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INCORPORATION OF DISSOLVED OXYGEN IN AQUATIC HABITAT ASSESSMENT FOR THE UPPER SANGAMON RIVER

by
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CONTENTS

LIST OF TABLES

LIST OF FIGURES

INCORPORATION OF DISSOLVED OXYGEN IN AQUATIC HABITAT ASSESSMENT FOR THE UPPER SANGAMON RIVER

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INTRODUCTION

Dissolved oxygen content in streams and rivers is a leading water quality parameter. The viability of the stream aquatic habitat is dependent upon a sufficient supply of oxygen; below critical concentration levels, streams may become uninhabitable for various fish species. Also, oxygen requirements may vary from species to species. Availability of dissolved oxygen must be considered for indigenous species in the evaluation and protection of aquatic habitats in streams and rivers.

The overall goal of this investigation was to incorporate an assessment of dissolved oxygen availability with an evaluation of aquatic habitat suitability of the main Sangamon River up to Lake Decatur. Historical water quality data collected at stations in the Ambient Water Quality Monitoring Network (AWQMN) in the basin as well as field measurements of water quality parameters were used to develop relations to assess the availability of oxygen along the study reach. The dissolved oxygen assessment was integrated with a basinwide flow model previously developed for evaluation of aquatic habitats, which follows the precepts of the Instream Flow Incremental Methodology (IFIM). The availability of suitable aquatic habitat was computed for selected stream segments along the main Sangamon for various flow conditions to illustrate the model results.

Acknowledgments

This study was jointly supported by the Division of Water Resources, Illinois Department of Transportation, and the Illinois State Water Survey (ISWS). Gary R. Clark of the Division of Water Resources served in a liaison capacity during the course of this study. This report was prepared under the general direction of Richard G. Semonin, Chief, and John M. Shafer, Head of the Hydrology Division, Illinois State Water Survey. Elizabeth Esseks performed calculations and data entry. Kathleen J. Brown typed and formatted the final report, and Eva Kingston edited the report.

BACKGROUND INFORMATION

Sangamon Basin

The Sangamon River Basin is located in central Illinois. At its confluence with the Illinois River, the Sangamon River has a drainage area of 5,452 square miles (sq mi). The stream network has three main branches: the Sangamon (main stem above Riverton, 1,445 sq mi drainage area); the South Fork Sangamon (883 sq mi drainage area); and Salt Creek (1,856 sq mi drainage area). Because of hydrologic and geomorphologic differences in the watersheds of these three streams, the Sangamon River Basin may be subdivided into three hydrologically homogeneous sub-basins corresponding to the three main tributaries. The study area of this investigation lies along the main Sangamon River above the dam that forms Lake Decatur (925 sq mi drainage area). Information on the geology, hydrology, stream slopes, and hydraulic geometry of the network of the three sub-basins is given by Singh et al. (1986) and Broeren and Singh (1990). The stream network of the entire basin is shown in Figure 1.

The Illinois Environmental Protection Agency (IEPA) uses five levels of aquatic life use support to classify streams: full support, full support/threatened, partial support/minor impairment, partial support/moderate impairment, nonsupport. The IEPA has assessed the aquatic life use support of a total of 1009.5 stream miles in the Sangamon River Basin. Of these, 16.8 miles (1.7%) were classified nonsupportive of aquatic life; 89.0 miles (8.8%) were classified partial support/moderate impairment; 639.1 miles (63.3%) were classified partial support/minor impairment; and 264.6 miles (26.2%) were classified fully supportive of aquatic life use (IEPA, 1990). The upper Sangamon (above Lake Decatur) has considerable agricultural nonpoint runoff, resulting in elevated levels of nutrients and siltation, as well as several small municipal wastewater treatment facilities. The upper Sangamon was rated by the IEPA as having partial support/minor use impairment. While major tributaries to the upper Sangamon River; Goose Creek, Camp Creek, and Friends Creek; were rated as having full aquatic life use support. The reach immediately below Lake Decatur was rated as non-supportive of aquatic life use. Salt Creek and its tributaries account for approximately two-thirds of the stream miles that were rated as having full aquatic life use support. The majority of the South Fork Sangamon Basin was rated as having partial support/minor impairment.

Instream Flow Incremental Methodology

The Instream Flow Incremental Methodology (IFIM), developed by the Cooperative Instream Flow Service Group (IFG) of the U.S. Fish and Wildlife Service, is the state-of-the-art methodology for defining the relationship between flow parameters (depth, velocity, and substrate) and usable aquatic habitat. These parameters have been identified as the most significant hydrogeologic channel characteristics defining the suitability of the aquatic environment for various fish species (Stalnaker, 1979). Fisheries supported by a given water body are indicative of the overall stream habitat conditions as fish are an end product of the aquatic food chain and thus reflect not only satisfactory water quality for themselves but also a suitable habitat for food supply, shelter, and breeding sites (Hammer and MacKichan, 1981). By providing the link between flow and stream characteristics and aquatic habitat suitability, the IFIM can be used to assess if these characteristics are limiting factors to fisheries support or may become limiting with flow or channel modification. Similarly the potential of a stream to support aquatic life given adequate water quality may be assessed as well as the impact of measures to restore the habitat through incorporation of habitat enhancing channel structures or flow modification.

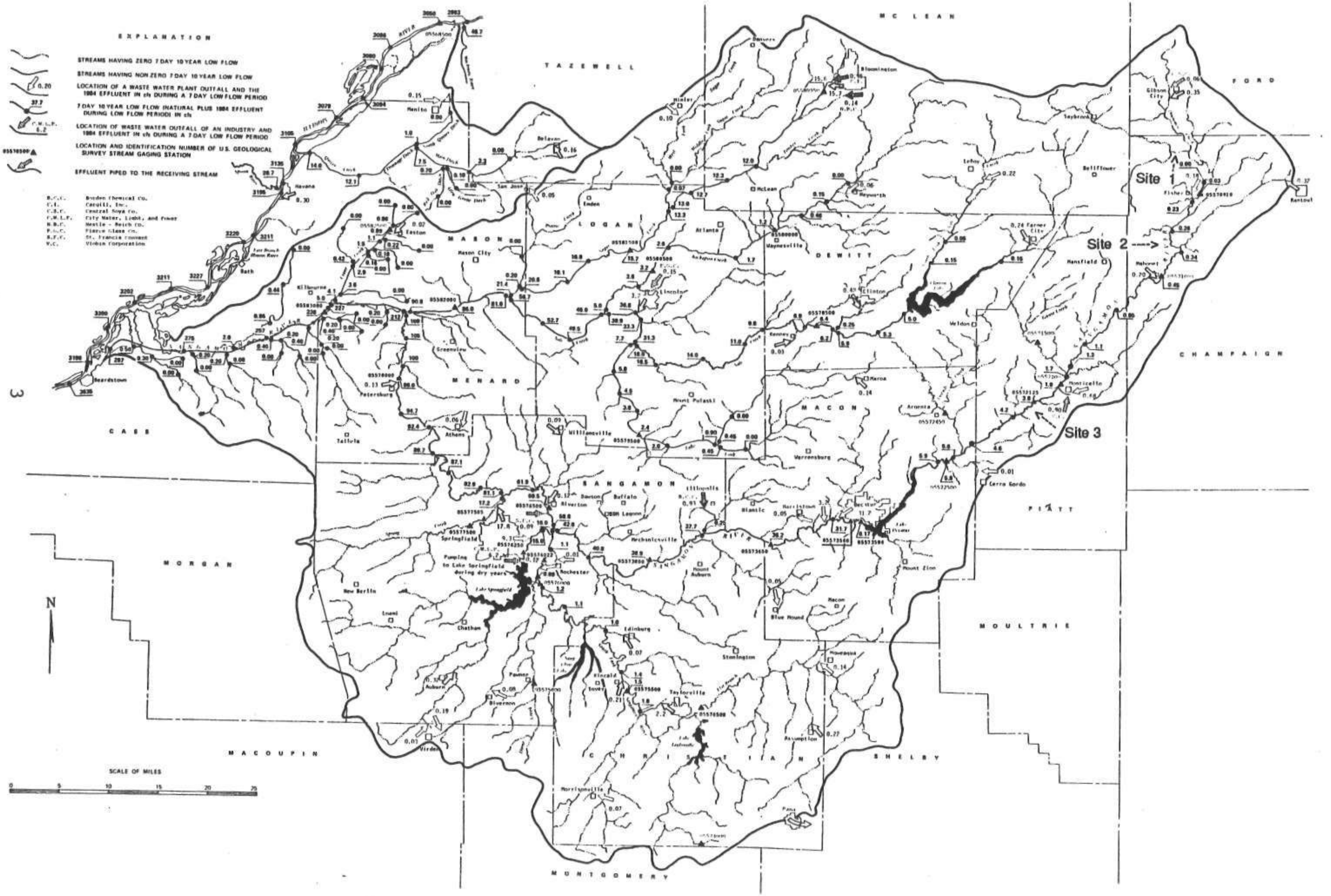

Figure 1. Sangamon basin map (after Singh et al., 1988)

The availability of useful habitat in a stream is quantified throughout the calculation of an index variable, the weighted usable area (WUA). The WUA of a stream can be computed for various fish species at different life stages under various flow conditions. Along a stream reach bed forms, such as riffles and pools, create a diversity of habitat conditions characterized by different substrates, depths, and velocities. In the IFIM the availability of different types of habitats is determined by conceptually segmenting the stream into cells. Each cell represents a different hydraulic environment characterized by local values of depth, velocity, and substrate. The utility of the environment in each cell is independently evaluated by fish preference indices for each of these three parameters (Bovee and Milhous, 1978; Bovee, 1982). The IFG has developed preference data (termed preference curves) for more than 500 fish species and is continuing research to improve and expand its database (Milhous et al., 1984). Habitat preference curves have been developed for Illinois fishes (Wiley et al., 1987) by the Illinois Natural History Survey (INHS). These curves were adopted for use in this study as they reflect local conditions. While beyond the scope of mis study, a comparison of the WUA calculated using the IFG and the INHS curves could demonstrate the sensitivity of the results for the Sangamon Basin. The WUA of a stream reach may be calculated by summing the product of the cell suitability index and the lateral flow surface area of the cell (a_i). At a selected discharge or flow duration this calculation is expressed mathematically as:

$$\mathrm{WUA} = \sum_{i=1}^{N} S(d_i) \times S(v_i) \times S(b_i) \times a_i \tag{1}$$

where N is the number of cells; S is the preference index value for depdi (d), velocity (v), or substrate (b) of cell i; d and v are functions of the selected discharge or flow duration; and a_i is the surface area of the cell. Local values of depdi, velocity, and substrate must be known to evaluate the WUA for a desired discharge or flow duration. The reach modeling grid must have a scale sufficiently small to simulate riffle and pool conditions.

Cover is another important component of the stream environment. The extent and type of existing cover along the stream network is a local condition mat must be determined by inspection. Stream projects that include changes in cover would require incorporation of this variable in the assessment.

The calculation of the WUA provides information on the suitability of the microhabitat defined by stream channel and hydraulic conditions. Other parameters that influence the habitability of a stream such as temperature (T) and dissolved oxygen (DO) are treated as macrohabitat parameters and determined for large segments or reaches in the stream network (Bovee, 1982). In the IFIM approach, water quality, as indicated by DO concentration, is evaluated first as part of a scoping process to identify potentially critical conditions. If the initial evaluation indicates water quality problems, a more intensive investigation is warranted. As part of the scoping process, an estimation of water quality may be gleaned from an evaluation of historical water quality data and a simplistic oxygen sag analysis or both. After the water quality of a stream segment is determined as suitable or unsuitable, the calculated WUA per unit stream length for a given discharge is multiplied by the length of stream having suitable water quality to support the specific fish, and thus the total WUA of the stream or basin is determined. Using multiple sites to characterize aquatic habitat conditions, the total habitat available for a given flow (HA) is calculated as:

$$HA = \sum_{i=1}^{n} WUA_i \times L_i \tag{2}$$

where n is the number of sites used to represent the stream or basin and L_i is the length of reach i with suitable water quality with weighted usable area, WUA;.

Basinwide Flow Model

Flow modeling of local depths and velocities is a critical aspect of the IFIM, because without the simulated hydraulic data the WUA could be determined only for field-measured flows. A methodology for basinwide flow modeling and habitat assessment using the IFIM has been developed and successfully applied to the Sangamon and Vermilion River Basins in Illinois (Singh and Broeren, 1985; Singh et al., 1986, 1987). The flow model relationships were developed using discharge equations defining discharge (Q) as a function of drainage area (DA). These equations are determined for each hydrologically homogeneous sub-basin. The relationship between Q and DA varies with flow duration. The equations are of the form:

$$Q_f = A_f + B_f\,(\log DA) \tag{3}$$

where f corresponds to the annual flow duration and the coefficients A and B vary with f. The coefficients determined for the Sangamon River up to Riverton are given in Table 1.

Table 1. Regression Coefficients for Discharge
Sangamon River up to Riverton
$\log Q_f = A_f + B_f(\log DA)$

	Annual flow duration, f								
	90	80	70	60	50	40	30	20	10
A_f	-2.8257	-2.2448	-1.7144	-1.1887	-0.7843	-0.5583	-0.3554	-0.0880	0.1903
B_f	1.3909	1.2864	1.2070	1.1220	1.0640	1.0507	1.0433	1.0222	1.0175

Basin hydraulic geometry relations are used to define average width (W), depth (D), and velocity (V) for a given flow duration for a stream reach with a specified drainage area. These relationships are determined from field measurements of W, D, and V routinely made by the U.S. Geological Survey (USGS) for establishing rating curves at gaging stations. These measurements are typically taken in relatively shallow areas and the results tend to reflect more riffle-like flow conditions. The hydraulic geometry equations derived by Broeren and Singh (1990) for the natural sections of the Sangamon River up to Riverton are:

for low flows, annual flow duration 90 to 60 percent:

$$\log W = 1.454 - 2.107 \times F + (0.352 + 0.356 \times F) \log DA \tag{4}$$

$$\log D = 0.213 - 1.794 \times F + (0.232 + 0.200 \times F) \log DA \tag{5}$$

$$\log V = 0.407 - 1.526 \times F + (0.009 + 0.323 \times F) \log DA \tag{6}$$

for median to high flows, annual flow duration 50 to 10 percent:

$$\log W = 0.476 - 0.397 \times F + (0.584 - 0.060 \times F) \log DA \tag{7}$$

$$\log D = -0.501 - 0.722 \times F + (0.469 - 0.153 \times F) \log DA \tag{8}$$

$$\log V = 0.417 - 1.268 \times F - (0.047 + 0.329 \times F) \log DA \tag{9}$$

where F is the decimal annual flow duration, DA is in square miles, and W, D and V are in units of feet, feet, and feet per second, respectively. Adjustment factors are applied to the results for better approximation of reach average values used in the flow model.

The range and frequency of local values of depth and velocity are determined from probabilistic distributions developed from field data. Data from a field study of substrate sizes and distributions along the Sangamon River were used to add substrate variations to the model for WUA evaluation (Broeren and Singh, 1990). An in-depth explanation of the flow model relations is provided in Singh et al (1987) and Broeren and Singh (1990). The basin flow model supplies needed hydraulic data for habitat assessment using the IFG or INHS habitat preference curves. The model adapts the IFIM to a basinwide scale without the prohibitive cost of individual site surveys to collect hydraulic data for each stream.

Successive calculations of the WUA for progressive drainage areas may be performed using the basinwide flow model. These values, coupled with an evaluation of stream segments having suitable water quality, may be integrated using equation 2 for a basinwide calculation of the WUA for various flow scenarios.

HABITAT RESPONSE CURVES AND WUA CALCULATIONS

The basinwide flow and aquatic habitat model was used to generate habitat response curves, WUA versus Q, for each of four selected fish species: two life stages were considered for illustrating the model results, juvenile and adult. The habitat response curves depict the relative availability of suitable habitat for various flow conditions at a given drainage area. Three parameters are considered in calculating WUA per unit stream length: depth, velocity, and substrate.

Selection of Target Fish Species for Habitat Assessment

Four target fish species (bluntnose minnow, channel catfish, longear sunfish, and smallmouth bass) were selected for the WUA calculations at various flow levels. These species are identified on the basin short list for the Sangamon Basin by Herricks and Himelick (1981). The Herricks and Himelick evaluation of indigenous fish species, their relative abundance in the Sangamon Basin, and the influence of water quality conditions were prepared for the IEPA as part of the Water Quality Management Information System database. Fisheries data from both the Department of Conservation and the INHS were used to perform the evaluation together with water quality data from the Ambient Water Quality Monitoring Network (AWQMN) maintained as a cooperative effort of the IEPA and the USGS. Stream segments are categorized on the basis of drainage area into seven categories defined as follows:

Category	*Drainage Area DA (sq mi)*	*Classification*
1	0 < DA < 10	Headwater
2	10 < DA < 50	Creek
3	50 < DA < 200	Small stream
4	200 < DA < 500	Large stream
5	500 < DA < 2,000	Small river
6	2,000< DA < 5,000	Medium river
7	5,000< DA	Large river

The Sangamon River above Lake Decatur Dam has a drainage area of 925 sq mi. The present study area falls within categories 1-5. The three stream drainage areas selected to demonstrate the model use are 100, 300, and 600 sq mi and they correspond to categories 3, 4, and 5, respectively.

The four fish species used to illustrate the model performance were selected on the basis of four criteria: 1) preference curves developed by both the INHS and the U.S. Fish and Wildlife IFG were available; 2) minimum DO requirements were proposed by the INHS; 3) the species were given in the basin short list for the three stream drainage area categories 3, 4, and 5; and 4) the species represented a variety of fish species in the basin. The four species meeting these criteria were not necessarily the most abundant in the basin but have been observed during fish surveys.

WUA for Selected Fish Species

Discharges selected for evaluation of the WUA correspond to annual flow durations from 10 to 90 percent. The habitat response curves for three drainage areas for each species are shown in Figures 2 and 3, as WUA per 1000 feet of stream length versus annual flow duration (F). The discharges in cubic feet per second (cfs) corresponding to each of the nine flow durations are also shown. Thus, the WUA for a given F may be compared at points along the network. The curves illustrate the relatively greater availability of suitable habitat for both life stages of channel catfish and adult smallmouth bass and longear sunfish compared to the juvenile life stage of the smallmouth bass and longear sunfish. Relatively less WUA is indicated for both life stages of bluntnose minnow.

The flow and habitat model may be used to compute the WUA per unit stream length corresponding to monthly or seasonal flow durations. This may be accomplished by determining the annual flow duration corresponding to the monthly flow of interest using equation 3 and the coefficient values in Table 1. The WUA may then be read from graphs such as those in Figures 2 and 3. Evaluation of the WUA for flows corresponding to selected monthly flow durations or droughts may be readily accomplished for the Sangamon Basin using the microcomputer streamflow assessment model for the Sangamon River Basin developed at the ISWS for the Illinois Department of Transportation, Division of Water Resources (Knapp et al., 1985). Integration of the streamflow assessment model with the basinwide flow and habitat model is illustrated by the following example.

The streamflow assessment model was used to compute the median discharge for July - November at three locations along the Sangamon River corresponding to drainage areas of 100, 300, and 600 sq mi, respectively. A simple linear interpolation was performed using basin discharge equations (Eq. 3) to compute the annual flow duration, F, corresponding to the monthly median discharges for July-November for the three drainage areas (Table 2). Inspection of the values in Table 2 shows that the median flow for July corresponds to about the 50% annual flow duration discharge, the median flow for November corresponds to annual flow durations around 68%. The WUA for a given fish species may be read from the plots of WUA versus F (Figures 2 and 3) for these flow durations, thereby estimating the WUA for the flow corresponding to the monthly median flow.

