CROPLAND, BUFFER, AND STREAM: A CASE STUDY IN AGRICULTURAL NONPOINT SOURCE WATER POLLUTION

By

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ABSTRACT

CROPLAND, BUFFER, AND STREAM: A CASE STUDY IN AGRICULTURAL NONPOINT SOURCE WATER POLLUTION

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Agricultural cropland runoff, a type of nonpoint source water pollution, can degrade the quality of surface waters. Several related programs, spawned by Section 208 of Public Law 92-500, are directed at reducing nonpoint source water quality problems through the implementation of agricultural "Best Management Practices". The practices include both traditional soil conservation techniques and some newer water quality enhancement methods.

One of the newer practices often mentioned is the streamside grassed buffer or filter strip. Very little research has been conducted on this topic, and the existing investigations are predominantly of the small plot type or are computer models targeted at gross assessments. Essential information appears to be missing at the scale where it may well have the most meaning; the farm or field scale. This would seem to be the scale at which a Best Management Practice, its cost, and its benefit could best be determined.

For the above mentioned reasons of interest and need, a field-scale research project utilizing a vegetated filter area was planned. With the assistance of the Michigan Agricultural Experiment Station and a cooperating farmer, work on the study began in January of 1978. The project is planned as a three-year study.

The project area consists of two similar and adjacent corn fields, the surface drainage from which enters a stream at the lower edge of

the area. Field work consisted of separation of the surface flows from the two fields, design and construction of a vegetated buffer area in one field, and the installation of three complete sets of monitoring equipment (weir, flow meter, automatic sampler). Monitoring stations are located in the stream, in the drainageway from the "buffered" field, and in the drainageway from the "control" field.

The stream is grab-sampled weekly, and is sampled automatically during each runoff event. The two surface drainage flows are sampled automatically, as well, during each runoff event. Laboratory tests for twelve water quality constituents are performed for the samples collected automatically. Tests for fourteen water quality constituents are performed for the stream grab samples. The flows are monitored continuously. The program of sampling and analysis was initiated in June of 1978.

Both corn fields are fertilized with liquid manure from a nearby confinement swine operation. The manure supplies substantial crop nutrients, and is supplemented as needed with commercial fertilizers. A continuous inventory of farm practices and events is kept for the cropped areas. Samples of the applied wastes are analyzed and precipitation data is continuously recorded. Farming practices are unchanged.

This dissertation presents conclusions concerning the vegetated buffer area based on one year of data collection and six major runoff occurrences. Statistically significant differences in water quality constituent concentrations and loads were measured in the runoff from the control and buffered fields. The data indicate that the vegetated buffer area reduced common agricultural water pollutants (nutrients, sediment, and oxygen demand) in the cropland runoff by about 25 percent. The runoff flows were found to have a fairly substantial impact on stream pollutant loads and a lesser, though quite variable, impact on stream pollutant concentrations. The water quality of the stream was marginal, though very few water quality standards violations were noted.

At an average annual equivalent cost of about $600.00, this vegetated buffer area's water quality enhancement cost is about $0.71 per kilogram of pollutant removed. The viability of this practice is best determined by personal values associated with such a pollutant reduction, when compared to this cost. The potential exists for reducing these costs through farmer design and/or installation of vegetated buffer areas, though the impact of such on pollutant reduction is unknown.

Approved Ted L. Loudon
Major Professor

Approved Richard L. Kuster
Department Chairman

To Anne, to Carson, and to Sam

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Chapter 1

SITUATION

1.1. Introduction

Agricultural nonpoint source water pollution has been blamed, in part, for many of the surface water quality problems associated with the American society. This type of pollution has come particularly into focus with the passage of Public Law 92-500 and its resulting pollution control programs administered by various governmental agencies.

The primary focus of Public Law 92-500, also known as the Federal Water Pollution Control Act Amendments of 1972, is the expressed national goal of "fishable and swimmable" surface waters wherever attainable by 1973 and the elimination of all discharges of pollutants into navigable waters by 1985. The importance of planned regional solutions to water quality problems would appear to be confirmed by Section 208 of this Act, entitled Areawide Waste Treatment Management. This Section provides for grants, from the U. S. Environmental Protection Agency to regional planning authorities, for the purposes of identifying regional water quality problems and proposing regional solutions to those problems. Several topics which should be addressed in such a planning document are specified within this Section. One of the topics mentioned is agricultural nonpoint source water pollution.

To paraphrase a portion of Section 208, each Areawide Management Plan must contain a process to identify agriculturally related nonpoint sources of water pollution, including runoff from land utilized for manure application or livestock and crop production, and must set forth procedures to control these sources to the extent feasible.

The degree and method of compliance with this provision of the law seems to vary somewhat among individual regional plans.

An approach seen in Michigan includes a limited amount of water quality sampling in rural areas, the conclusion that agricultural nonpoint sources may well have an adverse impact on water quality, and a listing of a large number of "Best Management Practices" which might be implemented on agricultural lands to reduce the pollutant load placed upon streams. These Best Management Practices include a number of cultural techniques such as no-till planting and strip cropping, as well as structural techniques such as the installation of grassed waterways and grade stabilization structures. Several management techniques, such as the timing of manure spreading or pesticide application, are also mentioned. Farmers are encouraged to implement these practices and techniques during a "voluntary compliance period" of several years. Technical assistance is to be provided through local Soil Conservation Districts and the Cooperative Extension Service. If limited amounts of activity take place during the voluntary compliance period, and if there is little improvement in surface water quality, then provisions exist to implement a "regulatory compliance period". Agricultural producers would be required to implement some of these Best Management Practices under such a program.

Unfortunately, actual field research trials of many Best Management Practices are yet to be conducted. Thus, the various agricultural agencies may soon be asked to assist farmers in selecting management practices for which actual water quality benefits are unknown. If the voluntary program is unsuccessful, and a regulatory program is instituted, farmers may be forced to install practices of unknown benefit.

One practice or technique often included in many of the various available lists of Best Management Practices is the streamside grassed filter strip. Other names, such as vegetated filter or buffer strip, are synonymously used. The goal of this practice is the attenuation of pollutant loads carried by runoff. A second potential benefit is the maintenance of streambank integrity. This is accomplished by planting a vegetated strip of some width along the banks of rural streams. All runoff leaving the land must then be filtered by the grassed strip before entering the stream, and the stability of the streambank may be somewhat enhanced by the presence of plant cover and root systems. Such a practice appears to enjoy much interest and support among environmental planners and concerned regulatory agencies. This is also a practice on which very little field research has been completed.

During the summer and fall of 1977, several persons with the Agricultural Engineering Department at Michigan State University decided that a field study relating particular Best Management Practices and their incremental water quality benefit should be performed. Financial limitations constrained the investigation to only one practice on only one site. It was agreed that probably the most important Best Management Practice for which research was needed was the streamside grassed filter strip.

A visit to several demonstration sites on which grassed filter strips had been installed suggested several problems with the practice. Both sides of the rural stream were literally paved with grass. While the waterway was quite aesthetic, almost park-like, a substantial amount of cropland had been taken out of production. A 10-meter strip on either side of a waterway represents about 2 hectares of cropland per kilometer of stream (or about 8 acres per stream mile). Also, as might be expected, field runoff did not appear to occur evenly throughout the length of the strip. The design of the filter strip suggested protection from sheet flow of runoff waters. Natural contours and gravity, however, generally serve to preclude this condition.

From these observations it was concluded that the streamside grassed filter strip might well be unacceptable to many agricultural producers due to the required land area. This could be particularly expected when it is realized that much of the length of the filter strip would only very rarely have occasion to act as a filter due to the very unlikely occurrence of sheet runoff flow. The cost to the farmer for such a practice might well be judged as excessive due simply to the ineffective character of some major portion of the filter strip.

This apparent flaw in one of the more popular recommended Best Management Practices is thought to be directly attributable to the classification of this type of surface water pollution. Agricultural runoff is classified as "nonpoint source" water pollution by the U.S. Environmental Protection Agency. This may lead those conducting regional plans for water quality enhancement to consider such sources as individually unidentifiable, or at least significantly less identifiable than major point sources such as the outfalls from municipal sewage works. Such a consideration has the effect of suggesting water quality enhancement measures of an all-encompassing nature. The classification tends to suggest that a buffer strip be required at all locations along a stream. Since nonpoint source discharges are thought to be individually unidentifiable, the filter or buffer strip is referenced and oriented with the stream.

Such an approach might be quite valid if runoff flows from agricultural land areas were truly nonpoint sources of water pollution. In all likelihood, however, agricultural runoff flows can be more correctly considered as intermittent point sources in the great majority of instances. While such flows do not generally emanate from pipe orifices as do the usual type of point sources, they do generally discharge at a location determined by the topographic features of the particular land area.

This point begins to illustrate the interrelated problems of water pollution source classification and the scale of the observer. To an environmental planner working on a regional scale, agricultural runoff may appear to be best defined as a nonpoint source. When one's scale is reduced to a particular rural stream and the cropland within its watershed, however, agricultural runoff flows are more correctly considered as intermittent point sources of surface water pollution. They are intermittent due to their nature, being quite dependent upon climate. They can also be considered to be point sources, since the surface runoff from a given land area will generally enter its drainage-way at a defined location.

These concepts suggest a possible solution to the previously discussed problems related to the streamside grassed filter strip idea. If the streamside filter strip could be transformed into specific runoff filter areas, less land would probably be removed from conventional crop production. If these filter areas could be located with a runoff flow orientation, rather than a streambank orientation, the water quality impact of a particular filter area would be at least as favorable as that of a filter strip protecting a stream from the runoff from the same land area.

Thus was created a somewhat new Best Management Practice, the vegetated buffer area. This practice was selected to be the topic of our field investigation.

The vegetated buffer area can best be described as the combination of a grassed filter, a vegetated waterway, and a sedimentation basin. It borrows its character and its design from these three other constructs in relatively equal amounts. It is a logical modification of the streamside grassed filter strip concept. The expected advantages of the vegetated buffer area, as compared to the grassed filter strip, include less dedicated land area and more effective utilization of that land, both in terms of runoff quality enhancement and capital cost. Greater costs, however, may be realized in design and in the administration of a public program to implement the practice. A program of grassed streamside filter strip installation can probably accomplish the majority of the design and monitoring work by aerial photography. Alternatively, a vegetated buffer area installation program would require topographic surveys, site-specific designs, and a greater technical expertise on the part of the decision makers.

The purpose of this dissertation is not to defend the design of the vegetated buffer area or to prove the superiority of the vegetated buffer area to the streamside grassed filter strip. The purpose is simply to explore the water quality impact of an example Best Management Practice, the vegetated buffer area.

1.2. Literature Review

In a recent report jointly published by the U.S. Department of Agriculture and the U.S. Environmental Protection Agency (Stewart, 1976), the "vegetated filter strip" is mentioned as a topic in need of additional research. The same can also be said for many of the other Best Management Practices, as the water quality impacts of agricultural land uses and the control of agricultural nonpoint source water pollution are relatively recent concerns.

The agricultural water pollutant most extensively studied is sediment. This is understandable in that soil erosion is probably the single greatest contributor of pollutants to our surface waters. One source (Wadleigh, 1968) estimates the annual sediment loss of this country at about 3600 teragrams (four billion tons). Erosion also represents a problem which is often visible to the agricultural producer. Investigations dealing with the quantification and prediction of erosion rates and amounts abound in the early soil and water literature, and continue to this day. Measures and methods to reduce or control erosion on agricultural lands have also been researched for some time.

Growing concern over the fate of pollutants in the environment during the past decade appears to have rekindled both the interest and the research effort in the erosion control area, but has also expanded that area. No longer are researchers concerned only with sediment, though it is of major importance. They have also become concerned with other classes of pollutants transported by water. The topic of erosion control seems to have evolved into the topic of runoff water quality.

The fact that agricultural cropland runoff can contribute pollutants to surface waters is quite well established. Ellis et al. (1978) found sediment losses of 26,600 Kg/ha, total nitrogen losses of 66.5 Kg/ha, and total phosphorus losses of 35.9 Kg/ha during a 27-month period for two small cropland watersheds near East Lansing, Michigan. Shelton and Lessman (1978) measured and reported concentrations of selected water quality constituents in runoff from four small agricultural watersheds in Tennessee. During the three-year study period, mean concentrations of nitrate-nitrogen, phosphate (as P), chlorides (as Cl), and sediment were 0.65, 0.61, 5.12, and 850 mg/L, respectively.

Data from another agricultural runoff and water quality study were presented by Ayars et al. (1979). Limited sampling and testing programs were conducted, but concentrations of several pollutants from samples of corn cropland runoff were reported. Means of the reported concentrations for ammonia-nitrogen, nitrate-nitrogen, and filterable residue were 38.7 mg/L, 21.3 mg/L, and 225.2 mg/L, respectively. A similar study on a heavily grazed grassland watershed in Arizona (Schreiber and Renard, 1978) found mean runoff concentrations of 0.30 mg/L for nitrate-nitrogen and 0.22 mg/L for total phosphate (as P) during one year of sampling and analysis.

Concern is not limited to sediment and plant nutrients, but covers nearly all classes of water pollutants. Studies involving farm contributions of oxygen demand from animal manures (Janzen et al., 1974), pesticides in cropland runoff (Baker et al., 1975), and the microbiological quality of agricultural runoff waters (Smith and Douglas, 1973) have been reported.

Much variation exists in the concentrations and loadings of the pollutants measured in agricultural runoff waters. A great many factors, such as soil type, topography, fertility, precipitation, and type of crop certainly influence this variation. A recent agricultural water quality investigation and field demonstration, known as the Black Creek Project (Lake and Morrison, 1977) aided in providing the scientific foundation necessary for future work dealing with the variability of runoff water pollutants and their control.

Utilizing data gathered during the Black Creek Project, several of the investigators (Monke et al., 1979) were able to reach some basic conclusions. It was found that the amounts of runoff, sediment, and nutrients discharged from the Black Creek watershed are greatly affected by precipitation. Further, it was discovered that reductions in rainfall result in even greater percentage reductions in runoff. In turn, an even greater percentage reduction in nutrient and sediment yields results. Land slope, for years of above average rainfall, was established as the dominant factor affecting sediment yield. During years with below average rainfall, however, the effect of land use was shown to become relatively more important. It was also concluded that the transport of sediment and nutrients by runoff into Black Creek is strongly associated with major runoff events which usually occur only a few times during a year.

The Black Creek Project data also indicate that a high percentage of the total phosphorus lost through runoff is sediment-bound. About 90 percent of the total phosphorus lost was associated with soil particles. About 50 percent of the total nitrogen lost was sediment-bound. The investigators found that the percentages of sediment-bound nitrogen and phosphorus are disproportionally lower (and the soluble percentages higher) for runoff events caused by snowmelt, rather than by rainfall. This appeared to be particularly the case with phosphorus. Also as had been established by several previous studies (Schumann and Burwell, 1974), losses of some soluble nutrients measured in the watershed's runoff were at least partially due to the input of those nutrients by precipitation. The sediment lost through erosion in the Black Creek watershed, however, had associated with it a high percentage of the nitrogen and phosphorus lost. Chemical analysis of sediments from Black Creek indicated these soil particles to be nutrient enriched, as they contained about three times the total phosphorus and nitrogen as was found attached to uneroded soils in the vicinity.

The results of an investigation of runoff water quality from three different agricultural land uses in South Dakota was reported by Harms et al. (1974). Watersheds of cultivated cropland (oats and corn rotation, alfalfa and brome mixture for hay, and continuous pasture) were compared over a two year period for runoff contributions of total residue, suspended solids, total phosphorus, nitrate-nitrogen, total Kjeldahl nitrogen, and chemical oxygen demand. It was noted that rainfall runoff contributed the majority of the residue lost, but that snowmelt runoff accounted for about 66 percent of the total Kjeldahl nitrogen, 62 percent of the nitrate-nitrogen, and 45 percent of the phosphorus lost. Thus, large portions of the nutrients lost were soluble. It was found that all of the nitrate-nitrogen, about 70 percent of the total Kjeldahl nitrogen, and about 28 percent of the phosphorus losses were independent of any sediment. The cultivated land contributed much greater loads of total residue, suspended solids, and chemical oxygen demand than either the pasture or hay watersheds. Comparable contributions of nitrogen and phosphorus were seen for the cultivated land and pasture, while the hay watershed's yield for both nutrients was somewhat less.

One conclusion of this South Dakota study is quite critical to the Best Management Practice concept. As is evidenced by the soluble nutrient and snowmelt nutrient contribution data, the usual and time-proven soil conservation practices successful in erosion control will probably not enjoy the same success, in terms of percentage reduction, in nutrient control. Limiting soil transport from a field will only partially limit nutrient transport.

This point is illustrated by a runoff study conducted in Iowa (Burwell et al., 1974) which compared the runoff quality of a traditional contour-farmed watershed to that of a well-planned conservation watershed. Both watersheds were of somewhat similar soil types and fertility levels, and similar row crop cultural practices were employed. A major difference in the two drainage areas was the planned level terraces which were constructed in the conservation watershed. The level terraces reduced the yield of both sediment and plant nutrients, thereby proving their viability as a conservation practice. Percentage differences in yields between the two cropland areas were 98, 83, and 54, respectively, for sediment, nitrogen, and phosphorus. It should be emphasized that these yields are for gross losses from the watersheds and that the watersheds were not identical. However, the superiority of the level terrace system when compared with traditional practice is evident. Also evident is the greater reduction achieved in sediment yield than nutrient yield, though both are quite substantial.

Two companion articles (Schuman et al., 1973) from a runoff study conducted on Missouri Valley loess soils report results from watersheds under several conservation practices and two fertility levels. Substantial reductions in sediment, nitrogen, and phosphorus were again reported for a level terrace system as compared to a contour-farmed area. As with the previous study, the reductions in the nutrients lost was primarily due to reductions in soil erosion. The authors conclude that an important first step in reducing nutrient losses is to reduce sediment losses, though lower percentage reductions in nitrogen and phosphorus accompany that of sediment.

Many other soil conservation practices have been investigated, though few exhibit a greater contrast in runoff quality than the level terrace systems of the studies mentioned. Examples include establishing a winter cover crop (Klausner et al., 1974), utilizing conservation tillage systems (Barisas et al., 1975, and Laflen et al., 1977), adopting a no-till planting scheme (Langdale et al., 1979), stubble mulching (Garland and Marston, 1979) and other more traditional techniques such as contour farming, strip cropping, and crop rotation. These practices are primarily directed toward keeping soil particles in place. This is not necessarily the primary purpose of the various agricultural Best Management Practices, as these practices are suggested for the reduction of pollutant loads placed upon surface waters. The difference may seem superficial, but it is real. This difference is also quite important in that the Best Management Practice concept appears to be partly the cause, and partly the result, of the recently expanding research effort in the area of agricultural runoff.

The vegetated buffer area, a modification of the grassed filter strip, fits nicely with this Best Management Practice concept. Its intended purpose is to reduce the pollutant load placed upon surface waters by cropland runoff. It is not a cultural practice, as would be strip cropping or stubble mulching, but can be more correctly classed as a structural practice. As such, it is intended to remove pollutants transported from the land by runoff flows rather than to prevent those pollutants from being transported.

Several studies involving filter strips and buffer strips have been conducted. A previous experiment here at Michigan State University (Thompson et al., 1978 and 1979) found various types of buffer areas, including a grassed filter, to be of benefit in improving the quality of winter and spring runoff from several small manured cropland plots. Substantial reductions in chemical oxygen demand, phosphorus, and nitrogen levels were found for a 12-meter grassed filter. Average reductions in the above constituents reported for a 36-meter grassed filter were in the range of 67 to 77 percent.

Doyle et al. (1975) reported on the effectiveness of a forest buffer strip in improving the quality of runoff from alfalfa plots receiving dairy manure at relatively high rates of application. A 30.5-meter forest area was shown to provide reductions in nitrogen, phosphorus, and potassium of 90 percent or more. The major reduction appeared to occur within the first 3.8 meters of the forested strip, though loading rates remained higher than that observed in control plots receiving no manure. Significant reductions in counts of fecal coliform and fecal streptococci organisms were also reported. A later report (Doyle et al., 1977) presented similar results for a similar plot trial using a grass buffer strip. As with the forest buffer, it was reported that a 4-meter grass buffer strip was effective in reducing surface runoff levels of nitrogen, phosphorus, potassium, and fecal bacteria.

Related research has been conducted with vegetative filters for use as feedlot runoff control systems. A study reported by Dickey et al. (1977) indicated that a vegetative filter in Illinois was quite effective in treating runoff from a dairy facility. The filter area was preceded by a runoff settling basin. Effluent from this basin was pumped to the vegetive filter and was distributed at the head of the filter area with gated pipe. A slight slope, about 0.5 percent, was maintained for the 91-meter length of the filter area in hope of achieving sheet flow. The filter was found to reduce the concentration of ammonia-nitrogen by 86.2 percent, total Kjeldahl nitrogen by 80.1 percent, total solids by 73.1 percent, chemical oxygen demand by 85.4 percent, and phosphorus by 78.2 percent. Pollutant concentrations in the filter effluent were still somewhat higher than would generally be allowed for point discharge into surface waters. Only slight reductions in counts of fecal bacteria were measured.

Since runoff volume was reduced, high percentage reductions in sediment, oxygen demand, and nutrient loads were also realized. On a mass-balance basis, an average of about 96 percent removal was reported for the constituents monitored. This system, along with several others, continued to perform in an acceptable manner and design criteria and performance standards were later presented (Vanderholm and Dickey, 1978).

Another research topic somewhat related to the vegetated buffer area is overland flow waste treatment. Experiments utilizing both human and livestock wastes have been conducted with several types of overland flow treatment systems. The principles of pollutant reduction are similar with the vegetated buffer area and overland flow treatment, though there are substantial differences in influent quality and pollutant loading. Overland flow treatment systems are generally loaded frequently and regularly with the influent wastewater. The influent of the vegetated buffer is cropland runoff, and the loading is infrequent and quite irregular. In addition, the overland flow system is treating wastewater of a different origin and character than that of the buffer area.

Overcash et al. (1976) reported on an overland flow system utilizing graded terraces for the treatment of poultry wastes. Reductions of 60 to 70 percent in nitrogen load were reported with a flow distance of 15 meters. Doubling the flow distance increased nitrogen load reduction to about 85 percent.

Myers and Butler (1974) published results of field trials in which the effectiveness of an overland flow system for nutrient removal from a secondarily treated effluent was evaluated. Only modest reductions of nitrate and phosphate concentrations were recorded, in comparison with studies mentioned previously. The investigators did conclude that increased flow distance, reduced effluent application rate, and reduced application frequency tended to improve nitrate and phosphate removal.

Modest reductions in nitrogen and phosphorus loads are also reported in a similar study (Wilson and Lehman, 1966) utilizing overland flow for final treatment of oxidation pond effluent. No reduction in phosphate was found. Total nitrogen removal averaged about nine percent and nitrate-nitrogen levels actually increased 25 percent. Yet another similar study reported by Thomas (1973) demonstrated quite effective treatment of comminuted and settled domestic wastewater in overland flow plots. Suspended solids and biochemical oxygen demand removals were 90 percent or better, with average removals of phosphorus and nitrogen of 50 percent and 75 percent, respectively.

It is apparent that some of these overland flow, grassed filter, and buffer strip schemes have been successful, while others have provided little water quality benefit. Precise causes of success or failure are not fully understood in all cases, as knowledge in this area is far from complete. The physical, biological and chemical processes at work in these soil, plant, water, and pollutant systems are understood to varying degrees. These processes include sedimentation, filtration, infiltration, biological degradation, volatilization, chemical fixation or adsorption, and nitrogen transformation.

In the case of the vegetated buffer area, sedimentation is probably the most important process. The widening of runoff channels into the broad buffer should facilitate a transition toward sheet flow, thus reducing velocity. Velocity will be further reduced, and depth of flow increased, by the increase in flow resistance resulting from contact with the dense grass media. The decreased velocity and increased depth of flow promotes sedimentation, as less energy is available for maintaining the suspension. Filtration by the grass media is also promoted, as larger particles may become lodged more readily at low velocities. Some very timely theoretical work on sedimentation in a grassed media is represented by a series of publications from Kentucky (Barfield et al., 1975, Tollner et al., 1975, and Kau et al., 1977). This work may soon make it possible to quite accurately predict the sedimentation performance of grassed filters.

Infiltration surely also occurs in the vegetated buffer area, though to a more and more limited extent as a runoff event progresses. The anticipated volumetric flows are quite large in relation to the area of the soil surface of the buffer and easily exceed any reasonable estimate of hydraulic conductivity or intake rate.

Chemical fixation can also be expected in the buffer. This process, often called adsorption, is the retention of ions by soil and vegetation. The mechanisms involved are rather poorly understood, but some researchers (Murrmann and Koutz, 1972) are of the opinion that adsorption is the most important process in removing phosphorus from wastewater. Besides phosphate, ammonia may also be adsorbed. Unlike phosphate, however, ammonia can also be lost by volatilization. A recent study from Louisiana (Khalid et al., 1978) emphasized the importance of this volatilization process.

Biological degradation, as is experienced in sewage treatment plants, is probably of very minor importance in a vegetated buffer area. Organic loads are anticipated to be relatively low, and the retention times of the runoff are probably insufficient. Some activity may occur, but sedimentation and filtration are probably more viable processes for oxygen demand reduction in a buffer area of this type.

Two common nitrogen transformation processes are known as nitrification and denitrification. Nitrification is the oxidation of ammonia and organic nitrogen to nitrites and nitrates. Denitrification is an anaerobic process by which certain bacteria are able to continue normal metabolism in the absence of free oxygen. In this process, the nitrate ion replaces the role of oxygen and is reduced as carbon compounds are oxidized. From a water quality perspective, denitrification is much more desireable than nitrification in that nitrogen is removed from the runoff water.

Conditions which favor denitrification, as reported by Myers and Butler (1974), include a microbial population of denitrifiers, an anaerobic environment, a near neutral pH, and an abundant carbon source. Nitrification is promoted by aerobic conditions and light organic loadings. Thomas (1973) reports, when speaking of overland flow waste treatment, that conditions promoting denitrification are best achieved by adjusting nutrient and hydraulic loadings to maintain the needed low oxygen levels. This is impossible in the vegetated buffer area, as hydraulic loading is predominantly controlled by environmental factors and nutrient loading is greatly influenced by hydraulic loading. It can be concluded, though, that nitrification and denitrification may both occur in the vegetated buffer area, depending on the specific conditions encountered.

Runoff from agricultural lands can contribute to surface water quality degradation. Plot investigations of vegetated strips have indicated that some runoff pollutants can be effectively removed. Related studies, involving the treatment of livestock and human wastes, report widely varying degrees of success. Sedimentation, filtration, and chemical fixation are probably the major processes involved in renovating cropland runoff with a vegetated buffer area. Biological activity, in terms of degradation of organic material, nitrification, and denitrification, may also occur, as may ammonia volatilization.

1.3. Experimental Design

The field experiment was planned as a side-by-side comparison of the runoff from two similar cropland areas, one of which would contain a vegetated buffer area. The other field would be unaltered, to serve as a control. It was desired that the two fields be immediately adjacent to a surface watercourse, and that the runoff from the two fields directly enter the surface watercourse.

Monitoring stations were planned for each of the two runoff flows and for the watercourse into which they would drain. Flows would be monitored continuously and water samplers would be operated during runoff events to provide time-series samples for laboratory analysis. Rainfall was to be monitored and snow accumulation was to be measured.

Both cropland areas were to be fertilized with livestock manure. Runoff from sites of land application of agricultural wastes is of current public concern, and it was felt that runoff from such an area would provide a good test for the buffer area. Another reason for selecting manure-fertilized cropland for this study is the continuing interest expressed by farmers in waste management. Michigan livestock farmers are increasingly selecting manure storage and application systems which maximize their utility with respect to nutrient conservation for use of field crops. This trend should continue due to increasing commercial fertilizer prices and expanding environmental awareness.

Four separate sampling and analysis programs were planned in support of the field study. Soil sampling and analysis plans for the two cropland areas included six samples per field gathered once per year. Samples were to be tested for phosphorus, potassium, calcium, magnesium, nitrate, percent organic matter, and pH. Based on these tests, recommendations for nitrogen, phosphorus, potassium and lime would be formulated in relation to the desired crop yield.

Manure sampling was planned for each occurrence of land application of the wastes. Testing included determinations for total Kjeldahl nitrogen, ammonia-nitrogen, total phosphate, total solids, and conductivity. It was anticipated that manure would be applied three times per year to the cropland areas.

Two distinct water sampling and analysis programs were developed. The first plan dealt with runoff events and provided for the analysis of water samples collected by the three automatic samplers. Experimental parameters included alkalinity, conductivity, 5-day biochemical oxygen demand, chemical oxygen demand, total Kjeldahl nitrogen, ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, total phosphate, total solids, fecal coliform bacteria, and pH. The second plan required sampling and analysis of the surface watercourse. Weekly stream grab samples were to be gathered and subjected to the same twelve determinations as the runoff event samples. In addition to the above, field measurements of water temperature and dissolved oxygen concentration were desired.

1.4. Objectives

The objectives of this study can be quite simply stated. The experiment is designed to provide answers to the following questions:

1. What are the flow and water quality characteristics of runoff from the control (unaltered) field?
2. What are the flow and water quality characteristics of runoff from the buffered field?
3. Is there a significant difference in the pollutant concentration or pollutant load of the two runoff flows?
4. What are the flow and water quality characteristics of the stream?
5. Does runoff from the site have an adverse environmental impact on the stream?
6. What costs and water quality benefits can be associated with the vegetated buffer area?

In order to adequately address these six questions, it is felt that a minimum of three years of data collection is needed. This dissertation is written to formalize the thought processes behind the planning of this project, to provide a description of the methods, procedures, and equipment selected, and to begin the complex task of attaining the full objectives of the study using data collected during the first year of the project. In addition, this document establishes both the scientific and statistical methods of analysis for all data collected, or to be collected in the future, as related to the objectives of the study. The work represented by this dissertation includes all conceptualization, planning, procurement, design, installation, construction, data collection, data analysis, reporting, and management activity required during the last 27 months to bring this project into existence and to lead it into its second year of operation.

Objectives 1, 2, and 4 will be addressed by presenting the actual data gathered for each of the runoff events occurring during the first year. Objective 3 will be addressed by three separate statistical analyses of the data. The first analysis consists of a t-statistic test using pollutant concentration values of the runoff from the two fields. The second analysis consists of a Wilcoxon test for paired observations using median pollutant concentrations from each runoff occurrence. The third analysis consists of a Wilcoxon test for paired observations using paired pollutant load values, corrected for watershed size, from the runoff events recorded.

Simple addition of several "worst-case" runoff pollutant concentrations and flows to those of the stream will partially address objective 5. The resulting predicted stream conditions will then be compared to measured stream conditions to better assess the magnitude of the water quality impact of the cropland runoff flows. Similarly, runoff pollutant loadings supplied to the stream by the two cropland areas will be calculated in order to complete this objective.

Objective 6 will entail a discussion of any and all water quality benefits apparent from the work on the first five objectives and the initial and recurring costs of the vegetated buffer area.

The possibility of satisfactorily addressing the six primary objectives of this study with only one years' data is quite limited. As with most research on natural systems, several years of data collection will be required to bring this study to full completion.

Chapter 2

PROCEDURES

2.1. Site Selection

Requirements for a suitable site for the field experiment included two similar cropland areas draining into an adjacent stream with a large confinement livestock facility located in close proximity. The desired soil textural class was loam, the desired crop was corn, and the desired livestock facility was a dairy with three to six months manure storage.

The search was confined to an area known as the Deer-Sloan Watershed. This is an area located east of the Michigan State University campus and drained by Deer Creek and Sloan Creek. The watershed contains an extensive network of recording rain gauges and two stream flow monitoring stations. The precipitation and flow measurements have been maintained for some 25 years, and have been the data source for several previous research investigations.

After consultations with the County Extension Director, an Extension Farm Management Agent, and personnel from the local Soil Conservation District, several potential sites were identified. These sites were evaluated for suitability utilizing land-use maps and topographic quadrangles. Finally, each of the sites was visited.

One of the sites met the requirements perfectly, with the exception of the type of livestock installation. This particular site contained a confinement swine operation, but cropland areas appeared ideal for the purposes of this project. The owner of the property indicated that he would be willing to cooperate in the proposed study. A conceptual layout of the selected project site is presented as Figure 1.

The project area is located in Wheatfield Township of Ingham County, and is about 25 kilometers from the Michigan State University campus. The site is located immediately to the east of Zimmer Road, between Holt Road to the south and Noble Road to the north. The project site is located on lands owned by Mr. Herbert Schultz.

Soil types present include Capac loam, Aubeenaubbee-Capac sandy loam, and Gilford sandy loam (Ingham Soil Conservation District, 1980). The first type is quite predominant, with the latter two types occurring only at the eastern edge of the site. Average gross slope over the entire site is about 1.8 percent, though localized variation exists.

2.2. Site Preparation

The first field task was to conduct a detailed topographic survey of the project area. This was done in March and April of 1978. Spring runoff flows were observed during the survey, and a limited number of water samples were gathered. Visual inspection and the topographic survey revealed that the great majority of runoff from the project area flowed to the head of a small ditch adjacent to the north field, and flowed down that ditch some 100 meters to its confluence with the stream. Laboratory analysis of the water samples indicated runoff pollutant concentrations in the general range of the values anticipated.

The topography of the site was such that surface runoff flows from the north and south fields were kept separate, except at the extreme lower end of the site. At this point, runoff from the south field flowed into the north field in a path roughly parallel to the flow of the stream, and entered the previously mentioned ditch adjacent to the north field. Thus, the only requirement for segregation of the two surface flows was a small berm at the lower end of the project area.

The vegetated buffer area was envisioned as somewhat bowl-shaped, so it appeared reasonable to locate it in the south field and have one of the side slopes serve as the needed berm. The south field would then serve as the experimental field, since all of the surface runoff from that field would flow to the planned buffer area. The north field would serve as the control field, and would remain unaltered.

