SEEPAGE from Fishponds

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Seepage from Fishponds

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INTRODUCTION

WATER REQUIREMENTS for fish farming commonly are estimated by means of hydrologic models in the form of water budgets. The budget balances, usually on a monthly basis, the magnitude of water flow into and out of a body of water. A general method for calculating water budgets for watershed ponds in Alabama was given by Swingle (*128*). Boyd (*20,21,23*) listed the various elements of the general hydrologic equation applied to fish ponds:

$$P + WR + RO = (S + E + OF) \pm \Delta V$$

where: P = precipitation
WR = water required from well or other source
RO = runoff
S = seepage
E = evaporation
OF = overflow
ΔV = change in storage volume

The magnitude of components in the model is variable. Seepage can be an important element in the hydrologic equation. Seepage from farm ponds was one of the major problems reported by the Soil Conservation Service (*38*) and it can be the most important loss of water (*20*). Yet little is known about seepage from fishponds. This bulletin presents a compilation of existing information on seepage as well as results from studies conducted at Auburn University and at Gualaca, Panama.

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SEEPAGE LITERATURE

Many factors contribute to the water-holding ability of a pond. Pond design, construction procedures and the textural classification, water content, and degree of compaction of the soil material are all important elements *(23)*. Microorganisms have been shown to reduce soil permeability *(2)*. Numerous studies have documented the effect of organic matter on permeability *(33,99,118,44)*.

The properties of the water also have to be considered. Glenn *(56)* and Bower *(16)* reported the effects of water quality on seepage. The quantity and composition of salts in soil solution are important factors in determining hydraulic conductivity *(40,41)*. This is particularly true for ponds in arid regions.

Seepage may affect fish production, although little is known of this relationship. Wolny and Grygierek *(138)* reported

TABLE 1. SEEPAGE AND WATER LOSS VALUES FOR PONDS AND RESERVOIRS

Location	Rate cm / day	Observations	Source
United States			
Alabama (Piedmont)	0.66	one pond	(107)
Alabama (Black Belt)	.07	observations, approximate	(128)
Alabama (Black Belt)	.16		(106)
Alabama (Auburn)	.51	average	(20)
Wyoming	.8	average for 31 reservoirs	(39)
Wyoming	.5	for 20 small reservoirs of less than 20 acre-feet, from Culler	(123) (39)
Arizona	.05 .15 .25 .30	for four stock-water reservoirs	(83)
Israel	1 to 2	seepage and evaporation	(61)
	<10	new ponds, sandy soil 0.5 seepage 0.5 evaporation	
Malacca	1.3	seepage and evaporation	(120)
Europe	.9	seepage and evaporation	(67)
Indonesia	5.2 to 10.4	seepage and evaporation	(67)

reduced fertility in ponds with higher seepage rates. In Panama, Teichert-Coddington and Phelps (unpublished manuscript) noted lower alkalinities in limed ponds that had higher rates of seepage. A few published studies on seepage from ponds exist; results from these studies are summarized in table 1.

Theory of Seepage

Seepage from a pond is governed by the laws of physics regarding flow through porous media. Seepage depends on hydraulic conductivity of the soil material (K) and on hydraulic gradient (I) in accordance with Darcy's Law. Hydraulic conductivity refers to the ability of soil to transmit water *(77)*, while the hydraulic gradient is a function of the head of water and the distance that the water travels through the soil *(32)*. Flow of water through soil materials used for ponds is relatively slow, and is considered to be laminar flow. Thus Darcy's equation:

$$Q = KIA$$

where Q = volume of flow
K = hydraulic conductivity
I = hydraulic gradient
A = unit of area

can be used to estimate seepage. It also provides the relation between seepage rate and hydraulic conductivity. Seepage from a pond usually is reported in terms of cm[2] of water lost per day, or Q/A. Although A refers to the wetted area, pond seepage is based on the area of the water surface. For large shallow ponds, the area of the wetted perimeter would be only slightly greater than the area of the water surface.

To obtain seepage estimates when K values are available requires that I be determined. The hydraulic gradient depends not only on the depth of water in a pond, but also on the soil profiles beneath the pond and in some cases, depth to the water table *(113,12)*. Bouwer *(12)* presented general

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[2] Conversions from metric to English measure shown on page 50.

theoretical models to solve for seepage from canals given K and certain soil profile conditions. Research on the relation between small bodies of water and groundwater was summarized by Hall *(58)*. Numerous models have been developed to simulate the complexity of seepage flow and its relation to groundwater *(119)*.

Hydraulic Conductivity

The permeability of soil is related to its particle-size distribution, porosity, particle form and orientation, and type of clay minerals *(135)*. Voluminous engineering studies exist on the permeability of soil material *(28,79)* and on methods for its determination *(105,59)*. Recent studies, prompted by concern over the disposal of toxic wastes but with applications to fishponds, concern the engineering properties of clay liners *(101,45,42,34)*. Hydraulic conductivity has been related to other soil properties, such as pore size *(57,55,49)*.

Values of hydraulic conductivity range from 10^{-2} cm per second to 10^{-9} cm per second. Bowler *(17)* stated: "No other engineering property of any material exhibits such a large range of values as does the permeability of soil." Laboratory tests commonly are used to obtain estimates of hydraulic conductivity. The accuracy of such tests is subject to question. Lee et al. *(86)* cited reports of coefficients of variation of 200 to 300 percent for standard permeability tests. Apparent deviations from Darcy's law have been observed in low gradient permeameter tests of certain soil materials, perhaps due to particle migration *(100)*. Glenn *(56)* stated that experience has shown that such tests can differ 5 to 10 times from that of field tests. For saturated soils, field tests are preferred, because the use of a larger volume of soil material permits the effects of macrostructure to be included in the tests *(105)*. Olson and Daniel *(105)* concluded that great care should be taken in conducting laboratory tests, or else the results could be in error by several orders of magnitude. A major thrust in permeability research deals with the design of apparatus to properly test soil samples *(43)*.

Soil scientists have attempted to relate the hydraulic conductivities of soils to other soil properties, such as texture.

Rawls et al. *(112)* provided values of saturated hydraulic conductivities for United States Department of Agriculture (USDA) soil texture classes. For soils in the Lower Coastal Plain, the percent clay content was found to be strongly correlated (negatively) with the saturated conductivity *(110)*. Other studies *(94,72)* have also linked conductivity and soil morphology.

The National Soil Handbook *(124)* presented a new system of "hydraulic conductivity classes." Descriptive soil properties are listed to help determine the appropriate class.

For the United States, local county soil surveys provide information on the engineering properties of soils, including ranges of permeability. Restrictions for water management are also presented, ranking the limitations for pond reservoir areas and embankments, dikes, and levees. The methodology used for these rankings is included in the National Soil Handbook *(124)* and could be adapted to other areas where soil surveys are not available. Ekse *(48)* pointed out the value of soil maps for planning purposes, since many times soil test data are available for the different soils.

The USDA Soil Conservation Service *(131)* provided ranges of hydraulic conductivity for soil material based on the Unified Soil Classification System (USCS). Brink et al. *(124)* reproduced a table giving K values for compacted soils, based on their USCS classification. More general charts are available in texts, such as Cedergren *(32)*.

Compaction

The amount and force of compaction can cause changes in seepage rates of ponds *(64,65,69)*. Moisture content at compaction is also critical *(66)*. For clayey soils, a slight change in moisture content can change the permeability by one or two orders of magnitude *(79,80,81)*. Engineers use a standard test (Procter test) to determine the relationship of soil material moisture content at compaction, and resulting dry density after compaction. This relation varies with soil material and force of compaction. For a given level of compaction, optimum moisture content is defined as the moisture content that results in the greatest dry density *(135)*.

Generally, for non-cohesive soils such as sands, permeability is lowest when soil material is compacted at optimum moisture content (greatest density). However, for soils with appreciable clay content, permeability is lowest at moisture contents greater than optimum *(80,81)*. To obtain the lowest permeability, soils should be compacted when "too wet for plowing" *(69)*. In fact, in certain areas, puddling of the soil is recommended to reduce seepage. Puddling refers to churning saturated pond bottom soil to break down soil structure *(36)*.

The hydraulic conductivity of soil material varies with time and space. Soils are heterogeneous and this natural variation is increased by processes such as erosion and sedimentation *(12)*. The conductivity of soils and soil material can differ with orientation. Horizontal hydraulic conductivity can be many times greater than vertical conductivity, therefore seepage can take place laterally *(82)*.

Pond Design

Earthen dams are designed to minimize seepage losses. Cores and core trenches are used to obstruct seepage under and through dams *(122)*. The theory of seepage through dams was presented by Casagrande *(30)* and Cedergren *(31)*.

Prevention of piping (where seepage water erodes a tubular channel through the dam) and other erosion problems that could lead to dam failure is critical. According to Talbot and Ralston *(129)*, "some cracking occurs in almost every dam." Leaks caused by hydraulic fracturing (differential settlement) are common even in low homogeneous dams *(121)*. Antiseep collars are no longer recommended, and filter diaphragms are now being used to control seepage through dams and to prevent piping *(129)*. Mantei *(90)* stated that "most serious seepage problems initiate from deficiencies in the natural foundation..." Underseepage and methods for its control were discussed in detail by Turnbull and Munsur *(130)*.

The type of pond may affect the seepage path. For embankment ponds, the majority of seepage losses should be through or under the dam *(107)*. The majority of seepage from clay-blanketed reservoirs can be assumed to take place vertically, rather than through the levees *(73)*.

Parsons *(106)* presented data indicating that, as pond size increases, the seepage rate decreases. For ponds at Auburn, Alabama, and vicinity, a regression of seepage rate versus pond area gave the following equation:

Seepage in inches per day = $0.33\ A^{-2/3}$

where A is pond area in acres. Parsons determined a similar relation for ponds in the Black Belt area of Alabama:

Seepage in inches per day = $0.06\ A^{-1/3}$

Seepage also may be related to the position of a pond on the watershed; ponds higher up on the watershed (greater slope) have higher rates of seepage *(106)*.

Irrigation Canal Studies

A wealth of information is available on water losses from irrigation canals, and several of the methods used for measuring seepage from canals are applicable to ponds. A major reason for measuring seepage from canals—to locate areas of excessive seepage—is also of importance in ponds.

There were several early studies concerning seepage from canals and use of seepage meters *(68,117,133,111,115)*. In 1963 and again in 1968 the Agricultural Research Service sponsored symposia on seepage *(1,102)*. Additional studies on seepage and seepage meters were those of Bouwer *(9,11,13)*, Bouwer and Rice, *(13,15)*, and Brockway *(25)*. Kraatz *(78)* summarized much of the available information pertaining to seepage from irrigation canals. Articles by Worstell *(139)* and Brockway and Worstell *(26)* evaluated different methods of estimating seepage losses.

Methods For Measuring Seepage From Ponds

Three methods are commonly employed in determining seepage rates. Each method has its advantages, and selection of a method depends on the type of results required.

Water Budget Method

Water inputs and losses for a pond are measured. After correction for rain and runoff, total water loss is then segregated into loss due to evaporation and that due to seepage by estimating pond evaporation. Evaporation is usually considered easier to estimate than seepage.

The rate of evaporation from a pond depends primarily on air and water temperatures, relative humidity, air pressure, and wind *(63)*. Methods used to calculate evaporation include energy balance equations, turbulent-transport equations, and combinations of aerodynamic and energy balance equations *(108)*. Data collection for such methods requires sophisticated instruments, and the data necessary for these equations are not published for many areas.

Evaporation from ponds can be estimated as a function of temperature and solar radiation *(52,126)* or as a function of temperature alone *(22)*. Limited information on solar radiation exists. Published data were available from only 38 stations in the United States in 1979 *(88)*. In contrast, official temperature data are available from approximately 8,000 sites in the United States *(88)*.

Several other methods have been developed to estimate pond evaporation. These include mass-transfer equations, empirical equations, and evaporation pan coefficients.

Mass-transfer equations are based on Dalton's equation, where:

$$E = (e_o - e_a)\, f(u)$$

where E = evaporation
e_o = saturation vapor pressure at water surface temperature
e_a = actual vapor pressure at air temperature
$f(u)$ = function of wind speed

The difference in vapor pressures of the air and water is multiplied by a function of wind speed. In simple terms, the equation serves as a model of the force "pushing" water molecules from the water into the air and of the rate at which that vapor is carried away. Numerous empirical equations based on mass-transfer theory have been developed *(91,3)*.

Langbein et al. *(83)* used a method where stage change measurements of a body of water for set periods of time are regressed against the corresponding mass-transfer equation values for the same periods. The intercept of the regression line on the stage change axis, where evaporation would theoretically be zero, gives the seepage rate. Wind speed to the 3/4ths power was considered to give a better fit to the regression line *(83)*.