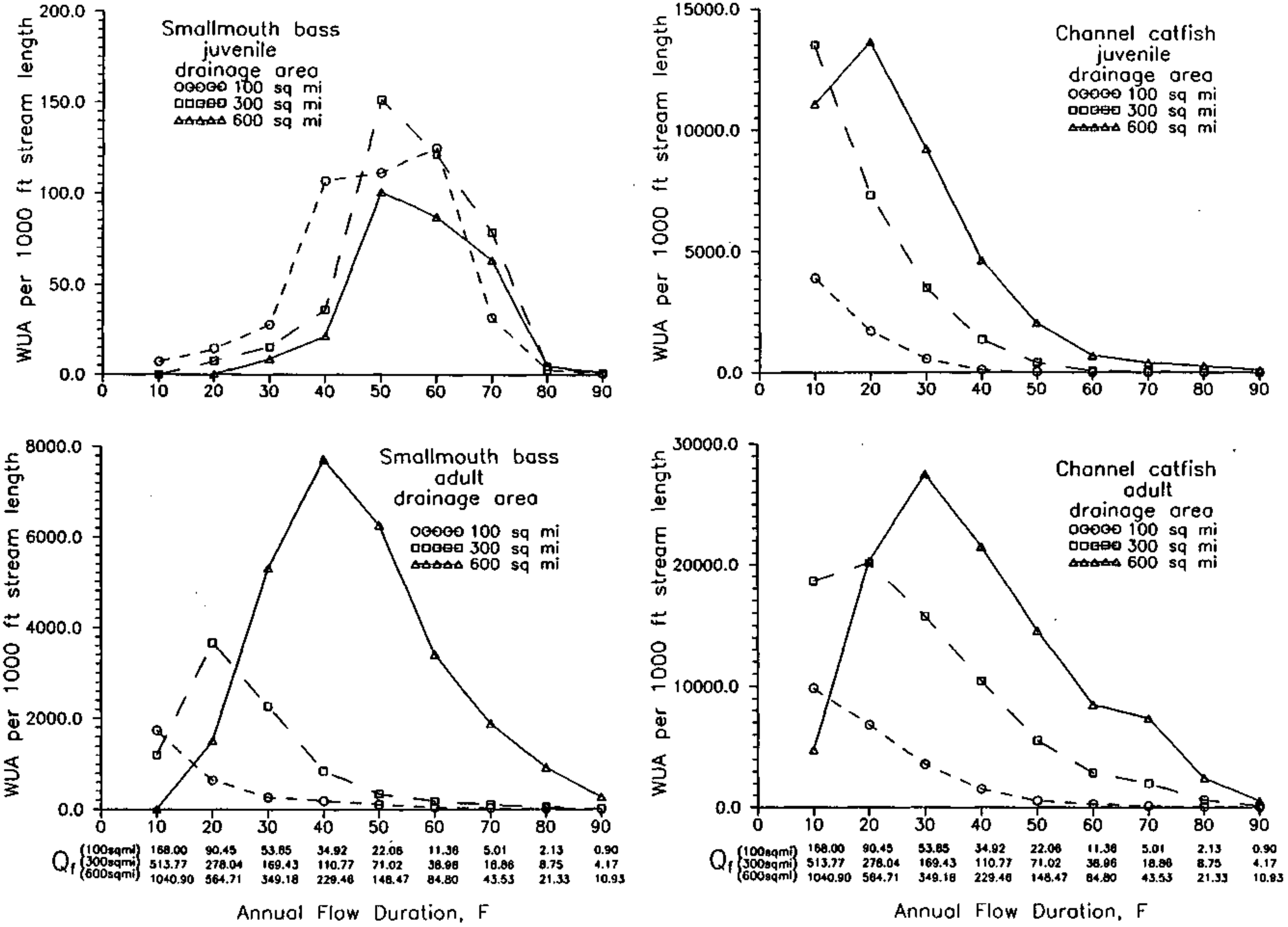

Figure 2 WUA versus F for smallmouth bass and channel catfish

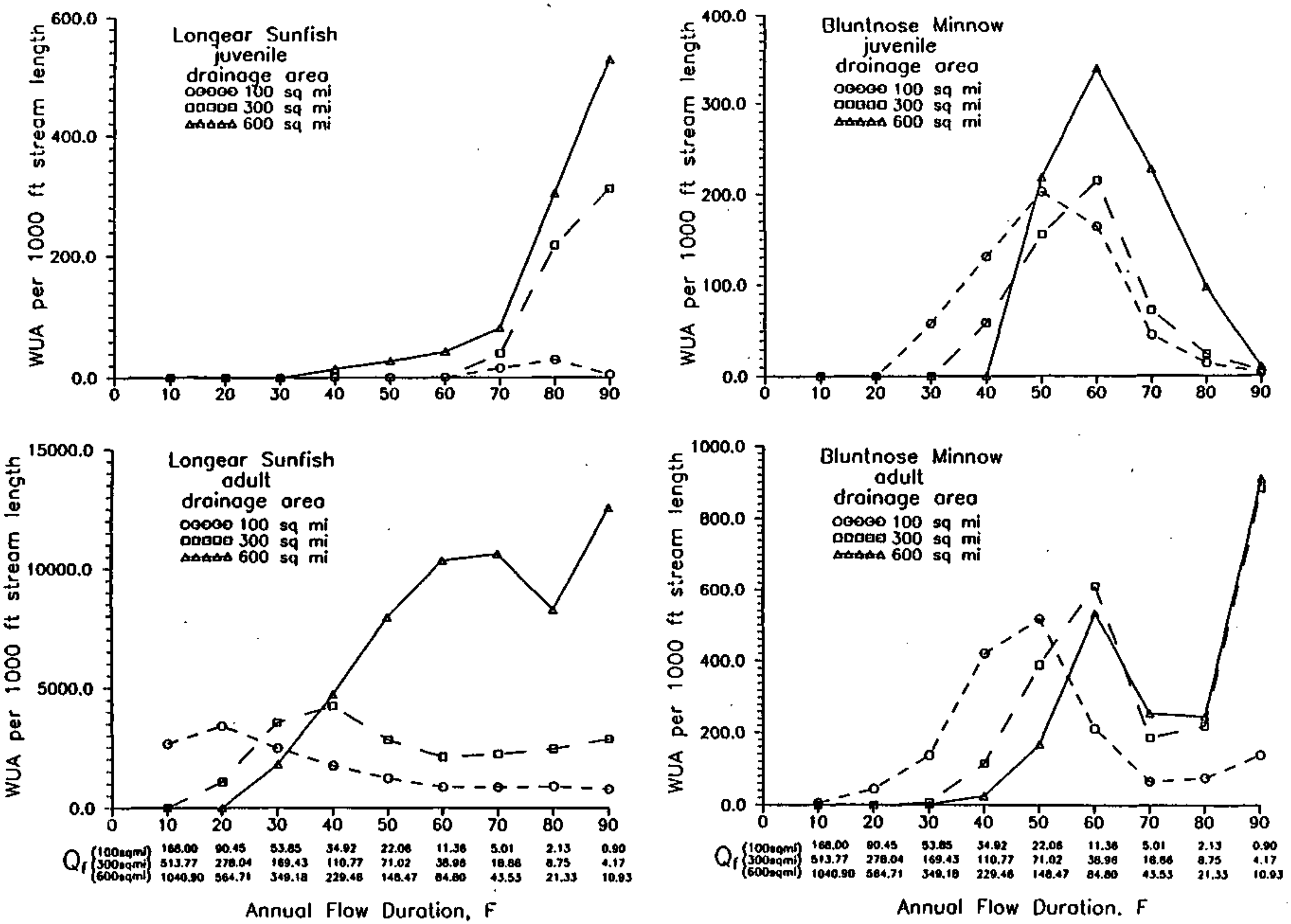

Figure 3 WUA versus F for longear sunfish and bluntnose minnow

Table 2. Annual Flow Duration Corresponding to Median Monthly Discharge

Drainage area, sq mi	Annual flow duration for median discharge, percent Jul	Aug	Sep	Oct	Nov
100	52	73	83	79	67
300	50	70	78	77	68
600	**48**	67	75	75	68

ASSESSMENT OF DISSOLVED OXYGEN AVAILABILITY

The availability of DO in flowing water is highly variable and a product of several factors. Temporal variations in DO may be observed over the seasons as well as large diurnal fluctuations. Seasonal variations in DO are largely attributable to temperature changes affecting the saturation concentration. The diurnal variations are primarily induced by photosynthetic activity of algae. The ability of a stream to absorb (or reabsorb) oxygen from the atmosphere is affected by the stream flow conditions, and typically expressed in terms of the reaeration coefficient. Factors that may represent significant sources of oxygen use or depletion include sediment oxygen demand (SOD), biochemical oxygen demand (BOD), including carbonaceous BOD (CBOD), and nitrogenous BOD (NBOD). BOD may be a product of both naturally occurring oxygen use in the decomposition of organic material, as well as oxygen use in the stabilization of effluents discharged from wastewater treatment plants. The significance of any of these factors depends on the specific stream conditions. It may be appropriate to consider one or all of these factors in an evaluation of the oxygen availability, depending on the purpose of the DO assessment and intensity level of the study.

The intent of this study was to provide an overview of me availability of DO as it relates to the minimum concentration level needed to support indigenous fish species. Local conditions immediately downstream of effluent outfalls of wastewater treatment plants were not considered specifically. Field measurements of various water quality parameters were conducted at three locations along the study reach. The field data provided information on the diurnal fluctuations in DO, reaerative capacity at the three field sites, and general water quality. The field work was conducted during the late summer and fall when DO levels are typically lowest. Historical water quality data available from stations in the AWQMN were used to explore seasonal variations in DO, as well as variations in DO with discharge.

Diurnal Dissolved Oxygen Field Study

Water quality measurements (with an emphasis on collecting diurnal DO data) were made at three locations along the upper Sangamon River. The field data collection and data assimilation were performed by the ISWS Office of River Water Quality. The locations of the three field sites are noted on the basin map in Figure 1. The sites were selected to represent conditions of various drainage areas along the river, located as far downstream from point-source effluent loadings as possible. The site descriptions are:

Site	*General location*	*River mile*	*Drainage area sq mi*
1	Below Highway 47 bridge below Gibson City	212.1	114.0
2	Above rural bridge above Mahomet	193.1	291.5
3	Above Hog Chute bridge below Allerton Park	154.3	613.0

The objectives of this part of the habitat availability study were to:

- ♦ Determine the diurnal variation in DO and associated water quality parameters such as pH, temperature, and algae counts for two different hydraulic and weather conditions at each site.
- ♦ Compare variations in water quality conditions between the sites for two different hydraulic and weather conditions.
- ♦ Determine primary productivity (algal DO production) using light and dark chamber techniques during two different hydraulic and weather conditions.
- ♦ Estimate the physical reaeration capacity of the river at each site.

Initially, two 48-hour events were scheduled: one during the week of June 11, 1990 and another during the week of August 27, 1990. However, persistent rain and high flows prevented the initiation of monitoring and sampling until mid-August so the first event was actually begun on August 17, 1990 and the second on September 7, 1990. Because these two dates were Fridays, the automatic water quality monitors that were used to collect data were set to record over 72-hour weekend periods.

Field Procedures

Hydrolab Corporation DataSonde I automatic water quality monitors were used in the field. Model 2070-DS units were employed during the first event while model 2030-DS units were employed during the second event. Model 2070-DS units measure and record temperature (° C), pH (pH units), conductivity (ms per centimeter), DO in milligrams per liter (mg/1), and oxidation/reduction potential or ORP (volts). Model 2030-DS does not measure ORP. The recording times can be set at intervals as low as 5 minutes.

Three DataSondes were placed at each site and set to record at hourly intervals over the 72-hour periods. Data recordings were initiated at 2:00 and 12:00 p.m. on August 17 and September 7, respectively. An ambient monitor, a light chamber monitor, and a dark chamber monitor were placed in the deepest portion of the river at each site. The dark chamber consists of 40-inch lengths of white PVC pipe and the light chambers consist of 35-inch lengths of 6 1/2-inch diameter clear plastic tubing. The top and bottom of each light chamber was sealed with clear plexiglass plates bolted to flanges glued to the tubing. A clear plastic gasket was secured between the plate and the flange for sealing purposes. The net water volumes of the light and dark chambers with the DataSondes in place were 13.830 and 12.875 liters, respectively. The ambient monitors were protected by their placement in 36-inch long, open-ended lengths of 6-inch diameter PVC pipe.

The light and dark chambers and ambient housing, designed to be suspended in the water, were laid flat with the axis of each cylinder in line with the stream flow because of the shallowness of the sampling locations. The chambers were filled in a prone position, and care was exercised so as not to disturb bottom sediments upstream of the fill openings. The caps and plates were installed in a manner so as to minimize air entrapment. The chambers and ambient housing were secured in the stream by a cable anchored on both banks.

Attendant to the installation of the DataSondes, water samples were collected for physical, chemical, and biological analyses in the laboratory. Water samples were collected for analyses of turbidity, suspended solids, total phosphorous (PO_4-P), nitrate (NO_3-N), and algae. Flow measurements were made by personnel from the Office of Surface Water Resources and Systems Analysis when the monitors were installed except during event 2 at site 3. This flow was obtained from the USGS Monticello gage records.

Data Reduction and Analyses

The DataSonde DO probe is relatively less responsive at low stream velocities. Consequently, correction factors (DO flow factors) are applied to meet hydraulic conditions as recommended by the manufacturer, the correction factors for high, medium, and low flows were 1.000, 1.042, and 1.087, respectively. All the chamber unit DO outputs were analyzed using the low-flow factor of 1.087, whereas me ambient unit's DO outputs were analyzed according to the following schedule:

	Flow factor for event	
Site	1	2
1	1.000	1.042
2	1.042	1.087
3	1.042	1.000

These ambient DO flow factors were selected primarily on the basis of providing the best match of the initial ambient DO concentrations with those recorded by the DataSondes in the chambers using the low-flow factor of 1.087.

The raw parametric values are stored in the DataSonde unit and are downloaded in the format shown in Table 3. Because of the voluminous amount of data generated and the fragmented nature of the printouts produced from the preprogrammed downloading program, the raw data and preprogrammed daily statistical summaries are not presented. These data, however, are available on floppy disks upon request.

Table 3. Example of DataSonde Output

```
TIME     TEMP      PH       COND      SALIN      DO        ORP      BATTERY
HHMM     DEG C     UNITS    MS/CM     PPT     MG/UPPM)    VOLTS     VOLTS
--------------------------------------------------------------------------
081890
0000    +23.91    +08.07   +0.725    +00.00    +08.48    +0.194    +05.75
0100    +23.86    +08.04   +0.725    +00.00    +08.33    +0.199    +05.75
0200    +23.78    +08.04   +0.727    +00.00    +08.19    +0.199    +05.74
0300    +23.65    +08.03   +0.727    +00.00    +08.09    +0.203    +05.74
0400    +23.57    +08.02   +0.726    +00.00    +07.95    +0.204    +05.74
0500    +23.48    +08.01   +0.723    +00.00    +07.84    +0.206    +05.74
0600    +23.44    +08.01   +0.724    +00.00    +07.69    +0.210    +05.74
0700    +23.36    +07.99   +0.721    +00.00    +07.62    +0.212    +05.74
0800    +23.32    +07.98   +0.722    +00.00    +07.55    +0.216    +05.74
0900    +23.36    +07.97   +0.721    +00.00    +07.54    +0.223    +05.74
1000    +23.57    +07.96   +0.722    +00.00    +07.57    +0.223    +05.74
1100    +23.95    +07.97   +0.726    +00.00    +07.69    +0.223    +05.74
1200    +24.54    +07.98   +0.726    +00.00    +07.88    +0.225    +05.74
1300    +25.05    +07.98   +0.730    +00.00    +08.00    +0.228    +05.74
1400    +25.60    +07.99   +0.735    +00.00    +08.18    +0.231    +05.74
1500    +26.06    +08.01   +0.737    +00.00    +08.30    +0.232    +05.74
1600    +26.40    +08.00   +0.739    +00.00    +08.45    +0.234    +05.74
1700    +26.65    +08.01   +0.739    +00.00    +08.46    +0.237    +05.74
1800    +26.82    +08.00   +0.737    +00.00    +08.42    +0.239    +05.74
1900    +26.95    +08.00   +0.735    +00.00    +08.28    +0.242    +05.74
2000    +26.91    +08.00   +0.732    +00.00    +08.06    +0.243    +05.75
2100    +26.82    +08.00   +0.726    +00.00    +07.86    +0.243    +05.74
2200    +26.65    +08.00   +0.726    +00.00    +07.78    +0.244    +05.74
2300    +26.53    +08.00   +0.725    +00.00    +07.66    +0.248    +05.74
```

```
DAILY STATISTICS HIT RETURN AGAIN TO ABORT STATISTICS

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MAXIMUM     : +026.948   081890  1900
MAX CHANGE  : +000.591   081890  1200
MEAN        : +024.926
STD DEV     : +001.433

PARAMETER   :    PH      UNITS
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# READINGS  : 00024
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STD DEV     : +000.025

PARAMETER   :   COND     MS/CM
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MAXIMUM     : +000.739   081890  1600
MAX CHANGE  : +000.006   081890  2100
MEAN        : +000.728
STD DEV     : +000.006

PARAMETER   :   SALIN     PPT
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MAXIMUM     : +000.000   081890  0000
MAX CHANGE  : +000.000   081890  0000
MEAN        : +000.000
STD DEV     : +000.000

PARAMETER   :    DO    MG/L(PPM)
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# READINGS  : 00024
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MAXIMUM     : +008.484   081890  0000
MAX CHANGE  : +000.216   081890  2000
MEAN        : +007.995
STD DEV     : +000.313

PARAMETER   :    ORP     VOLTS
# OVERRANGE : 00000
# READINGS  : 00024
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MAX CHANGE  : +000.007   081890  0900
MEAN        : +000.223
STD DEV     : +000.016
```

```
PARAMETER   :  BATTERY   VOLTS
# OVERRANGE : 00000
# READINGS  : 00024
MINIMUM     : +005.740   081890  1700
MAXIMUM     : +005.746   081890  0000
MAX CHANGE  : +000.004   081890  1700
MEAN        : +005.743
STD DEV     : +000.003
```

Estimates of physical reaeration and algal productivity were made using the following two schematic formulations:

physical aeration =ambient - light chamber + SOD (est.) (10a)

algal productivity = light chamber - dark chamber (10b)

"DO-used" curves (a form of a mass diagram) were developed for each DataSonde employed in order to achieve accurate results using the above formulations. The y-axis of a DO-used curve represents the difference between the initial DO and the DO at any other time along the x-axis. The dark-chamber DO-used plots represent the only true DO used at any time. The actual DO used within the light chamber is indeterminate since the net result at any time is influenced by photosynthetic oxygen production. The ambient DO-used values are even less indicative of the true DO usage since they include the effects of physical aeration in addition to photosynthetic oxygen production. Physical aeration estimates were made for the three SOD rates of 1.0, 2.0, and 3.0 grams per square meter per day ($g/m^2/day$). SOD rates ranging from 1.0 to 3.0 $g/m^2/day$ indicate moderately clean to moderately polluted benthic sediments (Butts and Evans, 1978).

DO saturation concentration for various water temperatures were computed using the American Society of Civil Engineers (1960) DO saturation formula:

$$DOsat = 14.652 - 0.41022T + 0.0079910T^2 - 0.000077774T^3 \qquad (11)$$

where

DOsat = DO saturation concentration, mg/1

T = water temperature, °C

This formula represents saturation levels for distilled water ($\beta = 1.0$) at sea-level pressure. Water impurities can increase the saturation level ($\beta > 1.0$) or decrease the

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saturation level ($\beta < 1.0$), depending upon the surfactant characteristics of the contaminant. For this study, β was assumed to be unity. The sea-level concentrations produced by the formula must be corrected for differences in air pressure caused by air temperature changes and for elevations above sea level. The following formula was developed for use during this study:

$$f = \frac{2116.8 - [(0.08 - 0.000115\,s)(E)]}{2116.8} \qquad (12)$$

where

/ = above sea-level correction factor

s = air temperature, °C

E = elevation of the site, feet above mean sea-level (ft-msl)

The elevations for the sampling sites were taken from USGS quadrangle maps. The elevations for site 1, 2, and 3 were 710, 670, and 630 ft-msl, respectively.

Natural, physical reaeration of water occurs at a rate proportional to the DO saturation deficit; i.e., water nearly devoid of DO will add oxygen at a much faster rate than will water that is nearly saturated with DO. Similarly, water containing supersaturated DO concentrations, due to algal productivity, will lose DO at a rate proportional to the excess up to 200 percent of saturation. This means that water containing 200 percent of saturation will lose DO at the same rate that oxygen is gained when the water is totally devoid of DO (0 percent saturation). Butts and Evans (1978a) have shown mat any supersaturation above 200 percent is immediately lost upon disturbance. Consequently, water saturated at 250 percent will be immediately reduced to 200 percent when any physical disturbance is encountered.

The natural reaeration phenomenon can be expressed mathematically as:

$$\frac{dD}{dt} = -K_2 D \tag{13}$$

where

D = saturation deficit $(DOsat - DO)$, mg/1

t = time, days

dt = elapsed time

dD = net change in saturation deficit for time dt

K_2 = volumetric reaeration coefficient, day^{-1}

$DOsat$ = DO saturation concentration, mg/1

DO = initial ambient DO concentration, mg/1

A relatively large number of empirical and semi-empirical algorithms and equations have been developed to estimate the reaeration coefficient (K_2). Three that are widely known and have been employed in stream work are:

Langbein and Durum (1967):

$$K_2 = \frac{7.63V}{H^{1.33}} \tag{14}$$

Churchill, Elmore, and Buckingham (1962):

$$K_2 = \frac{11.57V^{0.969}}{H^{1.673}} \tag{15}$$

O'Connor and Dobbins (1958)

$$K_2 = \frac{13.0V^{0.5}}{H^{1.5}} \tag{16}$$

where

K_2 = reaeration coefficient to the base e, day^{-1}

V = average velocity, feet per second (fps)

H = average depth, feet

Reaeration rates computed using field-measured stream depths and velocities in association with equations 14 - 16 may be compared with K_2-values directly ascertained from observed DO data as applied to equation 13. Since the DataSondes logged data at hourly intervals, the DO changes attributable to physical aeration (or deaeration) are available for small time frames, which permits the following modification of equation 13 to be used to compute K_2 - values.

$$24(r_{i+1} - r_i) = -K_2\left[\frac{C_{si} + C_{si+1}}{2} - \frac{C_i + C_{i+1}}{2}\right] \qquad (17)$$

where

r_i = an *ith* DO concentration value from the physical reaeration DO-used "mass diagram" curve

r_{i+1} = a DO concentration one hour later than r_i on the physical reaeration DO-used curve

C_{si} = an *ith* DO saturation concentration

C_{si+1} = a DO saturation concentration one hour later than C_{si}

C_i = an *ith* observed DO concentration

C_{i+1} = an observed DO concentration one hour later than C_i

Biologic Diversity Index

A biological diversity index provides a means of evaluating the richness of species within a biological community using a mathematical computation. A community consisting solely of one species has no diversity or richness and takes on a value of unity. As the number of species increase and as long as each species is relatively equal in number, the diversity index increases numerically. A diversity index would approach infinity when a large number of individual organisms are present and each one of these organisms belongs to a different species.

The Shannon-Weiner diversity index formula, as given by Smith (1980), was used to evaluate algal conditions. The formula is:

$$S = 3.322\left(\log N - \frac{\Sigma n_i \times \log n_i}{N}\right) \qquad (18)$$

where

S = the Shannon-Weiner diversity index

N = the total number of all organisms

n_i = the number of organisms for a given species

i = 1, 2, . . . k where k is the number of species

Results and Discussion

A summary of all the parameters for which field or laboratory data were collected is presented in Table 4. Plots of the DataSonde-generated data are presented in the order of parameters, site, and event. Those for DO are given in Figures 4 and 5; for pH in Figures 6 and 7; and for temperature in Figures 8 and 9.

The flow conditions of the river at each sampling site varied considerably from one event to the other. The flows during the first event were approximately twice those experienced during the second event. High flows preceded the August 17 placement of the monitors, resulting in elevated turbidity, suspended solids, phosphorus, and nitrate-N contents compared to those observed during event 2. Site 1, event 1 data dramatically reflect the effects of high rates of surface runoff on water quality in a headwater region of a stream draining an intensely farmed watershed. The phosphorus content at site 1 during August was approximately 3.3 times greater than during September. The 0.70 mg/1 of total phosphorous at site 1, event 1, exceeded twice the phosphorous level measured in the Illinois River at Peoria during this period. Note that the Illinois River is a large, enriched stream, and its DO balance is often drastically affected by cyclic photosynthetic oxygen production.

