1982

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The effects of Saylorville Reservoir and the Raccoon River on selected water quality parameters of the Des Moines River

by

David Paul Bierl

A Thesis Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of MASTER OF SCIENCE

Department: Civil Engineering Interdepartmental Major: Water Resources

Signatures have been redacted for privacy

Iowa State University Ames, Iowa 1982
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Flow

Biochemical oxygen demand

Suspended solids

Total phosphate

Organic nitrogen

Ammonia nitrogen

Nitrite plus nitrate nitrogen

Total nitrogen

Comparing the Water Quality of the Raccoon and Des Moines Rivers

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INTRODUCTION

In recent years, a great deal of interest has been generated concerning the water quality of lakes and rivers. In the past, most control and abatement efforts at both state and national levels have focused primarily on point sources of water pollution; however, nonpoint source pollutants have been recognized as a major cause of water quality deterioration. Nonpoint sources of pollution are especially evident in agricultural regions of the country.

Studies conducted by the United States Environmental Protection Agency (1977) found higher sediment and nutrient concentrations in streams draining agricultural lands than streams draining range lands, forest lands, or urban land areas. Cropland ranks first in the amount of relative total erosion and in the percent of sediment yield by source (Iowa Department of Environmental Quality, 1977).

Farming practices often leave the soil unprotected, and therefore highly vulnerable to water and wind erosion. Soil is an important nonpoint source pollutant because of the large volume it occupies in reservoirs and other sedimentation areas, and the murkiness it produces. Also, plant nutrients, bacteria, pesticides, and other polluting chemicals are often associated with soil particles. No other water pollutants occur in amounts comparable to sediment.
According to Troeh et al. (1980), streams in the United States carry over 700 times as much eroded soil as sewage. Because 75% of Iowa's land area is cropland, high sediment and nutrient loadings can be expected in Iowa's surface waters (Iowa Department of Environmental Quality, 1977). One of Iowa’s major drainageways, the Des Moines River Basin, is 73% cropland (Upper Mississippi River Basin Commission, 1981); therefore, one would expect nonpoint sources of pollution to be a major cause of water quality deterioration in this basin.

In July of 1967, a long-term water quality monitoring study on a portion of the Des Moines River upstream from the City of Des Moines was initiated. The purpose of this study was to determine the water quality of the river prior to impoundment by the then under construction Saylorville Dam and Reservoir. The Rock Island District of the United States Army Corps of Engineers contracted with the Engineering Research Institute at Iowa State University to carry out the preimpoundment study.

The study consisted of sampling at 5 stations on the river, extending from the headwaters of the proposed flood pool to a location 1.5 miles downstream of the dam site. Grab samples were collected weekly at each station and analyzed for selected chemical, physical, and biological constituents. The data collected are summarized in annual
reports. On April 12, 1977 the gates of Saylorville Dam were closed, thus completing the collection of preimpoundment data. Since closure, the study has continued, thus initiating postimpoundment data collection.

Currently, only 2 of the original 5 stations are being sampled, and 7 new stations have been added: Station 3, in Saylorville Reservoir at the point where the Des Moines River enters the conservation pool; Station 4, in Saylorville Reservoir near the dam; Station 10, on the Raccoon River upstream from the City of Des Moines; Station 6, on the Des Moines River downstream from the confluence of the Raccoon River and the Des Moines Water Pollution Control Plant; Station 7, on the Des Moines River upstream of the conservation pool of Red Rock Reservoir; Station 8, in the conservation pool of Red Rock Reservoir near the dam; and Station 9, immediately downstream from Red Rock Dam. Figure 1 shows the location of stations currently being sampled.

Undoubtedly, the operation of Saylorville Reservoir affects the downstream water quality of the Des Moines River. By examining the preimpoundment and postimpoundment data, and by comparing postimpoundment data at Stations 1 and 5, the effects of Saylorville Reservoir on the water quality of the Des Moines River can be seen. Also, by examining the data collected at Stations 5, 6, and 10, the water quality of the Des Moines and Raccoon Rivers can be compared.
Figure 1. Location map of current sampling stations on the Des Moines River, Raccoon River, Saylorville Reservoir, and Red Rock Reservoir.
Objectives

The primary objective of this thesis was to determine and to demonstrate quantitatively the downstream effects of Saylorville Reservoir on the following water quality parameters: flow, biochemical oxygen demand (BOD), suspended solids, total phosphate, ammonia nitrogen, organic nitrogen, nitrite plus nitrate nitrogen, and total nitrogen. The data collected on each parameter at Station 1 (above the reservoir), and at Station 5 (below the reservoir), are divided into 3 time periods: before closure, after closure, and total period of record. By comparing the mean concentrations and loadings of the above parameters, excluding flow, during the 3 time periods at the 2 stations, the downstream effects of the reservoir can be shown.

Secondary objectives of this thesis include: comparing the water quality of the Raccoon and Des Moines Rivers by examining mean BOD and suspended solids concentrations and loadings at Stations 10, 5, and 6, and estimating the relative amounts of point versus nonpoint sources of pollution in the Des Moines River.
Geographics of the Des Moines River

The Des Moines River with its tributaries is the largest river in Iowa. The source of the West Fork of the Des Moines River is in the glacial moraine area of Murray and Pipestone Counties, Minnesota, at an altitude of about 1,900 feet above sea level. The outlet of Okamanpeden Lake near the Iowa-Minnesota border is the source of the East Fork of the Des Moines River. The 2 forks of the river flow in a southeastwardly direction and eventually join below Humboldt, Iowa. Other major tributaries of the Des Moines River are the Boone River and the Raccoon River, with confluences just above Stratford, Iowa, and at Des Moines, Iowa, respectively. From Des Moines, the river flows southeastwardly and is joined by numerous smaller rivers before it empties into the Mississippi River at Keokuk, Iowa, at an altitude of 475 feet above sea level. The North, Middle and South Rivers join the Des Moines River between Stations 6 and 7, between the City of Des Moines and Red Rock Reservoir. These rivers carry very large sediment loads, but are not considered further in this thesis. The length of the Des Moines River from its source in Minnesota to where it empties into the Mississippi River is about 535 miles. Figure 2 shows a diagram of the Des Moines River Basin.

The Des Moines River Basin is divided into 3 major
Figure 2. General plan of the Des Moines River Basin
subbasins, as shown in Figure 3: the Upper Des Moines River Basin, the Raccoon River Basin, and the Lower Des Moines River Basin. The total drainage area of the Des Moines River is 14,540 square miles, of which 1,525 square miles are in Minnesota, 12,925 in Iowa, and 90 in Missouri. The area drained in Iowa represents 23% of the total area of the state. The 2 subbasins of particular interest in this study are the Upper Des Moines River and Raccoon River Basins, which drain 6,245, and 3,629 square miles, respectively, at their confluence in the City of Des Moines.

Saylorville and Red Rock Reservoirs

Two major United States Army Corps of Engineers impoundments are located on the Des Moines River. Red Rock Reservoir (or Lake), situated southeast of the City of Des Moines, began to form in March of 1969 when the gates of Red Rock Dam were closed. Red Rock Reservoir was built primarily for flood protection. Other purposes include: low flow augmentation, recreation, and enhancement of fish and wildlife resources. When the reservoir is at conservation pool level (728 feet above mean sea level), it covers an area of 10,400 acres and is 11.3 miles long. The flood control pool is 780 feet above mean sea level, covers 65,500 acres, and is 33.5 miles long (United States Army Corps of Engineers, 1979).

The gates to Saylorville Reservoir (or Lake), the other
Figure 3. Locations of subbasins in the Des Moines River Basin
Impoundment on the Des Moines River, were closed in April of 1977. Saylorville is also a multipurpose reservoir, having flood control as its primary function, and low flow augmentation, recreation, and fish and wildlife enhancement as secondary purposes. Saylorville Dam is located 11 miles upstream from the City of Des Moines, and in the near future, water supply for the city will be an additional benefit from the reservoir. The conservation pool of Saylorville Reservoir is 833 feet above mean sea level, it covers an area of 5,400 acres, and is 17 miles long. The flood control pool is 890 feet above mean sea level, covers 16,700 acres, and is 54 miles long (United States Army Corps of Engineers, 1976).

Climatology and Hydrology

The Des Moines River Basin receives an average of between 28 and 36 inches of rain annually. The average annual precipitation in the study area before 1980, as represented by data from the weather station at Boone, Iowa is 33.12 inches (Department of Commerce, 1980). During the 14 years of this study (1967-1980), the average annual precipitation has been 34.02 inches, ranging from 22.34 inches in 1980 to 47.01 inches in 1973. Nearly half of the annual precipitation in Iowa occurs during the months of May, June, July, and August.

The average discharge of the Des Moines River at Station 1 (as represented by the 57-year period of record at
a gaging station at the upper end of the flood pool near Stratford, Iowa) is 1,734 cfs (49.11 m\(^3\)/s), (United States Geological Survey, 1977). The maximum discharge for the period of record was 57,400 cfs (1,630 m\(^3\)/s) on June 22, 1954, and the minimum discharge was 13 cfs (0.28 m\(^3\)/s) on January 23, 1977.

The average discharge of the Raccoon River at Station 10 for the 62-year period of record is 1,291 cfs (36.56 m\(^3\)/s). The maximum discharge for the period of record was 41,200 cfs (1,170 m\(^3\)/s) on June 13, 1947, and the minimum discharge was 10 cfs (0.28 m\(^3\)/s) on January 22, 1940.

The mean runoff values for the Raccoon River near Station 10, and the Des Moines River near Stations 1 and 5 are 0.38 cfs/sq mi, 0.32 cfs/sq mi, and 0.41 cfs/sq mi, respectively.

Point Sources of Pollution

Point source pollution implies a wastewater discharge from a pipe or some identifiable, confined and distinct conveyance (Iowa Natural Resources Council, 1978). The 2 major point sources of pollution of the Des Moines River are municipal wastewater discharged from treatment facilities and treated wastewaters from meat processing plants.

The Des Moines Wastewater Treatment Plant is the largest point source of pollution in the Des Moines River Basin. According to Baumann et al. (1974a), communities above Red
Rock Dam adds about 20,934 lb BOD/day to the rivers and streams of the basin, of which 48% is contributed by the Des Moines metropolitan area. Table 1 lists the major point sources of pollution of the Des Moines River Basin near the study area.

Trickling filters and waste stabilization ponds are the principal methods of treating municipal waste in the Des Moines River Basin.

**Nonpoint Sources of Pollution**

Runoff from urban and rural land that cannot be readily identified as industrial, commercial, institutional, or domestic point discharges, is a nonpoint source of pollution. The 3 main categories of nonpoint pollution in the Des Moines River Basin are general rural runoff, animal feeding operations, and urban runoff.

Since over 95% of the Des Moines River Basin is classified as agricultural land, one would expect general rural runoff to have the greatest impact on surface water quality. Pollutants found in general rural runoff include sediments, nutrients, pesticides, bacteria, and organic matter. Pollution potential from agricultural land is heavily dependent upon land use. Agricultural land classified as cropland poses the greatest pollution threat (73% of the Des Moines River Basin is classified as cropland). Soils in the Raccoon and Lower Des Moines River Basins are potentially
Table 1. Location and discharge of the major point sources of pollution of the Des Moines River Basin near the study area (Iowa DEQ, 1977)

<table>
<thead>
<tr>
<th>Subbasin</th>
<th>Discharger</th>
<th>Receiving Segment</th>
<th>River&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Mile</th>
<th>Million Gallons/Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Des Moines</td>
<td>Fort Dodge WWTP&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Des Moines River</td>
<td>314</td>
<td>3.367</td>
<td></td>
</tr>
<tr>
<td>River</td>
<td>Iowa Beef Processors</td>
<td>Des Moines River</td>
<td>311</td>
<td>1.100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Webster City WWTP</td>
<td>Boone River</td>
<td>24</td>
<td>1.582</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Boone WWTP</td>
<td>Des Moines River</td>
<td>251</td>
<td>1.990</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Firestone Tire and Rubber Co.</td>
<td>Walfley Creek</td>
<td>---</td>
<td>1.270</td>
<td></td>
</tr>
<tr>
<td>Raccoon River</td>
<td>Jefferson WWTP</td>
<td>Drainage Ditch 132</td>
<td>---</td>
<td>0.485</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Perry WWTP</td>
<td>North Raccoon River</td>
<td>60.6</td>
<td>1.052</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oscar Mayer Co.</td>
<td>North Raccoon River</td>
<td>61.0</td>
<td>0.670</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adel WWTP</td>
<td>North Raccoon River</td>
<td>37.4</td>
<td>0.400</td>
<td></td>
</tr>
<tr>
<td>Lower Des Moines</td>
<td>Des Moines WWTP</td>
<td>Des Moines River</td>
<td>196</td>
<td>38.9</td>
<td></td>
</tr>
<tr>
<td>River</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Des Moines River: 0 mile at Mississippi River confluence.
Boone River: 0 mile at Des Moines River confluence.
North Raccoon River: 0 mile at Des Moines River confluence.

<sup>b</sup>Wastewater treatment plant.
more erodible than soils in the Upper Des Moines River Basin

The State of Iowa has the largest number of individual
livestock operations of any state in the nation. According
to Baumann et al. (1974a), the density of livestock in the
Raccoon River Basin (256 animals/sq mi), is greater than that
of the Upper Des Moines (115 animals/sq mi), or of the Lower
Des Moines (178 animals/sq mi) River Basins. Animal wastes
from these operations have a great potential for polluting
surface waters. Fish kills have been reported downstream of
large feeding operations following heavy rains.

The major pollutants found in wastes from livestock
operations are nutrients, suspended solids, organic matter
and bacteria. Organic matter washed into surface waters has
a high biochemical oxygen demand. The BOD of the livestock
waste produced in the Des Moines River Basin is equivalent to
that from a human population of at least 20 million people,
far exceeding that contributed by the human population of
500,000 (Baumann et al., 1974a).

The impact of urban runoff on water quality is difficult
to quantify based upon present information. In urbanized
areas, surface runoff and combined sewer overflows can
adversely affect surface water quality. Pollutants found in
urban runoff include tire and vehicular exhaust residues,
deicing compounds, fertilizers, pesticides, animal droppings,
air pollution fallout, and decayed vegetation.