The time interval over which values are averaged ranges from hours to days. Allred et al. *(3)* stated that time increments of 6 to 24 hours and longer have been used. In their own study, calculations were made at 2-hour intervals, however, intervals of 1 day or less are desirable *(70)*.

Another common method for estimating evaporation is the use of evaporation pans, and a number of different types of pans have been used *(116)*. The Class A evaporation pan of the United States Weather Bureau (121.9 cm in diameter, 25.4 cm deep) was selected as the standard in 1934 *(4)*. The U.S. Weather Bureau maintains a network of some 450 pans around the country *(53)*. Pond evaporation is estimated from pan evaporation through the use of a coefficient to account for differences between the pan and a pond. For the Class A pan, 0.7 (pond evaporation/pan evaporation) has been designated as the standard coefficient, with a "reasonable" range of 0.60 to 0.82 *(4)*. Follansbee *(54)*, Linsley et al. *(88)*, and Kohler *(74)* provided summaries of pan coefficients for water bodies in different locations.

While 0.7 has been generally accepted as the average pan coefficient, such coefficients are influenced by exposure and climatic conditions, and thus vary with location and season *(27)*. For a desert lake, a coefficient of 0.60 was determined (8). Blaney *(7)* stated that 0.7 is the usual pan coefficient at high altitudes. Fetter *(53)* presented data showing the variation in monthly pan coefficients for the Midwestern United States. Values ranged from 0.58 in December to 0.78 in May, with an annual average of 0.75. Kohler et al. *(76)* suggested that, to avoid error, the coefficients need to be adjusted for advected energy into the water body, and for heat transfer through the pan.

Boyd *(22)* developed a series of coefficients for estimating fishpond evaporation from pan evaporation. Evaporation from a lined pond with no seepage was compared to water loss from an adjacent Class A pan. The average annual coefficient was 0.81. The following equation was developed to calculate monthly pond evaporation (Y) from Class A pan evaporation (X):

$$Y = -2.755 + 0.848X$$

Despite the problems associated with the use of pans and the variation in pan coefficients, Christiansen *(35)* concluded that pan data are useful for estimating both evaporation and evapotranspiration. Procedures have even been developed to estimate pan evaporation from other meteorological data *(76,35)*. Stone *(127)* compared three methods (the pan method, an empirical equation, and a regression of stage change against a mass-transfer equation) for estimating evaporation to obtain seepage. He concluded that the pan method was the simplest and most consistent method.

The widespread availability of Class A evaporation pan data and the simplicity of the pan coefficient method are potent arguments for their use in water budget calculations. Nevertheless, coefficients have not been standardized, so considerable variation exists among recommended values. For the continental United States, a map of average annual pan coefficients was provided by Kohler et al. *(75)*. The FAO training manual, "Water for Freshwater Fish Culture" *(36)*, gave 0.75 as the pan coefficient for estimating evaporation from fishponds. In the absence of specific information, the pan coefficient could be estimated from the climate, as suggested by American Society of Civil Engineers *(4)*:

Arid	0.6
Intermediate	0.7
Humid	0.8

For a country with pronounced wet and dry periods, 0.8 could be used for the wet season and 0.6 for the dry season.

Direct Readings

A second method measures seepage at different points on the pond bottom. This can be done in situ, through the use of seepage meters, (see Materials and Methods section) or cores can be removed for laboratory analysis. A number of different permeameters and seepage meters have been developed. Meerscheidt *(97)* evaluated several different devices and factors affecting their accuracy.

The difficulty of confirming results of seepage meter tests has caused them to be viewed with suspicion. Rasmussen and Lauritzen *(111)* concluded that, under certain conditions, seepage meter results were of doubtful reliability. However, a later study compared seepage meter readings to seepage by other methods, and concluded that the meters gave accurate results except when seepage was similar to the magnitude of evaporation *(115)*. Worstell *(139)*, based on a survey of the literature, concluded that measurements by seepage meter compared favorably with measurements by ponding (water budget method). Belanger and Mikutel *(6)*, based on their results and on previous studies, concluded that use of seepage meters was an "excellent technique" for determining the quantity of seepage flow in water budget calculations.

Seepage meters have also been used to measure the flow of groundwater into and out of natural bodies of water *(85,137,93,37)*. Kadlec *(71)* used seepage meters in diked sections of marsh.

Tracers

Tracer compounds, such as salt or dye, are a third method of estimating seepage loss *(14,22)*. The rate of removal of the tracer is assumed to be proportional to the rate of water lost to seepage. Use of naturally occurring tracers, such as the chloride ion, requires that any inputs to the pond be analyzed for the tracer, and the results adjusted accordingly.

Variability in Seepage Measurements

A large number of factors affect seepage and the measurement of seepage. The rate of seepage is not static; Robinson and Rohwer *(115)* detected differences in seepage from one hour to the next. Changes in water depth and temperature can affect seepage *(123)*; barometric pressure may even affect the rate of seepage *(134)*. Fluctuations in seepage can result from the addition of water to a pond *(83)*. As the water level rises, water moves into the banks, and apparent seepage increases. As the pond level drops, part of that water re-enters the pond, causing a decrease in seepage measurements.

Part of the variation also could be due to errors in measurements used to calculate seepage. Even with the use of a stilling well, water level readings can be difficult to record accurately on windy days.

Another source of error in seepage measurements is due to the approximate nature of the methods themselves. The water budget method requires an estimate of pond evaporation. Boyd *(22)* found a coefficient of determination of 0.67 for the relation between daily values of pan evaporation and pond evaporation. The r^2 value increased considerably for weekly and monthly averages.

Seasonal Variation in Seepage Rate

Typically, a seepage rate is chosen for water budget calculations and used for the whole year. Yet seepage from fishponds has been shown to vary seasonally *(107)*.

While rainfall and perhaps depth to the water table may vary seasonally, the greatest effect of season in the Southeastern United States is the change in temperature. Viscosity and density of water vary according to temperature. Olson and Daniel *(105)* tested the effect of temperature on the conductivity of three fine-grained soils. They considered that the viscosity and density changes in water alone were adequate to explain the results. For sterile sand, the effect of temperature on permeability was totally due to viscosity changes *(109)*. Duley and Domingo *(47)*, looking at water infiltration into soil, found little relation between temperature and rate of water movement.

A common correction factor used to adjust measured permeabilities to 20°C is:

$$K^{20} = K^{x}(U^{x}/U^{20})$$

where K is the hydraulic conductivity, U the viscosity, and x the measured temperature *(92)*. Thus, the ratio of the relative viscosities can be used to correct for temperature.

Whitlow *(135)* presented a table, table 2, of temperature correction coefficients based on the same principle.

TABLE 2. VALUES OF TEMPERATURE CORRECTION COEFFICIENT K_t (135)

Temperature (°C)	Temperature correction coefficient	Temperature (°C)	Temperature correction coefficient
0	1.779	20	1.000
4	1.555	25	0.906
10	1.299	30	0.808
15	1.133	—	—

Predicting Seepage

Given the complex of factors that determines seepage from a pond, selection of seepage estimates for water budget construction is difficult. Certain assumptions need to be made in order to estimate seepage.

Assumptions in Selection of K Value

Brink et al. *(24)* gave permeability ranges for compacted soil material by USCS classification. These K values could be used to calculate seepage through a dam, or through the compacted bottom layer of a pond. Alternatively, Rawls et al. *(112)* listed K values for soils based on their USDA texture classification. These values are for the "natural soil fabric." For massive, structureless subsoil, these values might approach those of compacted material. On the average, they are an order of magnitude higher than K's for compacted material. Use of K's for soil would be appropriate for estimating seepage under a dam where the pond bottom was not specially compacted or lined.

Puckett et al. *(110)* found that for soils in the Lower Coastal Plain, the Southern United States, the saturated hydraulic conductivity (K^{sat}) of the soil was correlated with the percent clay content as follows:

$$K^{sat} = 4.36 \text{ x } ^{10-5} \text{ x } e^{-0.1975 \text{ x } \% \text{ clay}}$$

Clay content could then be used as a means to estimate the hydraulic conductivity for these soils.

Assumptions in the Selection of Hydraulic Gradient

Large levee ponds can be assumed to have most of the seepage leaving the pond vertically. If one further assumes that a thin layer in the bottom of the pond controls the permeability, the hydraulic gradient, I, can be estimated. A fishpond is generally shallow, with high levels of biological activity, and a bottom that was compacted during construction. In that case, the upper 15 cm of the bottom material could be given a K value based on the table in Brink et al. *(24)*. The average depth of water in the pond would then be used in calculating I. Negative pressures are possible under liners, and theoretically would serve to increase seepage *(96,103,73)*. A major advantage in estimating seepage in this manner is that it is not necessary to know anything about the soil profile below the pond or the depth to the water table, as noted by Kisch *(73)* for clay-blanketed reservoirs. Table 3 gives predicted seepage rates for different soil

TABLE 3. PREDICTED MAXIMUM, MINIMUM, AND MEAN SEEPAGE RATES BASED ON USCS (UNIFIED SOIL CLASSIFICATION SYSTEM) CLASSIFICATION AND WATER DEPTH

USCS classification		Seepage rate (cm/day)[1]		
		max.	mean	min.
SM	(silty sand, sand silt mixtures)	10	6	2
SC	(clayey sands, sand clay mixtures)	0.4	0.2	0.1
ML	(inorganic silts - very fine sands, silty, or clayey fine sands)	.6	.5	.3
MH	(elastic silts)	.2	.1	.05
CL	(low to medium plasticity clays)	.1	.1	.05
CH	(high plasticity clays)	.1	.01	.00

[1] Based on assumed average water depth of 120 cm, where I is equal to $\Delta h/\Delta L$= 135 cm, ΔL = 15 cm. Values of hydraulic conductivity used were from Brink et al. *(24)*.

materials (USCS classifications) based on these assumptions. The appropriate value can be substituted into a water budget.

Watershed ponds are normally deeper and are built in valleys that channel the flow of seepage water. It is generally assumed that seepage takes place under and/or through the dam. In this case, the use of flow nets or other means of estimating the hydraulic gradient may be appropriate. For seepage under the dam, the hydraulic conductivities provided by Rawls et al. *(112)* or by Puckett et al. *(110)* could be used. Seepage through the dam would better be calculated using K's for compacted material. Research into the mechanisms controlling seepage rates for watershed ponds is needed.

Control of Seepage

Methods to control and reduce seepage from ponds were examined by Jamison and Thornton *(69)* and Holtan *(64,65)*. Compaction and applications of soil dispersants or organic matter were tested. Decker *(46)* reported on the use of soil dispersants to seal small reservoirs. Linings of soil materials, a soil dispersant, and soil-cement were used by Maheshwari and Turner *(89)* to reduce seepage from ponds in India. Wilson and Snell *(136)* tested methods to control seepage from South Carolina farm ponds. A plastic liner, a plastic core inside a dam, compaction of existing soil, and addition of kaolinitic clay were all found to be effective in reducing seepage.

Attention to proper construction techniques *(84,132)* is essential, particularly for soil materials of marginal quality. Failure to properly moisten and compact soil material can result in excessive seepage regardless of the clay content of the soil material.

Seepage rate is determined by discontinuities in a pond. Generally, as can be seen by reference to tables of hydraulic conductivity values, most soils can be made relatively impermeable. Only by assuming that proper pond construction procedures are to be followed can one hope to predict a seepage rate.

MATERIALS AND METHODS

Studies were begun in 1985 to evaluate methods for measuring seepage and to determine the general characteristics of seepage from fishponds. Previous to this investigation, no direct methods for measuring seepage had been tested in fishponds. In these trials, the water budget method was used as a standard to evaluate direct measurement of seepage by capped pipes and by seepage meter.

Construction of fishponds usually includes transport and compaction of soil material *(184)*, which should reduce seepage to a minimum and result in relatively uniform seepage within and between ponds. Seepage meters were used to investigate variations in seepage rates within ponds.

Other factors influencing seepage were also examined. Seepage from ponds was measured throughout the year to determine seasonal changes in seepage. Individual seepage rates for large numbers of ponds in the same area were measured. This was to get an idea of the predictive value of using data from existing ponds as a means of estimating seepage of future ponds in that area.

Studies on pond hydrology were conducted at the Fisheries Research Unit, Alabama Agricultural Experiment Station, Auburn University, Auburn, Alabama (FRU/AU). As soil type and boundary conditions can affect seepage *(113,10)*, background information on construction of the study ponds and on depth to the water table was collected.

Ponds in the E-series, figure 1, were built on a base of the Toccoa series soil. This soil is alluvial, and rated as severely limiting for pond reservoir areas *(95)*. Soil material from the Pacolet soil series was brought in to form the levees and to blanket the pond bottoms. McNutt *(95)* listed Pacolet as a sandy loam, rated moderate for pond reservoir areas (limitation is seepage) and moderate for embankments, dikes, and levees (limitations are piping and hard to compact).

