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Number, size, distribution, and hydrologic role of small impoundments in Alabama

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Abstract: A small impoundment (SI) inventory was made by county for Alabama by using Landsat 5 TM satellite imagery from the winter of 2007 to enumerate and measure surface areas of water bodies. The result was identification of 278,787 SIs >0.18 ha (0.44 ac) and <2,000 ha (4,972 ac) in surface area with a combined water surface area of 261,880 ha (647,105 ac). The average surface area of SIs was 0.94 ha (2.32 ac)—84.8% were <1 ha (2.5 ac), and 92.7% were <2 ha (4.94 ac) in area. Ground-truthing in one county revealed that the procedure had an accuracy of 80% in identifying SIs. The density of SIs tended to increase slightly in counties of higher population density. Some physiographic provinces had greater density of SIs than others; however, the average surface area of individual ponds did not differ greatly among provinces. The total volume of SIs was estimated to be ≈ 6 km^3 (4,900,000 ac ft)—roughly 8.1% of annual runoff for the state. After initial filling by direct precipitation and runoff, SIs are seldom drained, and they overflow after periods of considerable rainfall minimizing retention of runoff. It was estimated that SIs in Alabama lessen annual runoff by about 0.35 cm y^{-1} (0.14 in yr^{-1})—a reduction of about 0.6%—mainly because evaporation from their surfaces exceeds evapotranspiration loss for an equal land area. Nevertheless, SIs probably flatten peaks of downstream hydrographs. It should be possible to use water from SIs to supplement existing water supplies in certain localities, and SIs create open-water, shoreline, and wetland habitat as well as detain and improve the quality of surface runoff.

Key words: Alabama water resources—ponds—small impoundments—surface water hydrology

Man-made impoundments are common features of the United States landscape. Surface areas of impoundments range from a few square meters to thousands of hectares, and collectively, impoundments represent a large water surface area and contain considerable water. Impoundments are beneficial to humans for flood control, water supply, power generation, transportation, fish production, recreation, and aesthetic and spiritual value. These water bodies provide habitat for wildlife and are an important aspect of the ecological landscape. Much of the emphasis on the influence of impoundments on hydrology has focused on large impoundments built on major streams. However, there is a tremendous number of small impoundments (SIs) that capture flow of intermittent or permanent first order streams and overland flow or only overland flow. Verdegem and Bosma (2009) emphasized that SIs increase the water surface area for evaporation, and Boyd et al. (2009) concluded that evaporation from surfaces of SIs exceeded evaporation from an equal land surface area in Alabama by an average of 18.2 cm y^{-1} (7.17 in yr^{-1}). Although SIs capture runoff, they are seldom drained, and they seep beneath their embankments and, to a lesser extent, through their bottoms (Yoo and Boyd 1994). Thus, except for the increase in evaporative loss, SIs have little effect in the volume of downstream flow because runoff entering them either overflows or becomes groundwater that can enter streams as base flow (Manson et al. 1968; Verdegem and Bosma 2009; Boyd et al. 2009). Nevertheless, SIs detain runoff and thereby may reduce the peaks of downstream hydrographs (Schoof and Gander 1982).

The southeastern United States is an area of relatively high rainfall; for example, Alabama has average annual precipitation of 142.6 cm y^{-1} (56.1 in yr^{-1}). Nevertheless, water shortages are not unusual in this region because of rapidly increasing population in several states and frequent droughts. Hook et al. (2008) suggested that many SIs on the Georgia Coastal Plain could be used for irrigation and reduce the dependency on groundwater and stream water for irrigation. Alabama has much less irrigated agriculture than Georgia, but there are many small- to medium-sized municipalities in Alabama—especially in the central and northeastern part of the state—where groundwater resources are limited and new sources of surface water are needed. Boyd et al. (2009) suggested that in some of these areas complexes of SIs could be organized to deliver water to municipalities and possibly to other water users. Development of such water-harvesting schemes could increase water supply and possibly provide an additional source of income for rural landowners through sale of water to municipalities and other users.

Recent research also demonstrated geochemical benefits of SIs. They increase sedimentation to lessen concentrations of suspended solids in runoff (Renwick et al. 2005) and contribute to sequestration of atmospheric carbon dioxide by burying organic carbon in sediment (Downing et al. 2008; Boyd et al. 2010).

More emphasis should be given to assessing interactions, both positive and negative, among impoundments, natural processes, and humans—in particular, attention should be focused on small and often privately-owned impoundments that have not been studied as thoroughly as larger, public works project impoundments. For this purpose, more precise inventories of impoundments extending down to the local level are needed. There are several sources of inventory data for impoundments. The National Inventory of Dams (NID) contains geographic coordinates for about 75,000 artificial dams across the conterminous United States (Graf 1999). An assessment of the NID by Smith et al. (2002) suggested that many entries were unreliable; eliminating these reduced the number of dams to about 43,000. The National Atlas is of little use in estimating

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the number of impoundments because it only includes about 5,000 large water bodies (Smith et al. 2002).

There are many impoundments smaller than those reported in the NID and National Atlas and located mostly on private lands. National estimates of private ponds in the conterminous United States made for 1969 and 1980 were 2,200,000 and 2,100,000, respectively (USDA SCS 1971, 1982). Smith et al. (2002) used United States Geological Survey National Land Cover Data (NLCD) for 1992 (USGS 1992), and estimated that there were 2,600,000 water bodies in the conterminous United States with a total water surface area of 2,100,000 ha (5,189,100 ac). However, Renwick et al. (2005) extrapolated from a sample of 336 of the approximately 54,000 USGS topographic quadrangles (1:24,000) that cover the conterminous United States and concluded that there might be as many as 8 to 9 million SIs.

Estimates of the number, total surface area, or both for ponds are available for a few states or regions in publications and online information related to sport fishing as follows: Alabama, 50,000 ponds and 61,000 ha (150,731 ac) (Alabama's Pond Management Biologists 2003); Georgia, 63,000 ponds and 126,000 ha (311,346 ac) (Georgia DNR 2001); Mississippi, 130,000 ponds and 93,000 ha (229,803 ac) (Strickland et al. 2007); Tennessee, 200,000 ponds and 40,000 ha (98,840 ac) (Cobb 2009); Texas, >800,000 ponds but no area estimate (Lock 1993). These publications do not divulge how the data on numbers and total surface areas of ponds were generated.

Management of small water bodies usually is a private effort with technical assistance from county- or state-level agencies. Increasingly, pond owners hire pond management consulting companies to manage their ponds, and these firms often rely heavily on advice from universities. Inventories of small water bodies should be available by state and subdivided to county level for use by those responsible for pond management.

The present study was conducted to estimate the number, size distribution, and total water surface area of small reservoirs, private ponds, and other small water bodies in Alabama. In addition, an estimate of the volume of water held in these water bodies was made because the amount of water stored in small ponds is needed by those who seek to enhance the water supply for agricultural, municipal, and other purposes.