Des Moines, Webster City, and Adel are 3 cities in the basin that have combined sewer systems. The only metropolitan area (population over 100,000) in the Des Moines River Basin is the City of Des Moines; therefore, urban runoff is probably not a major contributor to water quality deterioration in the basin.
LITERATURE REVIEW

Downstream Effects of Reservoirs

Several hundred flood control structures are built annually in the United States, many in agricultural areas. During the period 1962-1968, over 200 major dams were completed each year in North America (Beaumont, 1978). While the primary purpose of most of these structures is flood control, the quality of water within these reservoirs, and the quality of water released is important because of an increased demand for recreation and downstream uses of the waters (Schreiber et al., 1977). Small upstream reservoirs may be focal points in improving water quality from diverse nonpoint pollution sources within an agricultural watershed (Schreiber and Rausch, 1979).

Very little has been written on the influence of impoundment releases on downstream water quality, and those articles that have been published are concerned with the degradation of downstream water quality because of releases of poor quality water from impoundments (Symons et al., 1969). However, many articles are found in the literature concerning the effects of impoundments on water quality within reservoirs.

When water in a free-flowing stream is impounded in a large storage reservoir, changes in the physical, chemical, bacteriological, and mineral quality of the water occur.
Churchill (1958), Love (1961), and Symons et al. (1967) have outlined the possible beneficial and detrimental effects that may be realized when a free-flowing stream is dammed. Important beneficial effects of impoundment include: reduced turbidity and entrapment of sediment because of long detention times and low velocities, reduced water hardness brought about by algal utilization of carbon dioxide and subsequent precipitation of calcium carbonate, reduced BOD and color caused by long detention times permitting biodegradation, reduction in coliform bacteria caused by increased detention time permitting natural die-off, dilution of high concentrations of various incoming pollutants, and storage of water for release in dry periods for the dilution of downstream polluted waters.

Detrimental effects that may occur when water is impounded include: less mixing because reduced velocities might cause a waste that formerly was distributed throughout a stream to hug the shoreline, less atmospheric reaeration caused by lower velocities and increased depth, increased algal problems, either in the form of aesthetically displeasing scums, or taste and odor in the water, both of which are caused by longer detention times, no bottom scour because of increased depth, and thermal stratification which causes a decrease in dissolved oxygen and an increase in iron, manganese, hydrogen sulfide, and carbon dioxide in the
Water quality changes that occur in impoundments are the result of complex interactions between many factors such as: size and shape of the reservoir, storage management over the yearly cycle, outlet geometry and location, amount, distribution, and quality of the inflow, internal mixing processes, chemical and biological processes in the water, heat and mass transfer processes across the water surface and the ground, optical properties of the water, and climate of the environment (Wunderlich and Elder, 1973; Churchill and Nicholas, 1967; Hannan, 1979).

A factor not previously mentioned that has a large effect on water quality is the impoundment site preparation. Large amounts of inundated vegetation can have a rapid and profound effect on water quality in a new reservoir. Extensive blue-green algal blooms, taste and odor problems, and low dissolved oxygen concentrations near the surface in several new reservoirs have been attributed to decomposition of inundated original vegetation (Ball et al., 1975). The effects of inundated terrestrial vegetation on water quality are usually not permanent and can be partially or completely reversed over long periods of time. The rate of reversal depends primarily on flushing rates, initial vegetation loading, temperature, basin morphometry, and land use surrounding the reservoir. The decomposition rate of vegetation
is primarily dependent on tissue type. Wood and bark decompose and release nutrients at a slower rate than leaves.

In a study on the effect of original vegetation on reservoir water quality, Ball et al. (1975) concluded that:

1) Eutrophic waters leach nitrogen from vegetation at a faster rate than less productive waters.

2) Nutrients appear to leach rapidly from vegetation starting with the first day of inundation. After an initial rapid release, which may cover a 2 week period, the nutrients tend to leach at a slower rate.

3) Nutrient leaching occurs while oxygen is being utilized. If natural reaeration slows and sufficient vegetation is present, a significant dissolved oxygen problem may occur.

4) Phosphorus was found to leach from vegetation at a slower rate than nitrogen.

The clearing policy objective of the United States Army Corps of Engineers is to remove only that material required to reduce construction costs, to clear areas that would create hazards, and to consider maximizing the practical benefits to fish and wildlife. Another objective is to "eliminate pollution". The Corps estimates that water quality problems associated with original vegetation are negligible after a period of 10 years.

The soil underlying a new reservoir can also have
dramatic effects on water quality. Sylvester and Seabloom (1965) listed 3 possible effects of soil on the quality of overlying water in an impoundment. Physically, the soil can affect the color, turbidity, and taste and odor characteristics of the water. Chemically, the pH and nature and amounts of various dissolved solids and gases are influenced. Biologically, the soil may provide nutrients for the growth of algae and other aquatic organisms. Most of the water quality changes due to the soil originate from the decomposition of organic matter in the soil and in the water above it.

Flow

The primary function of most reservoirs is flood control. A flood control impoundment is designed to attenuate and delay peaks in the inflow hydrograph, thereby reducing potential damage caused by increased downstream water levels (Walburg et al., 1981; Churchill, 1958; Decoursey, 1975). The attenuation of peak flood flows occurs when water is stored during peak flow periods and then released gradually when river flows return to below flood stage. The reduction in peak flow results in longer periods of high flow downstream. Reservoir discharges are often reduced as high flows enter upstream to permit the downstream tributaries to discharge before reservoir flood waters are released.

The construction of a dam usually causes a decrease in the amplitude of annual variations in water levels down-
stream. However, if the dam has been built to generate electricity, the operation of the plant may introduce small-amplitude, short-period variations as the discharge is varied in accordance with the demands for electricity (Baxter, 1977). Releases are usually reduced during weekends and other periods of off-peak power loads.

In a study on mainstream reservoirs of the Colorado River System, Paulson and Baker (1980) found that following the formation of Lake Powell in 1963, the inflow into Lake Mead (the next reservoir downstream) has been altered. They observed a reduction of inflow in the spring and an increase in winter and late summer.

**Biochemical oxygen demand**

Biochemical oxygen demand is a measure of the amount of oxygen required by decomposing organisms to utilize carbonaceous and nitrogenous compounds under aerobic conditions (Baumann et al., 1982). The BOD is generally exerted in 2 stages: in the first stage the carbonaceous matter is oxidized, and in the second stage the nitrogenous substances are oxidized by nitrifying bacteria. Both stages are usually completed after 20 to 30 days. The 5-day BOD of typical municipal wastewater at 20°C is approximately two-thirds of the ultimate carbonaceous oxygen demand.

When water is stored in a reservoir for many weeks, or even months, its BOD will be substantially reduced. Oxygen
is supplied readily to the epilimnion by reaeration due to wave action and daily temperature changes, and through photosynthesis by phytoplankton. Consequently, the epilimnion serves as an efficient natural "treatment plant" for organic wastes. If heavy BOD loads are carried into the hypolimnion of a reservoir in a density underflow or interflow during the summer, dissolved oxygen concentrations may be reduced substantially. When heavy BOD loads flow directly into the hypolimnion, as was the case in the Watauga arm of Boone Reservoir in Tennessee, dissolved oxygen concentrations in the inflow are quickly reduced to essentially zero (Churchill, 1967). During winter months when no stratification exists, dissolved oxygen concentrations are high throughout the reservoir and BOD exertion rates are relatively low due to low temperatures.

When water low in dissolved oxygen and BOD is discharged from a storage reservoir, it absorbs a new supply of oxygen from the atmosphere through stream reaeration.

In a study of Cherokee Reservoir in Tennessee, Higgins, 1978, as cited in Hannan, 1979, found that the average annual BOD load discharged from the reservoir decreased each year over a 10-year period compared to the load entering the reservoir. A previous study on Cherokee Reservoir compared BOD concentrations of the inflow and outflow and found that the long-term BOD concentration of the inflow was reduced
approximately two-thirds by storage in the pool (Churchill, 1958).

Churchill (1958) also found that Douglas Reservoir in Tennessee reduced BOD concentrations by approximately 50%.

**Suspended solids**

One feature all reservoirs have in common is that they serve as settling basins for sediment (Glyph, 1973). When a river carrying suspended sediment enters a reservoir and its velocity decreases, the material may be deposited, forming a delta. Deposition of material may extend many miles upstream of the reservoir if the gradient of the river is not very steep. This can lead to a reduction in the capacity of the river channel and increase the danger of flooding at high flows.

Two major types of water quality problems are caused by sediment: problems caused by pollutants adsorbed to sediment, and problems caused by the sediment itself. Adsorption to suspended solids is one of the primary transport mechanisms for pollutants such as phosphorus and various pesticides.

Suspended solids entering a reservoir settle out and reduce the capacity of the impoundment. High suspended solids concentrations make a reservoir less desirable as a recreation area, reduce photosynthesis by aquatic plants, and may increase treatment costs significantly if the impoundment is used as a public water supply.
Suspended solids can also have adverse effects on fish and other aquatic life. The European Inland Fisheries Advisory Commission (1965) listed 4 means by which suspended solids adversely affect fish and fish food populations:

1) They act directly on fish, either killing them or reducing their growth rate and resistance to disease.
2) They prevent the successful development of fish eggs and larvae.
3) They modify natural movements and migrations of fish.
4) They reduce the abundance of food available to fish.

A number of studies have shown that decreases in the suspended solids concentrations occur below impoundments. Neel et al. (1963) found reductions in the suspended sediment load below Missouri River reservoirs.

Heinemann et al. (1973) determined the trap efficiency for 18 storms during 1969 and for 6 storms during 1970 by Callahan Reservoir in Missouri. The 1969 trap efficiency values ranged from 75 to 100 %, and the 1970 values ranged from 80 to 99 %. The average trap efficiency for 1969 was 84 %. They also studied 10 storms during 1969 on Bailey Reservoir in Missouri and obtained values ranging from 33 to 84 %.

In another study on Callahan Reservoir, Rausch and Schreiber (1977) found that in 1973 an average of 87 % of the incoming sediment was trapped by the reservoir.
Total phosphate

One of the most intensely studied elements in the field of limnology is phosphorus. In comparison to other major nutrients (carbon, hydrogen, nitrogen, oxygen, and sulfur), phosphorus is the least abundant, and yet it most commonly limits biological productivity (Hutchinson, 1957; Wetzel, 1975).

Phosphorus is vital to all life; it functions in the storage and transfer of a cell's energy and in genetic systems (Cole, 1975). The effects of excessive amounts of phosphorus on algal productivity is well-documented. Phosphorus and nitrogen are the chemical constituents usually considered responsible for the eutrophication of surface waters (Mackenthun, 1973).

Over 90% of the phosphorus in lake water is bound organically in organic phosphates and cellular constituents in the living particulate matter of the seston, or is variously associated with or adsorbed to inorganic and dead particulate organic materials (Wetzel, 1975). The only significant form of inorganic phosphorus in lake waters is orthophosphate (Stumm and Stumm-Zollinger, 1972; Hutchinson, 1957; Odum, 1971). Reactive soluble orthophosphate is the form that is immediately useful to autotrophic plants (Cole, 1975).

At any one time, most of the phosphorus is tied-up in
organisms, or in organic detritus and inorganic particles of the sediment. Rapid exchange between solid and dissolved states of phosphorus occurs constantly. When large amounts of soluble phosphate are added to a lake, it is rapidly taken up by the phytoplankton. The uptake rate is usually more rapid than the release rate. Phytoplankton will readily take up phosphorus in the dark or under other conditions when they cannot assimilate it (Odum, 1971). During the spring, all of the available phosphorus may become tied-up in producers and consumers. Eventually, the bodies and excrements of these organisms will decompose and the nutrients will be released.

The vertical distribution of phosphorus in a stratified body of water is quite variable. Phosphorus in the epilimnion fluctuates widely with oscillations in plankton populations, whereas phosphorus in the metalimnion and hypolimnion varies with sedimentation of plankton, rates of decomposition with depth, and the development of bacterial and other plankton populations with depth (Wetzel, 1975).

In eutrophic lakes, there is an increase in soluble phosphate in the oxygen-deficient part of the hypolimnion (Hutchinson, 1957). This is due in part to decomposition of sinking plankton, but is often primarily caused by liberation of phosphate from sediments on reduction.

The phosphorus content of the sediment is often several orders of magnitude greater than that of the overlying water.
Exchanges across the sediment-water interface are regulated by mechanisms associated with mineral-water equilibria, redox interactions dependent on oxygen supply, sorption processes, and the activities of bacteria, plankton, invertebrates, and fungi. Under aerobic conditions, the exchange equilibria are largely unidirectional towards the sediments. However, Hynes and Greib (1970) found that phosphorus in undisturbed anoxic sediments moved upward readily from at least a sediment depth of 10 cm to the overlying water.

The sorption of phosphates and polyphosphates on surfaces, particularly clay minerals, is well-known. High phosphate adsorption by clays is generally favored by pH levels of 5 to 6. Phosphates are also known to form chelates, complexes, and insoluble salts with a number of metal ions (Stumm and Morgan, 1970).

Phosphorus exists naturally in the environment as calcium phosphate rock, otherwise known as apatite. Other sources of phosphorus include the atmosphere, fertilizers, animal wastes, wastewater discharges, and guano from aquatic birds. Atmospheric sources of phosphorus are dust and ash generated over land and introduced in rain, snow, or dry fallout. The phosphorus content of precipitation over nonpopulated regions is generally low.

Phosphorus can enter a waterway in 2 ways: in solid form adsorbed to soil particles or as undissolved fertilizer
particles, or as dissolved phosphates in solution (Iowa Department of Environmental Quality, 1977). The transport of phosphorus in solution in runoff water has generally been considered so low that it has received little attention (Holt, 1973). Because of the high insolubility of minerals containing phosphorus, groundwater and tile drainage waters contain very small amounts of the nutrient.

Phosphorus is extremely immobile in the soil because of its high degree of reactivity with soil colloids and certain cations to form relatively insoluble salts (Wang and Evans, 1970). Because phosphorus is strongly adsorbed to soil particles, its principal transport mechanism to surface waters is through soil erosion (Taylor, 1967; Olness and Rausch, 1977; Iowa Department of Environmental Quality, 1977). Erosion removes the topsoil, where the highest concentrations of phosphorus are usually found. These high concentrations are due primarily to use of fertilizers and disposal of animal wastes to land. Clays which provide the high adsorptive sites for phosphorus are easily carried with runoff and are the last to be deposited as sediment. The quantities of phosphorus in runoff are influenced by the amount of phosphorus in the soil, topography, vegetative cover, quantity and duration of runoff, land use, and pollution (Wetzel, 1975).

Domestic wastewater containing 25–50 mg/l of phosphorus
is another large source of phosphorus in surface waters. The extent of loading of these waters is directly related to the population of the area serviced, and to the type of treatment involved (Souza, 1977). Most of the phosphorus found in domestic wastewaters is derived from human wastes, although a significant portion may be composed of phosphorus compounds from detergents.

