WATER-RESOURCES INVESTIGATIONS
REPORT 84-4051

EFFECTS OF URBANIZATION ON THREE PONDS IN MIDDLETON, WISCONSIN

REPARED BY
.S. GEOLOGICAL SURVEY
N COOPERATION WITH THE
ITIES OF MIDDLETON AND MADISON, WI

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By

L.B. House

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations
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Prepared in cooperation with the
Cities of Middleton and Madison, Wisconsin

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UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION TABLE

For the use of readers who prefer the International System of Units (SI), the conversion factors for the terms used in this report are listed below.

Multiply	By	To Obtain
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.59	square kilometer (km^2)
acre-foot	1,233.5	cubic meter (m^3)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

A digital hydrologic model was used to simulate the effects of future residential development on pond inflow volumes and resulting water levels of three ponds in Middleton, Wisconsin. The model computed the daily water budget and the resulting water level for each pond. The results of the model calibration are presented in the report, along with the existing watershed hydrologic conditions and runoff volumes for the 1982 study period. Data was collected during 1982 to calibrate the model; the data included pond stage, ground-water levels, precipitation and other meteorological characteristics. In addition, water-quality samples were collected at each pond to characterize water quality.

Simulation of pond levels with the 1982 rainfall and hypothetical, fully developed watersheds did not result in pond stages greater than those observed in 1982.

Simulation of pond levels with rainfall having a 20-year recurrence interval (1978) and hypothetical, fully developed watersheds resulted in maximum pond stages above those observed in 1982. Peak stage of Tiedeman's Pond would increase by 2.77 feet, Stricker's Pond by 3.91 feet, and Esser's Pond by 1.44 feet.

Simulation of pond levels with an estimated 100-year rainfall and hypothetical, fully developed watersheds result in peak stage increases of 5.30, 5.32, and 1.97 feet above the peak 1982 observed stages for Tiedeman's, Stricker's, and Esser's Ponds, respectively.

INTRODUCTION

Urbanization of rural watersheds is changing the hydrologic characteristics of many small lakes. Inflow volume and the receiving water quality of such lakes are likely to change due to urbanization. However, the specific effects are difficult to quantify. Both resource managers and city planners need more information on how small watersheds and lake systems change as a result of urban devlopment.

Tiedeman's, Stricker's, and Esser's Ponds in Middleton, Wis., (fig. 1) are examples of ponds in watersheds that are changing from rural to urban. The watersheds of these ponds presently are less than 50 percent developed. However, all three watersheds are expected to be fully developed into medium-density residential areas within 10 years. The change in land use from primarily row crops to streets, sidewalks, and lawns will increase each watershed's hydraulically connected imprevious area and increase runoff to the ponds. None of the ponds has a surface-water outlet; therefore, increased water levels is a likely result of developing the three watersheds.

This study was done by the U.S. Geological Survey in cooperation with the cities of Middleton and Madison, Wis. The three ponds studied are within the city of Middleton's jurisdiction, but two of the three have significant portions of their watershed within the city of Madison.

Purpose and Scope

The purpose of this study is to determine the effects of urbanization on the water levels of Tiedeman's, Stricker's, and Esser's Ponds in the Middleton, Wis., area (fig. 1). The effects of future watershed urbanization with various amounts of rainfall were estimated and presented in this report. An additional purpose of the study is to document existing (1982) nutrient and chloride conditions of the three ponds.

The scope of the study included data collection to determine the water balance of the three ponds. Stage observations and water-quality sampling were done at each pond and ground-water observation wells installed adjacent to the ponds. A meteorologic observation station was installed adjacent to Stricker's Pond to measure air temperature, rainfall, evaporation, and windspeed. The surface-water temperature of Stricker's Pond was also measured. The hydrologic model used to simulate water budgets and anticipated urbanization conditions was calibrated by use of data collected during the 1982 study period.

The study was performed, as follows:

1. Hydrologic data for the three ponds and their watersheds were obtained for the period September 1981 through early November 1982.

2. Nutrient and chloride concentrations in the ponds were sampled seasonally to document existing conditions.

3. A digital-computer model was developed to simulate a water balance for the ponds and to simulate future watershed urbanization conditions.

4. Two-, 20-, and 100-year recurrence interval rainfalls were used to simulate pond water levels for fully urbanized conditions. The rainfall season was defined as the period from April 15 through November 5, and measured as the total precipitation during that period.

Acknowledgments

The author wishes to acknowledge the financial support of the cities of Madison and Middleton making this study possible. The city of Middleton also provided personnel to construct and install two instrument shelters at Tiedeman's and Stricker's Ponds. The University of Wisconsin-Madison, Department of Civil Engineering, also provided additional ground-water seepage information for each pond.

DESCRIPTION OF MIDDLETON PONDS AND WATERSHEDS

The three ponds were in various stages of watershed development during the study period. Tiedeman's Pond had the most watershed development, and Esser's Pond the least. All three ponds are located in closed watershed drainage areas (fig. 1). There is no continuous source of surface-water inflow to any of the ponds, nor is there any surface-water outlet from any pond at normal pond elevations. Details of the conditions existing during the period of October 1981 through November 1982 are presented in the following sections.

Tiedeman's Pond

Tiedeman's Pond has a drainage area of 0.43 mi^2 (watershed 1, fig. 1). The pond watershed is approximately 28 percent developed (1982 study period). About half the drainage area lies within the city of Madison. The normal pond surface area is approximately 15 acres at an elevation of 910.0 ft. There is no surface-water outlet at any observed pond water level. The area adjacent to the pond is currently a medium-density[1] residential area. The city of Middleton park along the western and southwestern edge of the pond prevents further development adjacent to the pond. Three storm sewers discharge into the pond from the adjacent residential areas. The area immediately east of Gammon Road is under residential development, and the far southeastern area of the watershed is a light-density[2] residential area.

Stricker's Pond

Stricker's Pond has a drainage area of 0.87 mi^2 (watershed 2, fig. 1). Stricker's Pond has the largest watershed of the three study ponds having over twice the drainage area of the other two ponds. Approximately 22 percent of the watershed is developed (1982 study period). More than half the

[1] Medium-density residential areas typically have 20 to 35 percent hydraulically connected impervious areas.

[2] Light-density residential areas typically have 5 to 20 percent hydraulically connected impervious areas.

