SMALL IMPOUNDMENT COMPLEXES AS A POSSIBLE METHOD TO INCREASE WATER SUPPLY IN ALABAMA

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Abstract At some locations in Alabama, increasing the amount of surface water is the only option for adding to available water for use by municipalities, industry, and agriculture. Because of environmental concerns, there is limited opportunity for impounding major streams. There is, however, much overland flow from rural, upland watersheds that could be captured for use. Small impoundment complexes often have been used to capture and store overland flow for use in aquaculture. These impoundment complexes fill during periods of high rainfall and do not greatly impact downstream flow. Similar systems possibly could be used as an environmentally-responsible source of water for other purposes and provide income for rural land owners.

INTRODUCTION

The Southeastern United States normally receives abundant precipitation and has many streams, lakes, ponds, and reservoirs. There are, however, increasing instances of water shortages as the human population increases and demands more water. Groundwater also is abundant in the region, but there are many areas where this resource is limited and surface water must be used. Precipitation is not evenly distributed in time, and observed shortages of surface water usually result from lack of capacity to store runoff during periods of high precipitation for later use. Moreover, construction of new impoundments on major streams to increase surface water storage capacity is restricted by environmental concerns and regulations.

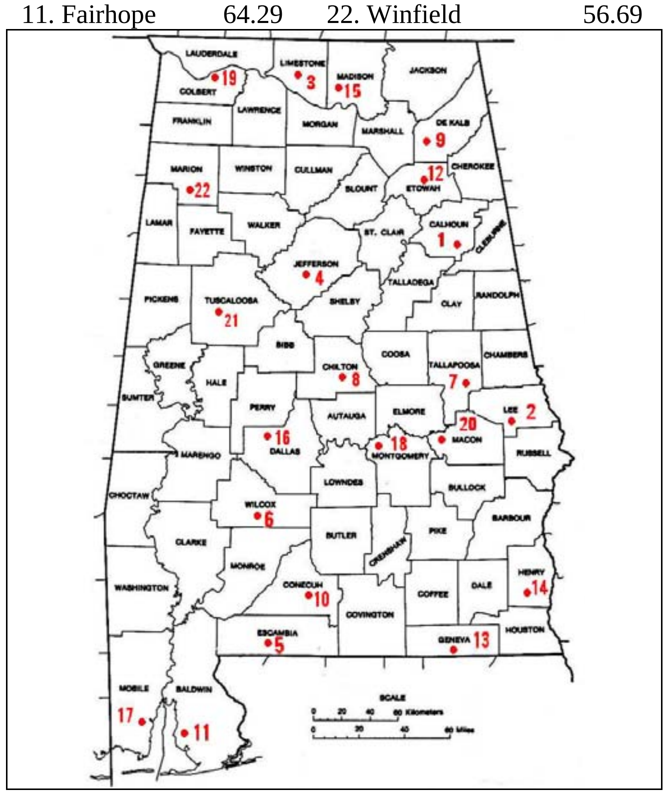
Small impoundments are used in the Southeastern United States to capture precipitation and surface runoff and provide water for sportfish culture and commercial aquaculture (Yoo and Boyd 1994). Ponds often are constructed in series one above the other on watersheds allowing upper ponds to overflow and seep into lower ones. Water levels decline considerably during summer and fall in upper ponds, but lower ponds remain nearly full or overflowing during summer and fall. Installation of small impoundments on rural, upland watersheds is a potential way of harvesting water for municipal, industrial, and agricultural use.

HYDROLOGIC BACKGROUND

Average, annual precipitation from records of 20 to 60 years at 22 locations in Alabama was 56.14 *in* with values ranging from 48.74 *in* at Anniston to 65.39 *in* at Mobile (Table 1). Louisiana, with an average, annual precipitation of 59.74 *in*, is the only state with greater average, annual precipitation.

Table 1. Average annual precipitation.

1. Anniston	48.74	12. Gadsden	52.17
2. Auburn	56.46	13. Geneva	56.65
3. Bell Mina	54.80	14. Headland	54.84
4. Birmingham	54.61	15. Huntsville	57.09
5. Brewton	62.60	16. Marion Junction	54.25
6. Camden	57.95	17. Mobile	65.39
7. Camp hill	56.85	18. Montgomery	50.67
8. Clanton	57.60	19. Muscle Shoals	51.85
9. Crossville	54.84	20. Shorter	52.87
10. Evergreen	61.57	21. Tuscaloosa	52.20
11. Fairhope	64.29	22. Winfield	56.69



Precipitation falling on the earth evaporates, becomes overland flow, or infiltrates the land surface to become soil moisture or groundwater. Soil moisture evaporates or is transpired by plants. Groundwater is removed by wells for human use, but a greater discharge of groundwater results from base flow into streams. Groundwater inflow sustains streams during dry weather.