Upon entering a reservoir, the amount of phosphate that may be retained will depend upon:

1) The nutrient loading to the reservoir,
2) The volume of the euphotic zone,
3) The extent of biological activity,
4) The detention time, or the time available for biological activity, and
5) The level of discharge from the reservoir (United States Environmental Protection Agency, 1976).

The effects of impoundments on phosphorus concentrations and transport have been examined in a number of studies. From March, 1945 to March, 1946, Churchill (1967) found that Cherokee and Douglas Reservoirs retained approximately 30% of the inflowing phosphorus. In a later study on Cherokee Reservoir, Hannan (1979) found the average annual phosphorus load in the outflow to be less than that of the inflow each year over a 10-year period.

In a study of Lake Powell on the Colorado River, Paulson
and Baker (1980) found a reduction in the annual phosphorus loading in the outflow compared to the inflow.

Heinemann et al. (1973) studied nutrient data for Callahan Reservoir from January, 1969 through June, 1970. They found total phosphorus inflows to be highest in the spring after the application of fertilizer to fields in the watershed. One-third of the total phosphorus load in 1969 occurred during the first storm in April (1.98 cm of runoff). The rate of total phosphorus inflow to the reservoir during 1969 increased with stream discharge. Total phosphorus concentrations were lower in the fall than in the spring and summer. Total phosphorus discharged from the reservoir was 44% of the total phosphorus inflow. In a similar study on Callahan Reservoir from 1973-1975, Schreiber and Rausch (1979) found a reduction in total sediment phosphorus and orthophosphate concentrations in the outflow relative to the inflow. The reservoir was most effective in reducing outflow orthophosphate concentrations when runoff and sediment concentrations were greatest.

In a 3-year study of Yellowtail Reservoir in Montana, Wright and Solterro (1973) found that only 14% of the total phosphorus concentration, and 68% of the orthophosphate concentration that entered the reservoir was discharged from it.

Neel et al. (1963) looked at average annual total
phosphorus concentrations in the inflows and outflows of Garrison and Fort Randall Reservoirs on the Missouri River. Decreases in concentration were seen in the outflow of Garrison Reservoir during 3 of the 4 years studied. However, increases in concentration were seen in the outflow for 3 of the 6 years studied at Fort Randall.

The water quality at the inlet and outlet of Howard A. Hanson Reservoir in Washington was studied in 1962 and 1963 (Sylvester and Seabloom, 1965). The investigators found the mean incoming and mean outgoing total phosphate concentrations to be 0.12 ppm and 0.08 ppm, respectively.

Higgins and Kim (1981) looked at monthly phosphorus concentrations and loadings for the inflows and outflows of 18 Tennessee Valley Authority Reservoirs. The reservoirs were divided into 2 groups: main stem and tributary reservoirs. The results of the 3-year study show a reduction in mean phosphorus concentration and load in the outflow of all 9 tributary reservoirs. However, only 4 of the 9 main stem reservoirs showed a reduction in mean phosphorus concentration and load in the outflow relative to the inflow. The investigators concluded that higher flows and shorter residence times in the 9 main stem reservoirs were responsible for the lower trap efficiencies.

Monthly total phosphorus data were collected from November, 1969 through January, 1971 in the inflow and outflow of
Canyon Reservoir in Texas (Hannan and Young, 1974). Total phosphorus concentrations in the inflow ranged from 0.021-0.025 mg/l, while those in the outflow ranged from 0.016-0.021 mg/l.

Finally, Toms et al. (1975), in a 5-year study of Grafham Water (a reservoir in England), found reductions in phosphate load and concentration on impoundment of the River Great Ouse.

Nitrogen

Nitrogen is another element often implicated in the eutrophication of surface waters. The nitrogen cycle is complex due to the several oxidation states that it can assume, and the fact that changes in oxidation state can be brought about by living organisms (Sawyer and McCarty, 1978).

Basically, 5 forms of nitrogen are found in lake waters:

1) Molecular nitrogen in solution.
2) Organic nitrogen compounds, including proteins, amino acids, urea, and amines.
3) Ammonia (ionized and un-ionized forms).
4) Nitrite.
5) Nitrate.

Virtually all nitrogen compounds of the biosphere result from fixation of atmospheric molecular nitrogen (Hutchinson, 1957). The fixation of molecular nitrogen by soil bacteria is the major source of nitrogen compounds (Southwick, 1972).
Less significant, but well-documented is the role of blue-green algae as nitrogen fixers. The ionizing effect of lightning and cosmic radiation can also fix nitrogen.

Green plants can use some organic forms of nitrogen, but most is taken up as ammonia or nitrate (Cole, 1975). Fixed nitrogen, or that nitrogen assimilated as ammonia or nitrate is aminated into organic nitrogenous compounds within organisms. Most organic nitrogen is bound and cycled in photosynthetic and microbial organisms. When these organisms die, the organic nitrogen is converted to ammonia through the action of heterotrophic bacteria. Under aerobic conditions, the ammonia may be subjected to nitrification.

Nitrification is the biological conversion of nitrogen in a reduced state to a more oxidized state. Ammonia is oxidized to nitrite primarily by bacteria of the genus *Nitrosomonas*. The oxidation of nitrite to nitrate is carried-out primarily by bacteria of the genus *Nitrobacter*. Stoichiometrically, 4.57 grams of oxygen are required to oxidize 1 gram of ammonia to nitrate (Goering, 1972). Therefore, the nitrification process can put a severe stress on dissolved oxygen concentrations.

Denitrification is the biological reduction of an oxidized form of nitrogen. Nitrate is reduced to molecular nitrogen particularly by anaerobic bacteria of the genus *Pseudomonas*. Some bacteria carry the reduction all the way
to ammonia. Denitrification reactions occur intensely in anaerobic environments, such as the hypolimnia of eutrophic lakes, and in anoxic sediments (Wetzel, 1975).

Sources of nitrogen compounds to a lake include: surface and groundwater drainage into the basin, precipitation on the lake surface, and nitrogen fixation in the lake and its sediments. The amount of nitrogen entering a lake due to precipitation is often considered minimal compared to other sources.

Losses of nitrogen compounds from a lake include: through the outflow, by denitrification in the lake, permanent loss to the sediments, and volatilization from the lake surface.

A seasonal distribution of the various forms of nitrogen has been reported for some eutrophic lakes in temperate regions. The ammonia content of the epilimnion is usually minimal during stratification. This is due to biological assimilation and nitrification. Maximum concentrations usually occur in the epilimnion during the fall turnover.

The seasonal cycle of ammonia in the hypolimnion is essentially the inverse of that of the epilimnion: maximal amounts are found here during stratification and minimal amounts during turnover. The increase of ammonia in the hypolimnion during stratification is due to large amounts of settling plankton undergoing decomposition, and anaerobic
conditions which prevent nitrification. During turnover, ammonia is mixed throughout the lake, thus reducing concentrations in the hypolimnion.

Nitrate concentrations in the epilimnion and hypolimnion are usually at a maximum during early spring. When stratification occurs, nitrate concentrations are reduced in the epilimnion due to assimilation by phytoplankton. At this time, nitrate concentrations are also at a minimum in the hypolimnion because anaerobic conditions prevent nitrification.

The main point sources of nitrogen to surface waters are municipal wastewater treatment plants. Ammonia is generally the most abundant form of nitrogen in municipal wastes. Nitrate, nitrite, and organic nitrogen compounds are usually present in smaller amounts.

The major nonpoint source of nitrogen is runoff from agricultural land. Nitrogen is present in animal wastes and crop residues, and is also applied as a fertilizer. Nitrogen in the ammonium form is adsorbed by, and transported with suspended clay particles. The amount of nitrogen transported in this form by runoff waters is considered to be minimal.

Nitrate is often the primary form of nitrogen transported with runoff because it is highly water soluble and it is not adsorbed to sediment. Although loss of nitrogen in surface runoff can be a problem, conditions generally favor
movement of soluble nitrogen into the soil before surface runoff begins (Iowa Department of Environmental Quality, 1977). Due to its high solubility, nitrate is often found in high concentrations in groundwater and in flows from tile drains.

**Organic nitrogen** Organic nitrogen can exist in the dissolved or particulate form. Dissolved organic nitrogen may consist of peptides, various amino acids, and other products resulting from biological processes. Materials containing proteins, such as biological cells, make-up most of the particulate organic nitrogen. Organic nitrogen in lake waters often accounts for more than half of the total dissolved nitrogen (Wetzel, 1975). Fewer studies have been done on the effects of impoundment on organic nitrogen than on other forms of nitrogen. In the study of Cherokee Reservoir by Churchill (1958), a decrease was found in organic nitrogen concentrations in the outflow relative to the inflow.

Sylvester and Seabloom (1965) found the mean incoming and mean outgoing organic nitrogen concentrations for Howard A. Hanson Reservoir to be equal. Decreases were found in the organic nitrogen concentrations of the outflows relative to the inflows for all years except 1 in the study of Garrison and Fort Randall Reservoirs (Neel et al., 1963).
Ammonia nitrogen  

Ammonia is the primary end-product of decomposition of organic matter by heterotrophic bacteria. Ammonia is also the primary excretory product of aquatic animals.

When ammonia dissolves in water, a chemical equilibrium is established between the ionized and un-ionized forms. This reaction is dependent upon water pH and temperature. As the pH and temperature increase, the percentage of ammonia in the un-ionized form increases. Unfortunately, the un-ionized form of ammonia is highly toxic to fish and other aquatic organisms. The water quality criterion for ammonia for protecting freshwater aquatic life is less than 0.02 mg/l as un-ionized ammonia (United States Environmental Protection Agency, 1976).

The findings of numerous researchers vary on the effects of impoundment on ammonia nitrogen concentrations. Churchill (1958) examined monthly ammonia nitrogen concentrations in the inflow and outflow of Cherokee Reservoir during 1952. He found reductions of ammonia in the outflow relative to the inflow, and he attributed this to nitrification within the reservoir. In a year-long study of Yellowtail Reservoir, Wright and Soltero (1973) found a 20% decrease in ammonia concentrations in the outflow as compared to the inflow.

Sylvester and Seabloom (1965), in a study of Howard A. Hanson Reservoir, and Heinemann et al. (1973), in a study
of Callahan Reservoir, found approximately equal amounts of ammonia in the inflows and outflows.

In a study of Canyon Reservoir, Hannan and Young (1974) found an increase in ammonia in the outflow relative to the inflow. However, their results are based on data from only 3 sampling days.

During 1973, Rausch and Schreiber (1977) found a 28% increase in ammonia in the outflow of Callahan Reservoir as compared to the inflow. They attributed the increase to biological degradation of organic matter.

Neel et al. (1963) compared annual mean inflow and outflow ammonia concentrations for Garrison and Fort Randall Reservoirs. The annual mean ammonia concentrations varied: some years there was an increase in the outflow, some years there was a decrease, and in other years the concentrations in the inflow and outflow were approximately equal.

**Nitrite plus nitrate nitrogen** Nitrite and nitrate are considered together because in an environment where sufficient oxygen is present, nearly all nitrite would be immediately oxidized to nitrate, thus nitrite concentrations would be extremely low.

Although it is the principal source of nitrogen used by aquatic plants, nitrate can be toxic to newborn warmblooded animals, including humans. Nitrate concentrations in excess of 10 mg/l can cause methemoglobinemia in infants under 3
months of age (Steel and McGhee, 1979). Nitrate is reduced in the infants body to nitrite, which impairs the oxygen-carrying capacity of hemoglobin, and can cause death.

Numerous studies are reported in the literature on the effects of impoundment on nitrate concentrations. In a study of Lake Powell, Paulson and Baker (1980) found increases in annual nitrate loading in the outflow during the first 5 years of impoundment. During the ensuing 5 years, they found a decrease in annual nitrate loading in the outflow relative to the inflow.

In a year-long study, Wright and Soltero (1973) found an 11% increase in nitrate concentration in the outflow of Yellowtail Reservoir compared to the inflow.

Rausch and Schreiber (1977) found that Callahan Reservoir trapped 34% of the incoming nitrate in 1973. The amount of nitrate trapped increased with runoff volume. The percentage trapped decreased with runoff volume because of a greater increase in the amount of nitrate in the inflow.

A decrease in nitrate concentration was found in the outflow of Canyon Reservoir relative to the inflow (Hannan and Young, 1974). Similar results were found by Wang and Evans (1970) in a study of Lake Bloomington in Illinois.

Heinemann et al. (1973), in a study of Callahan Reservoir, and Sylvester and Seabloom (1965), in a study of Howard A. Hanson Reservoir, found equal nitrate concentrations in
the inflows and outflows.

Grafham Water was studied by Toms et al. (1975), who found reductions in nitrate concentrations when the waters of the River Great Ouse were impounded.

In a study of Garrison and Fort Randall Reservoirs, Neel et al. (1963) found a reduction in nitrate concentrations in the outflows relative to the inflows during most years.

**Total nitrogen**  Total nitrogen is the sum of ammonia, organic, and nitrite plus nitrate nitrogen. Wang and Evans (1970), and Hannan (1979) found reduced total nitrogen concentrations and loadings, respectively, in the outflows relative to the inflows of the reservoirs they studied.

Churchill (1967), Wright and Soltero (1973), and Heinemann et al. (1973) reported the following nitrogen trap efficiencies for the reservoirs they studied: 16 %, 25 %, and 20 %, respectively.

Sylvester and Seabloom (1965) found equal concentrations of total nitrogen in the inflow and outflow of Howard A. Hanson Reservoir.
RESEARCH METHODS

Water Sampling

Over the years, the method of collecting samples at the Des Moines River sampling stations has remained basically the same. Grab samples have been collected weekly, weather permitting, using a plastic bucket and a dissolved oxygen dunker. The dunker contains 2, 300-ml BOD bottles and was constructed according to Standard Methods for the Examination of Water and Wastewater (APHA, 1976). Water from the BOD bottles was used to perform dissolved oxygen and alkalinity tests.

Water collected in a plastic bucket was poured into polyethylene bottles. Nitrogen samples were poured into a 1-quart polyethylene bottle and acidified with 2 milliliters of concentrated sulfuric acid. Total phosphate, suspended solids, and BOD samples were poured into a 1-gallon polyethylene bottle. All bottles were then put on ice to slow biological activity.

River station samples were all collected by lowering the bucket and dunker from a bridge. During winter months, a motor-driven auger was used to drill a hole in the ice and the sample was then collected.
Water Analysis

Total phosphate, BOD, suspended solids, organic nitrogen, ammonia nitrogen, nitrite plus nitrate nitrogen, and total nitrogen determinations were performed by personnel of the Analytical Services Laboratory of the Engineering Research Institute at Iowa State University.