Water Table Measurement

A series of 12 wells was bored around the main section of study ponds to monitor the depth to water table, figure 2. A

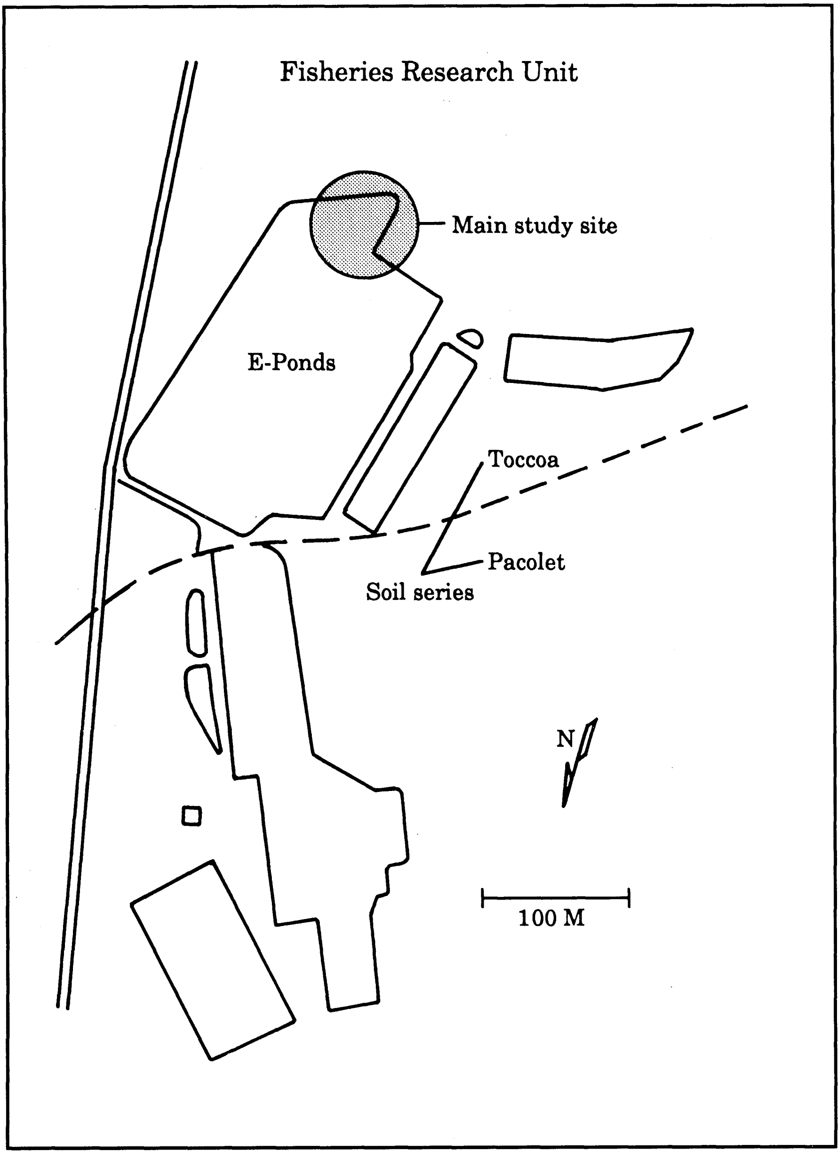

FIG. 1. Study site at the Fisheries Research Unit, Auburn University. Based on Mevel (98) and McNutt (95).

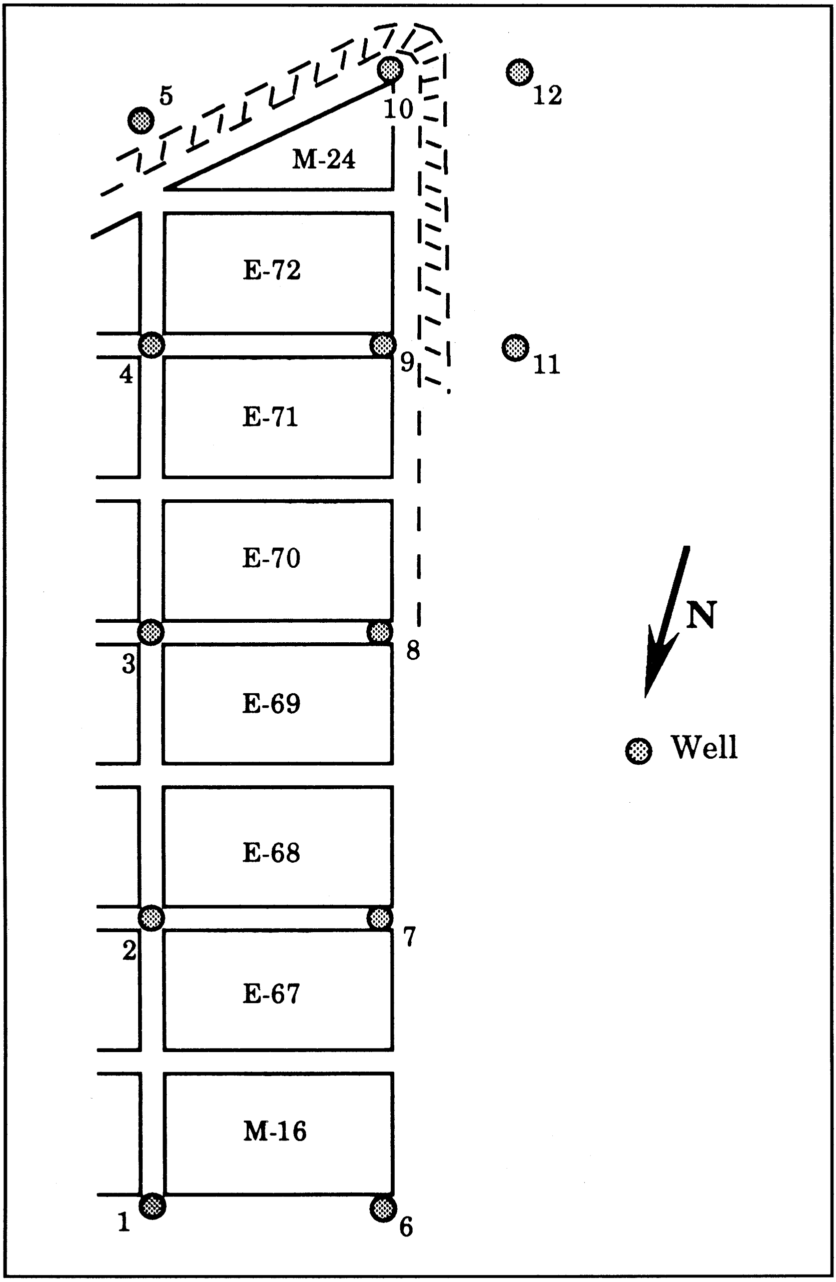

FIG. 2. Location of wells around study ponds.

bucket auger was used to dig the holes to a depth of approximately 2.4 m. A casing of 3.8 cm perforated plastic pipe was installed. Tops of the pipes were encased in concrete and capped to prevent the entrance of rainwater.

After a 4-day period of equilibration, the depth to the water table was measured at least once per week from September 13, 1985, through August 9, 1986. A rain gauge dipstick attached to a measuring tape was lowered into the wells to detect the water level. The study ponds and the tops of the well casings were surveyed so that all measurements of water table depth could be made relative to the same benchmark.

Comparison of Methods for Estimating Seepage

Water Budget Method

Twelve 0.02 to 0.07-ha levee ponds at the FRU/AU were monitored for a 6-month period beginning on June 1, 1985. Stilling wells of 10.2 cm diameter pvc pipe were driven into the bottom of each pond. Water level measurements were taken daily (7 to 9 a.m.) with a hook gauge. Rainfall was measured daily at the same time, using a standard 20.32 cm Weather Service rain gauge. Pan evaporation from a Class A pan also was recorded. A standard weather box at the Research Unit was equipped with maximum and minimum thermometers.

Pond bottom temperatures were recorded daily (7 to 9 a.m.) in three ponds by inserting a thermometer 2 to 5 cm into the bottom mud in shallow water (20 to 30 cm).

Pond water levels were maintained 8 to 15 cm below the lip of the drain pipe by periodic additions of water from the supply reservoir. Water was normally added rapidly, within a period of 1 hour, and the pond level was remeasured. Occasionally water flowed longer to fill the ponds to the desired level; these days were excluded from the data set.

Daily changes in water level were calculated for all ponds, with corrections for rain when necessary. Days with rainfall totals in excess of 0.64 cm were excluded from the study since the noticeable runoff could not readily be estimated.

Pond evaporation was estimated to permit calculation of seepage. Pan evaporation readings were multiplied by the appropriate monthly coefficient *(22)* to approximate pond evaporation.

Seepage Meters

Twelve seepage meters, based on a modification of the USDA Salinity Laboratory meter *(68)*, were constructed, figure 3. The bottom 25 cm of 20-l plastic carboys were cut off and discarded, and the cut edges smoothed and bevelled. A small hole was drilled through the shoulder of each carboy, and a plastic nipple (from a filter assembly) glued into the hole. A 1.2- to 1.6-m section of plastic tubing was then pushed onto the nipple, and a short piece of copper tubing was inserted in the far end of the plastic tubing, to serve as a connector to the plastic bag. A plastic bobber was attached to the end of the tubing with a length of nylon twine, to facilitate its location in turbid water.

For the initial trials in 1985, plastic intravenous solution IV bags were used with the meters. These bags were flexible yet tough, and came complete with plastic tubes to make the connection to the meters. Later, for the 1987 readings, "flexible bag" assemblies were made, figure 4, using 4-l plastic food storage bags. The opening of each bag was gathered and fastened with rubber bands around the outside of a short length of plastic pipe. This facilitated filling and emptying the bags. A one-hole stopper fitted with a short glass tube and piece of plastic tubing was used to seal off the bag after filling. The plastic tubing allowed the bag assembly to be attached to the seepage meter connector.

Meters were inserted into the pond bottom by hand. The screw tops were removed to allow water to escape. Usually little force was required to set a meter in firmly, although on occasion it was necessary to step lightly on the top edges of the meter. Depth of installation varied with the firmness of the bottom soil. Usually a meter would be inserted 2 to 3 cm into the bottom. Deep sections of ponds often had a thick layer of soft sediments, and the meter would sink in approximately 15 cm. Care was taken to keep depth to a minimum, since Meerscheidt *(97)* found that measured seepage rates

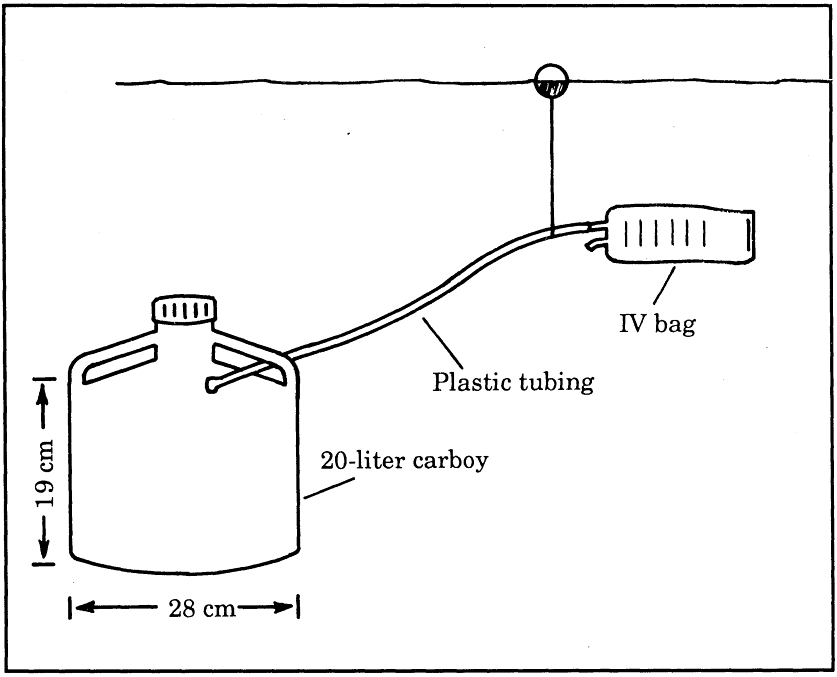

FIG. 3. Seepage meter.