Data were obtained from the United States Geological Survey website for discharge of 73 selected Alabama streams. Streams were not impounded by large dams, and watershed areas above gauging stations ranged from 6.16 to 2,058 *mi*^{2} (average = 256.9 *mi*^{2}). Watersheds had a combined area of 18,750 *mi*^{2} or 35.77% of the state's land area. Average, annual runoff was 20.75 *in* or 37.0% of annual precipitation. The greatest runoff, 24.39 *in/yr*, occurred on the Lower Coastal Plain in the far south where precipitation is greatest. The lowest runoff, 17.99 *in/yr*, was in the Blackland Prairie that receives less precipitation than the far south and has little relief (Table 2).

Under normal conditions, soil moisture content and groundwater storage volume are roughly equal on the same dates in successive years. Thus, average, annual stream flow (runoff) for a land mass, can be subtracted from average, annual precipitation to provide an estimate of evapotranspiration (Leopold 1997).

Table 2. Runoff (*in/yr*) for regions of Alabama.

Region	Measured stream discharge	Estimated P - PET
Appalachian Plateau	23.49	20.72
Blackland Prairie	17.99	16.04
Limestone Valleys	22.05	19.08
Lower Coastal Plain	24.59	22.32
Piedmont Plateau	19.22	20.23
Upper Coastal Plain	20.80	18.93
Average	21.32	19.55

Annual, potential evapotranspiration (PET) estimated by the Thornthwaite method (Thornthwaite and Mather 1957) was 33.46 *in* at Belle Mina and 34.79 *in* at Winfield in the north, 36.60 *in* at Auburn and 36.75 *in* at Marion Junction in the central area, and 38.6 *in* at Headland and 40.97 *in* at Fairhope in the south. The state average was 36.78 *in/yr*. Average, annual stream flow estimated by subtracting PET from average, annual precipitation did not differ greatly from measured stream flow (Table 2). This relationship can be used to estimate annual flow of gauged streams.

Monthly PET is greater in summer and early fall when precipitation is lowest (Fig. 1). Overland flow will occur mainly during the period November through April when precipitation exceeds PET. From May until October, base flow of groundwater will be the major component of stream flow.

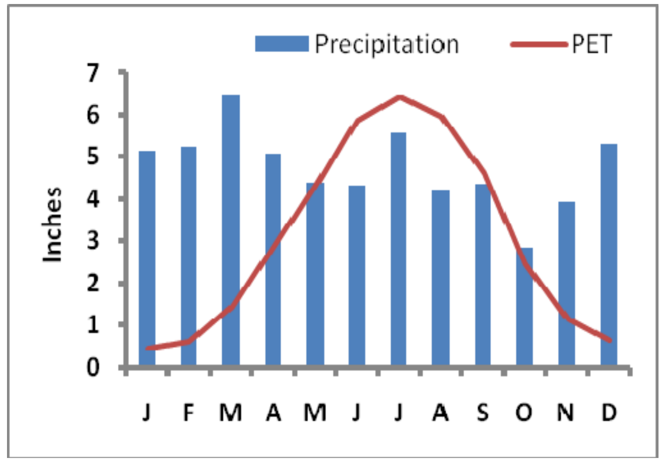


Figure 1. Average, monthly values for precipitation and potential evapotranspiration in Alabama.

Data for three streams, Painted Rock River near Woodville in the Huntsville area of north Alabama, Catoma Creek at Montgomery in the central part of the state, and Murder Creek at Evergreen in the south, confirms that runoff is highest in winter and early spring, when precipitation is high and PET is low, while lowest stream flow occurs in late summer and fall (Fig. 2). Maximum, monthly stream flow was three and six fold greater than minimum monthly flow.