Suspended solids and BOD analyses were made according to APHA (1976, pages 543 and 94, respectively). Organic nitrogen, ammonia nitrogen, nitrite plus nitrate nitrogen, and total phosphate analyses were made according to Methods for Chemical Analysis of Water and Wastes (USEPA, 1979, pages 350.1, 353.2, 365.4, and 365.1, respectively). Total nitrogen is the sum of organic nitrogen, ammonia nitrogen, and nitrite plus nitrate nitrogen.

Statistical Analysis

The raw data utilized in this study were obtained from the following 13 annual reports: Baumann and Dougal (1968), Baumann (1969), Baumann and Kelman (1970, 1971), Baumann and DeBoer (1972), and Baumann et al. (1973, 1974b, 1975, 1977a, 1977b, 1979, 1980, 1981).

The collection of BOD data was initiated at Stations 1 and 5 on July 6, 1967, at Station 10 on August 3, 1972, and at Station 6 on July 21, 1971. Concentrations were reported weekly except from August 1, 1974 through July 29, 1975, when values were reported biweekly (once every 2 weeks).
Suspended solids data were reported weekly at all 4 stations beginning on August 3, 1973. Since August 1, 1974, suspended solids concentrations have been reported biweekly.

The collection of total phosphate data began at Stations 1 and 5 on February 26, 1971, at Station 10 on August 3, 1972, and at Station 6 on July 21, 1971. From December 4, 1974 through October 31, 1978, concentrations were reported biweekly, otherwise they were reported weekly.

Organic nitrogen, ammonia nitrogen, nitrite plus nitrate nitrogen, and total nitrogen data collection began at Stations 1 and 5 on July 6, 1977, at Station 10 on August 3, 1972, and at Station 6 on July 21, 1971. All nitrogen forms have been collected weekly throughout the study period.

Flow data found in the annual reports for the dates of sampling at each station were obtained from the United States Geological Survey and the United States Army Corps of Engineers, and are reported in cubic feet per second (cfs).

The data for all parameters examined extend to October 28, 1980.

To determine the transport of each parameter on a given sampling day, the product of the flow (cfs) and concentration (mg/l) was multiplied by a conversion factor of 2.445 (see Appendix). This method gives a transport value in kg/day. A problem using this method occurs when the flow varies a great deal between sampling days. For example, if a storm event
occurs during the week between 2 sampling days, the river may fall before the second sampling day and the storm event would go unnoticed. Thus, the increased transport due to the storm event would be overlooked. Conversely, if the flow on 2 consecutive sampling days was high, and low flows occurred in the week between, transport would be overestimated.

By sampling nearly 52 times (26 times in a few cases) a year, it is assumed that any weekly (biweekly) overestimations or underestimations of transport due to uneven flow between sampling days will balance out. Also, the size of the watershed is large enough that a normal storm runoff event lasts 10 to 14 days (Butler, 1981); therefore, most storm events would be reported.

The transport values for each sampling day in a certain month were summed, and then divided by the number of days sampled during that month to determine the average transport for that month. To determine the average transport for a particular month during a particular period (before closure period, after closure period, total period), the average transport values for that month were summed, and then divided by the number of times that month appeared in the period. For example, to determine the average BOD transport for May, at Station 1 after closure, the average transport values for May, 1977, May, 1978, May, 1979, and May, 1980 would be summed and divided by 4.
The average concentration of a certain parameter for a particular month was calculated by summing the concentrations for each sampling day in that month, and then dividing by the number of days sampled during that month.

The average concentration for a particular month during a particular period was figured basically in the same way that average transport was determined.

A particular period average concentration was computed by summing the monthly means for that period and dividing by 12. This value as seen in Tables 2-10 is referred to as the sample-weighted mean concentration. The flow-weighted mean concentration for a particular period, also found in Tables 2-10, is the transport divided by the product of the flow ($m^3/s$) and a conversion factor of 86.4 (see Appendix). The flow data reported in the annual reports as cfs were converted to $m^3/s$ by dividing by 35.3 (see Appendix).

For each parameter examined, the data have been divided into 3 periods: before closure, after closure, and total period. The month of April, 1977 marks the beginning of the after closure period.

The monthly average transport values and concentrations of each parameter for a certain period have been computed as a percentage of the overall average of that parameter for that particular period, and are plotted as bar charts. For example, the average BOD transport at Station 1, for January,
during the after closure period is 2,760 kg/day. The average BOD transport for the period of record at this station is 28,090 kg/day. The percent of the total period mean is obtained by dividing these 2 values, and then multiplying by 100. The value obtained, 9.8 %, is plotted as a short dashed line above January in Figure 8.

Basically, the y-axis of the bar charts for each parameter takes on 1 of 2 values: the percent of total period mean is a percent of the long-term mean (includes the before and after closure data), and the percent of period mean is a percent of the after closure period mean during these months.
RESULTS AND DISCUSSION

The Effects of Saylorville Reservoir on the Flow and Quality of the Des Moines River

Flow

The monthly flows at Station 1, for the 3 time periods, are plotted as a percentage of the total period mean in Figure 4. Examining the total period data, it can be seen that the greatest percentage of flow occurred during the months of March through July, with the maximum occurring in April. These high-flow months coincide with snowmelt and above-average precipitation months in Iowa. Small percentages of flow occurred during August through February, with the minimum falling in January. This was expected because these low-flow months represent times of ice cover and below-average precipitation in Iowa.

The before closure plot shows a pattern very similar to the total period plot: high flows occur during March through July, and low flows occur from August through February.

The after closure plot illustrates a pattern somewhat different from those of the other 2 periods. This might be expected, since the after closure period contains only 3.5 years of data. In the after closure period, there are significantly lower flows occurring from May through July, and significantly higher flows occurring in August, Septem-
Figure 4. Station 1 monthly flows plotted as a percentage of the total period mean for the three time periods.
ber, November, and December. The remaining months have approximately the same flows as those of the total and before closure periods.

Figure 5 represents the monthly flows at Station 5 for the 3 time periods. Since there are no major tributaries of the Des Moines River between Stations 1 and 5, the before closure flow plot for Station 5 is almost identical to the before closure flow plot for Station 1. This is shown more clearly in Figure 6.

Due to the closure of Saylorville Dam in April, 1977, some differences are seen between the after closure and total period flow plots for Stations 1 and 5. By plotting the after closure flows of Stations 1 and 5 on the same graph in Figure 7, the effects of Saylorville Reservoir on the flow of the Des Moines River is seen. From results reported in the literature, the reservoir is expected to reduce peak flows and increase flows during dryer months. Saylorville Reservoir has done this to some degree. High inflows to the reservoir in March and August were significantly reduced in the outflow. These high inflows were stored in the reservoir and then slowly released during May through July, and September and October, thus increasing flow slightly at Station 5 during these months. During the remaining months of the year, the flows at Stations 1 and 5 are approximately equal. Since the reservoir has only been in operation for
Figure 5. Station 5 monthly flows plotted as a percentage of the total period mean for the three time periods
Figure 6. Before closure monthly flows at Stations 1 and 5 plotted as a percentage of the total period mean.
Figure 7. After closure monthly flows at Stations 1 and 5 plotted as a percentage of the total period mean.
3.5 years, its effect on flow is not so evident yet. In the future, as more flood and drought years are added to the data-set, decreases in the amplitude of annual variations in water levels downstream caused by Saylorville Reservoir should be more dramatic.

**Biochemical oxygen demand**

Figure 8 represents the monthly BOD transport and concentrations at Station 1, plotted as a percentage of the total period mean. The before closure and total period plots are very similar. During these 2 periods, high percentages of BOD transport coincide with the high-flow months of March through July. The after closure plot has the same basic shape as the other 2 plots during the high-flow months, but the percentages of transport during these months, for the after closure period, are comparatively lower. In August, a rather high percentage of transport occurs during the after closure period relative to the other 2 periods. This is because above-average flows occurred during August, after closure. The BOD transport from September through February is almost identical for the 3 periods.

The total period BOD concentration is at a minimum during January, follows an upward trend till it reaches a maximum in October, and then declines through December. The maximum in October is probably due to 2 factors: lower flows causing less dilution, and greater algal populations as evi-
Figure 8. Station 1 monthly BOD transport and concentration plotted as a percentage of the total period mean.
denced by the very high chlorophyll concentrations measured during October, 1980.

Station 5 BOD transport and concentration is shown in Figure 9. The before closure transport is very similar to that at Station 1. The effects of Saylorville Reservoir on BOD transport are dramatically seen in the after closure plot. Reductions in transport are especially significant during the high-flow months of March through July. Smaller decreases are noticed during August, and from October through February. A slight increase was observed in September. This could be due to 2 reasons: first, more water was being released in the outflow than entered in the inflow during September of the after closure period, and second, since water is released from the hypolimnion of Saylorville Reservoir, many reduced compounds may be present in the outflow, thus creating an oxygen demand.

The BOD concentration at Station 5 is similar to Station 1 in that it tends to increase from January through October, and then decrease through December. However, due to the reservoir, the changes in concentration from month to month at Station 5 are not as large as those that occur at Station 1. Also, the difference between the maximum and minimum concentrations at Station 5 is smaller than that at Station 1.

Figure 10 demonstrates how the BOD transport percentages
Figure 9. Station 5 monthly BOD transport and concentration plotted as a percentage of the total period mean.
during each month at Station 5 have shifted since closure of
the dam. Saylorville Reservoir has had an evening-out effect
on monthly BOD transport. Since closure, a greater percent­
age of transport occurs at Station 5 during April, May, June,
September, November, December, and January, and less occurs
during February, March, July, August, and October. The high
transport in April was caused by the unusually high BOD
concentration during that month. This high concentration
might have been caused by organic matter carried to the river
in snowmelt.

The reservoir has also had an evening-out effect on BOD
concentration. In general, concentration percentages at
Station 5 were higher during low-flow months, and lower
during high-flow months. From November through April, and
during June, BOD concentration percentages at Station 5 were
higher than those at Station 1. During the remaining months,
BOD concentration percentages were lower at Station 5.

The BOD means at Stations 1 and 5 during the 3 periods
are given in Table 2. The average flow during the total and
before closure periods was slightly greater at Station 5 than
at Station 1. This is due to the larger drainage area above
Station 5. During the after closure period, the flow at
Station 5 was less than that at Station 1. This is because
water from the river was used to fill the reservoir.

The average sample-weighted BOD concentration before
Figure 10. After closure monthly BOD transport and concentration at Stations 1 and 5 plotted as a percentage of the period mean.
Table 2. BOD means for Stations 1 and 5

<table>
<thead>
<tr>
<th></th>
<th>Station 1</th>
<th>Station 5</th>
<th>Station 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL PERIOD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Jul 1967 - Oct 1980)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>66.11</td>
<td>70.30</td>
<td>1.06</td>
</tr>
<tr>
<td>BOD concentration (mg/l)</td>
<td>6.94$^a$</td>
<td>6.41 (4.67)</td>
<td>0.92 (0.95)</td>
</tr>
<tr>
<td>BOD transport (kg/day)</td>
<td>28,090</td>
<td>28,380</td>
<td>1.01</td>
</tr>
<tr>
<td>BEFORE CLOSURE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Jul 1967 - Mar 1977)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>65.30</td>
<td>70.85</td>
<td>1.08</td>
</tr>
<tr>
<td>BOD concentration (mg/l)</td>
<td>7.60 (5.30)</td>
<td>7.84 (5.46)</td>
<td>1.03 (1.03)</td>
</tr>
<tr>
<td>BOD transport (kg/day)</td>
<td>29,710</td>
<td>33,410</td>
<td>1.12</td>
</tr>
<tr>
<td>AFTER CLOSURE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>71.20</td>
<td>69.42</td>
<td>0.98</td>
</tr>
<tr>
<td>BOD concentration (mg/l)</td>
<td>5.12 (3.81)</td>
<td>2.56 (2.16)</td>
<td>0.50 (0.57)</td>
</tr>
<tr>
<td>BOD transport (kg/day)</td>
<td>23,450</td>
<td>12,940</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Percentage change in transport after closure

Station 1

Before closure transport - After closure transport

\[
\frac{29,710 - 23,450}{29,710} \times 100 = 21.1 \% \text{ decrease}
\]

Station 5

Before closure transport - After closure transport

\[
\frac{33,410 - 12,940}{33,410} \times 100 = 61.3 \% \text{ decrease}
\]

$^a$Sample-weighted mean concentration.

$^b$Flow-weighted mean concentration.
closure was less at Station 1 (7.60 mg/l) than at Station 5 (7.84 mg/l). However, after closure, the average sample-weighted BOD concentration at Station 5 (2.56 mg/l) was half that at Station 1 (5.12 mg/l). Churchill (1958) found comparable BOD concentration reductions in the reservoirs he studied: Douglas Reservoir reduced concentrations by 50 % and Cherokee Reservoir reduced concentrations by two-thirds. This reduction in BOD concentration is primarily due to the settling and decomposition of organic matter within the reservoir.

The results for BOD transport were similar to that for BOD concentration. Before closure, the transport at Station 1 (29,710 kg/day) was less than that at Station 5 (33,410 kg/day). After closure, there was a significant reduction in BOD transport at Station 5. The reservoir reduced the transport from 23,450 kg/day at Station 1, to 12,940 kg/day at Station 5. This represents a 45 % BOD trap efficiency.

To determine if the reduction in BOD transport at Station 5 after closure was, in fact, due to the reservoir, the percentage change in BOD transport after closure for Stations 1 and 5 was compared. A 21.1 % decrease in BOD transport was noted at Station 1 after closure. However, a 61.3 % decrease was found at Station 5. Therefore, Saylorville Reservoir does play an important role in reducing the
BOD transport of the Des Moines River.

**Suspended solids**

The parameter that has been most significantly affected by Saylorville Reservoir is suspended solids. Figure 11 shows monthly suspended solids transport and concentration at Station 1 plotted as a percentage of the total period mean. Suspended solids transport is low from October through February during all 3 periods. This is due to the low flows and concentrations which occur during these months.

During March through June of the before closure period, the suspended solids transport was comparatively high, primarily due to high flows which occurred during these months. Fairly high flows were observed during July, before closure, but due to low suspended solids concentrations, the transport was relatively low this month. The percentage of suspended solids transport occurring in August and September was also quite small. This is due to the low flows during these months before closure.

Suspended solids transport after closure was unlike that before closure. High transport occurring in March, April, August, and September paralleled high flows during these months. In June, concentrations were high, but flow was below average, so transport was below average.

