The Corps of Engineers have undertaken numerous structural modifications in an attempt to provide the authorized channel on a year-round basis. These include five dams on the Chattahoochee River, an extensive network of dike fields on the Apalachicola River, six cutoffs, removal of rock shoals at ten locations and annual maintenance dredging and snagging.

Despite these efforts, the channel has not been available on a year-round basis. The authorized channel dimensions were available 80 percent of a relatively wet period [4], [7] between 1970 and 1980 and has been available considerably less since then. The flow at which the authorized channel can be provided after dredging (11,300 cfs at the Blountstown, FL gage) has been available only 80 percent of the time for the 65 year period of record. The discharge that has been available on a reliable year-round basis (i.e., 95 percent of the time) is 7,800 cfs.

2.2. WATER RESOURCES

All three river basins are of concern relative to the issue of irrigation withdrawals. Although the Chattahoochee and Flint sub-basins are nearly equal in area, their effects on flow in the Apalachicola River differ. The Chattahoochee is a regulated stream whose flow is primarily from surface runoff. Its contribution to the major portion of flow in mean- to high-water events is typical. In contrast, the Flint as unregulated stream has a major spring-fed flow component and should contribute to a larger share of flow during low-flow periods.

Although the Chattahoochee is regulated, management of its resevoirs is limited by the fact that the two reservoirs which contain over 80 percent of the conservation storage impound less than 18 percent of the watershed. Thus, the potential for refilling them during low-flow events is constrained and they must be managed conservatively. Furthermore, the majority of the designated storage capacities in these two reservoirs have been captured by recreational interests and adjacent land-owners or allocated to municipal water supply. Historically, the reservoir system has been shown to have had a limited effect on the overall flow regime of the Apalachicola River [4], [6], [7].

Management options of the reservoirs are further constrained because hydropower facilities are managed as part of a grid with the Alabama–Coosa–Tallapoosa and Savannah basins. Providing water to Apalachicola Bay is not an authorized purpose of the federal reservoirs; thus the water is not released from the reservoir system to enhance shellfish productivity or major nursery areas.

Taking account of a groundwater, the area of concern is the Dougherty Plain district of the lain physiographic province. The underlying Floridan aquifer in the region makes the area well suited for irrigation wells. At the same time, however, the Floridan aquifer is closely linked hydrologically to the Flint River. Aquifer discharge to the Flint River downstream from Lake Worth dam has been computed to be one billion gallons per day [9]. The ground water level in the Upper Floridan aquifer is generally at a maximum during February through April, declines through summer, and is at a minimum during November and December, when flows in the Apalachicola River are also at a minimum. Seasonal water fluctuations in the aquifer near major agricultural and industrial centers can exceed 30 feet [9]. These seasonal depressions of the aquifer, in turn, translate into reduced flow in the Flint and its tributaries as they recharge the Floridan aquifer, and this translated into a reduction of base flow in the Apalachicola River.

2.3. IRRIGATION

Historically, agriculture has been significant patr of the economy of Georgia, and the large portion of that agricultural activity is in the southwest part of the state, where soil and climatic conditions are favourable. Although rainfall is plentiful in Georgia, in the past twenty years the use of ground water for irrigation and the use of center-pivot type irrigation systems have increased substantially (table). The combination of technological innovations in irrigation, a robust aquifer, and

Table

Irrigation acreage in Georgia, 1970–1989 [1]

Year	Total acreage (all systems)	Center-pivot systems (number)
1970	144,627	87
1973	193,857	238
1975	307,416	478
1978	72,075	1,636
1980	988,356	2,858
1982	1,104,992	3,597
1984	1,069,221	3,794
1986	1,128,584	4,191
1989	1,223,836	4,865

favourable profit margins for field crops in the early- and mid-seventies provided the incentives for the conversion of marginal land (woodland and pasture) into row crops [13]. Increased agricultural use of marginal land resulted in a need for additional fertilizers and pesticides, which conveniently could be applied via sprinkler irrigation systems. Nearly three-fourths of the new marginal farmlands were used to grow soybeans and corn, crops with high water requirements.

Rural lands of southwest Georgia typically receive about 50 inches of rain annually, but most of this occurs in the early spring when seedling row crops require less water. During the summer, when many crops need more water, rainfall typically declines. Although the amount of irrigated acreage has stabilized in recent years, table shows that the number of center-pivot systems continues to increase. These systems have the advantages of being relatively cheap compared to other types, adaptable to the sandy soils in the region, easy to operate and low in maintenance [8]. Center-pivot irrigation systems provide the most efficiently pesticides [2] and ensure the most uniform application of water to both foliage and soil.