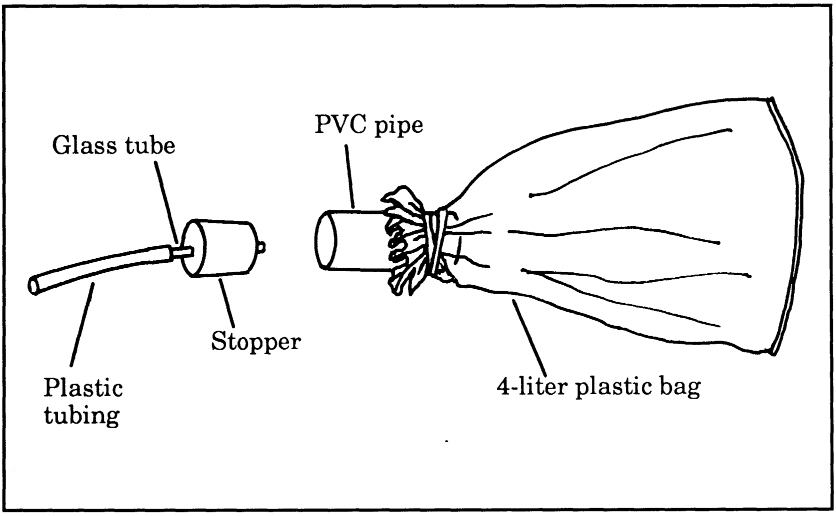

FIG. 4. "Flexible bag" assembly.

could be reduced because of compression of the soil upon installation.

The plastic carboys had several advantages over other designs tested. The meters were lightweight and easy to move. Sloping shoulders on the carboy allowed air bubbles to escape. This was particularly important for meters inserted into deep, thick sediments, where disturbance of the bottom material often resulted in the release of gas bubbles.

An initial concern with the use of a plastic dome was that the plastic would flex or distort upon installation. Other designs *(9,85)* used metal domes or drums. In practice, rarely did the meters show any signs of flexing. On a few occasions one side would bulge slightly, due to the meter hitting a rock or hard spot on entering the bottom. The ponds used in the study were 13 to 15 years old and had an accumulation of sediment in the bottom.

After the meters had been installed and the caps placed on tightly, the plastic bags were filled with a measured amount of water. The amounts chosen (800 ml for the IV bags, 1,000 ml for the "flexible bags") filled the bags only partially, leaving room for water to enter or leave. Upon attaching the bag to the meter, care was taken to remove as much air as possible from the bags.

Seepage readings were taken by attaching a bag with a measured amount of water to a meter, waiting a measured length of time, then removing the bag. The contents were then remeasured in a graduated cylinder. The loss or gain in water for that time period was converted to ml per day. This value was then divided by the area of the bottom of the meter (580 cm^2) in order to obtain seepage in cm per day, for the wetted area of the pond.

In November 1985, seepage meter tests were run in the same 12 ponds used in the water budget study. Each pond was divided into 12 parts in a grid pattern, and a meter installed within each quadrant. Six ponds were measured once with the meters, resulting in 12 seepage values for each pond. The other six ponds were tested twice, for a total of 24 locations within each pond. In addition, three runs were made for each meter in each location. A run consisted of attaching the bag to the meter, then removing it after a measured time interval. The time period varied; bags normally were left attached for 4 to 24 hours. Occasionally a bag would be emptied, in which case the test was re-run for a shorter period.

In June and July of 1987, nine of the same ponds were retested, using the "flexible bag" assemblies. Water depth next to each meter was recorded to the nearest cm. Each pond was tested once, resulting in 12 measurements per pond.

Capped Pipes

Three of the 0.02-to 0.07-ha ponds employed in the water budget study were used. Four 10.2- cm- diameter PVC pipes were driven 0.1 to 0.2 m into the bottom of each pond. The top of each pipe projected 0.3 to 0.5 m above the water level. The pipes were installed at different locations within each pond, some along the shallow edges and others out in deep water. Water was added to each pipe to bring the level inside to a point approximately 2 cm above the water level of the pond. The level in each pipe was then measured to the nearest 0.03 cm with a hook gauge. Tops of the pipes were covered with plastic bags fastened with rubber bands. The caps prevented rain from entering and reduced evaporation to a minimum.

The pipes were installed on May 31, 1985, and monitored through December 13, 1985. Initially the water level in each pipe was recorded twice per week, until August 2, 1985. Measurements were then taken at weekly intervals for the remainder of the study. Each time the water level in a pipe was measured, additional water was added if the level in the pipe was below the level of the pond. If the water level in the pipe was above that of the pond no water was removed.

The pipes served as crude seepage meters, something between a variable head and a constant head permeameter. The rate of water loss from a pipe would depend not only on the conductivity of the soil material in the bottom of the pipe but also on whether the soil at the pipe bottom was saturated or not. The water level in a pipe in saturated soil would theoretically drop at a decreasing rate until it reached a point where seepage in would balance the head in the pipe. A pipe in unsaturated soil would have a water level that would be expected to drop at a decreasing rate until the pipe was empty.

Variations In Seepage Rates for Ponds in the Same Location

Two separate locations were studied to determine variations in seepage rates for ponds. The first was the Gualaca Freshwater Experiment Station in Gualaca, Chiriqui, Republic of Panama. The second location was the Fisheries Research Unit of the Alabama Agricultural Experiment Station near Auburn (FRU/AU).

Gualaca Study

Twenty-seven 0.09-ha earthen ponds were selected for study out of a total of 33 similarly sized ponds. The ponds were approximately 1 year old, and had been renovated. In some cases ponds had been partially lined with clay material to reduce seepage. Eighteen ponds were monitored daily from January 11 to April 31, 1985. This interval corresponded to the dry season, the time of maximum water loss and minimum rainfall. Stage change readings for the other nine ponds were taken sporadically during this same time interval because high rates of seepage caused difficulty in supplying sufficient water to measure the seepage. A minimum total of five daily measurements was made for each pond.

Staff gauges were placed in each pond and daily stage change readings made to the nearest 1 mm. Days on which water was added to the ponds to maintain the average water depth of 0.9 m were excluded. A rain gauge was placed adjacent to the ponds and read daily. Pan evaporation was measured at the weather station of the Instituto de Investigacion Agropequaria, located 0.6 km away. The evaporation pan had been painted white inside.

Pond evaporation was estimated by multiplying the average pan evaporation value by 0.81 *(22)*. No attempt was made to correct for the painted pan. Pan evaporation data were available for only 70 days out of the total 110-day period, so pan evaporation and total water loss data were averaged separately for 2-week intervals. Seepage was then calculated by subtracting estimated pond evaporation from total water loss for each pond as measured by stage change. Corrections were made for rainfall as needed.

Auburn Study

Out of a total of 170 levee ponds, 70 were randomly selected for study. Stilling wells were installed in each pond and water levels recorded with a hook gauge at 24-hour intervals. Measurements were taken during two 5-day periods in July and August of 1986. The reported seepage rate for each pond represents the average of three to five daily measurements. Pond evaporation was estimated from Class A pan evaporation data by use of Boyd's *(22)* coefficients for those months. Seepage was calculated by subtracting pond evaporation from total water loss, after correcting for rain if necessary. Days with rainfall in excess of 0.64 cm were excluded from the data.

A number of ponds had water supply valves that were cracked or could not be shut completely. For these ponds, inflow was estimated by capturing the water in a bucket for a set time period, then using a graduated cylinder to measure the volume of water caught. Three replicates were run, then the average used to correct stage change readings by dividing the daily inflow volume by the surface area of the pond.

Seasonal Variation in Seepage Rates

Stilling wells were installed in two small (0.022-and 0.047-ha) levee ponds at FRU/AU. Daily stage change readings were taken to the nearest 0.03 cm with a hook gauge. Water was added to the ponds periodically to maintain water levels, resulting in average depths of 0.7 m and 0.6 m for ponds M-23 and M-24, respectively.

Meteorological data were obtained from a weather station at the FRU/AU. Rainfall, as measured by the catch of a 20.32-cm standard gauge, and evaporation, from a Class A pan, were recorded daily. Days with rainfall totals exceeding 0.64 cm were excluded from the study due to the difficulty in calculating runoff. Pond bottom temperatures were taken daily in the early morning by inserting a thermometer 3 to 5 cm into the bottom mud near the pond edge. Average daily air temperature was calculated from the average of maximum and minimum thermometer readings. The study began in June 1985 and lasted 13 months.

Daily stage change readings were corrected for rain when necessary, then averaged on a monthly basis. The coefficients determined by Boyd *(22)* were used to estimate pond evaporation from monthly averages of daily pan evaporation. These estimates of pond evaporation were subtracted from the monthly averages of total water loss to obtain seepage rates.

Mean daily air temperatures and early morning pond bottom temperatures were also averaged by month. The month was chosen as a unit of time over which to average values since most water budgets are calculated on a monthly basis.

RESULTS AND DISCUSSION

Water Table Measurement

Depth to the water table in the wells varied over the year at Auburn. The deepest levels generally were in late October, the shallowest in late March. Water levels in wells in the floodplain outside the main dike varied only slightly during the year, apparently in response to rainfall. These wells, in contrast to the others, showed no response when the ponds were drained briefly.

The water table inside the main dike, figure 5, sloped towards the center of the series of ponds. It appeared likely that seepage water drained down into the more permeable Toccoa series soil underneath the ponds.

Comparison of Methods For Estimating Seepage

The direct methods for estimating seepage were compared to seepage rates obtained by the water budget method (pan method). As actual seepage rates remain unknown, the only

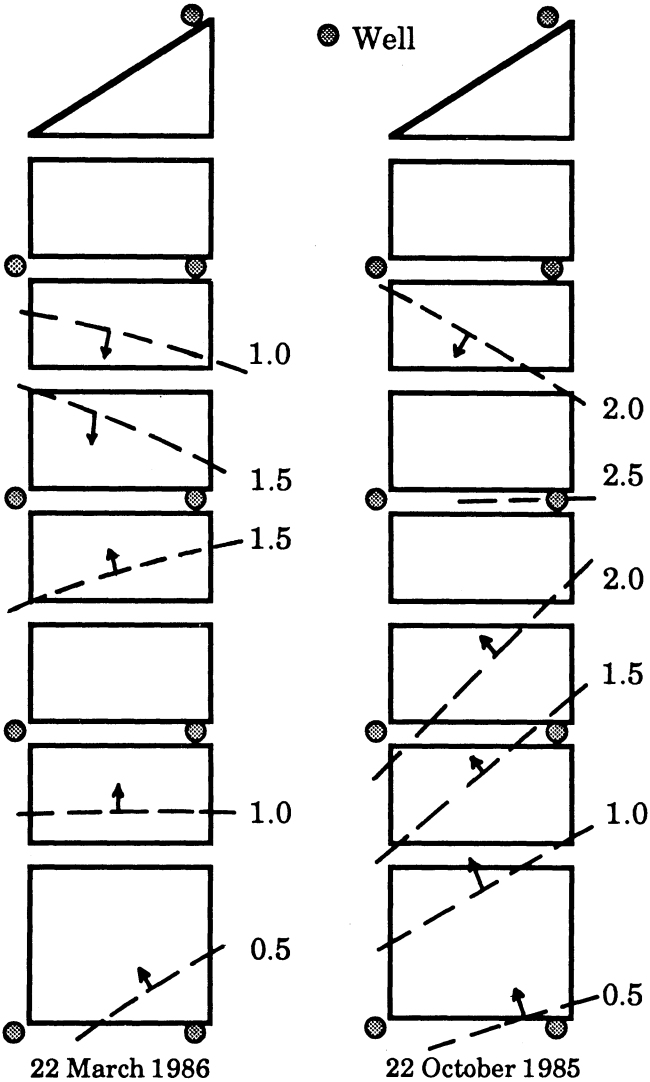

FIG. 5. **Contours of depth to water table (m) showing range in water table levels under study ponds during the year.**

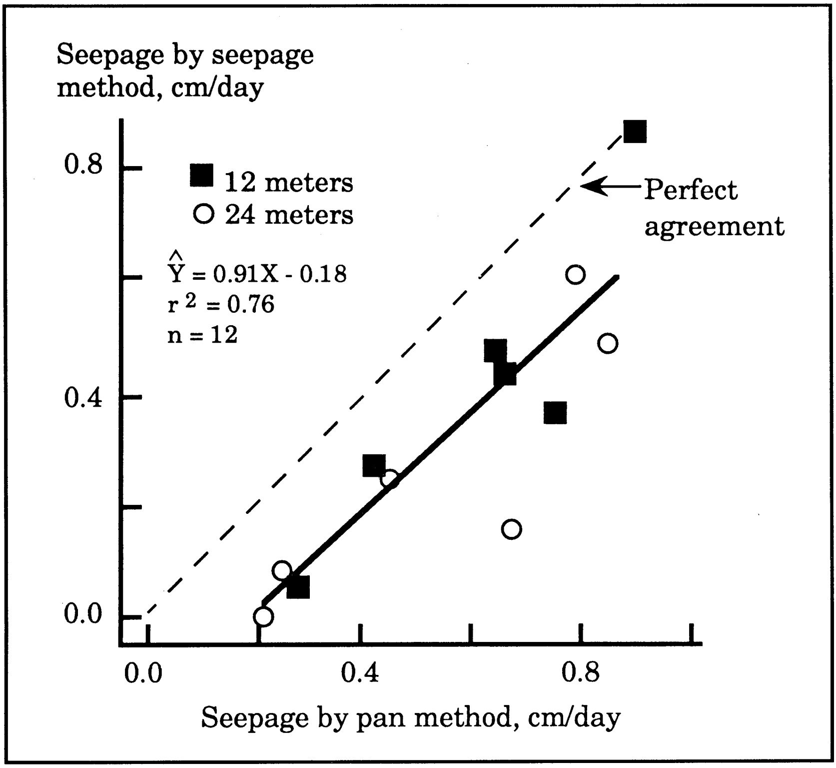

FIG. 6. Comparison of seepage rates of 12 ponds determined by the pan method and by the average of seepage meters.

means to evaluate the methods is by comparison. Water budget methods are generally considered to be the most accurate. Results of the November 1985 comparison of seepage meter tests and the pan method are given in figure 6. Although there was considerable variation, values obtained by seepage meter were approximately 0.2 cm per day less, on the average, than rates calculated by the pan method.