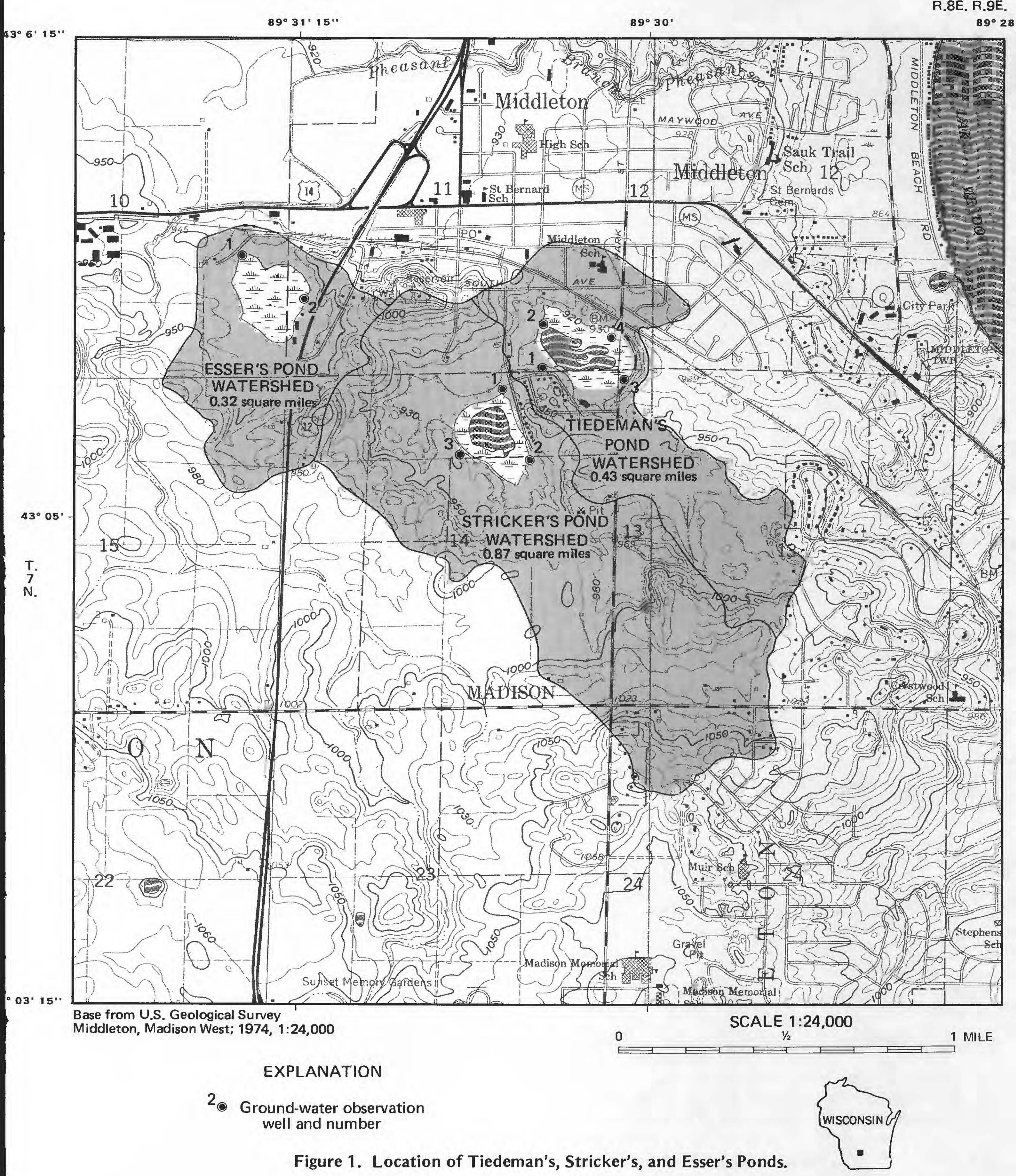

Figure 1. Location of Tiedeman's, Stricker's, and Esser's Ponds.

drainage area lies within the city of Madison. The normal pond-surface area is approximately 10 acres at an elevation of 920.2 ft. Stricker's Pond will drain eastward and spill into Tiedeman's Pond at water levels above 927.3 ft elevation. Medium-density residential areas are adjacent to the east and west edges of the pond. The northern edge of the pond is a greenway that acts as a buffer to the developed area to the north. The area to the south of the pond is used for agriculture. A large storm sewer draining the watershed southeast of the pond discharges into the south edge of the pond area. The area east of Gammon Road is undergoing rapid development. Areas to the south of Old Sauk Road are already developed as medium-density residential areas.

Esser's Pond

Esser's Pond watershed has a drainage area of 0.32 mi^2 and is the smallest of the three watersheds (watershed 3, fig. 1). The normal pond surface area is approximately 15 acres at an elevation of 928.0 ft. The "pond" was actually a cattail marsh during the 1982 study period. The watershed is essentially undeveloped (1982). At water levels above 934.0 ft elevation, Esser's Pond will drain to the west into the South Fork of Pheasant Branch Creek. The area adjacent to the pond and most of the watershed are in agricultural use. There are some scattered commercial facilities, most to the east of U.S. Highways 12 and 14.

HYDROLOGY OF MIDDLETON PONDS AND WATERSHEDS

Ground- and Surface-Water Levels

Continuous-stage recorders were installed at Tiedeman's and Stricker's, Ponds in September 1981 and operated during open-water periods until mid-November 1982. A staff gage was installed at Esser's Pond and read weekly.

Ground-water observation wells were installed within 150 ft of each pond to monitor the ground-water levels. Four wells were installed around Tiedeman's Pond, three around Strickers Pond, and two around Esser's Pond (fig. 1). Water levels in these observation wells were read weekly by city of Middleton observers. A previous study by the U.S. Geological Survey has concluded that the regional ground-water flow is eastward from the ponds toward Lake Mendota (U.S. Geological Survey Water-Supply Paper 1779-U).

Recorded surface-water levels for Tiedeman's Pond ranged from a low of 909.30 ft in October 1982 to a high of 910.76 ft in May 1982. The average pond elevation was 910.05 ft. The highest ground-water elevation observed was 906.26 ft in November 1982. Ground-water elevations for the eastern edge of the pond were consistently 3 to 6 ft lower than the western edge ground-water elevations. This indicates ground-water flow to the east-northeast towards Lake Mendota.

Recorded surface-water levels for Stricker's Pond ranged from a low of 918.73 ft elevation in October 1982 to a high of 922.49 ft in April 1982. The average pond elevation was 919.97 ft. The highest ground-water elevation observed was 912.76 ft in April 1982. The southwestern ground-water elevation was consistently about 3 ft higher than the southeastern and northern elevations. This also indicates ground-water flow toward Lake Mendota.

The staff gage readings for Esser's Pond indicate that the lowest surface-water level of 928.88 ft occurred in August 1982; the highest level of 930.49 ft occurred in April 1982. The highest ground-water elevation observed was 926.42 ft in April 1982. The northwest ground-water elevation was consistently from 8 to 10 ft higher than the east edge ground-water elevation.

For each of the three ponds, the highest observed ground-water elevation is below the lowest pond water-surface elevation and also below the pond-bottom elevation. This suggests recharge to the local water table beneath each pond. Figure 2 depicts the general relationship between the pond water level, pond bottom, local water table, and the observation wells.

Water Quality of Ponds

The three ponds were sampled seasonally for nutrients and chlorides during the study period to document existing conditions. Each pond was sampled at three surface locations each time to determine an average concentration value. The samples were analyzed for total nitrogen, total phosphorus, and dissolved chlorides. The results of these analyses are shown in table 1.