The results of the samples collected on August 17 and September 7 for algae identification and enumeration are presented in Table 5. Somewhat surprisingly, the algae numbers at site 1 were higher during August, after the advent of high river flows, than during the period of sustained lower flows during September. In any event, no site exhibited prolific planktonic algae growth, although some counts did exceed 500 cells per milliliter, which can cause algal production/respiration (P/R) to affect the corporeity of the DO resources in a stream. This effect is clearly demonstrated by the cyclical nature of the ambient DO curve for site 1 shown in Figure 4, when the algae count was 659 cells per milliliter. In stark contrast to this curve is the almost flat ambient DO curve that materialized at site 2 during event 1 (Figure 4) when the algal count was 246 cells per milliliter. Although the cell count was relatively low at site 3 during event 1, the influence of algal P/R on the diurnal DO curve is still evident here (Figure 4).

Algal P/R appeared to influence the DO balance to some degree at all three locations during event 2 (Figure 5). Although site 1 had a very low cell count, significant photosynthetic oxygen production appeared to occur during the last two days. In fact, this production was sufficient to maintain supersaturation levels throughout the final 48 hours. One reason that this location may be more sensitive to diurnal DO fluctuations caused by algal activity is that the river channel flows through a wide, open pasture while the other two locations are enveloped in dense canopies of overhanging trees.

With the exception of site 2, event 1 (Figure 4), the ambient DOs hover closely around the saturation lines. While this bodes well for water quality and the ecological health of the stream, it makes performing an accurate assessment of stream physical aeration coefficients difficult. The DO

Table 4. Summary of Ambient Water Quality Conditions

		Parameter values for sites					
	Station No.	**1**	**1**	**2**	**2**	**3**	**3**
Parameter	*Date*	**8/17-8/20**	**9/07-9/10**	**8/17-8/20**	**9/07-9/10**	**8/17-8/20**	**9/07-9/10**
*Flow (cfs)		18.10	9.40	46.50	22.80	104.90	55.30
*Velocity (fps)		0.83	0.60	1.22	1.18	0.67	0.58
*Average depth (ft)		0.87	0.75	0.76	0.44	2.23	1.29
*Maximum depth (ft)		1.40	1.20	1.10	0.70	3.00	2.50
*Turbidity (NTU)		17	14	46	20	32	13
*Suspended solids (mg/l)		36	12	66	29	22	15
*Total P04 - P (mg/l)		0.70	0.16	0.18	0.15	0.16	0.16
*NO3 - N (mg/l)		5.81	3.33	4.85	2.13	3.68	2.68
Temperature (C)	72- hr min	22.68	21.67	22.68	22.51	22.64	22.47
	avg	25.47	22.91	25.06	23.32	24.42	23.65
	max	28.17	24.54	26.86	25.64	26.36	25.43
pH	72- hr min	7.88	7.55	7.94	7.88	7.73	8.03
	avg	7.99	7.57	7.97	7.98	7.90	8.08
	max	8.08	7.62	8.00	8.19	7.79	8.18
Conductivity (ms/cm)	72- hr min	0.683	0.566	0.697	0.541	0.596	0.595
	avg	0.722	0.617	0.732	0.589	0.632	0.610
	max	0.739	0.639	0.716	0.621	0.659	0.620
DO (mg/l)	72- hr min	6.17	7.53	6.33	7.13	7.16	7.29
	avg	7.53	8.71	6.60	8.23	7.85	7.97
	max	9.01	9.67	6.91	10.04	8.51	8.96
DO saturation (mg/l)	72- hr min	7.50	8.02	7.70	7.88	7.78	7.92
	avg	7.90	8.29	7.97	8.24	8.08	8.20
	max	8.33	8.50	8.34	8.37	8.36	8.39
Oxy/Red potential (V)	72- hr min	0.144	-	0.120	-	0.183	-
	avg	0.250	-	0.245	-	0.276	-
	max	0.310	-	0.316	-	0.322	-

*Values for either 8/17/91 or 9/07/91

Table 5. Algae Identification and Enumeration

		Cell counts (no./ml) for sites					
		1	1	2	2	3	3
Classification	*Genus/species*	*8/17*	*9/07*	*8/17*	*9/07*	*8/17*	*9/07*
Blue green	*Aphanizomenon flos-aquae*		23				
	Oscillatoria sp.		6				
Green	*Chlorosarcina consociata*						2
	Crucigenia rectangularis		34				
	Oocystis borgei				71		15
	Pediastrvm duplex						4
	Scenedesmus dimorphus	27	4	21	11	19	2
Diatom	*Cyclotella acellata*						15
	Cyclotella atomus						48
	Cyclotella meneghiniana	116	48	78	769		237
	Cymbella affinis	11					
	Gyrosigma kutzingii	11		19			
	Gyrosigma macrum			4			23
	Gyrosigma scalproides						2
	Hantzschia virgata			8		11	
	Melosira granulata	82					
	Navicula cryptocephala		11	13		59	
	Navicula gastrum	15					
	Stephanodiscus niagarae				15		
	Surirella avata		6				
	Synedra acus				15		17
	Synedra ulna					25	
Flagellate	*Euglena gracili*	393		88	6	34	498
	Phacus pleuronectes					15	
	Trachelomonas crebea			15			23
Desmid	*Cosmarium sp.*	4					
	Total	659	132	246	887	163	886
	Total taxa	8	7	8	6	6	12
	Shannon-Weiner Diversity Index	1.81	2.33	2.37	0.80	2.36	1.88

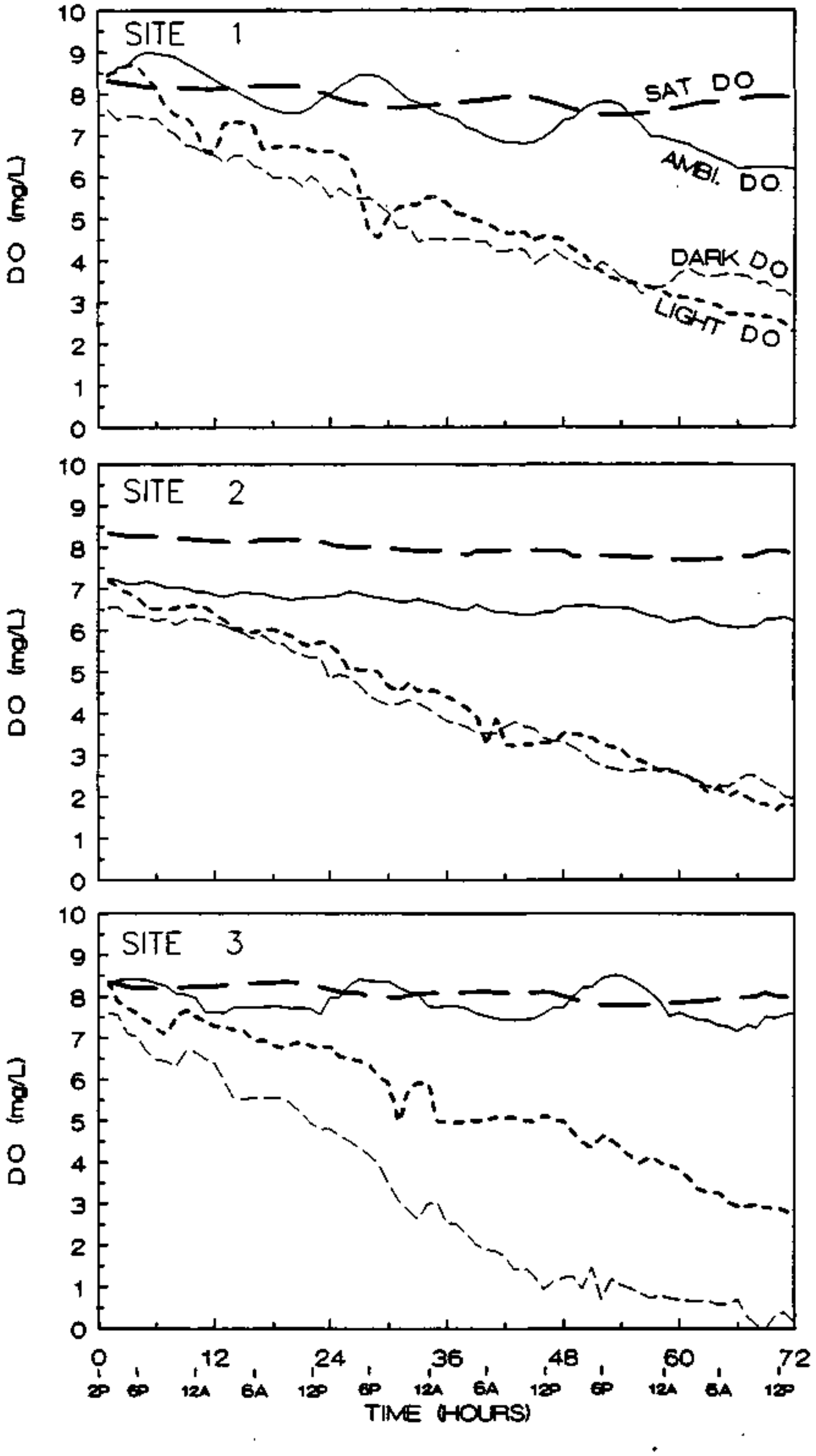

Figure 4 Diurnal DO variation for field sites during event 1, 08/17/90 2:00 PM to 08/20/90 2:00 PM

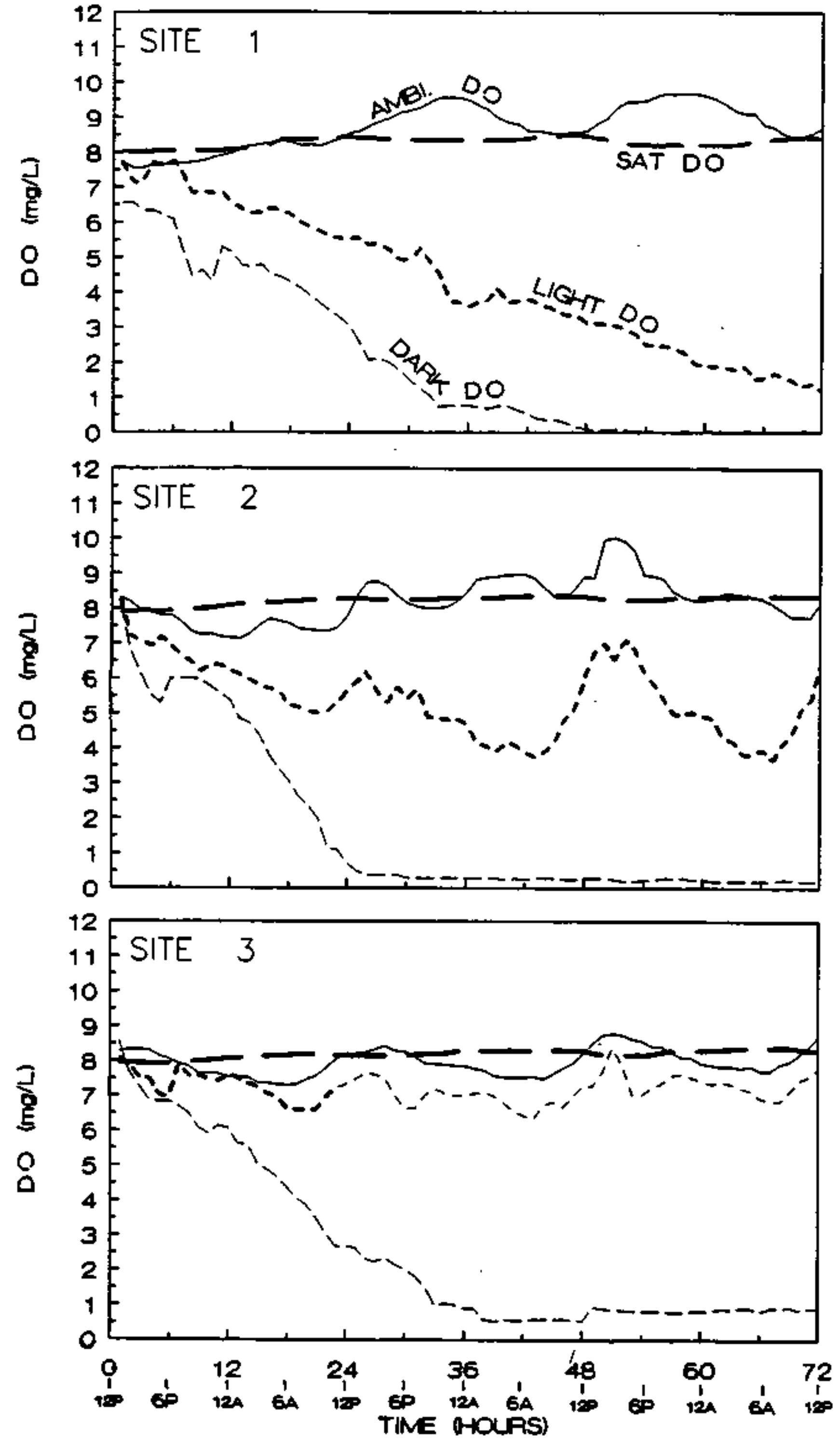

Figure 5 Diurnal DO variation for field sites during event 2, 09/07/90 12:00 PM to 09/10/90 12:00 PM

data in Table 4 show that the differences between the average saturation and ambient DO over the 72-hour periods are small with the exception of site 2, event 1 when the difference was 1.64 mg/1, whereas the average difference for the other five sites and events was only 0.25 mg/1. Note that the average DO for site 1, event 2 was 0.42 mg/l above the average saturation value, and the average observed and saturation DOs were essentially equal for site 2, event 2.

The ambient pH values fluctuate within a narrow range of values (Figures 6 and 7). Nevertheless, careful comparisons between the respective pH and DO curves show that pH values rise and fall somewhat with rises and falls in DO concentrations. Streamwaters reflective of even minimal algal activity generally demonstrate this correlation while maintaining pH levels in the high 7 to low 8 range.

The temperature plots (Figures 8 and 9) are rather interesting for a number of reasons. First, note that the temperature rose steadily over the 72-hour period at all three sites during event 1 (Figure 8). However, during event 2, temperatures exhibited steady declines over the 72-hour period (Figure 9). Evidently warm, sunny conditions persisted during event 1, while cloudy conditions must have dominated during event 2. This possibility is further exemplified by the high-amplitude, sinusoidal temperature curve produced at site 1, event 1 (Figure 8). Site 3, event 1 displays a lesser sinusoidal curve, whereas site 2, event 1 displays almost no sinusoidal tendency. Since the river at site 1 is smaller and unprotected by a canopy of trees, it is more subject to diurnal fluctuations in temperature. Trees shade both sites 2 and 3 but slightly more at site 2. The phenomenon is reflected in both the temperature and DO curves for event 1. Even during the "cloudy" event 2, site 1 displayed more temperature variability than did the other two locations.

The DO-used curves generated from the data collected using the ambient and the light and the dark chambers are presented in Figures 10 and 11. The values used to produce these curves were used to compute reaeration coefficients using equations 10a and 17, and algal productivity using equation 10b. The results of these analyses are summarized in Tables 6 and 7. Table 6 presents algal productivity and physical reaeration in terms of grams of oxygen per square meter per day. Negative signs for productivity indicate that more oxygen was used by the algal cells than produced over a 24-hour period.

Accurate computation of the "theoretical" K_2-values using equation 17 was made difficult because the DO deficits were small, which can distort the results considering the limitations and accuracies of the measurements. An error of a few tenths in DO at a low DO deficit is very significant, whereas the same error in DO at a high deficit means very little relative to the final K_2 analysis. For example, if the factor $(r_{i+1} - r_i)$ in equation 17 equals 0.01, the average saturation value equals 8.0 mg/1, and the average observed DO equals 7.90 mg/1, then K_2 equals 2.4 day^1. However, if the observed DO is read as 7.95 instead of 7.90, the resultant computed K_2 would be 4.8 day^1. On the other hand for the saturation value of 8.0 mg/1, if the observed DO equals 4.0 mg/1, then K_2 equals

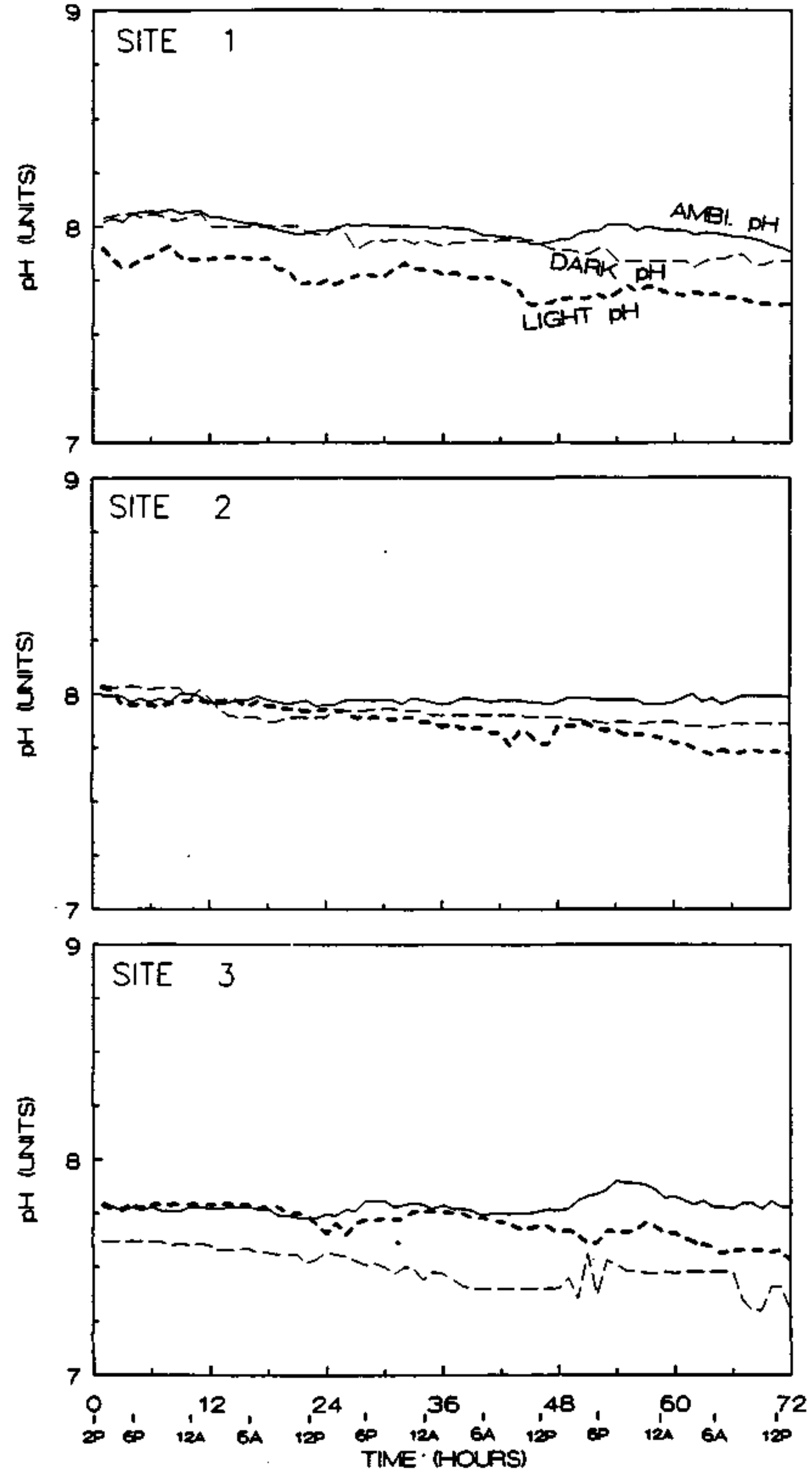

Figure 6. Diurnal pH variation for field sites during event 1, 08/17/90 2:00 PM to 08/20/90 2:00 PM

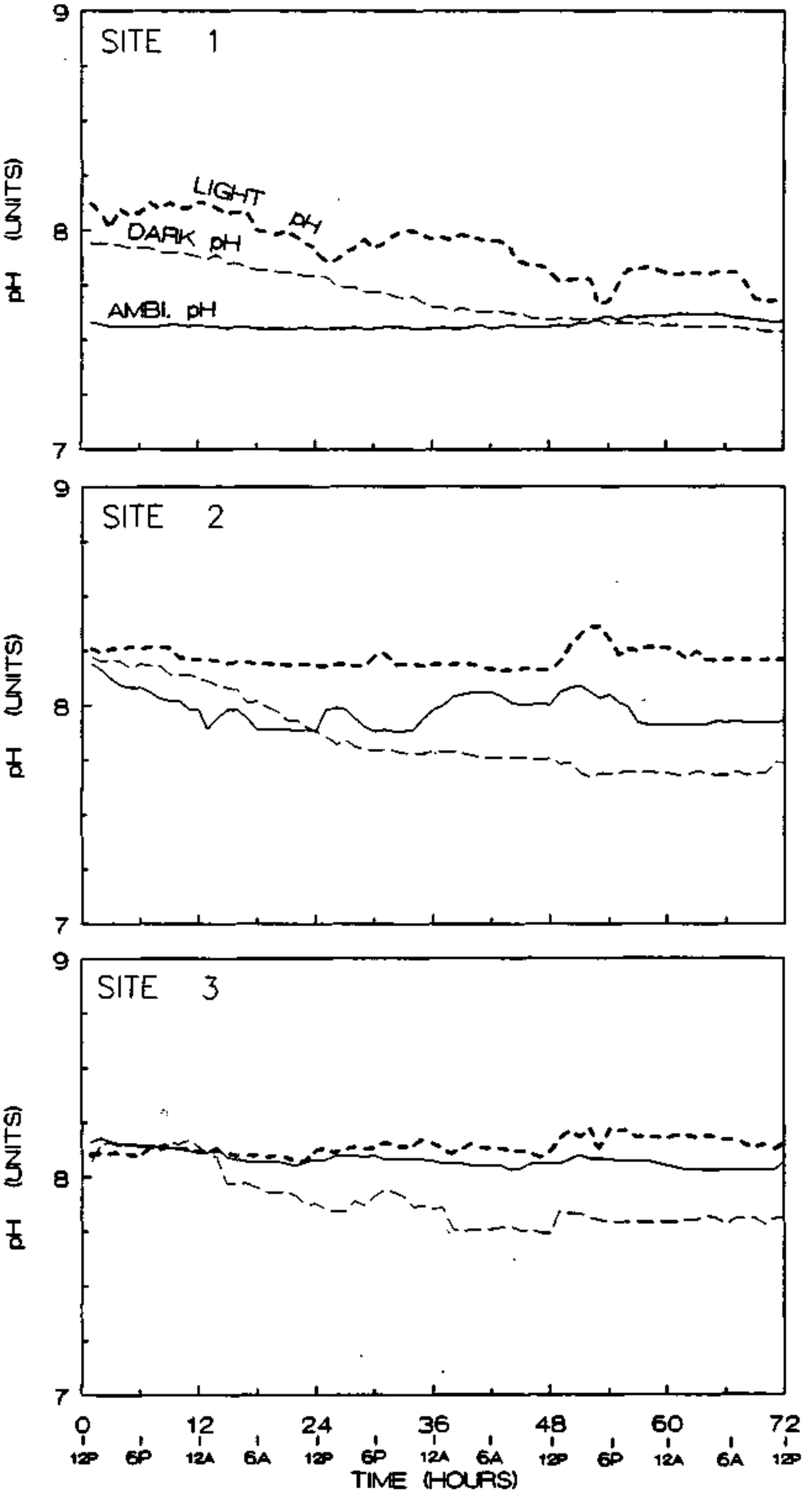

Figure 7. Diurnal pH variation for field sites during event 2, 09/07/90 12:00 PM to 09/10/90 12:00 PM