In 1970, the 22-county area in southwest Georgia and the middle Flint withdrew 13.19 milion gallons per day (mgd) for irrigation purposes; 3.30 mgd from ground water sources and 9.89 mgd from surface water sources [1]. In 1990, the same counties withdrew 211.22 mgd for irrigation; 54.34 from ground water and 156.88 mgd from surface water [3]. Over 80 percent of the increase in water use in this region from 1970 to 1990 can be attributed to increases in irrigation withdrawals.

These increases in irrigation activity, the physical relationship between the Floridan aquifer and the Flint River and the importance of inflow from the Flint River to base flow in the Apalachicola River deserve closer study. In this paper we investigate whether base flow in the Flint and Apalachicola Rivers has been affected by the recent increases in irrigation withdrawals.

3. METHODOLOGY

Evaluation of man-induced changes in the flow of a river is complicated because flow normally varies both seasonally and annually. In a typical year, average daily flow in the Apalachicola River varies about ten-fold. The annual minimum flow has varied nearly three-fold over the period-of-record. Our task is to discern significant long-term change in flows in a system that has considerable inherent variation. To do this, effects of irrigation in the Flint basin on base flow in the Apalachicola River are evaluated through two procedures: 1) comparison of the relative contributions of the Flint and Chattahoochee to flow in the Apalachicola River over time; 2) analysis of changes in the flow of the Flint relative to similar rivers in the region using multiple mass balance analysis.

For the relative contribution analysis, mean monthly flow data for USGS gages on the Flint and Chattahoochee were compared with data from a gage on the Apalachicola River. Data from the gages for the Flint River at Newton, Georgia, and Ichawaynochaway Creek at Milford, Georgia, were used for the Flint flow. These were combined with data for the Chattahoochee at Columbus, Georgia, and the

Apalachicola at Chattahoochee, Florida. These gages were selected because of their availability during period of record and location within each sub-basin. All three gages consisted of continuous records from the 1938 to 1992, with the exception of the Newton gage which was missing 1946, 1948, 1951–1956 and 1990. Selection of the Flint and Chattahoochee gages provided a pair which measured similar drainage areas. The Flint River gages were located in the middle of the Dougherty Plain and downstream from some of the most intense irrigation activity in the region. The Chattahoochee gage provided a measurement of Apalachicola River flow immediately below the confluence of its two main tributaries.

To determine relative contributions, the monthly mean flow value for the gages on the Flint and Chattahoochee Rivers were divided into the corresponding monthly mean flow of the Apalachicola River at the Chattahoochee gage for the period of 1938–1992. Data were grouped into two periods: before increased irrigation use (before 1970) and after the growth (1978 to 1992).

For the multiple mass balance analysis, flow at a gage on the Flint River at Newton, Georgia, was compared with the total flow of five other streams in the region. This analysis isolates a trend in the divergence of one data set from another which has been labelled as a control. Selection of rivers for the control was based on similarities to the Flint basin in rainfall and land use. Rivers used in this analysis were the Econfina, Ochlock-onee, Choctawhatchee, Withlacoochee and Chipola Rivers in north Florida. The analysis consisted of a time-series comparison of the ten-year moving average of monthly data for the Flint gages to the combined and individual flow of the above rivers.

4. RESULTS

Figures 2a and 2b show the relative contributions of the Flint and Chattahoochee Rivers to the minimum monthly flows of the Apalachicola River before and after substantial increases in irrigation in the lower Flint basin. These figures show that the relative contributions of the Flint and Chattahoochee Rivers to flow in the Apalachicola River has changed dramatically since irrigation activity in southwest Georgia increased in the 1970s. When compared with the pre-irrigation period, the relative contribution of the Flint to flow in the Apalachicola decreases in the post-irrigation period as flow in the Apalachicola decreases.

Possible explanations for this change are: 1) base flow in the Flint River has been lowered; 2) low-flow augmentation releases from the reservoir system in the Chattahoochee basin have altered the relative contribution relationship between the Flint and Chattahoochee Rivers; 3) rainfall patterns in the Flint and Chattahoochee basins have changed over time; 4) there have been significant land use changes in one of the basins which altered its hydrology; 5) some combination of the above.

A review of rainfall data for gages throughout the Flint and Chattahoochee basins did not show differences to cause the above changes in relative flow relationships.