Suspended solids concentrations were below average from October through February due to low flows. High concentra-
Figure 11. Station 1 monthly suspended solids transport and concentration plotted as a percentage of the total period mean.
tions coincided with high flows during March, June, April, and August. The months of May and July saw above-average flows, but for some reason concentrations were about average during these months. Possibly during May the higher flows were due to long-duration, low-intensity rainfalls, and so soil erosion would not be as great. During July, crops cover a greater percentage of the soil surface, and this also helps reduce soil erosion.

Figure 12 shows the dramatic reduction in suspended solids transport at Station 5 after the closure of Saylorville Dam. A reduction in suspended solids transport occurred every month except August and September. These 2 months experienced an increase because of significantly greater flows which occurred during the after closure, relative to the before closure period. In general, the greatest reductions in the after closure period occurred during months which had high suspended solids transport during the before closure period.

Suspended solids concentrations at Station 5 follow a similar pattern to those at Station 1, in that concentrations from October through February were comparatively low. From March through September, suspended solids concentrations did not vary as much from month to month at Station 5 as they did at Station 1. This is due to the evening-out effect of the reservoir.
Figure 12. Station 5 monthly suspended solids transport and concentration plotted as a percentage of the total period mean.
Suspended solids transport and concentration at Stations 1 and 5 are shown in Figure 13 as a percentage of the period mean. By comparing the after closure plots at Stations 1 and 5, the monthly shifts in transport due to the reservoir become apparent. In all months where below-average transport occurred at Station 1, increases in transport were noted at Station 5. A combination of high flows and high concentrations at Station 5 after closure, during April, caused the high transport value.

The evening-out effect of the reservoir is also seen in comparing suspended solids concentrations at Stations 1 and 5. In general, months that experienced relatively low concentrations at Station 1, show an increase at Station 5. Conversely, months that experienced relatively high concentrations at Station 1, show a decrease at Station 5.

The suspended solids means for the 3 periods are shown in Table 3. Before closure, the average sample-weighted concentration at Station 1 (148 mg/l) was less than that at Station 5 (153 mg/l). However, after closure, the sample-weighted mean concentration at Station 5 (25 mg/l) was only 17% of that at Station 1 (145 mg/l).

Average suspended solids transport showed the same trend as concentration. The average transport at Station 5 (1,464,762 kg/day) was greater than that at Station 1 (1,149,404 kg/day) before closure, but after closure, the
Figure 13. After closure monthly suspended solids transport and concentration at Stations 1 and 5 plotted as a percentage of the period mean.
Table 3. Suspended solids means for Stations 1 and 5

<table>
<thead>
<tr>
<th></th>
<th>Station 1</th>
<th>Station 5</th>
<th>Station 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL PERIOD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>61.06</td>
<td>64.13</td>
<td>1.05</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>143$^a$ (309)$^b$</td>
<td>85 (137)</td>
<td>0.59 (0.44)</td>
</tr>
<tr>
<td>concentration (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended solids</td>
<td>1,630,293</td>
<td>758,158</td>
<td>0.46</td>
</tr>
<tr>
<td>transport (kg/day)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BEFORE CLOSURE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>53.49</td>
<td>60.72</td>
<td>1.14</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>148 (249)</td>
<td>153 (279)</td>
<td>1.03 (1.12)</td>
</tr>
<tr>
<td>concentration (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended solids</td>
<td>1,149,404</td>
<td>1,464,762</td>
<td>1.27</td>
</tr>
<tr>
<td>transport (kg/day)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AFTER CLOSURE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>71.20</td>
<td>69.42</td>
<td>0.98</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>145 (345)</td>
<td>25 (27)</td>
<td>0.17 (0.08)</td>
</tr>
<tr>
<td>concentration (mg/l)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Suspended solids</td>
<td>2,125,311</td>
<td>162,407</td>
<td>0.08</td>
</tr>
<tr>
<td>transport (kg/day)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Percentage change in transport after closure

**Station 1**

Before closure transport - After closure transport
--------------------------------------------- x 100

Before closure transport

1,149,404 - 2,125,311

= --------------------- x 100 = 84.9 % increase

1,149,404

**Station 5**

Before closure transport - After closure transport
--------------------------------------------- x 100

Before closure transport

1,464,762 - 162,407

= --------------------- x 100 = 88.9 % decrease

1,464,762

$^a$Sample-weighted mean concentration.

$^b$Flow-weighted mean concentration.
average transport at Station 1 was 2,125,311 kg/day, compared to 162,407 kg/day at Station 5. This represents a 92 % trap efficiency of suspended solids by Saylorville Reservoir. This value is comparable to the 84 % trap efficiency of Callahan Reservoir in 1969 (Heinemann et al., 1973), and the 87 % trap efficiency by the same reservoir in 1973 (Rausch and Schreiber, 1977).

The percentage change in transport after closure shows how efficient Saylorville Reservoir is in reducing suspended solids. At Station 1 there was an 84.9 % increase in suspended solids transport after closure. However, an 88.9 % decrease in suspended solids transport was noted at Station 5 after closure.

**Total phosphate**

Like the parameters previously examined, total phosphate transport appears to be correlated with flow. Total phosphate transport and concentration as a percentage of the total period mean at Station 1 are given in Figure 14. During all 3 periods, the total phosphate transport is comparatively low from September through February.

Comparatively high total phosphate transport percentages occur from March through July during the before closure period. The maximum transport, which occurs in March, could be due primarily to animal wastes transported with snowmelt. The below-average total phosphate transport experienced in
Figure 14. Station 1 monthly total phosphate transport and concentration plotted as a percentage of the total period mean.
August is due to low flows in August before closure.

After closure, relatively high transport percentages were experienced in March, April, and August. This is because of above-average flows during these months after closure. The below-average total phosphate transport from May through July, after closure, is due to the relatively low concentrations experienced during these months.

Total phosphate concentrations were above average during January, February, March, and September, and below average the remaining months. High concentrations from January through March could be due to a reduction in phytoplankton numbers under the snow and ice covered river. There may also be small amounts of phosphorus entering the river from groundwater sources during these months. The high concentration in September could be caused by reduced phytoplankton numbers due to temperature changes at this time.

Figure 15 shows total phosphate transport and concentration at Station 5. Relative to the before closure period, reductions in total phosphate transport occur every month except September of the after closure period. The increase in September is due to high flows and concentrations that occurred after closure. The reservoir appears to be most effective in reducing total phosphate transport during the months which experienced above-average transport percentages before closure.
Figure 15. Station 5 monthly total phosphate transport and concentration plotted as a percentage of the total period mean.
Monthly total phosphate concentration percentages at Station 5 are almost identical to those at Station 1. Apparently the reservoir has had little effect on the total period monthly total phosphate concentration percentages. This could be because the reservoir has only been in operation for 3.5 years.

Total phosphate transport and concentration, as a percentage of the period mean are given in Figure 16. Shifts in monthly transport percentages due to the reservoir can be seen. For the most part, months that experienced below-average transport at Station 1, showed increases at Station 5, and months that had above-average transport at Station 1, showed decreases at Station 5. Exceptions to this were the months of April and June. In April, above-average total phosphate concentrations led to the unusually high transport percentage, and in June, comparatively lower flows and concentrations at Station 5 led to the lower transport percentage.

The effect of Saylorville Reservoir on monthly total phosphate concentration percentages is not as apparent as its effect on transport. There appears to be little difference between concentration percentages at Stations 1 and 5 for all months except April and August. The greater percentage at Station 5 during April could be caused by phosphorus being resuspended from the sediments due to spring turnover in
Figure 16. After closure monthly total phosphate transport and concentration at Stations 1 and 5 plotted as a percentage of the period mean.
Saylorville Reservoir at this time. The smaller percentage at Station 5 during August could be due to algal uptake of phosphorus in the epilimnion of Saylorville Reservoir at this time.

Table 4 gives the total phosphate means for the 3 periods at Stations 1 and 5. Before closure, the sample-weighted mean total phosphate concentration at Station 5 (1.09 mg/l) was 98% of that at Station 1 (1.11 mg/l). After closure, the sample-weighted mean concentration at Station 5 (0.58 mg/l) was only 55% of that at Station 1 (1.06 mg/l). This 45% reduction in total phosphate concentration is similar to the 33% reduction found by Sylvester and Seabloom (1965) in their study of Howard A. Hanson Reservoir.

The average total phosphate transport at Station 5 (8,630 kg/day) before closure, was 26% greater than that at Station 1 (6,820 kg/day). After closure, the transport at Station 5 (3,840 kg/day) was only 44% of that at Station 1 (8,730 kg/day). This represents a 56% trap efficiency of total phosphate by the reservoir. Heinemann et al. (1973) reported a 56% total phosphorus trap efficiency in their study of Callahan Reservoir.

The effectiveness of Saylorville Reservoir in reducing total phosphate transport is seen vividly by examining the percentage change in transport after closure at Stations 1 and 5. Although a 28.0% increase in total phosphate
Table 4. Total phosphate means for Stations 1 and 5

<table>
<thead>
<tr>
<th></th>
<th>Station 1</th>
<th>Station 5</th>
<th>Station 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL PERIOD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Feb 1971 - Oct 1980)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>68.51</td>
<td>73.08</td>
<td>1.07</td>
</tr>
<tr>
<td>Total phosphate</td>
<td>1.07$^a$</td>
<td>0.96 (1.08)</td>
<td>0.90 (0.86)</td>
</tr>
<tr>
<td>concentration (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total phosphate</td>
<td>7,480</td>
<td>6,850</td>
<td>0.92</td>
</tr>
<tr>
<td>transport (kg/day)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEFORE CLOSURE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Feb 1971 - Mar 1977)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>66.98</td>
<td>74.73</td>
<td>1.12</td>
</tr>
<tr>
<td>Total phosphate</td>
<td>1.11 (1.18)</td>
<td>1.09 (1.34)</td>
<td>0.98 (1.14)</td>
</tr>
<tr>
<td>concentration (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total phosphate</td>
<td>6,820</td>
<td>8,630</td>
<td>1.26</td>
</tr>
<tr>
<td>transport (kg/day)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AFTER CLOSURE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>71.20</td>
<td>69.42</td>
<td>0.98</td>
</tr>
<tr>
<td>Total phosphate</td>
<td>1.06 (1.42)</td>
<td>0.58 (0.64)</td>
<td>0.55 (0.45)</td>
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<tr>
<td>concentration (mg/l)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Total phosphate</td>
<td>8,730</td>
<td>3,840</td>
<td>0.44</td>
</tr>
<tr>
<td>transport (kg/day)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Percentage change in transport after closure

Station 1

\[
\frac{6,820 - 8,730}{6,820} \times 100 = 28.0\% \text{ increase}
\]

Station 5

\[
\frac{8,630 - 3,840}{8,630} \times 100 = 55.5\% \text{ decrease}
\]

$^a$Sample-weighted mean concentration.

$^b$Flow-weighted mean concentration.
transport occurred at Station 1 after closure, a 55.5% decrease occurred at Station 5, due to Saylorville Reservoir.

**Organic nitrogen**

In Figure 17, organic nitrogen transport and concentration at Station 1 are plotted as percentages of the total period mean. As with the parameters previously studied, organic nitrogen transport appears to be correlated with flow.

Comparatively low organic nitrogen transport percentages before closure were experienced from August through February. Relatively high transport percentages occurred from March through July. The maximum transport during May was due to the relatively high flows and organic nitrogen concentrations experienced this month.

After closure, below-average transport is noted from October through February. The higher percentage of transport during November after closure, relative to before closure is due to significantly higher flows experienced in November after closure. The comparatively high transport percentages during March, August, and September, were due to higher flows during these months after closure. The high transport in April was primarily due to higher organic nitrogen concentrations during this month after closure, relative to before closure. Relatively high transport percentages occurred from May through July; however, these values were less than those
Figure 17. Station 1 organic nitrogen transport and concentration plotted as a percentage of the total period mean.
experienced before closure because of the lower flows during these months after closure.

Organic nitrogen concentration is at a minimum during January, increases to a maximum in July, maintains this peak through September, and then decreases through December. High concentrations from July through September could be due to plant material being eroded from fields.

Organic nitrogen transport and concentration percentages at Station 5 are shown in Figure 18. The before closure organic nitrogen transport plot at Station 5 is similar to that at Station 1. This is expected because there are no major tributaries of the Des Moines River between Stations 1 and 5, and also, the distance between the 2 stations is not very great.

After closure, above-average transport occurs from March through September, and below-average transport is experienced from October through February. Again, the evening-out effect of the reservoir can be seen. The conspicuously high transport peaks that occurred during March, April, and August, at Station 1 after closure, have been "chopped-off" by the reservoir. Also, the noticeable dip in transport during May at Station 1 after closure, has been "lifted-up" by Saylorville Reservoir.

The evening-out effect of the reservoir is also noted in the organic nitrogen concentration plot. The pattern of the
Figure 18. Station 5 organic nitrogen transport and concentration plotted as a percentage of the total period mean.
concentration plot at Station 5 is very similar to that at Station 1; however, the monthly changes in concentration percentages at Station 5 are much smaller than those at Station 1.

The after closure organic nitrogen concentration and transport percentages at Stations 1 and 5 are plotted as a percentage of the period mean in Figure 19. The transport at Station 5 has obviously been affected by the reservoir. Especially notable are the decreases in transport percentages at Station 5 during March and August. These decreases are due to reductions in flow percentages in the outflow, relative to the inflow during these months. Increases in transport percentages at Station 5 from May through July, and during September and October, are due to increased flow percentages in the outflow, relative to the inflow during these months. From November through January, and during April, flow percentages at Stations 1 and 5 are about equal, but due to the higher organic nitrogen concentration percentages experienced at Station 5 during these months, there are increases in transport percentages.

The reservoir also has an evening-out effect on organic nitrogen concentration percentages. Generally, when concentration percentages at Station 1 are relatively low, increases are seen at Station 5. When concentration percentages at Station 1 are relatively high, decreases are seen at
Figure 19. After closure monthly organic nitrogen transport and concentration at Stations 1 and 5 plotted as a percentage of the period mean.
Station 5. Increases in concentration percentages at Station 5, relative to Station 1 occur from November through May, and decreases occur from June through October.

Table 5 shows the organic nitrogen means at Stations 1 and 5 for the 3 periods. The sample-weighted mean organic nitrogen concentration before closure at Station 5 (0.94 mg/l) was 4% greater than that at Station 1 (0.90 mg/l). After closure, the sample-weighted mean organic nitrogen concentration at Station 5 (0.82 mg/l) was only 75% of that at Station 1 (1.09 mg/l). Reductions in organic nitrogen concentration in the outflow, relative to the inflow were also found by Churchill (1958) in his study of Cherokee Reservoir, and Neel et al. (1963) in their study of Garrison and Fort Randall Reservoirs.