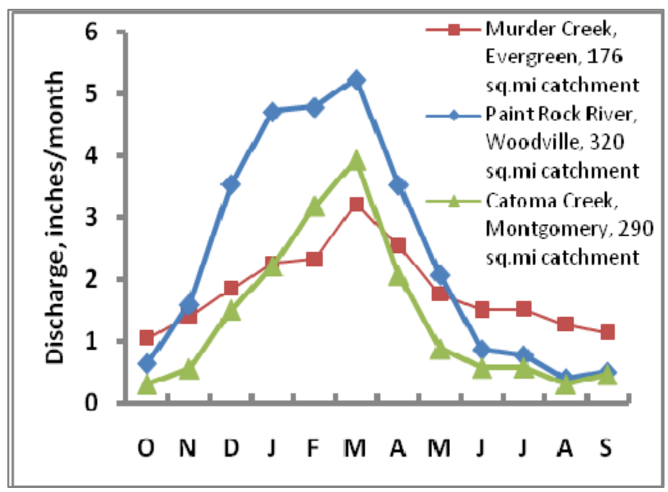


Figure 2. Average, monthly discharge of three creeks in Alabama.

Average, annual runoff varies from year to year as stream discharge data for three streams clearly reveals (Fig. 3). Much of the variation in annual, stream discharge was in response to differences in annual precipitation. Discharges of streams were positively correlated ($P < 0.01$) with annual precipitation: correlation coefficients were as follows: Catoma Creek, $r^2 = 0.502$; Murder Creek, $r^2 = 0.646$; Painted Rock River, $r^2 = 0.605$. High air temperature also lessens stream flow by increasing evapotranspiration, but air temperature data were not available for analysis.

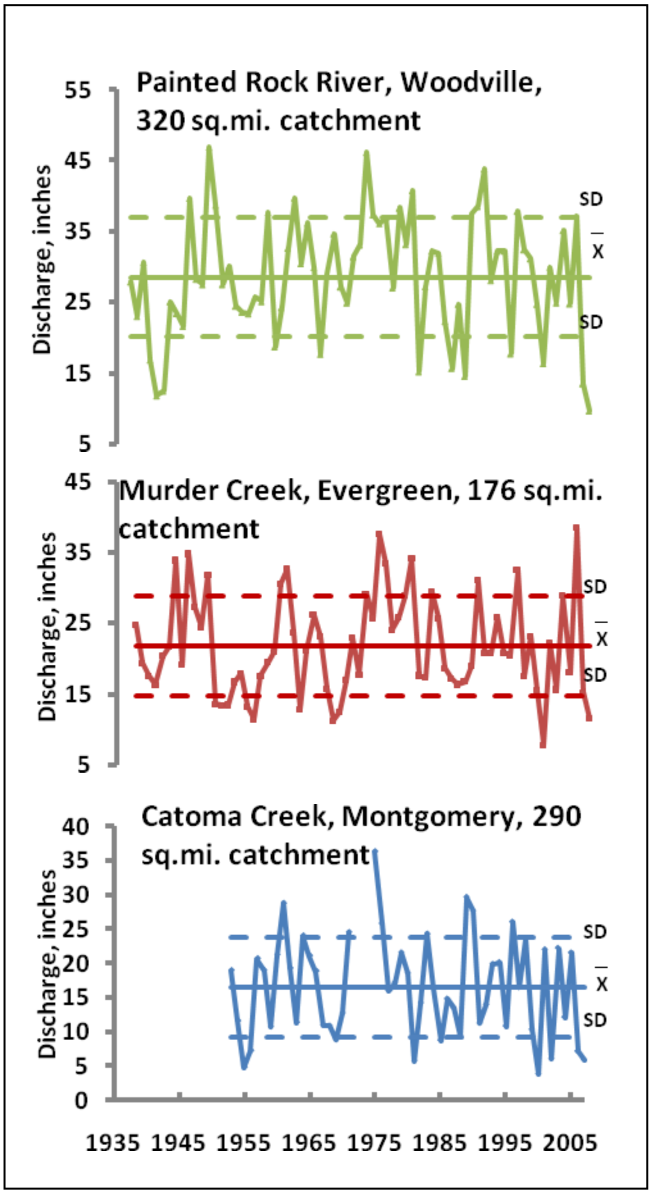


Figure 3. Average, annual discharge records of three streams in Alabama.

During 2006 and 2007, precipitation was especially low compared to normal precipitation across Alabama. Data for 11 stations revealed average precipitation about 20% less than normal in 2006 and nearly 40% below normal in 2007.