Materials and Methods

Mapping Small Impoundments. Alabama records show 46 public reservoirs ranging from 229 ha (565 ac) to 27,960 ha (11,315 ac), with an average area of 5,030 ha (12,429 ac). The majority (27) of these reservoirs are over 2,000 ha (5,000 ac), which falls outside the limit of what is generally considered a small impoundment. The definition of a small impoundment as <1 ha (Smith et al. 2002) would exclude these large reservoirs. It would also exclude the smaller reservoirs, Alabama's 23 public fishing lakes, nearly all of the catfish ponds in the western part of the state, and a great number of farm ponds. We opted for a more inclusive approach by defining a small impoundment as a water body with a surface area ≤2,000 ha (5,000 ac). We fully expected, however, that the overwhelming majority of water bodies in this size category would be ≤40 ha (99 ac).

The process of mapping small water bodies in Alabama included three major tasks. The first was to use satellite imagery to produce a base map of surface water only. The second task was to isolate the small water bodies by removing streams and water bodies >2,000 ha (5,000 ac) in area. The third task was to sort small water bodies into categories based on surface area for inventory purposes.

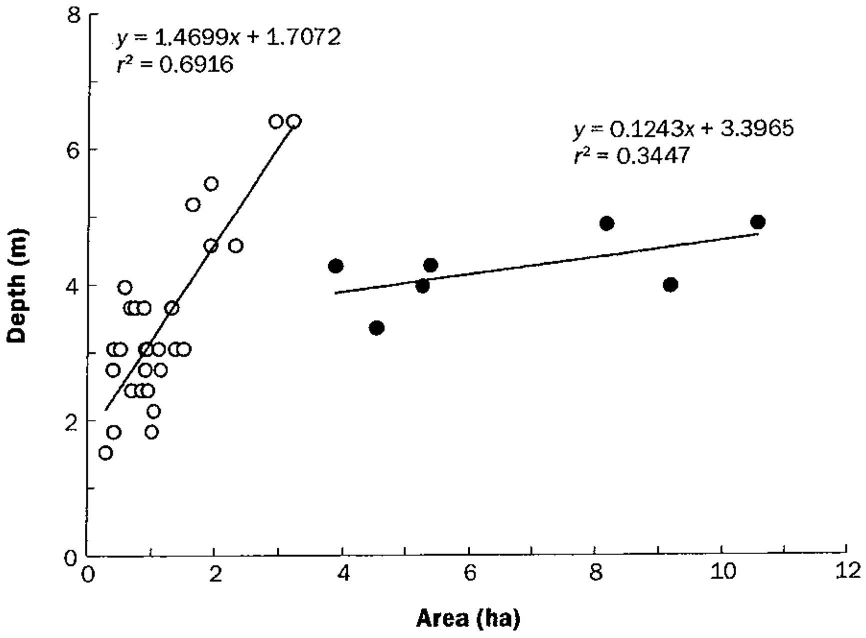
Eleven, Landsat 5 TM scenes (30 m [98 ft] spatial resolution) covering the state of Alabama were acquired for the winter "leaf-off" period of December 22, 2006, to March 23, 2007. The imagery was terrain-corrected and geo-rectified (WGS84; UTM Zone 16) before delivery. In stage one, each scene was processed individually with ERDAS Imagine software. The first step in processing a scene was to subset the layers to produce a 4-5-3 false color image. Unsupervised classification by the ISODATA method (Jensen 2004; Leica Geosystems 2007) was used to sort the data into 100 clusters, which were reclassed to produce a binary map of water (1) and not water (0). Ancillary data in the form of recent (2008) aerial photographs, US Geological Survey quad maps, and Alabama Department of Transportation state and county highway maps were used to determine which clusters represented water. The number of clusters identified as water varied from 20 to 28 per scene. It is difficult to detect a clear, concise boundary between land and water in some cases due to the problem of satellite image grid cells along the shoreline encompassing both land and water. These grid cells are commonly known as edge pixels or mixed pixels (Clarke 2011). Shallow water along the shoreline enhances this problem, and small, shallow water bodies might go completely undetected. We took a conservative approach in determining the boundary between water and land by classifying a cluster as not water (0) whenever its characteristics were in question. The individual maps were then merged to produce a final state map of surface water only.

In stage two, TIGER vector files of streams and major water bodies (United States Census Bureau 2009), obtained from the Environmental Systems Research Institute web site in ArcGIS shapefile format (ESRI 2009), were used to construct a mask or buffer for removing streams and water bodies >2,000 ha (5,000 ac) in area from the map developed in stage one. The TIGER files also included small water bodies (see Smith et al. 2002) that had to be deleted in order for the mask to produce the desired result. ArcGIS software was used to remove water bodies (>2,000 ha [5,000 ac]) from the TIGER files. The edited TIGER files were merged into a single file covering the entire state; then, the vector file was converted to raster format (30 × 30 m grid) in ERDAS.

The potential exists for the vector version of the streams and major water bodies (and the converted raster format version) to be slightly different than the satellite image version created in stage one for various factors (e.g., stream meandering, digitizing error), which might result in a portion of a stream or large water body extending outside the mask. For example, the TIGER vector files represent stream locations at a different time period (circa 2000). Furthermore, the TIGER files were derived from 1:100,000 scale Digital Line Graph (DLG) files developed by the US Geological Survey with a horizontal accuracy of 50.8 m (167 ft) according to National Map Accuracy Standards (O'Grady and Godwin 2000; USGS 1999). The standard error for digitizing these files is 7.6 m (25 ft). Therefore, a three-grid-cell (90 m [295 ft]) buffer zone was created around the raster version of the streams and major water bodies to avoid this potential source of error. Note that the 90 m (295 ft) wide buffer was determined to be the best option after testing at various locations across the state. The mask with the 90 m (295 ft) buffer zone was

Figure 1

Relationship of area of small impoundments to maximum depth. There are two groups of ponds (<3.2 ha, open dots, and >3.8 ha, solid dots) and a separate regression line for each group.



then used to isolate the small water bodies outside the masked area from the streams and large water bodies within the masked area. The 90 m (295 ft) buffer zone likely resulted in the omission of some small water bodies. However, this is a common technique used to reduce the potential for the final map to include unintended water bodies (see Smith et al. 2002) that represent an imminent source of error. The final product was a state map consisting entirely of water bodies of <2,000 ha (5,000 ac) in surface area.

In stage three, the "clump" routine in ERDAS was used to group contiguous grid cells of surface water into unique entities. For example, a group of three contiguous grid cells would be recognized as a unique water body with a surface area of 0.27 ha (0.67 ac). Note that all clumps consisting of one grid cell (0.09 ha [0.27 ac]) were deleted from the map at this point because they were deemed to be insignificant artifacts such as swimming pools, runoff collected on parking lots, barren surface mining areas, or fragments of wetlands (Smith et al. 2002). This last step eliminated approximately 56% of the clumps but only 11% of the area. This step has the potential to introduce omission error (i.e., water misclassified as not water) in that some of the clumps might be small impoundments. We investigated this potential source of error by evaluating the omission error in Lee County (see Results and Discussion).

Accuracy Assessment. The accuracy of the identification and surface mensuration of SIs on the small water bodies map was evaluated at two geographic scales. The first test used existing records to evaluate how accurately the map represented water bodies of various sizes across the entire state. The second test used field verification of randomly selected sample sites to evaluate the map's accuracy within a single county—Lee County in east-central Alabama. Two measures of accuracy were used in the tests: accuracy rate and area correlation. Accuracy rate indicates the percentage of SIs found at the geographic location of the sample sites, i.e., water or not water. Area correlation indicates the correlation of surface water area on the map with existing records or field measurements.