The mean organic nitrogen transport before closure at Station 5 (4,560 kg/day) was 4% greater than that at Station 1 (4,360 kg/day). After closure, only 74% of the organic nitrogen transport at Station 1 (6,400 kg/day) was accounted for at Station 5 (4,710 kg/day).

The reductions in mean organic nitrogen concentration and transport at Station 5 after closure, are due primarily to sedimentation and biological decomposition of nitrogenous organic matter within Saylorville Reservoir.

The percentage change in organic nitrogen transport at the 2 stations after closure shows how effective Saylorville
Table 5. Organic nitrogen means for Stations 1 and 5

<table>
<thead>
<tr>
<th></th>
<th>Station 1</th>
<th>Station 5</th>
<th>Station 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL PERIOD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Jul 1967 - Oct 1980)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>66.11</td>
<td>70.30</td>
<td>1.06</td>
</tr>
<tr>
<td>Organic nitrogen concentration (mg/l)</td>
<td>0.95$^a$ (0.86)$^b$</td>
<td>0.91 (0.75)</td>
<td>0.96 (0.87)</td>
</tr>
<tr>
<td>Organic nitrogen transport (kg/day)</td>
<td>4,920</td>
<td>4,580</td>
<td>0.93</td>
</tr>
<tr>
<td><strong>BEFORE CLOSURE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Jul 1967 - Mar 1977)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>65.30</td>
<td>70.85</td>
<td>1.08</td>
</tr>
<tr>
<td>Organic nitrogen concentration (mg/l)</td>
<td>0.90 (0.77)</td>
<td>0.94 (0.74)</td>
<td>1.04 (0.96)</td>
</tr>
<tr>
<td>Organic nitrogen transport (kg/day)</td>
<td>4,360</td>
<td>4,560</td>
<td>1.04</td>
</tr>
<tr>
<td><strong>AFTER CLOSURE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>71.20</td>
<td>69.42</td>
<td>0.98</td>
</tr>
<tr>
<td>Organic nitrogen concentration (mg/l)</td>
<td>1.09 (1.04)</td>
<td>0.82 (0.78)</td>
<td>0.75 (0.75)</td>
</tr>
<tr>
<td>Organic nitrogen transport (kg/day)</td>
<td>6,400</td>
<td>4,710</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Percentage change in transport after closure

Station 1

\[
\frac{\text{Before closure transport} - \text{After closure transport}}{\text{Before closure transport}} \times 100
\]

\[
\begin{align*}
\text{Before closure transport} &= 4,360 - 6,400 \\
\text{Percentage change} &= \frac{-2040}{4,360} \times 100 = 46.8 \% 
\end{align*}
\]

Station 5

\[
\frac{\text{Before closure transport} - \text{After closure transport}}{\text{Before closure transport}} \times 100
\]

\[
\begin{align*}
\text{Before closure transport} &= 4,560 - 4,710 \\
\text{Percentage change} &= \frac{-150}{4,560} \times 100 = 3.3 \% 
\end{align*}
\]

$^a$Sample-weighted mean concentration.

$^b$Flow-weighted mean concentration.
Reservoir is in trapping organic nitrogen. At Station 1 there was a 46.8 % increase in organic nitrogen transport after closure; however, at Station 5 there was only a 3.3 % increase in transport after closure.

**Ammonia nitrogen**

Ammonia nitrogen transport and monthly concentrations at Station 1 are plotted as percentages of the total period mean in Figure 20. Below-average ammonia nitrogen transport reported for August through February during all 3 periods, was primarily due to low flows during these months.

The comparatively high ammonia nitrogen transport percentages experienced from March through July before closure, appear to be well-correlated with high flows during these months. Above-average flow and concentration during March before closure, contributed to the maximum ammonia nitrogen transport that occurred this month.

After closure, above-average ammonia nitrogen transport occurs during March and April. The maximum in March is due to a combination of high flows and concentrations this month. Unlike the before closure period, below-average transport was experienced from May through July after closure. This is due to the lower flows that occurred during these months after closure, relative to before closure.

Ammonia nitrogen concentrations were below average from April through November, and above average from December
Figure 20. Station 1 monthly ammonia nitrogen transport and concentration plotted as a percentage of the total period mean.
through March. This is because ammonia nitrogen concentrations are highly dependent on nitrification rates. According to Tchobanoglous (1979), overall nitrification rates decrease with decreasing temperature. During the warmer months, nitrifying bacteria are more active, and so most of the ammonia nitrogen is oxidized to nitrate. However, from December through March, when the water is colder, nitrification decreases, and ammonia nitrogen is not oxidized as quickly.

Figure 21 shows the ammonia nitrogen transport and concentration percentages at Station 5. Similar to Station 1, ammonia nitrogen transport and concentration percentages are relatively low from August through December during all periods.

As expected, the before closure transport percentages at Station 5 are almost identical to those at Station 1. However, after closure, shifts in monthly percentages are noticed. Since Saylorville is a hypolimnetic release reservoir, greater amounts of ammonia are expected in the outflow during periods of stratification. This could explain the increases in ammonia nitrogen transport percentages at Station 5 during May, June, and July, relative to Station 1. The high transport percentage in April is most likely due to the increase in ammonia nitrogen concentration percentage experienced after closure. Also, during April, nitrogen
Figure 21. Station 5 monthly ammonia nitrogen transport and concentration plotted as a percentage of the total period mean.
fertilizer is added to fields, and so it may be prevalent in runoff. The decrease in transport during March could possibly be caused by spring turnover at this time.

The ammonia nitrogen concentration plot at Station 5 is hard to distinguish from that at Station 1. However, the evening-out effect due to Saylorville Reservoir is apparent. Reductions in concentration percentages at Station 5 have occurred during months that had relatively high concentration percentages at Station 1. Conversely, increases occurred at Station 5 during months that had relatively low concentration percentages at Station 1.

Ammonia nitrogen transport and concentration at Stations 1 and 5 are plotted as a percentage of the period mean in Figure 22. Monthly shifts in transport percentages due to the reservoir are evident. From April through November, greater percentages of ammonia nitrogen transport are seen at Station 5 relative to Station 1. This is because water released from the hypolimnion of Saylorville Reservoir contains relatively high concentrations of ammonia nitrogen. From December through March, lower percentages of ammonia nitrogen transport are seen at Station 5 relative to Station 1. This could be due to warmer temperatures in the reservoir compared to the river during winter months, causing more nitrification to take place.

Ammonia nitrogen concentration percentages follow the
Figure 22. After closure monthly ammonia nitrogen transport and concentration at Stations 1 and 5 plotted as a percentage of the period mean.
same pattern as transport percentages during all months, except November. From December through March, the concentration percentages at Station 5 are less than those at Station 1, and from April through October they are greater. In November, the concentration percentages at the 2 stations are about equal.

The ammonia nitrogen means for the 2 stations, during the 3 time periods, are given in Table 6. Before closure, the sample-weighted mean ammonia nitrogen concentration at Station 5 (0.38 mg/l) was 68 % of that at Station 1 (0.56 mg/l). After closure, the sample-weighted mean concentration at Station 5 (0.30 mg/l) increased to 88 % of that at Station 1 (0.34 mg/l). Water high in ammonia nitrogen drawn from the hypolimnion of Saylorville Reservoir is a major factor contributing to the increased concentration percentage at Station 5.

Ammonia nitrogen mean transport at Station 5 (1,760 kg/day) before closure, was 94 % of that at Station 1 (1,870 kg/day). However, after closure, the transport at Station 5 (1,720 kg/day) was 8 % greater than that at Station 1 (1,600 kg/day). Rausch and Schreiber (1977) found a 28 % increase in ammonia in the outflow of Callahan reservoir compared to the inflow. They attributed the increase to biological degradation of organic matter within the reservoir. This could be what is happening at Saylorville Reservoir. Also,
Table 6. Ammonia nitrogen means for Stations 1 and 5

<table>
<thead>
<tr>
<th></th>
<th>Station 1</th>
<th>Station 5</th>
<th>Station 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL PERIOD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Jul 1967 - Oct 1980)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m³/s)</td>
<td>66.11</td>
<td>70.30</td>
<td>1.06</td>
</tr>
<tr>
<td>Ammonia nitrogen concentration (mg/l)</td>
<td>0.50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(0.31)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.36 (0.29)</td>
</tr>
<tr>
<td>Ammonia nitrogen transport (kg/day)</td>
<td>1,780</td>
<td>1,740</td>
<td>0.98</td>
</tr>
<tr>
<td><strong>BEFORE CLOSURE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Jul 1967 - Mar 1977)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m³/s)</td>
<td>65.30</td>
<td>70.85</td>
<td>1.08</td>
</tr>
<tr>
<td>Ammonia nitrogen concentration (mg/l)</td>
<td>0.56 (0.33)</td>
<td>0.38 (0.29)</td>
<td>0.68 (0.88)</td>
</tr>
<tr>
<td>Ammonia nitrogen transport (kg/day)</td>
<td>1,870</td>
<td>1,760</td>
<td>0.94</td>
</tr>
<tr>
<td><strong>AFTER CLOSURE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m³/s)</td>
<td>71.20</td>
<td>69.42</td>
<td>0.98</td>
</tr>
<tr>
<td>Ammonia nitrogen concentration (mg/l)</td>
<td>0.34 (0.26)</td>
<td>0.30 (0.29)</td>
<td>0.88 (1.12)</td>
</tr>
<tr>
<td>Ammonia nitrogen transport (kg/day)</td>
<td>1,600</td>
<td>1,720</td>
<td>1.08</td>
</tr>
</tbody>
</table>

Percentage change in transport after closure

Station 1

Before closure transport - After closure transport x 100

Before closure transport

1,870 - 1,600

= ———— x 100 = 14.4 % decrease

1,870

Station 5

Before closure transport - After closure transport x 100

Before closure transport

1,760 - 1,720

= ———— x 100 = 2.3 % decrease

1,760

<sup>a</sup>Sample-weighted mean concentration.

<sup>b</sup>Flow-weighted mean concentration.
low dissolved oxygen concentrations often found in the hypolimnion of Saylorville Reservoir would enhance the denitrification process, thus increasing the amount of ammonia nitrogen.

Looking at the percentage change in ammonia nitrogen transport after closure, relative to before closure at the 2 stations, it is apparent that Saylorville Reservoir causes an increase in ammonia nitrogen transport downstream. After closure, there was a 14.4% decrease in ammonia nitrogen transport at Station 1; however, at Station 5 there was only a 2.3% decrease.

**Nitrite plus nitrate nitrogen**

Monthly transport and concentration of nitrite plus nitrate nitrogen at Station 1 are plotted as percentages of the total period mean in Figure 23. Compared to other parameters studied, greater percentages of nitrite plus nitrate transport and concentration occur during low-flow months because of high nitrate concentrations in groundwater.

Before closure, above-average transport occurs from March through July. The peaks in April, May, and June are probably due to leaching and runoff of nitrogen fertilizer from agricultural fields. Below-average nitrite plus nitrate nitrogen transport is experienced from August through February. This is due primarily to low flows during these months.

In his study of 3 rivers in Great Britain, Edwards
Figure 23. Station 1 monthly nitrite plus nitrate nitrogen transport and concentration plotted as a percentage of the total period mean.
(1973) found nitrate loading to be highly correlated with discharge. This appears to be true for the Des Moines River. Months that experienced higher flows after closure, compared to before closure, had higher transport percentages, and those having lower flows had lower transport percentages, with the exception of April.

Nitrite plus nitrate nitrogen concentrations were above average from April through July, and also from November through January. The high concentrations from April through July are probably due to runoff and leaching of nitrogen fertilizer from fields, and those from November through January are probably due to groundwater inputs. Below-average concentrations occurred from August through October, and also during February and March.

Station 5 nitrite plus nitrate nitrogen transport and concentration percentages are plotted in Figure 24. As expected, the before closure transport plot at Station 5 is very similar to that at Station 1.

After closure, only slight changes in transport due to the reservoir are evident. Apparently, Saylorville Reservoir does not have as great an impact on nitrite plus nitrate nitrogen as it has on other parameters. With the exceptions of March and August, all months at Station 5 experienced nitrite plus nitrate transport percentages similar to those at Station 1. The reduced percentages at Station 5 during
Figure 24. Station 5 monthly nitrite plus nitrate nitrogen transport and concentration plotted as a percentage of the total period mean.
March and August are due to the significant reductions in flow during these months after closure.

Nitrite plus nitrate nitrogen concentration percentages at Station 5 are almost identical to those at Station 1. As with transport, nitrite plus nitrate nitrogen concentration percentages appear to be affected little by Saylorville Reservoir.

Figure 25 shows after closure nitrite plus nitrate nitrogen concentration and transport at Stations 1 and 5 plotted as percentages of the period mean. In this figure, the effects of the reservoir are more evident, but compared to other parameters examined, Saylorville Reservoir appears to have little impact on monthly nitrite plus nitrate transport percentages. The reservoir has the greatest impact on nitrite plus nitrate nitrogen transport during March. The significant decrease in flow percentage at Station 5 during this month caused the decrease in transport percentage. Greater percentages of flow at Station 5 during May, July, and September are responsible for the increases in transport percentages during these months. The sharp reduction in flow percentage at Station 5 during August is responsible for the decrease in transport percentage during this month. Little difference is noted between the nitrite plus nitrate nitrogen transport percentages at Stations 1 and 5 during the remaining months.
Figure 25. After closure monthly nitrite plus nitrate nitrogen transport and concentration at Stations 1 and 5 plotted as a percentage of the period mean.
As with transport, the reservoir appeared to have little effect on nitrite plus nitrate nitrogen concentration percentages. There is little difference between the concentration percentages at Stations 1 and 5 during all months.

A possible explanation of the relatively minor impact Saylorville Reservoir has on nitrite plus nitrate nitrogen transport and concentration percentages could be due to the high solubility of nitrate nitrogen. Since the majority of nitrate nitrogen is in solution, it will not settle out like the other parameters studied would. Another point to consider is that it is hard to quantify the effects of nitrification, denitrification, nitrogen fixation, and biological uptake on nitrite plus nitrate nitrogen concentration and transport. It is possible that the processes of nitrification and nitrogen fixation, which increase the amount of nitrate, are balanced-out by the processes of denitrification and biological uptake, which decrease the amount of nitrate, and so the amount of nitrite plus nitrate nitrogen leaving the reservoir would be approximately equal to that entering it.