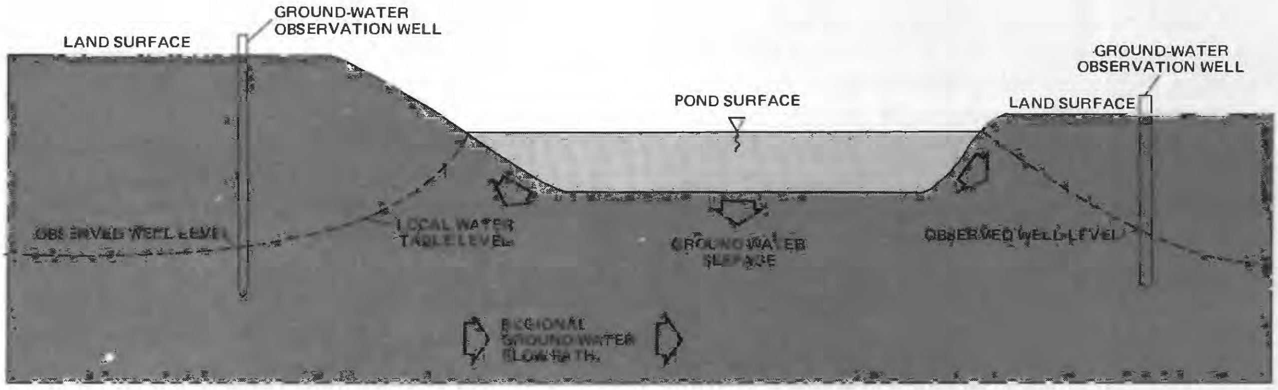

Figure 2. General relationship between pond water level, pond bottom, local water table, and observation wells.

The water-quality samples of September 1981 were collected after a major thunderstorm that raised water levels on all three ponds over 0.5 ft. These samples reflect watershed runoff contributions to the nutrient and chloride concentrations. Esser's Pond had far higher nitrogen and phosphorus concentrations, probably due to runoff from the surrounding agricultural area. Stricker's Pond had greater nitrogen and phosphorus concentrations than Tiedeman's Pond; also probably due to runoff from the agricultural area to the south of the pond. Tiedeman's Pond had the greatest chloride concentration. This may be due to runoff from the adjacent residential area and storm-sewer inflow. Chloride was not determined at Esser's Pond because extremely turbid water conditions clogged the filtering apparatus.

Water-quality samples were collected in December 1981 before the ponds froze. Tiedeman's Pond had the greatest nitrogen concentration--more than twice the September concentration. Nitrogen and phosphorus concentrations for Stricker's and Esser's Ponds were lower in December than in September. Dissolved chloride concentrations were greater in December than in September for Tiedeman's and Stricker's Ponds.

The April 1982 water-quality samples were collected after the spring runoff at relatively high pond levels. The large pond water volumes makes concentration comparison with other periods difficult. However, Tiedeman's Pond had the highest total nitrogen concentration; it had nearly twice the concentration of the other two ponds.

The August 1982 water-quality samples were collected after a long summer dry period. Esser's Pond nutrient concentrations were more than double those in April. Nutrient concentrations for Stricker's and Tiedeman's Ponds were similar to those in April. Chloride concentrations in all three ponds were generally lower than those in April.

The April concentrations of nitrogen and phosphorus greatly exceed the critical spring season eutrophic levels of 0.3 milligrams per liter (mg/L) and 0.01 mg/L identified by Sawyer (1947) for Wisconsin lakes. All three ponds exhibit nuisance growths of algae and macrophytes during the summer and fall. This is typical of small ponds and impoundments located in southern Wisconsin.

Meteorologic Conditions

A meteorologic station was established next to Stricker's Pond to collect data needed to construct a water budget for the ponds. The data collected include daily precipitation, daily pan evaporation, daily pan maximum and minimum water temperature, and windspeed. An accumulating mileage wind meter was installed 3 ft above the pond surface and read weekly to determine average windspeed for the period. Stricker's Pond surface water temperature was measured using a thermistor probe connected to a 5-minute recorder. Meteorologic data were collected during October and November of 1981 and from April through November of 1982.

Daily precipitation data have been collected at the University of Wisconsin Charmany Farms observation station (National Oceanographic and Atmospheric Administration, 1964-82) located approximately 2 mi southeast of the Stricker's Pond station. An annual summary of this data is presented in table 2. The 1982 rainfall was 2.3 percent above the average total for the 1964-82 period. The maximum 1978 precipitation was 22.7 percent greater than the 1982 total.

Daily pan evaporation at the Stricker's Pond site ranged from 0.00 to 1.30 cm/d. Average daily pan evaporation was 0.37 cm during the period from April 15 through November 5, 1982. Total pan evaporation during this period was 75.56 cm. There was no nearby long-term evaporation station with which to compare records.

A summary of 1982 monthly average air temperature, evaporation pan water temperature, and Stricker's Pond water temperature are shown in table 3. These data are presented to document the meteorologic conditions that existed during the study period. The daily average air and pan water temperatures used to derive the monthly data shown in the table were determined as the average of the high and low temperature readings for the day. Air temperature data are from the University of Wisconsin Charmany Farms station.

Table 1. Summary of chemical analysis of water from ponds

[Results in milligrams per liter]

		Total nitrogen (N)	Total phosphorus (P)	Chloride (Cl)
Stricker's Pond	[1] Sept. 2, 1981	1.8	0.36	6
	[2] Dec. 3, 1981	.25	.13	8
	[3] Apr. 13, 1982	1.3	.19	20
	[4] Aug. 12, 1982	.87	.18	11
Tiedeman's Pond	[1] Sept. 2, 1981	.97	.26	20
	[2] Dec. 3, 1981	2.9	.21	48
	[3] Apr. 13, 1982	2.5	.26	35
	[4] Aug. 12, 1982	2.3	.51	31
Esser's Pond	[1] Sept. 2, 1981	2.8	1.3	---
	[2] Dec. 3, 1981	1.8	.55	35
	[3] Apr. 13, 1982	1.2	.32	17
	[4] Aug. 12, 1982	2.8	.73	8

[1] Sampled after major thunderstorm runoff.
[2] Sampled after fall mixing before freezeup.
[3] Sampled after spring thaw.
[4] Sampled late summer dry period.

Table 2. Summary of total annual precipitation at U.W. Charmany Farms

Calendar year	Total precipitation (in.)	Calendar year	Total precipitation (in.)
1982	31.69	1972	28.99
1981	31.76	1971	29.02
1980	33.17	1970	28.63
1979	30.36	1969	30.90
1978	38.89	1968	36.37
1977	31.17	1967	32.73
1976	22.72	1966	26.51
1975	31.51	1965	31.69
1974	31.91	1964	23.70
1973	36.78	Records prior to 1964 not available	

Average annual total precipitation, 1964-82 = 30.97 in.
Maximum annual total in 1978, 38.89 in.
Minimum annual total in 1976, 22.72 in.

Table 3. Summary of monthly average air and water temperatures, April through November, 1982

Month	Average air temperature[3] (°C)	Average evaporation pan temperature (°C)	Average Stricker's Pond temperature (°C)
April[1]	9.3	12.7	13.0
May	14.7	20.1	19.5
June	15.8	20.6	21.4
July	21.4	26.0	25.6
August	19.1	23.2	[4] 20.5
September	14.0	18.5	[5] 18.2
October	9.8	11.8	---
November[2]	4.5	5.3	---

[1] Period April 15-30.
[2] Period November 1-5.
[3] Based on the daily average of maximum and minimum observed temperatures.
[4] Recorder malfunctioned August 3-16, average based on August 17-31 period.
[5] Average based on September 1-17 period only.