In test one, surface water impoundment datasets were acquired for public reservoirs and fishing lakes (Alabama DCNR 2009a, b), NRCS PL-566 dam impoundments (Alabama NRCS 2009), and commercial catfish ponds in west Alabama (Alabama Fish Farming Center 2009). Twenty-nine of the state's 46 reservoirs were eliminated from the test for various reasons, e.g., difficulty in defining reservoir/river boundaries or reservoir crossed state boundary lines. Furthermore, only seven of the remaining 17 reservoirs had a surface area of <2,000 ha (5,000 ac). Rather than ignore these 10 large reservoirs, they were evaluated with the original map created in stage one to provide additional insight on the accuracy of the methodology used in this research. The NRCS PL-566 dam records included location maps with a minimum and maximum capacity elevation contour. These contours were used to estimate a midlevel contour, which was then used to compute surface area values for the correlation test.

In test two, ERDAS was used to generate a randomly selected set of 300 points within Lee County for evaluating the accuracy of the map for an individual county. Fifty-nine points were determined to be duplicates, i.e., two or more points in the same water body, and were discarded from the test. An additional 19 sites in rural areas were discarded when access to the property was not granted. The remaining 222 sample sites were inspected in the field (May to August 2009) to verify the existence of the water bodies and to measure their surface area with aid of a range finder.

Storage Volume. An SI is formed by constructing a dam to contain runoff, and water depth depends upon dam height and topography. Although water depth can be greater in regions of steeper topography, dams usually are not constructed to maximum height allowed by topography because of construction costs, safety concerns, and management issues; thus, SIs tend to have similar morphometric proportionalities. One method for estimating the average depth of SIs is to multiply maximum depth by 0.4 (USDA SCS 1982). However, Boyd and Boyd (2010) found that multiplication of the factor 0.46 by maximum depth gave the best approximations of average depths for 36 SIs ranging in surface area from 0.29 to 10.52 ha (0.72 to 26 ac) and located on the Piedmont Plateau Province of Alabama.

Data for the 36 SIs mentioned above revealed that there also was a relationship between water surface area at full pool and maximum depth (figure 1). However, the relationship between surface area and maximum depth was different for SIs of 0.3 to 3.2 ha (0.7 to 7.9 ac) than for SIs of 3.8 to 10.5 ha (9.4 to 25.9 ac). The maximum depth of SIs increased steeply with increasing surface area up to about 3.5 ha (8.6 ac). At about 4 ha (9.9 ac), there was an abrupt decrease in maximum depth, and the

Figure 2

Surface area of small impoundments (0.09 to 2,000 ha) in Alabama by size class as determined in the present study from Landsat 5 TM satellite imagery.

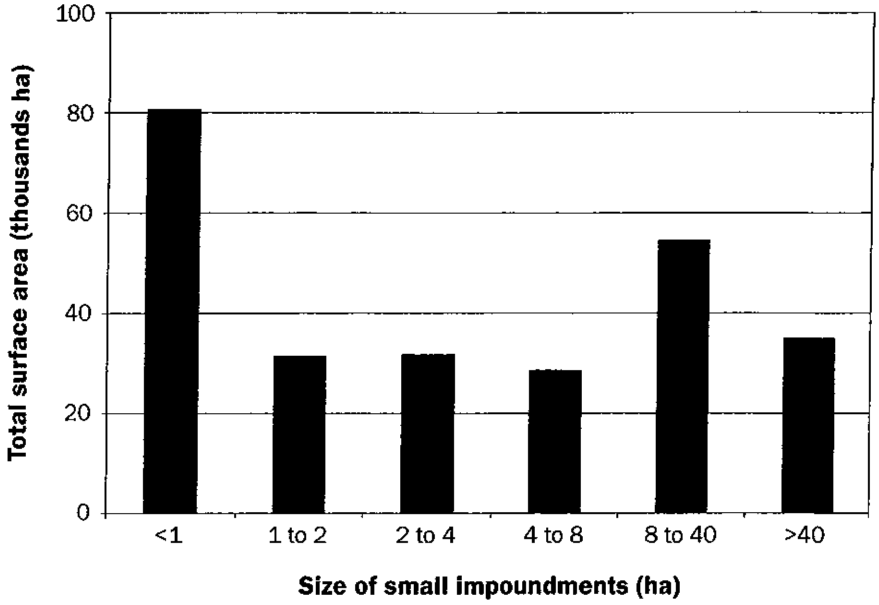
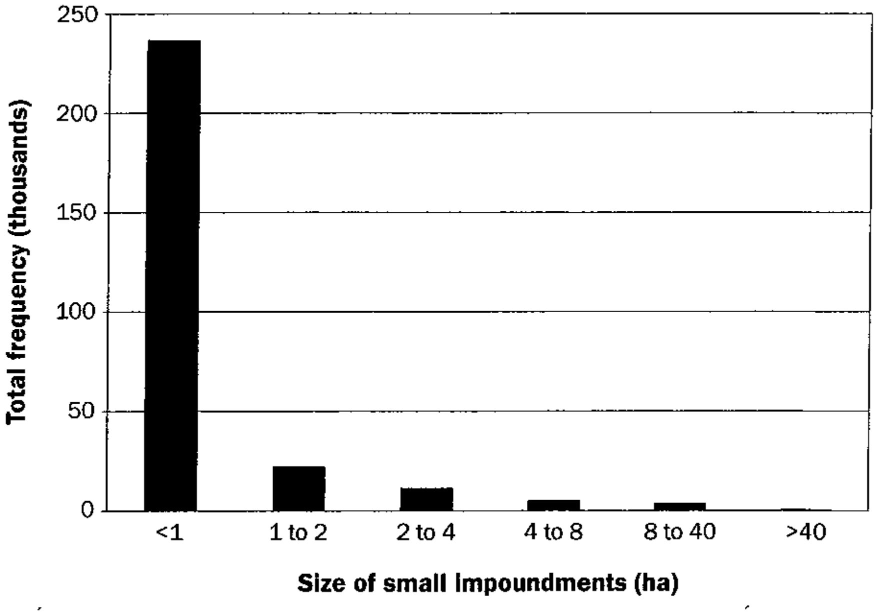


Figure 3

Frequency of small impoundments (0.09 to 2,000 ha) in Alabama by size class as determined in the present study from Landsat 5 TM satellite imagery.



increase in maximum depth with increasing surface area became more gradual. Most SIs are constructed in water courses or channels that form in watersheds. Land slope tends to increase progressively with increasing elevation on watersheds while channels become narrower. Smaller SIs are usually situated higher on watersheds, but in order to accommodate their greater area, larger SIs must be sited lower on watersheds where channels are wider (Boyd and Shelton 1984; Yoo and Boyd 1994). Thus, the maximum depth of SIs, which typically occurs near the midpoints of the inside toe of the dams, is usually greater per unit of water surface for SIs built higher on watersheds than for SIs constructed further downslope.