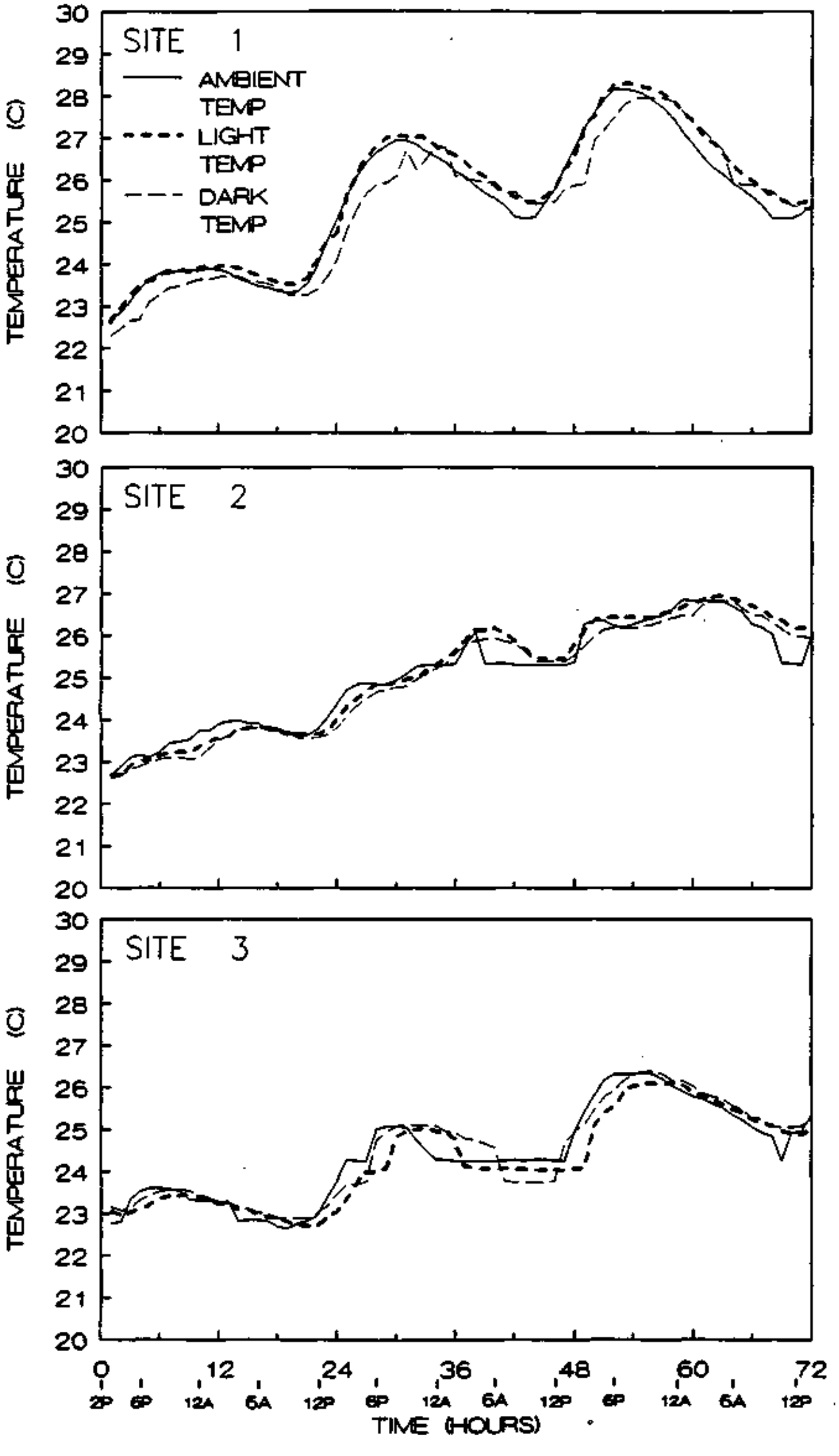

Figure 8. Diurnal T variation for field sites during event 1, 08/17/90 2:00 PM to 08/20/90 2:00 PM

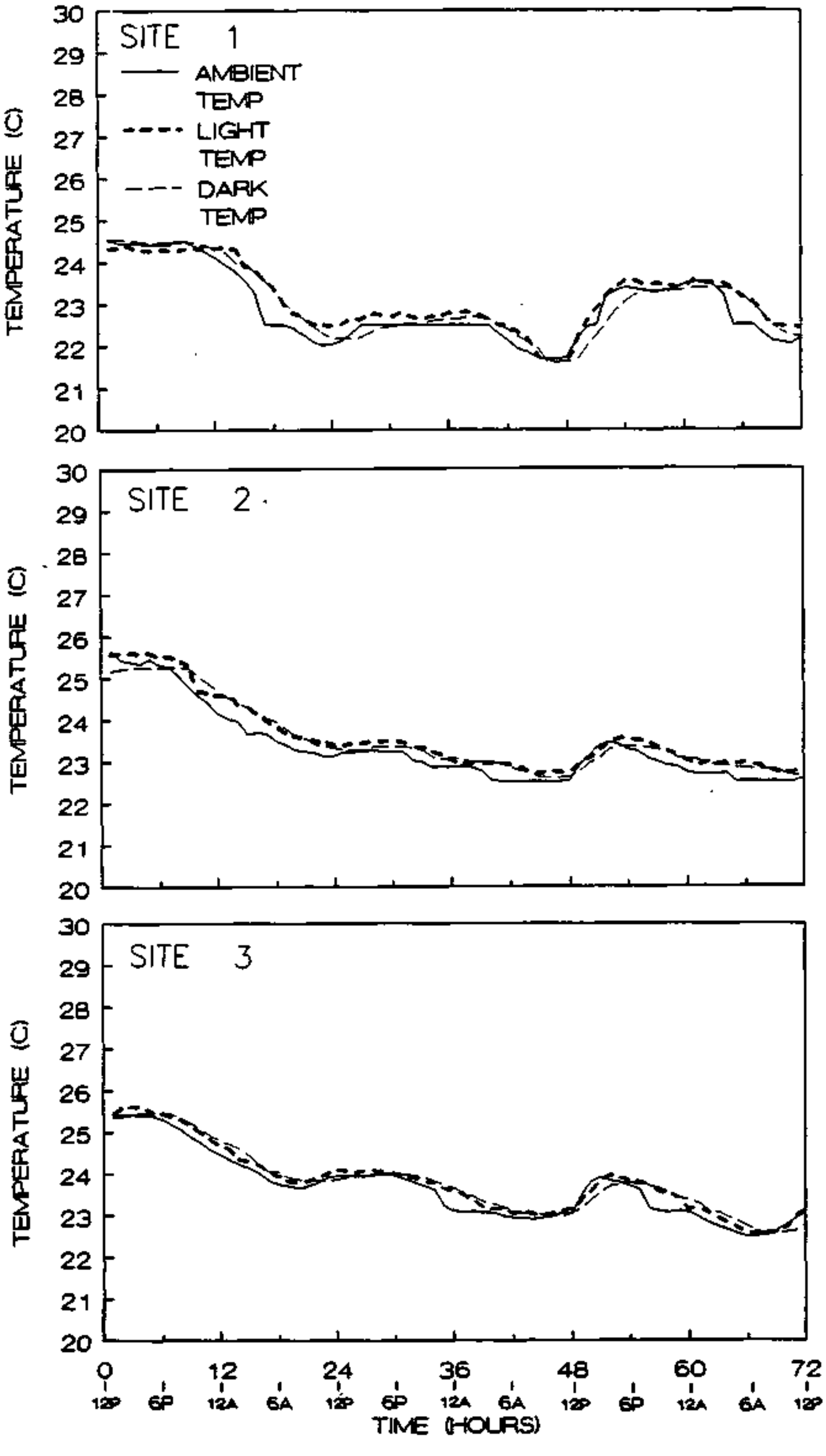

Figure 9. Diurnal T variation for field sites during event 2, 09/07/90 12:00 PM to 09/10/90 12:00 PM

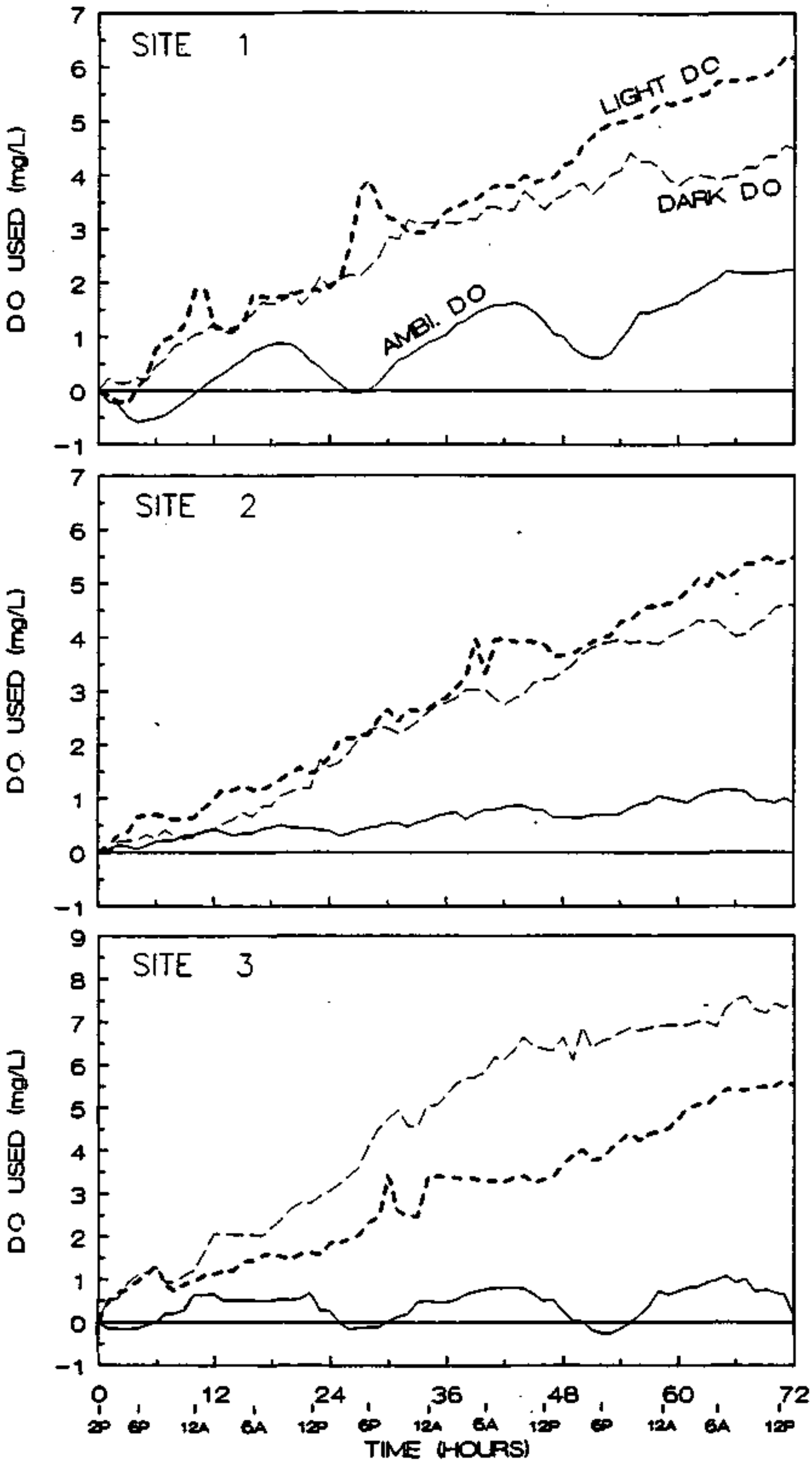

Figure 10. Diurnal DO-Used variation for field sites during event 1, 08/17/90 2:00 PM to 08/20/90 2:00 PM

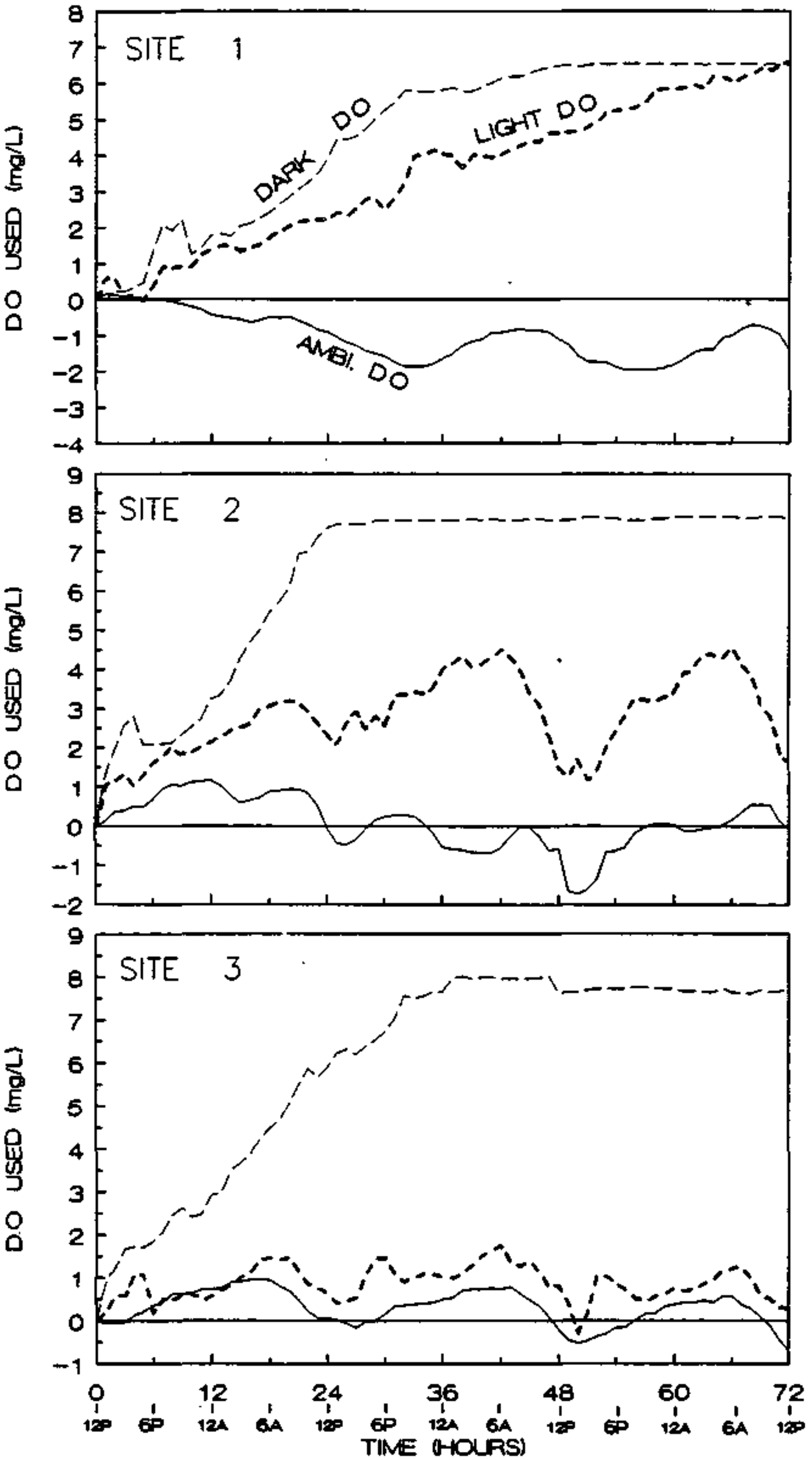

Figure 11. Diurnal DO-Used variation for field sites during event 2, 09/07/90 12:00 PM to 09/10/90 12:00 PM

Table 6. Calculated Productivity and Physical Aeration

					Physical aeration at SOD rates of:								
Inclusive 1990 dates	*Begin 24 hr period*	*Productivity at site*			*1 g/m²/day at site*			*2 g/m²/day at site*			*3 g/m² /day at site*		
		1	2	3	1	2	3	1	2	3	1	2	3
8/17-8/18	14:00	-0.02	-0.04	0.74	0.49	0.36	1.12	0.54	0.40	1.16	0.58	0.44	1.20
8/18-8/19	14:00	-0.13	-0.03	1.65	0.41	0.38	1.25	0.44	0.43	1.29	0.47	0.47	1.33
8/19-8/20	14:00	-0.30	-0.14	1.58	0.19	0.36	1.33	0.24	0.40	1.37	0.28	0.44	1.41
	Average:	-0.15	-0.07	1.32	0.36	0.37	1.23	0.41	0.41	1.27	0.44	0.45	1.31
9/07-9/08	12:00	0.40	0.71	2.08	0.75	0.36	0.26	0.79	0.40	0.31	0.83	0.45	0.35
9/08-9/09	12:00	0.55	1.28	1.53	0.60	-0.41	0.18	0.64	0.00	0.23	0.68	0.04	0.27
9/09-9/10	12:00	0.61	1.16	2.05	0.52	-0.51	-0.01	0.56	-0.01	0.03	0.60	0.03	0.07
	Average:	0.52	1.05	1.89	0.62	-0.19	0.14	0.66	0.13	0.19	0.70	0.17	0.23

Note: g/m^2/day = grams per square meter per day

Table 7. Reaeration Coefficient (K_2) Computed to the Base e Using Observed Field Data

K_2 *Values at a Station, 1/day*

Criteria for K2 estimation: Maximum incremental K2, 1/day	*Site No.*		*1*	*1*	*2*	*2*	*3*	*3*
	Date		*8/17-8/20*	*9/07-9/10*	*8/17-8/20*	*9/07-9/10*	*8/17-8/20*	*9/7-9/10*
	Parameter							
1000	*No. usable*		36	34	49	33	35	41
	K_2	max	171.06	1000.00	20.31	577.45	1000.00	1000.00
		min	0.14	0.34	0.26	0.27	0.36	1.19
		avg	18.04	71.97	4.84	42.47	52.78	47.37
		std	33.43	216.57	4.71	102.08	170.41	159.59
45	*No. usable*		36	34	49	33	35	41
	K_2	max	45.00	45.00	20.31	45.00	45.00	45.00
		min	0.14	0.34	0.26	0.27	0.36	1.19
		avg	12.18	15.03	4.84	19.92	14.65	14.18
		std	14.69	14.38	4.71	16.79	16.18	16.19
30	*No. usable*		36	34	49	33	35	41
	K_2	max	30.00	30.00	20.31	30.00	30.00	30.00
		min	0.14	0.34	0.26	0.27	0.36	1.19
		avg	10.50	13.07	4.84	16.15	11.69	11.35
		std	11.19	10.78	4.71	11.94	10.63	10.92
10	*No. usable*		36	34	49	33	35	41
	K_2	max	10.00	10.00	10.00	10.00	10.00	10.00
		min	0.14	0.34	0.26	0.27	0.36	1.19
		avg	5.39	6.96	4.15	7.65	6.67	6.33
		std	4.20	3.53	3.08	3.62	3.69	3.33

Table 8. Reaeration Coefficients (K_2) Computed to the Base e Using Published Formulas

K_2 *Values at a Station, 1/day*

Equation	*Site No.*		1	2	2		
	Date	8/17-8/20	9/07-9/10	8/17-8/20	9/07-9/10	8/17-8/20	9/7-9/10
Name	*No.*						
Langbein & Durum	14	7.62	6.71	13.41	26.83	1.76	3.15
Churchill et al.	15	12.19	11.41	22.20	53.64	2.05	4.46
O'Connor & Dobbins	16	14.59	15.50	21.67	48.38	3.20	6.76

0.060; if the observed DO were read as to 4.5 mg/l, K_2 would equal 0.069 day"^{1}, which represents only a 15 percent change compared to the 100 percent change for the low deficit example.

With the above in mind, K_2-values were computed by setting upper acceptable limits to remove the undue influence of extreme outliers. The results in Table 7 are predicated on setting upper K_2-values of 1,000 day^1, 45 day^1, 30 day^1, and 10 day^1 as noted in the table. If a computed value exceeded the stated value, it was assigned mat specific value for determining the statistical summaries.

Another factor that had to be considered in computing K_2 is the anomalies that appear in reaeration or deaeration computation when observed DO and saturation levels are nearly equal. Negative K_2-values will occur when negative deaeration values are matched with positive changes in deficit; that is, deaeration appears to occur in conjunction with an observed increase in DO. Negative K_2-values will also occur when reaeration appears to occur when the observed DO is above saturation. The resultant negative value from either case was rejected from the statistical results presented in Table 7.

Table 8 lists K_2-values computed using equations 14-16 for comparison with the "theoretical" values contained in Table 7. Note from Table 7 mat considerable variability occurs between the three "textbook" K_2-formulas at a given site and between sites. Note also that at upper K_2-limits of 45 day^{-1} or less, the computed "theoretical" K_2-values show little variability between either sites or events. The differences are probably statistically insignificant. The Langbein and Durum equation appears to closely predict the reaeration coefficient at site 1 when all outliers above 10 are eliminated. When the upper limit was set at 45 day , both the Churchill, Elmore, and Buckingham equation and the O'Connor and Dobbins equation provided reasonable estimates. The equation-values did not match very well with any of the "theoretically" computed values for the other two sites during either event. A very general conclusion could be made that the reaeration coefficients appear to be higher at low flows at sites 1 and 2, whereas no discernible difference appears to occur between the coefficients for each flow at site 3.