SIMULATION OF WATERSHED DEVELOPMENT

Simulation of daily average water levels in the three ponds was accomplished with a digital computerized hydrologic model developed specifically for this study. The model was calibrated for existing watershed conditions with observed water levels during the period April 15 through November 5, 1982. After calibration was completed, the model was used to simulate water levels in each pond for various watershed development and rainfall conditions. The details of the model development, calibration, calibration results, and future condition simulations are presented in the following sections.

Model Development

The digital water-budget model was developed to simulate the hydrologic processes depicted in figure 3.

The water budget for the ponds can be mathematically described as:

$$\Delta S = RAIN + INFLOW1 + INFLOW2 - SEEPAGE - EVAP - OUTFLOW$$

where:

ΔS = change in pond storage volume,

RAIN = direct rainfall volume over pond surface,

INFLOW1 = storm runoff inflow volume from hydraulically connected watershed impervious areas,

INFLOW2 = storm runoff inflow volume from pervious watershed areas (overland flow),

SEEPAGE = pond volume lost due to ground-water seepage,

EVAP = pond volume lost due to pond surface evaporation, and

OUTFLOW = pond volume lost through a surface-water outlet.

There are no surface-water inflow streams or significant ground-water inflows to any of the ponds.

The model operates on a daily computation interval. Each day the model adds the volume of rain falling directly on the pond surface (direct precipitation) along with any watershed runoff volume to the pond volume existing at the start of the day. The model subtracts the volume of pond surface evaporation and seepage out the pond bottom. After computing the resulting pond volume and stage, any volume in excess of a specified overflow elevation is removed and the stage lowered to that elevation. The overflow volume is assumed lost to overland infiltration. No computation was included for ground-water inflow because the observation wells indicated there would not be any.

The model has three main computational elements. There is a rainfall-runoff computation program that determines pond inflow from the watershed. Runoff from the hydraulically connected impervious areas (streets, sidewalks, and driveways)

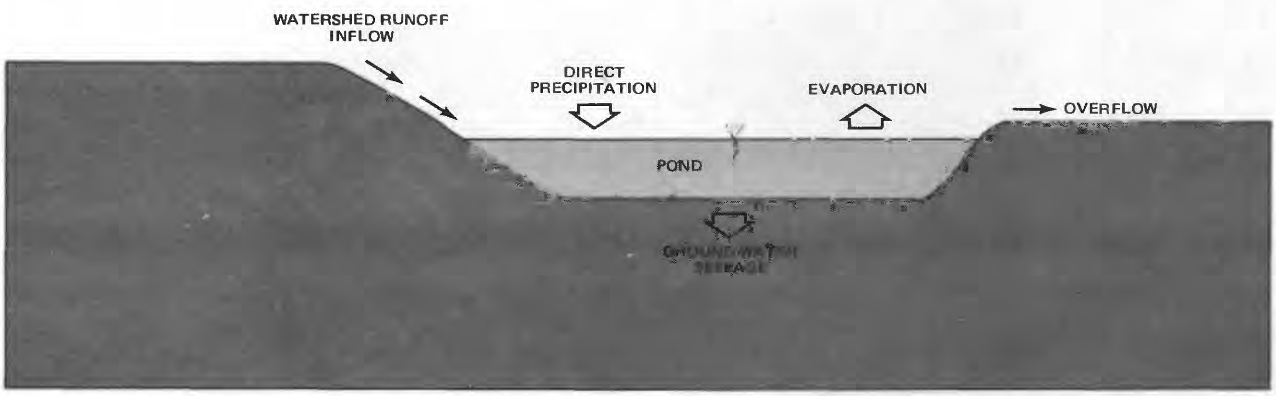

Figure 3. Components of the simulated water budget.

is computed separately from other areas. The model also has a water-budget accounting routine to compute net gain or loss in pond volume, and a pond volume-elevation curve routine to compute resulting pond stage. The resulting stage approximates a daily mean stage value.

Input data to the model include daily precipitation, daily pond-surface evaporation, pond elevation-area geometry, pond watershed area, and a set of computation control parameters. These computation control parameters include initial condition data, watershed land-use parameters, ground-water seepage rate parameters, and optional factors to adjust the input precipitation and evaporation data.

Outputs from the model are a daily listing of computed pond stage, and the volumes of impervious area runoff, pervious area runoff, direct precipitation, evapotranspiration loss, and ground-water seepage loss. Volume totals for each component are provided in a summary at the end of each simulation.

The model uses the U.S. Soil Conservation Service method to compute runoff from the pervious areas of the watershed (Soil Conservation Service, 1972). This method involves using an appropriate "curve number" to reflect the land use in the watershed. The curve number relates to the initial rainfall abstraction depth and the percent of remaining rainfall depth that produces runoff. The initial abstraction depth accounts for rainfall interception storage, immediate infiltration, and ground surface depression storage. The percentage of remaining rainfall depth that does not produce runoff is assumed lost to overland flow infiltration.

Runoff from the hydraulically connected impervious areas such as streets and sidewalks occurs after rainfall equals a detention-storage depth. The model keeps track of the current detention-storage depth and adjusts it daily for rainfall and evaporation.

Precipitation and evaporation volumes are computed directly with daily precipitation and evaporation input data. The volume of water gained from precipitation is computed by multiplying the pond-surface area by the precipitation depth for the day. The volume of water lost by evaporation is similarly computed. An average pond-surface area for the day is used in the computations.

Ground-water seepage is computed by multiplying the pond-surface area by the seepage rate. The seepage rate is computed by an equation that relates pond stage above a specified elevation to a daily seepage rate in inches per day. This equation reflects the increase in seepage volume due to increasing water pressure and increasing pond-surface area.

The model does not compute a ground-water inflow because observation wells around each pond show that the ground-water gradient is away from the ponds.

The model computes the water volume in the pond at the end of each day by adding all inflows and subtracting all outflows from the water volume present at the start of the day. An interpolation method is applied to the pond storage-elevation data to compute the new pond elevation.

Model Calibration

Input Data

The model was calibrated for each pond by comparing simulated pond stage to observed stage for the period April 15 through November 5, 1982. Daily precipitation and evaporation records from the Stricker's Pond meteorologic station were used as input. The daily pan evaporation values were modified using a U.S. National Weather Service (NWS) equation (Linsey, Kohler, Paulus, 1982) to estimate actual pond-surface evaporation. The NWS equation related pan evaporation, pan water temperature, wind speed, and air temperature to pond-surface evaporation.

The drainage area for each pond was determined from U.S. Geological Survey 7½ minute topographic quadrangle maps of the area. Drainage boundary divides were verified by field inspection. The elevation-surface area data for each pond was determined from 2-ft contour interval maps provided by the city of Middleton. The Soil Conservation Service (SCS) land-use curve numbers were determined for each watershed's pervious area by field inspection and use of aerial photographs. Hydraulically connected impervious areas were estimated using 1-in to 100-ft scale maps of the study area that show impervious street, sidewalk, and apartment rooftop areas.

Parameter Adjustment

Several model parameters were adjusted to obtain better agreement between simulated and observed pond stage.