The Piedmont Plateau Province of east central Alabama is somewhat intermediate in steepness of topography; the Highland Rim Province of north Alabama and the East Gulf Coastal Plain Province tend to have flatter topography while topography is steeper for the Alabama Valley Ridge and Cumberland Provinces of northeast Alabama (Hodgkins 1965). Thus, it seems reasonable to use regression equations developed for SIs on the Piedmont Plateau for estimating average depths of SIs statewide (figure 1). The average maximum depth for each SI surface area class interval (total SI surface area in class interval ÷ *n* for class interval [figure 2]) was calculated. Extrapolation beyond the available data was necessary for the 8 to 40 ha (20 to 99 ac) and >40 ha (99 ac) class intervals, and the resulting estimates should be considered approximate. The resulting maximum depths for each class interval were multiplied by 0.46 to provide an estimate of average depth for each SI surface area class interval for use in calculating volumes.

Results and Discussion

Number, Sizes, and Distribution of Impoundments. A total of 278,787 clumps of two grid cells (0.18 ha [0.44 ac]) or larger with a total area of 261,880 ha (647,105 ac) were identified statewide. There are some small oxbow lakes in the state (Joo et al. 1992; Anderson and Benke 1994), but we could find no records of their number. Most oxbow lakes were likely eliminated by the mark or buffer zone created around the raster version of the streams and major water bodies. Thus, the water bodies identified in this inventory were thought to consist almost entirely of SIs. A digital version of the final map will be made available online by the Auburn University Department of Fisheries and Allied Aquacultures (http://www.ag.auburn.edu/fish).

Most SIs were small: 84.8% were <1 ha (2.5 ac) and 92.7% were <2 ha (4.9 ac). The average size of SIs was 0.94 ha (2.32 ac), and small SIs also comprised a large proportion of the total surface area: 30.8% for SIs <1 ha (2.5 ac) and 42.9% for SIs <2 ha (4.9 ac) (figures 2 and 3). However, larger SIs represented a disproportionate amount of surface area with respect to their number, e.g., SIs >40 ha

Table 1

Accuracy assessment of surface water impoundments of various sizes for Alabama.

Dataset	Min. area (ha)	Max. area (ha)	Accuracy rate (% [n])	Area correlation (*r*-value)
Recreation lakes	14.97	74.05	100 (19)	0.97
Reservoirs (>2,000 ha)	2,367.41	18,283.70	100 (10)	0.84
Reservoirs (<2,000 ha)	228.65	1,699.68	100 (7)	0.95
NRCS PL-566 dams	1.74	237.75	100 (99)	0.65
Catfish ponds	1.25	174.05	100 (17)	0.99

Note: Minimum and maximum surface areas based on existing records. n = number.

Table 2

Accuracy assessment of small water bodies in Lee County based on 222 randomly selected sample sites in rural areas (169) and urban areas (53).

Sample sites	Min. area (ha)	Max. area (ha)	Accuracy rate (% [n])	Area correlation (*r*-value)
Rural sites	0.04	121.40	84 (142)	0.95
Urban sites	0.45	16.19	66 (35)	0.81
Total sites	0.04	121.40	80 (177)	0.95

Note: Minimum and maximum surface areas based on field measurements in summer 2009.

(99 ac) made up 13.1% of total surface area but accounted for only 0.14% of all SIs.

The accuracy rate was 100% for each dataset used in test one, which indicates that the methodology used to develop the map was effective at identifying water bodies at multiple scales (table 1). The surface area correlations of 0.90 and above for the state recreation lakes, state reservoirs, and catfish ponds suggest that the map represents a reasonably accurate estimate across a broad range. However, the accuracy of the map's representation of the catfish ponds needs clarification because 8 of the 17 catfish ponds listed in table 1 are actually pond "clusters" and not unique entities. Ponds isolated from neighboring ponds by one or more grid cells (i.e., 30 m or greater) were clearly identified as unique entities. Ponds less than one grid cell apart were not identified as separate entities, e.g., two small ponds appeared as one larger pond, but the estimate for total surface area of the "composite" pond matched the sum of the recorded areas of the individual ponds. The accuracy assessment statistics for catfish ponds should therefore be used with caution.

The lower correlation of 0.65 for the NRCS PL-566 dam impoundments was expected because of the problem of determining a value to use as the official record for surface area. Future studies should consider investigating the status of these water bodies during the study period if they are to be included in the accuracy assessment.

The accuracy rate of 80% and area correlation of 0.95 for ponds ≤121.4 ha (300 ac) in Lee County (table 2) suggest that the methodology was effective at mapping the smaller SIs. Accuracy rate and area correlation were higher in rural areas than urban areas. This discrepancy might be related to the smaller surface area of SIs in urban areas as well the complexity of the urban landscape. For example, ground-truthing indicated that some of the urban sites were actually lawn sprinkler systems, large air conditioning systems, and places where precipitation might collect such as large parking lots in commercial districts. These sites are known as commission error (i.e., not water misclassified as water). Two rural sites were also determined to be commission error because the summer vegetation cover made it impossible to discern whether or not surface water was present, and one site was a new construction zone. Of the 45 sample sites that were found to be misses (not water), 51% were identified as some type of urban land cover, 47% were forest, and 2% were agriculture. We also investigated omission error (i.e., water misclassified as not water) by checking 250 random sites within the area of Lee County that had been classified as not water. Only 1 of the 250 sites was found to be water (0.4%).

Field investigation of sample sites during winter season would likely produce higher accuracy rates in rural areas, but it is not clear what effect this might have on accuracy rates in urban areas. For example, small water bodies in rural fields might be more easily detected in the winter wet season when water level is higher and vegetation cover is lower. In urban areas, rainfall collection on lawns or impervious surfaces such as parking lots is a potential source of error, but it seems unlikely that these sites would be mistaken for water bodies during field investigation in any season. Alabama is largely rural with only 183,928 ha (454,486 ac) or 1.3% of its area classified as urban, so accuracy in rural areas is of greater concern statewide.

The number of SIs found for Alabama in this survey was unexpectedly large. The ground-truthing exercise for Lee County suggests that the procedure used for enumerating SIs was relatively accurate. Lee County is rather heavily populated with more urban area than most counties in the state; thus, the percentage accuracy for identifying the presence of SIs was likely higher statewide than in Lee County. For example, if the accuracy results for Lee County (80%, table 2) were applied to the statewide SI results reported at the beginning of this section, the results for Alabama would be approximately 223,030 SIs and 209,504 ha (517,684 ac). A better approach would be to use the accuracy results for the rural areas in Lee County (84%), which would indicate that Alabama has approximately 234,181 SIs and 219,979 ha (543,567 ac) surface area. However, we recommend conducting an accuracy assessment at the local county scale and using those values.

The statewide data were subdivided by county (table 3). The task resulted in double-counting of SIs located on county boundary lines by the computer software. Thus, the total number and total surface area of ponds given in table 3 is slightly greater than the values given above (+698 SIs; +222 ha [549 ac]). There was an average of 4,161 SIs per county, ranging from 1,096 in Cherokee County to 15,222 in Jefferson County (table 3). The average surface area of SIs per county was 3,909 ha (9,659 ac) and ranged from 915 ha (2,261 ac) in Lauderdale County to 14,040 ha (34,693 ac) in Jefferson County. As already mentioned, SIs associated with many catfish farms could not be accurately enumerated because adjacent ponds appeared as one pond.