Overall, the general water quality during the 72-hour study period was good. DO concentrations were maintained close to saturation levels without the benefit of high algal productivity. In fact, algal activity actually imposed a slight drain on the DO resources of the stream at sites 1 and 2 during event 1 (Table 6).

Historical Data

Water quality data collected at 20 stations in the Sangamon River Basin is stored in the WATSTORE database maintained by the USGS. The stations, their USGS gage numbers, locations, basins, drainage areas, river miles from the mouth, and years of record are presented in Table 9. The number of records noted in the table is the number of samples for which Q, T, and DO were available and indicates the number of datapoints considered in the analysis. Discharge data is not available for gages 5573504 on the Sangamon River (immediately below Lake Decatur dam) and 5576250 on Sugar Creek near Springfield. There are two gages within the project study reach, 5570910 with drainage area 240 square miles, and 5572125 with 573 square mile drainage area. There are four other gages located on the main Sangamon River. Gage 5573540 is located 1.2 miles downstream of Lake Decatur dam and gage 5573650 is 10 miles downstream of Decatur's waste water treatment plant discharge. Discharge and dissolved oxygen levels are modified by these facilities. Gage 5576500 is below the confluence of the Sangamon and the South Fork Sangamon Rivers. Gage 5583000 is below the confluence of the Sangamon River and Salt Creek. Data from all of the stations in the basin were reviewed and provided a basis for evaluating trends observed in the data from the two gages in the study area.

The locations of the various AWQMN gages and point discharges of effluents, as well as the 1984 7-day 10-year low flows of the streams and wastewater treatment plant effluents (Singh, Ramamurthy, and Seo, 1988), are shown in Figure 1. The 1984 effluent discharge volumes were compared to 1970 effluent discharges reported by Singh and Stall (1973) as well as reported minimum average monthly discharges for the treatment plants in 1989 and 1990. These values are presented in Table 10. It may be observed from the tabulated values that for the most part there have been no significant changes in quantity of effluent discharged by these plants between 1970 and 1990; This time period also coincides with the bulk of the AWQMN station water quality data used in the analysis. The AWQMN station below the effluent outfalls is also listed in Table 10 following the upstream discharge points.

The emphasis of the analysis was to evaluate seasonal trends in DO and the variation of DO with discharge. Q, T, and DO data for all stations in the basin were retrieved from the WATSTORE database, along with the year, month, day, and time of the sample collection. The data were screened to eliminate multiple measurements during the same day. The saturation concentration of dissolved oxygen (DOsat) was computed using equation 11 for the reported water temperature for each recorded DO and adjusted for the site elevation using equation 12. The oxygen deficit (D), was calculated as the difference between DOsat and DO. Thus, a positive value of D indicates an oxygen concentration less than saturation, a negative value indicates supersaturation.

Monthly Average DO Values, Temperature Dependence, and Data Trends

For each set of gage data, the monthly average, minimum, maximum, and standard deviation of measured Q, T, and DO were determined. Similarly, the average, minimum, and maximum values of the calculated D and DOsat values were computed. This information for the eight gages located on the main Sangamon River is presented in Tables 11-18. The number of data samples available from each site for each month is noted. Due to diurnal fluctuations in DO, the time of sampling will influence the DO measured therefore the sampling times of the data from the network were reviewed.

Table 9. Basin Drainage Area, River Mile, Years of Record, and Number of Records for USGS Gages in the Sangamon River Basin

USGS gage no.	*Stream/ gage name*	*Sub-basin*	*Drainage area (sq mi)*	*River mile**	*Years of record*	*Number of records*
5570910	**Sangamon River at Fisher**	US	**240**	**201.1**	**1979-89**	**92**
5572125	**Sangamon River at Allerton Pk**	US	**573**	**158**	**1978-89**	**100**
5573504	**Sangamon River below L Decatur**	**LS**	**927**	**130.1**	**1979-89**	
5573540	**Sangamon River at IL Hwy 48**	**LS**	**938**	**129**	**1978-89**	**138**
5573650	**Sangamon River near Niantic**	**LS**	**1054**	**116.9**	**1977-89**	**137**
5573800	**Sangamon River at Roby**	**LS**	**1264**	**98.5**	**1977-89**	**122**
5576500	**Sangamon River at Riverton**	**LS**	**2618**	**83.1**	**1971-89**	**99**
5578000	**Sangamon River at Petersburg**	**LS**	**3063**	**45.9**	**1965-89**	**72**
5583000	**Sangamon River near Oakford**	**LS**	**5094**	**25.7**	**1956-89**	**113**
5577505	**Spring Creek at Burns Lane Bridge at Springfield**	**LS**	**109**	**8.2 (approx.)**	**1979-89**	**102**
,5576250	**Sugar Creek near Springfield**	**LS**	**270**	**7.4 (approx.)**	**1979-89**	
5574500	**Rat Branch near Taylorville**	**SF**	**276**	**1.6**	**1965-89**	**90**
5575500	**South Fork Sang. at Kincaid**	**SF**	**562**	**37.8**	**1972-89**	**101**
5576022	**South Fork Sang. below Rochester**	**SF**	**870**	**5**	**1977-89**	**105**
5579500	**Lake Fork near Cornland**	**SC**	**214**	**12.9**	**1964-89**	**123**
5580000	**Kickapoo Creek at Waynesville**	**SC**	**227**	**25.3**	**1966-89**	**111**
5580500	**Kickapoo Creek near Lincoln**	**SC**	**306**	**7.4**	**1966-89**	**94**
5581500	**Sugar Creek near Hartsburg**	**SC**	**333**	**15.4**	**1964-89**	**92**
5578500	**Salt Creek near Rowell**	**SC**	**335**	**65.3**	**1964-89**	**97**
5582000	**Salt Creek near Greenview**	**SC**	**1804**	**4.9**	**1964-89**	**93**

Notes:
US = Sangamon Basin above Lake Decatur
LS = Sangamon Basin below Lake Decatur
SF = South Fork Sangamon Basin
SC = Salt Creek Basin
*** from the mouth of the river**

Table 10. Effluent Discharges in the Upper Sangamon Basin

	Effluent discharge (cfs) during a 7-day low flow period		1990 Minimum average monthly discharge ,cfs (1)	
Facility	*Year 1970 (2)*	*1984 (3)*	*1989*	*1990*
Gibson City	0.46	0.35	0.41	0.43
Central Soya Co. (DS WQS:05570910)	0.37	0.06	ND	ND
Fisher	0.18	0.18	0.102	0.085
Rantoul	0.27	0.32	ND	ND
Mahomet	0.15	0.20	0.15	0.17
Monticello	1.1	0.68	0.68	0.62
Viobin Corp. (DS WQS: 0552125)	ND	0.9	ND	ND
Cerro Gordo (DS WQS: 05573540)	ND	0.01	0.044	0.05
Decatur (DS WQS: 05573650)	23.2	31.2	21.18	20.52
Harristown	ND	0.05	0.067	0.082
Borden Chemical Co. (DS WQS: 05573800)	0.25	0.93	ND	ND

Notes:
(1) IEPA municipal NPDES permitted discharges database
(2) Singh and Stall, 1973
(3) Singh et al., 1988
DS WQS = downstream water quality monitoring station
ND= no data

Table 11. Average Monthly Temperature, Discharge, and Dissolved Oxygen Data, Sangamon River at Fisher

USGS Gage 5570910 Drainage area 240 sq. mi.

Month	*N*		*Temp (*C)*	*Q(cfs)*	*DO(mg/l)*	*D (mg/l)*	*DOsaf (mg/l)*
January	8	avg	1.213	127.886	12.625	1.193	13.818
		min	0.000	7.200	8.000	-1.105	12.795
		max	4.000	400.000	14.700	5.880	14.272
		std	1.687	133.667	2.080	2.153	0.624
February	7	avg	1.300	176.050	11.386	2.397	13.782
		min	0.000	8.300	8.200	0.572	12.593
		max	4.600	350.000	13.700	5.680	14.272
		std	1.611	140.529	1.974	1.974	0.588
March	11	avg	5.573	295.700	11.882	0.460	12.342
		min	1.000	65.000	9.900	-1.167	10.722
		max	11.000	807.000	13.500	1.267	13.880
		std	3.325	276.397	1.307	0.818	1.065
April	8	avg	8.850	344.000	10.713	0.675	11.388
		min	1.500	195.000	8.400	-0.110	9.779
		max	15.000	696.000	13.800	2.038	13.690
		std	4.222	167.429	1.715	0.750	1.222
May	9	avg	15.600	608.375	8.722	0.970	9.693
		min	11.000	76.000	7.900	-0.478	8.794
		max	20.000	2120.000	11.200	2.072	10.722
		std	3.323	740.985	1.165	0.797	0.715
June	9	avg	21.856	422.556	7.211	1.273	8.484
		min	20.000	11.000	5.700	0.074	7.674
		max	27.000	1910.000	7.900	2.749	8.794
		std	2.180	621.268	0.633	0.739	0.348
July	7	avg	22.671	239.500	7.229	1.125	8.354
		min	19.000	10.000	6.600	-0.379	7.821
		max	26.000	572.000	8.200	2.019	8.977
		std	2.637	258.652	0.544	0.764	0.430
August	8	avg	23.050	44.314	6.900	1.396	8.296
		min	18.500	1.000	5.600	-0.568	7.674
		max	27.000	179.000	8.600	2.706	9.070
		std	2.922	64 890	1.128	1.103	0.479
September	8	avg	18.850	19.413	7.563	1.454	9.017
		min	16.000	0.000	5.600	-0.230	8.619
		max	21.000	114.000	9.300	3.019	9.567
		std	1.999	38.813	1.388	1.199	0.375
October	4	avg	13.625	66.800	7.800	2.292	10.092
		min	12.000	1.600	6.000	1.172	9.779
		max	15.000	169.000	9.300	4.001	10.472
		std	1.250	78.597	1.374	1.251	0.289
November	5	avg	7.320	9.200	7.980	3.776	11.756
		min	4.500	0.800	6.300	1.595	11.090
		max	9.600	28.000	9.800	5.533	12.627
		std	1.920	12.641	1.350	1.627	0.580
December	8	avg	3.725	270.171	12.763	0.174	12.936
		min	0.800	1.200	9.800	-3.742	11.538
		max	8.000	934.000	17.700	1.738	13.958
		std	2.794	322.017	2.404	1.767	0.948

Notes:

N = number of data points

Q = discharge, cfs

DO = dissolved oxygen concentration, mg/l

DOsat = saturation concentration of dissolved oxygen, mg/l

D = oxygen deficit, (DOsat-DO), mg/l

avg = arithmetic average

std = standard deviation of data

Table 12. Average Monthly Temperature, Discharge, and Dissolved Oxygen Data, Sangamon River at Allerton Pk.

USGS Gage 5572125 Drainage area 573 sq. mi.

Month	*N*		*Temp (*C)*	*Q(cfs)*	*DO (mg/l)*	*D (mg/l)*	*DOsat (mg/l)*
January	8	avg	0.800	170.286	12.663	1.334	13.996
		min	0.000	96.000	10.000	0.033	13.171
		max	3.000	270.000	14.000	4.303	14.303
		std	1.130	59.960	1.300	1.446	0.428
February	8	avg	1.513	411.000	12.825	0.910	13.735
		min	0.000	21.000	11.600	-1.097	12.488
		max	5.000	1350.000	15.400	1.933	14.303
		std	1.769	466.252	1.386	0.985	0.647
March	9	avg	5.344	743.375	11.567	0.851	12.418
		min	1.000	85.000	10.500	-0.381	11.279
		max	9.000	1660.000	13.100	1.771	13.911
		std	2.661	645.574	0.825	0.638	0.869
April	10	avg	11.300	797.900	10.200	0.520	10.720
		min	7.000	90.000	8.500	-0.878	9.800
		max	15.000	1550.000	12.100	1.445	11.859
		std	3.293	535.331	1.123	0.791	0.848
May	7	avg	15.229	754.667	8.714	1.065	9.779
		min	12.000	155.000	7.400	0.300	8.996
		max	19.000	3010.000	9.600	1.602	10.494
		std	2.791	1116.497	0.884	0.504	0.599
June	12	avg	21.167	913.818	6.908	1.715	8.624
		min	17:000	42.000	5.200	0.685	7.988
		max	25.000	5250.000	8.500	3.267	9.382
		std	2.380	1518.317	0.831	0.622	0.413
July	8	avg	23.850	1332.557	6.275	1.895	8.170
		min	22.000	3.900	3.500	-0.057	7.837
		max	26.000	5750.000	8.200	4.643	8.467
		std	1.361	2066.447	1.352	1.319	0.215
August	8	avg	22.613	32.750	6.850	1.531	8.381
		min	19.000	16.000	5.600	-0.682	7.618
		max	27.500	61.000	8.300	2.867	8.996
		std	2.627	17.078	0.802	1.063	0.426
September	8	avg	20.150	28.363	7.175	1.621	8.796
		min	17.000	0.000	6.100	0.613	8.467
		max	22.000	85.000	8.200	2.367	9.382
		std	1.823	28.954	0.736	0.696	0.333
October	10	avg	11.260	109.000	8.090	2.646	10.736
		min	5.000	0.000	5.900	0.987	9.587
		max	16.000	468.000	9.100	4.353	12.488
		std	3.464	165.698	0.980	1.190	0.908
November	3	avg	6.333	23.900	7.133	4.972	12.106
		min	4.000	5.700	5.500	3.588	11.006
		max	10.000	41.000	8.900	7.323	12.823
		std	3.215	17.676	1.704	2.046	0.967
December	9	avg	2.989	435.625	10.989	2.237	13.226
		min	0.000	14.000	7.900	0.188	11.563
		max	8.000	1450.000	12.900	6.011	14.303
		std	2.872	492.259	1.719	2.027	0.996

Notes:

N = number of data points

Q = discharge, cfs

DO = dissolved oxygen concentration, mg/l

DOsat = saturation concentration of dissolved oxygen, mg/l

D = oxygen deficit (DOsat-DO), mg/l

avg = arithmetic average

std = standard deviation of data

Table 13. Average Monthly Temperature, Discharge, and Dissolved Oxygen Data, Sangamon River at IL Hwy 48

USGS Gage 5573540 Drainage area 938 sq. mi.

Month	*N*		*Temp (*C)*	*Q(cfs)*	*DO(mg/l)*	*D (mg/l)*	*DOsat (mg/l)*
January	10	avg	1.890	147.700	12.140	1.463	13.603
		min	1.000	3.100	3.400	-3.167	13.016
		max	3.500	475.000	17.100	70.008	13.933
		std	1.016	179.265	4.464	4.211	0.375
February	10	avg	2.920	553.011	12.280	0.957	13.237
		min	1.000	3.100	7.200	-1.045	12.187
		max	6.000	2000.000	14.600	6.355	13.933
		std	1.605	702.084	2.316	2.330	0.565
March	11	avg	6.655	994.510	11.964	0.164	12.127
		min	0.000	5.100	8.600	-1.056	9.458
		max	16.700	3500.000	14.200	2.424	14.326
		std	5.099	1202.889	2.143	1.065	1.516
April	12	avg	11.558	1173.600	10.750	-0.053	10.697
		min	5.000	4.200	7.400	-1.189	9.010
		max	19.000	3400.000	12.700	2.638	12.508
		std	4.047	999.937	1.494	0.932	1.015
May	11	avg	16.191	1650.000	9.936	-0.341	9.595
		min	12.000	39.000	8.400	-1.730	8.650
		max	21.000	4750.000	12.000	0.302	10.511
		std	2.983	1516.283	0.978	0.597	0.616
June	14	avg	23.614	641.446	7.821	0.402	8.223
		min	21.000	5.800	2.200	-0.836	7.849
		max	26.000	2360.000	9.400	5.649	8.650
		std	1.716	669.513	1.810	1.666	0.273
July	10	avg	25.820	466.111	6.250	1.630	7.880
		min	24.000	1.000	1.900	-0.482	7.418
		max	29.000	1760.000	8.200	5.920	8.155
		std	1.423	664.975	2.335	2.430	0.211
August	17	avg	25.324	825.620	5.547	2.415	7.962
		min	21.000	2.600	0.600	-2.552	7.348
		max	29.500	6000.000	9.900	7.715	8.650
		std	2.343	1653.887	3.318	3.324	0.358
September	14	avg	21.171	244.217	4.093	4.550	8.643
		min	16.200	0.220	0.100	-0.790	7.879
		max	25.800	1220.000	9.800	8.727	9.561
		std	2.831	423.861	3.235	3.433	0.495
October	9	avg	15.167	7.486	4.011	5.801	9.812
		min	10.000	3.200	0.900	0.211	9.104
		max	18.500	17.000	10.300	10.124	11.024
		std	2.839	5.575	3.091	3.118	0.639
November	10	avg	7.860	216.967	4.860	6.818	11.678
		min	5.000	0.100	0.800	0.011	10.038
		max	14.000	1740.000	11.800	11.387	12.508
		std	3.276	574.516	4.368	4.666	0.910
December	10	avg	3.610	827.490	11.740	1.286	13.026
		min	0.600	4.600	6.400	-0.956	10.762
		max	11.000	3500.000	14.200	6.444	14.088
		std	2.834	1177.502	2.667	2.621	0.896

Notes:

N = number of data points

Q = discharge, cfs

DO = dissolved oxygen concentration, mg/l

DOsat = saturation concentration of dissolved oxygen, mg/l

D = oxygen deficit (DOsat-DO), mg/l

avg = arithmetic average

std = standard deviation of data

Table 14. Average Monthly Temperature, Discharge, and Dissolved Oxygen Data, Sangamon River near Niantic

USGS Gage 5573650 Drainage area 1054 sq. mi.

Month	*N*		*Temp (*C)*	*Q(cfs)*	*DO(mg/l)*	*D(mp/l)*	*DOsat (mg/l)*
January	10	avg	3.480	294.500	10.640	2.430	13.070
		min	1.000	29.000	4.700	-0.314	11.886
		max	7.000	690.000	14.000	7.555	T3.943
		std	2.464	250.425	3.574	2.991	0.849
February	12	avg	3.475	450.300	11.475	1.595	13.070
		min	0.000	28.000	9.300	0.065	11.886
		max	7.000	1500.000	13.500	4.836	14.336
		std	2.364	481.891	1.247	1.359	0.824
March	10	avg	6.940	1800.750	10.770	1.244	12.014
		min	1.000	131.000	7.900	-0.683	9.630
		max	15.900	4890.000	13.400	3.639	13.943
		std	4.502	1825.248	2.054	1.298	1.312
April	13	avg	11.738	1473.667	9.192	1.462	10.654
		min	6.000	113.000	7.600	0.589	9.206
		max	18.000	3440.000	11.400	2.969	12.195
		std	3.883	1085.001	1.453	0.664	0.970
May	11	avg	17.636	1659.333	7.982	1.341	9.323
		min	12.800	379.000	4.800	-0.685	8.161
		max	24.000	3960.000	10.400	3.361	10.324
		std	3.733	1142.042	1.583	1.071	0.710
June	16.	avg	23.319	822.385	6.019	2.256	8.275
		min	21.000	46.000	2.100	0.421	7.708
		max	27.000	2870.000	7.900	5.608	8.656
		std	1.527	793.881	1.538	1.374	0.242
July	10	avg	26.450	485.429	5.280	2.512	7.792
		min	24.000	24.000	3.100	0.530	7.423
		max	29.000	1540.000	7.400	4.464	8.161
		std	1.624	578.474	1.512	1.404	0.239
August	13	avg	25.585	832.900	5.269	2.656	7.925
		min	22.000	27.000	0.400	-0.336	7.284
		max	30.000	3000.000	7.900	6.884	8.486
		std	2.175	1244.542	2.346	2.233	0.327
September	13	avg	22.546	419.800	4.500	3.919	8.419
		min	17.600	27.000	0.900	1.121	7.708
		max	27.000	2510.000	7.200	8.306	9.284
		std	3.079	765.406	2.244	2.307	0.515
October	7	avg	15.857	1120.200	7.143	2.538	9.681
		min	11.000	42.000	3.800	0.869	8.744
		max	20.500	4570.000	9.900	4.944	10.769
		std	3.400	1953.706	2.260	1.556	0.727
November	11	avg	11.336	716.778	5.336	5.397	10.733
		min	7.000	14.000	0.800	0.715	9.206
		max	18.000	3650.000	9.900	9.805	11.886
		std	3.270	1243.227	3.445	3.544	0.798
December	11	avg	4.409	1391.889	10.655	2.110	12.765
		min	0.000	20.000	4.800	-0.405	10.769
		max	11.000	5290.000	13.600	7.717	14.336
		std	2.905	2037.278	2.771	2.560	0.952

Notes:

N = number of data points

Q = discharge, cfs

DO = dissolved oxygen concentration, mg/l

DOsat = saturation concentration of dissolved oxygen, mg/l

D = oxygen deficit (DOsat-DO), mg/l

avg = arithmetic average

std = standard deviation of data

Table 15. Average Monthly Temperature, Discharge, and Dissolved Oxygen Data, Sangamon River at Roby

USGS Gage 5573800 Drainage area 1264 sq. mi.