Design parameters for vegetated buffer areas are generally unavailable. A vegetated buffer area, however, does share some characteristics with sedimentation basins, grass filter strips, and vegetated waterways. The design for the buffer area was developed from standard practices generally employed during the design of these related conservation practices.

The size of the vegetated buffer area is about 0.2 hectare and was determined by the available area at the selected site. This area can best be described as a poorly drained depression located at the northeast corner of the south field. It was through this area that runoff from the south field flowed to the north field, though with insufficient volumetric rate to keep the area from ponding. The site was overgrown with numerous types of undesireable vegetation, contained sizeable piles of both stones and waste grain, and was generally unproductive. Topography was such that the area aided flooding of the lower elevations of both fields and was unsuitable for agricultural production. Figure 2 is a topographic map of the area prior to construction.

The desired length of flow path from the leading edge of the vegetated buffer to the outlet was a minimum of 30 meters. This length of flow had performed satisfactorily in a previous study (Thompson et al., 1978 and 1979) and lent itself well to the field site. The actual length of flow path employed was about 40 meters.

The cover crop was selected in conformance with standard recommendations by the Michigan State University Cooperative Extension Service for vegetated waterways (Hill, 1974). A mixture of Kentucky bluegrass, creeping red fescue, and domestic rye was recommended at a 4:4:1 ratio. Such a seeding mixture allows for fairly rapid early cover, due to the rye, with the other varieties later dominating and establishing a permanent stand. When mowed several times a year to a height of about 15 centimeters, this cover can be considered of "retardance class C" and capable of withstanding flow velocities in the range of 1 to 2 meters per second without adversity (Schwab et al., 1966).

The slope along the path of water flow within the buffer area

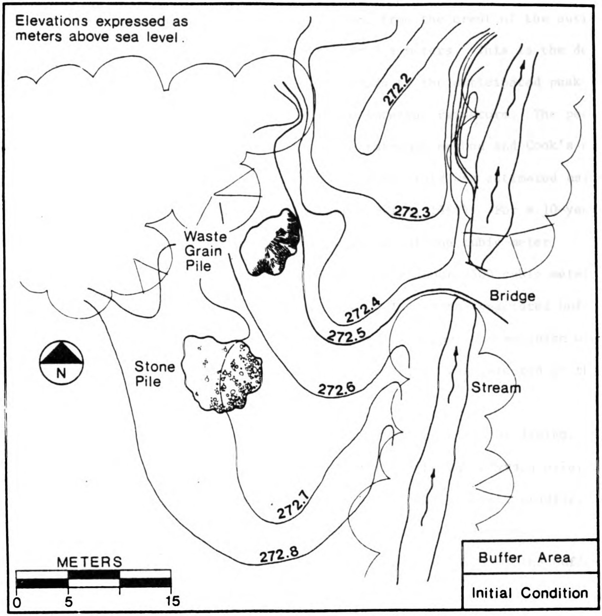

Figure 2. Buffer Area Site, Initial Condition

was selected to insure velocities below the permissible velocity for this type of cover. Slopes average about 3 percent in the direction of flow. Much steeper slopes were used for the berm, since it functions as a dam rather than a water conveyance.

The overall depth of the buffer area, from the crest of the outlet weir to the crown of the berm, was set at 0.8 meters. This is the depth of flow at the outlet weir which corresponds to the anticipated peak flow resulting from a 10 year recurrence interval rainstorm. The peak runoff rate was estimated using both the rational method and Cook's method, as presented by Schwab et al. (1966). Runoff yield was estimated using the SCS method (U. S. Soil Conservation Service, 1964). For a 10-year storm, the calculated peak runoff flow was about one cubic meter per second and the calculated runoff yield was about 3500 cubic meters.

Using the parameters mentioned, the design of the vegetated buffer area was finalized. Figure 3 shows the design topography and plan of the buffer area site. The elevation of the buffer was selected so there would be no net spoil or fill.

The site was staked and graded in conformance with the design, with only slight modification. The pile of stones, the waste grain pile, and several trees were removed from the site. All removal, grading, and smoothing work was done with a Caterpillar D-3 bulldozer.

Upon completion of earthmoving activities, the soil of the buffer area was fertilized with liquid swine manure. The manure was applied at the rate of about 35,000 liters per hectare with a tractor and vacuum wagon. The manure was then incorporated with one pass of a cultivator/ mulcher, and seeded by hand. Seeding was in conformance with standard practice, utilizing the previously mentioned three grass blend at the

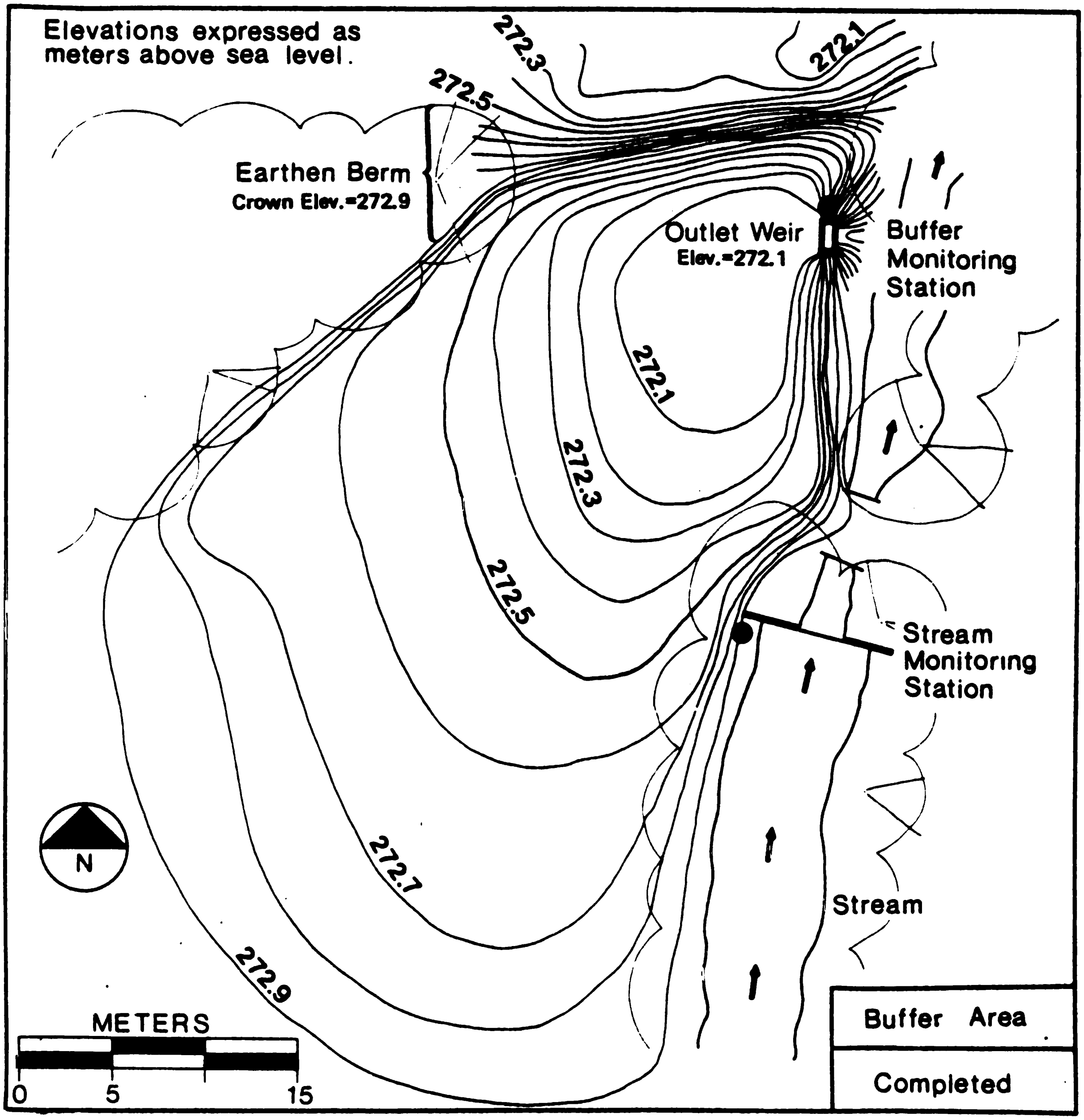

Figure 3. Buffer Area Site, Completed

rate of 50 kilograms per hectare. To complete the construction of the buffer area, and mix the seed with the soil, the surface was lightly smoothed by dragging the area with a roll of woven wire fencing towed behind a light all-terrain vehicle.

The topographic survey, along with close visual inspection of the cropland areas during runoff, revealed that not all of the land drained to either the buffer area or the ditch. The drainage area in the north or control field contributing to the ditch is about 10.6 hectares. The drainage area contributing to the vegetated buffer area is about 9.3 hectares. These drainage areas represent about 75 percent of the total cropland area of the project site.

2.3. Field Instrumentation and Monitoring

With the layout and objectives of this project in mind, the primary information needs are seen to be data on flow and water quality for the two runoff flows and for the stream. Ideally, this information would be in the nature of a continuous record. A complementary activity needed is precipitation monitoring. This measurement is not immediately crucial to the objectives of the project, but is needed to link a runoff event with its cause. Thus, the three main required measurements are flow, water quality, and precipitation.

Of these three measurements, the one involving the most judgement is water quality; not only in how to measure it, but in what to measure. Parameter selection is probably best begun by looking again at the objectives and by considering the target groups of the research findings. Regulatory agencies generally define water quality in terms of stream standards. These standards usually take the form of a minimum dissolved oxygen concentration, an allowable pH range, a maximum fecal coliform bacteria count, a maximum level of one of the various residue measurements, and limits for many of the toxic and exotic wastes.

For budgetary reasons, the decision was made to eliminate toxics and exotics from consideration. There is no reason to suspect unusually high concentrations of any particular compound of this nature, and a series of survey-type analyses would be prohibitively costly. The only possible exceptions to this are pesticides which may be present in the runoff water. Since it is known which pesticides are applied in the fields, it would be a relatively simple, though expensive, matter to conduct analyses for them in the runoff. Investigation indicated costs to be prohibitively high, so no pesticide monitoring was planned. Such an activity may be added to the project in future years if funds become available.

It was decided that dissolved oxygen, pH, and fecal coliform measurements would be made, since this information ties the data to stream standards. In support of these measurements, it appeared advisable to include temperature, since the maximum dissolved oxygen concentration of water varies with temperature. It also appeared advisable to include some measure of oxygen demand. This is an indication of the materials in the water which will tend to lower the dissolved oxygen concentration, and is generally used in wastewater studies as an indication of the strength of the waste. Biologists and environmental scientists generally express demand as 5-day biochemical oxygen demand, while engineers and physical scientists more often deal with chemical oxygen demand. The former parameter is more indicative of what will occur in the stream and the latter is a somewhat more repeatable determination. Since a wide target group is desired for the research findings, it was decided that both determinations would be performed.

The major water pollution problems generally associated with agriculture are plant nutrients and sediment. This is a major focus of the research effort. For this reason, it appeared essential to monitor nitrogen, phosphorus, and residue or solids. It was decided to monitor four forms of nitrogen (nitrate, nitrite, ammonia, and total Kjeldahl), total phosphate, and total solids. Two other parameters, conductivity and alkalinity, were added since they provide some additional insight and are relatively simple determinations.

From the character of the parameters to be estimated, it is apparent that some must be measured in the field and some must be measured in the laboratory. Measurements which can be made in the field by accepted methods are flow, precipitation, dissolved oxygen, pH, temperature, and conductivity. All of the parameters, except flow and precipitation, can be measured in the laboratory by accepted methods. Thus, two measurements must be made in the field, ten measurements must be made in the laboratory, and four can be made at either location. A choice is possible with the latter four parameters due to the accepted and accurate portable probes with which they can be estimated. Since many of the important determinations must be made in the laboratory, the need of sampling, storing, and transporting water is seen as an extremely critical portion of the study.

For reason of budgetary limitation, it was determined that the only truly continuous measurements which would be possible were flow and precipitation. It would be possible to continuously record dissolved oxygen, pH, temperature and conductivity in the field, but instrumentation costs for such are prohibitive, given the available funding. Truly continuous measurements of the other parameters are virtually impossible. The best which can be generally attained is a time series or a composite over time.

As the sampling program was being designed, it was decided that the ambient water quality of the stream would be estimated by analysis of weekly grab samples. It was further decided that the water quality of both runoff flows and the stream would be estimated by analyses of time series samples during runoff events. Since dissolved oxygen and temperature measurements must be made with a fresh sample, as rapid changes occur with storage, it was decided that these measurements would be made in the field. Since pH and conductivity are relatively unaffected by short storage periods, the decision was made to conduct these tests in the laboratory. Precipitation, flow, dissolved oxygen concentration, and temperature must be estimated using field instrumentation. In addition, water samples must be collected on a time series basis for laboratory analysis. It is imperative that precipitation and flow be continuously monitored. While it would be desirable to have continuous dissolved oxygen and temperature data, it is not particularly critical to the success of the project.

Requirements for precipitation measurement are simply that a dependable and continuously recording rain gauge be located within the project area. The amount and intensity of snowfall are not critical, and need not be carefully monitored. It is important, however, to know the equivalent depth of water contained in the winter snow pack. This is readily accomplished by taking weekly snow cores, melting them slowly, and measuring the water depth. The only needed equipment, then, is a recording rain gauge for rainfall monitoring and a lightweight steel pipe for sampling snow cores. A Belfort model 5-780 rain gauge was obtained and installed. This precipitation monitor is a revolving drum type instrument, and is quite satisfactory for this type of application.

Several options were available in the area of a known section coupled with a depth-of-flow recorder for monitoring the two runoff flows. The three major options considered were an orifice, a flume, and a weir. Problems are associated with each of the three methods. The orifice requires two depth recorders, since the desired information is the difference in head across the orifice. There is also the problem of storage behind the orifice, as the study required "natural" flow without ponding. The flume solves both of these problems, in that only one instrument is needed and no man-made ponding occurs with proper design. But with the flume come two new problems. First, a sufficient flow depth is needed from which to pump a sample. This is not always available under low flow conditions in a flume, particularly one of sufficient size to handle peak flows. The other problem is the cost. A flume is an empirical device, so it is necessary to either very carefully construct one to established dimensions or buy an off-the-shelf model of steel or fiberglass.

The design and construction of a weir is easier and cheaper than that of a flume, in that it is a rational device. The volumetric flow rate can be computed simply by knowing the lip configuration and the depth of flow. But as with the orifice scheme, water is impounded behind it. Some amount of ponding is needed for sampling purposes, and yet this should be held to a minimum since the "natural" flow condition is desired. A solution suggested by an old text book was the weir box. The boxes were constructed of 1.91-centimeter (0.75-inch) treated exterior plywood, with 5.1-centimeter x 10.2-centimeter (2-inch x 4-inch) construction grade lumber used as stiffeners and as tension bands, and with aluminum sheet stock used as the weir lip. A check of discharge formulas for the various different lip configurations against the needed flow range indicated the 90° v-notch to be the best choice.

The weir boxes, nominally, are 1.83 meters (6 feet) wide, 1.83 meters (6 feet) deep, and 1.22 meters (4 feet) broad. The v-notch weir lip is 0.91 meters (3 feet) deep and is located in the back wall of the box. The front wall of the box, which is 0.91 meters (3 feet) deep, serves as a 1.83-meter (6-foot) long inlet weir. Thus, runoff first fills the weir box to a depth of 0.91 meters (3 feet), and then exits through the aluminum v-notch weir as the runoff event progresses. This allows quite accurate flow monitoring under relatively "natural" flow conditions and with sufficient depth for sampling.

The weir boxes were constructed indoors and transported to the project site upon completion. The boxes were placed in two dug earthen pits. The installations were finished by attaching soil wings to minimize frost heaving and floatation, setting surface and subsurface flow retainers, and backfilling.

For continuous monitoring of flow over a weir, a continuously recording depth-of-flow meter is needed. Many makes and variations of instruments of this type are available, and many of them are satisfactory for this application. Several Leupold-Stevens type F flow meters were already owned by the Agricultural Engineering Department, however, so these instruments were utilized. The type F flow meter contains a clock-driven stylus and a float-driven drum chart to provide a continuous depth-of-flow record. Installation of the two meters was completed with the construction of a wooden enclosure fastened on top of each weir box, and the setting of a 15.2-centimeter (6-inch) PVC stilling well and a 1-meter staff gauge in each weir box.

Similar options to those discussed above are available for measuring stream flow. With similar requirements, and similar reasoning, it was decided to also utilize a weir and depth-of-flow meter for this task.

Selection of a weir type was less easily made. A great many factors, such as the anticipated range of flow, the physical size of the streambed, the character of the streambank, and available elevation, were considered. Preliminary decisions were made and design begun. The final design called for a 2.44-meter (8-foot) wide and 0.91-meter (3-foot) deep Cipolletti weir mounted in a bat-wing-shaped plywood dam 2.13 meters (7 feet) tall and 7.32 meters (24 feet) long. This dam was partially constructed indoors and transported to the project site. There, it was mounted between four wooden posts set in concrete in a trench excavated across the streambed from bank to bank. The dam was then secured by constructing a w-shaped brace system lagged to two additional posts set in concrete downstream from the weir. Stiffness was enhanced by driving 13 steel fence posts into the earth along the trench and bolting them into the dam structure. Finally, the trench was backfilled, rip-rap was set around the dam, and the aluminum weir lip was installed.

The dam is equipped with an orifice plate and capped pipe mounted at natural streambed elevation. This readily facilitates drainage of the weir pool, should it ever become necessary, and could also be used to modify the dam into an orifice-type section for low flow determinations. Installation was completed by adding an equipment enclosure, a stilling well, and a staff gauge. In conclusion, it should be mentioned that the building of the stream flow monitoring station was probably the most difficult individual construction activity of the project.

Time series water samples must be taken at the stream weir and at each of the two runoff weirs. Preliminary investigations indicated that a sample volume of about 400 mL was sufficient for performing all laboratory determinations. Thus, it was seen that two devices were needed which would operate automatically and repeatedly sample the runoff flows during runoff events. In addition, a third similar instrument was needed to sample the stream. The ISCO model 1680 automatic water sampler was selected. The model 1680 includes an intake line, a sample pump, a rotating distributor, a funnel plate, a sample compartment, and a programmable controller. It is quite flexible in its operating characteristics, due to the design of the controller, and was selected for this primary reason.

The only real shortcoming found with the sampler, for the needs of this study, was the time lag following activation of the unit. When the controller is programmed, for example, to sample every 30 minutes, the controller sets the minute counter to 30 as the unit is activated. Thus, the time interval selected for samples is also the amount of idle time between activation and collection of the first sample. Engineers at ISCO agreed to supply samplers with an "instant reset modification". This addition would allow the first sample to be taken at the instant of activation, and the timed interval program then initiated.

Since runoff flows are not particularly predictable and are anticipated on only a few days per year, it was necessary to activate the samplers with the sensing of flow. This explains the primary need for the instant reset modification. The sampler is on "stand-by" until flow is sensed and at that time the sampler is activated. This being the case, the initial runoff flows would not be sampled without the modification. Another reason for the modification, since the flow meters and samplers are not physically linked, is to establish the time of collection of the first samples and all succeeding samples. The time on the flow chart at which the "trigger depth" of the samplers is reached is the time the first sample was collected. This link is needed to relate pollutant concentrations to the hydrograph and to calculate total pollutant loads.

Sampler installation was accomplished by constructing and anchoring equipment enclosures adjacent to the two runoff weir boxes and the stream monitoring station. Screw eyes, in each of the three instances, were mounted at points above the maximum and below the minimum anticipated flow depths. Between these two eyes was tightly strung a 0.32-centimeter (0.125-inch) diameter nylon line, this line running through a plastic swimming pool float. The configuration is such that the float may freely rise and fall on the line with the flow of water. Sampler intakes were hung from, and immediately below, each of the three floats. Clear suction tubing was then run from the intakes, into the enclosures, and to the samplers to complete the installation.

A great deal of effort was directed toward selecting the correct instrumentation to provide the needed information at an appropriate cost. Due to the particular circumstances of this research project, however, it was necessary to spend much additional effort on the support of the individual instrument systems. This support was mainly needed in the areas of protecting, switching, and synchronizing equipment to insure proper operation under quite adverse conditions.

The needed task to be performed by the required signal and control system is the simultaneous activation of the samplers at the start of a runoff event. The ISCO sampler is designed to accept information from a flowmeter for composite sampling. The flow meter input is a 6-pin amphinol plug and jack. Two particular pins, when connected, hold the controller in a "stand-by" attitude. The pre-programmed sampling routine is begun only when this circuit is broken. Thus, any sampler can be controlled by this same switch by adding them to the circuit. If multiple remote switches are desired, they too can be added to the circuit. Finally, if the switches are activated by flow, then the system will simultaneously and automatically operate multiple samplers at the instant runoff is sensed in any one of several locations. Such a system was designed and installed at the project site.

Components for this system included two microswitches, one toggle switch, two PVC stilling wells, three weatherproof enclosures, two junction blocks, two fishing bobbers, twelve feet of fishing line, eight lead weights, three amphinol plugs, and about 300 meters of signal cable. A microswitch was mounted in each of the two weir boxes and was loaded with a bobber and weights. Lines from these two switches were brought into a central control box, as were lines from each of the samplers. When runoff occurs at either weir box, the bobber floats, the microswitch opens, and all three samplers operate. A schematic diagram of this system is presented at Figure 4.

Notification of the investigator is another task of the signal and control system. Essential components are an IMSAI minicomputer, a cassette deck, a telephone, and about 600 meters of signal cable. Simply stated, the minicomputer "reads" the microswitch and sampler circuit every few seconds. If an open circuit is detected, a telephone dialing program is initiated. The dialing program is a loop of four telephone numbers. The loop is repeated until one of the investigators answers and returns an audible signal. The minicomputer and appurtenances were not installed until the second year of the study.

Electrical power is required since the ability to sample water under all weather conditions, including freezing temperatures and severe storms, is crucial. The vulnerable spots for freezing are the three sampler intakes, the three intake lines, the three flow meter stilling wells, and the two microswitch stilling wells. Ice formation at any of these locations could easily result in a malfunction. The problem associated with a violent storm is the increased probability of a power outage. Power is needed to operate the samplers, and the importance of remaining operational during a storm is somewhat proportional to its severity. The flowmeters and rain recorder are not affected, since they are spring-drive instruments.

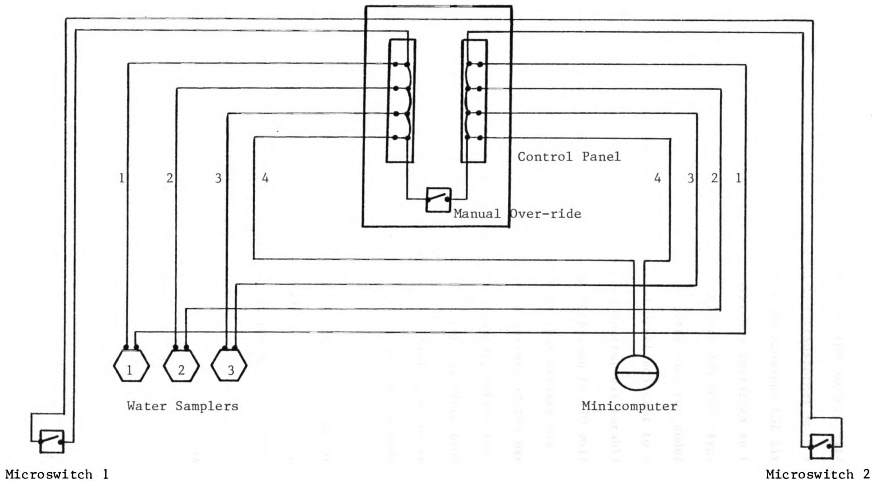

Figure 4. Signal/Control System Schematic

The only viable, though expensive, solution to the freeze protection problem was to provide electric service to the project site. A 60-amp service and meter box were placed on the transformer pole at the west end of the property. From there, three #4 aluminum USE lines were run underground some 100 meters to a breaker box installed in the project's storage shed. Two 110 volt circuits and one 220 volt circuit were established. Two #6 aluminum USE lines were then run underground from the shed some 600 meters to the control panel adjacent to the buffer area. At the control panel, a grounded neutral was established and an autotransformer installed. After the step-down to 110 volts, two separate circuits were established in another breaker box. One of these circuits is for lighting and convenience outlets at the panel. The other, protected by a ground-fault interrupter, serves the three monitoring stations. A duplex outlet is located at each station, providing power to "roof-and-gutter" type heat tapes. The storm problem was solved, again at no small cost, by utilizing individual nickle-cadmium batteries for sampler power.

Just as the ability to sample runoff under adverse conditions is required, so must the investigators have ready access to the site and the ability to transport samples and equipment under adverse conditions. This may not be a serious problem in most research work, but is quite crucial to the operation of this project. The samplers are located about 670 meters from the nearest all-weather roadway. During the periods of most interest, this is 670 meters of mud and/or melting snow. During runoff events, three sampler bottoms containing 28 full half-liter sample bottles must be transported from the site to the road and on to the laboratory as often as every four hours. The time and weight involved, particularly when considering distance and terrain, require some type of all-terrain vehicle. A Honda ATC-90 was selected for reason of dependability and price. Conditions so severe that the site cannot be reached with the Honda and its essential payload are yet to be encountered. The machine has also proven itself to be quite versatile, particularly with the addition of a trailer hitch, a small utility cart, and a rotary mower.

2.4. Laboratory Instrumentation and Technique

Tests for alkalinity, conductivity, 5-day biochemical oxygen demand, chemical oxygen demand, total Kjeldahl nitrogen, ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, total phosphate, total solids, fecal coliform bacteria, and pH were, and continue to be, conducted at the Agricultural Fermentation and Pollution Control Laboratory located on the Michigan State University campus. Supplying the physical systems needed to handle these determinations, particularly at the required capacity, has been a major undertaking. Significant new instrumentation purchases have been made, many operations have been modified, some existing equipment has been altered or expanded, and the laboratory personnel have continued to do an excellent job during a period of many frustrations.

Methods used for the laboratory analyses are presented in Table 1. A flow chart of laboratory operations for runoff samples is shown in Figure 5.

Laboratory methods utilized, as indicated from the references at the bottom of Table 1, are quite standard techniques and procedures. Several alternative methods are acceptable for many of the tests conducted. Experimental work with several of the various alternative procedures and previous experience with many of the determinations guided the choices of the specific methods utilized.

Replication of laboratory determinations was not possible due to financial limitation. It appeared more desireable, for purposes of this study, to conduct one analysis per sample for each of the twelve water quality parameters than to conduct analyses for four parameters in triplicate for each sample. During the course of the study, however, duplicate tests were occasionally conducted as a check on the general

Table 1

Parameters and Laboratory Methods

Parameter	Method
Alkalinity	Potentiometric determination using standard acid titration to end point of pH 4.5; Markson model 1808 electrode and Corning model 12 pH/mv meter utilized.
Ammonia-Nitrogen	Electrometric determination using Orion specific ion electrode and Beckman model 4500 pH/mv meter.
Biochemical Oxygen Demand	Standard 5-day test using known volumes of sample and nutrient solution; not seeded; D.O. measurements with YSI model 54 meter and probe; later, used Beckman model 0260 D.O. system.
Chemical Oxygen Demand	Dichromate reflux digestion method under condensers with standard ferrous ammonium sulfate titration.
Conductivity	Specific conductance cell, platinum-electrode type; Markson model 10 conductivity meter.
Fecal Coliform Bacteria	Multiple tube fermentation with lauryl tryptose presumptive and E. Coli. medium confirmed test; clouded tube and gas production indicates positive; bacterial density estimation by the MPN method.
Total Kjeldahl Nitrogen	Sulfuric acid, potassium sulfate digestion with mercuric sulfate catalyst; digestion on Tecator DS 40; determination with Orion specific ion electrode and Beckman model 4500 pH/mv meter.
Nitrate-Nitrogen	Electrometric determination with Orion specific ion electrode with KF reference electrode and Beckman model 4500 pH/mv meter.
Nitrite-Nitrogen	Colorimetric determination using Bausch and Lomb Spectronic 70 spectrophotometer; 520 nm used for determination.
pH	Electrometric determination with Markson model 1808 electrode and Corning model 12 pH/mv meter following manufacturers' manuals.

Table 1 (cont'd).

Total Phosphate	Sulfuric acid, nitric acid digestion with ascorbic acid colorimetric determination; Bausch and Lomb Spectronic 70 spectrophotometer used at 660 nm for determination.
Total Solids	Gravimetric determination with drying of known sample volume at 103^{o}C.

References: American Public Health Association (1976)
USEPA National Environmental Research Center (1974)

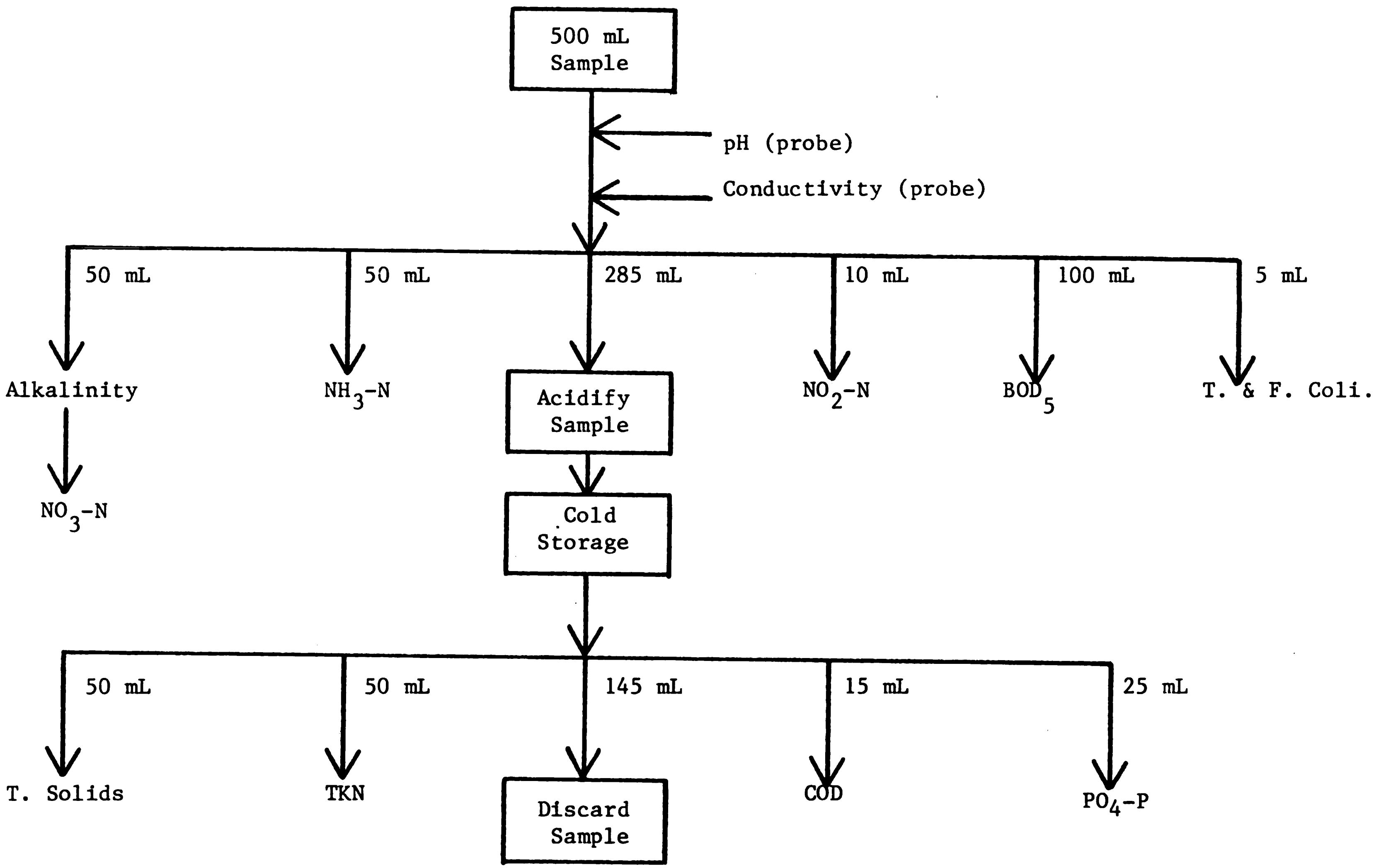

Figure 5. Laboratory Flow Chart

reliability of the observations. Repeatability was generally quite good, as measurements checked were usually reproducible to within a few percent. Poorer repeatability, as could be expected, was often associated with determinations yielding results approaching the lower limit of the particular test. This appeared to be a particular problem with the nitrite-nitrogen tests. Relatively poor repeatibility was also associated with the 5-day biochemical oxygen demand determinations checked.

With these two possible exceptions, the data are believed to be quite reliable. The confidence which can be placed in the results reported, however, is less than if extensive laboratory replication had been performed.

2.5. Farming Practices

The two fields of the project site have been farmed in a similar manner for at least the seven-year period immediately preceeding the research study. Field corn was grown every year, and continues as the crop grown during the project period.

Farming practices have remained essentially the same as in the past, with only one exception. This exception is that a purposeful effort is made to treat the two fields as nearly alike as possible in terms of plowing date, planting date, cultivation date, harvesting date, manure application rate and date, and commercial fertilizer and chemical application rate and date. The cropland areas are treated as similarly as is possible under commercial farming conditions.

The generalized management plan utilized for this research project is presented as Table 2. Of particular note are the liquid manure applications. The manure applications are planned at a yearly rate of about 45,000 liters per hectare and supply a substantial portion of the needed crop nutrients.