There are two areas in Alabama with particularly high SI density (figure 4). One is a 15-county area in the southeastern part of the state in which 7 counties have high densities of SIs (3 to 6 km^{-2} [8 to 16 mi^{-2}])

Table 3

Inventory of small water bodies (0.09 to 2,000 ha) by county in Alabama.

	Size of small water bodies													
	<1		1 to 2		2 to 4		4 to 8		8 to 40		>40		Total	
County	Freq	Size (ha)	Freq	Size (ha)	Freq	Size (ha)	Freq	Size (ha)	Freq	Size (ha)	Freq	Size (ha)	Freq	Size (ha)
Autauga	1299	416	91	132	50	141	28	154	21	367	2	168	1491	1378
Baldwin	3022	1078	364	519	191	532	106	592	72	1188	33	3754	3788	7663
Barbour	9957	3179	689	976	352	985	137	764	67	997	4	277	11206	7179
Bibb	2065	701	193	279	79	227	38	211	14	186	0	0	2389	1603
Blount	3873	1354	348	481	191	543	70	394	43	656	7	604	4532	4032
Bullock	6095	1923	424	596	227	655	112	618	78	1227	14	844	6950	5863
Butler	5285	1797	486	693	197	547	68	388	56	889	3	201	6095	4516
Calhoun	4502	1561	477	675	259	716	132	730	85	1246	8	569	5463	5497
Chambers	1350	471	141	198	51	142	16	91	9	142	1	77	1568	1121
Cherokee	875	306	112	163	64	181	27	163	16	300	2	138	1096	1251
Chilton	2318	758	128	176	41	113	19	98	8	94	0	0	2514	1240
Choctaw	3948	1345	311	439	136	389	56	318	30	455	4	223	4485	3169
Clarke	7665	2552	591	829	274	768	150	852	94	1496	11	1000	8785	7497
Clay	2848	1031	241	336	109	308	58	311	34	605	7	700	3297	3291
Cleburne	4452	1632	455	643	198	552	88	463	46	718	7	613	5246	4622
Coffee	3639	1156	299	424	162	443	53	285	27	359	1	42	4181	2708
Colbert	1777	621	137	197	90	252	22	124	11	175	1	50	2038	1418
Conecuh	3025	1016	240	333	133	373	47	252	34	481	2	158	3481	2614
Coosa	3120	1088	261	371	109	306	25	136	8	89	1	47	3524	2036
Covington	4882	1666	506	725	266	753	109	636	61	875	4	283	5828	4938
Crenshaw	3740	1230	299	421	149	412	50	275	27	461	3	221	4268	3020
Cullman	4453	1588	347	483	144	388	45	274	19	265	0	0	5008	2998
Dale	3653	1129	254	358	108	299	40	221	19	255	1	47	4075	2308
Dallas	3822	1375	446	637	279	787	132	712	133	2232	18	1847	4830	7590
DeKalb	1824	607	159	231	62	178	33	187	29	451	3	224	2110	1878
Elmore	1881	657	138	199	78	225	29	157	20	362	3	158	2149	1758
Escambia	2665	980	327	476	196	566	107	604	55	821	12	835	3362	4282
Etowah	1944	642	151	219	86	253	61	358	66	984	4	289	2312	2746
Fayette	2448	881	224	313	102	293	31	170	30	515	2	110	2837	2281
Franklin	1784	602	126	178	54	149	10	62	7	97	1	83	1982	1170
Geneva	2432	817	311	443	218	618	87	495	65	973	6	386	3119	3732
Greene	1145	448	256	375	190	542	137	788	102	1673	8	639	1838	4466
Hale	1297	503	254	375	215	635	137	800	144	2544	10	602	2057	5458
Henry	3925	1180	285	401	140	385	52	290	27	396	1	44	4430	2696
Houston	5071	1608	430	618	248	701	134	760	90	1307	7	381	5980	5375
Jackson	2798	1025	378	556	243	696	123	708	119	1783	3	141	3664	4909
Jefferson	13004	4548	1219	1731	567	1588	245	1401	166	2623	21	2149	15222	14040
Lamar	1079	400	128	185	78	229	53	313	48	788	10	625	1396	2540
Lauderdale	1440	464	83	117	20	57	13	68	5	70	1	139	1562	915
Lawrence	2267	809	269	369	102	279	43	238	8	178	1	416	2690	2289
Lee	1998	698	272	381	121	330	52	281	29	407	2	159	2474	2256
Limestone	1857	638	178	257	106	308	37	225	29	490	6	821	2213	2739
Lowndes	4540	1604	459	647	236	664	97	543	69	1022	10	850	5411	5330
Macon	2314	745	198	290	108	304	55	298	38	600	3	173	2716	2410
Madison	4145	1377	381	540	192	540	104	602	83	1356	8	688	4913	5102
Marengo	3415	1145	326	461	207	606	97	560	88	1318	4	255	4137	4346
Marion	2987	1072	289	410	90	246	28	144	7	130	0	0	3401	2002
Marshall	1742	593	142	200	84	255	40	217	39	616	0	0	2047	1881