Nine of the same ponds were re-tested in June and July of 1987 using the "flexible bag" assemblies in place of the IV bags used previously. Seepage meter results were compared to pan method values for June and July of 1985, figure 7. The resulting regression line was closer to the theoretical line of equal values than was the case for the tests using the

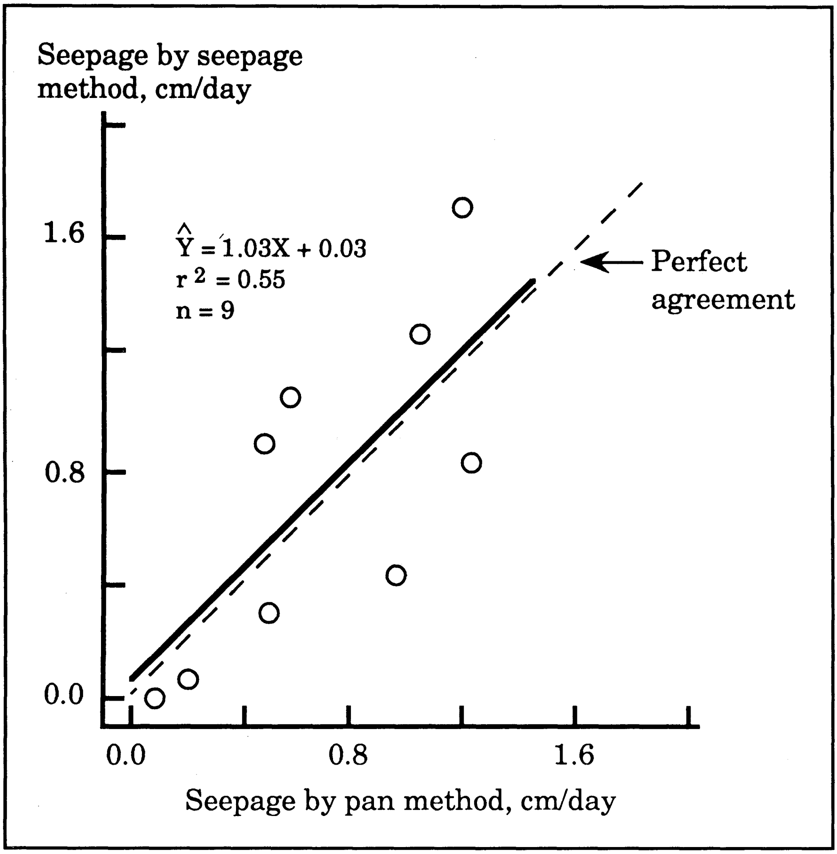

FIG. 7. Comparison of seepage rates from nine ponds as determined by the pan method in 1985 and by seepage meters in 1987.

IV bags. The "flexible bag" assemblies did have the disadvantage that in ponds with bluegill, holes were found in a number of the bags.

Use of 1985 pan method data for comparison with 1987 seepage meter test data may contribute to variation in the comparison. A limited amount of data is available (see section on seepage over time) that indicates that seepage in these ponds for a given month varies little from year to year.

As seepage meters provide only point measurements of seepage, it is not surprising that the mean of 12 or 24 seepage meters within a pond should differ from the mean of the pond as a whole, even assuming that all measurements are accurate. A large number of measurements would be required to obtain an acceptable mean value. Brockway and Worstell *(26)* gave a procedure for estimating the number of seepage meter tests required. Coefficients of variation among seepage rates obtained within a pond range from 100 percent to 400 percent (see section on variation within ponds). Even with a CV of 100 percent, according to the calculations of Brockway and Worstell *(26)*, for a confidence level of 90 percent, and accepting a computed mean within 30 percent of the true mean, some 30 tests are required.

Of course, the number of tests is independent of the size of the pond, so that as long as the CV does not change, a 0.04-ha pond would require as many measurements as a 40-ha pond. Techniques developed for dealing with the spatial heterogeneity of conductivity in soils could be applied to seepage measurements from ponds.

Seepage rates varied considerably among capped pipes in the same pond. Figure 8 gives data from Pond M-23 as an

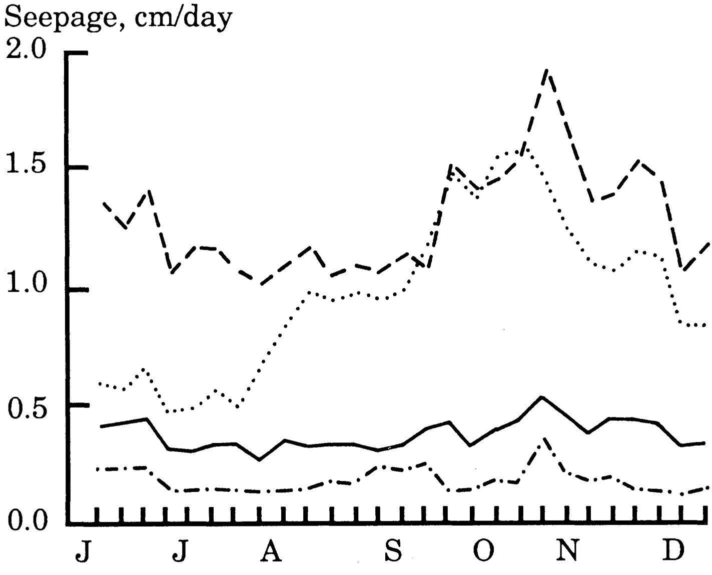

FIG. 8. Seepage rate calculated from weekly measurements of water levels in four capped pipes in Pond M-23.

example. Some pipes consistently lost little water over the study period. Rates of seepage from other pipes fluctuated from week to week. The average monthly seepage rate, as a mean of the four pipes in each pond, was compared to the seepage rate calculated by the pan method, figure 9. Pipes provided estimates that were usually well within 50 percent

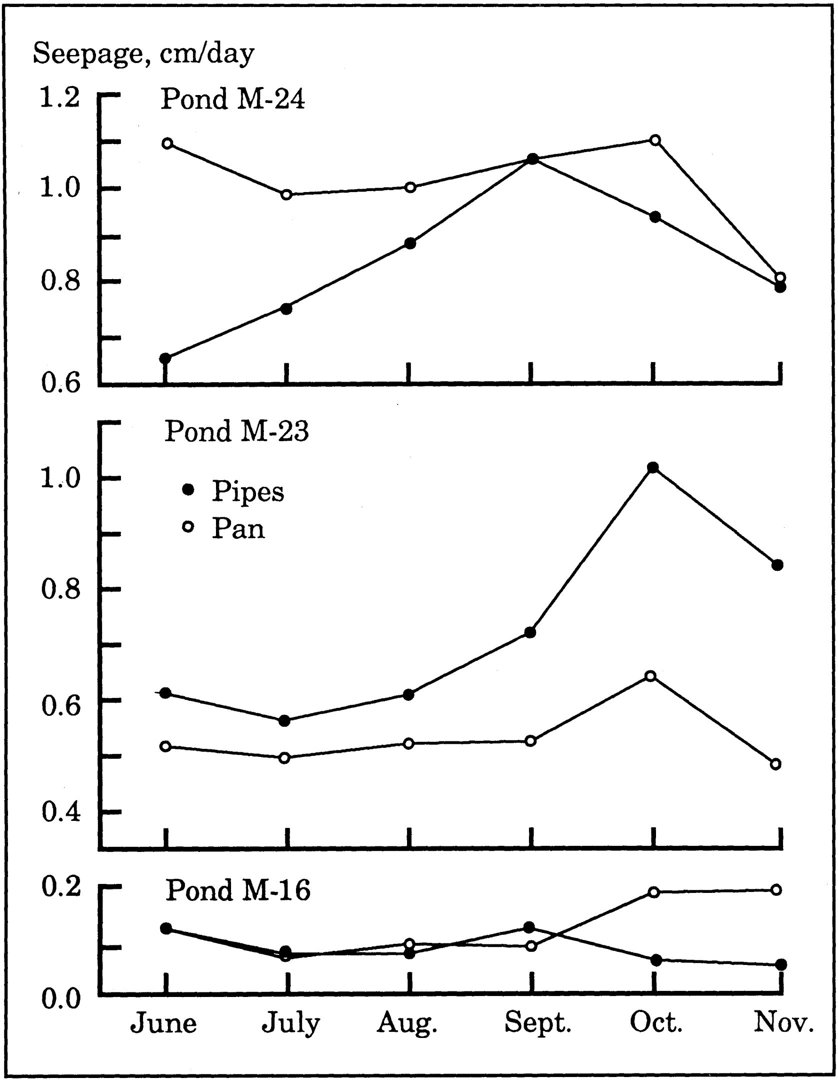

FIG. 9. Average monthly seepage rate as computed by the pan method and by the average of four capped pipes.

TABLE 4. COMPARISON OF AVERAGE SEEPAGE RATES (cm/day) CALCULATED BY THE PAN METHOD AND BY CAPPED PIPES FOR A 6-MONTH PERIOD

Pond number	Seepage rate	
	Pan method	Capped pipes*
M-16	0.14	0.08
M-23	.53	.73
M-24	1.01	.85

*Average of four pipes

of values obtained by the pan method. When averaged for the entire 6-month period, means of the pipes were close to those calculated by the pan method, table 4.

The pipes provided only point measurements of seepage. The discussion in the section on seepage meters regarding the number of measurements necessary applies to the pipes as well. In addition, the pipes had other potential problems. Driving the pipes into the pond bottom could cause compression of the soil, thereby reducing seepage, as theorized by Meerscheidt *(97)* for similar devices. The head inside each pipe varied over time and in relation to the water level of the pond. Use of the pipe method should be restricted to those situations where no other method is practical. Increasing the number of pipes per pond would theoretically give more accurate results.

Number of Measurements Required

Estimates of seepage by the pan method showed considerable daily variation. As an example, calculated seepage rates from two ponds for a 2-week interval in September 1985 are given in figure 10. This time period was chosen because it was the longest period of consecutive days without rain in the data set. Steins two-stage sample procedure *(125)* was employed to determine the sample size necessary to estimate mean seepage within certain limits. The variances of seepage measurements for the 2-week period were calculated for the two ponds and then averaged. To be 95 percent confident that the calculated mean would be within 0.1 cm of the actual mean, nine daily measurements would

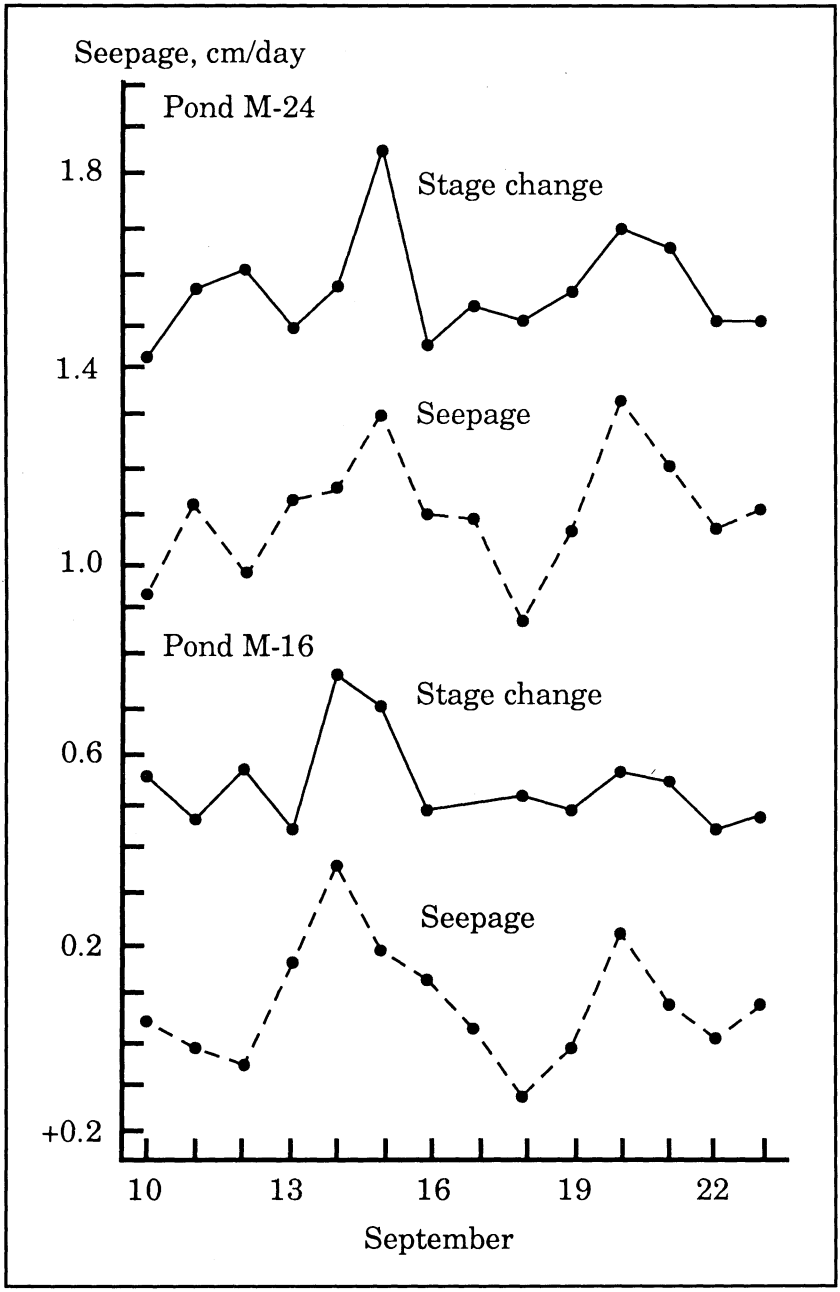

FIG. 10. Stage change and estimated seepage for two ponds during a period without rain.

be required. Typically, readings are taken for 3 to 4 days. For 3 days, at the 95 percent confidence level, the calculated mean would have a value within 0.17 cm of the actual mean.