There was great concern over this drought, for many water supplies declined drastically, and water shortages occurred at some locations. The decade 1998-2007 had 9.45% less precipitation than the period 1948 to 1997. Average, annual precipitation for each of the five decades between 1948 and 1997 also was higher than for the decade 1998-2007. Precipitation records revealed individual years and spans of two or more consecutive years with unusually low precipitation had occurred previously as illustrated in Fig. 4 with records from three locations. There is not clear evidence of declining precipitation in Alabama. The human population, however, increased from near 3 million in 1950 to about 4.5 million in 2006. Water supplies previously adequate during droughts are no longer sufficient.

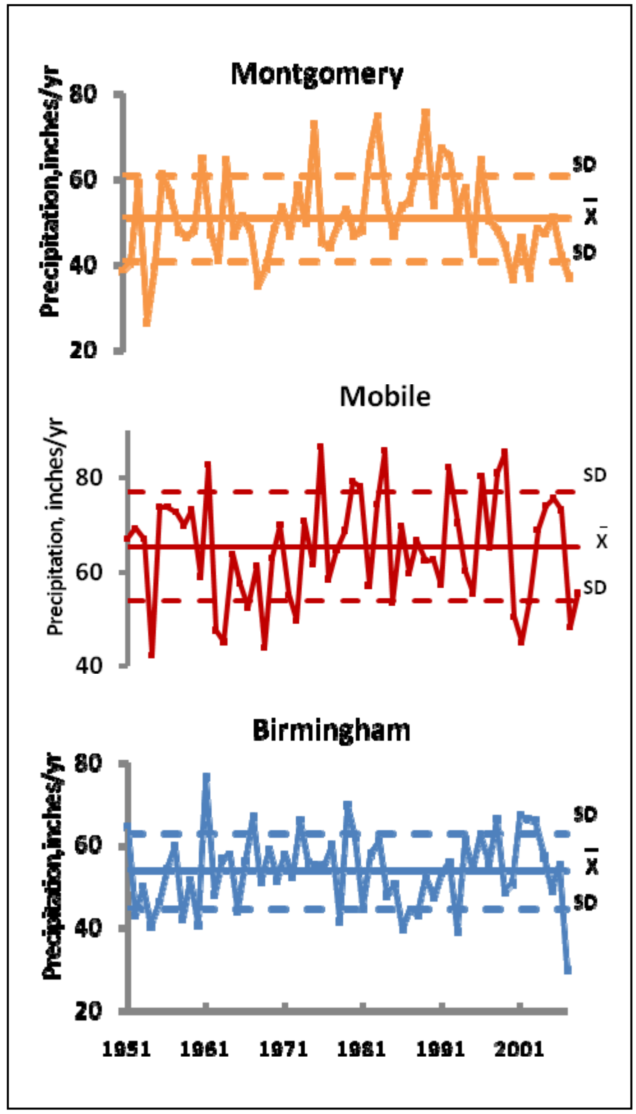


Figure 4. Average, annual precipitation at three locations in Alabama.

In summary, Alabama receives much precipitation and has considerable runoff. The water supply problem results from insufficient capacity to store this runoff for use during prolonged dry weather.

WATER HARVESTING IN SMALL IMPOUNDMENTS

The E. W. Shell Fisheries Center at Auburn University has 33 watershed ponds with a total water surface area of 204 *acres* on 2,310 *acres* of hilly, forested land of the Piedmont Plateau near Auburn, Alabama. The area contains three hydrologic units, and one (Fig. 5) will illustrate the potential of water harvesting in small impoundments for increasing water supply. Overland flow enters ponds and all surface waters discharged from the catchment ultimately passes through Pond S-8.

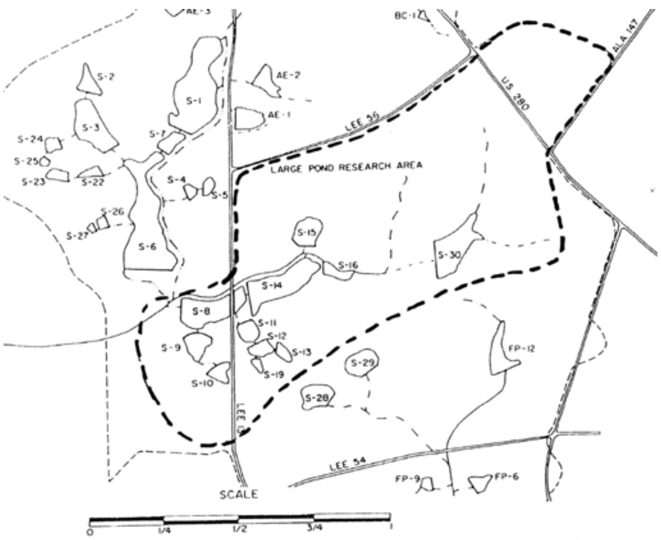


Figure 5. A partial map of the E. W. Shell Fisheries Center with the hydrologic unit for the water harvesting example outlined by dashed lines.