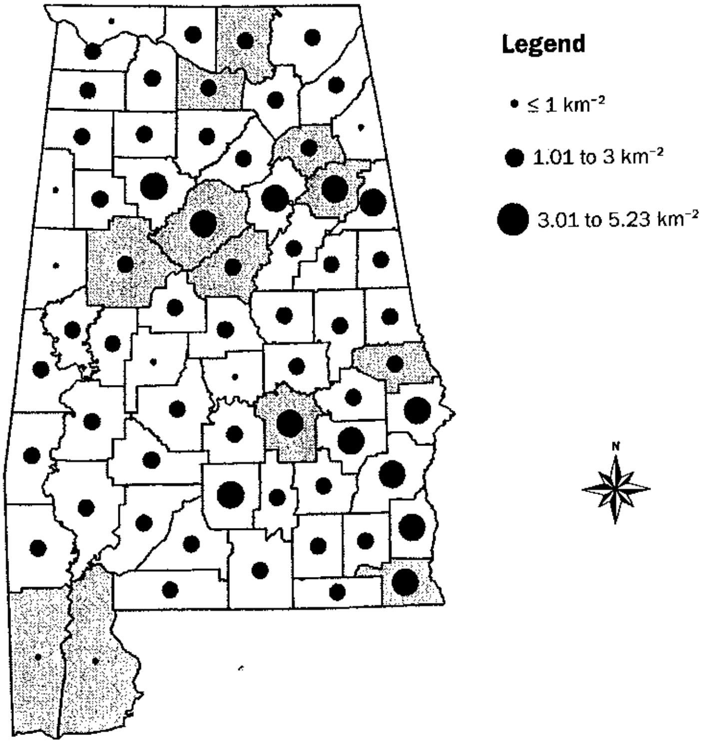
Continued

Table 3 Continued

	Size of small water bodies												Total	
	<1		1 to 2		2 to 4		4 to 8		8 to 40		>40			
County	Freq	Size (ha)	Freq	Size (ha)	Freq	Size (ha)	Freq	Size (ha)	Freq	Size (ha)	Freq	Size (ha)	Freq	Size (ha)
Mobile	3041	1075	353	500	211	588	93	532	75	1243	15	1786	3788	5725
Monroe	5189	1745	436	616	204	545	84	460	60	960	8	567	5981	4894
Montgomery	6319	2164	671	950	360	1013	184	1034	87	1342	5	458	7626	6962
Morgan	3176	1074	299	423	154	427	67	362	44	624	3	225	3743	3135
Perry	1253	441	166	242	94	272	58	333	53	890	4	199	1628	2377
Pickens	1337	509	249	357	121	337	75	437	58	922	5	290	1845	2853
Pike	4247	1369	395	562	182	516	88	485	52	705	1	53	4965	3689
Randolph	2594	860	201	283	92	260	33	186	34	610	9	839	2963	3038
Russell	4693	1501	392	559	232	667	103	571	79	1180	6	444	5505	4922
St. Clair	5578	1855	491	697	244	682	129	744	106	1772	18	1778	6566	7528
Shelby	4053	1404	444	635	228	652	84	470	70	1119	19	1786	4898	6065
Sumter	2038	749	301	425	170	486	88	491	65	988	5	486	2667	3626
Talladega	3666	1193	263	374	132	382	74	423	36	558	6	348	4177	3278
Tallapoosa	2326	741	115	161	34	91	4	18	2	26	1	47	2482	1083
Tuscaloosa	6694	2397	684	973	343	961	142	800	102	1728	14	1300	7979	8159
Walker	6521	2384	694	986	296	804	100	556	35	486	5	320	7651	5536
Washington	2897	1055	353	497	203	563	98	564	63	1060	10	595	3624	4334
Wilcox	5467	1844	477	667	259	726	123	712	79	1269	10	797	6415	6015
Winston	4280	1500	361	516	135	370	33	184	13	159	0	0	4822	2729
Totals	237036	80876	22168	31481	11296	31799	5093	28694	3488	54901	404	34350	279485	262102

Note: Freq = number of small water bodies.

Figure 4
Density of small impoundments in Alabama. Shaded counties have the highest population (>100,000).

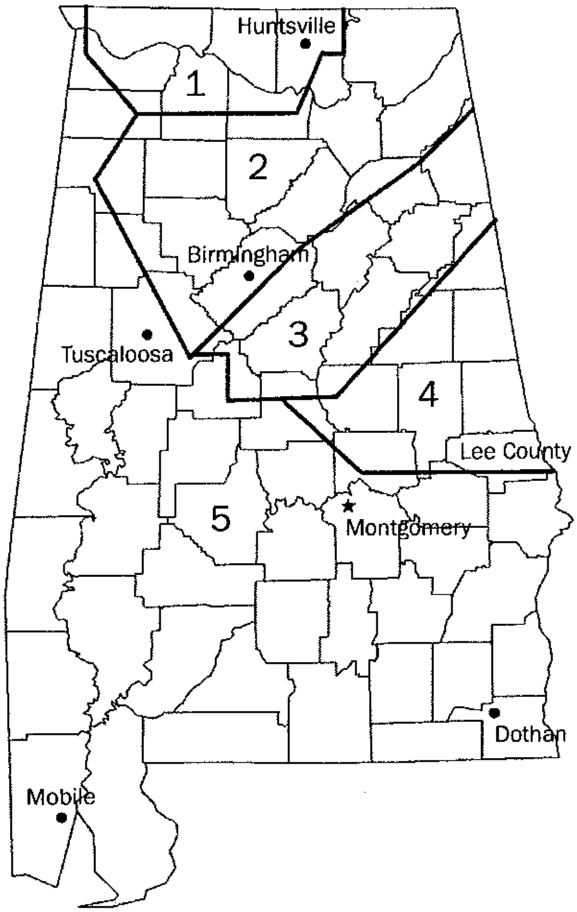


and the other 8 counties have medium SI densities (1 to 3 km^{-2} [2.5 to 5 mi^{-2}]). This area of high SI density lies in the East Gulf Coastal Plain Province (figure 4) and includes Montgomery County and the City of Montgomery—the state capitol and a major metropolitan area. The second area of high SI density is a five-county area in north-central Alabama including Jefferson County in which lies Birmingham, the largest metropolitan area in the state; three counties between Jefferson County and the eastern boundary of the state; and the county northeast of Jefferson County. This area is mainly in the Cumberland Plateau Province, but it also extends into the Alabama Valley and Ridge and Piedmont Plateau Provinces (figure 5). Four of the 12 counties with high densities of SIs are in counties with high population. With the exception of the 2 coastal counties (Mobile and Baldwin)—where soil tends to be sandy and unfavorable for pond construction—the other high population density counties had a medium density of SIs. Although there was a correlation (r = 0.605) between population density and SI density in the 12 most populous Alabama counties, the correlation was much lower (r = 0.119) statewide.

The ratio of SI surface area:land surface area (figure 6) presents a pattern similar to

Figure 5

Physiographic provinces and major cities in Alabama. Numbers on map indicate physiographic provinces: (1) Highland Rim, (2) Cumberland Plateau, (3) Alabama Valley and Ridge, (4) Piedmont Plateau, (5) East Gulf Coastal Plain.



that seen for SI density (figure 4). The main exception is a few counties in west-central Alabama that had low or medium SI densities, but moderate or high water surface:land surface ratios (figures 4 and 6). These counties comprise the catfish farming region of the state, and catfish ponds usually are 4 to 10 ha (10 to 25 ac) in area (Boyd et al. 2000)—larger than the typical SI in Alabama. Moreover, on farms where ponds were constructed in blocks separated only by embankments, an entire block of ponds appeared on the images as one pond as discussed earlier.

The East Gulf Coastal Plain covers about 60% of Alabama, while the other four provinces are fairly similar to each other in area (figure 5). Based on the county-level data, the Coastal Plain Province contained 61.3% of the SIs—density of 2.11 km^{-2} (5.46 mi^{-2}). Percentages of SIs on other provinces ranged from 6.1% for the Highland Rim to 13.4% for the Alabama Valley and Ridge; the respective densities were 1.41 km^{-2} (3.65 mi^{-2}) and 3.07 km^{-2} (7.95 mi^{-2}) (table 4). The density of SIs is greatest in the Alabama Valley and Ridge Province, intermediate in the East Gulf Coastal Plain and Cumberland Plateau Provinces, and lowest in the Piedmont Plateau and Highland Rim Provinces.

The SI water surface area:land surface area ratio averaged 0.019 and ranged from 0.012 to 0.031 for the five physiographic provinces (table 4). Provinces with high, intermediate, and low values for water:land ratio were the same as those with high, intermediate, and low SI density. If all SIs >8 ha (19.8 ac) are removed, the water:land ratio declines from 0.019 to 0.013, but the effect on SI density is slight—2.06 to 2.03 km^{-2} (5.34 to 5.26 mi^{-2}).

Average surface area per SI was similar among physiographic provinces, ranging from 0.81 ha (2.00 ac) in the Piedmont Plateau Province to 1.01 ha (2.50 ac) on the Coastal Plain. Removing all SIs >8 ha (19.8 ac) causes the statewide average surface area per SI to drop from 0.94 ha (2.32 ac) to 0.63 ha (1.56 ac).