The detention-storage depth parameter for the impervious watershed areas was adjusted using low-intensity storm data that did not produce pervious area (overland) runoff to the ponds. The land-use curve numbers and percent impervious area parameters were adjusted using data from larger storms that produced overland runoff to the ponds.

Ground-water seepage rates were estimated for each pond using stage record analysis during periods of little or no precipitation. Initial estimates were made in part using results of a University of Wisconsin class project (oral commun., Potter, 1983). The seepage-rate equations were adjusted to compute the estimated seepage rates for the 1982 record period.

The parameters used in the final model calibration are given for each pond in table 4. The ground-water seepage-rate equation used is also shown for each pond in the table. A graphical comparison of simulated versus observed pond stage for the period April 15 through November 5, 1982, is shown in figure 4. There is good agreement between simulated and observed pond stage for each pond.

All three ponds have generally declining water levels throughout the simulation period because evaporative and seepage losses exceed direct precipitation and runoff inflow.

It was determined in the calibration process that the most sensitive parameters were the seepage-rate

Table 4. Model-calibration parameters

Calibration parameter	Tiedeman's Pond	Stricker's Pond	Esser's Pond
Drainage area (square mile)	[1] 0.35	0.87	0.32
Percent impervious	7.5	6.0	0.0
Retention storage depth (in.)[2]	.35	.35	N/A
Pervious area curve number[3]	66	68	81
Maximum seepage rate (inch per day)	.168	.539	.214
Minimum seepage rate (inch per day)	.075	.101	.042

Ground-water seepage rate equation: (Inches per day)[4]
Seepage rate = [(pond stage - A) X B] + C

Coefficient 'A'	908.0	918.0	925.5
Coefficient 'B'	.050	.131	.100
Coefficient 'C'	.020	.018	- .280

[1] 0.08 of the 0.43 mi^2 area did not contribute runoff in 1982.
[2] For hydraulically connected impervious areas only.
[3] Includes lawns and nonconnected impervious areas.
[4] Pond stage given in mean sea level elevation.

coefficients. Small changes in the coefficients result in large differences in simulated pond stages. The coefficients determined by calibration give good results for the 1982 range of pond stages. However, use of these coefficients to simulate higher pond stages is less reliable.

Simulated Conditions and Results

The hydrologic model was used to simulate pond stages for various rainfall and watershed conditions. An analysis of the University of Wisconsin Charmany Farms rainfall records indicated that the 1982 rainfall total was approximately the 2-year recurrence interval total. The 1978 rainfall approximates the 20-year recurrence interval total. The 100-year recurrence interval rainfall total was estimated by extrapolating a frequency plot of the annual Charmany Farms total rainfall. This extrapolation indicated a rainfall total equal to 41.5 in., or the 1978 total plus 14.4 percent. Therefore, the 100-year recurrence interval rainfall record for the model was estimated by increasing the 1978 daily values by 14.4 percent.

The 1982 daily evaporation data was used in all simulations. No evaporation data for other years was available for the study area. This assumption should not result in significant errors in peak stage because total inflow volume is great compared to evaporation loss during intense storm events.

All five simulated conditions are for the period April 15 through November 5. The five conditions simulated are as follows:

Condition no. 1 simulated the existing 1982 watershed development with the observed 1982 rainfall record (the 2-year recurrence interval

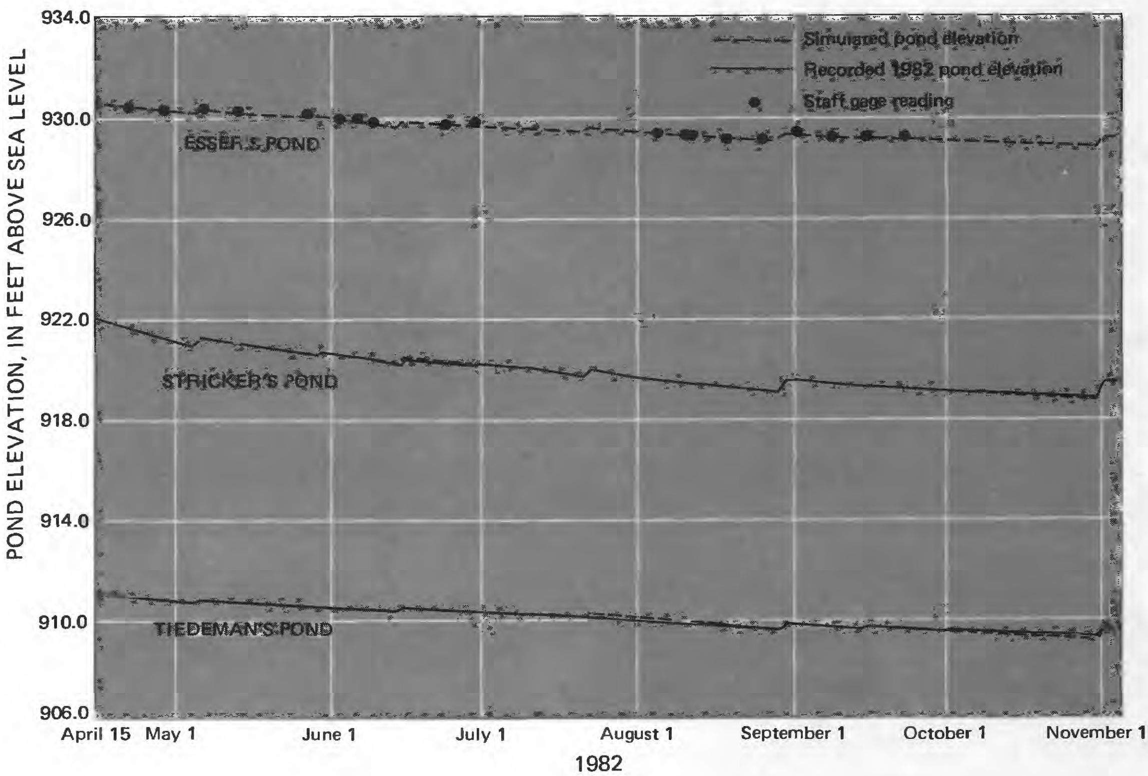

Figure 4. Comparison of simulated and recorded 1982 stages at Tiedeman's, Strickers, and Esser's Ponds.

rainfall). A plot of the simulated pond stage is shown in figure 3 for each pond. All other simulated conditions are shown compared to the 1982 existing conditions in figures 5 through 8. Note that these stages are daily mean values.

Condition no. 2 simulated fully developed watershed conditions with the 1982 (2-year) rainfall record. The hydraulically connected impervious area was increased to 27 percent of the drainage areas to reflect medium-density residential development. The drainage area of Tiedeman's Pond was increased to the full 0.43 mi^2 from the 0.35 mi^2 used in condition no. 1, as it was felt the total area would contribute runoff when fully developed. The land-use curve numbers for the pervious areas of Stricker's and Esser's Ponds watersheds were reduced to 66 from 68 and 81, respectively. This was done to account for the change from the existing agricultural use into the lawns and park areas of a residential neighborhood. Plots of the simulated pond stages are shown in figure 5.