Methodology suggested by Boyd (1982) for developing water budgets for aquaculture ponds was followed. Data on size of the catchment, pond areas and depths, seepage and evaporation losses from ponds, and overland flow were obtained from a hydrological assessment made in 1983 and 1984 (Boyd and Shelton 1984). These data, normal precipitation at Auburn (Table 1), and average, annual stream flow for the Piedmont Plateau (Table 3) allowed estimation of the water balance for the hydrologic unit using an expansion of the equation,

$$Q_{in} = Q_{out} \pm \Delta S$$

where Q_{in} and Q_{out} = all inflows and outflows, respectively and ΔS = change in storage.

Table 3. Data for water harvesting example.

Total hydrologic unit	688.17 *acres*
Pond surface area	61.26 *acres*
Land surface area	626.91 *acres*
Pond average depth	5.09 *ft*
Pond volume	311.8 *acre-ft*
Precipitation	4.705 *ft/yr*
Evapotranspiration	3.103 *ft/yr*
Total runoff	1.602 *ft/yr*
Overland flow	0.804 *ft/yr*
Groundwater discharge	0.798 *ft/yr*
Pond evaporation	3.701 *ft/yr*
Pond seepage	2.100 *ft/yr*

Direct precipitation and overland flow provided inflow of 792.2 *acre-ft* to ponds, while seepage and evaporation losses from ponds were 355.3 *acre-ft* (Table 4). Inflows exceeded outflows by 436.9 *acre-ft*; 311.8 *acre-ft* were stored in ponds and 125.1 *acre-ft* overflowed. Upper ponds overflowed and seeped into lower ponds. Water levels declined by 2 to 3 *ft* in upper ponds but were stable in lower ponds (Boyd and Shelton 1984).

Table 4. Water balance in ponds for water harvesting.

Variable	**(A*cre-ft/yr*)**
Inflows	
Direct precipitation	288.2
Overland flow	504.0
Total	792.2
Outflows	
Evaporation	226.7
Seepage	128.6
Total	355.3
Inflows – Outflows – Excess	436.9
Pond storage	311.8
Overflow (Excess – Pond storage)	125.1

The calculations assumed ponds were empty at the beginning of the year, full at the end of the year, and water was not withdrawn for consumptive use. The following year, ponds would be full at the beginning of the year and water entering them would evaporate, seep out, or overflow. Seepage would become groundwater, and reduction in downstream flow caused by ponds would be equal to the difference between pond evaporation and the amount of evapotranspiration that would occur from land occupied by the ponds had they not been there. This difference is 36.85 *acre-ft* [(3.701 – 3.103) *ft/yr* × 61.62 *acres*]. Without ponds, the hydrologic unit would discharge 1,102.4 *acre-ft/yr* (1.602 *ft/yr* × 688.17 *acres*). Ponds would reduce discharge by 3.3%. Of course, ponds operated for water harvesting would lessen downstream flow by 3.3%

plus the amount of water removed for consumptive use. Many water uses involve removing water, using it, possibly treating it to improve its quality, and discharging it again. When water withdrawn for consumptive use is released back to the same drainage basin, there is little reduction in downstream flow.

An alternative way of storing runoff for later use is pump storage. This method requires storage basins to be constructed near major streams and water pumped into them during peak flow. Although this method is in principle similar to water harvesting in ponds, major streams are involved and pumping costs are incurred in transferring water from streams to storage basins.

IMPLEMENTATION ISSUES

Ponds should be carefully laid out in the landscape to maximize capture of water and facilitate movement of water from upper ponds to lower ones. If possible, the scheme should be designed to deliver the water to the user's system by gravity flow. Calculations should be made of expected consumptive use and reduction in downstream flow. Catchment areas and pond storage volumes should be designed to capture enough water for drought years and also to assure adequate downstream flow.