An inventory of all farming practices and events is continually maintained for the two cropland areas. Actual fertilizer and manure applications occurring between the spring of 1978 and the spring of 1979 are listed in Table 3. As will later be seen, the amounts of nitrogen, phosphorus, and potassium applied during the first year of this study were in excess of the recommendations. This situation was corrected during the second year by eliminating the applications of dry fertilizer and reducing the application rate of anhydrous ammonia.

Table 2

Generalized Cropland Management Plan[a]

Date	Activity
January 15	liquid manure application [b]
May 1	liquid manure application[b]
May 5	field tillage operations
May 10	chemical fertilizer application[c]
May 15	corn planting[d] and pesticede application
July 1	field cultivation
October 15	corn harvest
November 1	liquid manure application[b]

(a) all dates approximate

(b) manure applied to soil surface with vacuum wagon

(c) primarily amhydrous ammonia

(d) 3965 Pioneer F13; liquid "starter fertilizer" applied also

(e) AAtrex, Lasso, and Furadan

Table 3

Fertilizer and Manure Applications[a]

Date	Material Applied	Equivalent Application[b], Kg/ha		
		N	P	K
4/24 - 4/26/78	Dry Fertilizer	0	0	134
4/24 - 4/26/78	Dry Fertilizer	0	52	0
5/6 - 5/24/78	Liquid Swine Manure	55[c]	13	(d)
5/26 - 5/31/78	Anhydrous Ammonia	112	0	0
5/29 - 6/1/78	Liquid "Starter" Fertilizer	1.8	5.6	0.7
1/16 - 1/20/79	Liquid Swine Manure	55[c]	13	(d)

(a) occurring between April 14, 1978, and April 14, 1979
(b) identical applications to both fields
(c) assuming a 50 percent volatilization loss
(d) not measured

Chapter 3

DATA

3.1. Soils Analysis

Soil samples from the project site are gathered periodically for analysis. All samples are subjected to standard analyses by the Michigan State University Soil Testing Laboratory, and standard fertility recommendations are made. This is the same service which is available to all Michigan farmers for a fee.

Tests are performed for phosphorus, potassium, calcium, magnesium, nitrate, percent organic matter, and pH. Recommendations for nitrogen, phosphorus, potassium, and lime application rates are formulated according to the standard practices of the Soil Testing Laboratory. Results are used in planning the fertility program for the project area and for comparing the fertility levels of the two fields. Samples are individually analyzed rather than composited, as would be the case with most agricultural cropland.

Results and recommendations from the initial samples, taken in April of 1978, are presented as Table 4. Tables 5 and 6 contain the results and recommendations from the November, 1978, and the November, 1979, samplings.

The initial soils analysis indicates that the fertility of the two fields is quite comparable, though some minor differences are probable. Similar indications are apparent from the later analyses. Ideally, of course, the fertility level of the two fields should be identical. This may well be impossible, at least in terms of practicality, for a large field site such as was employed with this experiment.

While the confidence intervals for the mean values from the various

Table 4

Soils Analysis - April, 1978

Test Results[a]	Mean and 95% Confidence Interval	
	Control Field	Buffered Field
Phosphorus, kg/ha[b]	203 ± 131	163 ± 71.0
Potassium, kg/ha	543 ± 301	401 ± 167
Calcium, kg/ha	3900 ± 1570	3430 ± 1490
Magnesium, kg/ha	503 ± 242	415 ± 352
Nitrate, ppm	3.55 ± 2.10	3.59 ± 1.37
% Organic Matter	3.36 ± 0.69	2.90 ± 0.57
pH	6.73 ± 0.62	6.55 ± 0.93
Recommendations [c]	**Control Field**	**Buffered Field**
Nitrogen, Kg/ha	168	168
Phosphorus, Kg/ha	6.0	10.3
Potassium, Kg/ha	0	0
Lime, Kg/ha	1400	2400

(a) six samples per field, individually analyzed
(b) 1 kg/ha = 0.89 lb/ac
(c) average recommendation for each field based upon test results and anticipated corn yield

Table 5

Soils Analysis - November, 1978

Test Results[a]	Mean and 95% Confidence Interval	
	Control Field	Buffered Field
Phosphorus, kg/ha[b]	348 ± 335	203 ± 70.8
Potassium, kg/ha	388 ± 165	296 ± 50.4
Calcium, kg/ha	3420 ± 1630	3050 ± 1740
Magnesium, kg/ha	470 ± 204	348 ± 225
Nitrate, ppm	53.4 ± 71.9	24.2 ± 33.4
% Organic Matter	3.27 ± 1.29	3.22 ± 1.50
pH	6.50 ± 0.49	6.37 ± 0.50

Recommendations[c]	Control Field	Buffered Field
Nitrogen, kg/ha	168	168
Phosphorus, kg/ha	0	0
Potassium, kg/ha	0	0
Lime, kg/ha	1300	2100

(a) six samples per field, individually analyzed
(b) 1 kg/ha = 0.89 lb/ac
(c) average recommendation for each field based upon test results and anticipated corn yield

Table 6

Soils Analysis - November, 1979

Test Results[a]	Mean and 95% Confidence Interval	
	Control Field	Buffered Field
Phosphorus, kg/ha[b]	315 ± 117	262 ± 85.2
Potassium, kg/ha	577 ± 126	441 ± 122
Calcium, kg/ha	5160 ± 2090	3470 ± 1040
Magnesium, kg/ha	685 ± 284	396 ± 171
Nitrate, ppm	12.5 ± 6.90	37.4 ± 61.7
% Organic Matter	5.54 ± 2.29	4.11 ± 1.03
pH	7.0 ± 0.93	6.2 ± 0.89

Recommendations[c]	Control Field	Buffered Field
Nitrogen, kg/ha	168	168
Phosphorus, kg/ha	2.1	2.1
Potassium, kg/ha	0	0
Lime, kg/ha	1900	5300

(a) six samples per field, individually analyzed
(b) 1 kg/ha = 0.89 lb/ac
(c) average recommendation for each field based upon test results and anticipated corn yield

analyses of the two fields' soils overlap considerably, the control field is probably a bit more fertile than the buffered field. Thus, the fields are quite comparable in terms of phosphorus, potassium, calcium, magnesium, percent organic matter, and pH, but are probably not identical. Measured nitrate values exhibited such extreme variation among samples from the same field that no conclusion is possible.

The recommendations for fertilization are nearly identical for the two fields in each of the three separate analyses. Lime recommendations reflect the lower mean pH of the buffered field throughout the course of the project to date. No lime was applied, and the fertilizer applications have been identical.

3.2. Waste Analysis

A confinement farrow-to-finish swine operation is located on the farm which serves as the project site. Waste storage of about 90-day capacity is provided by under-slat liquid manure pits. The wastes are taken from the storage pits and applied uniformly to the cropland of the project area with a vacuum wagon and a tractor. Table 7 contains the results from the analyses of pit contents during the first year of the project.

Table 7

Analysis of Under-Slat Manure Pit Contents[a]

Constituent	Range	Weighted Average[b]
Total Kjeldahl Nitrogen, mg/L	2000 - 25,000	6820
Ammonia-Nitrogen, mg/L	2500 - 10,400	5100
Total Phosphate, mg/L (as P)	600 - 1070	710
Total Solids, mg/L	8000 - 82,000	40,700
Conductivity, μ mho/cm	25,000 - 46,000	35,700

(a) Two samples taken from manure storage pits in each of the three swine barns (gestation/breeding, nursery, and finishing) at the start of each of the manure applications.

(b) Volume-weighted average concentration for the entire swine complex.

3.3. Ambient Stream Quality

Stream flows were continuously monitored at the Cipoletti weir located in the streambed immediately upstream from the vegetated buffer area. Weekly grab samples were gathered and tests for dissolved oxygen, pH, alkalinity, ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, total Kjeldahl nitrogen, biochemical oxygen demand, chemical oxygen demand, conductivity, fecal coliform bacteria, total phosphate, and total solids were performed.

Results from the laboratory testing and field monitoring of the stream are presented in Figures 6 through 19 and Table 8. The curves presented, except for the continuous flow record, were constructed by plotting the weekly values obtained and assuming linearity between any two consecutive points. This is probably not indicative of precisely the levels of the various parameters estimated, since many undetected fluctuations could have occurred in the periods between samplings. However, it does provide a general indication of the quality of this particular stream during one yearly cycle.

Values are not plotted for weeks 38, 42, or 43. These times represent the periods during March and April of 1979 when runoff occurred and when the stream was subjected to extensive water quality sampling and testing. Results of the analyses performed during these periods are presented in Section 3.4.

The time designated as week 0 in Figures 6 through 19 corresponds to the week beginning on June 15, 1978. Note that the ordinates of the various curves, representing measured demands, concentrations, or values, are not of identical scale or dimension.