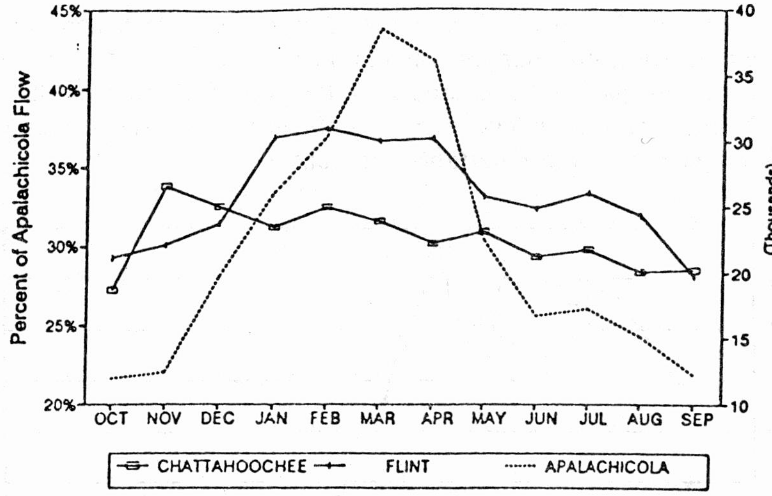

Fig. 2a. Relative contribution of the Flint and Chattahoochee Rivers to flow in the Apalachicola River, 1939–1970

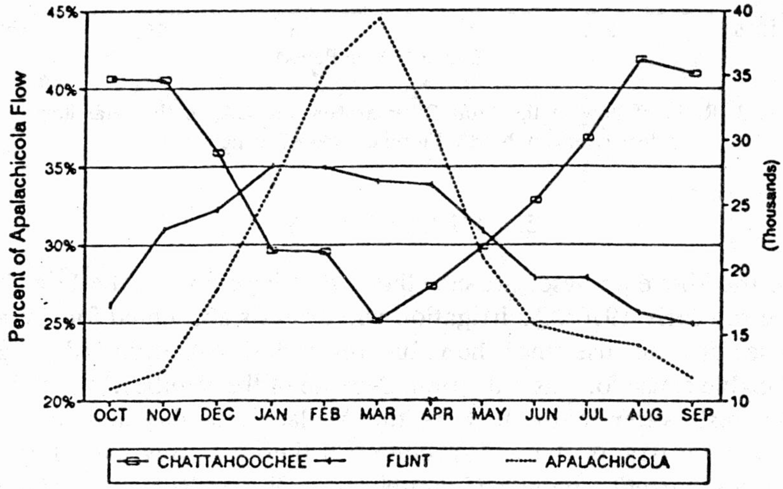

Fig. 2b. Relative contribution of the Flint and Chattahoochee Rivers to flow in the Apalachicola River, 1979–1991

Taking account of a recent review of land use changes in the basin, it can be concluded that although there is a general trend in land use in the ACF basin from farmland to urban areas, or reversion of farmland to woodland, the changing land use patterns were not believed to have a significant effect on river flows in the drainage basin [7].

Figure 3 shows the ratio of flow in the Flint to that of the five other rivers prior to screening them. This figure also suggests that the base flow of the Flint has been lowered since irrigation activities increased. These results support our conclusion that rainfall is not the cause of relationship changes noted in the relative flow contribution. As the Chattahoochee was not part of the comparison, the perceived lowering of base flow in the Apalachicola River is independent of influence by low-flow augmentation releases from reservoirs in the Chattahoochee basin.

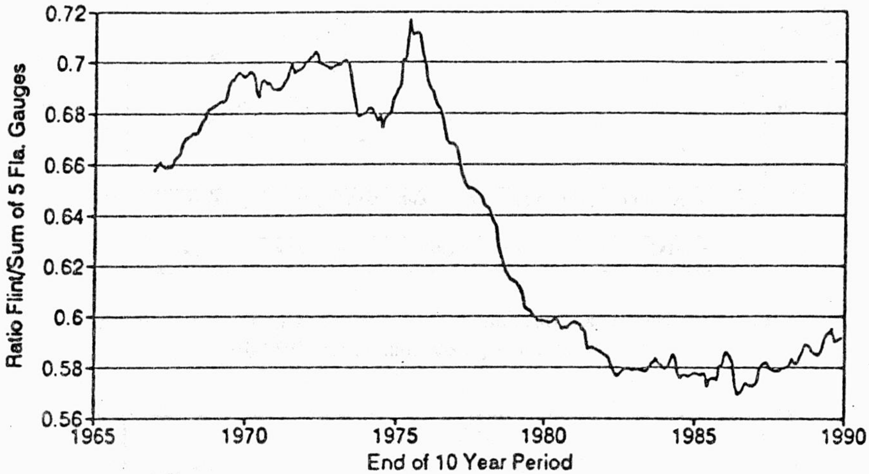

Fig. 3. Ratio of flow in the Flint River at Newton, GA, to the total flow in five rivers in North Florida; 1966–1990 navigation