The variance used for these calculations is for a period without rain. If measurements are taken during or between rainy periods, the variance could be larger, and more measurements would be required for the same level of precision.

Variation in Seepage Meter Readings

Results from seepage meter tests conducted in November 1985 were examined. Repeated measurements had been taken in six ponds with three runs per location and two locations per pond. It was observed that, for the three ponds in which rain fell during the test period, there was a reduction in the mean seepage rate measured over time, table 5. This was not the case for the other three ponds tested during dry weather, table 6. A study of seepage in Florida lakes by Fellows and Brezonik *(51)* noted a short-term increase in seepage inflow after a rain. However, there is some variation found among average seepage rates in all ponds. A study specifically designed to determine the effects of rain on seepage measurement is needed.

TABLE 5. SEEPAGE ON DAYS WITH RAIN, AS MEASURED BY AVERAGE SEEPAGE FROM 12 SEEPAGE METERS IN TWO LOCATIONS, IN CENTIMETERS PER DAY

Item	Result, by location						
	Location A				Location B		
Pond E-63							
Date	Nov. 2	Nov. 2	Nov. 3		Nov. 3	Nov. 4	Nov. 4
Rain	-----0-----			-----1.63-----		--0--	--0--
Location	A	A	A		B	B	B
Seepage	0.14	0.17	0.14		0.11	+0.01	0.04
Pond E-68							
Date	Nov. 5	Nov. 6	Nov. 6		Nov. 7	Nov. 8	Nov. 9
Rain	--0--	------.03-----			-.08-	--0--	--0--
Location	A	A	A		B	B	B
Seepage	.20	.29	.18		.20	.10	.08
Pond M-16							
Date	Nov. 18	Nov. 19	Nov. 20		Nov. 20	Nov. 21	Nov. 22
Rain	-.03-	--0--		-----.48-----		-.91-	--0--
Location	A	A	A		B	B	B
Seepage	.06	.05	.00		+.01	+.03	+.05

TABLE 6. SEEPAGE ON DAYS WITHOUT RAIN, AS MEASURED BY AVERAGE SEEPAGE FROM 12 SEEPAGE METERS IN TWO LOCATIONS, IN CENTIMETERS PER DAY

Item	Result, by location					
	Location A			Location B		
Pond E-71						
Date	Nov. 9	Nov. 10	Nov. 10	Nov. 11	Nov. 11	Nov.12
Location	A	A	A	B	B	B
Seepage	0.33	0.30	0.31	0.64	0.69	0.64
Pond M-24						
Date	Nov. 12	Nov. 13	Nov. 13	Nov. 14	Nov. 15	Nov. 16
Location	A	A	A	B	B	B
Seepage	.67	.75	.65	.45	.59	.62
Pond M-23						
Date	Nov. 23	Nov. 23	Nov. 24	Nov. 24	Nov. 25	Nov. 26
Location	A	A	A	B	B	B
Seepage	.56	.61	.48	.09	.04	.06

For seepage meters in ponds tested during dry weather, the coefficient of variation for the three consecutive tests was compared to the average seepage rate for that meter, figure 11. Meters that had run dry were excluded from the data.

Results indicated that when using the IV bag, a seepage rate of at least 0.5 cm per day is necessary in order to consistently obtain a coefficient of variability below 20 percent. Robinson and Rohwer *(115)* stated that seepage meters were accurate except when seepage was of the same order of magnitude as evaporation. Pond evaporation at Auburn runs 0.1 to 0.6 cm per day.

Seepage meters provided "order of magnitude" values for seepage from a pond. Meters were originally developed for measuring seepage from irrigation canals. The rates of seepage from such canals, even in clayey soils, are measured in terms of feet per day *(60,50)*. The level of accuracy of the meters is probably not sufficient to detect low rates of seepage reliably.

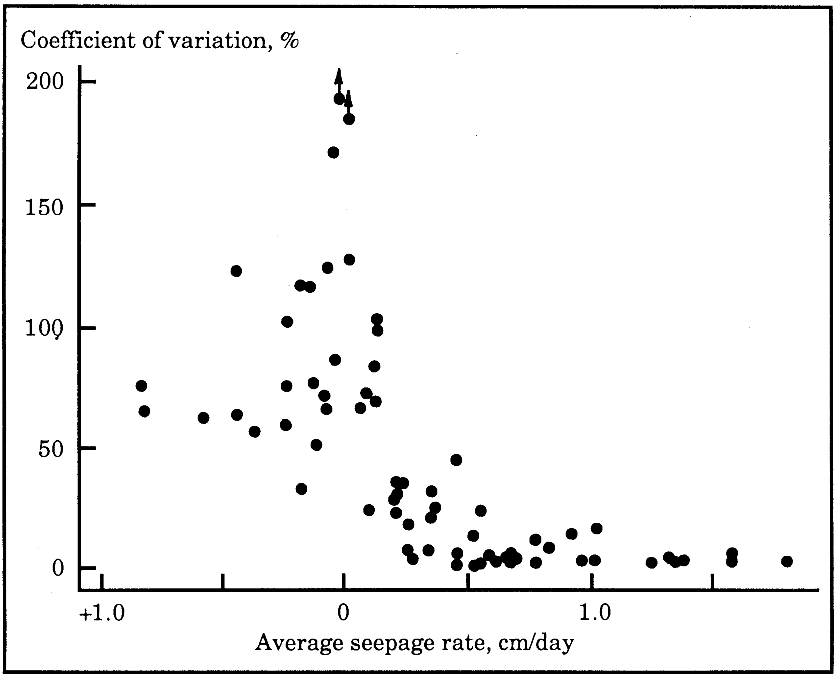

FIG. 11. Coefficients of variation for repeated seepage meter measurements compared to the magnitude of average seepage, rate recorded.

Variations in Seepage Within a Pond

Typical frequency distributions of seepage values within a pond obtained by seepage meter are shown in figure 12. As average seepage rate increases, the distribution becomes log-normal in shape. Relatively few measurements were taken per pond. Table 7 presents data from the 1987 "flexible bag" study on the variation in seepage rate between 12 meters in the same pond. Coefficients of variation ranged from 111 percent to 356 percent. Values for the standard error of the mean and the coefficient of variation are only approximate since the distribution is apparently log-normal.

Data from the nine ponds measured in 1987 (89 observations) were combined and graphed, figure 13. The resulting

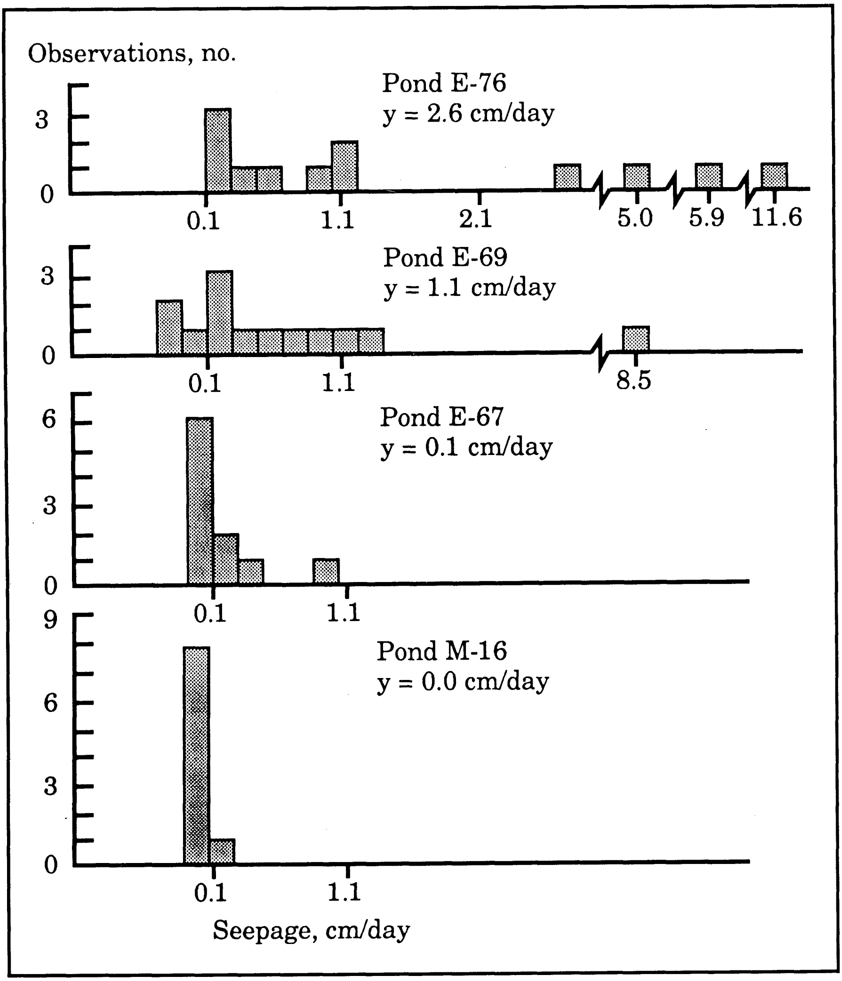

FIG. 12. Frequency distribution histograms of seepage rates for seepage meter measurements in three ponds.

TABLE 7. MEAN SEEPAGE, STANDARD ERRORS (S.E.), AND COEFFICIENTS OF VARIABILITY (CV) FOR MEASUREMENTS BY 12 SEEPAGE METERS PER POND, SUMMER 1987

Pond	Mean seepage cm/day	S.E.	CV pct.
M-16	0.01	+/- 0.02	356
E-67	.10	+/- .10	333
E-68	.26	+/- .10	135
E-70	.44	+/- .18	137

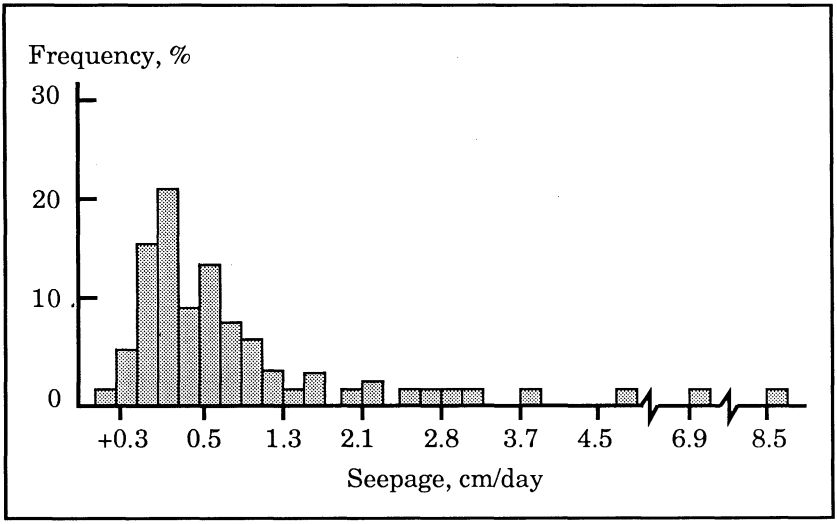

FIG. 13. Frequency distribution histogram of 89 seepage meter measurements in nine ponds, June and July 1987.

frequency distribution appears log-normal. This is not unexpected. Hydraulic conductivity measurements for steady state infiltration within a field have been shown to have a log-normal distribution *(104).* Further studies involving numerous observations within one pond would be needed to confirm the shape of the seepage rate frequency distribution pattern.