Condition no. 3 simulated the existing (1982) watershed land-use conditions with the 1978 (20-year) rainfall record. It was felt that the full 0.43 mi^2 of Tiedeman's Pond drainage area would contribute runoff under such rainfall conditions. The curve numbers used and percent of hydraulically connected impervious area are the same as for condition no. 1. Plots of the simulated pond stages are shown in figure 6.

Condition no. 4 simulated fully developed watershed conditions with the 1978 (20-year) rainfall record. The starting pond elevations were increased 1 ft to account for the spring thaw runoff prior to the April 15 simulation start from increased connected impervious areas. Land-use curve numbers and percent impervious values were the same as for condition no. 2. Plots of the simulated pond stages are shown in figure 7.

Condition no. 5 simulated fully developed watershed conditions with an estimated 100-year recurrence interval rainfall record. The starting pond elevations were increased by 1 ft as in condition no. 4, and the percentage of impervious areas was as in condition no. 2. Land-use curve numbers were increased to 82 for all ponds to reflect the very wet antecedent moisture conditions likely to occur under such extreme rainfall conditions. Plots of the simulated pond stages are shown in figure 8.

A summary of simulated conditions and results is given in table 5.

For condition no. 1 (existing 1982 development, 2-year rainfall), the largest source of water to the ponds is direct precipitation. Runoff volume from hydraulically connected impervious areas of Tiedeman's and Stricker's Ponds watersheds greatly exceeds that from pervious areas of the watershed. The peak daily mean pond stage for each pond equals the initial simulation starting elevation because the ponds steadily lost net volume for the duration of the simulation period.

For condition no. 2 (fully developed watershed, 2-year rainfall), the largest source of inflow to Tiedeman's and Stricker's Ponds is from the hydraulically connected impervious areas. Direct precipitation is the largest source of inflow to Esser's Pond due to the large pond-surface area relative to the total watershed area. There was no increase in maximum pond stage above that simulated for condition no. 1 because similar net water loss conditions prevailed.

For condition no. 3 (existing 1982 development, 20-year rainfall), the largest source of inflow to Tiedeman's Pond was direct precipitation. However, the largest source of inflow to Stricker's Pond was from pervious area runoff. This was due to the greater pervious area of the Stricker's Pond watershed relative to the pond-surface area. The 20-year rainfall magnitude caused large pervious area runoff contributions that exceeded impervious area runoff for all three ponds. These greater inflow volumes resulted in peak daily mean stages greater than the 1982 existing development and rainfall. The peak daily mean stage simulated for Tiedeman's, Stricker's, and Esser's Ponds was 0.94, 1.21, and 1.41 ft, respectively, above that for the condition no. 1 simulation.

For condition no. 4 (fully developed watershed, 20-year rainfall), the largest source of inflow to all three ponds was the hydraulically connected impervious area runoff. Direct precipitation was the second largest source of inflow. Peak daily mean pond stage for Tiedeman's, Stricker's, and Esser's Pond was 2.77, 3.91, and 1.44 ft, respectively, above that simulated in condition no. 1.

For condition no. 5 (fully developed watershed, 100-year rainfall), the impevious and pervious areas

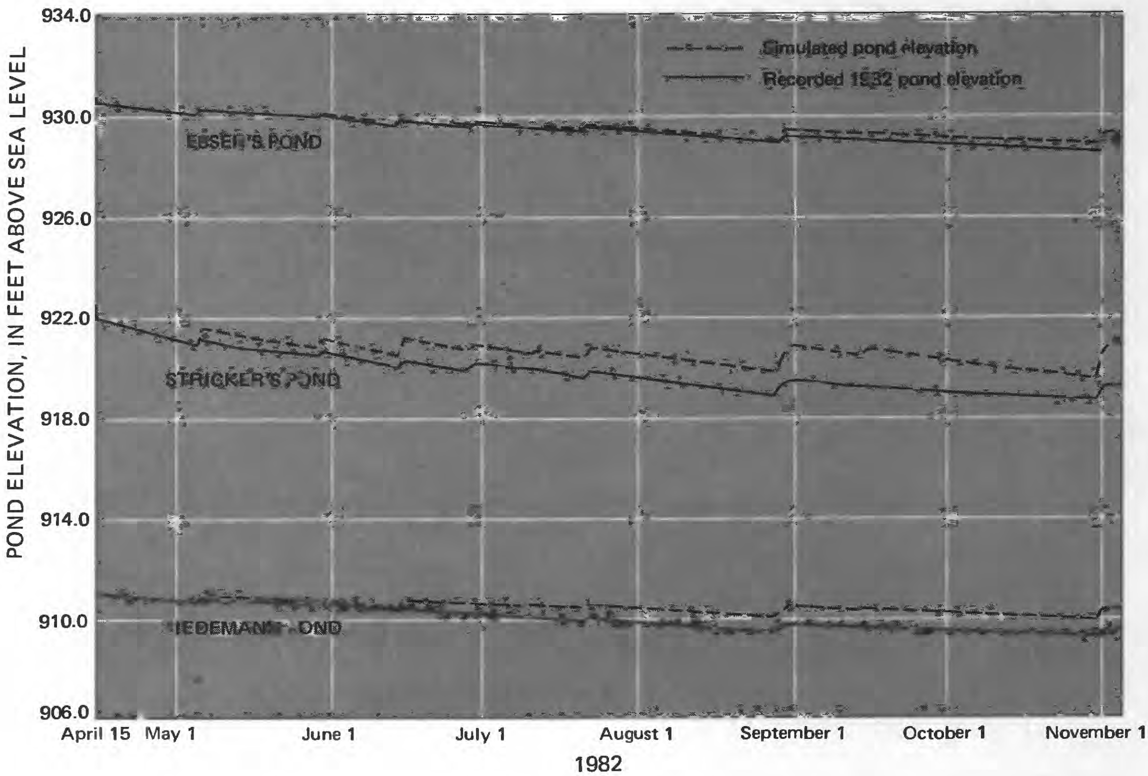

Figure 5. Comparison of simulated pond elevation for fully developed watershed with 2-year rainfall versus recorded 1982 elevations.

of each watershed contributed approximately equal volumes of runoff to each of the ponds. The direct precipitation volume was approximately equal for all three ponds. However, direct precipitation was the single largest source of inflow to Esser's Pond while it was the smallest source to Tiedeman's and Stricker's Ponds. This was due to the greater pond area relative to watershed area for Esser's Pond.

Peak daily mean pond stage was well above that simulated for condition no. 1 and also significantly above that simulated for condition no. 4. The peak daily mean pond stage for Tiedeman's, Stricker's, and Esser's Ponds was 5.30, 5.32, and 1.97 ft, respectively, above that simulated for condition no. 1. This would result in peak daily mean stage elevations of 916.26, 927.30, and 933.41 ft above sea level for Tiedeman's, Stricker's, and Esser's Ponds, respectively. These increased peak stages will result in shallow flooding of some structures adjacent to the ponds. The maximum flooding extent for each pond is shown on plate 1.

Tiedeman's Pond will flood Gammon Road adjacent to the pond's east edge at elevations above 913.90 ft. Condition no. 5 simulates this flooding condition for 146 of the 205-day simulation period.