Smith et al. (2002) stated that there were 2,600,000 small water bodies in the conterminous United States—a density of 0.33 km^{-2} (0.85 mi^{-2}). They defined small water bodies as <1 ha (2.5 ac). Their findings revealed an average small water body density of 0.33 km^{-2} (0.85 mi^{-2}) for the contermininous United States, but density with region varied from <0.03 to 3 km^{-2} (0.08 to 7.777 mi^{-2}). The impoundment density map of Smith et al. (2002) suggests that one of three factors greatly influences impoundment density in a particular area: relatively high rainfall favors a high density of small water bodies in areas east of the Mississippi River, low to moderate rainfall in highly agricultural areas leads to the need for many small impoundments for farm water supply in the central part of the country west of the Mississippi River, and arid conditions in vast areas of the west do not allow many impoundments. The impoundment density map of Smith et al. (2002) indicates that most of Alabama has 0.1 to 0.3 impoundment km^{-2} (0.25 to 0.78 impoundment mi^{-2}) and a few areas have 0.3 to 1 impoundments km^{-2} (0.78 to 2.59 impoundments mi^{-2}). Our findings show a much greater density of SIs in Alabama than do the findings of Smith et al. (2002). This difference is related most likely to two factors:

1. definition of SI (<1 ha [2.5 ac] versus ≤2,000 ha [5,000 ac] in our study)
2. basic map for conducting inventory (NLCD of multiple land cover types in 1992 versus Landsat 5 TM from 2007 processed specifically for identifying surface water in our study).

For example, the NLCD 1992 landcover map was constructed from both winter "leaf-off" and summer "leaf-on" imagery that would likely result in some water bodies being partially, if not completely, covered by overhanging trees (USGS 1992). It was not possible to conduct ground-truthing for the entire state, but we conducted a field test for Lee County. Our map identified water bodies that were not recorded on the NLCD 1992 map. The NLCD 1992 map was compared with the 222 random sample sites used to evaluate our map of Lee County (table 2). Of the 177 sites where we found water on our map, 30% were also water on the NLCD 1992

Figure 6

Small impoundment water surface area:land surface area in Alabama. Shaded counties have the highest total population (>100,000).

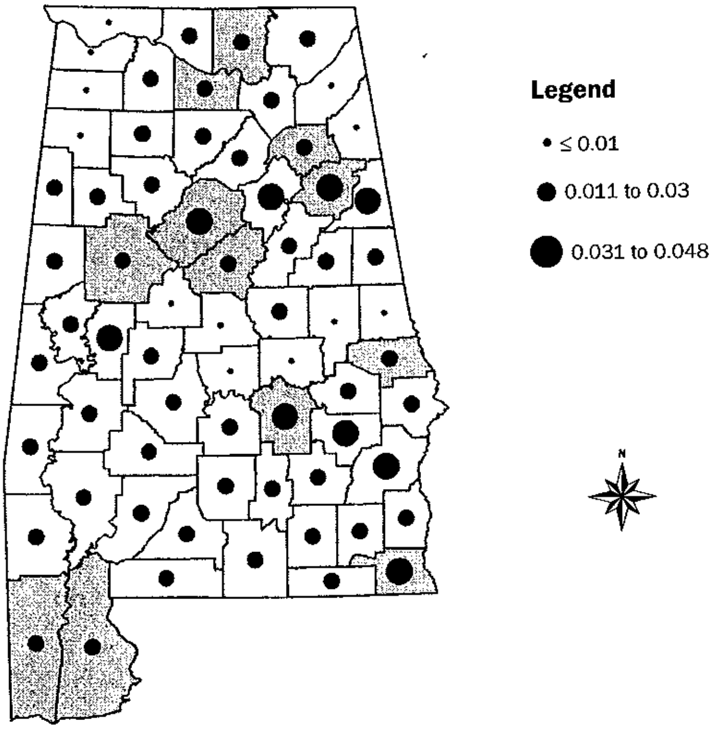


Table 4

Number, average surface area, density, and water:land surface area ratios for small impoundments (SIs) in Alabama by physiographic province.

Physiographic province	Number	Average SI surface area (ha)	SI density (SI km^{-2})	SI surface area: land surface area
Highland Rim	17,159	0.91	1.41	0.013
Cumberland Plateau	32,146	0.83	1.98	0.016
Alabama Valley and Ridge	37,422	1.01	3.07	0.031
Piedmont Plateau	21,554	0.81	1.51	0.012
East Gulf Coastal Plain	171,204	0.96	2.11	0.020
Total	279,485	0.94	2.06	0.019

map, and the remaining 70% were clearly not water. We took photographs of all sites where we found water on our map during the field test and were able to use these photos to confirm the results. The landcover types of the 70% of sites that were not in water were 9% urban, 72% forest, 15% agriculture, and 3% wetland. All 45 sites where we did not find water on our map were also not water on the NLCD 1992 map. The landcover types of these sites were 20% urban, 44% forest, 24% agriculture, and 11% wetland.

Possible reasons for the greater number and surface area of ponds reported in this study than in other studies were discussed above. However, a study of water bodies in an 8 km (5 mi) radius of the general aviation airport at Stillwater, Oklahoma (Robinson et al. 2008) identified 1,339 water bodies with a combined surface area of 617 ha (1,525 ac). These water bodies were initially identified from satellite images and then verified by field observation. The entities averaged 0.46 ha (1.14 ac) and the smallest was 0.09 ha (0.22 ac).

The area of the Oklahoma study was 20,342 ha (50,266 ac). Expanded to an area the size of Lee County, Alabama (160,064 ha [395,520 ac]), there would be 10,536 SIs totaling 4,853 ha–about twice the number and area of SIs and percentage water cover that we found in Lee County (table 3). Thus, the large number and area of SIs found for Alabama in the present study do not appear unreasonable when compared to the Oklahoma data.

The other data on SI density available for comparison with those of the present study are estimates of numbers of private "fish" ponds in five states: Alabama, Georgia, Mississippi, Tennessee, and Texas (Alabama's Pond Management Biologists 2003; Georgia DNR 2001; Strickland et al. 2007; Cobb 2009; Lock 1993). Three of these states share a border with Alabama and might be expected to have relatively similar densities of ponds. The density of ponds in Georgia was similar to that reported for Alabama, while Mississippi and Texas had pond densities about twice those of Alabama and Georgia. Tennessee had higher pond densities than the other four states and was the only one of the five states that reported pond densities similar to SI density found for Alabama in the present study. Average pond size for Tennessee was 0.2 ha (0.5 ac)—about the same as the minimum size of SIs reported in the present study for Alabama. The topography of Tennessee tends to be much steeper than that of Mississippi and large parts of Alabama and Georgia. Thus, the terrain in Tennessee is generally not as favorable for construction of larger ponds as it is in the other three states. This may explain the small, average sportfish pond size in Tennessee. Overall, data presented in table 5 suggest that the larger number and associated high SI density for Alabama reported in the present study were the result of a lower minimum reporting size for SIs than used in the other enumerations.