Month	*N*		*Temp (*C)*	*Q(cfs)*	*DO(mg/l)*	*D(mg/l)*	*DOsat (mg/l)*
January	10	avg	2.040	585.111	12.150	1.461	13.611
		min	0.000	36.000	8.500	-1.317	11.489
		max	8.400	2610.000	14.900	5.855	14.355
		std	2.602	792.332	1.719	2.039	0.897
February	11	avg	1.818	932.400	11.645	2.039	13.684
		min	0.000	35.000	9.400	-0.038	11.902
		max	7.000	5070.000	14.000	4.183	14.355
		std	2.261	1520.774	1.458	1.161	0.804
March	10	avg	5.640	2584.000	11.450	0.906	12.356
		min	2.000	137.000	9.100	-0.066	11.046
		max	10.000	7100.000	13.300	3.111	13.583
		std	2.279	3013.900	1.143	0.935	0.722
April	15	avg	11.507	1956.500	9.687	1.008	10.695
		min	7.000	67.000	6.700	-0.942	9.727
		max	15.500	5580.000	11.400	3.027	11.902
		std	2.852	1684.171	1.217	0.950	0.732
May	12	avg	17.117	1467.400	7.600	1.827	9.427
		min	12.000	242.000	5.600	0.176	8.331
		max	23.000	5250.000	9.200	3.618	10.532
		std	3.112	1659.792	1.130	0.905	0.637
June	13	avg	23.077	1161.909	6.515	1.816	8.331
		min	18.000	58.000	4.000	0.271	7.940
		max	25.500	4430.000	7.900	3.940	9.218
		std	2.216	1500.936	1.125	1.029	0.374
July	5	avg	24.400	1975.250	6.180	1.931	8.111
		min	23.000	220.000	4.900	0.716	7.865
		max	26.000	5470.000	7.300	3.431	8.331
		std	1.140	2465.324	0.998	1.126	0.177
August	13	avg	25.023	211.100	6.838	1.181	8.020
		min	22.000	34.000	5.000	-0.869	7.432
		max	29.000	1220.000	8.900	3.078	8.497
		std	1.955	364.692	1.276	1.236	0.295
September	11	avg	19.727	128.100	6.455	2.472	8.926
		min	15.700	44.000	3.600	-0.807	7.791
		max	26.500	488.000	10.300	5.618	9.685
		std	3.383	134.447	2.121	2.259	0.596
October	4	avg	14.875	401.333	6.125	3.766	9.891
		min	12.500	35.000	4.900	2.010	9.028
		max	19.000	1120.000	8.400	4.935	10.410
		std	2.955	622.423	1.628	1.242	0.626
November	10	avg	9.410	470.556	7.660	3.619	11.279
		min	4.500	39.000	3.400	0.019	9.621
		max	16.000	2060.000	11.000	6.658	12.700
		std	3.801	705.500	2.832	2.444	1.032
December	8	avg	3.100	1926.286	12.250	0.954	13.204
		min	0.300	48.000	9.600	-1.464	12.211
		max	6.000	6060.000	15.700	3.983	14.236
		std	1.831	2234.357	2.056	1.691	0.648

Notes:
N = number of data points
Q = discharge, cfs
DO = dissolved oxygen concentration, mg/l
DOsat = saturation concentration of dissolved oxygen, mg/l
D = oxygen deficit, (DOsat-DO), mg/l
avg = arithmetic average
std - standard deviation of data

Table 16. Average Monthly Temperature, Discharge, and Dissolved Oxygen Data, Sangamon River at Riverton

USGS Gage 5576500 Drainage(area 2618 sq. mi.

Month	*N*		*Temp (*C)*	*Q(cfs)*	*DO(mg/l)*	*D (mg/l)*	*DOsat (mg/l)*
January	7	avg	1.357	1313.857	12.086	1.766	13.852
		min	0.000	86.000	8.900	-1.470	13.230
		max	3.000	4810.000	14.700	5.268	14.367
		std	1.547	1633.503	2.038	2.101	0.585
February	6	avg	2.167	6680.833	12.133	1.441	13.575
		min	0.000	85.000	10.600	0.567	12.222
		max	6.000	14100.000	13.800	2.373	14.367
		std	2.639	6128.266	1.350	0.665	0.945
March	9	avg	5.289	2472.111	11.246	1.253	12.499
		min	0.000	306.000	10.400	0.091	11.301
		max	9.100	13000.000	12.500	2.480	14.367
		std	2.857	4021.415	0.688	0.800	0.966
April	11	avg	12.091	4317.455	9.582	0.969	10.550
		min	8.000	382.000	7.700	-1.534	9.843
		max	15.000	12500.000	11.600	2.366	11.614
		std	2.625	4126.280	1.177	1.275	0.663
May	13	avg	18.208	2858.308	7.869	1.339	9.209
		min	12.000	434.000	6.900	-0.313	8.504
		max	22.000	10900.000	9.500	2.135	10.541
		std	2.553	3068.601	0.826	0.717	0.520
June	9	avg	23.433	1396.556	7.322	0.957	8.279
		min	20.000	84.000	5.700	-3.777	7.886
		max	25.900	6550.000	11.800	2.400	8.852
		std	2.157	2017.086	1.858	2.012	0.353
July	5	avg	25.500	5310.600	5.720	2.234	7.954
		min	23.000	763.000	5.500	1.879	7.579
		max	28.000	13800.000	6.000	2.678	8.338
		std	2.179	5150.939	0.228	0.323	0.330
August	9	avg	26.533	251.667	8.544	-0.734	7.811
		min	21.500	38.000	5.200	-6.390	6.892
		max	33.000	860.000	13.800	3.138	8.588
		std	3.527	253.875	3.254	3.652	0.520
September	7	avg	20.957	1543.143	6.943	1.751	8.694
		min	17.000	50.000	4.700	-1.996	8.178
		max	24.000	9320.000	10.500	4.152	9.424
		std	2.140	3436.672	2.116	2.197	0.383
October	8	avg	15.563	575.875	6.863	2.902	9.765
		min	11.000	56.000	5.100	0.235	8.943
		max	19.500	1870.000	8.800	5.693	10.793
		std	3.385	623.239	1.514	1.895	0.729
November	8	avg	8.688	457.625	8.575	2.919	11.494
		min	4.000	43.000	5.300	-0.545	9.629
		max	16.000	1700.000	11.600	5.614	12.880
		std	3.936	621.824	2.187	2.085	1.081
December	7	avg	3.286	2397.429	11.414	1.722	13.136
		min	2.000	40.000	10.300	0.530	12.544
		max	5.000	10100.000	12.700	2.794	13.594
		std	1.075	3622.102	0.915	0.842	0.378

Notes:

N = number of data points

DOsat = saturation concentration of dissolved oxygen, mg/l

Q = discharge, cfs

D = oxygen deficit (DOsat-DO), mg/l

DO = dissolved oxygen concentration, mg/l

avg = arithmetic average

std = standard deviation of data

Table 17. Average Monthly Temperature, Discharge, and Dissolved Oxygen Data, Sangamon River at Petersburg

USGS Gage 557800C) Drainage area 3063 sq. mi.

Month	*N*		*Temp (*C)*	*Q(cfs)*	*DO (mg/l)*	*D(mg/l)*	*DOsat (mg/l)*
January	5	avg	1.900	3836.000	13.380	0.283	13.663
		min	0.000	1140.000	11.800	-0.553	13.070
		max	3.500	5710.000	14.800	1.270	14.386
		std	1.557	2331.680	1.180	0.784	0.587
February	6	avg	1.667	2068.333	12.133	1.624	13.758
		min	0.000	1300.000	10.800	0.512	12.560
		max	5.000	2770.000	13.100	2.886	14.386
		std	1.862	614.603	0.878	0.892	0.681
March	9	avg	5.389	6713.667	11.978	0.525	12.503
		min	1.000	263.000	10.300	-1.631	11.069
		max	10.000	16900.000	15.100	2.391	13.991
		std	3.462	6142.907	1.401	1.295	1.131
April	8	avg	10.400	5495.000	9.875	1.117	10.992
		min	7.000	1080.000	8.300	0.079	9.966
		max	14.500	12400.000	11.200	3.043	11.927
		std	2.515	4288.426	0.866	0.921	0.657
May	6	avg	17.933	2950.333	7.850	1.416	9.266
		min	15.000	432.000	7.400	0.846	8.685
		max	21.000	6240.000	8.400	1.841	9.856
		std	2.304	2551.710	0.409	0.332	0.450
June	7	avg	24.071	2863.429	7.186	1.007	8.192
		min	21.000	151.000	5.100	-2.309	7.391
		max	29.400	8740.000	9.700	3.248	8.685
		std	2.896	3182.863	1.381	1.728	0.449
July	7	avg	26.314	2254.571	6.900	0.936	7.836
		min	24.500	176.000	5.600	-0.811	7.589
		max	28.000	6460.000	8.400	2.281	8.110
		std	1.084	2736.219	0.933	1.017	0.161
August	5	avg	26.020	1720.000	6.940	0.955	7.895
		min	22.500	168.000	5.200	-0.932	7.171
		max	31.000	7110.000	9.200	2.374	8.431
		std	3.497	3023.312	1.737	1.467	0.518
September	4	avg	21.125	654.750	8.050	0.638	8.688
		min	18.500	100.000	6.400	-0.459	7.881
		max	26.000	1480.000	9.600	2.285	9.141
		std	3.425	631.528	1.308	1.258	0.573
October	6	avg	15.750	1349.667	7.683	2.036	9.719
		min	12.500	133.000	6.400	0.894	8.953
		max	19.500	4510.000	9.300	3.066	10.431
		std	2.679	1641.887	1.182	0.780	0.567
November	5	avg	8.900	4718.200	9.400	2.023	11.423
		mm	5.500	101.000	7.600	0.727	10.079
		max	14.000	22300.000	11.200	2.576	12.397
		std	3.380	9831.820	1.371	0.748	0.918
December	4	avg	4.375	2071.250	11.950	0.834	12.784
		min	2.000	121.000	11.200	0.412	12.237
		max	6.000	4770.000	13.200	1.160	13.612
		std	1.702	2121.401	0.900	0.335	0.588

Notes:

N = number of data points
Q = discharge, cfs
DO = dissolved oxygen concentration, mg/l
DOsat = saturation concentration of dissolved oxygen, mg/l
D = oxygen deficit (DOsat-DO), mg/l
avg = arithmetic average
std = standard deviation of data

Table 18. Average Monthly Temperature, Discharge, and Dissolved Oxygen Data, Sangamon River near Oakford

USGS Gage 5583000 Drainage area 5093 sq. mi.

Month	*N*		*Temp (*C)*	*Q(cfs)*	*DO(mg/l)*	*D (mg/l)*	*DOsat (mg/l)*
January	10	avg	2.090	2282.500	12.060	1.551	13.611
		min	0.100	368.000	9.000	0.040	12.572
		max	5.000	5870.000	14.200	3.909	14.359
		std	1.737	1681.935	1.512	1.326	0.636
February	8	avg	2.963	2465.750	12.088	1.240	13.328
		min	0.000	270.000	10.800	0.008	11.495
		max	8.500	8180.000	13.600	3.519	14.399
		std	2.990	2578.130	0.863	1.133	1.034
March	6	avg	6.900	9536.667	11.317	0.738	12.054
		min	2.000	2090.000	10.000	-1.462	10.088
		max	14.000	19200.000	13.400	2.772	13.624
		std	4.128	7272.190	1.569	1.445	1.208
April	13	avg	13.100	10022.310	9.531	0.809	10.339
		min	7.500	2160.000	7.900	-0.821	9.245
		max	18.000	45100.000	11.900	1.788	11.787
		std	3.064	11398.830	1.261	0.733	0.735
May	9	avg	17.600	6967.778	8.411	0.937	9.348
		min	13.400	1260.000	6.800	-0.778	8.522
		max	22.000	21900.000	10.400	2.162	10.227
		std	2.698	6737.249	1.061	0.999	0.535
June	8	avg	21.713	3758.750	7.875	0.699	8.574
		min	19.000	1500.000	6.300	-0.545	8.356
		max	23.000	9270.000	9.600	2.393	9.055
		std	1.232	2754.448	0.974	0.905	0.216
July	15	avg	26.014	2793.867	8.813	-0.514	8.299
		min	22.500	290.000	6.600	-3.925	7.524
		max	28.500	11400.000	12.200	2.404	14.004
		std	1.807	3115.412	1.657	1.643	1.600
August	9	avg	23.389	871.556	9.478	-1.165	8.313
		min	19.000	254.000	6.700	-5.086	7.740
		max	27.000	2130.000	12.900	1.556	9.055
		std	2.987	651.431	2.665	2.813	0.485
September	4	avg	21.250	1749.000	9.250	-0.579	8.671
		min	17.000	463.000	7.100	-2.505	8.195
		max	24.000	5430.000	10.700	1.422	9.444
		std	2.986	2454.674	1.559	1.604	0.538
October	13	avg.	12.900	1234.308	10.200	0.201	10.401
		min	8.000	211.000	7.700	-1.935	9.245
		max	18.000	9830.000	12.800	1.840	11.640
		std	3.506	2616.826	1.428	1.176	0.850
November	13	avg	8.100	1476.385	11.562	0.089	11.650
		min	4.500	294.000	8.500	-2.728	10.563
		max	12.000	4410.000	15.300	2.214	12.738
		std	2.682	1445.688	1.876	1.575	0.780
December	5	avg	2.000	6448.400	12.300	1.347	13.647
		min	0.500	335.000	10.700	0.100	12.572
		max	5.000	20900.000	14.100	2.059	14.200
		std	1.969	9060.790	1.416	0.829	0.715

Notes:

N = number of data points

Q = discharge, cfs

DO = dissolved oxygen concentration, mg/l

DOsat = saturation concentration of dissolved oxygen, mg/l

D = oxygen deficit, (DOsat-DO), mg/l

avg = arithmetic average

std = standard deviation of data

Table 19. Average Monthly Temperature, Discharge, and Dissolved Oxygen Data, Kickapoo Creek at Waynesville

USGS Gage 5580000 Drainage area 227 sq. mi.

Month	*N*		*Temp (*C)*	*Q(cfs)*	*DO(mg/l)*	*D (mg/l)*	*DOsat (mg/l)*
January	9	avg	0.900	83.813	12.722	1.243	13.966
		min	0.000	8.500	9.200	-0.762	12.827
		max	4.000	128.000	14.800	3.907	14.307
		std	1.356	44.417	2.004	1.810	0.505
February	9	avg	1.511	188.875	12.478	1.258	13.736
		min	0.000	8.000	9.300	-0.293	12.827
		max	4.000	679.000	14.600	4.809	14.307
		std	1.554	238.691	1.463	1.500	0.580
March	12	avg	6.483	178.727	11.875	0.263	12.138
		min	2.000	54.000	9.300	-0.808	9.803
		max	15.000	550.000	13.300	1.327	13.538
		std	4.641	159.993	1.432	0.661	1.319
April	9	avg	10.400	439.250	10.544	0.445	10.989
		min	5.500	61.000	8.700	-0.703	8.980
		max	19.100	983.000	12.000	1.782	12.330
		std	4.310	319.836	0.995	0.770	1.072
May	10	avg	14.900	288.400	9.640	0.236	9.876
		min	8.500	74.000	8.400	-0.304	8.727
		max	20.500	1270.000	11.400	1.103	11.423
		std	3.573	363.084	0.911	0.496	0.804
June	10	avg	20.800	92.444	8.010	0.675	8.685
		min	17.000	15.000	7.200	-0.595	8.145
		max	24.000	221.000	8.900	1.269	9.385
		std	1.927	64.642	0.509	0.519	0.340
July	13	■ avg	23.177	139.500	7.877	0.414	8.291
		min	17.900	2.300	6.100	-0.560	7.840
		max	26.000	718.000	8.800	1.890	9.207
		std	2.504	226.428	0.689	0.642	0.416
August	9	avg	23.778	21.763	7.822	0.376	8.198
		min	20.000	0.300	6.600	-2.051	7.408
		max	29.000	68.000	9.600	1.786	8.816
		std	3.022	23.439	1.024	1.282	0.469
September	7	avg	18.786	21.414	8.071	0.992	9.063
		min	14.000	1.900	6.300	-0.512	8.305
		max	23.000	102.000	9.700	2.516	10.025
		std	2.856	35.866	1.195	0.943	0.548
October	11	avg	11.982	55.990	8.991	1.633	10.624
		min	5.000	1.500	6.900	-0.402	8.998
		max	19.000	434.000	10.900	4.292	12.492
		std	5.165	134.194	1.359	1.689	1.276
November	9	avg	5.744	640.475	11.489	0.829	12.318
		min	2.000	7.800	8.000	-0.908	10.025
		max	14.000	4860.000	13.500	2.025	13.538
		std	3.491	1705.249	1.758	1.109	1.009
December	3	avg	2.667	291.333	12.000	1.320	13.320
		min	0.000	29.000	10.700	0.427	12.827
		max	4.000	538.000	12.900	2.127	14.307
		std	2.309	254.861	1.153	0.853	0.855

Notes:

N = number of data points

Q = discharge, cfs

DO = dissolved oxygen concentration, mg/l

DOsat = saturation concentration of dissolved oxygen, mg/l

D = Oxygen deficit (DOsat-DO). mg/l

avg = arithmetic average

std - standard deviation of data

Table 20. Average Monthly Temperature, Discharge, and Dissolved Oxygen Data, Kickapoo Creek near Lincoln

USGS Gage 5580500 Drainage area 306 sq. mi.

Month	*N*		*Temp (*C)*	*Q(cfs)*	*DO(mqA)*	*D (mg/l)*	*DOsat (mg/l)*
January	8	avg	0.738	122.800	14.013	0.046	14.058
		min	0.000	12.000	10.000	-2.250	13.208
		max	3.000	223.000	16.200	4.343	14.343
		std	1.032	89.592	1.894	2.103	0.392
February	8	avg	2.350	715.000	12.575	0.884	13.459
		min	0.000	35.000	11.800	0.302	12.689
		max	4.500	3180.000	13.600	1.408	14.343
		std	1.602	1103.626	0.690	0.391	0.596
March	9	avg	8.500	219.000	11.600	0.003	11.603
		min	3.000	85.000	9.300	-1.208	9.613
		max	16.000	700.000	13.300	0.959	13.208
		std	5.477	204.322	1.697	0.789	1.498
April	7	avg	14.000	573.167	10.000	0.164	10.164
		min	7.000	109.000	8.700	-1.140	8.660
		max	21.000	1420.000	11.800	1.292	11.892
		std	5.292	519.522	0.978	0.750	1.263
May	8	avg	15.525	183.714	8.900	0.838	9.738
		min	12.200	101.000	7.900	-0.187	8.837
		max	20.000	303.000	10.000	1.650	10.474
		std	2.581	60.596	0.762	0.548	0.543
June	9	avg	21.956	137.429	7.767	0.742	8.509
		min	18.000	22.000	7.200	-0.042	7.858
		max	26.000	300.000	8.300	1.174	9.210
		std	2.182	94.021	0.339	0.372	0.370
July	9	avg	24.167	274.600	7.178	0.975	8.153
		min	19.700	10.000	4.800	-0.389	7.711
		max	27.000	1220.000	8.200	3.209	8.891
		std	2.554	528.766	1.049	1.026	0.413
August	8	avg	22.588	42.286	6.800	1.604	8.404
		min	19.000	12.000	5.000	-0.791	8.009
		max	25.000	120.000	8.800	3.087	9.020
		std	2.262	36.436	1.160	1.204	0.378
September	7	avg	20.357	81.086	8.043	0.751	8.794
		min	17.000	7.600	6.200	-0.592	8.087
		max	24.500	306.000	10.000	1.887	9.408
		std	2.749	104.014	1.325	1.000	0.488
October	10	avg	14.040	88.378	8.850	1.269	10.119
		min	6.400	4.000	6.700	0.176	8.928
		max	19.500	586.000	11.900	2.504	12.076
		std	4.304	188.112	1.487	0.937	1.006
November	7	avg	5.529	66.833	11.771	0.592	12.363
		min	4.000	29.000	10.300	-0.077	11.595
		max	8.000	164.000	12.600	1.295	12.859
		std	1.468	49.069	0.894	0.479	0.466
December	4	avg	2.875	270.750	12.200	1.062	13.262
		min	1.000	11.000	10.300	-0.868	12.859
		max	4.000	606.000	13.900	2.559	13.950
		std	1.315	284.760	1.494	1.523	0.480

Notes:

N = number of data points

Q = discharge, cfs

DO = dissolved oxygen concentration, mg/l

DOsat = saturation concentration of dissolved oxygen, mg/l

D = oxygen deficit, (DOsat-DO), mg/l

avg = arithmetic average

std = standard deviation of data

With the exception of a few special studies when multiple samples were taken over a one- or two-day period, the recorded sampling times ranged from 8:00 a.m. to 4:00 p.m. The vast majority of samples were taken between 10:00 a.m. and 2:00 p.m. when DO levels are typically rising due to algal photosynthetic activity. The diurnal variation is illustrated in the plots of DO versus time (Figures 4 and 5), developed from the field data. The recorded DO at the three field sites shows a daytime increase between 1 and 2 rag/I during the events monitored. Differences between the minimum and maximum over the 72-hour period range from 2.91 to 1.35 mg/1, the difference between minimum and average values ranges from 1.36 to 0.68 mg/l. The WATSTORE data included information from a 1982 study in which DO was monitored during two 2-day periods (8/17-8/18 and 9/14-9/15) at four sites below Lake Decatur Dam (gages 5573540, 5573650, 5573800, and 5576500). Diurnal variations in DO observed at these stations ranged from 2 to 9 mg/1. Because the historical data was not collected at the same time of day, a degree of variability is inherent in the data set.