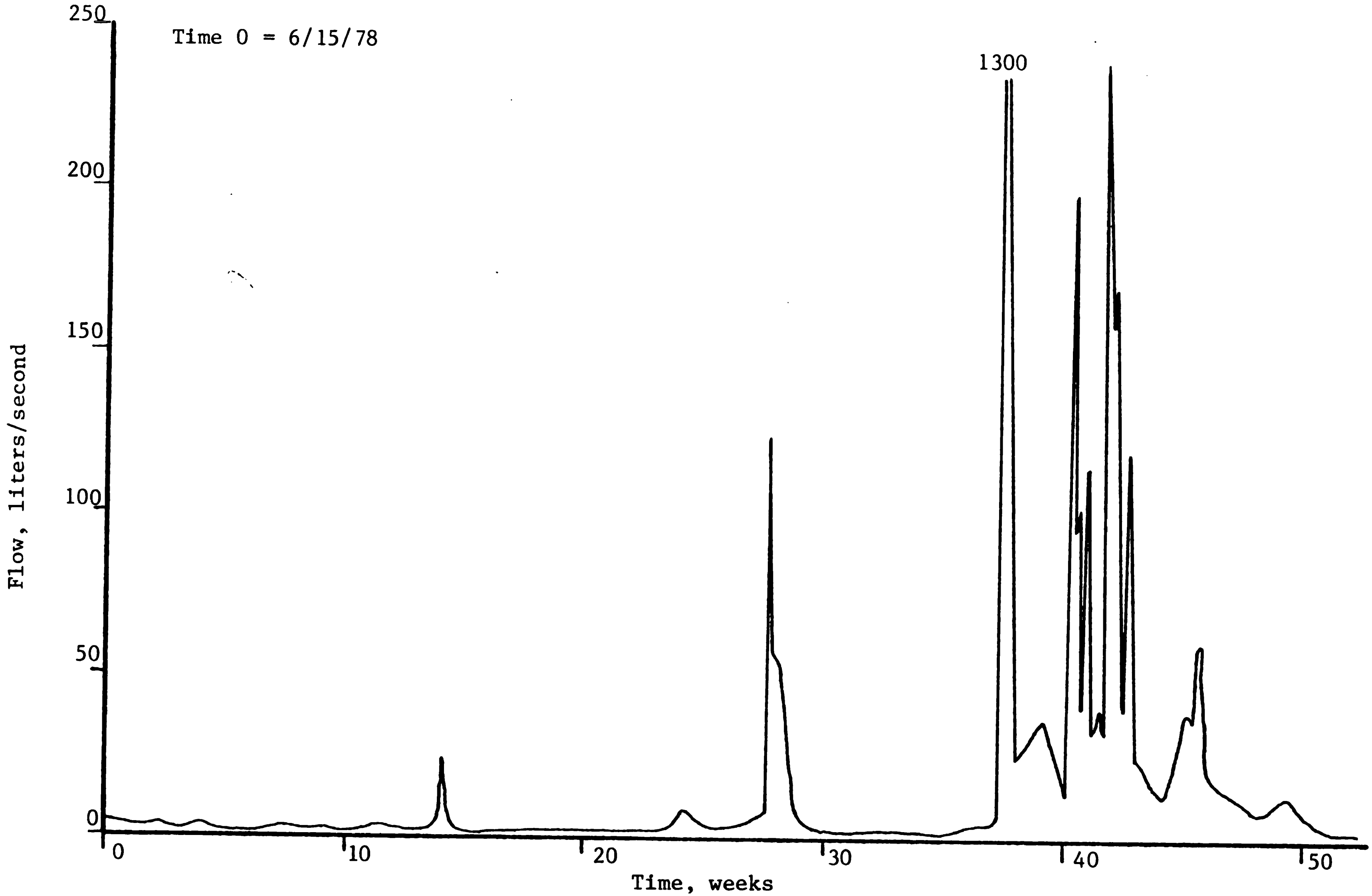

Figure 6. Flow vs. Time, Stream

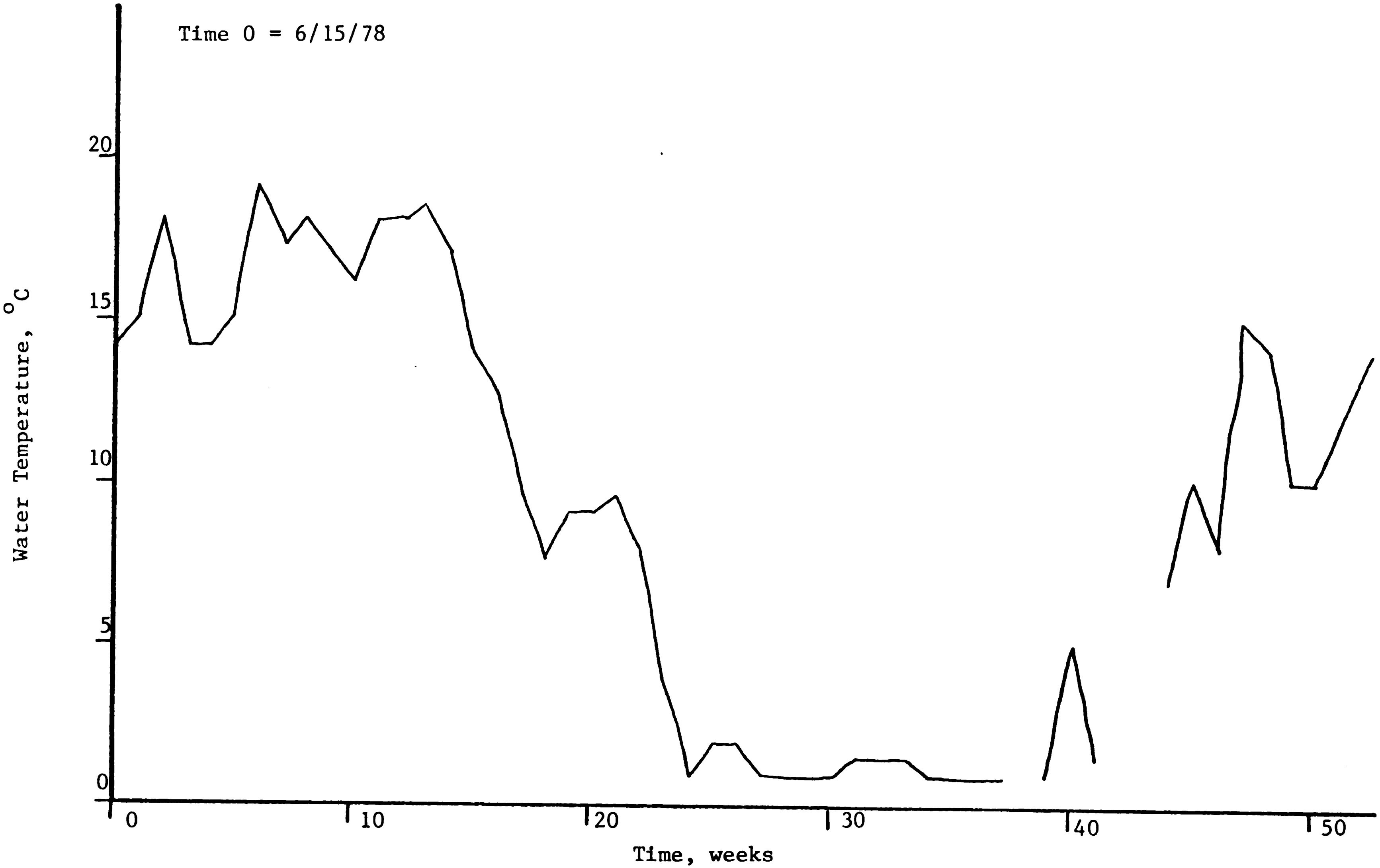

Figure 7. Water Temperature vs. Time, Stream

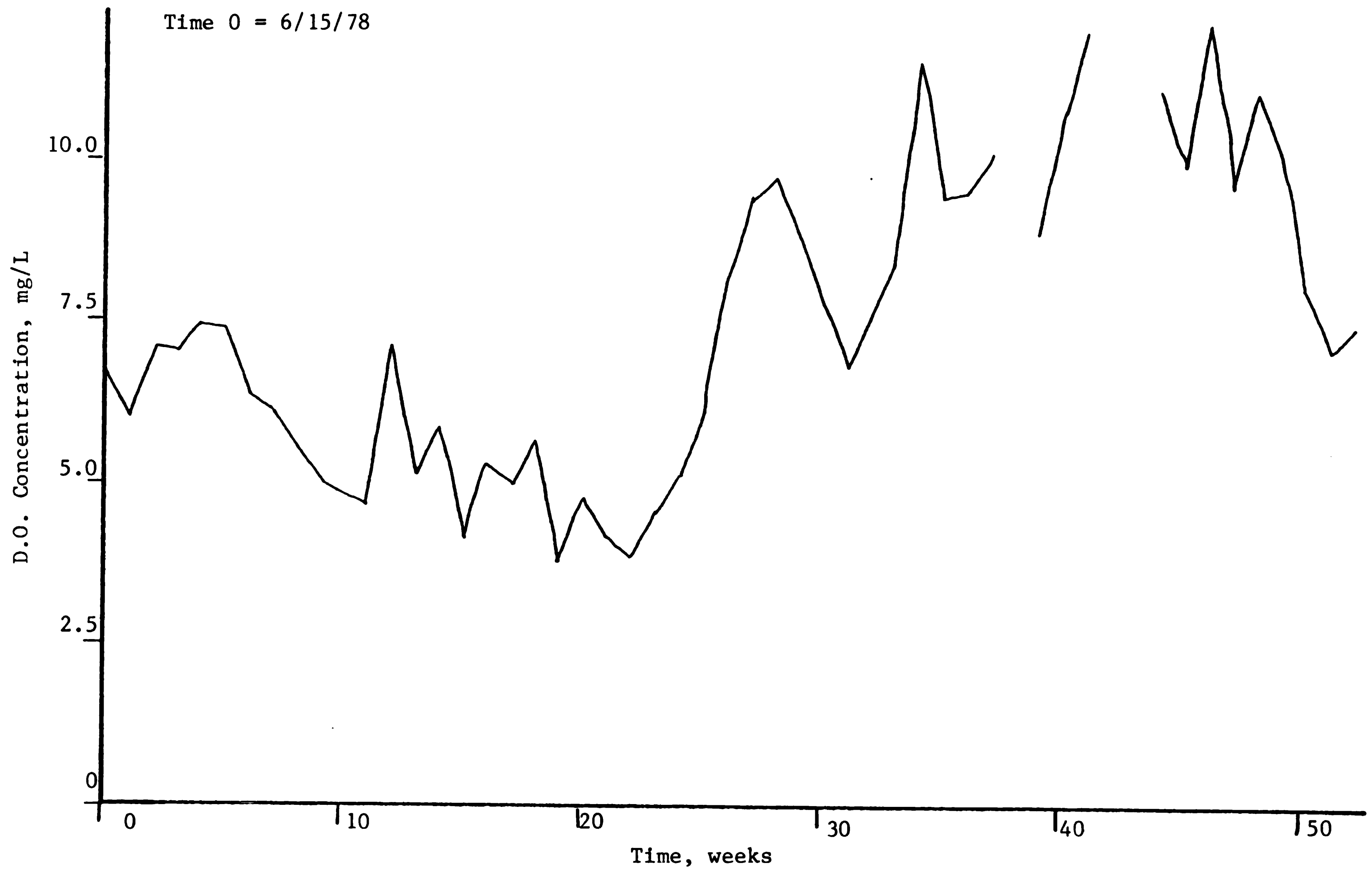

Figure 8. Dissolved Oxygen Concentration vs. Time, Stream

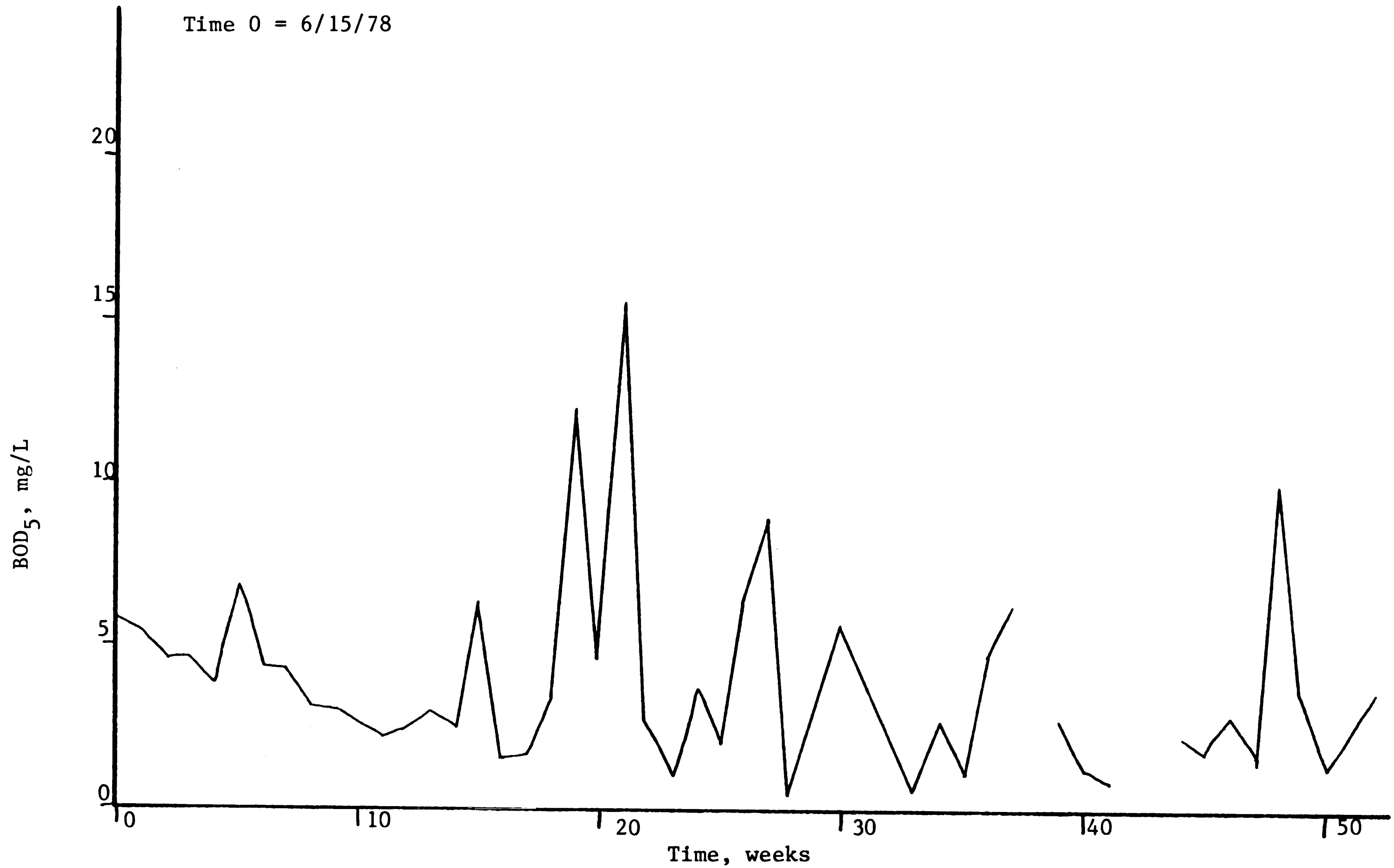

Figure 9. 5-day Biochemical Oxygen Demand vs. Time, Stream

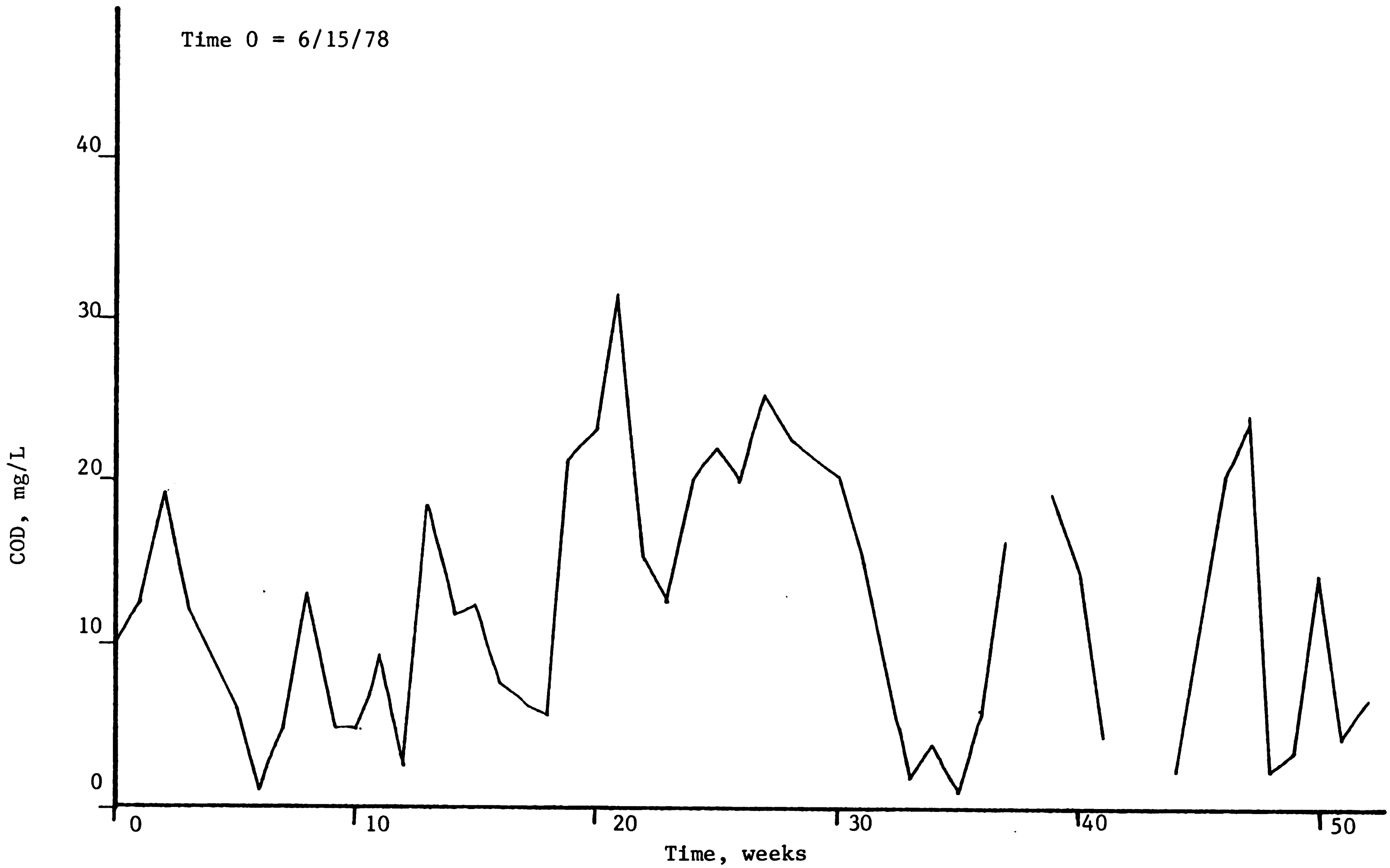

Figure 10. Chemical Oxygen Demand vs. Time, Stream

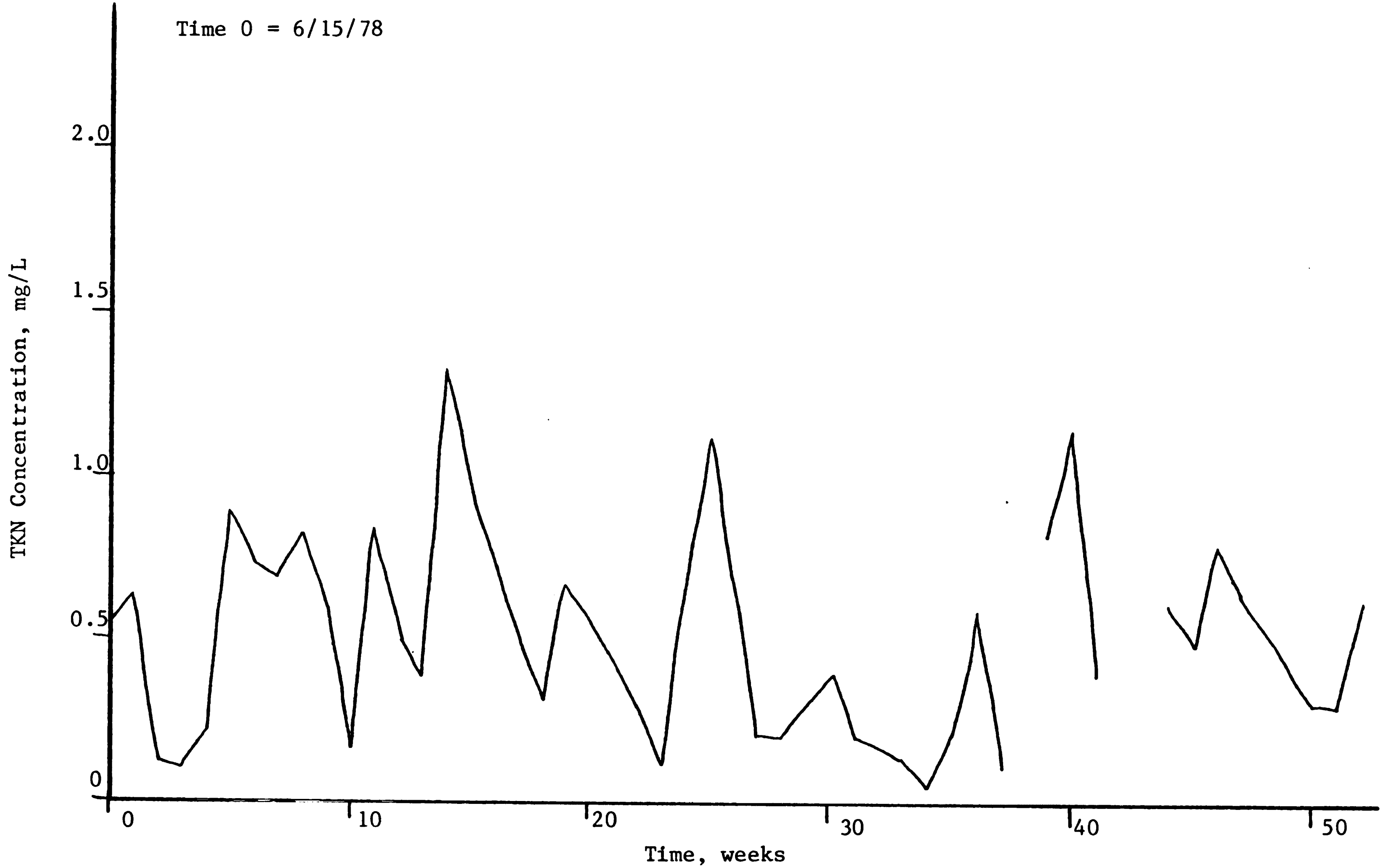

Figure 11. Total Kjeldahl Nitrogen Concentration vs. Time, Stream

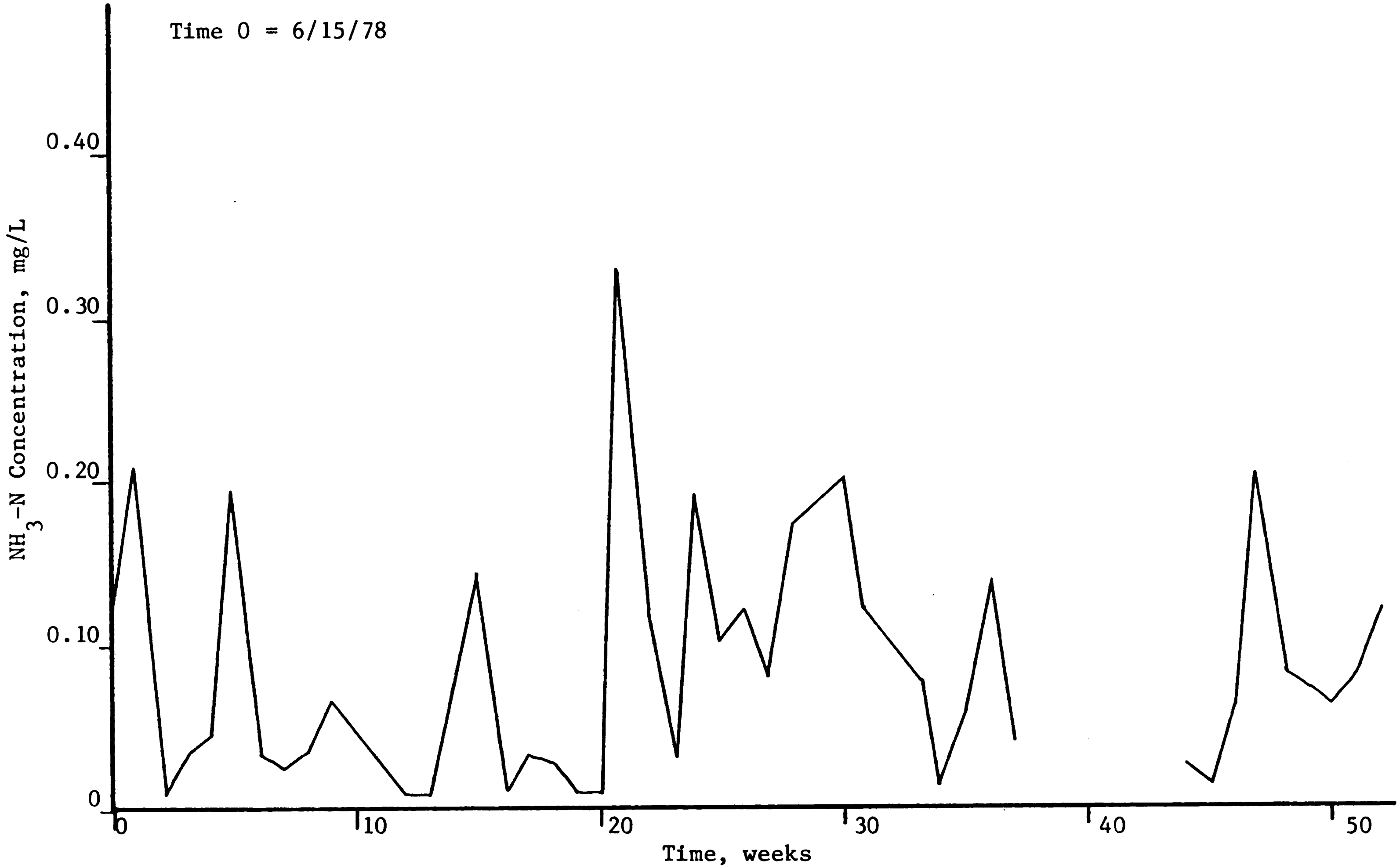

Figure 12. Ammonia-Nitrogen Concentration vs. Time, Stream

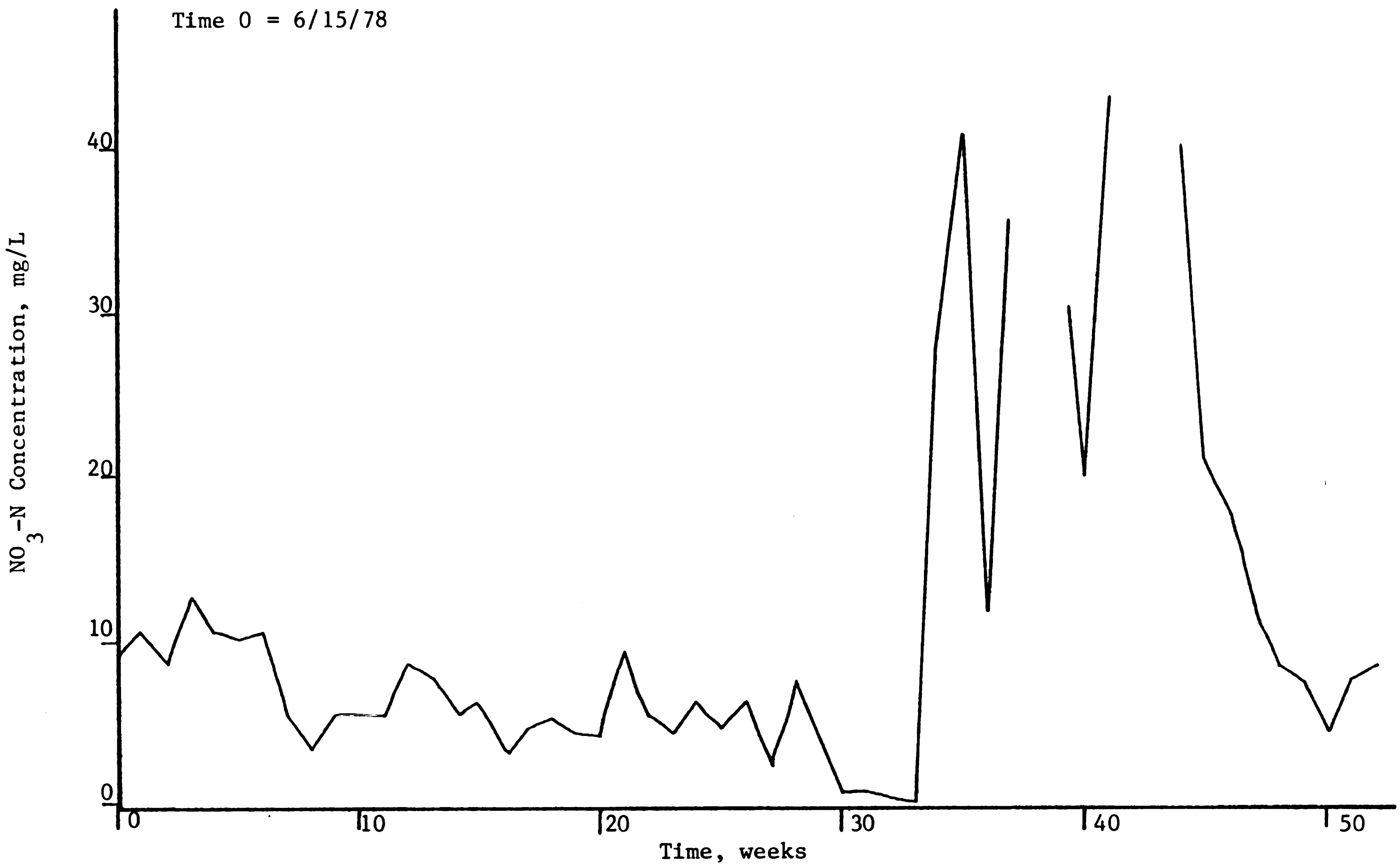

Figure 13. Nitrate-Nitrogen Concentration vs. Time, Stream

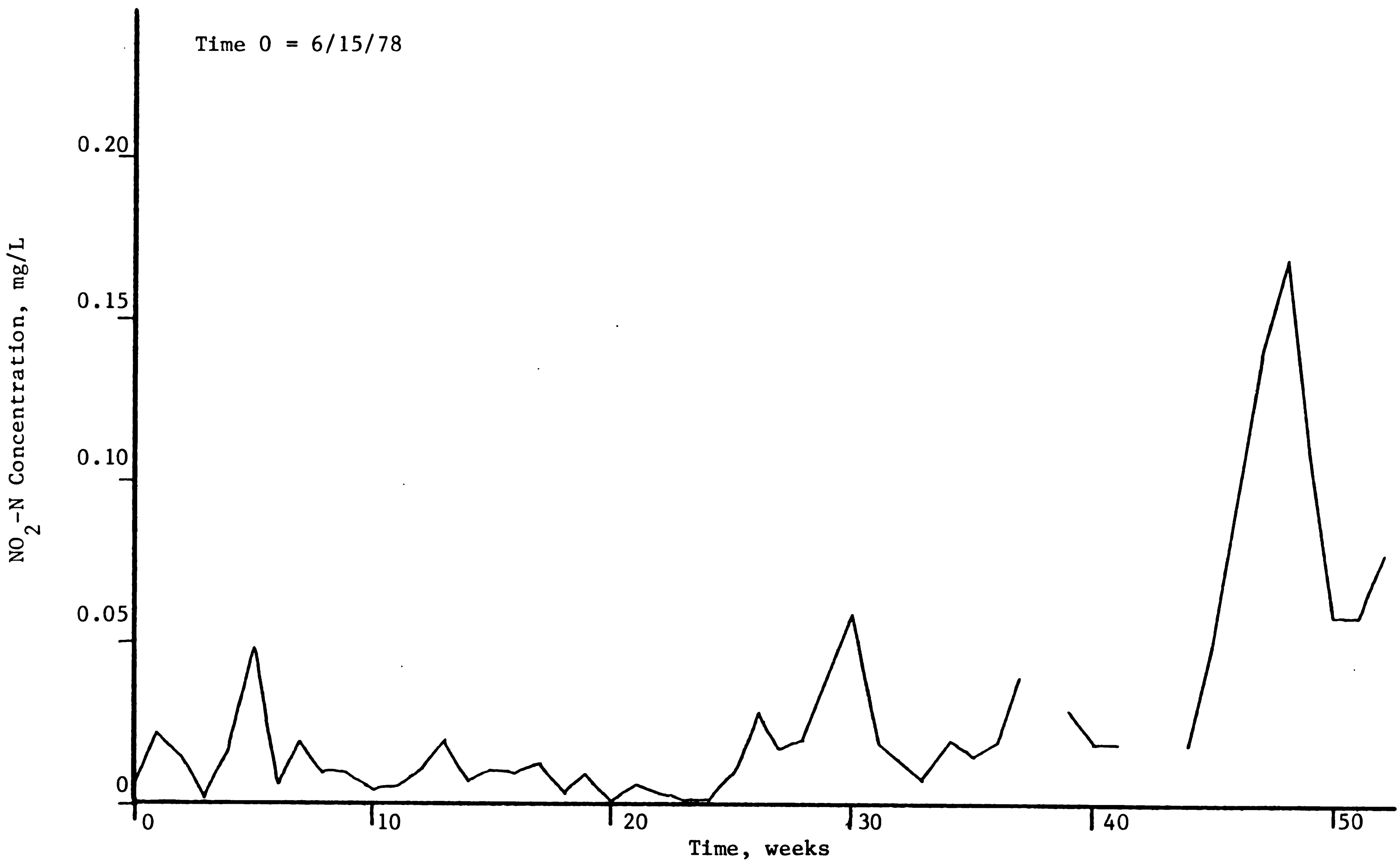

Figure 14. Nitrite-Nitrogen Concentration vs. Time, Stream

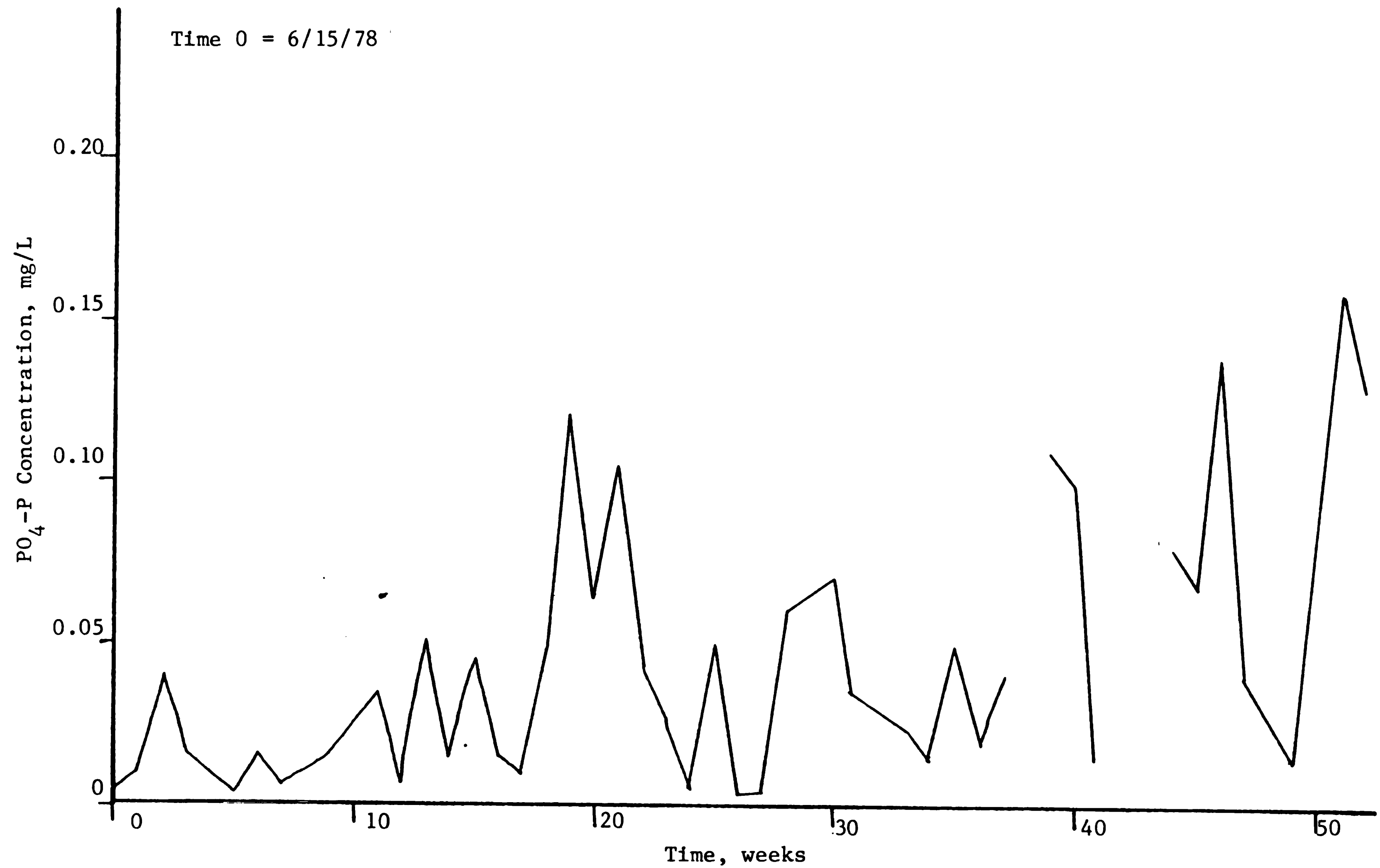

Figure 15. Total Phosphate Concentration vs. Time, Stream

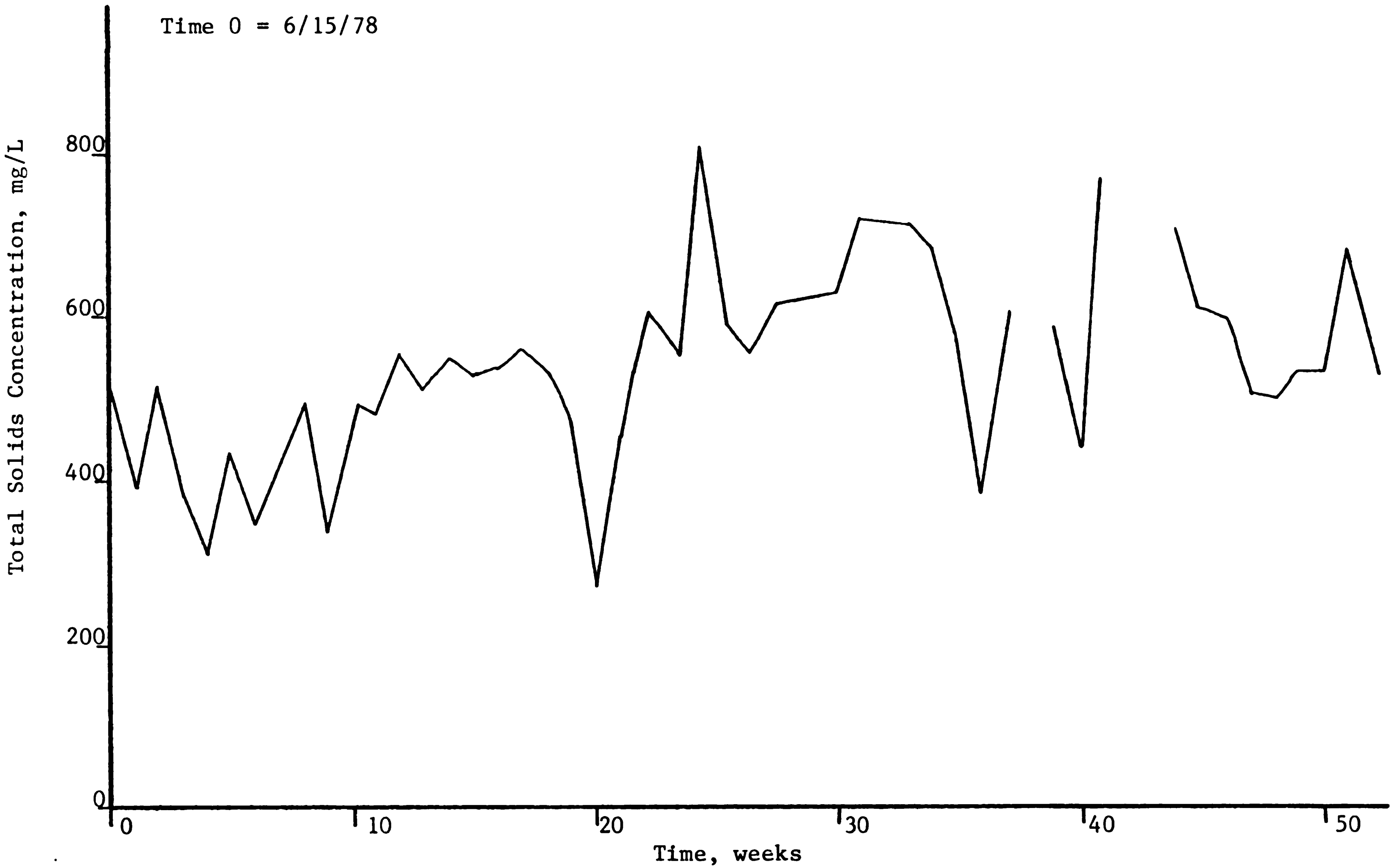

Figure 16. Total Solids Concentration vs. Time, Stream

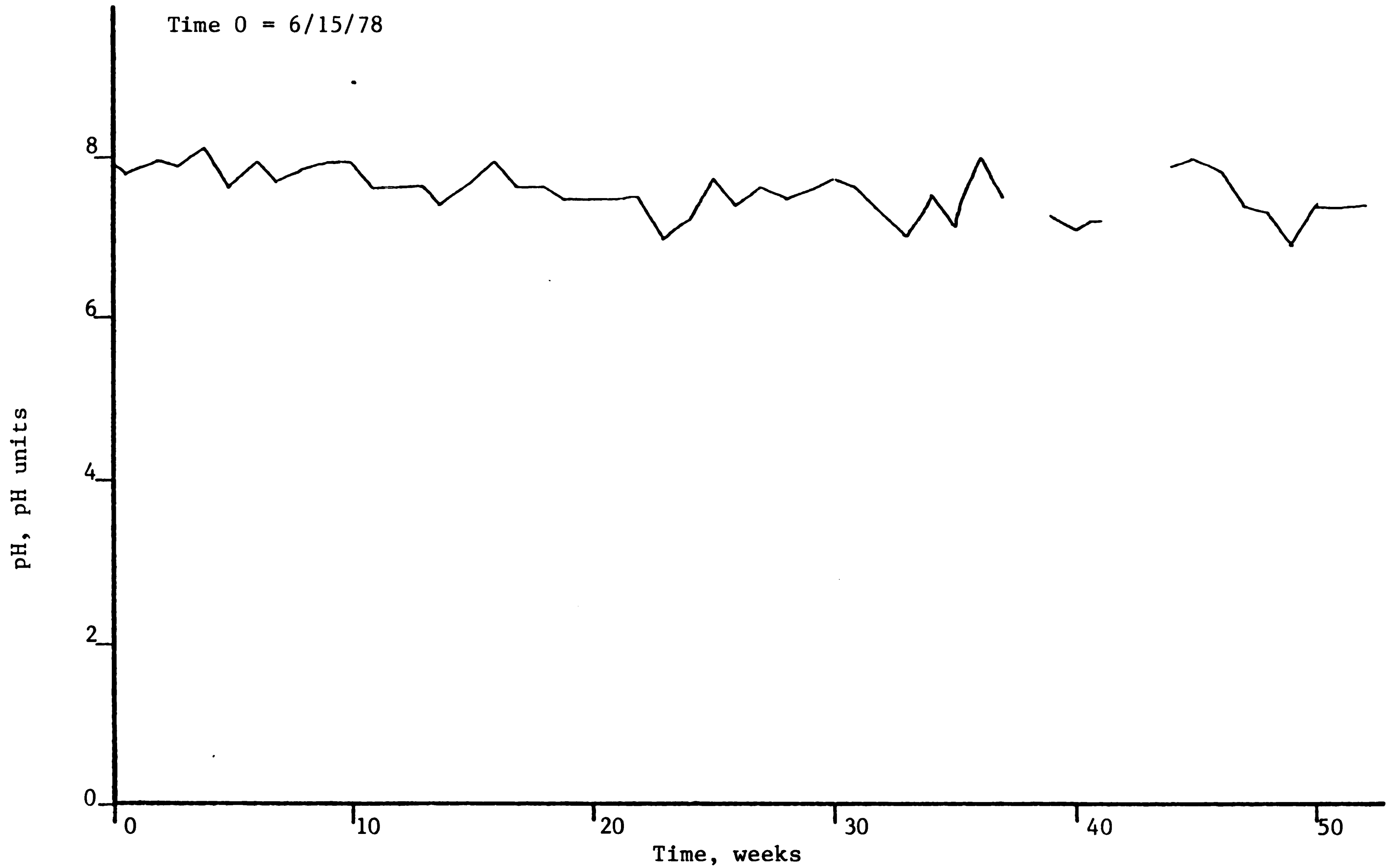

Figure 17. pH vs. Time, Stream

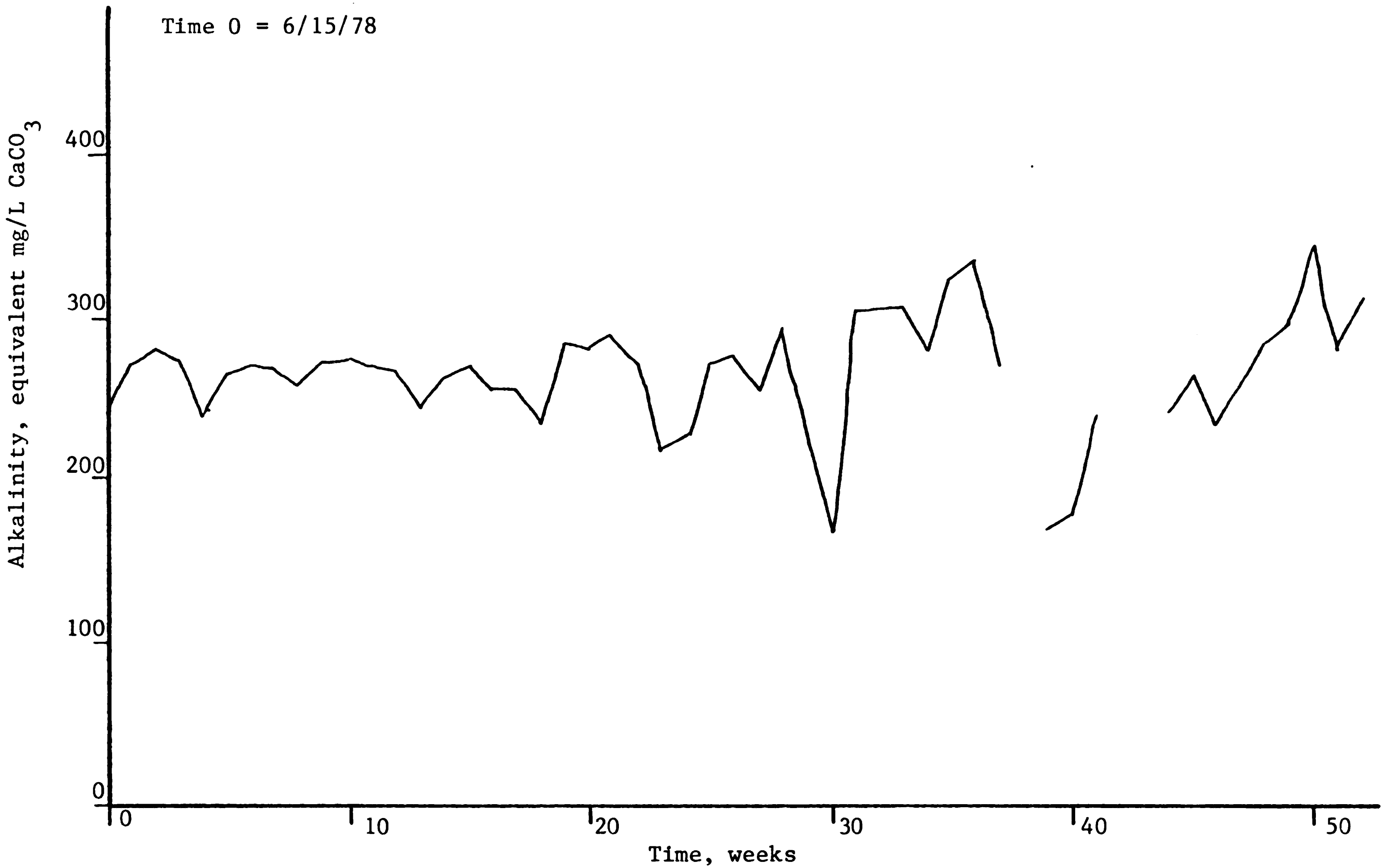

Figure 18. Alkalinity vs. Time, Stream

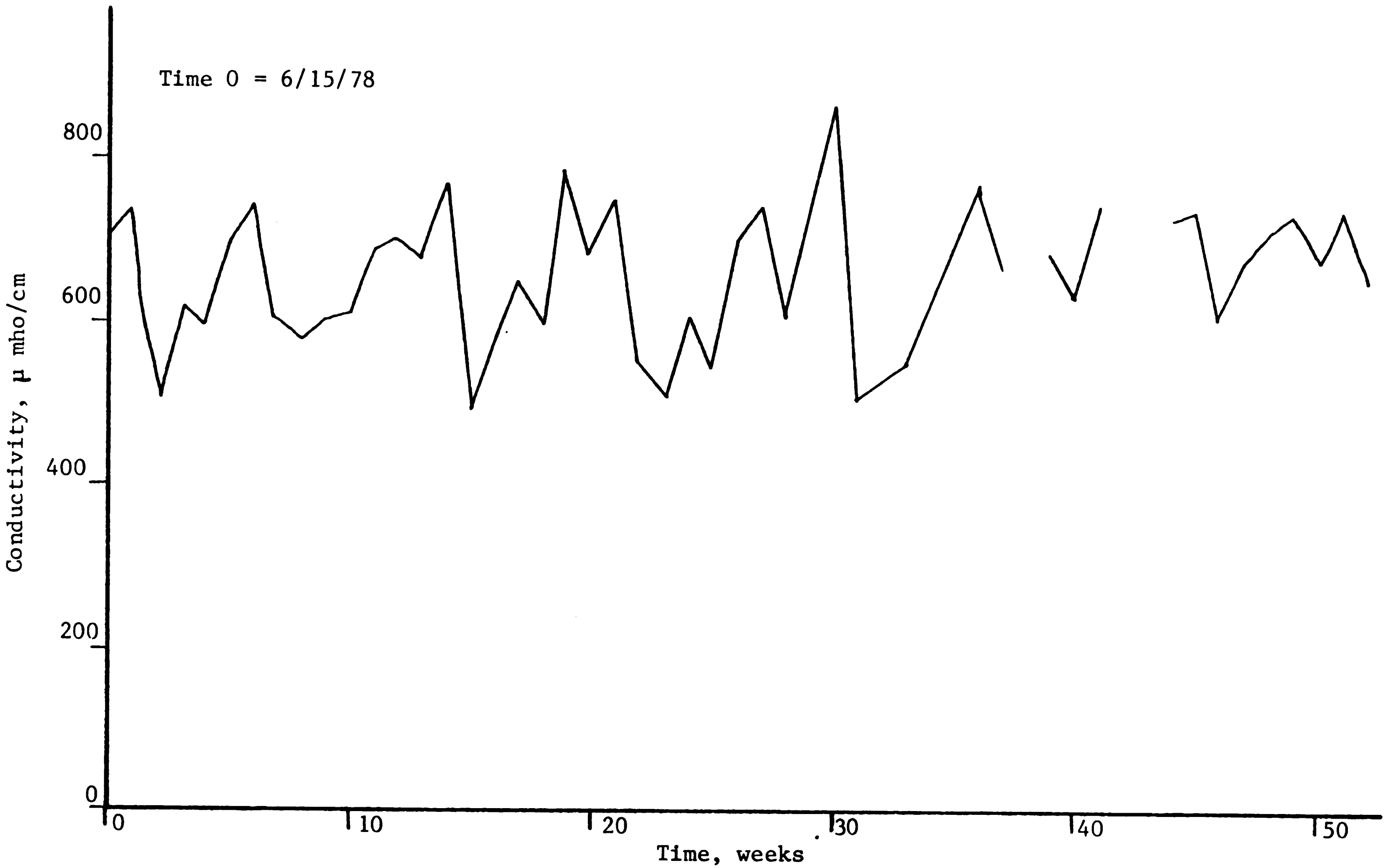

Figure 19. Conductivity vs. Time, Stream

Table 8

Ambient Stream Quality[a]

Water Quality Constituent	Mean and 95% Confidence Interval
pH	7.57 ± 0.08
5-day Biochemical Oxygen Demand, mg/L	3.90 ± 0.87
Chemical Oxygen Demand, mg/L	11.86 ± 2.25
Total Kjeldahl Nitrogen, mg/L	0.515 ± 0.089
Ammonia-Nitrogen, mg/L	0.096 ± 0.027
Nitrate-Nitrogen, mg/L	11.17 ± 3.16
Nitrite-Nitrogen, mg/L	0.037 ± 0.024
Total Solids, mg/L	533.5 ± 33.3
Conductivity, μ mho/cm	664.9 ± 25.4
Total Phosphate (as P), mg/L	0.044 ± 0.012
Water Temperature, °C	9.44 ± 1.86
Dissolved Oxygen, mg/L	7.48 ± 0.70
Alkalinity, equivalent mg/L $CaCO_3$	265.6 ± 10.7

	Percentage of Determinations			
	≤ 200/100 mL	201-999/100 mL	≥1000/100 mL	Total
Fecal Coliform Bacteria	74	19	7	100

(a) Results from weekly grab samples taken 6/15/78 through 6/15/79, excluding periods of runoff.

3.4. Runoff Occurrences

3.4.1. General

Eight runoff events occurred during the first year of the project. Six of these are considered substantial. The other two were quite minor, and the limited data gathered from them is not reported.

The first of these minor events occurred during the construction of the vegetated buffer area, and was the result of several small showers followed by a short thunderstorm of 3.8 centimeters accumulation. No flow was detected at the control field monitoring station and total water yield from the buffered field was less than 2000 liters.

The second minor event occurred during the evening of December 31, 1978. This event resulted from a rain, misting rain, and sleet storm which continued intermittently for two days. Air temperatures were above freezing during the daylight hours of December 31, and quickly dropped with the sunset. Runoff flows were not detected until air temperatures were well below freezing, and flows soon subsided. The movement of the runoff water was apparent along the slightly frozen soil surface and under the snow pack, which remained through the storm.

The low air temperatures experienced during this runoff event, along with substantial winds, served to severely restrict the number of samples which could be gathered. The heat tapes proved to be ineffective under these conditions, as freezing occurred in the intakes of the automatic water samplers. Laboratory analyses were performed for the water samples which were gathered. The results indicated the runoff water to be of high quality, as quite low concentrations of each of the monitored constituents were found.