Municipal water supplies must comply with EPA water quality standards for pesticides, heavy metals, industrial chemicals, coliform organisms, and certain other variables. Water should not be excessively turbid, contain nutrient concentrations sufficient to cause algal blooms – especially blue-green algae capable of producing taste and odor compounds, have excessive alkalinity, hardness, and total dissolved solids, or be highly colored. Ponds are sedimentation basins and natural processes in ponds purify water (Boyd and Tucker 1998). Nevertheless, it would be unacceptable to have pastures, row crops, industrial facilities or other sources of pollution on watersheds for public water supplies. Such watersheds should be covered mainly with trees or grass.

Ponds in Alabama tend to have high quality water (Arce and Boyd 1980). Waters from ponds in the Piedmont Plateau, Coastal Plains, and Appalachian Plateau regions are generally softer and less mineralized than those from ponds in the Blackland Prairie and Limestone Valleys and Uplands regions (Table 5). Trace metal concentrations did differ with respect to physiographic region. However, total iron and total manganese concentrations did not exceed 1.7 and 0.15 mg/L, respectively. Averages were 0.2 mg/L for total iron and 0.03 mg/L for total manganese. Probably the greatest problem with respect to water quality would be highly colored water in ponds on some forested watersheds – especially in south Alabama. Soils in many areas of the state are acidic, and in such areas, pond waters are acidic and of low total alkalinity. Water from water harvesting ponds usually would not require a lot of treatment before being used for municipal or industrial purpose. Probably, treatment would be necessary for agricultural use.

Table 5. Basic composition of water in small impoundments in Alabama.

Region	TA[1]	TH[2]	TDS[3]	SC[4]
Piedmont Plateau	11.6	12.3	34.5	40.2
Coastal Plains	13.2	12.9	44.3	48.5
Appalachian Plateau	18.9	22.0	60.2	73.8
Limestone Valleys and Uplands	42.2	49.2	112	146
Blackland Prairie	51.1	55.5	94.4	161

[1]TA = total alkalinity (*mg/L*);
[2]TH = total hardness (*mg/L*);
[3]TDS = total dissolved solids (*mg/L*);
[4]SC = specific conductance (μ*mho/cm*).

The cost of water from public water systems in the United States averages about $2.49/1,000 *gal* ($811.42/*acre-ft*), an amount consistent with several municipalities contacted in Alabama. The water balance example for the E.W. Shell Fisheries Center suggests that about 0.453 *acre-ft* (147,620 *gal*) of water could be captured per acre. Average water use in the United States is about 32,000 *gal/yr* per capita, and 1 *acre* of watershed could supply water for four people. The value of this water at the consumer level would be $367.57/*acre*. Of course, on a dry year, precipitation possibly could be 50% less than normal, and estimates above should be reduced proportionally to provide a margin for drought years.

A municipality or other water user could purchase or lease a catchment area and construct water harvesting infrastructure. There usually would be multiple land owners, and a possible alternative would be to organize land owners into a cooperative to construct ponds and infrastructure for transferring water to the user's system. Rent for land in Alabama is about $5 to $7/*acre* for hunting, and average rent for pasture and cropland is $19 and $41/*acre*, respectively. Converting watersheds for water harvesting possibly could become a lucrative land use option.

REFERENCES

Arce, R.G., and C.E. Boyd. 1980. Water chemistry of Alabama ponds. Bulletin 522, Alabama Agricultural Experiment Station, Auburn University, Alabama.

Boyd, C.E. 1982. Hydrology of small experimental fish ponds at Auburn, Alabama. Transactions of the American Fisheries Society 111:638-644.

Boyd, C.E., and J.L. Shelton, Jr. 1984. Observations on the hydrology and morphometry of ponds on the Auburn University Fisheries Research Unit. Bulletin 558, Alabama Agricultural Experiment Station, Auburn University, Alabama.

Boyd, C.E. and C.S. Tucker. Pond Aquaculture Water Quality Management. Kluwer Academic Publishers, Boston, Massachusetts.

Leopold, L.B. 1997. Water, Rivers, and Creeks. University Science Books, Sausalito, California

Thornthwaite, C.W., and J.R. Mather. 1957. Instructions and tables for computing potential evapotranspiration and the water balance. John Hopkins University, Publication in Climatology 10(3):185-311.

Yoo, K.H, and C.E. Boyd. 1994. Hydrology and Water Supply for Aquaculture. Chapman and Hall, New York, New York.