Stricker's Pond will spill eastward into the Tiedeman's Pond watershed at elevations above 927.30 ft. Condition no. 5 simulates four such spillovers during the simulation period with a total duration of 14 days. This could result in an even higher peak stage for Tiedeman's Pond than shown in table 5 if the spillover from Stricker's Pond reaches Tiedeman's Pond as inflow. Some shallow flooding of structures in the flow path from Stricker's to Tiedeman's Pond is possible.

The increased peak stage of Esser's Pond is predicted to cause shallow flooding of the adjacent structures. If the peak stage of Esser's Pond exceeds 934.00 ft, a spillover westward into the South Fork of the Pheasant Branch Creek watershed would occur. Although condition no. 5 does not

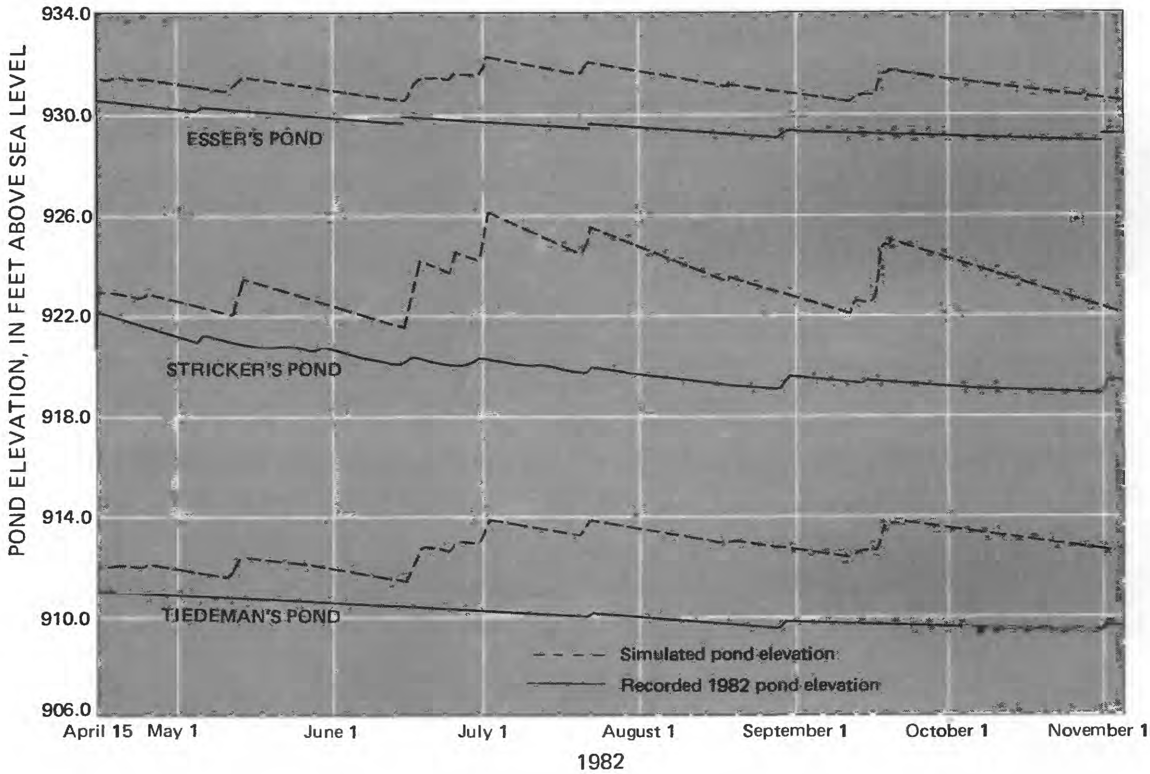

Figure 7. Comparison of simulated pond elevation for fully developed watershed with 20-year rainfall versus recorded 1982 elevations.

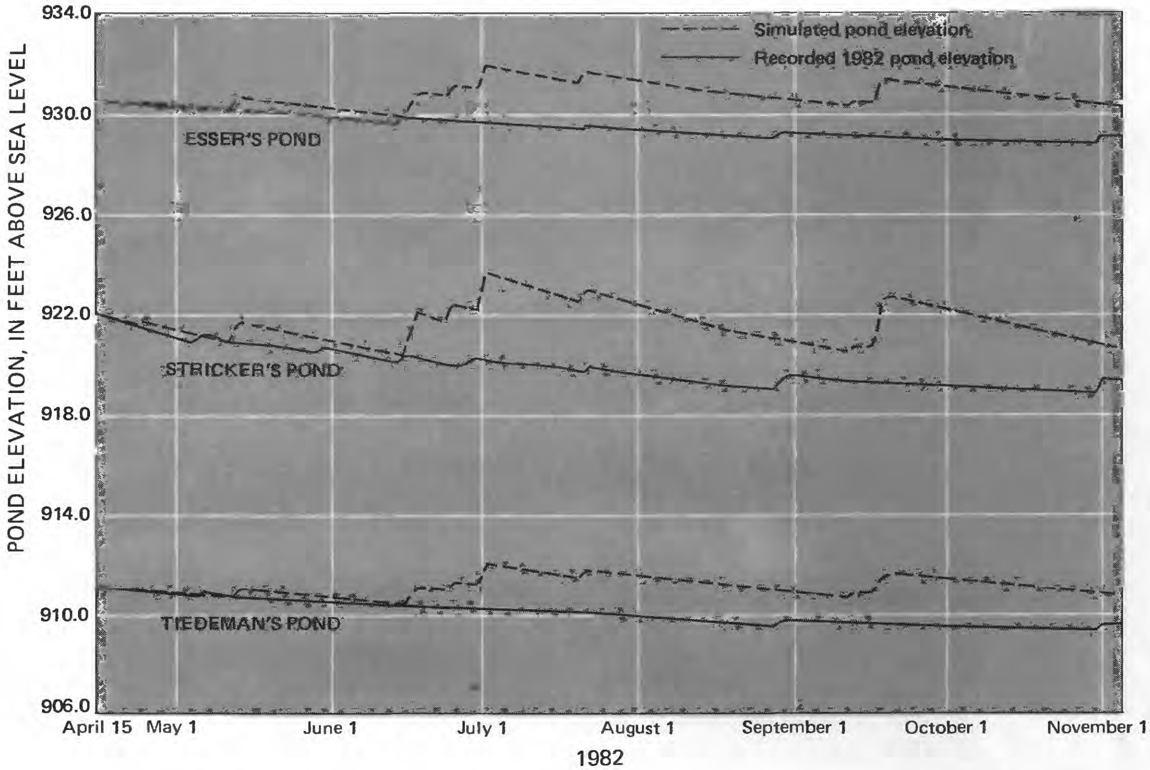

Figure 6. Comparison of simulated pond elevation for existing watershed development with 20-year rainfall versus recorded 1982 elevations.