Extensive amounts of data were gathered for the six major runoff events occurring during the first year of the study. The involved personnel and equipment were both hard-pressed in this task, as all six of these events took place within a forty-day period of March and April of 1979. These data are presented in the following subsections.

Rainfall intensity, runoff and stream flows, and water quality constituent concentration values are plotted as a function of time for the six major runoff events. The time designated as hour 0 on the graphs for each of the runoff events, except for event one, is the time when the first water samples were taken. This time often lags the initiation of runoff by varying periods (usually 5 to 60 minutes) as the automatic water samplers did not begin operation until about 550 liters of runoff had been collected in either of the two runoff weir boxes. This volume represents the "trigger depth" of the float and microswitch assemblies which control the initiation of the sampling routine.

The flow curves result from continuous depth-of-flow measurements converted to flow rate using standard weir calibrations. Rainfall intensity is plotted as hourly accumulation, as taken from the continuous precipitation record. On several occasions, particularly during freeze and thaw cycles, the rain gauge at the project site malfunctioned. Data for these time periods were obtained by averaging rainfall intensity values from two nearby recording precipitation stations being utilized in another research effort. The curves of water quality constituent concentrations were constructed by plotting the actual values obtained for each of the various parameters and assuming linearity between any two chronologically consecutive values. Financial and physical limitations made it impossible to perform laboratory replication. Each runoff water and stream water sample was tested only once for each of the various parameters.

Two hundred and four individual curves, graphic representations of data collected, are presented in the following six subsections. Note that the ordinates of the various figures, representing values, concentrations, or demands, are not identical in scale or in dimension. Also note that, in the opinion of the author, these data are not yet suitable for mathematical model calibration, but may well be suitable for model testing and could aid model specification.

3.4.2. Runoff Event One

The first major runoff event of the study began on March 3, 1979 and continued for six days. This event was caused by sufficiently high temperatures to melt the winter snow pack along with several short rainstorms of low intensity.

The winter of 1978-79 in Michigan was somewhat colder than average, with a temperature departure of about 4.5°C below the 30-year mean during January and February. Snow cover was preserved from December until March. Snow accumulation, however, was not unusually heavy. Snow cores gathered randomly from the project site during the last week of February contained an average of about 6.0 equivalent centimeters of water.

Runoff flow began and was detected at the weir below the control field at 2:15 p.m. on March 3. Shortly thereafter, the sampling process was electronically initiated and all three water samplers began operation. Runoff flow from the buffered field was first detected five hours later at 7:15 p.m. A sampling interval of 30 minutes was maintained for the rising hydrograph. This interval was later increased as the flows subsided. Data gathered from the field measurement, sampling, and laboratory analysis of this runoff event are presented in Figures 20 through 32. The time designated as hour 0 in each of the figures corresponds to noon on March 3, 1979, the time the author arrived at the site and began making observations.