The nitrite plus nitrate nitrogen means at Stations 1 and 5 during the 3 periods are given in Table 7. Before closure, the sample-weighted mean concentration at Station 5 (4.22 mg/l) was 96% of that at Station 1 (4.37 mg/l). The sample-weighted mean concentration after closure at Station 5
Table 7. NO$_2$ + NO$_3$ nitrogen means for Stations 1 and 5

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>Station 1</th>
<th>Station 5</th>
<th>Station 1</th>
<th>Station 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL PERIOD (Jul 1967 - Oct 1980)</td>
<td>66.11</td>
<td>70.30</td>
<td>1.06</td>
<td>1.03</td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>4.92$^a$ (7.54)$^b$</td>
<td>4.71 (7.28)</td>
<td>0.96 (0.97)</td>
<td></td>
</tr>
<tr>
<td>NO$_2$ + NO$_3$ nitrogen concentration (mg/l)</td>
<td>43,100</td>
<td>44,240</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO$_2$ + NO$_3$ nitrogen transport (kg/day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEFORE CLOSURE (Jul 1967 - Mar 1977)</td>
<td>65.30</td>
<td>70.85</td>
<td>1.08</td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>4.37 (7.32)</td>
<td>4.22 (7.22)</td>
<td>0.96 (0.99)</td>
<td></td>
</tr>
<tr>
<td>NO$_2$ + NO$_3$ nitrogen concentration (mg/l)</td>
<td>41,290</td>
<td>44,180</td>
<td>1.07</td>
<td></td>
</tr>
<tr>
<td>NO$_2$ + NO$_3$ nitrogen transport (kg/day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AFTER CLOSURE (Apr 1977 - Oct 1980)</td>
<td>71.20</td>
<td>69.42</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>6.54 (8.01)</td>
<td>6.38 (7.53)</td>
<td>0.98 (0.94)</td>
<td></td>
</tr>
<tr>
<td>NO$_2$ + NO$_3$ nitrogen concentration (mg/l)</td>
<td>49,290</td>
<td>45,160</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>NO$_2$ + NO$_3$ nitrogen transport (kg/day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Percentage change in transport after closure

Station 1

\[
\text{Before closure transport} - \text{After closure transport} = \frac{41,290 - 49,290}{41,290} \times 100 = 19.4\% \text{ increase}
\]

Station 5

\[
\text{Before closure transport} - \text{After closure transport} = \frac{44,180 - 45,160}{44,180} \times 100 = 2.2\% \text{ increase}
\]

$^a$Sample-weighted mean concentration.

$^b$Flow-weighted mean concentration.
(6.38 mg/l) was 98% of that at Station 1 (6.54 mg/l).

Nitrite plus nitrate nitrogen mean transport before closure at Station 5 (44,180 kg/day) was 7% greater than that at Station 1 (41,290 kg/day). After closure, the mean transport at Station 5 (45,160 kg/day) was only 92% of that at Station 1 (49,290 kg/day). This 8% trap efficiency is considerably smaller than the 34% trap efficiency reported by Rausch and Schreiber (1977) for Callahan Reservoir.

The slight reduction in nitrite plus nitrate nitrogen transport in the outflow relative to the inflow is probably due to the hypolimnetic water released from Saylorville Reservoir. Since the hypolimnion frequently has low dissolved oxygen concentrations, denitrification would occur, hence lowering the amounts of nitrite plus nitrate nitrogen found here.

Increases in the percentage change in nitrite plus nitrate nitrogen transport after closure occurred at both Stations 1 and 5. At Station 1, there was a 19.4% increase in nitrite plus nitrate nitrogen transport after closure, and at Station 5, due to the reservoir, there was only a 2.2% increase.

**Total nitrogen**

The total nitrogen plots are basically a weighted average of the ammonia, organic, and nitrite plus nitrate nitrogen plots. Since the major component of total nitrogen
is nitrite plus nitrate nitrogen, the plots of total nitrogen are almost identical to those of nitrite plus nitrate nitrogen. Figure 26 shows total nitrogen transport and concentration at Station 1 plotted as percentages of the total period mean. Before closure, above-average transport occurs during March through July, and below-average transport occurs from August through February.

After closure, above-average transport occurs from March through August, and also during November. Below-average transport is experienced during the remaining months.

Relatively high total nitrogen concentrations were experienced from April through July, and from November through January. Comparatively low total nitrogen concentrations were observed from August through October, and during February and March.

Total nitrogen transport and concentration at Station 5 are plotted as percentages of the total period mean in Figure 27. These plots are also almost identical to the nitrite plus nitrate nitrogen plots at Station 5.

Figure 28 shows after closure total nitrogen transport and concentration at Stations 1 and 5 plotted as percentages of the period mean. Again, the plots are virtually identical to the after closure nitrite plus nitrate nitrogen plots at these stations.

The total nitrogen means at Stations 1 and 5 are given
Figure 26. Station 1 monthly total nitrogen transport and concentration plotted as a percentage of the total period mean.
Figure 27. Station 5 monthly total nitrogen transport and concentration plotted as a percentage of the total period mean
Figure 28. After closure monthly total nitrogen transport and concentration at Stations 1 and 5 plotted as a percentage of the period mean.
in Table 8. The before closure sample-weighted mean concentration at Station 5 (5.53 mg/l) was 95% of that at Station 1 (5.83 mg/l). After closure, the sample-weighted mean concentration at Station 5 (7.34 mg/l) was 92% of that at Station 1 (7.98 mg/l).

Mean total nitrogen transport before closure at Station 5 (50,420 kg/day) was 6% greater than that at Station 1 (47,790 kg/day). After closure, the transport at Station 5 (51,590 kg/day) was only 90% of that at Station 1 (57,310 kg/day). This 10% trap efficiency is comparable to the following total nitrogen trap efficiencies found in the literature: 16% (Churchill, 1967), 25% (Wright and Soltero, 1973), and 20% (Heinemann et al., 1973).

The percentage change in total nitrogen transport after closure at Station 1 was a 19.9% increase, while that at Station 5 was only a 2.3% increase.

Comparing the Water Quality of the Raccoon and Des Moines Rivers

Two parameters were examined to compare the water quality of the Raccoon and Des Moines Rivers: BOD and suspended solids. Data from Station 10 at Van Meter, Iowa were used to determine the water quality of the Raccoon River. Stations 1 and 5, and Station 6 below the City of Des Moines were examined to see how the water quality of the Des Moines River changes after it is joined by the Raccoon River.
Table 8. Total nitrogen means for Stations 1 and 5

<table>
<thead>
<tr>
<th></th>
<th>Station 1</th>
<th>Station 5</th>
<th>Station 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL PERIOD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Jul 1967 - Oct 1980)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m³/s)</td>
<td>66.11</td>
<td>70.30</td>
<td>1.06</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>6.37ᵃ (8.75)b</td>
<td>5.96 (8.32)</td>
<td>0.94 (0.95)</td>
</tr>
<tr>
<td>concentration (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>49,990</td>
<td>50,560</td>
<td>1.01</td>
</tr>
<tr>
<td>transport (kg/day)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BEFORE CLOSURE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Jul 1967 - Mar 1977)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m³/s)</td>
<td>65.30</td>
<td>70.85</td>
<td>1.08</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>5.83 (8.47)</td>
<td>5.53 (8.24)</td>
<td>0.95 (0.97)</td>
</tr>
<tr>
<td>concentration (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>47,790</td>
<td>50,420</td>
<td>1.06</td>
</tr>
<tr>
<td>transport (kg/day)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AFTER CLOSURE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m³/s)</td>
<td>71.20</td>
<td>69.42</td>
<td>0.98</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>7.98 (9.32)</td>
<td>7.34 (8.60)</td>
<td>0.92 (0.92)</td>
</tr>
<tr>
<td>concentration (mg/l)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>57,310</td>
<td>51,590</td>
<td>0.90</td>
</tr>
<tr>
<td>transport (kg/day)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Percentage change in transport after closure

**Station 1**

Before closure transport - After closure transport

\[
\frac{47,790 - 57,310}{47,790} \times 100 = 19.9 \% \text{ increase}
\]

**Station 5**

Before closure transport - After closure transport

\[
\frac{50,420 - 51,590}{50,420} \times 100 = 2.3 \% \text{ increase}
\]

ᵃSample-weighted mean concentration.

ᵇFlow-weighted mean concentration.
Biochemical oxygen demand

The BOD means for Stations 1, 5, 6, and 10 are given in Table 9. Before closure, the mean flow at Station 5 (80.4 m$^3$/s) was 10% greater than that at Station 10 (73.1 m$^3$/s). The mean flow at Station 5 plus that at Station 10 was 86% of the flow at Station 6 (179.0 m$^3$/s). Beaver Creek and other small tributaries account for the remaining flow at Station 6.

The before closure sample-weighted mean BOD concentration at Stations 1 and 5 was 6.0 mg/l. This was 53% greater than that at Station 10 (3.92 mg/l). The mean concentration at Station 6 was 6.4 mg/l. The higher mean BOD concentration at Station 6 is largely due to effluent from the wastewater treatment plant in Des Moines.

The mean BOD transport before closure at Station 5 (26,600 kg/day) was 8% greater than that at Station 10 (24,700 kg/day). The combined BOD transport of Stations 5 and 10 accounted for only 76% of that at Station 6 (67,900 kg/day). The remaining 24% at Station 6 is, for the most part, due to point sources of pollution within the City of Des Moines.

After closure, the flow at Station 5 (69.42 m$^3$/s) was 49% greater than that at Station 10 (46.5 m$^3$/s). The combined flow of Stations 5 and 10 was 92% of that at Station 6 (125.7 m$^3$/s).
Table 9. BOD means for all stations

<table>
<thead>
<tr>
<th></th>
<th>Station 1</th>
<th>Station 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL PERIOD</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>70.20</td>
<td>75.00</td>
</tr>
<tr>
<td>BOD concentration (mg/l)</td>
<td>5.70$^a$ (3.89)$^b$</td>
<td>4.60 (3.15)</td>
</tr>
<tr>
<td>BOD transport (kg/day)</td>
<td>23,600</td>
<td>20,400</td>
</tr>
</tbody>
</table>

| **BEFORE CLOSURE**       |           |           |
| (Aug 1972 - Mar 1977)    |           |           |
| Flow (m$^3$/s)           | 71.00     | 80.40     |
| BOD concentration (mg/l) | 6.00 (3.93) | 6.00 (3.83) |
| BOD transport (kg/day)   | 24,100    | 26,600    |

| **AFTER CLOSURE**        |           |           |
| Flow (m$^3$/s)           | 71.20     | 69.42     |
| BOD concentration (mg/l) | 5.12 (3.81) | 2.56 (2.16) |
| BOD transport (kg/day)   | 23,450    | 12,940    |

$^a$Sample-weighted mean concentration.

$^b$Flow-weighted mean concentration.
<table>
<thead>
<tr>
<th>Station 6</th>
<th>Station 10</th>
<th>Station 5</th>
<th>Station 5 + Station 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>153.10</td>
<td>59.90</td>
<td>1.25</td>
<td>0.88</td>
</tr>
<tr>
<td>5.80 (4.15)</td>
<td>4.06 (4.21)</td>
<td>1.13 (0.75)</td>
<td>--</td>
</tr>
<tr>
<td>54,900</td>
<td>21,800</td>
<td>0.94</td>
<td>0.77</td>
</tr>
<tr>
<td>179.00</td>
<td>73.10</td>
<td>1.10</td>
<td>0.86</td>
</tr>
<tr>
<td>6.40 (4.39)</td>
<td>3.92 (3.91)</td>
<td>1.53 (0.98)</td>
<td>--</td>
</tr>
<tr>
<td>67,900</td>
<td>24,700</td>
<td>1.08</td>
<td>0.76</td>
</tr>
<tr>
<td>125.70</td>
<td>46.50</td>
<td>1.49</td>
<td>0.92</td>
</tr>
<tr>
<td>4.70 (3.66)</td>
<td>4.13 (4.83)</td>
<td>0.62 (0.45)</td>
<td>--</td>
</tr>
<tr>
<td>39,800</td>
<td>19,400</td>
<td>0.67</td>
<td>0.81</td>
</tr>
</tbody>
</table>
The sample-weighted mean BOD concentration after closure at Station 5 (2.56 mg/l) was only 62% of that at Station 10 (4.13 mg/l). The mean BOD concentration at Station 6 after closure was 4.70 mg/l.

The after closure mean BOD transport at Station 5 (12,940 kg/day) was only 67% of that at Station 10 (19,400 kg/day). The combined mean BOD transport of Stations 5 and 10 accounted for 81% of the transport at Station 6 (39,800 kg/day).

Although comparisons can be made about the water quality of the Des Moines River at Station 5, and the Raccoon River at Station 10, it is impossible to quantify the effects of the Raccoon River on the water quality of the Des Moines River at Station 6 without knowing the point source inputs from the City of Des Moines.

It has been shown that before closure, the BOD concentration and transport means at Station 5 were greater than those at Station 10. The mean transport at Station 10 before closure was 36% of that at Station 6. After closure, however, due to the reservoir, the BOD concentration and transport means at Station 5 were considerably less than those at Station 10. The mean transport at Station 10 after closure, rose to 48% of that at Station 6. Therefore, after closure, the Raccoon River has the greater effect on the BOD transport of the Des Moines River.
Suspended solids

Table 10 shows the suspended solids means for Stations 1, 5, 6, and 10. The mean flow before closure at Station 5 (60.72 m$^3$/s) was 20% greater than that at Station 10 (50.70 m$^3$/s). The combined flow of Stations 5 and 10 was 86% of that at Station 6 (129.60 m$^3$/s).

The before closure sample-weighted mean suspended solids concentration at Station 5 (153 mg/l) was 56% of that at Station 10 (274 mg/l). The mean concentration at Station 6 (193 mg/l) was less than that at Station 10.

The mean suspended solids transport before closure at Station 5 (1,464,762 kg/day) was 57% of that at Station 10 (2,561,989 kg/day). The combined transport of Stations 5 and 10 was 88% of that at Station 6 (4,589,569 kg/day).

After closure, the flow at Station 5 (69.42 m$^3$/s) was 49% greater than that at Station 10 (46.50 m$^3$/s). The combined flow of Stations 5 and 10 was 92% of that at Station 6 (125.70 m$^3$/s).

The sample-weighted mean suspended solids concentration after closure at Station 5 (25 mg/l) was only 9% of that at Station 10 (287 mg/l). The mean suspended solids concentration at Station 6 (270 mg/l) after closure, was slightly less than that at Station 10.