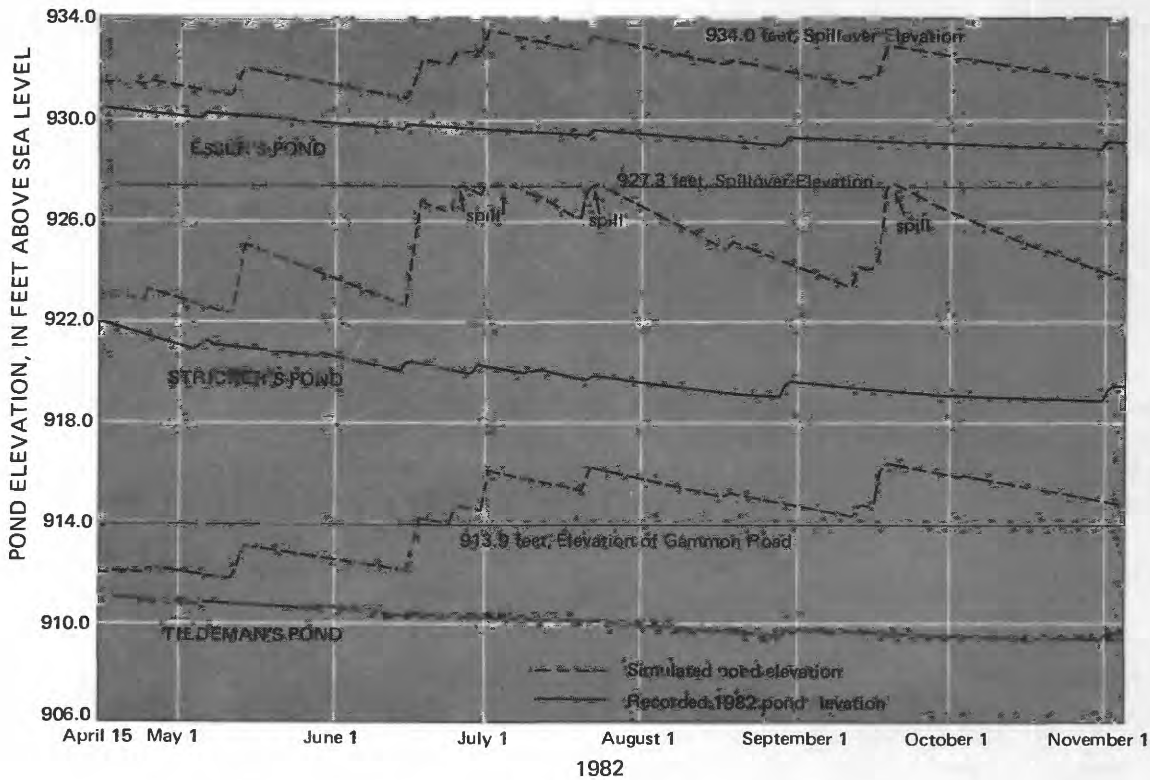

Figure 8. Comparison of simulated pond elevation for fully developed watershed with 100-year rainfall versus recorded 1982 elevations.

simulate such a spillover, it does indicate a peak stage less than 0.60 ft below the spillover elevation.

In addition to the specific flooding problems outlined above for condition no. 5, structures adjacent to any of the ponds may be subject to basement flooding if they have basement elevations below the peak pond elevation shown in table 5 for any condition.

SUMMARY AND CONCLUSIONS

The watershed, pond level, and meteorologic conditions were monitored on three ponds in Middleton during the 1982 open-water period. This information was used as input to calibrate a hydrologic model developed to simulate the effects of future watershed urbanization. In addition, water quality was monitored seasonally to document existing conditions.

All three pond watersheds are expected to be fully developed into medium-density residential neighborhoods. This will increase the hydraulically connected impervious area to an average of 27 percent of each watershed. The pervious area of each watershed will be correspondingly reduced and the land use changed from primarily row crops to urban lawns.

Analysis of past meteorologic records from the nearby University of Wisconsin Charmany Farms station indicated that the observed 1982 rainfall total had an approximately 2-year recurrence interval. Analysis of the nutrient samples collected from each pond indicated all three ponds exceeded eutrophic limits of nitrogen and phosphorus.

The hydrologic model was calibrated by adjusting model parameters so that simulated pond stage agreed with that observed from April 15 through November 5, 1982. The most sensitive model parameters were the coefficients of the groundwater seepage-rate equation. Other adjusted model parameters include impervious-area detention depth, connected impervious area in the watershed, and a pervious-area land-use curve number. An impervious-area detention depth of 0.35 in. was used to calibrate the model. The percentage of connected impervious area was 7.5, 6.0, and 0.0 for Tiedeman's, Stricker's, and Esser's Ponds watersheds, respectively. Land-use curve numbers for these three ponds were 66, 68, and 81, respectively.

After calibration, the model was used to simulate various watershed development and rainfall conditions for the period April 15 through November 5. The existing 1982 watershed development and observed rainfall was used as a comparison against other simulated conditions. The other conditions simulated were full watershed development with a 2-year recurrence interval (1982) rainfall record, existing watershed development with a 20-year rainfall, full watershed development with a 20-year rainfall, and a fully developed watershed with an estimated 100-year recurrence interval rainfall record.

The simulation of a fully developed watershed with the estimated 100-year rainfall record predicted numerous flooding problems would occur adjacent to each pond. The peak daily mean stage of Tiedeman's, Stricker's, and Esser's Ponds would rise 5.30, 5.32, and 1.97 ft, respectively, above those simulated for the 1982 existing conditions. This would result in Tiedeman's pond flooding Gammon Road; Stricker's Pond would spill over into Tiedeman's Pond's watershed; and Esser's Pond would flood the existing buildings adjacent to it.

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Table 5. Summary of simulation conditions and results

	Percentage of impervious area	Rainfall record used	Pervious area curve number	Starting pond elevation (ft)	Maximum pond elevation (ft)	Impervious area runoff (acre-ft)	Pervious area runoff (acre-ft)	Direct precipitation volume (acre-ft)	Increase above 1982 peak (ft)
Tiedeman's Pond									
Condition No. 1	7.5	1982	66.0	910.96	910.96	8.3	0.8	27.5	N/A
No. 2	27	1982	66.0	910.96	910.96	37.0	.8	31.6	0
No. 3	7.5	1978	66.0	910.96	911.92	24.5	25.9	56.2	.94
No. 4	27	1978	66.0	911.96	913.73	106.9	24.7	76.9	2.77
No. 5	27	100 year	82.0	911.96	916.26*	127.6	125.0	96.6	5.30
*NOTE: Gammon Road low point elevation = 913.90 feet.									
Stricker's Pond									
Condition No. 1	6.0	1982	68.0	921.98	921.98	17.4	3.9	19.9	N/A
No. 2	27	1982	66.0	921.98	921.98	78.0	1.6	24.5	0
No. 3	6.0	1978	68.0	921.98	923.19	52.1	85.0	49.1	1.21
No. 4	27	1978	66.0	922.98	925.89	231.7	53.6	65.2	3.91
No. 5	27	100 year	82.0	922.98	927.30*	276.4	272.5	91.9	5.32
*NOTE: Pond spills into Tiedeman's watershed at elevation above 927.30 feet.									
Esser's Pond									
Condition No. 1	0	1982	81.0	930.44	930.44	0.0	16.4	36.9	N/A
No. 2	27	1982	66.0	930.44	930.44	26.3	.5	37.7	0
No. 3	0	1978	81.0	930.44	931.85	.0	89.0	66.9	1.41
No. 4	27	1978	66.0	931.44	932.88	77.0	17.8	72.2	1.44
No. 5	27	100 year	82.0	931.44	933.41	91.0	89.2	94.1	1.97