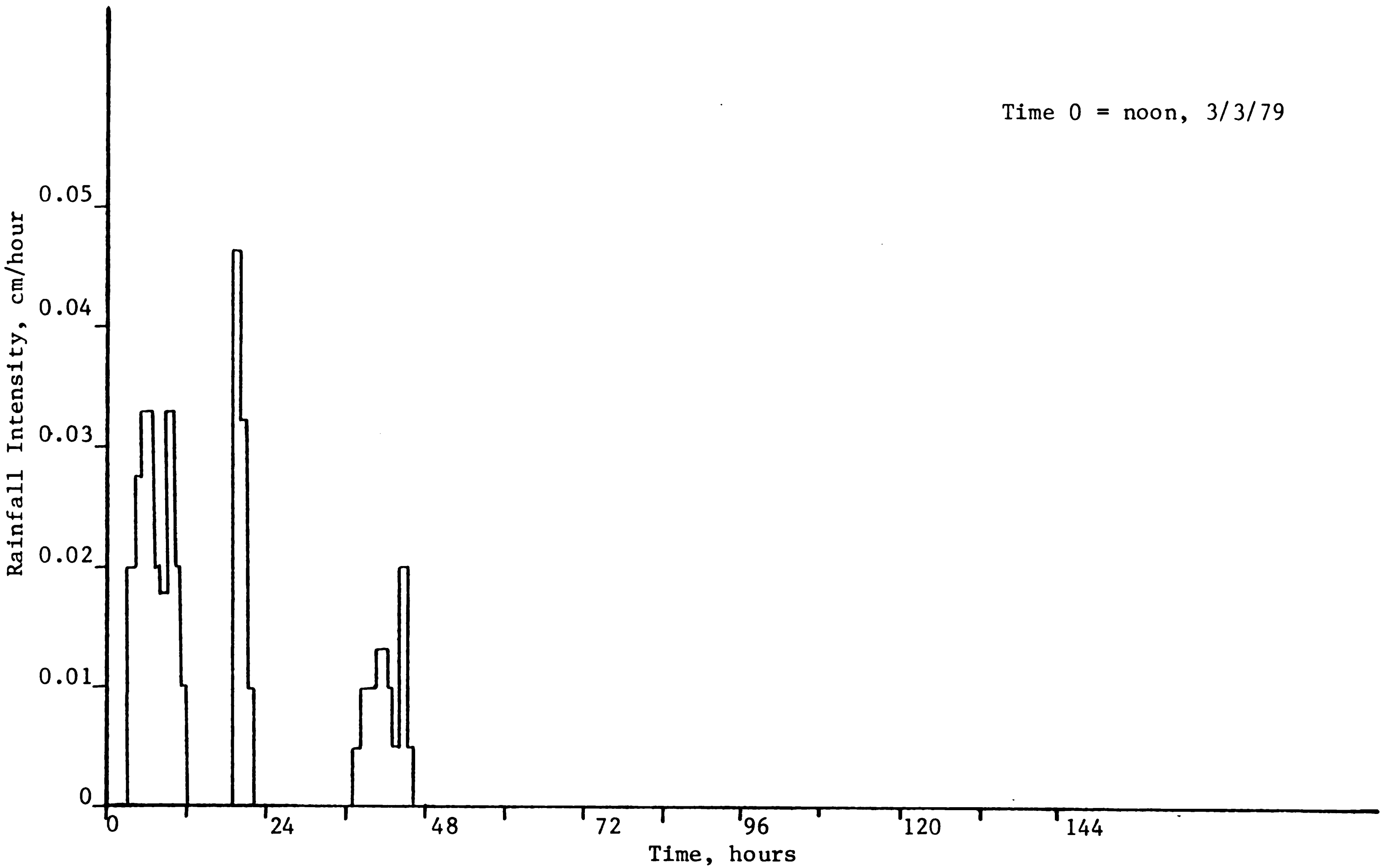

Figure 20. Rainfall Intensity vs. Time, Event 1

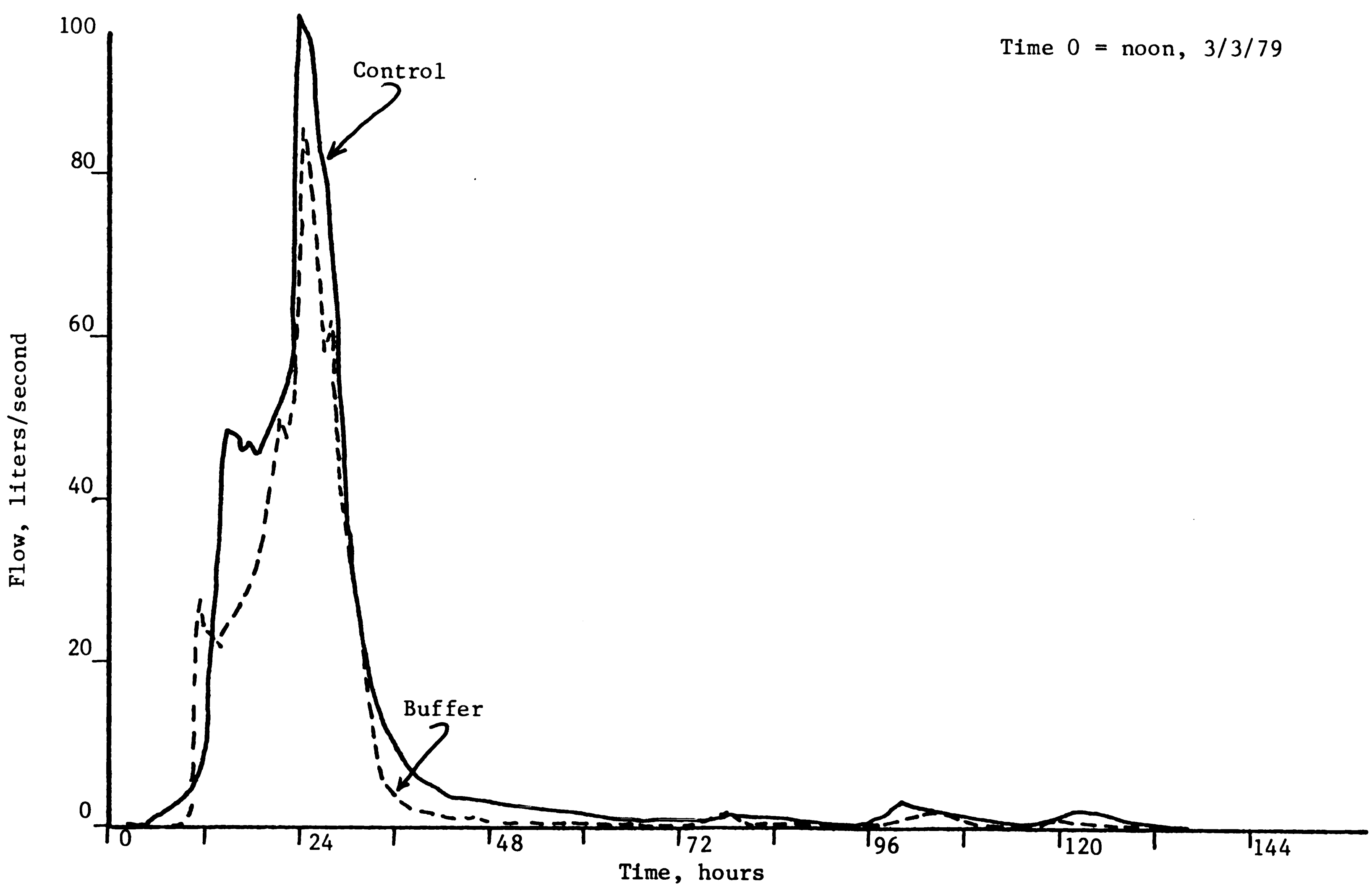

Figure 21. Runoff Flow vs. Time, Event 1

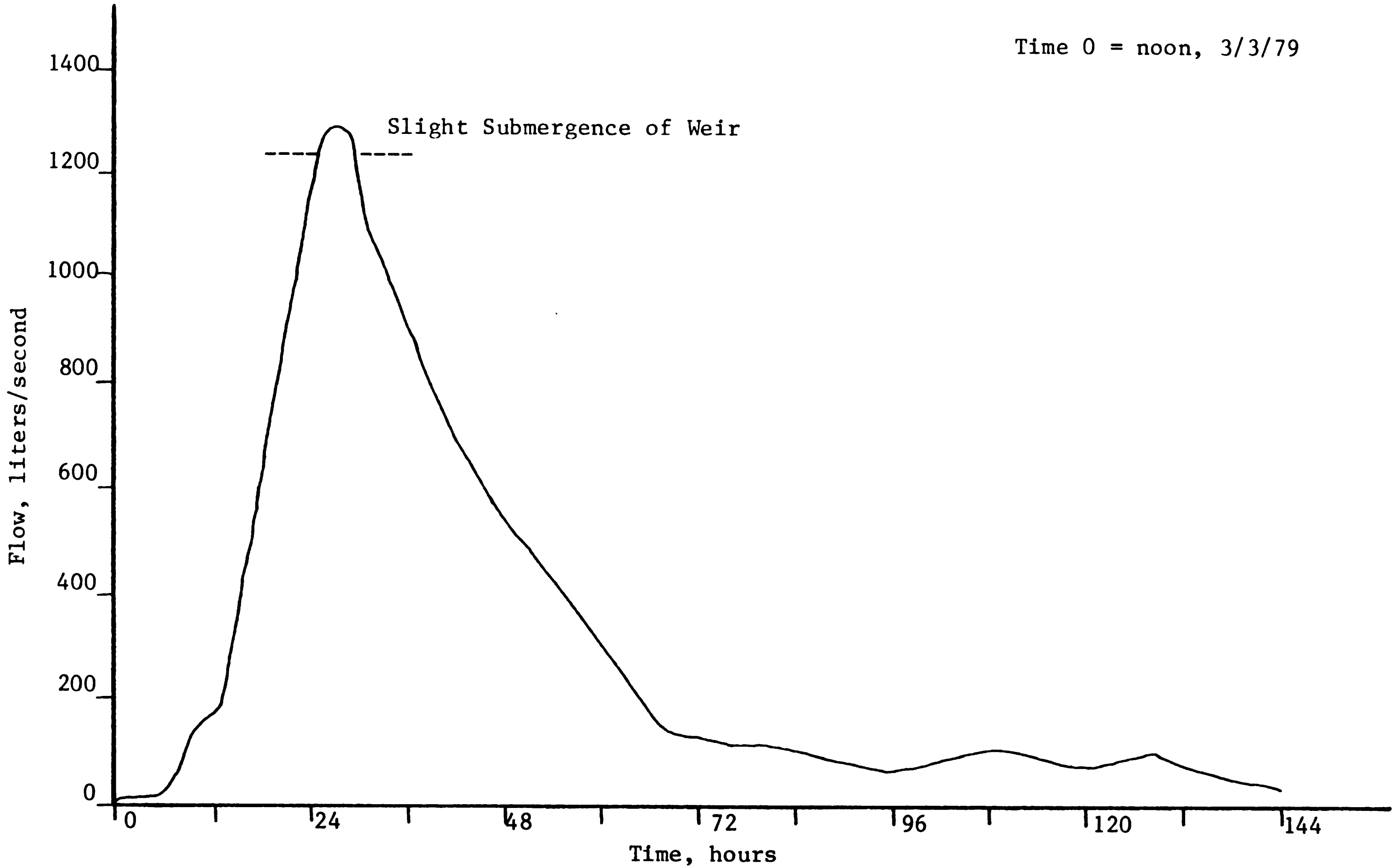

Figure 22. Stream Flow vs. Time, Event 1

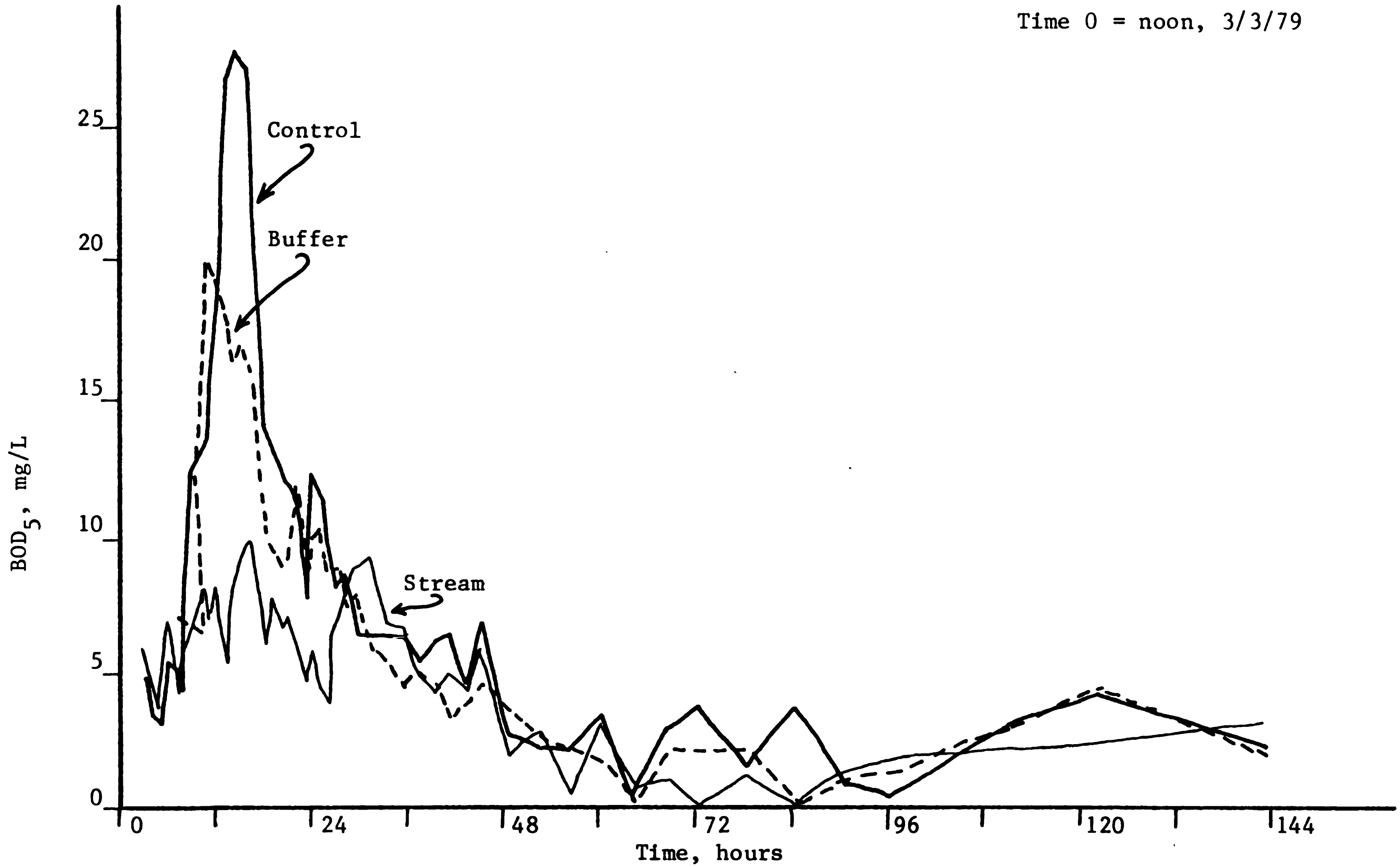

Figure 23. 5-day Biochemical Oxygen Demand vs. Time, Event 1

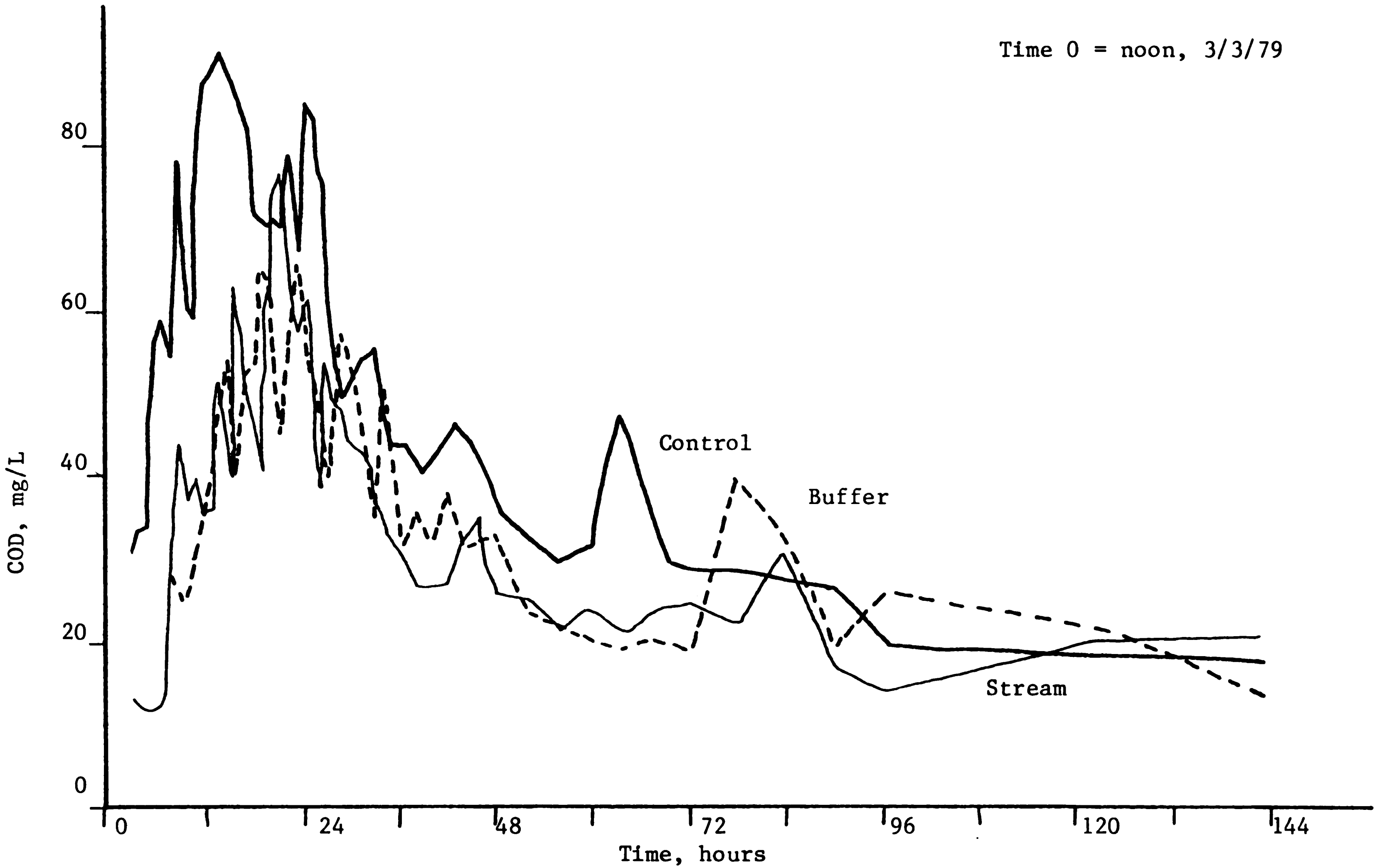

Figure 24. Chemical Oxygen Demand vs. Time, Event 1

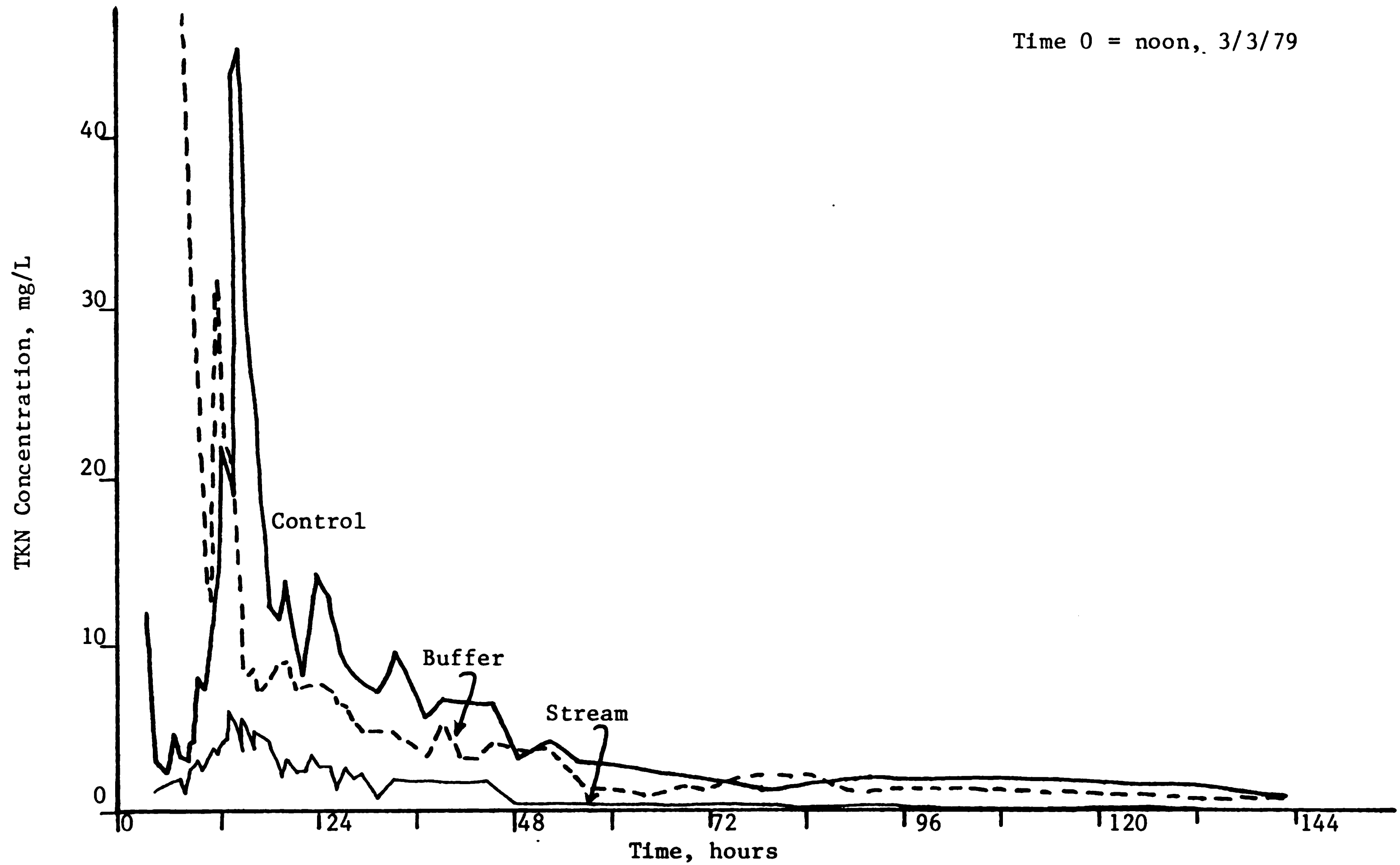

Figure 25. Total Kjeldahl Nitrogen Concentration vs. Time, Event 1

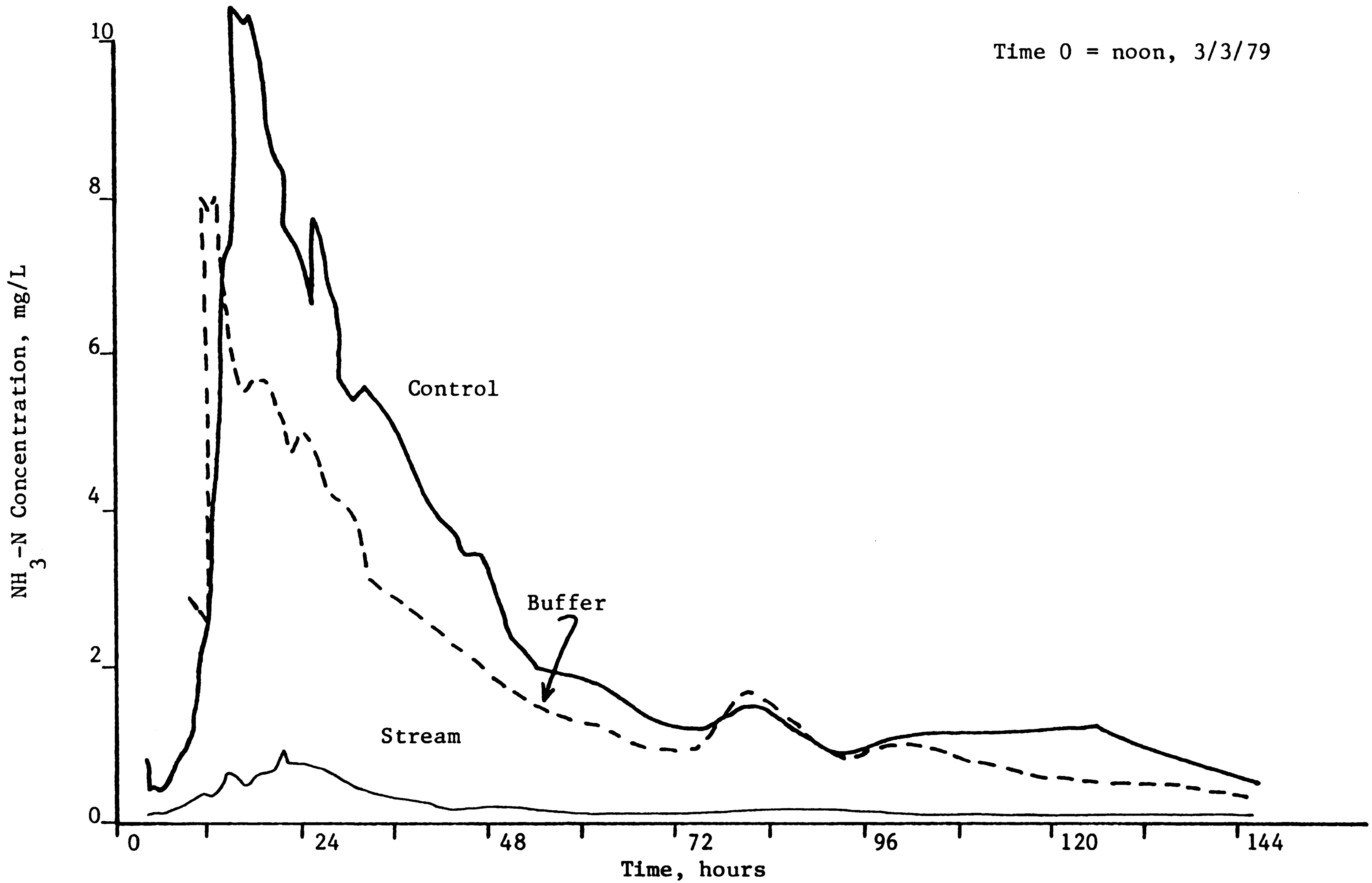

Figure 26. Ammonia-Nitrogen Concentration vs. Time, Event 1

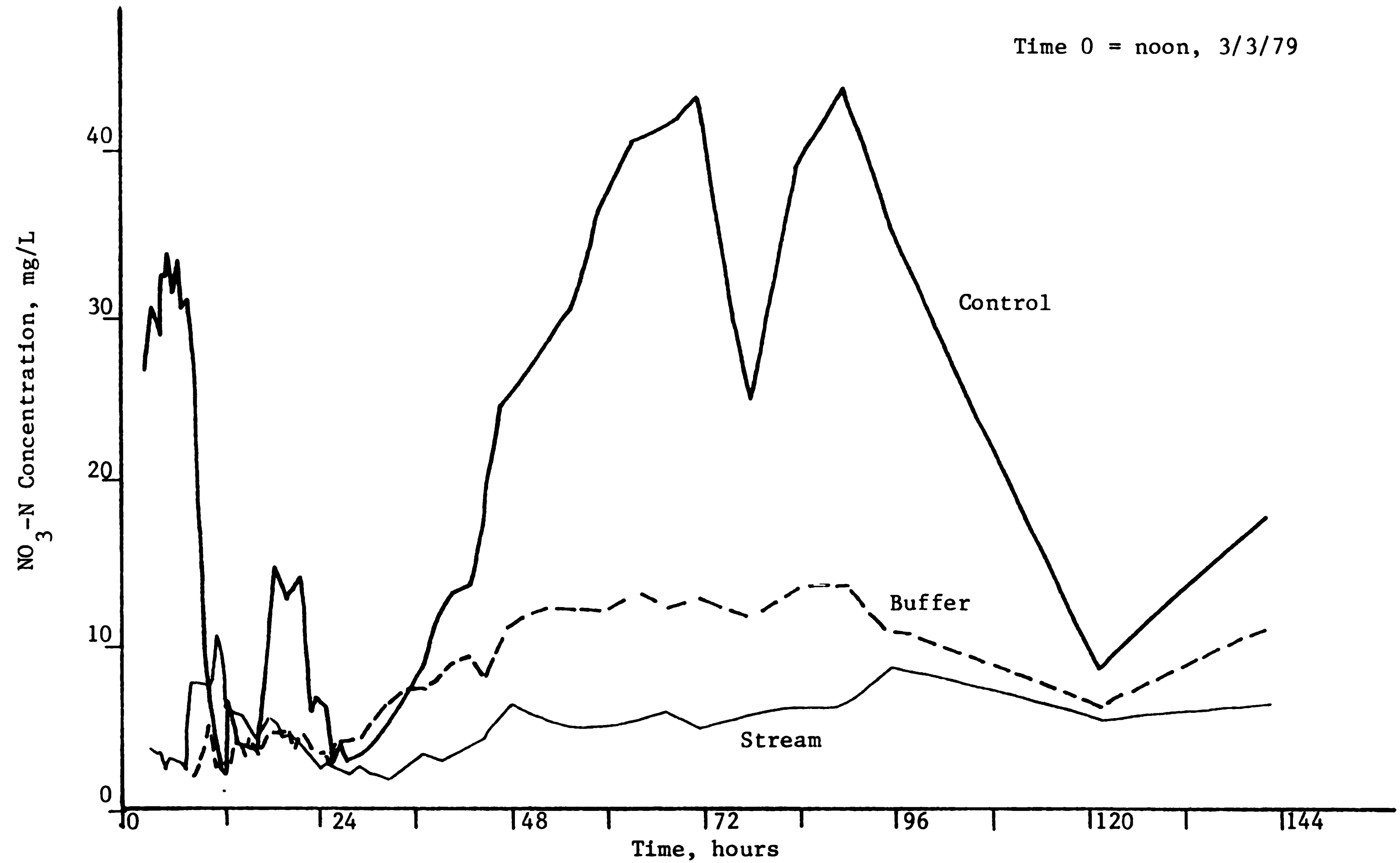

Figure 27. Nitrate-Nitrogen Concentration vs. Time, Event 1

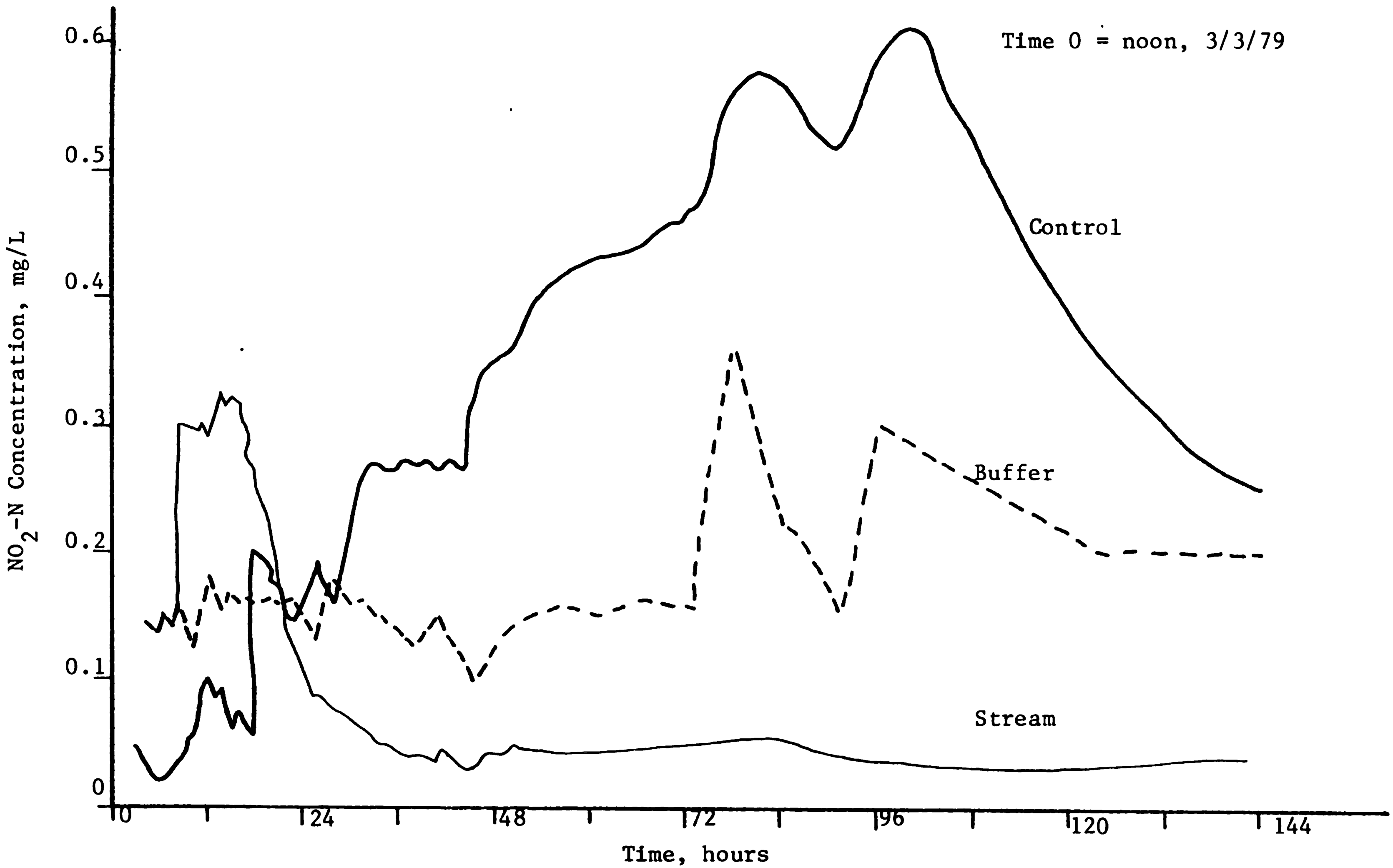

Figure 28. Nitrite-Nitrogen Concentration vs. Time, Event 1

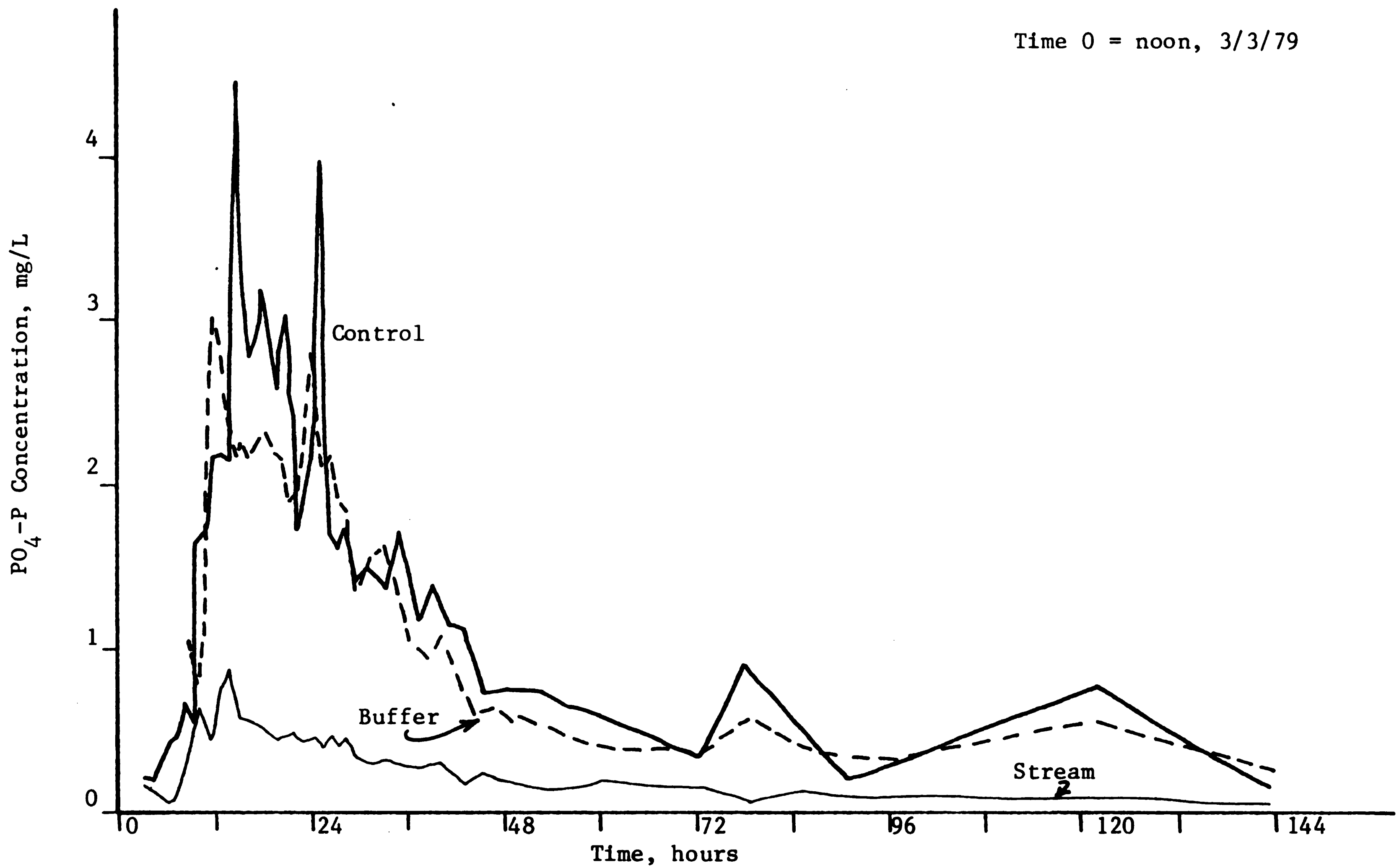

Figure 29. Total Phosphate Concentration vs. Time, Event 1

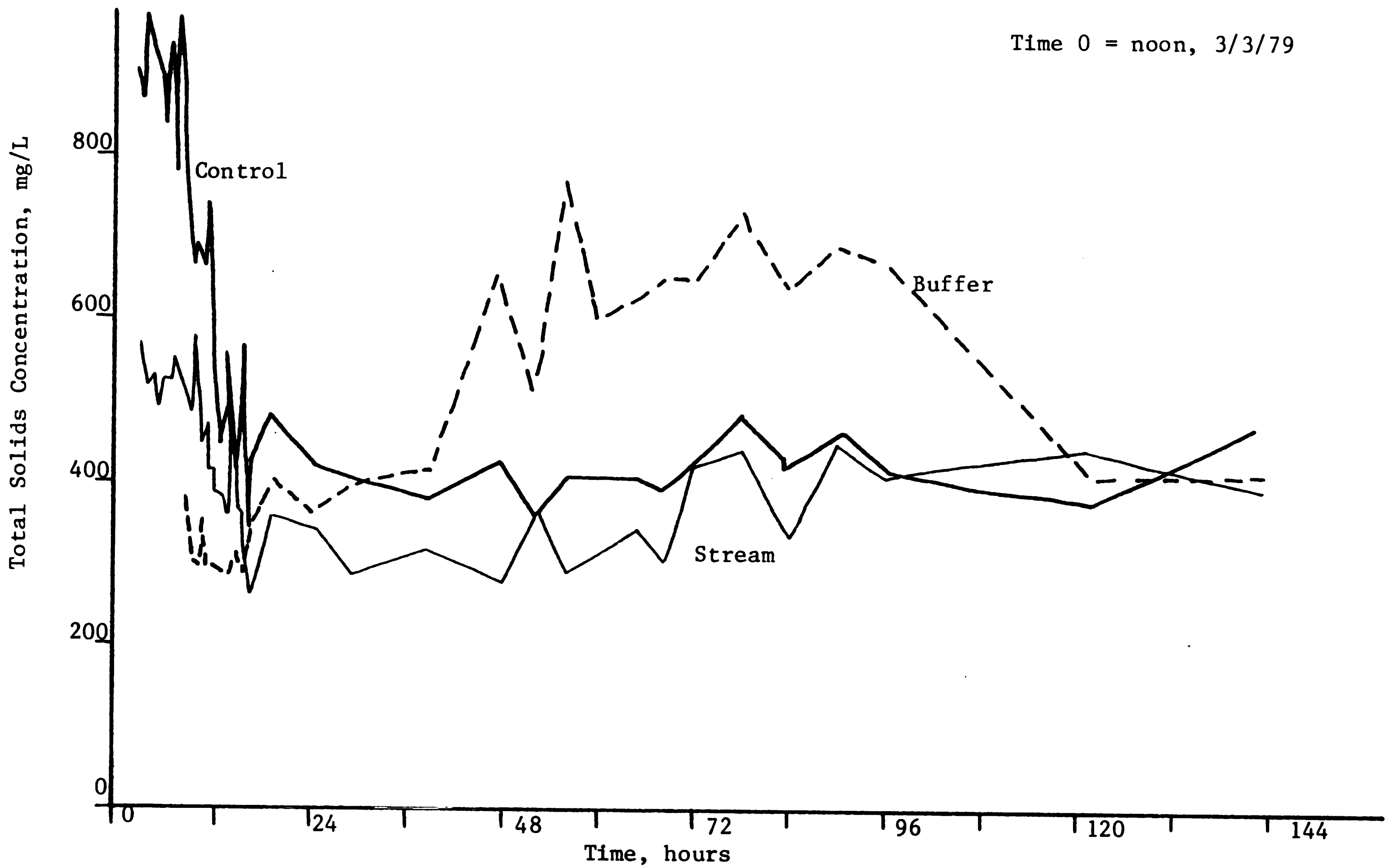

Figure 30. Total Solids Concentration vs. Time, Event 1

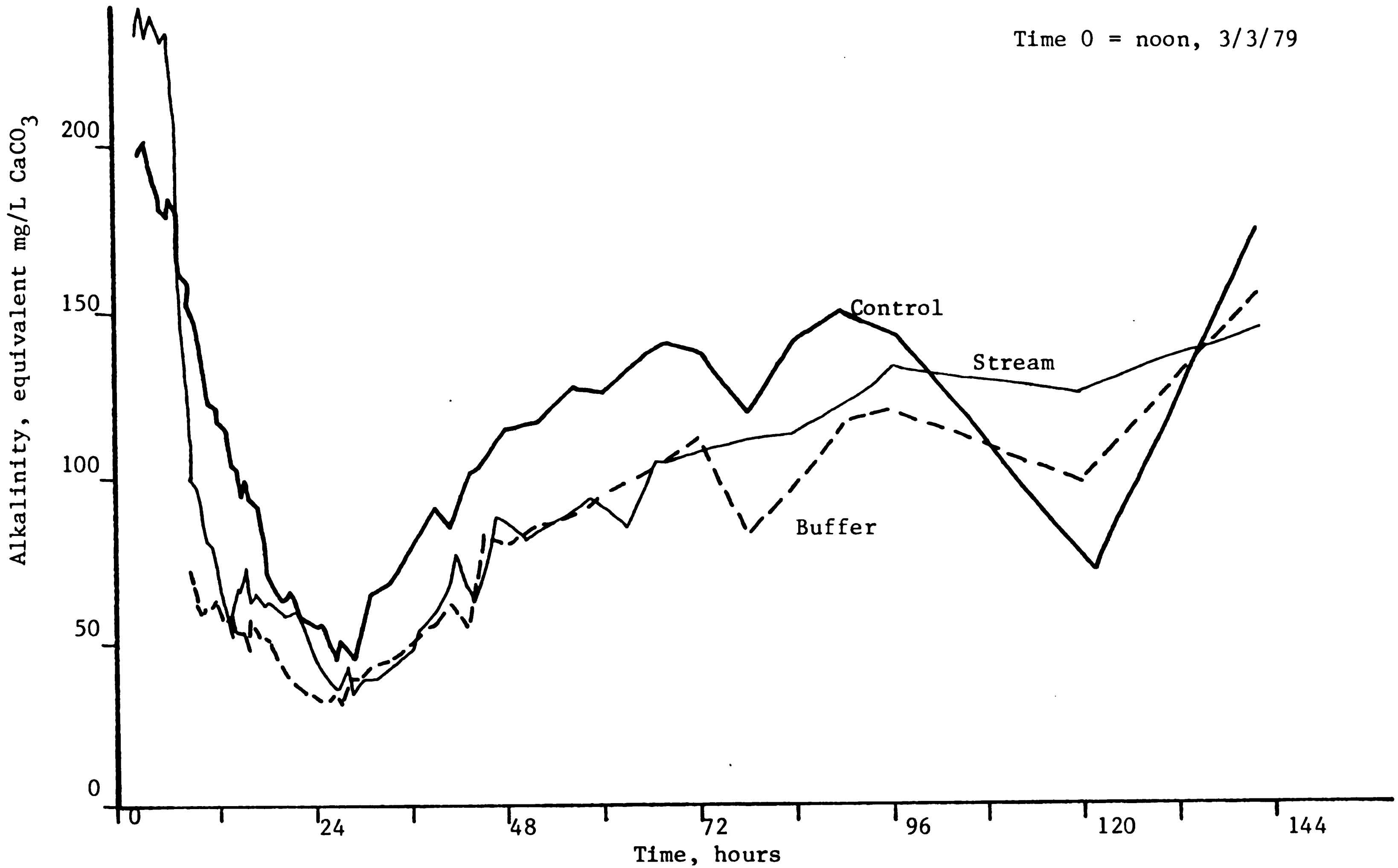

Figure 31. Alkalinity vs. Time, Event 1

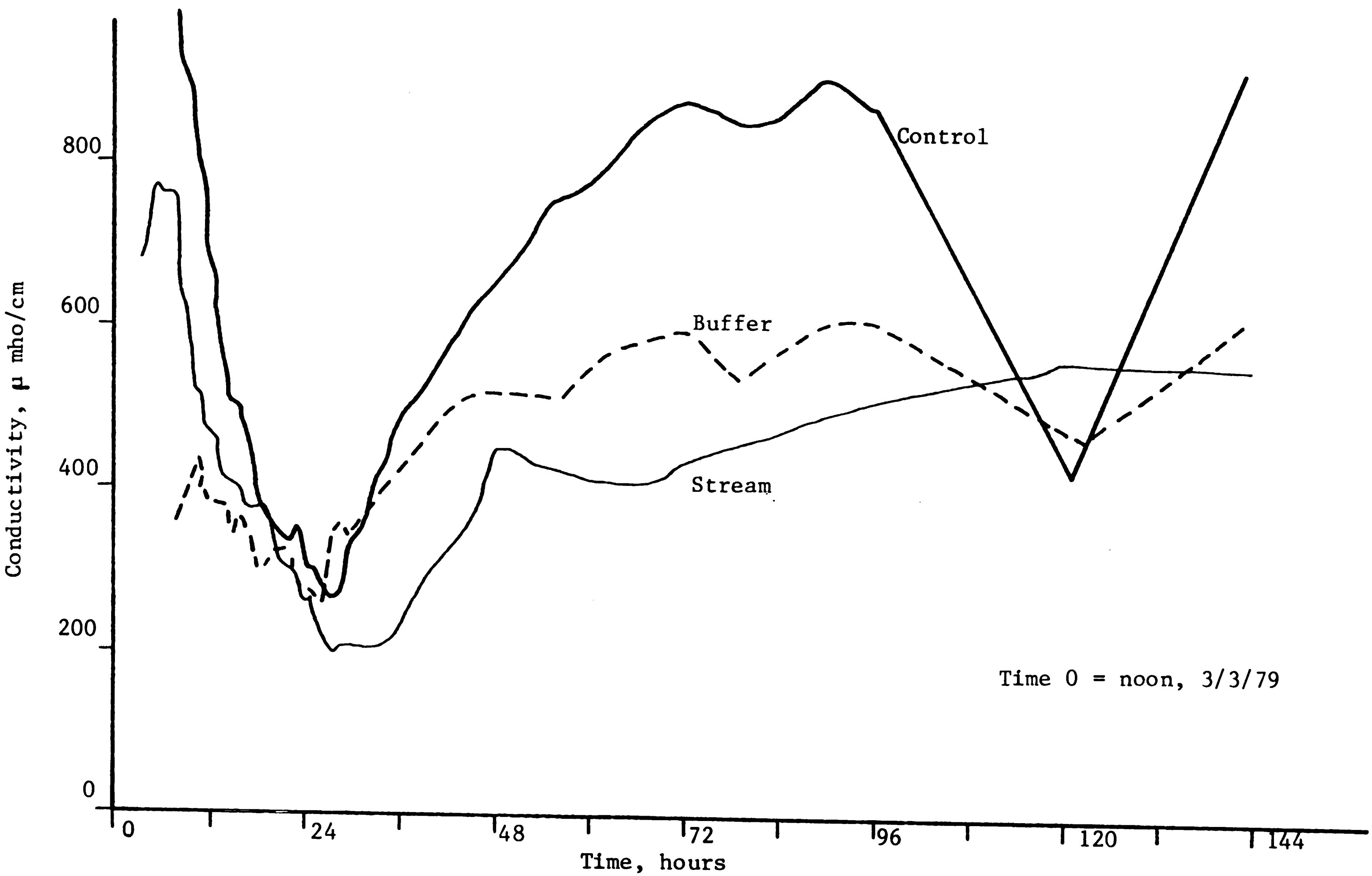

Figure 32. Conductivity vs. Time, Event 1

The runoff hydrographs for the control and buffered fields are quite similar in shape. The lag of five hours is apparent in the buffered field hydrograph. This is most likely due to the storage facilitated by the buffer area. Runoff volumes are consistent with the areas of the two drainage basins, the control field being some ten percent larger. Peak stream flow occurred about three hours after the peak runoff flows. The Cipolletti weir mounted in the streambed experienced slight submergence at the time of peak flow. Flow rates during the time period of this submergence are estimated.

Measured values of biochemical oxygen demand, chemical oxygen demand, total Kjeldahl nitrogen, ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, total phosphate, alkalinity, and conductivity were generally greater for the control field runoff than for the buffered field runoff. Total solids concentrations were consistently higher in the runoff from the control field from the beginning of the event through the peak flow period. Thereafter, the buffered field runoff exhibited higher concentrations. This was quite unexpected, but was probably due to a localized soil erosion problem which developed adjacent to the outlet weir in the buffer area. Little variation in pH was noted among the time-series runoff samples from each field or between the fields' runoff. Stream values for each of the constituents measured are generally lower than those of either of the runoff flows.

3.4.3. Runoff Event Two

The second major runoff event began just before 6:00 p.m. on March 29, 1979 and lasted for two days. Flow began entering the control field weir box approximately 30 minutes before runoff was detected at the buffered field weir box. The event was caused by somewhat saturated soil conditions and a rainstorm which began about 3 hours prior to runoff detection. The period of runoff was lengthened by a second rainstorm which began at about 7:00 p.m. on March 30. Both storms were of relatively mild intensity.

The automatic water samplers began operation shortly after runoff was detected. The sampler controllers were set to collect half-liter samples at 30-minute intervals. This sampling procedure was maintained for the 45-hour duration of this event. Data from this event are presented in Figures 33 through 45. The time designated as hour 0 on these figures is 6:00 p.m. on March 29, 1979.

As with the first runoff event, the shapes of the two runoff hydrographs are quite similar. A lag of about four hours between the runoff flow peak and the stream flow peak was observed, as was the previously mentioned half-hour lag in the start of runoff between the two fields. The second storm of this event resulted in a second peak in each of the hydrographs. Similar lags in flow, though less apparent, are seen between the two fields and between the fields and the stream. Measured chemical oxygen demand, concentrations of total Kjeldahl nitrogen, total phosphate, and total solids, and conductivity and alkalinity values were generally higher in the control field runoff than in runoff from the buffer area. Little difference was apparent between the two cropland watershed in terms of the 5-day biochemical oxygen demand or ammonia-nitrogen concentration found for the samples analyzed.

The concentration versus time curves of this runoff event for nitrate-nitrogen are of particular interest. Runoff nitrate levels are quite low (0.4-3.0 mg/L) and are relatively constant from the beginning of the event through the first peak of the hydrograph. Nitrate concentrations