Variations in Seepage with Depth

Results of the 1987 seepage meter tests in each of nine 0.02- to 0.07-ha ponds were analyzed to determine if seepage rate was correlated with depth. For ponds with low average seepage rates, seepage did not appear to have any relation to depth. In ponds with higher average seepage rates, seepage appeared to be higher closer to the pond edge.

Seepage readings in all ponds taken at 50 cm depth and less were compared to seepage rates for depths of 90 cm and greater, using Student's t-test. Mean seepage for the shallower depths was 1.55 cm +/-0.48; deeper depths averaged 0.27 cm +/- 0.07. Results of the +/- test indicated a significant difference (alpha=0.05). One difficulty in making such a comparison is that ponds have different depths, different seepage rates and different depths to water table.

It is interesting that seepage is not the highest in the deepest part of the pond, as would be expected because of the increased head. Boyd *(18,19)* analyzed fishpond bottom material, and found that the proportions of clay and organic material increased with water depth. A layer of clay and organic matter would help seal the pond bottom. It is also possible that the bottoms of the ponds were at or above the water table, so that seepage was reduced. In 1985, wells were bored along these series of ponds (see section on study site). It appears that the water table is above the pond bottom for a number of ponds for at least part of the year.

Variation in Seepage Over Time

Generally, the seepage rate of a new pond decreases with time. At some point the seepage rate would be expected to stabilize at a minimum value. A comparison of seepage measurements from Lichtkoppler *(87)* and from Boyd *(20)* with 1985 data allows a limited look at seepage over time.

Sixty-six, 0.04-ha ponds were built at the FRU/AU in 1969. These were created by subdividing existing ponds. An additional 10 ponds were constructed in 1970 and 1971. The bottoms of these 10 ponds were sealed in 1972 to reduce seepage.

Lichtkoppler *(87)* conducted a fertilizer study in some of these ponds in 1976. He recorded stage change and pan evaporation data three to seven times per month for 3 months. Boyd *(20)* later measured seepage from four ponds at the FRU/AU including one previously studied. The present study included seven of the ponds used in 1976 and three used by Boyd. Stage change measurements minus pan evaporation (times 0.7) were totaled on a monthly basis and compared for the three studies, table 8.

Measurements made in 1985 were almost identical to those recorded in 1981 *(20)*, indicating little change in seepage rate. Seepage rates in 1985 were reduced from levels obtained by Lichtkoppler *(87)*. The two ponds showing the least amount of change, E-63 and E-64, were ponds built in

TABLE 8. COMPARISON OF SEEPAGE RATES OVER YEARS FOR PONDS AT THE FISHERIES RESEARCH UNIT, AUBURN UNIVERSITY

Pond number	Seepage, cm/month								
	1976[1]			1981[2]			1985[3]		
	July	Aug.	Sept.	July	Aug.	Sept.	July	Aug.	Sept.
E-67				7.8	10.0	7.5	7.5	7.7	7.0
E-70				32.4	34.9	35.0	31.5	32.3	33.7
E-71	79.7	95.5	81.6				38.9	42.4	42.7
E-72	67.3	64.8	43.5	39.0	39.6	37.1	38.5	41.3	43.1
E-63	19.5	9.6	6.9				10.2	10.3	9.6
E-64	25.1	20.8	15.6				12.3	14.7	11.7
M-23	45.9	43.4	39.0				17.9	17.8	17.1
M-24	66.3	50.2	69.0				33.1	33.8	35.3
M-16	22.9	11.5	34.8				4.6	5.7	4.6
Pond evaporation in cm/month (Pan evap. X 0.7)	10.2	11.8	9.6	14.9	8.8	9.6	12.8	11.6	10.5

[1] Source *(87)*.
[2] Source *(20)*.
[3] Present study.

1969. The other ponds had been finished in 1971 and reworked in 1972.

Variations in Seepage Rates for Ponds in the Same Location

Frequency distribution histograms of seepage rates were graphed for ponds at Auburn and at Gualaca, figures 14 and 15. In both cases the distributions were skewed to the right, approximating a log-normal distribution. A striking characteristic of seepage values for both Auburn and Gualaca is the wide range in seepage rates recorded for ponds in the same general location. Using the average of seepage values of ponds in the vicinity to predict the seepage rate of a new pond entails a certain amount of risk.

One important consideration in the interpretation of the results is that, as is logical, fishponds are usually constructed together in blocks. Ponds adjacent to one another do not act as entirely independent units. Differences in pond elevation, depth, and water level can cause variation. Seepage from one pond could appear to be low because of inflow from a neighboring pond. Similarly, seepage could be accelerated by the emptying of an adjacent pond.

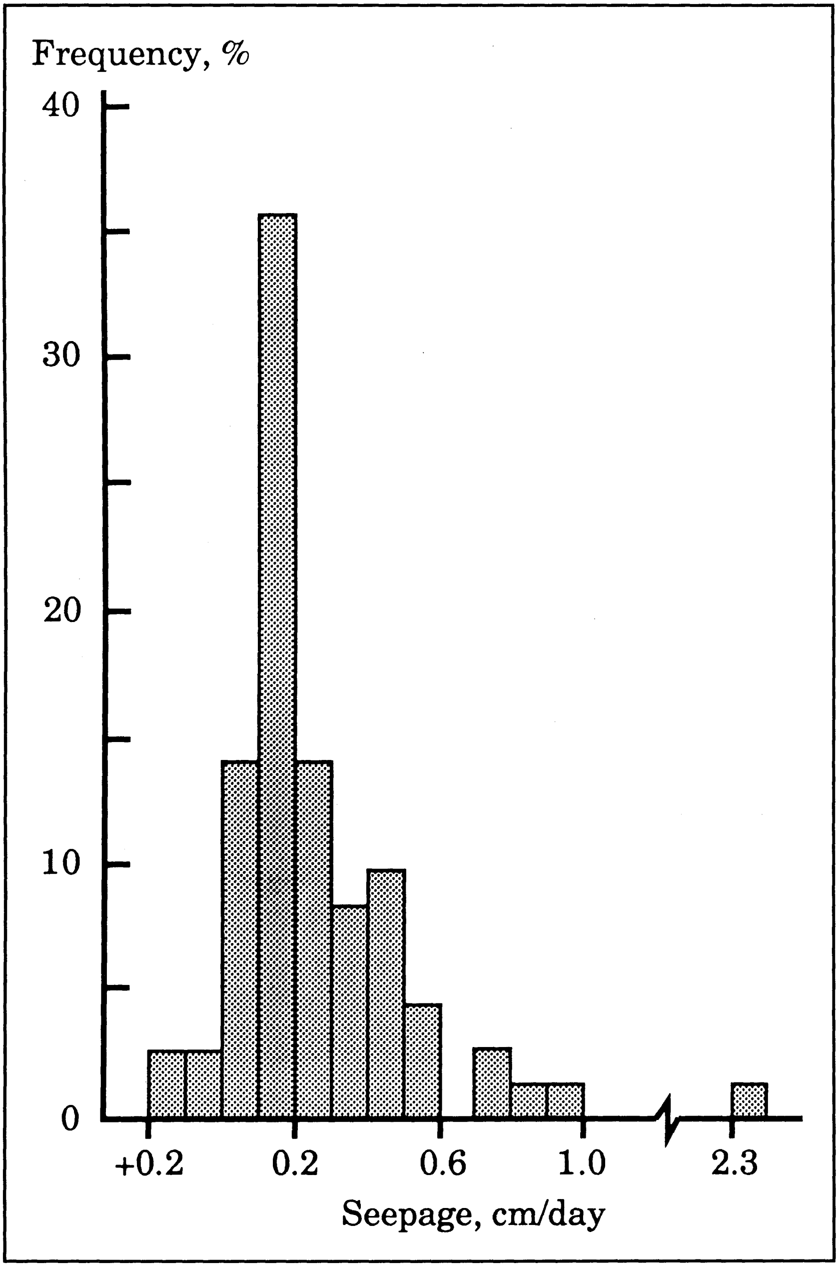

FIG. 14. Frequency distribution histogram of seepage rates from 70 ponds at Auburn University.

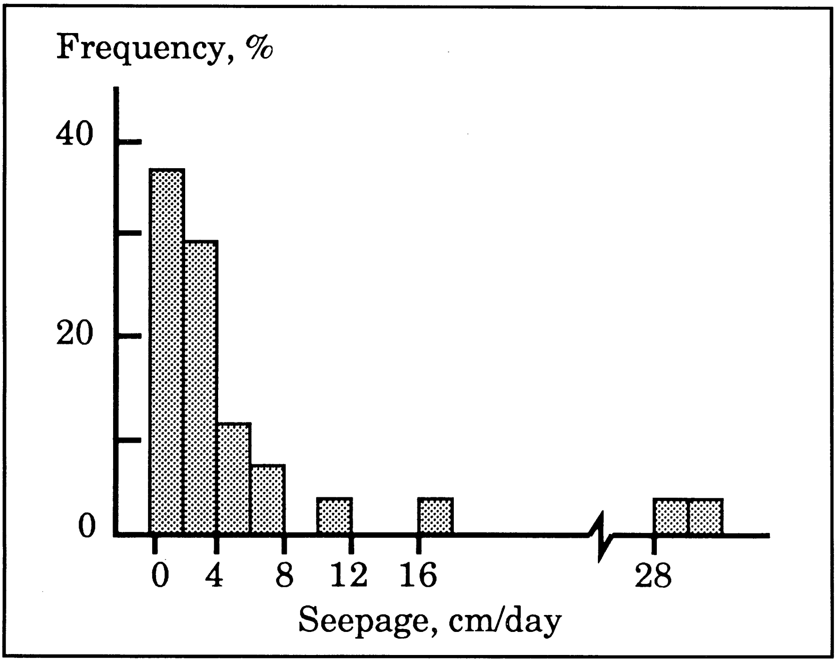

FIG. 15. Frequency distribution histogram of seepage rates for 27 ponds at Gualaca, Panama.

At Gualaca, some clay material had been brought in, so that the soil material was not identical in all ponds. The lower seepage rates recorded were from untreated ponds; ponds that had been treated still had moderate to severe seepage problems, so the treatments did not appear to reduce the variability in seepage rates recorded.

Seasonal Variation in Seepage Rate

Seepage rates of both ponds tested were found to vary with season, figure 16. Rates recorded during the winter months were some 25 to 32 percent lower than summer readings. Highest seepage occurred in June 1985, June 1986, and October 1985. The two ponds were drained briefly in the latter month. This did not appear to affect seepage as readings were similar before and after drainage. A large number of ponds in the same general area were also drained

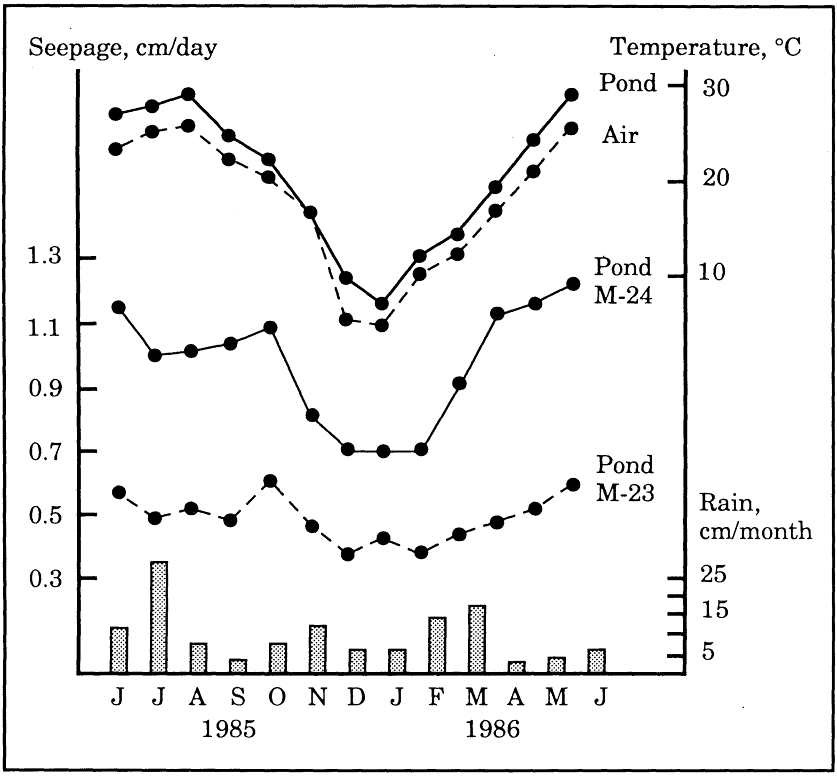

FIG. 16. **Seepage rates for two ponds at the Fisheries Research Units, Auburn University.**

in October. Whether this influenced the seepage rates from M-23 and M-24 is not known. Seepage did not appear to be related to average monthly rainfall.