The after closure mean suspended solids transport at Station 5 (162,407 kg/day) was only 3% of that at Station 10.
Table 10. Suspended solids means for all stations

<table>
<thead>
<tr>
<th></th>
<th>Station 1</th>
<th>Station 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL PERIOD</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>61.06</td>
<td>64.13</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>143$^a$ (309)$^b$</td>
<td>85 (137)</td>
</tr>
<tr>
<td>concentration (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended solids</td>
<td>1,630,293</td>
<td>758,158</td>
</tr>
<tr>
<td>transport (kg/day)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BEFORE CLOSURE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>53.49</td>
<td>60.72</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>148 (249)</td>
<td>153 (279)</td>
</tr>
<tr>
<td>concentration (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended solids</td>
<td>1,149,404</td>
<td>1,464,762</td>
</tr>
<tr>
<td>transport (kg/day)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AFTER CLOSURE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow (m$^3$/s)</td>
<td>71.20</td>
<td>69.42</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>145 (345)</td>
<td>25 (27)</td>
</tr>
<tr>
<td>concentration (mg/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended solids</td>
<td>2,125,311</td>
<td>162,407</td>
</tr>
<tr>
<td>transport (kg/day)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$Sample-weighted mean concentration.

$^b$Flow-weighted mean concentration.
<table>
<thead>
<tr>
<th>Station 6</th>
<th>Station 10</th>
<th>Station 10</th>
<th>Station 5</th>
<th>Station 5 + Station 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>125.90</td>
<td>47.20</td>
<td>1.36</td>
<td></td>
<td>0.88</td>
</tr>
<tr>
<td>231 (511)</td>
<td>276 (1018)</td>
<td>0.31 (0.14)</td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>5,555,331</td>
<td>4,151,005</td>
<td>0.18</td>
<td></td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>129.60</td>
<td>50.70</td>
<td>1.20</td>
<td></td>
<td>0.86</td>
</tr>
<tr>
<td>193 (410)</td>
<td>274 (585)</td>
<td>0.56 (0.48)</td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>4,589,569</td>
<td>2,561,989</td>
<td>0.57</td>
<td></td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>125.70</td>
<td>46.50</td>
<td>1.49</td>
<td></td>
<td>0.92</td>
</tr>
<tr>
<td>270 (624)</td>
<td>287 (1466)</td>
<td>0.09 (0.02)</td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>6,781,454</td>
<td>5,891,629</td>
<td>0.03</td>
<td></td>
<td>0.89</td>
</tr>
</tbody>
</table>
(5,891,629 kg/day). The combined mean suspended solids transport of Stations 5 and 10 was 89% of the transport at Station 6 (6,781,454 kg/day).

Unlike BOD, suspended solids concentration and transport means before closure were less at Station 5 compared to Station 10. The mean transport at Station 10 before closure was 56% of that at Station 6. Because of Saylorville Reservoir, the suspended solids concentration and transport means after closure at Station 5 were considerably less than those at Station 10. The mean transport at Station 10 after closure increased to 87% of that at Station 6. Therefore, after closure, the Raccoon River has a much greater impact on the suspended solids transport of the Des Moines River.

It is apparent that the Raccoon River causes a significant deterioration in the water quality of the Des Moines River. This deterioration is especially noticeable after closure. Suspended solids concentration and transport in the Des Moines River are more adversely affected by the Raccoon River than BOD concentration and transport.

Point Versus Nonpoint Source Pollution in the Des Moines River

In determining the relative amounts of point versus nonpoint source pollution in the Des Moines River, 2 basic assumptions were made. The first assumption was that there is virtually no nonpoint source pollution entering the river
in January. This is because the river is usually frozen over, and also, most precipitation falls as snow during January, so there would be little runoff. An exception to this assumption could be significant nitrite plus nitrate transport due to groundwater inputs. The second assumption is that the amount of point source pollution entering the river throughout the year is fairly constant.

The following steps were taken to determine what percentage of each parameter was due to point or nonpoint source pollution:

1) The monthly total period transport of each parameter was plotted as a percentage of the total period mean.
2) A horizontal line was drawn that started at the January transport percentage for the particular parameter and extended through December.
3) The areas of the sections enclosed by the plot above, and below the horizontal line were determined.
4) The percentage of the total area represented by each of the 2 sections was determined.
5) The percentage enclosed in the above section represents pollution due to nonpoint sources, and that enclosed in the section below represents pollution due to point sources.

Nonpoint sources of pollution were responsible for the majority of transport of each parameter studied. Figures
29-35 show the relative amounts of transport due to point and nonpoint sources for each parameter at Station 1. The percentages of each parameter due to nonpoint sources were determined to be: suspended solids (99.2 %), total phosphate (78.9 %), ammonia nitrogen (60.2 %), organic nitrogen (83.7 %), nitrite plus nitrate nitrogen (75.9 %), total nitrogen (76.0 %), and BOD (85.7 %).

Station 6 was studied to see how the City of Des Moines affected the percentage of BOD transport due to point sources. Figure 36 shows the relative amounts of BOD transport due to point and nonpoint sources at Station 6. As expected, the BOD transport due to point sources at Station 6 (34.6 %) was greater than that at Station 1 (14.3 %).

Of the parameters examined, ammonia nitrogen had the greatest percentage of transport due to point sources. This could be due to 2 factors: first, most of the ammonia that is applied to fields as fertilizer is probably nitrified by soil bacteria before it reaches the river as runoff, and second, wastewater treatment plants are a major source of ammonia nitrogen.
Figure 29. Station 1 monthly suspended solids transport plotted as a percentage of the total period mean. The dashed line separates suspended solids transport due to point (below) sources from that due to nonpoint (above) sources.
Figure 30. Station 1 monthly total phosphate transport plotted as a percentage of the total period mean. The dashed line separates total phosphate transport due to point (below) sources from that due to nonpoint (above) sources.
Figure 31. Station 1 monthly ammonia nitrogen transport plotted as a percentage of the total period mean. The dashed line separates ammonia nitrogen transport due to point (below) sources from that due to nonpoint (above) sources.
Figure 32. Station 1 monthly organic nitrogen transport plotted as a percentage of the total period mean. The dashed line separates organic nitrogen transport due to point (below) sources from that due to nonpoint (above) sources.
Figure 33. Station 1 monthly nitrite plus nitrate nitrogen transport plotted as a percentage of the total period mean. The dashed line separates nitrite plus nitrate nitrogen transport due to point (below) sources from that due to nonpoint (above) sources.
Figure 34. Station 1 monthly total nitrogen transport plotted as a percentage of the total period mean. The dashed line separates total nitrogen transport due to point (below) sources from that due to nonpoint (above) sources.
Figure 35. Station 1 monthly BOD transport plotted as a percentage of the total period mean. The dashed line separates BOD transport due to point (below) sources from that due to nonpoint (above) sources.
Figure 36. Station 6 monthly BOD transport plotted as a percentage of the total period mean. The dashed line separates BOD transport due to point (below) sources from that due to nonpoint (above) sources.
CONCLUSIONS AND RECOMMENDATIONS

The effects of Saylorville Reservoir on downstream water quality, as shown by this study, appear to be quite beneficial. Of the 8 parameters studied, ammonia nitrogen was the only one not to show an improvement downstream.

In general, most parameters exhibited peak loadings during the high-flow months of March through June. Minimum loadings were often experienced during the low-flow months of November through February. With the closure of Saylorville Dam, the monthly flow regime was altered, and therefore, the monthly transport and concentration percentages of most parameters were altered. Basically, Saylorville Reservoir had an evening-out effect on most parameters: peak transport percentages during high-flow months were reduced, and minimum transport percentages during low-flow months were raised.

The most noticeable effect Saylorville Reservoir had on flow was a reduction in flow percentage during the months of March and August. Increases in flow percentage during low-flow months were not as obvious. When more drought and high-flow years are added to the data-set, the evening-out effect of the reservoir on flow should be more apparent.

The parameter most significantly affected by Saylorville Reservoir was suspended solids. As river water enters the reservoir it spreads out and slows down, and thus suspended material tends to settle out. The reservoir trapped 92% of
the suspended solids that entered it. The reservoir was particularly efficient in trapping suspended solids during high-flow months.

Saylorville Reservoir also had a significant impact on BOD and total phosphate. The reservoir trapped 45% of the BOD, and 56% of the total phosphate. The BOD of the inflow was reduced within the reservoir due to settling out of suspended matter, and also because of bacteriological decomposition. Total phosphate was trapped because it sorbed to particulate matter which settled out.

Saylorville Reservoir was not as effective in trapping nitrogen. Only 10% of the total nitrogen was trapped. The reservoir trapped 26% of the organic nitrogen, and 8% of the nitrite plus nitrate nitrogen. The only parameter to show an increase in the outflow was ammonia nitrogen. The ammonia nitrogen transport in the outflow was 8% greater than that in the inflow. This is because relatively high concentrations of ammonia are found in the hypolimnion, where little nitrification takes place, and since Saylorville is a hypolimnetic release reservoir, more ammonia nitrogen is found in the outflow.

This study has also shown that the Raccoon River has a pronounced effect on the water quality of the Des Moines River, especially after Saylorville Reservoir closure. Before closure, the Raccoon River accounted for 36% of the
BOD transport at Station 6 on the Des Moines River. After closure, this value rose to 48 %. The Raccoon River accounted for 56 % of the suspended solids transport at Station 6 before closure, and this increased to 87 % after closure. The Raccoon River has a greater impact on the water quality of the Des Moines River after closure because the water quality of the Des Moines River at Station 5 after closure, is significantly better than that before closure.

The relative amounts of point versus nonpoint sources of pollution in the Des Moines River have been examined. Because the Des Moines River Basin is primarily an agricultural area, nonpoint sources of pollution far outweigh point sources. Over 99 % of the suspended solids transport at Station 1 was estimated to be of a nonpoint origin. Only 60.2 % of the ammonia nitrogen transport at Station 1 was of a nonpoint origin. Total phosphate, organic nitrogen, BOD, nitrite plus nitrate nitrogen, and total nitrogen all had over 75 % of their transport originate from nonpoint sources.

With so much pollution being attributed to nonpoint sources, the regulation of effluents only from point sources, such as wastewater treatment plants, will not greatly improve the water quality of the Des Moines River. To significantly improve the water quality of the Des Moines River, steps must be taken to curtail nonpoint sources of pollution. The use of soil conservation practices by farmers in the basin would
greatly improve the water quality of the Des Moines River.

In the wake of future budget cuts, it is recommended that statistical analyses be conducted on the postimpoundment water quality data-set to determine which parameters could be collected less frequently.

It is also recommended that a new sampling station be established immediately below the confluence of the Raccoon and Des Moines Rivers. By comparing data from this station with those from Station 6, the effect of the City of Des Moines on the water quality of the Des Moines River could be determined.

Finally, it is recommended that this sampling program be continued to further determine the long-term effects of Saylorville and Red Rock Reservoirs on the water quality of the Des Moines River.
LITERATURE CITED


Ball, J., C. Weldon, and B. Crocker. 1975. Effects of original vegetation on reservoir water quality. Texas Water Resources Institute, Texas A and M University, College Station, Texas. 120 pp.


ACKNOWLEDGEMENTS

I express my deepest thanks to my wife, Kathy, whose constant faith and support kept me going when quitting would have been so much easier.

The guidance of my major professor, Dr. E. R. Baumann, and the helpful suggestions of my committee members, Dr. Roger W. Bachmann, Dr. T. A. Austin, and the late Dr. Merwin D. Dougal, are much appreciated.

I would like to thank the Rock Island District of the United States Army Corps of Engineers for its financial support of the sampling program, and the personnel of the Engineering Research Institute Analytical Services Laboratory for their assistance over the past two years.

I am especially indebted to Dave Schoeller, who developed the plotting program, and whose advice on computer matters was invaluable.

Finally, I would like to thank my pals, Donna "Sotos" Schulze and Ed "Lyle" Ricci, who made sampling days on the Des Moines River a memorable and event-filled experience.
Derivation of conversion factor constants.

I) Conversion factors used.

\[
\begin{align*}
1 \text{ ft}^3 &= 0.0283 \text{ m}^3 \\
1 \text{ l} &= 0.001 \text{ m}^3 \\
1 \text{ day} &= 86,400 \text{ sec} \\
1 \text{ kg} &= 1,000,000 \text{ mg}
\end{align*}
\]

II) Examples using conversion factor constants.

A) Conversion factor constant 2.445.

At Station 1 on November 6, 1979 the flow was 4,590 cfs, the BOD concentration was 3.5 mg/l, and the calculated transport was 39,279 kg/day.

\[
\frac{0.0283 \text{ m}^3}{\text{ft}^3} \times \frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{1,000,000 \text{ mg}} \times \frac{1}{0.001 \text{ m}^3} \times \frac{2.445 \text{ sec} \times \text{kg} \times 1}{\text{ft}^3 \times \text{day} \times \text{mg}}
\]

\[
= \frac{4,590 \text{ ft}^3 \times 3.5 \text{ mg}}{2.445 \text{ sec} \times \text{kg} \times 1} \times \frac{1}{\text{sec} \times 1 \times \text{ft}^3 \times \text{day} \times \text{mg}}
\]

\[
= 39,279 \text{ kg/day}
\]

B) Conversion factor constant 86.4.

The mean BOD transport at Station 1 for the total period was 28,090 kg/day, the mean flow was 66.11 m³/s, and the calculated flow-weighted mean concentration was 4.92 mg/l.

\[
\frac{86,400 \text{ sec}}{\text{day}} \times \frac{\text{kg}}{1,000,000 \text{ mg}} \times \frac{1}{0.001 \text{ m}^3} \times \frac{86.4 \text{ sec} \times \text{kg} \times 1}{\text{day} \times \text{mg} \times \text{m}^3}
\]

\[
= \frac{28,090 \text{ kg/day}}{86.4 \text{ sec} \times \text{kg} \times 1} \times \frac{1}{1 \times 1 \times \text{sec} \times \text{kg} \times \text{m}^3}
\]
28,090 kg/day

\[
\frac{28,090 \text{ kg/day}}{66.11 \text{ m}^3 \times 86.4 \text{ sec} \times \text{kg} \times \text{l}} \times \frac{\text{sec}}{\text{day} \times \text{mg} \times \text{m}^3} = 4.92 \text{ mg/l}
\]

C) Conversion factor constant 35.3.

The flow at Station 1 on November 6, 1979, 4,590 cfs, was converted to a flow of 129.9 m³/s.

\[
\frac{0.0283 \text{ m}^3 \times 4,590 \text{ ft}^3}{\text{ft}^3 \times \text{sec}} = 129.9 \text{ m}^3/\text{s}
\]