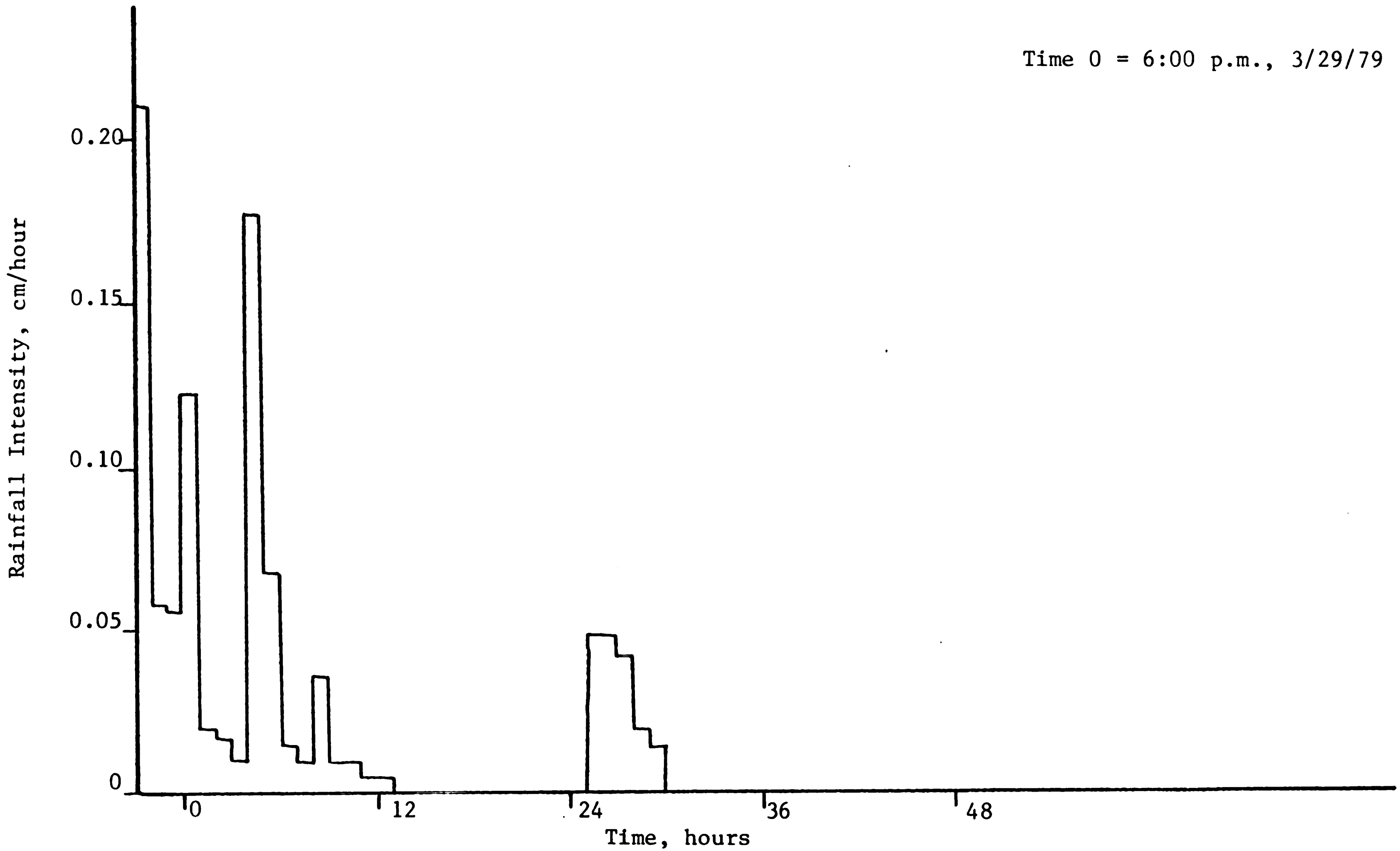

Figure 33. Rainfall Intensity vs. Time, Event 2

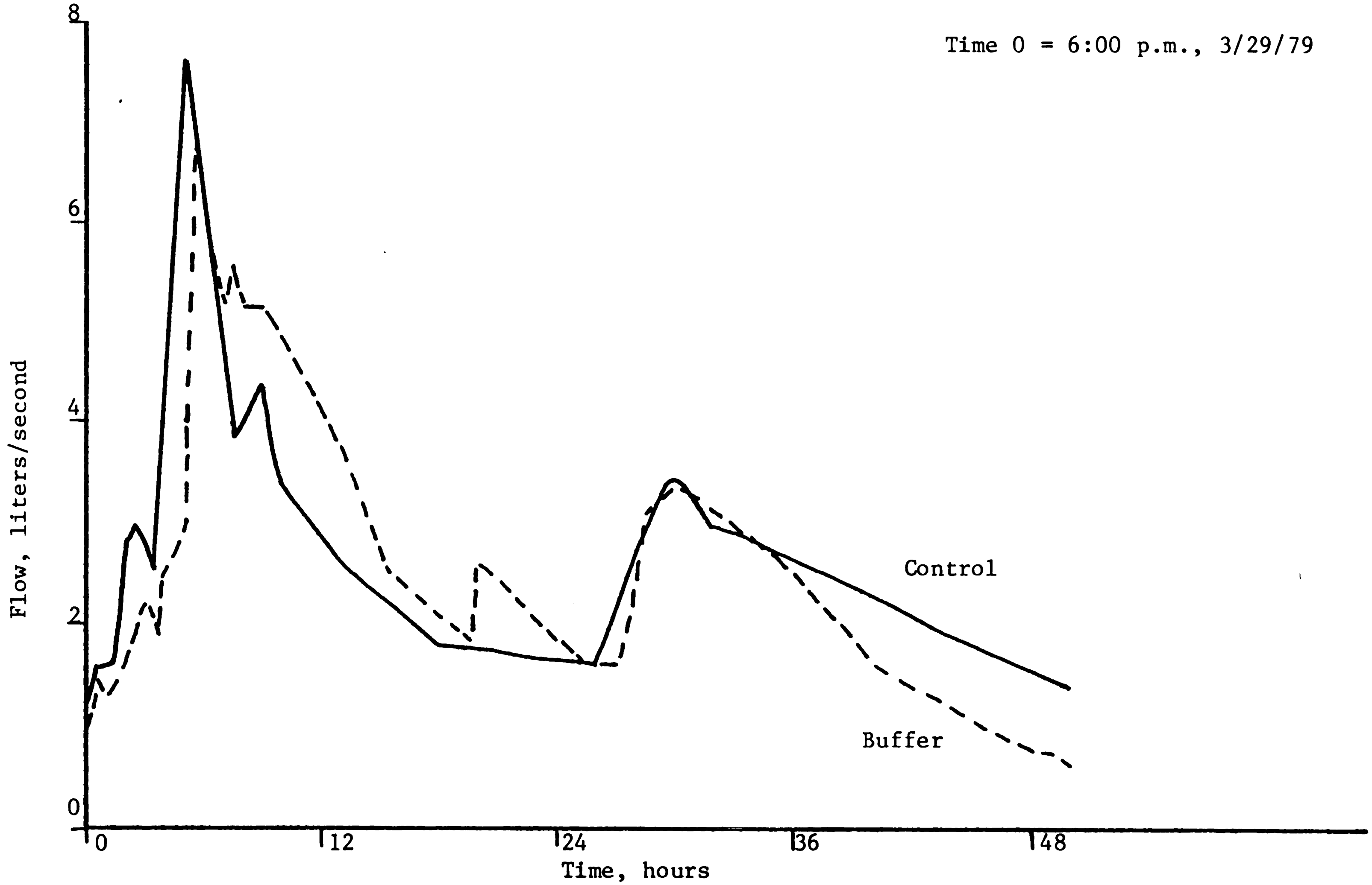

Figure 34. Runoff Flow vs. Time, Event 2

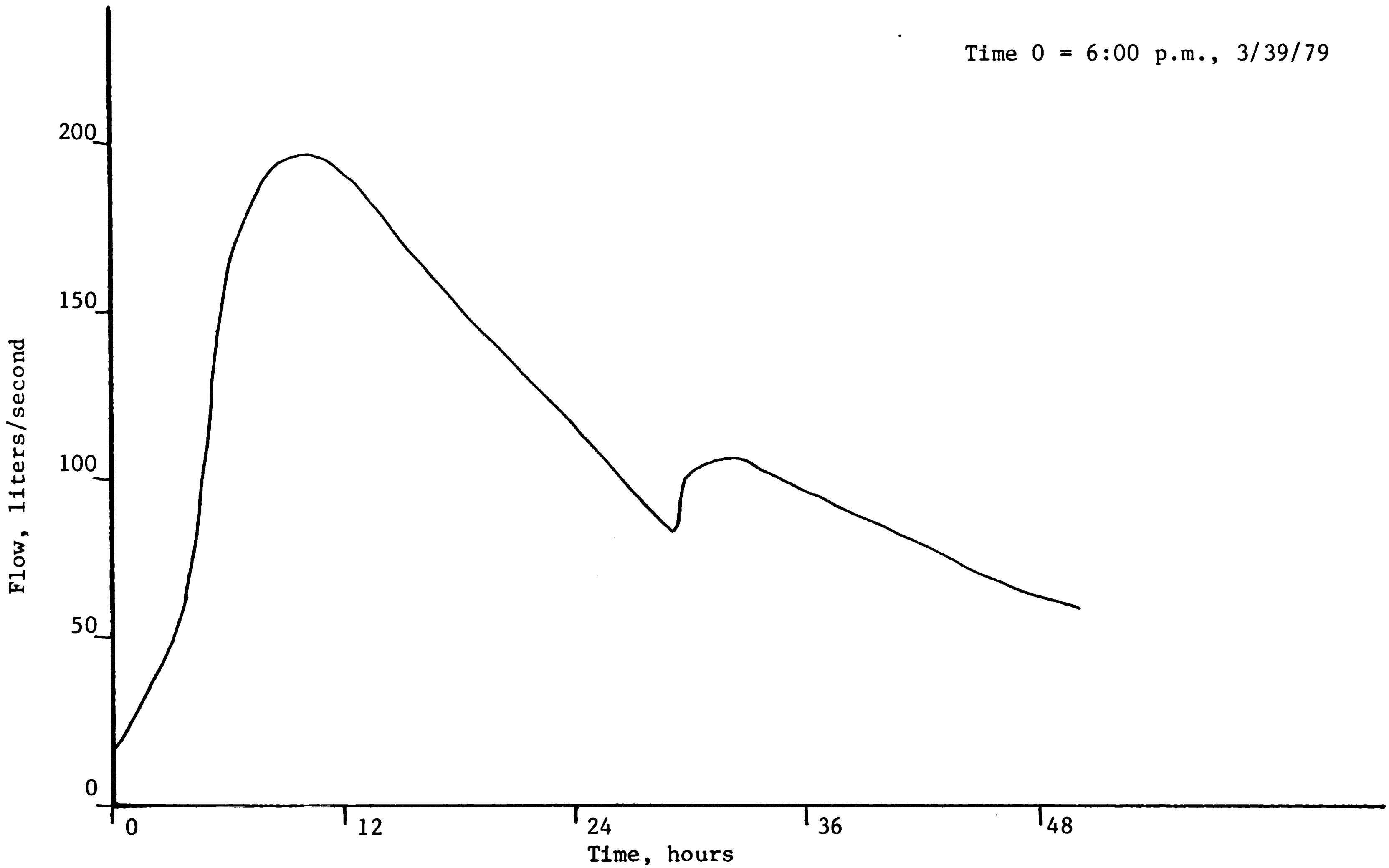

Figure 35. Stream Flow vs. Time, Event 2

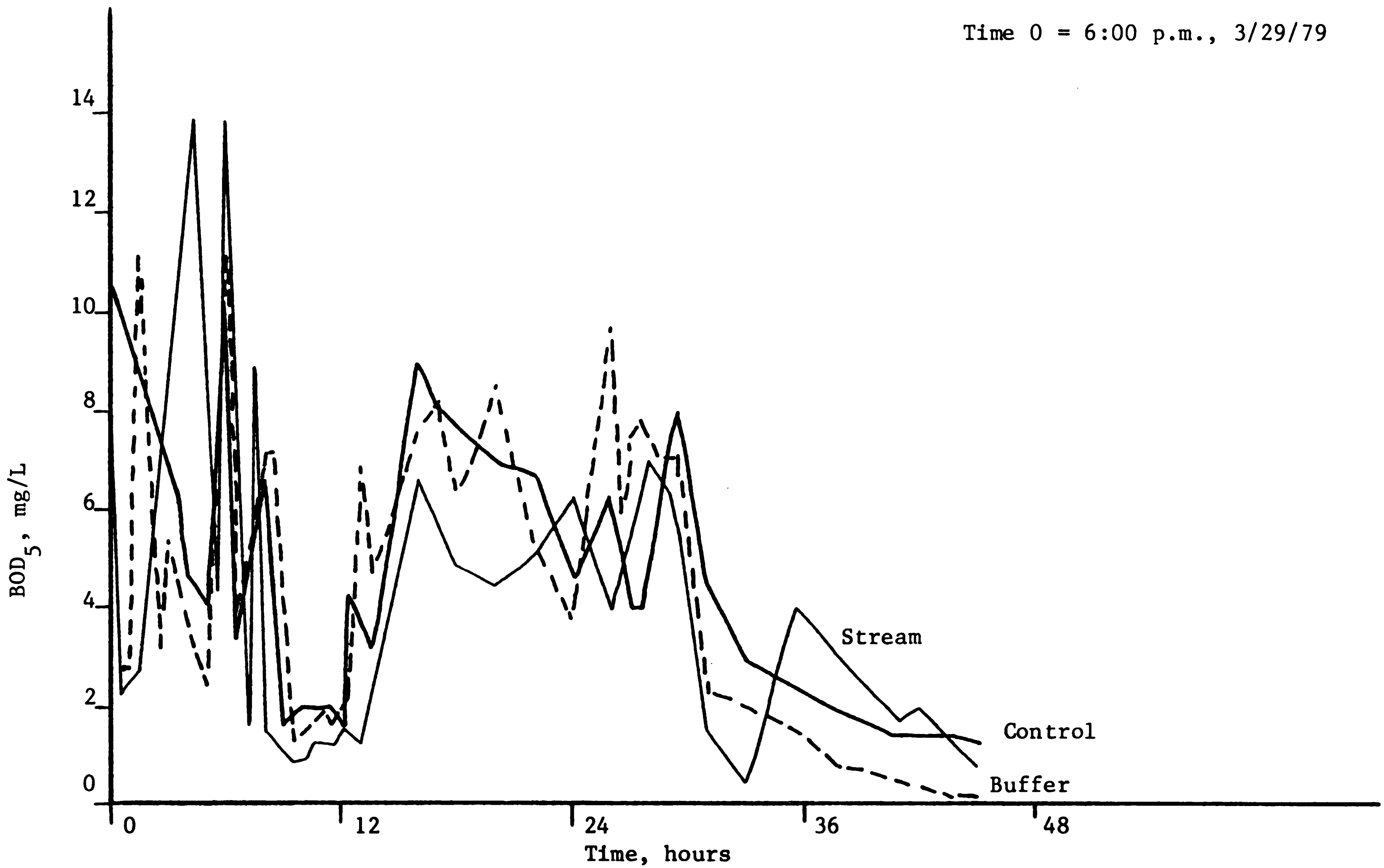

Figure 36. 5-day Biochemical Oxygen Demand vs. Time, Event 2

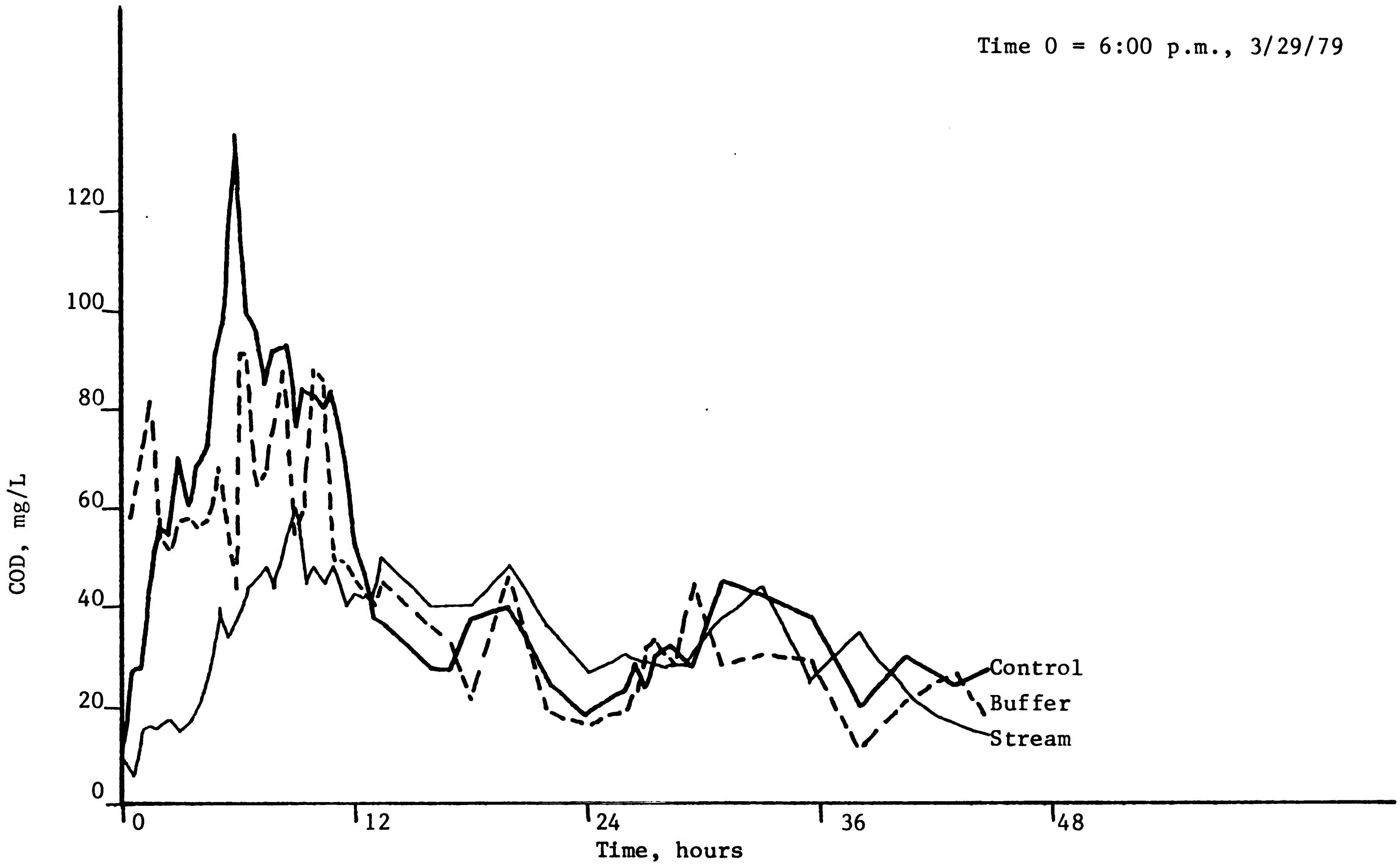

Figure 37. Chemical Oxygen Demand vs. Time, Event 2

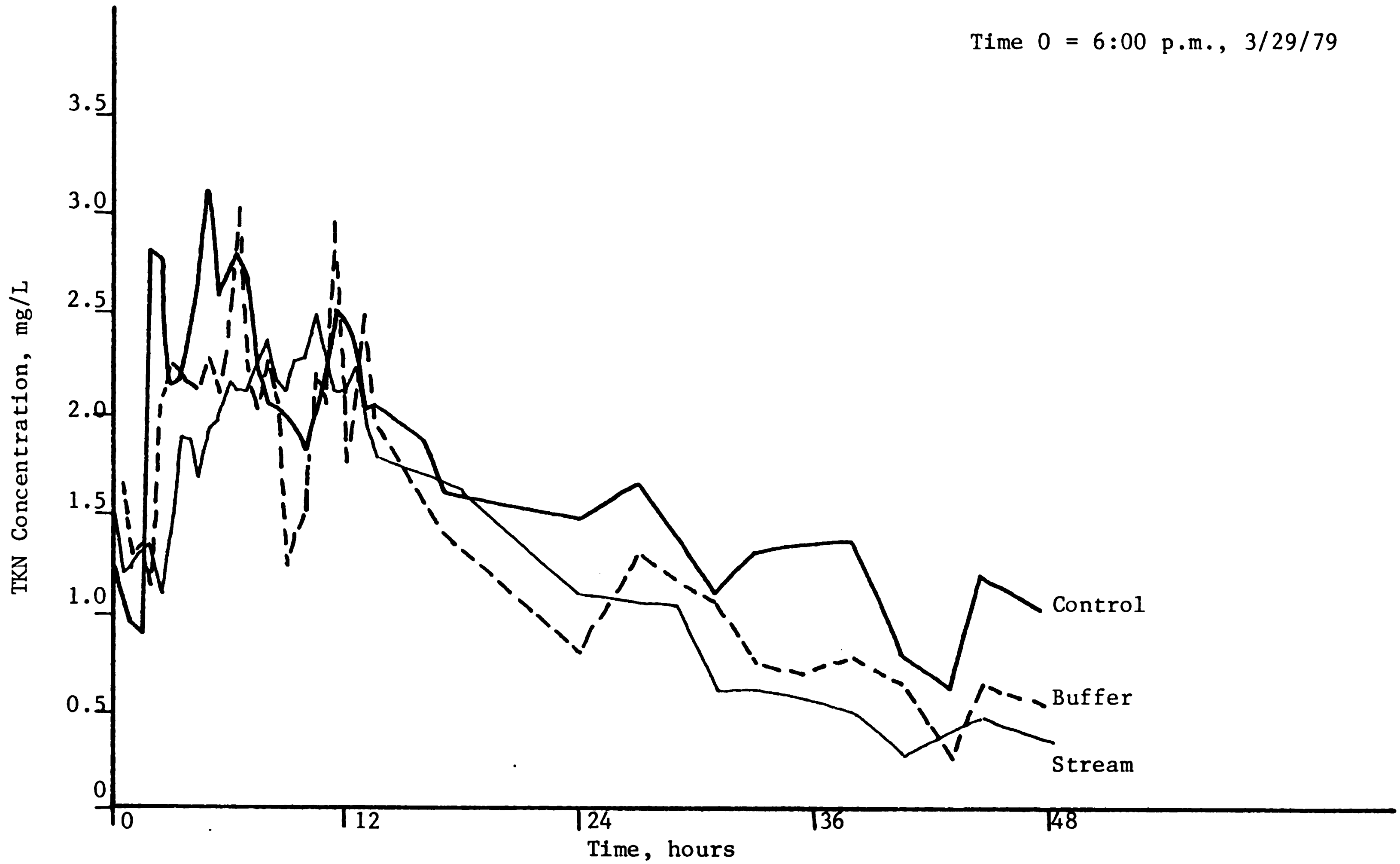

Figure 38. Total Kjeldahl Nitrogen Concentration vs. Time, Event 2

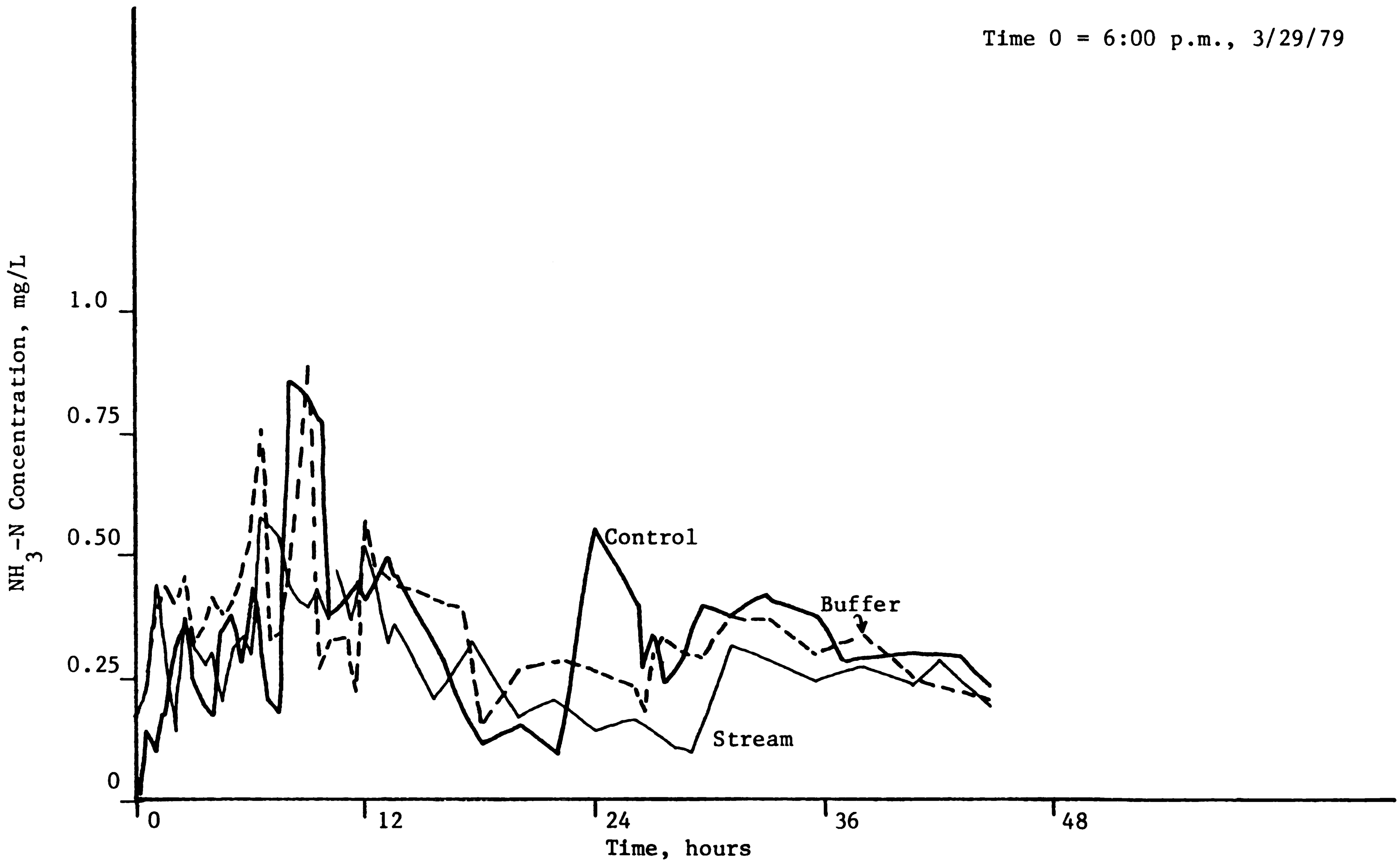

Figure 39. Ammonia-Nitrogen Concentration vs. Time, Event 2

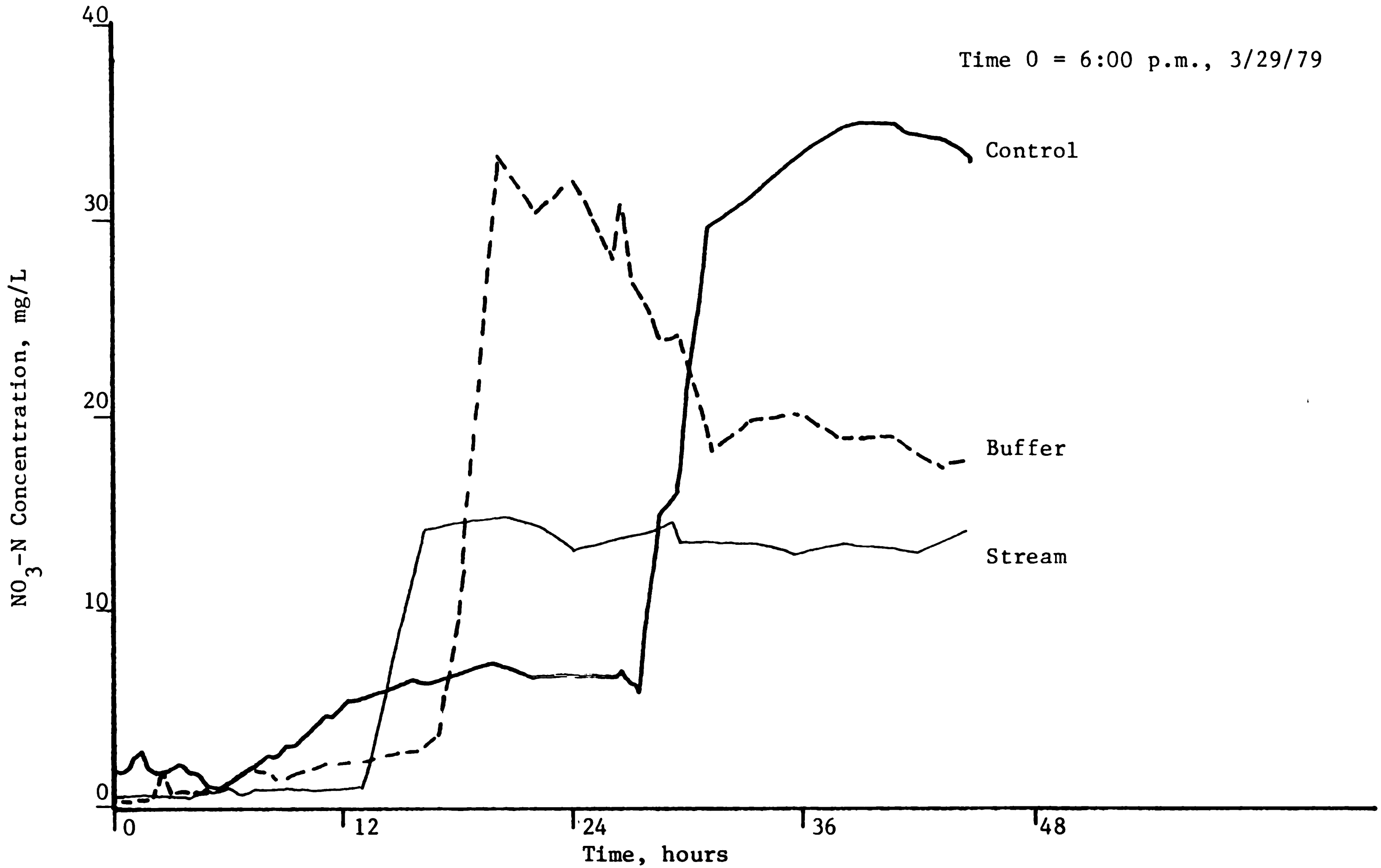

Figure 40. Nitrate-Nitrogen Concentration vs. Time, Event 2

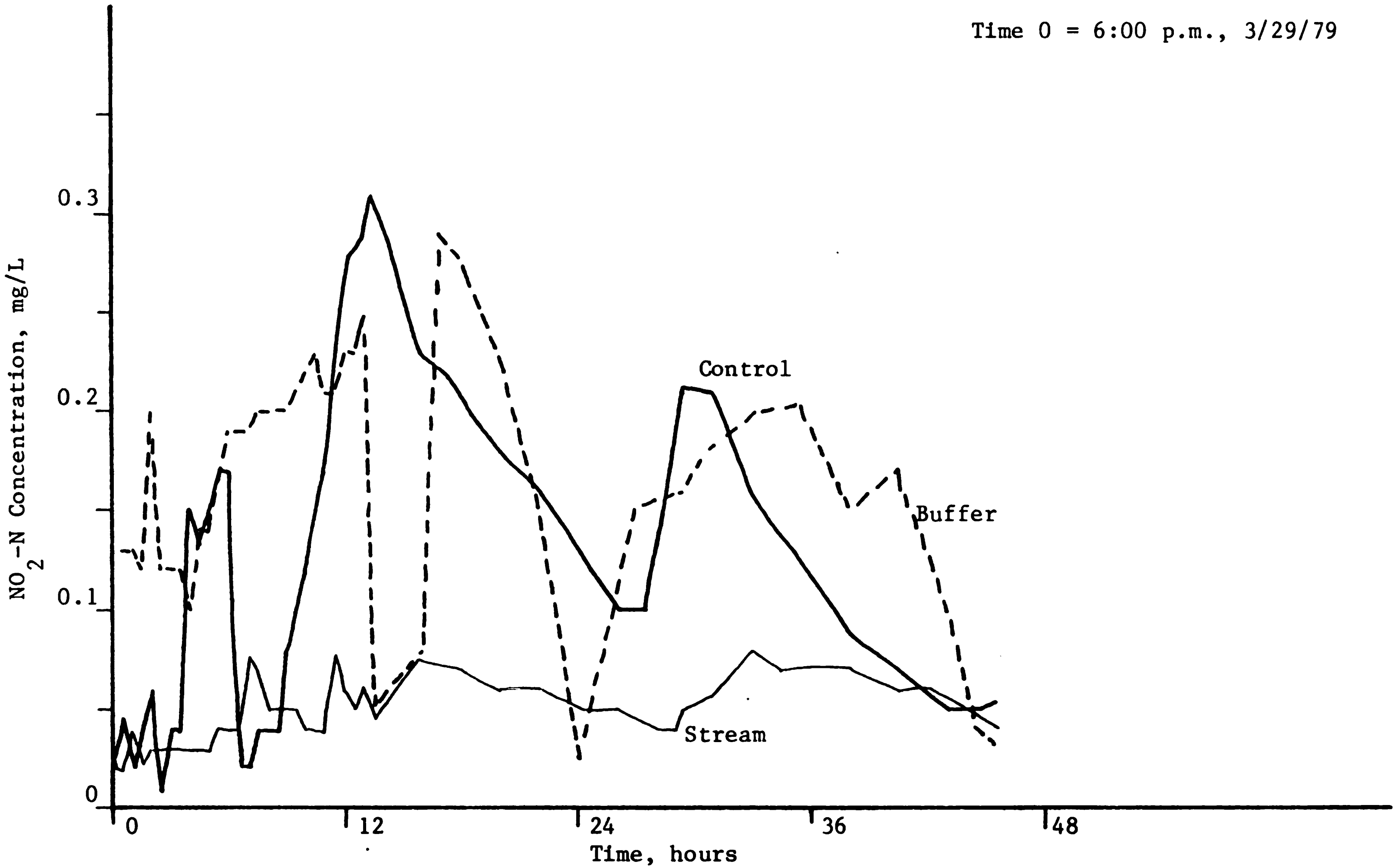

Figure 41. Nitrite-Nitrogen Concentration vs. Time, Event 2

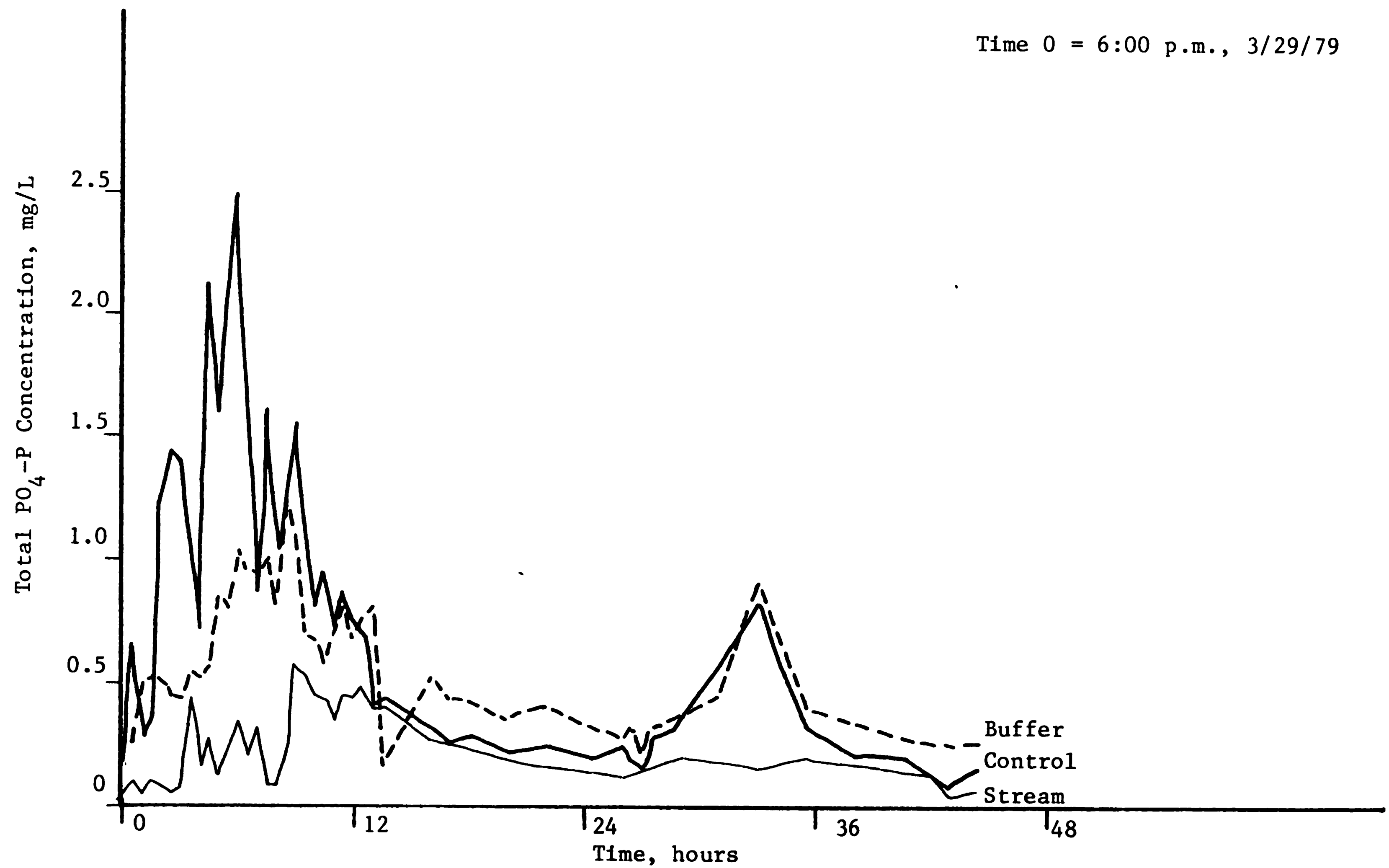

Figure 42. Total Phosphate Concentration vs. Time, Event 2

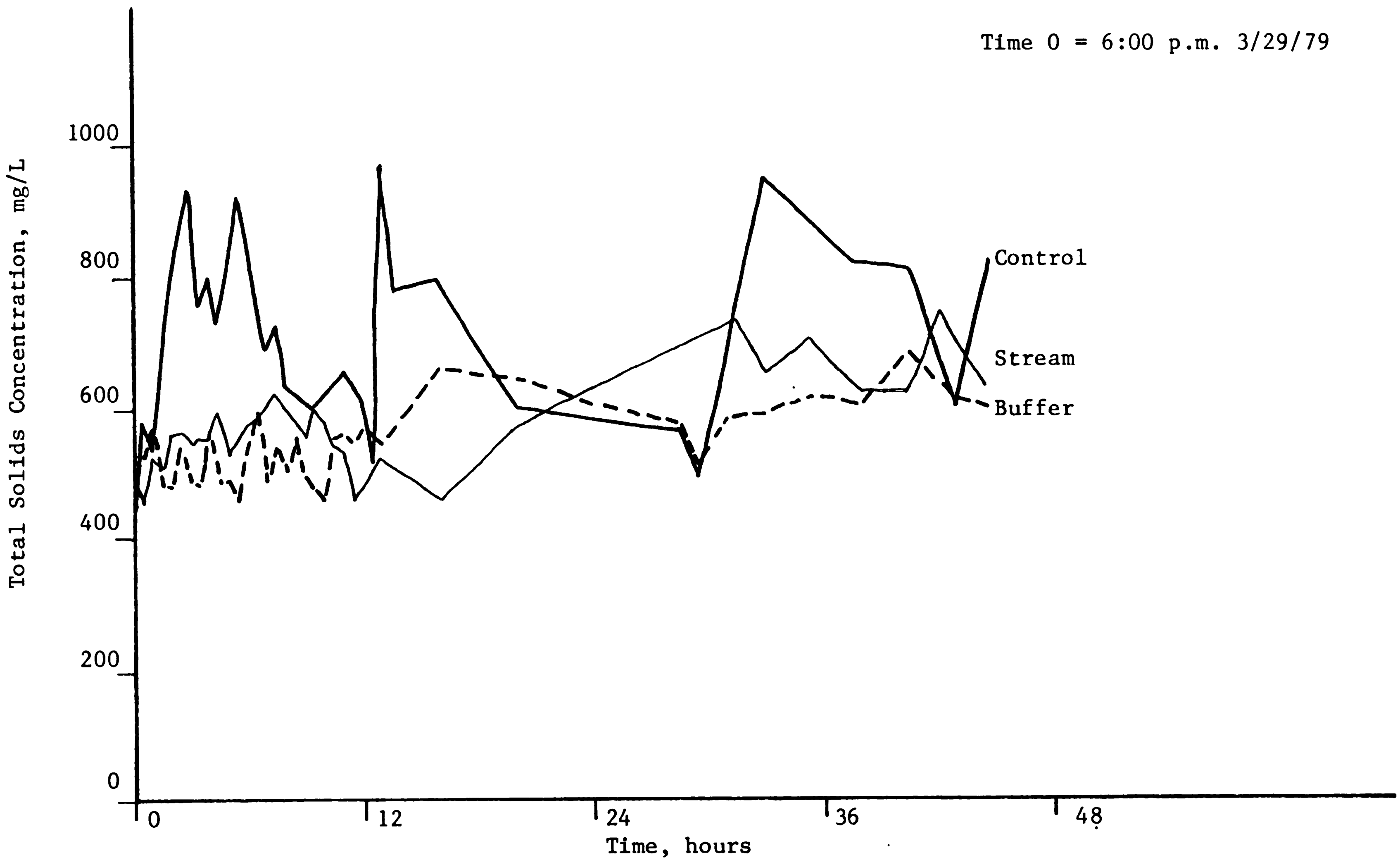

Figure 43. Total Solids Concentration vs. Time, Event 2

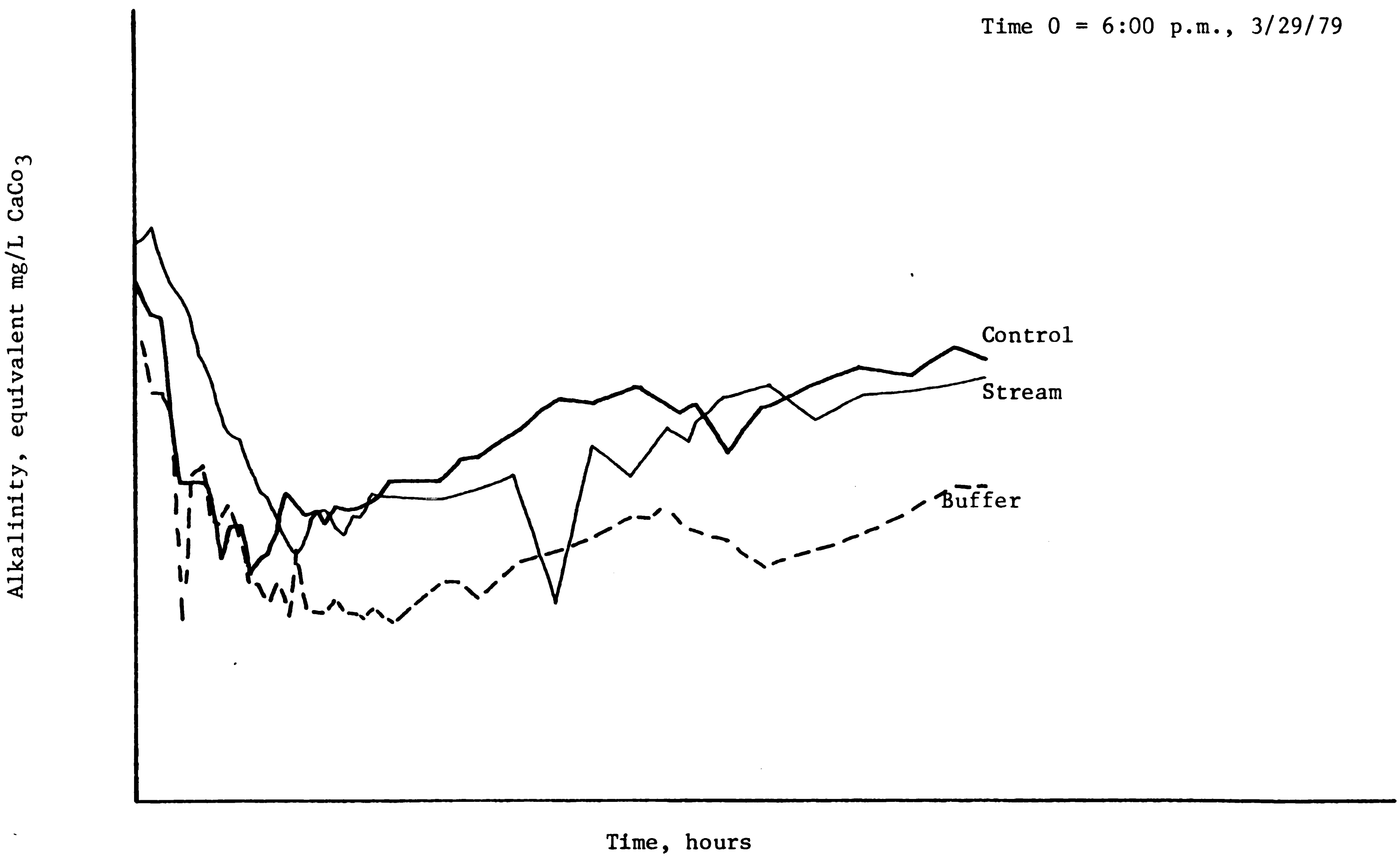

Figure 44. Alkalinity vs. Time, Event 2

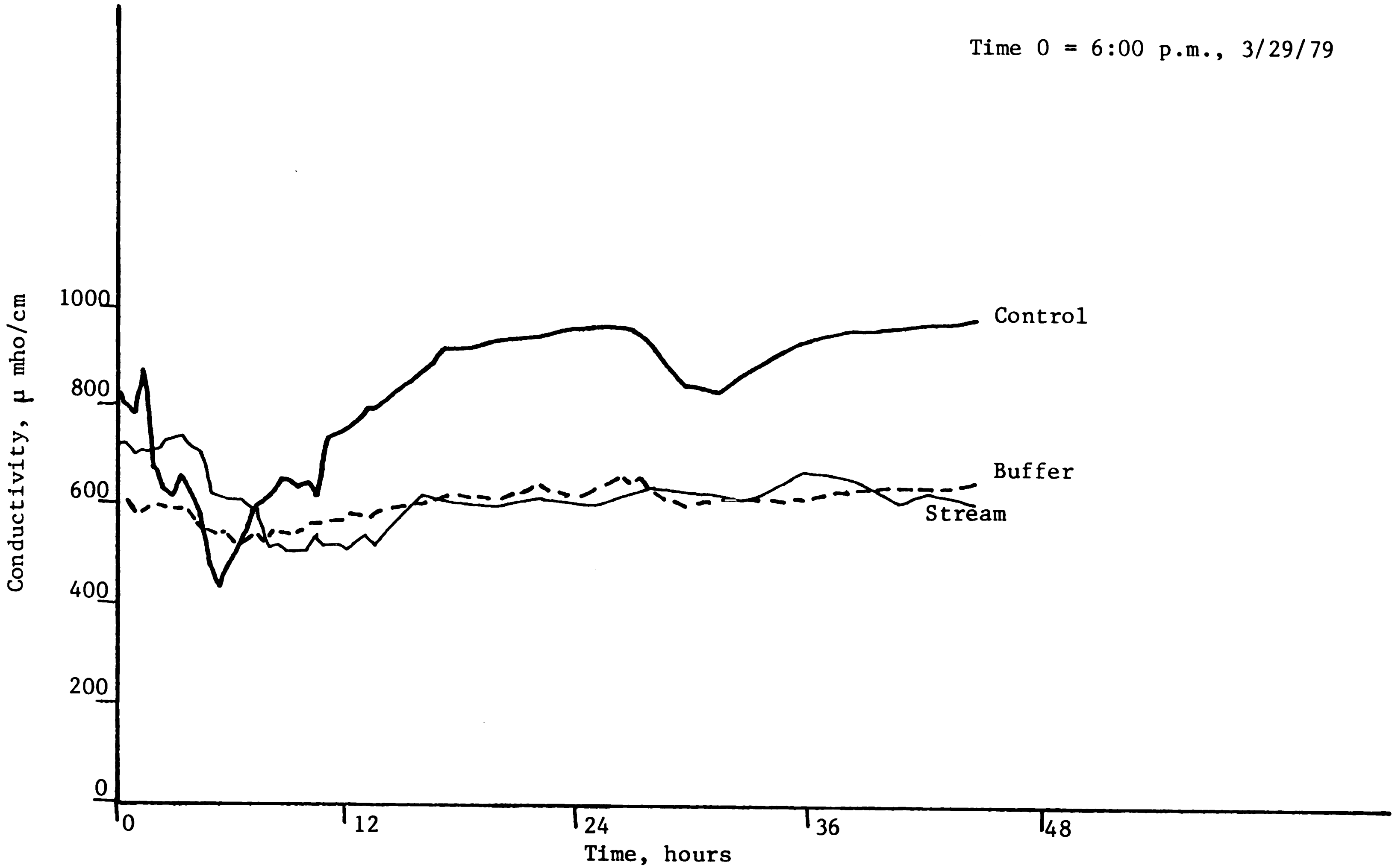

Figure 45. Conductivity vs. Time, Event 2

then begin to increase slowly with the decreasing flow. The increase is somewhat greater in the control runoff from about hour 8 through hour 17, at which time a substantial and rapid increase in nitrate-nitrogen levels occurs in the buffered field runoff. No such increase is seen in the control field runoff until about hour 27, when flow rates increase in response to the previously mentioned second storm. These nitrate-nitrogen concentraion increases are quite similar in rate and magnitude, but occur at difference times under different flow conditions.