The influence of temperature on DO is evident in seasonal variations in temperature, DO and calculated DOsat. The average daily water temperature was computed using the available temperature data from the 18 sites throughout the basin. This information is presented in Figure 12, with the computed average daily temperature plotted versus the day of the year. The solid line plotted in the figure represents a best-fit polynomial approximation of the data. A sixth-order polynomial of T as a function of the day of the year (N), was used to construct the curve shown. A lower order polynomial provides a good correlation but had a rather poor fit at the extremes (days 1-10 and 355-365). The sixth-order polynomial, given below (Equation 19), has a standard error of 1.66 and a correlation coefficient of 98 percent.

$$T = 1.482681 + 2.93176\mathrm{X}10^{-2} \times N - 1.74772\mathrm{X}10^{-3} \times N^{2} + 4.44898\mathrm{X}10^{-5} \times N^{3} - 2.77068\mathrm{X}10^{-7} \times N^{4} + 6.55373\mathrm{X}10^{-10} \times N^{5} - 5.36613\mathrm{X}10^{-13} \times N^{6} \qquad (19)$$

Using T from the above expression and equation 11, DOsat (at mean sea-level elevation) was computed for each day (Figure 12). Because saturation concentrations are inversely proportional to temperature, they are lowest during the summer months when temperature is highest. The saturation concentration increases with decreasing temperature and measured DO likewise is highest during the coldest months. It can be seen from Figure 12 that in the Sangamon Basin, on the average, the highest T and lowest DOsat occur in mid-July. The minimum DOsat plotted is 7.5 mg/1. Adjustments for elevation using equation 12 reduce the computed values of DOsat. The multiplier at T=20° C ranges from 0.975 at the highest elevation gage at Fisher to 0.983 at the lowest elevation gage near Oakford. The temperatures and thus DOsat values represent data taken during the day when temperatures would tend to be higher and DOsat lower than nighttime values. Diurnal temperature fluctuations recorded during the field study are typically about 2° C, (Figures 8 and 9). Over the 72-hour period, the largest difference

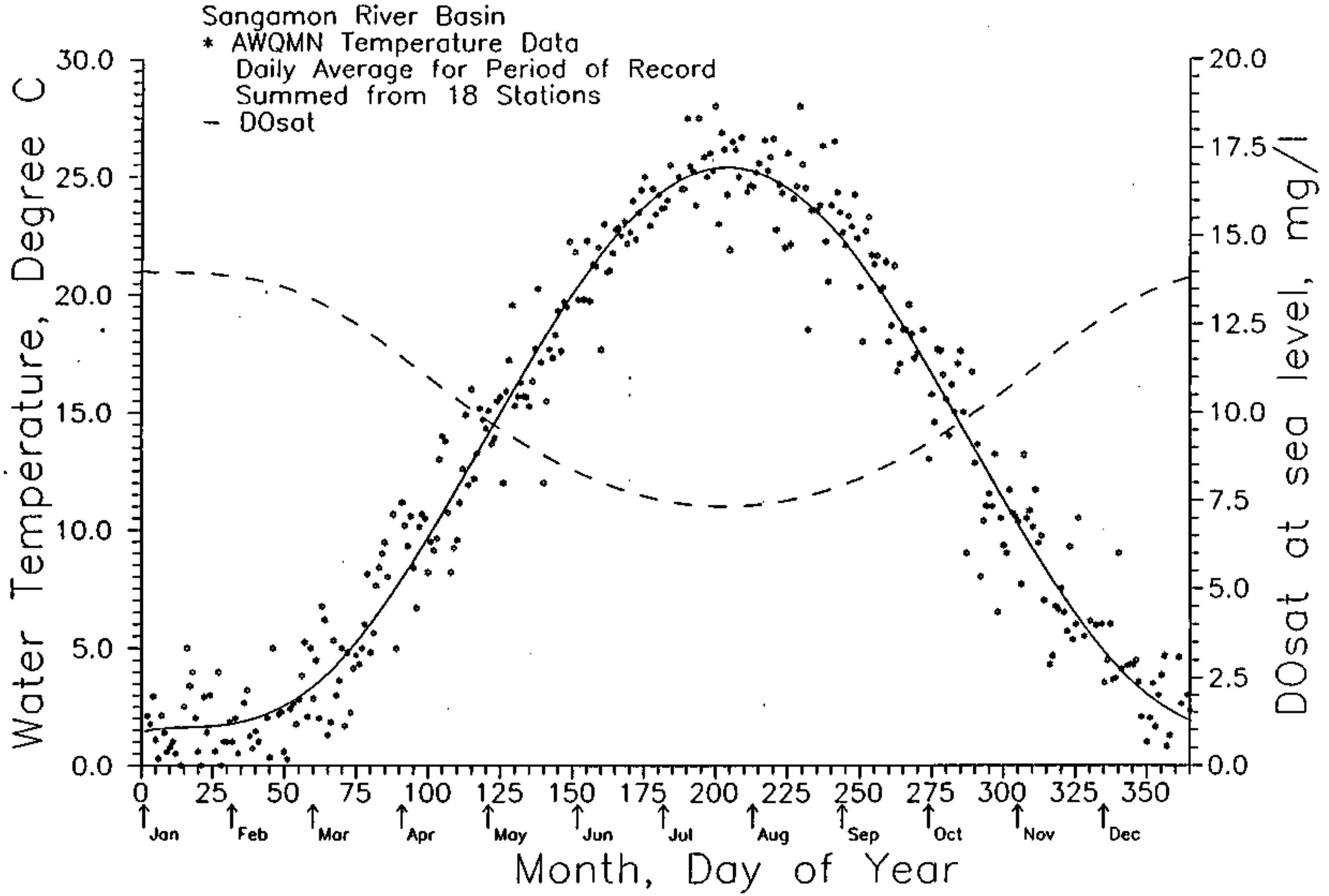

Figure 12. Average daily water temperature and corresponding DOsat

between recorded temperatures at a site was 5.49° C, corresponding to a difference in DO sat of about 0.8 mg/1 in this temperature range.

Monthly average DO, DOsat, and D are plotted versus the month of the year for each of the eight gages in Figures 13-15. It may be observed from both the tabulated values and the graphs that upstream of Lake Decatur (gages 5570910 and 5572125), the trend in DO values closely follows the saturation concentration. This trend also occurs at the three largest drainage area gages (5573540, 5573650, and 5573800). A greater departure from the saturation concentration may be observed in the data collected at the first three stations (gages 5573540, 5573650, and 5573800) located downstream of Lake Decatur Dam. At the gages upstream of Lake Decatur, the lowest monthly average DO (6.90 mg/1) occurs in August at gage 5570910 (240 sq mi) and at gage 5572125 (573 sq mi) the lowest monthly DO (6.28 mg/l) occurs in July. The next three gages downstream of Lake Decatur (5573540, 5573650, and 5573800) show the lowest average monthly DO values in September and October. The trend in monthly average DO values at the three gages with drainage areas in excess of 2,000 sq mi, more closely resembles the first two upstream gages, with lowest average DO occurring in June and July. Streamflow and water quality are modified by Lake Decatur. An investigation DO availability along the Sangamon from Lake Decatur to Petersburg is planned for a future study.

Monthly statistics for the two gages within the study reach are quite similar. The largest standard deviation of DO data occurs in December at each gage: 2.4 and 1.7 mg/1 for 05570910 and 5572125, respectively; and the smallest standard deviation occurs in July and August at these gages: 0.54 and 0.80 mg/1 for 5570910 and 5572125, respectively. The largest variability in measured DO during any month (as measured by the standard deviation) occurs at the first three stations below Lake Decatur Dam. Considering all eight gages the standard deviation in DO values during any given month ranges from the lowest value of 0.54 mg/1 (Gage 5570910 in July) to 4.464 mg/1 (gage 5573540 in January). The degree of influence of the time-of-sampling on the data variability was not explored; however, it is recommended for future research.

The DO deficit, D, difference between saturation concentration (DOsat), and measured concentration (DO), is indicative of oxygen use and the ability of the stream to re-absorb oxygen. As noted earlier, actual DO values tend to follow the temperature-dependent trends of DOsat. Examination of trends in D gives some insight as to months in which there is greater imbalance between oxygen use and make-up. The largest monthly average D occurs in November or October for seven of the eight gages along the Sangamon, the one exception being gage 5573000 near Oakford (5094 sq mi) where the largest average D occurs in January.

Similar statistics were developed from the data collected at the gages in the South Fork Sangamon and Salt Creek Basins. There are three gages in the South Fork Sangamon Basin where water quality data is collected, listed in Table 9. The lowest monthly average DO values are somewhat less than observed at the Sangamon River gages, with values in August ranging from 3.74 mg/1 at gage

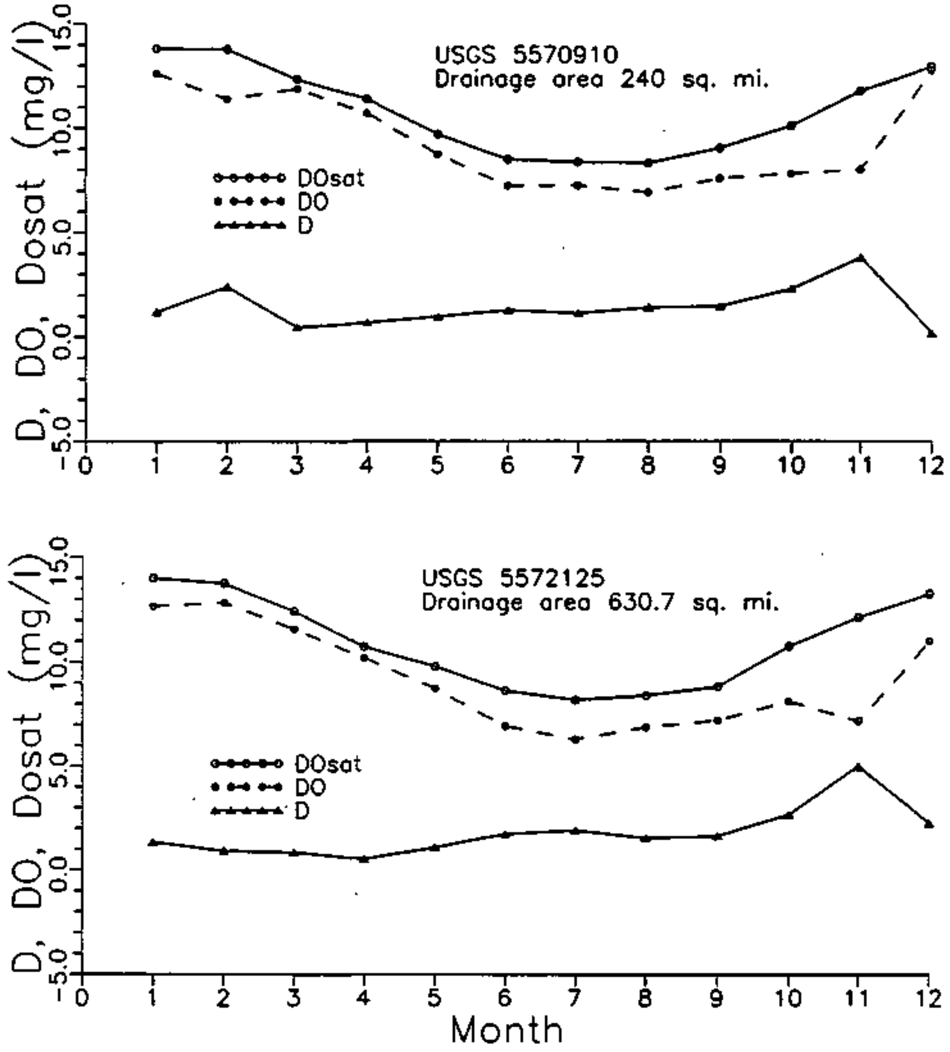

Figure 13. Yearly variation of DO parameters for USGS AWQMN gages 5570910 and 5572125

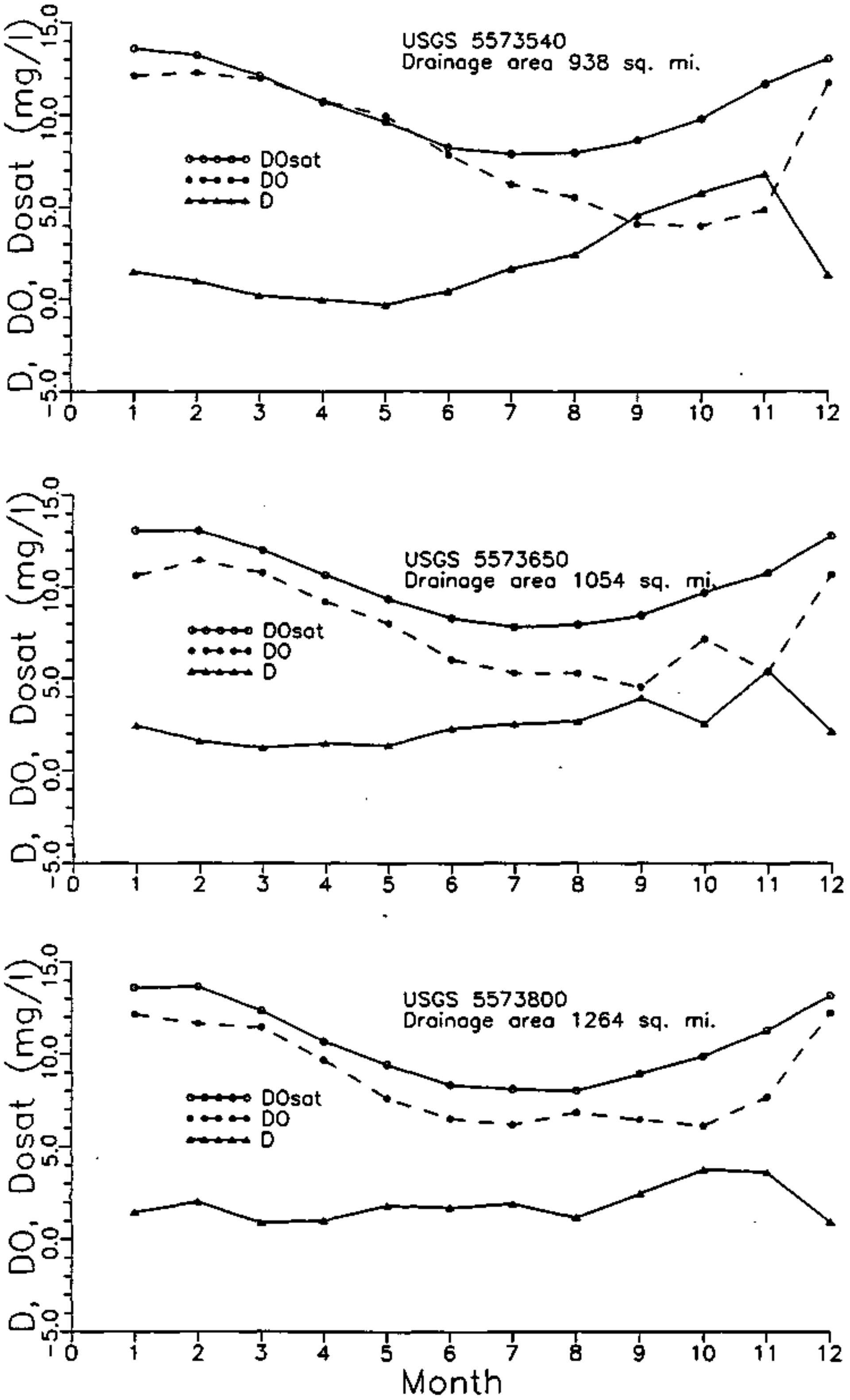

Figure 14. Yearly variation of DO parameters for
USGS AWQMN gages 5573540, 5573650, and 5573800

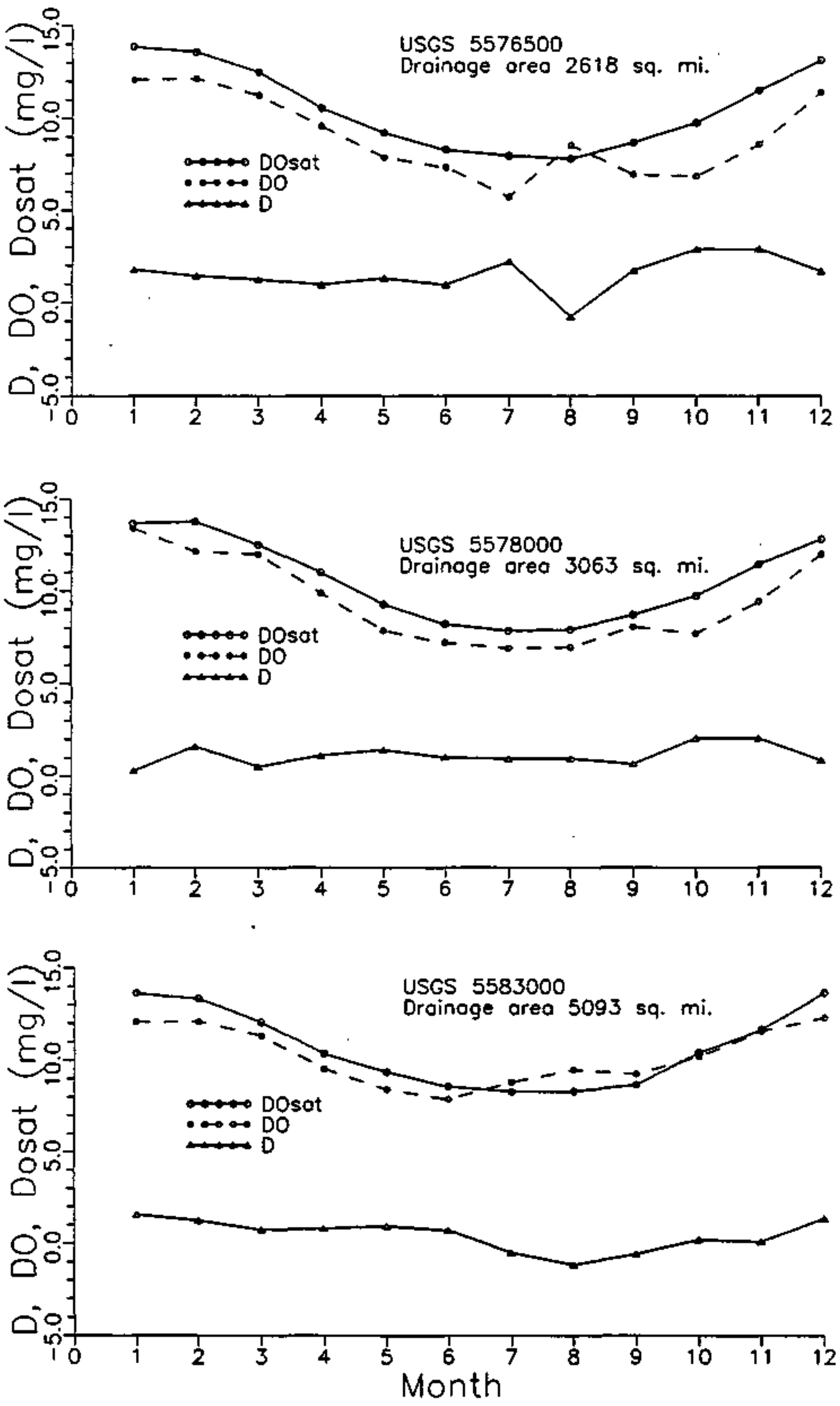

Figure 15. Yearly variation of DO parameters for
USGS AWQMN gages 5576500, 5578000, and 5583000

55774500 to 5.67 mg/1 at gage 5576022. The highest monthly average D values are comparable to the Sangamon gages, occurring in October and November and ranging from 3.36 to 4.60 mg/1. Water quality data is collected at six gages in the Salt Creek Basin (Table 9). Two AWQMN stations are located on Kickapoo Creek in the Salt Creek Basin. Monthly statistics are provided for these stations in Tables 19 and 20 for comparison to the Sangamon River stations. Kickapoo Creek is rated by the IEPA (1990) as having full aquatic life use support, their highest rating. The drainage areas of the two Kickapoo Creek stations 5580000 and 5580500 are 227 and 306 sq mi which is within the range of drainage areas considered in the upper Sangamon Basin. Similar to the Sangamon River stations, the lowest average monthly DO occurs in August at both stations, 7.8 mg/1 at station 5580000 and 6.8 mg/1 at station 5580500. The lowest, average-monthly DO values are in general slightly higher than those from gages along the Sangamon River. The range of lowest monthly average values is narrower for the Salt Creek Basin gages (6.8 to 7.99 mg/1) man along the Sangamon. From Figure 1 it may be observed mat mere are several wastewater treatment plant outfalls upstream of the gages in the South Fork Sangamon Basin whereas, with the exception of the Bloomington Waste Treatment Plant discharge, the effluent discharges in the Salt Creek Basin are comparatively small. The Salt Creek Basin gages are also located relatively further downstream of any effluent discharges man those in the Sangamon and South Fork Sangamon Basins. Overall, the average mondily DO values tabulated for the Sangamon River gages (Tables 11-18) lie between those computed for gages in the other sub-basins.

Summarizing, along the main Sangamon, the lowest average available DO tends to occur in the late summer, July-August, while the largest deficit (D) lags somewhat, occurring in the fall, October-November. Thus on the basis of the average mondily, daytime DO, the most stressful or critical months for aquatic life are during the late summer. In general, the measured values of DO tend to exhibit the same trends as the DOsat computed from the measured water temperature. Seasonal variability in DO is considerably greater mat variations in DO in any given month for the eight gages. At the two gages in the study reach, upstream of Lake Decatur, temperature-dependent seasonal variability in DO is considerably greater man the measured diurnal fluctuations. Lowest DO and greatest D are observed at the first two gages downstream of Lake Decatur Dam. At some of me larger drainage area gages, average monthly DO greater than DOsat (negative average D) is found in April and May at gage 5573540 just below Lake Decatur Dam, in August at gage 5576500 below the confluence of the Sangamon and South Fork Sangamon Rivers, and from July-September at gage 5573000 below the confluence of the Sangamon River and Salt Creek.

Variation of Oxygen Deficit with Discharge

The availability of DO may be affected by the discharge in several ways. For example, at higher discharges more water is available to dilute agents mat create an oxygen demand; also the reaerative capacity of a stream is a function of flow velocity and depth, which vary with discharge. The variation of DO with discharge was investigated in terms of the oxygen deficit. The oxygen deficit parameter was used to filter out some of the temperature dependence of oxygen concentrations imposed by the saturation concentration limit. Inspection of Tables 11-18 shows that the number of datapoints available for any given month at the eight stations ranges from 3 to 17, with most months having less man 10 datapoints. To conduct a meaningful statistical analysis of the relationship between oxygen deficit (D) and discharge (Q), the data was grouped into four seasons. Each season comprises three inclusive months of data that were grouped on the basis of similarity in T, Q, and DO: season 1 (December-February), season 2 (March-May), season 3 (June-August), and season 4 (September-November).

Plots of D versus the logarithm of Q were developed for each season at each gage. The logarithm of Q was used because Q values tend to be two to three orders of magnitude larger than D values. Datapoints plotted outside of the general pattern of data were dropped. While there was considerable scatter in the data, in part a product of the time-of-sampling, trends were observed. A linear regression analysis was performed for the seasonally grouped data at each gage. The linear regression coefficients were determined using the least-squares criteria. The computed coefficients, the simple regression coefficient, and the standard error of the estimate are presented for the eight gages in Tables 21 and 22, as well as the average and standard deviations of the data set used. In Table 21, the regression statistics are listed by gage for seasons 1-4 so that the degree of dependence of D on Q from season to season at a particular gage may be readily observed. Table 22 presents the same information in a different order: the information is grouped by season and the statistics for each gage are presented in order of increasing drainage areas, thus, providing a streamwise perspective of the seasonal average values of D and the relationship between D and Q.