The SI water surface area:land surface ratio also was higher for the present study than reported for water bodies of the conterminous United States (Smith et al. 2002) and for sportfish ponds in several states (table 5). One reason for the greater SI density in Alabama as compared to the estimate for the conterminous United States has to do with a lower density of SIs in the vast arid regions of the west as compared to the more humid climate of Alabama. A likely reason for the lower water surface area:land ratio for "fish" ponds (table 5) than found in the present study is that fish pond assessment probably included few SIs >4 ha (10 ac) in area. Removing SIs >4 ha (10 ac) from

Table 5
Summary of sportfish pond inventory data for five states compared with Alabama for small impoundment (SI) inventory data of the present study.

State	Area of state (km^2)	Number of ponds	Surface area of ponds (km^2)	Average pond size (ha)	Density of ponds (Number km^{-2})	Water surface area: land surface area
Alabama	135,768	50,000	610	1.22	0.37	0.004
Georgia	155,430	63,000	1,260	2.00	0.41	0.008
Mississippi	125,434	130,000	930	0.72	1.04	0.007
Tennessee	109,150	200,000	400	0.20	1.83	0.004
Texas	692,408	800,000	–	–	1.16	–
Alabama SIs	135,768	278,787	2,619	0.94	2.05	0.019

our database would reduce SI water area from 262,102 ha (647,654 ac) to 144,156 ha (356,209 ac) in Alabama—a SI density of 0.01. Although this SI density is still more than twice the value previously reported for sportfish ponds in Alabama, it is more in line with sportfish pond densities reported for Georgia and Mississippi (table 5).

It also is interesting to compare the number and sizes of SIs on the Alabama Coastal Plain with those reported by Hook et al. (2008) for the adjoining Georgia Coastal Plain. Using a map of SIs produced by the Georgia Department of Transportation (DOT), a total of 80,000 SIs were found for the Georgia Coastal Plain, of which 44,760 were larger than 0.40 ha (1 ac) (Hook et al. 2008). The density of all SIs on the Georgia Coastal Plain was 0.86 km^{-2} (2.23 mi^{-2})—this is about five times the sportfish pond density for Georgia (table 5), but the Alabama Coastal Plain was found in the present study to have a SI density more than twice that reported for the Georgia Coastal Plain. We suspect that one reason why more ponds were found on the Alabama Coastal Plain than on the Georgia Coastal Plain was that the technique used included smaller SIs than mapped by the Georgia DOT; SIs >1,800 m^2 (0.18 ha [0.44 ac]) were included in the Alabama SI inventory. Another contributing factor is that the Georgia Coastal Plain tends to have a greater extent of sandy soils unfavorable for SI construction than does the Alabama Coastal Plain (Hodgkins 1965). This hypothesis is supported by the findings of the present study that SI density was low in the two Alabama coastal counties where sandy soils are common.

Storage Volume and Hydrological Effects. The amounts of water stored in SIs of each surface area class were as follows: <1 ha, 0.825 km^3 (686,866 ac ft); 1 to 2 ha, 0.548 km^3 (444,289 ac ft); 2 to 4 ha, 0.855 km^3 (436,993 ac ft); 4 to 8 ha, 0.539 km^3 (693,188 ac ft); 8 to 20 ha, 1.03 km^3 (835,069 ac ft); >40 ha, 2.21 km^3 (1,791,750 ac ft). The total water volume was 6.01 km^3. It is interesting to note that the small proportion (1.4%) of SIs >8 ha in area contributed 54% of water storage, while SIs less than 2 ha in surface area and comprising 92.7% of total SIs contributed only 23% of total storage.

Alabama has a total surface area of 135,768 km^2 (52,420 mi^2); the amount of water that can be stored in SIs is equal to a depth of 4.4 cm (1.7 in) spread over the entire state or about 8.1% of the average annual runoff of 54.2 cm y^{-1} (21.34 in yr^{-1}) (Boyd et al. 2009). However, ponds are seldom drained, and most of the runoff entering them overflows or seeps out. Evaporation from 2,621 km^2 (1,012 mi^2) of SIs represents a 0.477 km^3 (386,673 ac ft) increase over evapotranspiration from an equal land surface area. Spread over the state, this would represent a runoff reduction of about 0.35 cm y^{-1} (0.89 in yr^{-1}) or about 0.6%. Thus, the major influence of SIs on stream flow is likely temporary detention of runoff causing a flattening of downstream hydrographs.

Ecological Effects. Open-water aquatic habitat obviously is increased by SIs, but SIs also contribute shoreline that connects aquatic and terrestrial habitats and creates a highly productive zone of high biodiversity. Shore development (*SD*)—the ratio of the shoreline length of a water body to the circumference of a circle of the same area as that of the water body—measured for 36 ponds in Alabama ranged from 1.03 to 1.86 and increased with increasing pond water surface area (*A*) in hectares ($SD = 1.186 + 0.053A$; $r^2 = 0.701$) (Boyd and Shelton 1984). The relationship between shore development and pond area was used to estimate shoreline length for the average size SI in each pond size class interval (figure 2), and total length of shoreline of SIs in each class interval was estimated by multiplication of shoreline length by number of SIs. The results follow: <1 ha (2.5 ac), 58,880 km (36,586 mi); 1 to 2 ha (2.5 to 5 ac), 11,786 km (7,323 mi); 2 to 4 ha (5 to 10 ac), 8,972 km (5,575 mi); 4 to 8 ha (10 to 20 ac), 6,356 km (3,949 mi); 8 to 40 ha (20 to 100 ac), 9,906 km (6,155 mi); >40 ha (100 ac), 7,517 km (4,671 mi) for a total shoreline of 103,417 km (64,263 mi).

Wetland area is created by SIs because downward seepage causes the water table to rise in the vicinity of SIs (Stone and Boyd 1989)—especially in areas around the upper ends where the inflow of permanent or intermittent streams often enters. Data were not found for estimating how much wetland area usually formed around SIs, but observations suggest that a wetland area equal to 10% or more of SI surface area typically forms. Thus, a large amount of wetland area is associated with SIs, and wetlands are considered important for natural purification of runoff and as habitats of high biodiversity (Dahl 2006).

The watershed areas of the SIs were not assessed, but in Alabama, landowners are advised to allow for at least 10 times as much watershed area as SI water surface area (Yoo and Boyd 1994). The average watershed area:water surface area for 36 SIs on the E. W. Shell Fisheries Center near Auburn, Alabama, was 11.6 (Boyd and Shelton 1984). Assuming that the watershed:water ratio is 10 statewide, SIs in Alabama have a combined watershed area of 26,188 km^2 or 19.3% of land surface. This means that nearly 20% of the annual surface runoff of the state enters SIs and is detained at least briefly before flowing downstream. During detention in SIs, suspended solids settle out and natural processes improve water quality.

Summary and Conclusions

Alabama has over 250,000 small impoundments (SIs), most of which are <8 ha (19.8 ac) in surface area. These water bodies store ≈ 6 km^3 (4,900,000 ac ft) of water, but they do not appear to have a large impact on the quantity of surface runoff. Nevertheless, SIs may be important in the future as alternative sources of water for irrigation, municipal water supply, and other uses. As an important aspect of the ecological landscape, they contribute open water, shoreline, and wetland habitats as well as provide natural purification of surface runoff.

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