Fair correlations were obtained between air temperature and pond seepage, with r^2 values of 0.62 for pond M-23 and 0.69 for pond M-24, figure 17. Results for the relation between pond seepage and pond bottom temperature were very similar, with $r^2 = 0.61$ for M-23 and $r^2 = 0.73$ for M-24, figure 18.

The seepage rate at 20°C for each pond, as determined by linear regression, was used, together with Whitlow's *(135)* temperature correction coefficients, table 2, to construct theoretical lines for the change in seepage with changing water temperature. The theoretical lines for both ponds

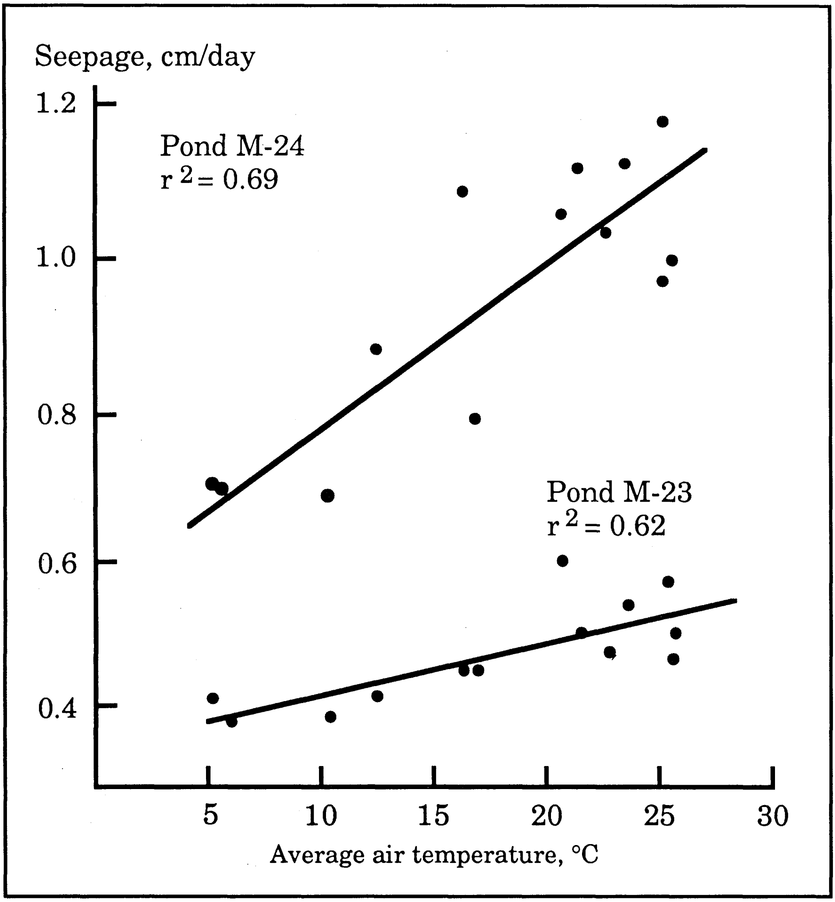

FIG. 17. The relation between mean monthly air temperature and daily seepage rate for two ponds.

indicate that actual seepage varies somewhat less with temperature than predictions based on changes in water viscosity. Robinson and Rohwer *(115)* considered that while seepage would increase with increasing water temperature because of viscosity changes, the concurrent change in the vapor pressure of entrained air would partially counteract that.

As an improvement to the present method of calculating water budgets, average daily air temperature can be used to

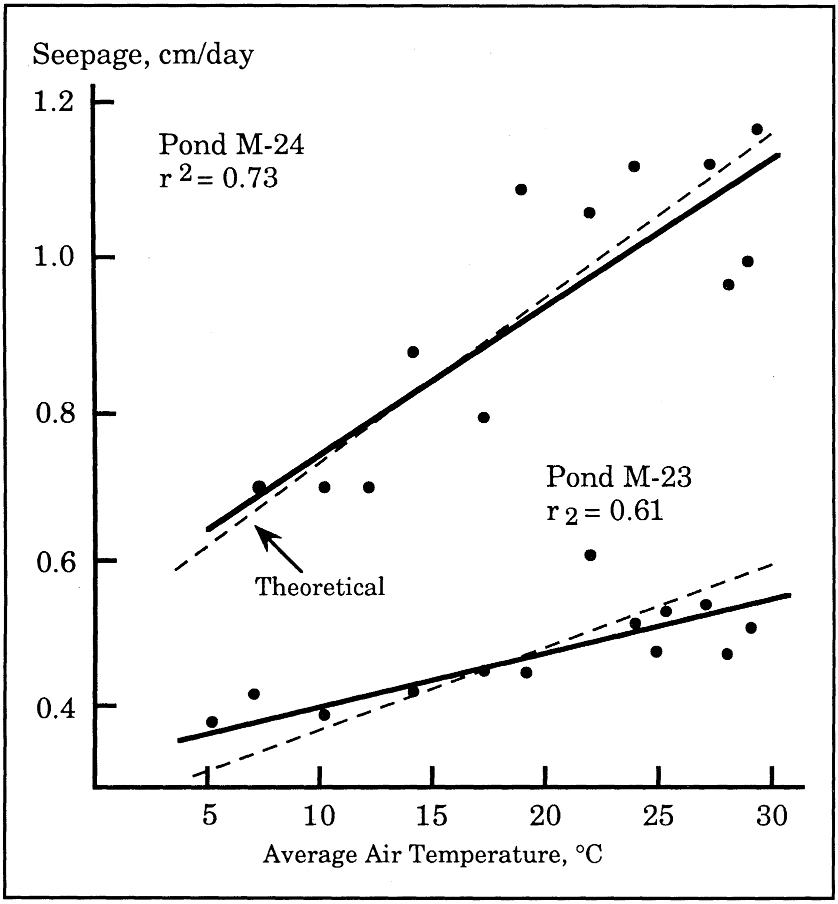

FIG. 18. The relationship between mean monthly early morning pond bottom temperature and daily seepage for two ponds.

adjust seepage rate estimates on a monthly basis. Using the average of the percent change in seepage per unit change in temperature for the two ponds, seepage can be estimated to change by 9 percent of its value at 20^0 C for each 5^0 C change in air temperature. Alternatively, if water temperature data are available, approximate corrections could be made based on the viscosity and density changes of water. The results indicate that, at least for these shallow ponds, seepage varies with the temperature of the water.

SUMMARY

This bulletin summarizes available literature on seepage and reports the results of studies on the characteristics of seepage from fishponds. Although a considerable volume of literature on seepage exists, this is the first attempt we know of to summarize material on seepage relevant to fishponds.

The water budget method (pan method) has been employed previously to estimate seepage from fishponds. In certain cases it is desirable to measure seepage directly. Some ponds and fish culture facilities, such as earthen raceways, are subject to a continual flow of water. Frequent rains can also cause problems with seepage measurements using a water budget method *(3)*. Under those circumstances, seepage meters provide a means to estimate seepage. The average of seepage measurements by 12 to 24 seepage meters per pond showed a fair correlation ($r^2 = 0.76$) with estimates obtained by the pan method. Coefficients of variation for repeated seepage meter measurements in the same location consistently dropped below 20 percent when seepage equalled or exceeded 0.5 cm per day.

Pipes in the bottom of a pond share many of the characteristics of the seepage meters. Seepage from individual capped pipes within a pond varied widely. However, average water loss for 6 months from four pipes per pond was similar to pan method estimates. Measurements by the pipes would be expected to be less reliable than those of the meters due to: greater disturbance of the pond bottom, relatively smaller area of pond bottom enclosed by a pipe, and deviations from constant head. Nevertheless, pipes would be easier to install in deep water.

Seepage varied considerably within ponds; seepage rates exhibited an apparent log-normal distribution. For the study ponds, seepage rates were higher in shallow water than in deep water. The meters can be used to detect discontinuities in pond seepage, albeit the chances of finding such spots is slim unless a great many tests are run. Where an area is suspected of having a high seepage rate, the meters could be used to check.

Tremendous variations were found for seepage rates of

ponds in the same location. Predicting seepage of future ponds in an area by using the seepage rates of existing ponds does not appear valid, at least for the sites studied.

Seasonal changes in temperature were found to be correlated with changes in the seepage rates of ponds. On the average, seepage changed 9 percent from its value at 20^0 C for each 5^0 C change in temperature.

As fish farming expands and as groundwater levels decline, water required to fill and maintain ponds will become even more valuable. Research into the mechanisms controlling seepage could lead to improved pond construction techniques and a reduction in water lost to seepage.

CONVERSION FACTORS FOR ENGLISH AND METRIC UNITS

Column 1		Column 2	To convert column 2 to column 1, multiply by
	Length		
2.540	Inch	Centimeters	0.3937
0.3048	Feet	Meters	3.281
1.609	Miles (statute)	Kilometers	0.6214
30.48	Feet	Centimeters	0.0328
0.9144	Yards	Meters	1.094
	Area		
0.4047	Acres	Hectares	2.471
6.452	Square inches	Square centimeters	0.1550
	Volume		
0.9463	Quart, liquid, U.S. (32 ounce)	Liter	1.057
1.136	Quart, imperial (40 ounce)	Liters	0.8799
3.785	Gallon, U.S. (4 quarts)	Liters	0.2642
4.546	Gallon, imperial	Liters	0.2200
29.57	Ounce (U.S. fluid)	Milliliters	0.0338
	Weight		
28.35	Ounces (avoirdupois)	Grams	0.0353
0.4536	Pounds (avoirdupois)	Kilograms	2.205
1.016	Tons (gross or long)	Metric ton	0.9842
0.9072	Tons (short or net)	Metric ton	1.102
	Pressure		
70.31	Pounds per square inch	Grams per square centimeter	0.0142
0.0703	Pounds per square inch	Kilograms per square centimeter	14.22
	Other conversions		
1.12	Pounds per acre	Kilograms per hectare	0.892
10.76	Foot candles	Lux	0.0929

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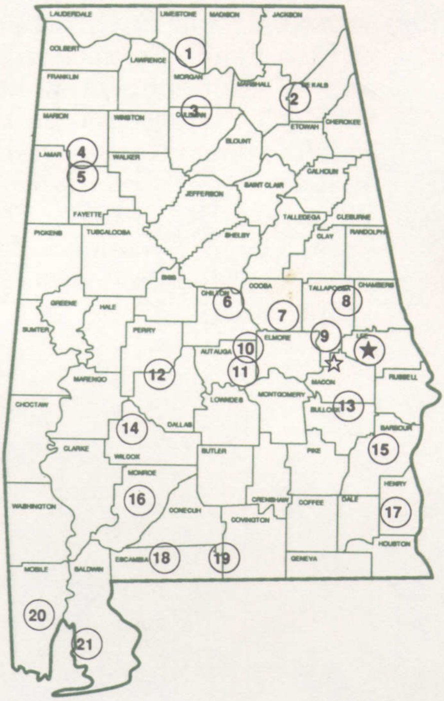
Alabama's Agricultural Experiment Station System
AUBURN UNIVERSITY

With an agricultural research unit in every major soil area, Auburn University serves the needs of field crop, livestock, forestry, and horticultural producers in each region in Alabama. Every citizen of the State has a stake in this research program, since any advantage from new and more economical ways of producing and handling farm products directly benefits the consuming public.



Research Unit Identification

★ **Main Agricultural Experiment Station, Auburn.**
☆ **E. V. Smith Research Center, Shorter.**

1. Tennessee Valley Substation, Belle Mina.
2. Sand Mountain Substation, Crossville.
3. North Alabama Horticulture Substation, Cullman.
4. Upper Coastal Plain Substation, Winfield.
5. Forestry Unit, Fayette County.
6. Chilton Area Horticulture Substation, Clanton.
7. Forestry Unit, Coosa County.
8. Piedmont Substation, Camp Hill.
9. Plant Breeding Unit, Tallassee.
10. Forestry Unit, Autauga County.
11. Prattville Experiment Field, Prattville.
12. Black Belt Substation, Marion Junction.
13. The Turnipseed-Ikenberry Place, Union Springs.
14. Lower Coastal Plain Substation, Camden.
15. Forestry Unit, Barbour County.
16. Monroeville Experiment Field, Monroeville.
17. Wiregrass Substation, Headland.
18. Brewton Experiment Field, Brewton.
19. Solon Dixon Forestry Education Center,
    Covington and Escambia counties.
20. Ornamental Horticulture Substation, Spring Hill
21. Gulf Coast Substation, Fairhope.