5. CONCLUSIONS

Based on the above analyses, we concluded that base flow in the Flint has been reduced since the early 1970s. As irrigation withdrawals accounted for the majority of the increases in water use since the reduction in base flow occurred, irrigation is the most probable cause for this reduction. Because of the ramifications of a reduced base flow on fresh water inflow to both the Apalachicola Bay and to the federal channel, the issue warrants closer inspection. Furthermore, any hydrologic models developed in the current ongoing Comprehensive Water Resources Management Study of the ACF basin need to account for these apparent inflow reductions. Using the long-term historical record for the Flint will provide an inaccurate portrait of the present. Depletion analysis, as has been done in several basins in the West, is needed.

If the base flow of the Flint has been lowered as a result of irrigation activity, these withdrawals need to be controlled either through regulations or market mechanisms. As noted earlier, irrigation withdrawals in Georgia are essentially unregulated so long as the user does not seek the way to increase the capacity of an existing well. The root cause of the overuse of water by agriculture is a failure to price water properly. If the price of water reflects its true value (including all environmental and social costs), users should behave more conservatively. The use of economic incentives and disincentives to encourage development and use of alternative irrigation systems warrants further consideration.

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WPŁYW POBORU WÓD GRUNTOWYCH W GEORGII NA MINIMALNY PRZEPŁYW WÓD W RZEKACH FLORYDY

Apalachicola jest największą rzeką Florydy, a jej pełne wykorzystanie dla celów żeglugowych i rekreacyjnych stanowi znaczący składnik gospodarki tego stanu. Utrzymanie minimalnego przepływu w rzece jest niezbędne do nawigacji wodnej oraz do utrzymania prawidłowych warunków ekologicznych w miejscu ujścia rzeki do Zatoki Meksykańskiej, koniecznych do hodowli ostryg, krewetek, niebieskich krabów oraz specjalnych gatunków ryb. Celem pracy było zbadanie, jak wpływa nawadnianie pól w dorzeczu rzeki Flint w stanie Georgia na wielkość minimalnego przepływu wód w rzece Apalachicola, biorącej początek ze zlewni rzek Flint i Chattahoochee na granicy Florydy, Georgii i Alabamy. Statystyczna analiza porównawcza miesięcznych danych, określających pobór wód gruntowych do celów irygacyjnych w Alabamie, oraz poziomu wód w rzece Apalachicola w okresie ponad dwudziestoletnim wskazują na wyraźne, negatywne zależności między tymi danymi. Wyniki analizy świadczą o zdecydowanie ujemnym wpływie rolniczego wykorzystania wód gruntowych do nawadniania w Georgii na minimalny poziom wód w rzece Apalachicola i jej ujściu, szczególnie w okresie niskich stanów wód.

ВЛИЯНИЕ РАЗБОРА ГРУНТОВЫХ ВОД В ДЖОРДЖИИ НА МИНИМАЛЬНОЕ ТЕЧЕНИЕ ВОД В РЕКАХ ФЛОРИДЫ

Аппалачиколя является самой большой рекой Флориды, а ее полное использование для целей плавания и рекреации составляет значащий компонент для экономики етого штата. Сохранение минимального течения в реке необходимо для навигации, а также для сохранения правильных экологических условий в устье реки в Мексиканский залив, необходимых для развода рыбы, креветок или синих крабов. Целью работы было исследование, как орошение полей в речной системе реки Флинт в Джорджии влияет на минимальное течение вод в реке Аппалачиколя, имеющей свое начало в водосборном бассейне рек Флинт и Чаттагучи на границе Флориды, Джорджии и Алабамы. Статистический сравнительный анализ данных, собранных в течение месяца, определяющих забор грунтовых вод для ирригационных целей в Алабаме, а также уровня вод в реке Аппалачиколя в течение свыше двадцати лет указывают на резкие, негативные зависимости между этими данными. Результаты исследований свидетельствуют об отрицательном влиянии земледельческого использования грунтовых вод для орошения в Джорджии на минимальный уровень вод в реке Аппалачиколя и в ее устье, особенно в период низких состояний вод.