The values of the simple correlation coefficients for the regression of D on log Q are for the most part not statistically significant, in part attributable to the inherent variability in the data discussed above. However, some comparative observations may be made with regard to seasonal trends as well as along the river course. The correlation between D and log Q is not consistently positive or negative (sign of r in Tables 21 and 22). A negative correlation implies mat as discharge increases the oxygen deficit decreases, a positive correlation implies that as discharge increases, the oxygen deficit also increases. The two gages below Decatur Dam (5573540 and 5573650) consistently show negative correlation of D with Q. This may be related to algal production of DO in the lake, which is carried downstream by the spillway discharge. While the two largest drainage area gages, Sangamon River at Petersburg and Near Oakford (5578000 and 5583000), consistently show a positive correlation. The trend of increasing D with Q at the larger drainage area gages may be due to the cumulative effect of oxygen depletion as the various major tributaries merge. Referring to Table 22, several observations may be made concerning seasonal patterns along the Sangamon. During the winter, season 1, the

Table 21. Main Sangamon River Dissolved Oxygen Deficit
Regression Coefficents and Descriptive Statistics

USGS gage	*Drainage area (sq mi)*	*Season*	$D = a + b \log Q$					*D. mg/l*	
			a	*b*	*r*	*SE*	*N*	*Avg*	*Std*
5570910	240	1	3.038	-0.820	-0.309	1.869	20	1.458	1.913
		2	-1.301	0.815	0.397	0.768	26	0.673	0.820
		3	1.372	-0.069	-0.064	0.847	21	1.251	0.827
		4	2.965	-6.852	-0.409	1.552	16	2.262	1.643
5572125	573	1	0.828	0.107	0.099	0.858	19	0.958	0.837
		2	-0.201	0.341	0.216	0.675	24	0.720	0.676
		3	2.446	-0.343	-0.289	0.972	26	1.701	0.995
		4	3.283	-0.585	-0.381	1.525	20	2.605	1.605
5573540	938	1	4.350	-1.711	-0.629	2.102	28	0.982	2.653
		2	1.544	-0.603	-0.563	0.767	32	-0.076	0.913
		3	6.051	-2.132	-0.856	1.419	37	1.817	2.708
		4	8.037	-2.616	-0.803	2.333	26	5.730	3.830
5573650	1054	1	6.962	-2.022	-0.601	1.803	27	2.125	2.211
		2	5.680	-1.400	-0.648	0.761	29	1.438	0.981
		3	6.396	-1.531	-0.593	1.415	30	2.616	1.727
		4	10.487	-2.975	-0.830	1.618	24	4.059	2.837
5573800	1264	1	4.653	-1.131	-0.486	1.402	26	1.727	1.572
		2	1.727	-0.157	-0.062	1.106	34	1.323	1.091
		3	0.427	0.472	0.198	1.949	27	1.149	1.950
		4	8.059	-2.337	-0.571	1.901	22	3.217	2.260
5576500	2618	1	2.281	-0.207	-0.120	1.351	20	1.653	1.324
		2	-0.861	0.629	0.310	0.910	33	1.192	0.942
		3	-7.988	3.012	0.528	2.417	23	0.573	2.780
		4	6.389	-1.453	-0.443	1.607	20	2.910	1.745
5578000	3063	1	-0.595	0.477	0.225	0.927	15	0.966	0.917
		2	-2.447	0.972	0.467	0.927	23	0.964	1.024
		3	-3.629	1.534	0.700	0.991	19	0.967	1.349
		4	0.513	0.414	0.261	1.061	15	1.659	1.059
5583000	5094	1	-0.759	0.661	0.276	1.110	23	1.398	1.128
		2	-3.027	1.020	0.397	0.901	28	0.835	0.963
		3	-9.697	2.890	0.667	1.477	31	-0.484	1.948
		4	-3.699	1.308	0.424	1.280	30	0.048	1.389

Notes:

Season 1 = Dec, Jan, Feb
Season 2 = Mar, Apr, May
Season 3 = Jun, Jul, Aug
Season 4 = Sep, Oct, Nov

D= oxygen deficit, (DOsat-DO), mg/l
Q= discharge, cfs
r= simple correlation coefficient
SE= standard error of estimate
Avg = arithmetic average
Std= standard deviation of the data
N= number of data points
DOsat= saturation concentration of dissolved oxygen, mg/l
DO= dissolved oxygen concentration, mg/l

Table 22. Main Sangamon River Dissolved Oxygen Deficit Variation of Regression Coefficients with Drainage Area

USGS gage	*Drainage area (sq mi)*	*Season*	D = *a + b log Q*					*D, mg/l*	
			a	*b*	*r*	*SE*	*N*	*Avg*	*Std*
5570910	240		3.038	-0.820	-0.309	1.869	20	1.458	1.913
5572125	573		0.828	0.107	0.099	0.858	19	0.958	0.837
5573540	938		4.350	-1.711	-0.629	2.102	28	0.982	2.653
5573650	1054		6.962	-2.022	-0.601	1.803	27	2.125	2.211
5573800	1264		4.653	-1.131	-0.486	1.402	26	1.727	1.572
5576500	2618		2.281	-0.207	-0.120	1.351	20	1.653	1.324
5578000	3063		-0.595	0.477	0.225	0.927	15	0.966	0.917
5583000	5094		-0.759	0.661	0.276	1.110	23	1.398	1.128
5570910	240	2	-1.301	0.815	0.397	0.768	26	0.673	0.820
5572125	573	2	-0.201	0.341	0.216	0.675	24	0.720	0.676
5573540	938	2	1.544	-0.603	-0.563	0.767	32	-0.076	0.913
5573650	1054	2	5.680	-1.400	-0.648	0.761	29	1.438	0.981
5573800	1264	2	1.727	-0.157	-0.062	1.106	34	1.323	1.091
5576500	2618	2	-0.861	0.629	0.310	0.910	33	1.192	0.942
5578000	3063	2	-2.447	0.972	0.467	0.927	23	0.964	1.024
5583000	5094	2	-3.027	1.020	0.397	0.901	28	0.835	0.963
5570910	240	3	1.372	-0.069	-0.064	0.847	21	1.251	0.827
5572125	573	3	2.446	-0.343	-0.289	0.972	26	1.701	0.995
5573540	938	3	6.051	-2.132	-0.856	1.419	37	1.817	2.708
5573650	1054	3	6.396	-1.531	-0.593	1.415	30	2.616	1.727
5573800	1264	3	0.427	0.472	0.198	1.949	27	1.149	1.950
5576500	2618	3	-7.988	3.012	0.528	2.417	23	0.573	2.780
5578000	3063	3	-3.629	1.534	0.700	0.991	19	0.967	1.349
5583000	5094	3	-9.697	2.890	0.667	1.477	31	-0.484	1.948
5570910	240	4	2.965	-0.852	-0.409	1.552	16	2.262	1.643
5572125	573	4	3.283	^0.585	-0.381	1.525	20	2.605	1.605
5573540	938	4	8.037	-2.616	-0.803	2.333	26	5.730	3.830
5573650	1054	4	10.487	-2.975	-0.830	1.618	24	4.059	2.837
5573800	1264	4	8.059	-2.337	-0.571	1.901	22	3.217	2.260
5576500	2618	4	6.389	-1.453	-0.443	1.607	20	2.910	1.745
5578000	3063	4	0.513	0.414	0.261	1.061	15	1.659	1.059
5583000	5094	4	-3.699	1.308	0.424	1.280	30	0.048	1.389

Notes:

Season 1 = Dec, Jan, Feb
Season 2 = Mar, Apr, May
Season 3 = Jun, Jul, Aug
Season 4 = Sep Oct, Nov

D= oxygen deficit, (DOsat-DO), mg/l
Q= discharge, cfs
r= simple correlation coefficient
SE= standard error of estimate
Avg = arithmetic average
Std= standard deviation of the data
N= number of data points
DOsat= saturation concentration of dissolved oxygen, mg/l
DO= dissolved oxygen concentration, mg/l

pattern is for D to decrease with increasing Q up to gage 5578000. Rapid DO depleiton occurs in stream water under winter ice conditions. Runoff from precipitation events has higher DO, thus DO levels rise (and D decreases) with increasing discharge during the winter. During the spring, season 2, D increases with Q except for the three gages following the dam and effluent outfall. A relatively high negative correlation exists at the first two gages downstream of the dam and the trend reverses at the next gage 5573800 where the correlation is negative but very small. Season 3 includes the summer months with lowest DOsat, where D decreases with increasing Q for the four smaller drainage area gages but increases with Q for the four largest drainage area gages. It may be observed from the 7-day 10-year low flows shown on the map in Figure 1 that during very low streamflow periods, a significant portion of the flow downstream of Decatur's effluent outfall is treated waste water. During the fall, season 4, mere is a clear correlation between D and Q: D decreases as Q increases except the two gages furthest downstream.

The strongest correlation between D and log Q are found at gage 5573540, the first gage downstream of Lake Decatur Dam, and 5573650, which follows it and is downstream of Decatur's water treatment plant outfall. On the average, the two furthest upstream stations (those within the study reach) have the smallest simple correlation coefficients, or least correlation between D and log Q. For the eight stations, the magnitude of the positive, (DO less than DOsat) mean D values computed ranges from 0.048 to 5.730 mg/1, 75 percent are less than 2 mg/1. Of the 25 percent of the mean D values over 2 mg/1, half are found at the two gages following the dam and the remainder occur in the fall (season 4). Thus with the exception of the reach below the dam and effluent outfall, the daytime oxygen levels on the average are less man 2 mg/1 below the saturation concentration. In the study area DO tends to be near saturation concentration (DOsat), and there may be little opportunity for variations in discharge to produce definable differences in DO (or D). The strongest correlation coefficients are found at gage 5573540 (1.2 miles below the dam and approximately 2.5 miles upstream of Decatur's effluent outfall) and 5573650 (approximately 9.6 miles downstream of Decatur's effluent outfall). The next gage (5773800), about 18 miles further downstream (approximately 27.9 miles downstream of the effluent outfall), may be affected by these facilities, particularly during the low-flow season. Further downstream Springfield also has a large effluent discharge; however, the nearest AWQMN gage (5578000) is more than 28 miles downstream from the outfall and the gage data shows no apparent impact on DO levels. Furthermore, the Sangamon has a considerably larger drainage area at Springfield than at Decatur. The presence of Lake Decatur has a significant impact on downstream water quality. Algal production is enhanced, reaeration is effected by flow over the dam, and seasonal patterns in water quality are effected by the fall and spring lake turnover. Furthermore, the relative influence of these various components may vary from time to time and little correlation between DO (or D) and Q may be discernible. A more in-depth discussion and investigation of the impact of the dam and effluent discharges below Lake Decatur Dam are planned for the next phase of this study. In general, the largest mean D value at any gage occurs during the fall (season 4). At most gages, the strongest correlation between D and Q tends to occur during the summer or fall (seasons 3 and 4, respectively), when flows and DOsat are lowest and D is largest. Because there are several factors influencing DO along the river, it is not atypical that a strong correlation between DO (or D) and Q cannot be observed.

Dissolved Oxygen Requirements

A DO level of 5 mg/1 is commonly seen in the literature as a minimum requirement to support a diverse fish population. Various fish species have differing DO needs that also vary with life stage. Cold-water fish tend to have higher DO requirements (6 to 7mg/l), while warm-water fish are more tolerant and tend to survive lower DO levels (4 to 5 mg/1) (Viessman and Hammer, 1985). DO needs are also related to temperature. Wiley et al. (1987) proposed temperature-dependent minimum oxygen concentrations for the maintence of selected fish species common to Illinois. The temperature-dependent minimum DO equations were developed by Wiley et al. on the basis of laboratory determination of lethal levels of DO. The State of Illinois Water Pollution Control Rules, as amended through April 24, 1990, establish General Use Water Quality Standards, Public and Food Processing Water Supply Standards, and Secondary Contact and Indigenous Aquatic Life Standards for DO. The general use standards, more stringent than the secondary contact standards, are applicable to all portions of the Sangamon Basin with the exception of the Sangamon River at Decatur's water supply intakes where more stringent public water supply standards apply.

The minimum DO concentration levels proposed by Wiley et al. (1987) are given in Table 23 for several fish species indigenous to the Sangamon Basin. These equations indicate lethal levels and do not imply long-term maintenance levels. Using the average monthly temperatures determined from Equation 19, minimum DO concentrations were computed from the equations in Table 23, and are presented in Table 24. The functions and tabulated results show DO requirements increasing with increasing temperature, the highest value calculated from the functions being' 4.96 mg/1. These equations were developed on the basis of laboratory data and do not represent a recognized standard.

The standards established by the Illinois Pollution Control Board are somewhat higher man the results of the equations. Section 302.206 of the Pollution Control Rules provides that DO shall <u>not.be</u> less than 6.0 mg/1 during at least 16 hours of any 24-hour period, nor less man 5.0 mg/1 at any time. These regulations address a time-average condition of DO needed to support the aquatic community. To evaluate compliance with these rules, the diurnal variation of DO must be considered.

Discussion of Findings

The AWQMN water quality data provide a historical perspective of the water quality conditions along the stream network. Typical (average) DO concentrations in the basin may be

Table 23. Minimum Oxygen Concentrations as a Function of Temperature
(after Wiley et al. ,1987)

Species	*Minimum DO, mg/l*
Smallmouth bass	$0.40T^{0.73}$
Golden redhorse	$0.16T^{0.9}$
Orangethroat darter	3.0
Channel catfish	$1.16T^{0.4}$
Horneyhead chub	$1.74T^{0.22}$
Longear sunfish	$1.88T^{0.301}$
Common carp	2.0
Bluntnose minnow	2.0

Note: T= temperature in degrees C

Table 24. Minimum Oxygen Concentrations for Selected Fish Species Calculated from Equations Proposed by Wiley et al., 1987

		Minimum DO. concentration, mg/l			
Month	*Avg. monthly temp., C*	*Smallmouth bass*	*Channel catfish*	*Longear sunfish*	*Bluntnose minnow*
1	1.61	0.57	1.40	2.17	2.00
2	2.36	0.75	1.64	2.44	2.00
3	5.37	1.36	2.27	3.12	2.00
4	10.85	2.28	3.01	3.85	2.00
5	17.26	3.20	3.62	4.43	2.00
6	22.59	3.89	4.04	4.80	2.00
7	25.14	4.21	4.21	4.96	2.00
8	24.11	4.08	4.14	4.90	2.00
9	19.83	3.54	3.83	4.62	2.00
10	13.63	2.69	3.30	4.13	2.00
11	7.47	1.74	2.59	3.44	2.00
12	3.17	0.93	1.84	2.66	2.00

Note:
Avg. monthly temperatures calculated from a polynomial fit to average daily temperatures recorded at 18 gages in the Sangamon Basin.

determined as well as correlation between Q and DO, and the representativeness of the field-measured data may be evaluated. The field data provided the critical information defining the diurnal variations in DO.

The field measurements were conducted during August and September when DO and Q tend to be lowest. The discharges measured at the three sites during event 1 and event 2 correspond to an annual flow durations of 56 and 67 percent, respectively. These flows are less than the long-term median flows for these months (see Table 2). During the field measurements, average DO concentration ranged between 6.60 and 8.71 mg/1, with a recorded minimum of 6.17 and maximum of 10.04. Referring to two AWQMN gages in the study reach (Tables 11 and 12), the field values are comparable to the long-term average DO but are not as low as recorded minimum DO concentrations. From the field data (Figures 4 and 5), it may be surmised that when the DO follows the classic sinusoidal pattern, typically the peak DO occurs between 3:00 and 9:00 p.m. as algal activity creates supersaturation conditions during the daylight hours; DO concentrations fall below DOsat sometime after dark (usually between 5:00 and 11:00 p.m.) and minimum DO most frequently occurs around 8:00 or 9:00 a.m. On the basis of the field data the difference between the measured peak and minimum in any 24-hour period was typically on the order of 1.0 to 1.7 mg/1 during the two events; over the entire 72-hour period the maximum difference at any site was 2.91 mg/1. On the basis of these observations and the observation that the AWQMN data is most often collected between 10:00 a.m. and 2:00 p.m., generally the AWQMN data may not include either the peak or the minimum DO. During the two events monitored, DO concentrations were above the minimums established by the IEPA.

Examination of the data summarized for AWQMN gages 5570910 and 5572125 (Tables 11 and 12), with respect to the IEPA standards shows that the DO may fall below the standards set by the IEPA. The minimum DO recorded was 5.6 mg/1 in August at 5570910 and 3.5 mg/1 in July at 5572125. The lowest monthly averages (6.9 and 6.3 mg/1) also occurred in August and July, respectively. One standard deviation below the average (from Tables 11 and 12) gives concentration levels of 5.8 and 4.9 mg/1. If nighttime minimums fall 1.0 mg/1 or more below diese values, they are clearly less man the IEPA standards and could reach lethal levels. For the majority of the time, however, DO concentrations were in compliance.

These DO levels may be compared to the stations on Kickapoo Creek (5580000 and 5580500) which has the highest use assessment rating given by the IEPA. At station 5580000 the minimum DO of 6.1 mg/1 was recorded in July; at station 5580500 the minimum DO of 4.8 mg/1 was recorded in July as well. A DO level of 4.8 mg/1 is already in violation of the IEPA standard and nighttime decrease in DO greater than 1.1 at stations 5580000 would indicate violation of the standard at the station also. Subtracting the standard deviation from the lowest mondily averages, which occur in August at both stations gives DO levels of 6.8 and 5.6 mg/1 at 5580000 and 5580500, respectively.

Water quality, as indicated by DO, appears somewhat better along Kickapoo Creek than along the upper Sangamon. However, violations of the IEPA standards may still occur.

Integration of Basinwide Flow Model and DO Information

Along the study reach, the main Sangamon River up to Lake Decatur, water quality as measured by DO levels is fairly good. There is some indication that IEPA standards may occasionally be violated, particularly in July and August. During July and August flows are comparable to discharges having annual flow durations in the range of 50 to 70 percent. At these flow levels, the WUA calculations for juvenile and adult life stages (Figures 2 and 3) of four selected fish species (smallmouth bass, channel catfish, longear sunfish, and bluntnose minnow) indicate that hydraulic conditions provide relatively little habitat along the study reach except for the adult bass, catfish, and sunfish along the larger downstream portion of thereach as illustrated by the habitat response curves (WUA vs. F) for the 600 sq mi drainage area (Figures 2 and 3). The availability of habitat for other species such as bluegill, which are prominent along thestudy reach, could also be examined.

The flow and habitat model could be used to generate the WUA corresponding to monthly or seasonal flow durations to provide a more detailed evaluation of the stream systems. However, habitat response curves plotted as functions of annual flow duration (F), may be readily interpreted for various seasonal or monthly discharges of interest as demonstrated in this report. As DO availability varies throughout the year, depending on temperature, an evaluation of the WUA for flows typical of a month or season will illustrate if a flow, DO conditions in the stream segment, or both are limiting for a particular species. The basinwide model simulates the hydraulic data needed to compute the WUA using the preference curves developed by biologists and fisheries experts. The resulting WUA curves and hydrologic data identifying typical seasonal flows may be used by these experts to identify critical time periods in the developmental stages for target fish species in a basin.

SUMMARY AND CONCLUSIONS

The integration of water quality data with a basinwide flow and habitat model is demonstrated in an evaluation of the habitat potential of the upper Sangamon River. The basinwide flow and habitat model used provides information on the suitability of the hydraulic conditions along the stream network, over a range of discharge conditions, for habitation by various fish species. Preference curves for depth, velocity, and substrate for selected fish species are used in the flow and habitat model to assess the quantity of suitable habitat. The habitat assessment portion of the model is based on the Instream Flow Incremental Methodology proposed by the Instream Flow Group of the U.S. Fish and Wildlife Service. Historical data for DO from water quality monitoring stations were analyzed to evaluate the availability of DO along the main Sangamon River. . The focus of the study was the Sangamon River up to Lake Decatur. However, data from stations throughout the Sangamon basin were reviewed to provide a basis for judging the representativeness of the stations in the study area. Diurnal variations of DO as well as other water quality parameters were measured at three field sites located in the upper Sangamon River. Typical DO levels were compared to IEPA standards for support of suitable aquatic habitat. The study demonstrates a methodology for evaluating if flow and/or water quality conditions may be limiting factors for a stream to support various aquatic life forms.

The results of the study indicate that water quality along the upper Sangamon is generally good. The greatest variation in DO over the year is attributable to the temperature influence on DO saturation concentration. DO levels along the upper Sangamon are on the average slightly lower than found along other streams in the basin mat receive less effluent loading. DO levels in streams mat receive relatively small quantities of effluent discharge may still fall below IEPA standards, likely due to constituents carried to the streams by agricultural runoff. On the basis of data collected at water quality monitoring stations above Lake Decatur Dam, the average monthly DO levels are typically not more man 3 mg/1 below saturation concentration and typically above the current IEPA minimum standard of 5 mg/1 for DO. However, me lowest (minimum) DO levels measured have in me past fallen below me 5 mg/1 standard. The historical water quality data is collected during me day, when DO levels are higher due to algal activity. Field data collected over two 72-hour periods at three sites indicates mat while diurnal variations are not extreme, during summer mondis when DO is already lowest, decreases in DO during the night may cause DO levels to fall below IEPA standards more frequently than indicated by the historical data. In addition to the minimum DO standard of 5 mg/1, the IEPA standards also include the requirement that DO shall not be less than 6 mg/1 for 16 hours of any 24-hour period. At the two water quality monitoring stations above Lake Decatur, the mondily average DO computed from the data is very close to 6 mg/1 in July or August.

Low flows typical of summer conditions do not provide an abundance of suitable habitat for the four fish species considered along the upper portion of the river (drainage areas less man about 500 sq mi). The four fish species considered were bluntnose minnow, channel catfish, longear sunfish, and smallmouth bass. Thus in terms of hydraulic conditions (discharge) and water quality (DO levels), me availability of suitable habitat is limited during summer mondis (particularly July and August). Other indigenous fish species, such as bluegill, could be targeted for consideration as habitat needs vary from species to species. Increases in effluent loading or maintenance of lower flows due to diversion could extend the period of time mat suitable habitat is limited.

Review of the water quality station data at locations downstream of Lake Decatur and downstream of Decatur's wastewater treatment plant clearly shows mat DO levels are effected by these facilities. Investigation of DO and habitat conditions in me Sangamon River between L
and Petersburg is planned for a future study.

The basinwide flow and habitat model provides a means to evaluate the habitat potential of any stream in the network. The model facilitates the assessment in terms of the basin's hydrologic and hydraulic conditions. The present study demonstrates how water quality data defining DO levels may be integrated with the habitat model to identify locations where water quality could be the limiting condition given the physical and hydrologic constraints of a particular basin. The detailed field data collected may be used with a water quality model to evaluate diurnal variations in DO for different oxygen demand conditions, possibly arising from changes in effluent loads.

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