The nitrite-nitrogen data are also quite interesting and unusual. Concentrations measured in runoff samples from the control field are graphed, as a function of time, as a curve with a series of three peaks. The first and third peaks correspond quite closely with the two rising portions of the hydrograph. The second peak, however, with maximum values of some 50 to 60 percent greater than those of the other peaks, occurs during the low flow period between storms. The buffer area runoff also exhibits a series of three peaks in nitrite-nitrogen concentration when plotted against time. While of similar magnitude, these peaks are generally more sustained through time and lag the three corresponding peaks in the curve for the control field.

Again, only slight variation was seen in pH values between samples and between fields. Stream concentrations for most of the various constituents monitored, unlike the previous runoff event, are quite comparable to the concentrations measured in the runoff. The only real exceptions are found with nitrate-nitrogen, nitrite-nitrogen, chemical oxygen demand, and total phosphate levels.

3.4.4. Runoff Event Three

A low-intensity and intermittent rainfall on the evening of April 1, 1979, aided by the moist antecedent condition of the soil

surface, caused the third major runoff event. The rainstorm began at about 9:00 p.m., and runoff was first detected at the monitoring stations shortly before 5:00 a.m. on April 2. Precipitation intermittently continued until about 3:00 a.m. on April 3, and runoff continued until about 9:00 a.m. on April 3.

The first water samples were automatically collected at 5:00 a.m. on April 2, and samples were collected at 30-minute intervals for the next 28 hours. All samples taken on the rising hydrograph were subjected to laboratory testing. Samples taken as flows subsided were selectively analyzed, with analyses performed on every third or fourth sample. Data from this event are presented in Figures 46 through 58. The time designated as hour 0 in these figures corresponds to 5:00 a.m. on April 2, 1979.

The runoff hydrographs for the two cropland watersheds are again quite similar in shape. Water yield from the control watershed appears to be more than would be expected due to its approximately ten percent greater area, as compared to the buffered watershed. The lag between the two fields in the time of runoff initiation is not noticed with this event, though the magnitudes of early flows are greater at the control monitoring station than from the buffer area. The peak of the stream flow hydrograph, as seen before, occurred several hours after the maximum runoff flows.

Nitrate-nitrogen, total phosphate, alkalinity, and conductivity values were consistently lower in the runoff from the buffered field than from the control field. The concentrations of the other water quality parameters for the two watersheds are quite comparable, though control field levels are generally greater during the period of peak runoff flow. Pollutant concentrations observed in the stream are in the same range,

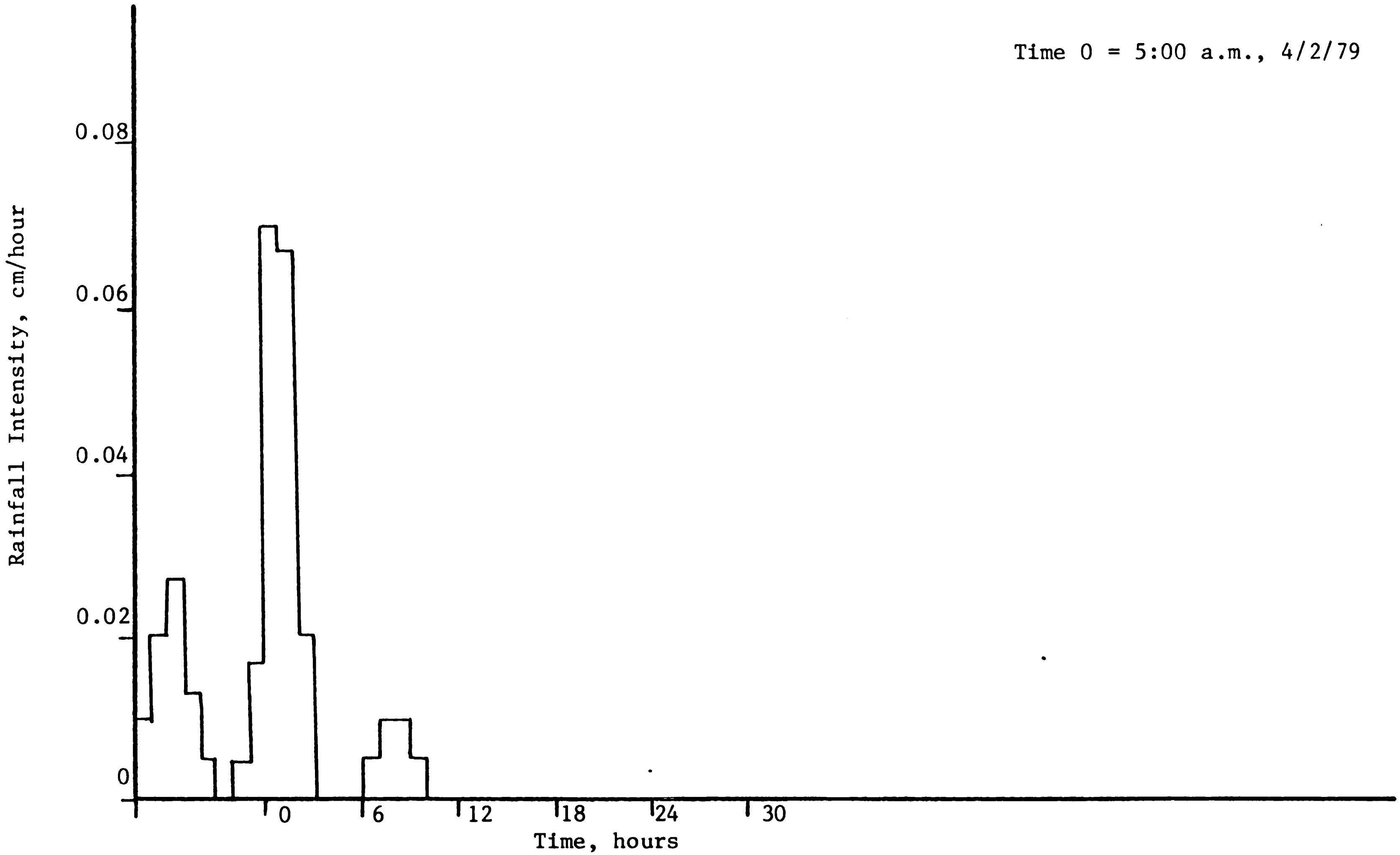

Figure 46. Rainfall Intensity vs. Time, Event 3

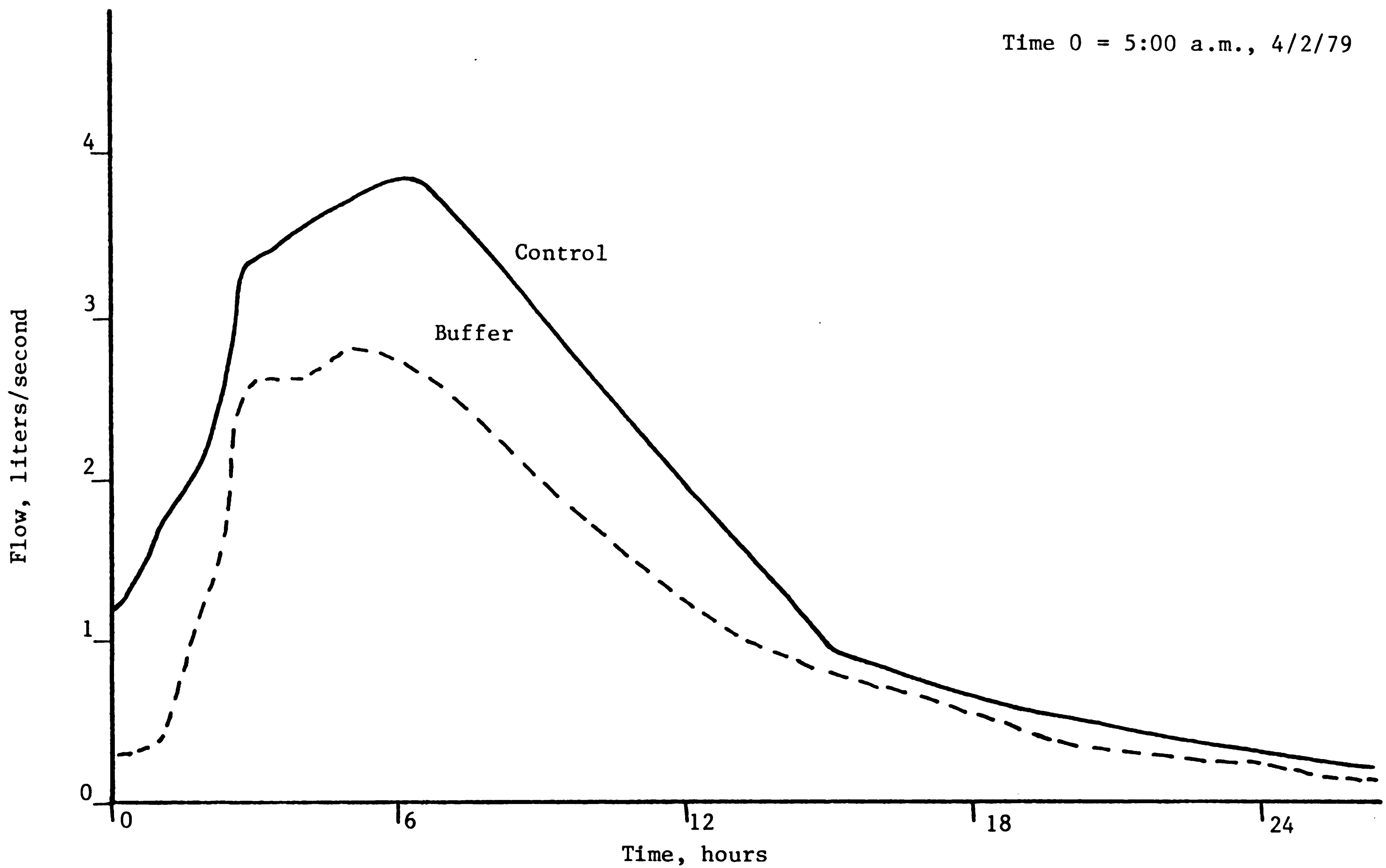

Figure 47. Runoff Flow vs. Time, Event 3

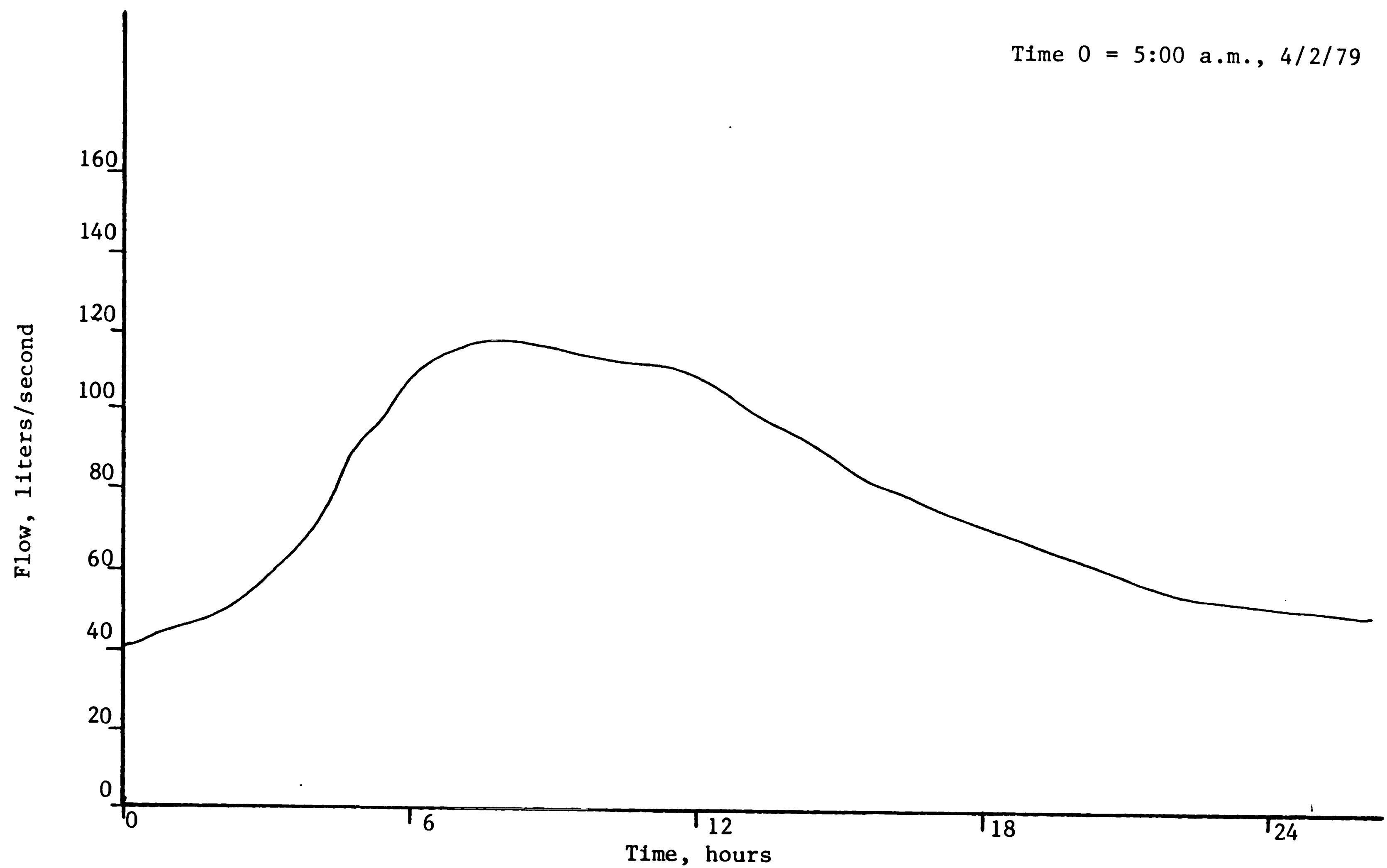

Figure 48. Stream Flow vs. Time, Event 3

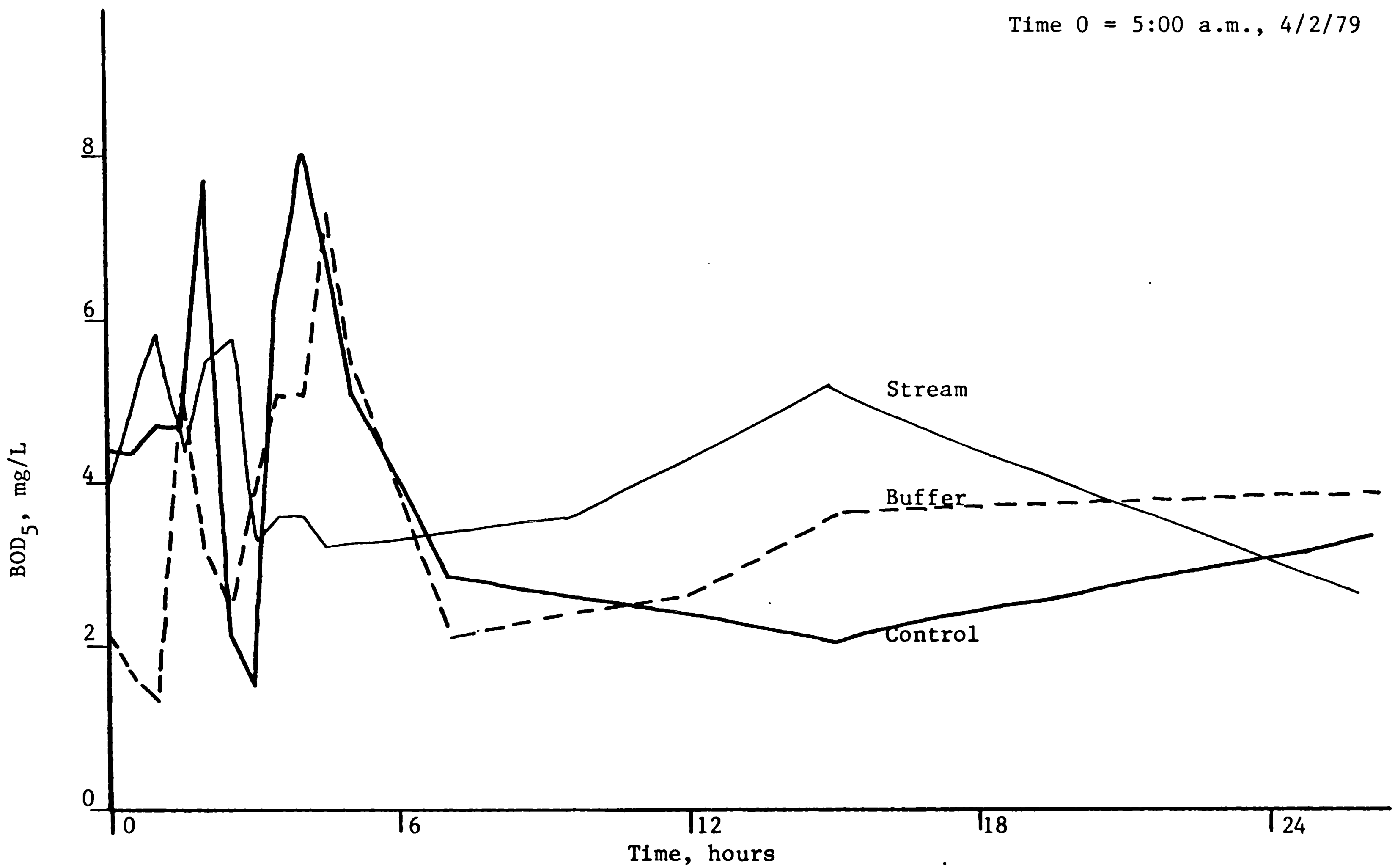

Figure 49. 5-day Biochemical Oxygen Demand vs. Time, Event 3

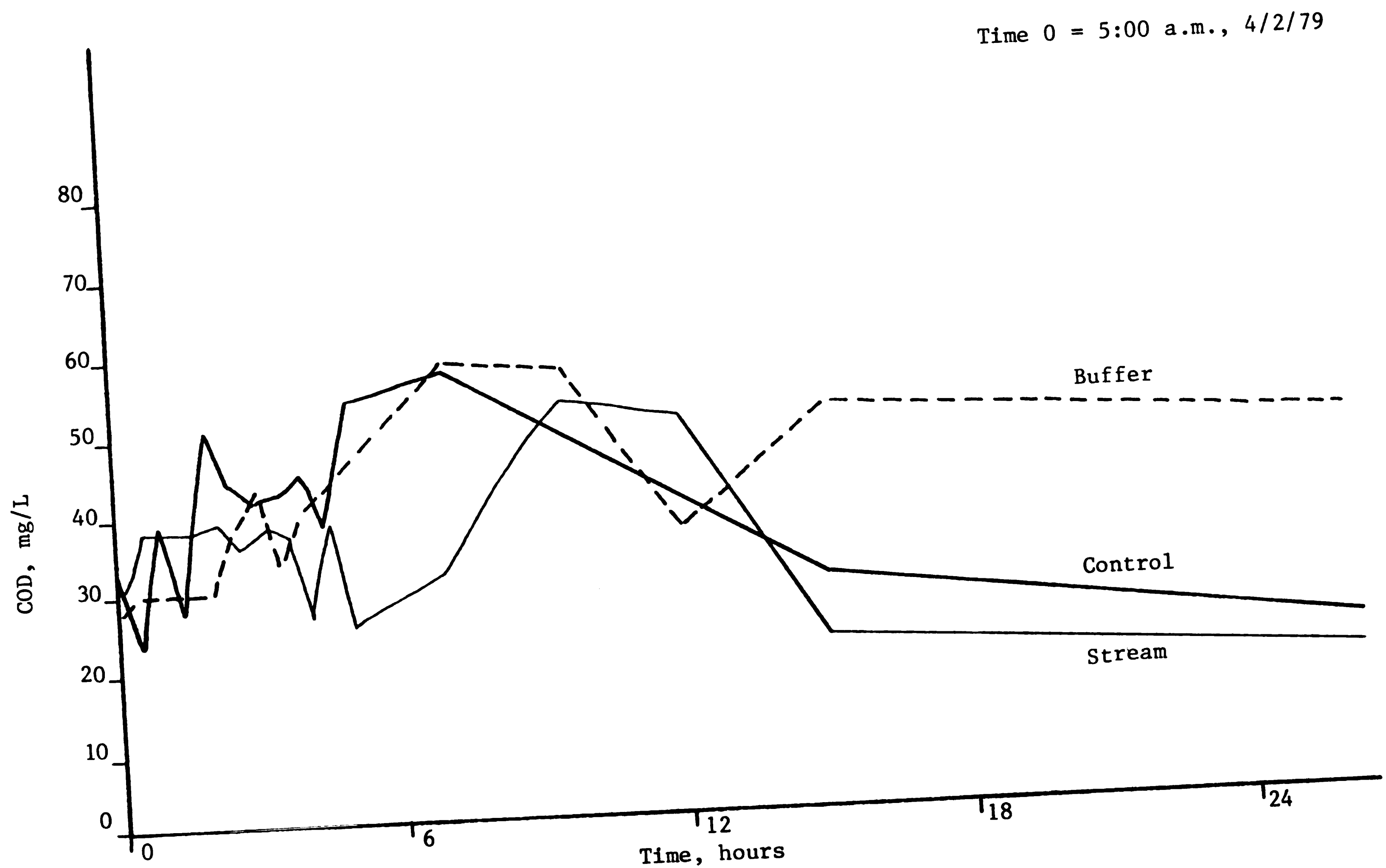

Figure 50. Chemical Oxygen Demand vs. Time, Event 3

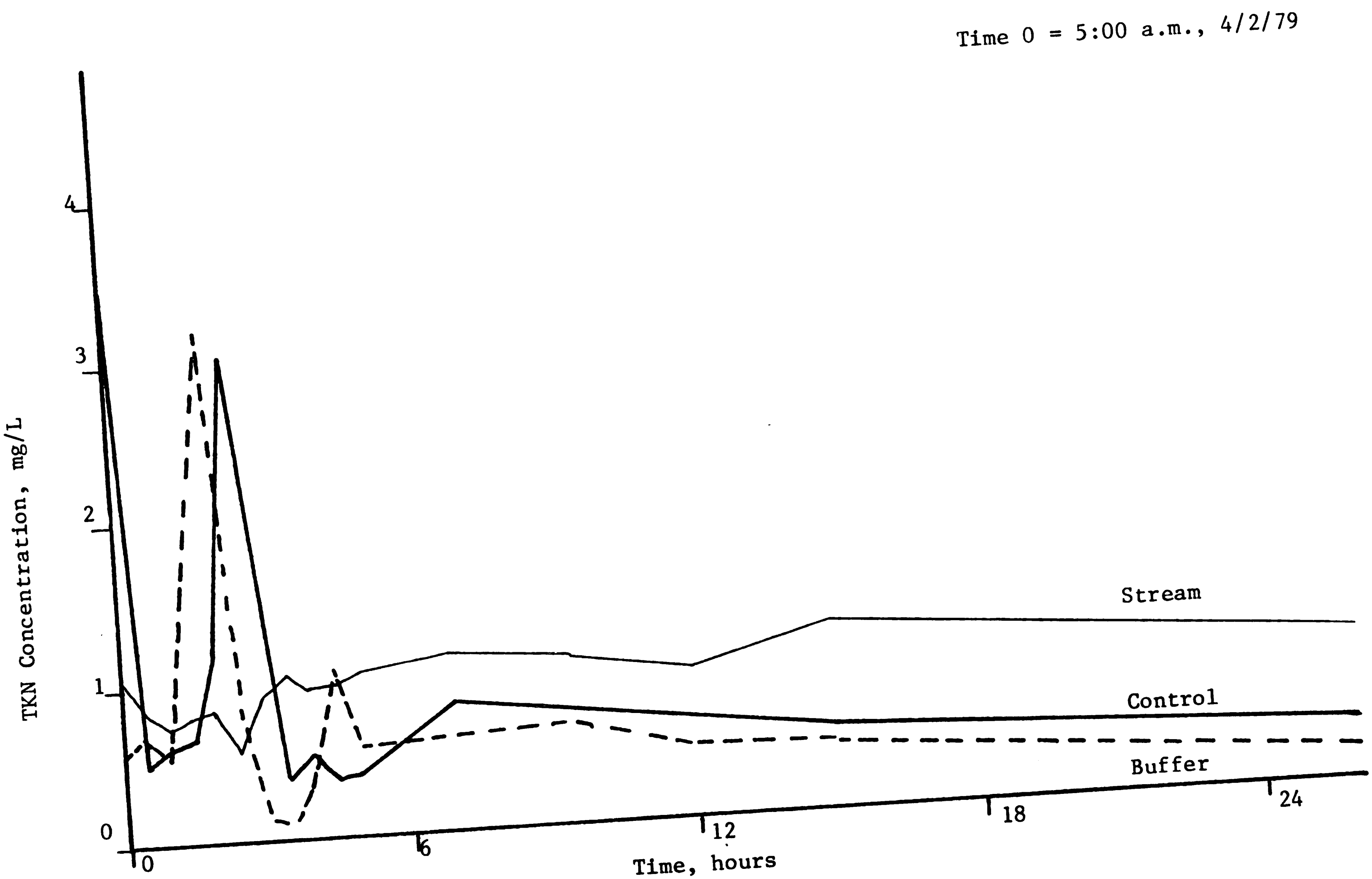

Figure 51. Total Kjeldahl Nitrogen Concentration vs. Time

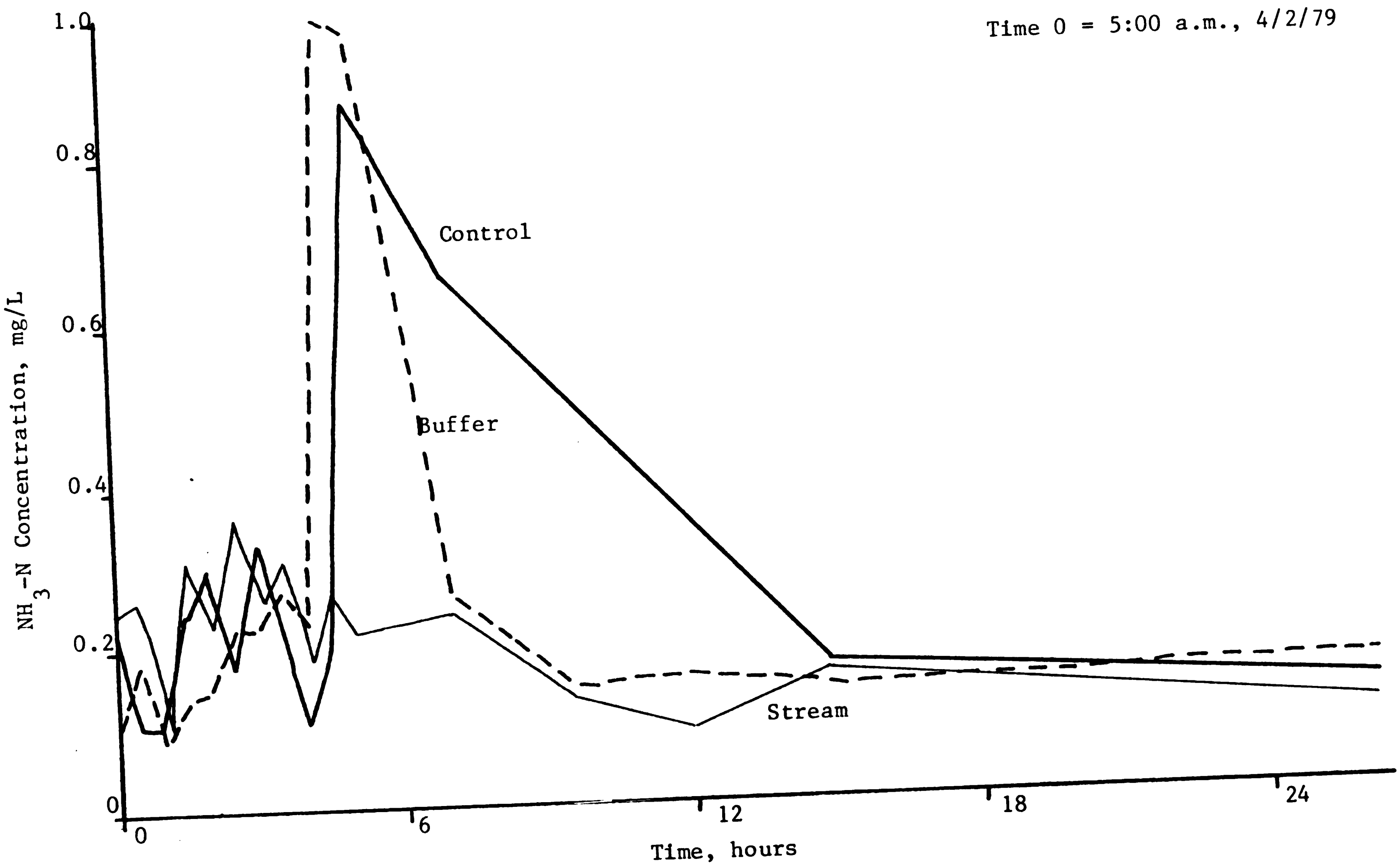

Figure 52. Ammonia-Nitrogen Concentration vs. Time, Event 3

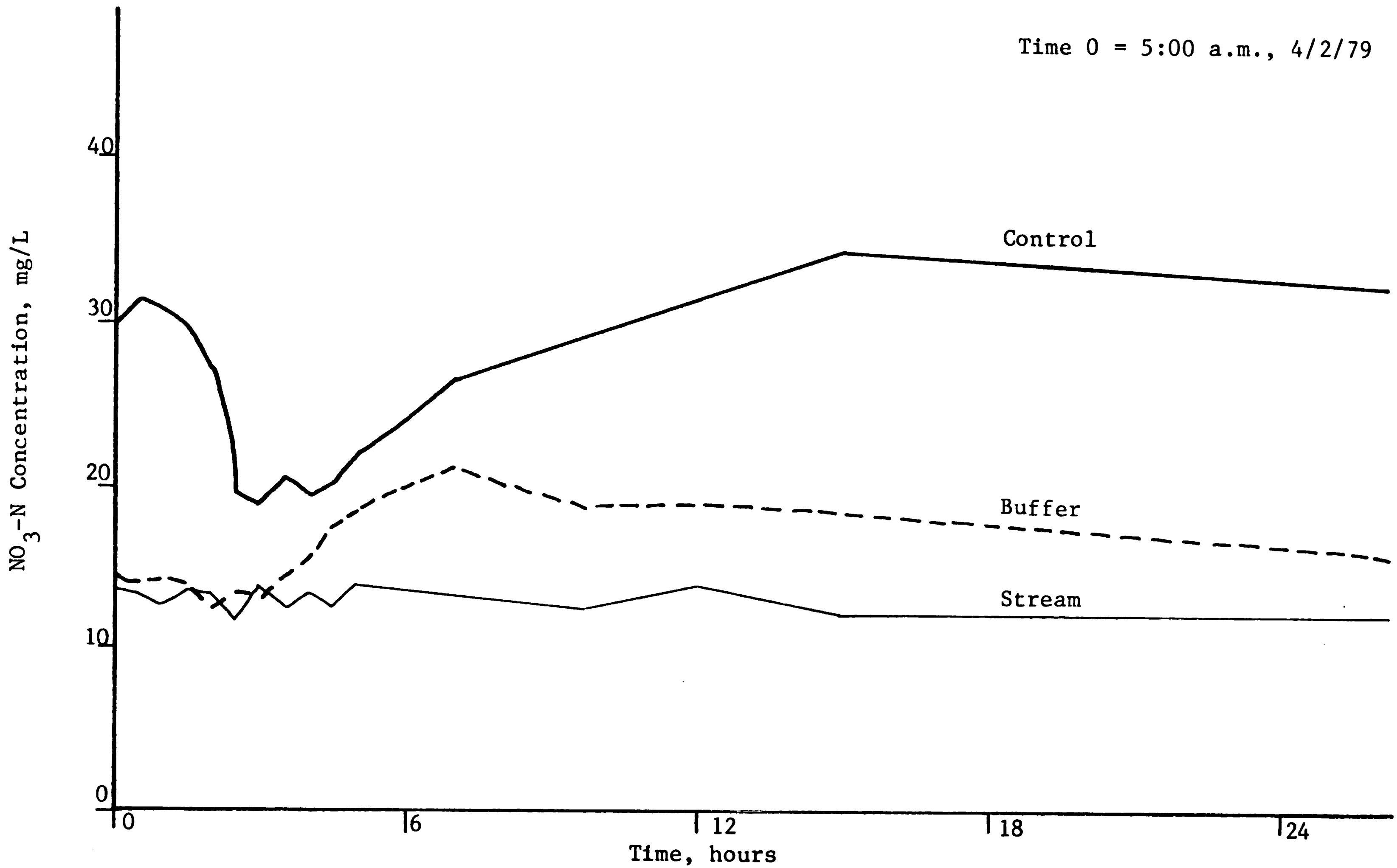

Figure 53. Nitrate-Nitrogen Concentration vs. Time, Event 3

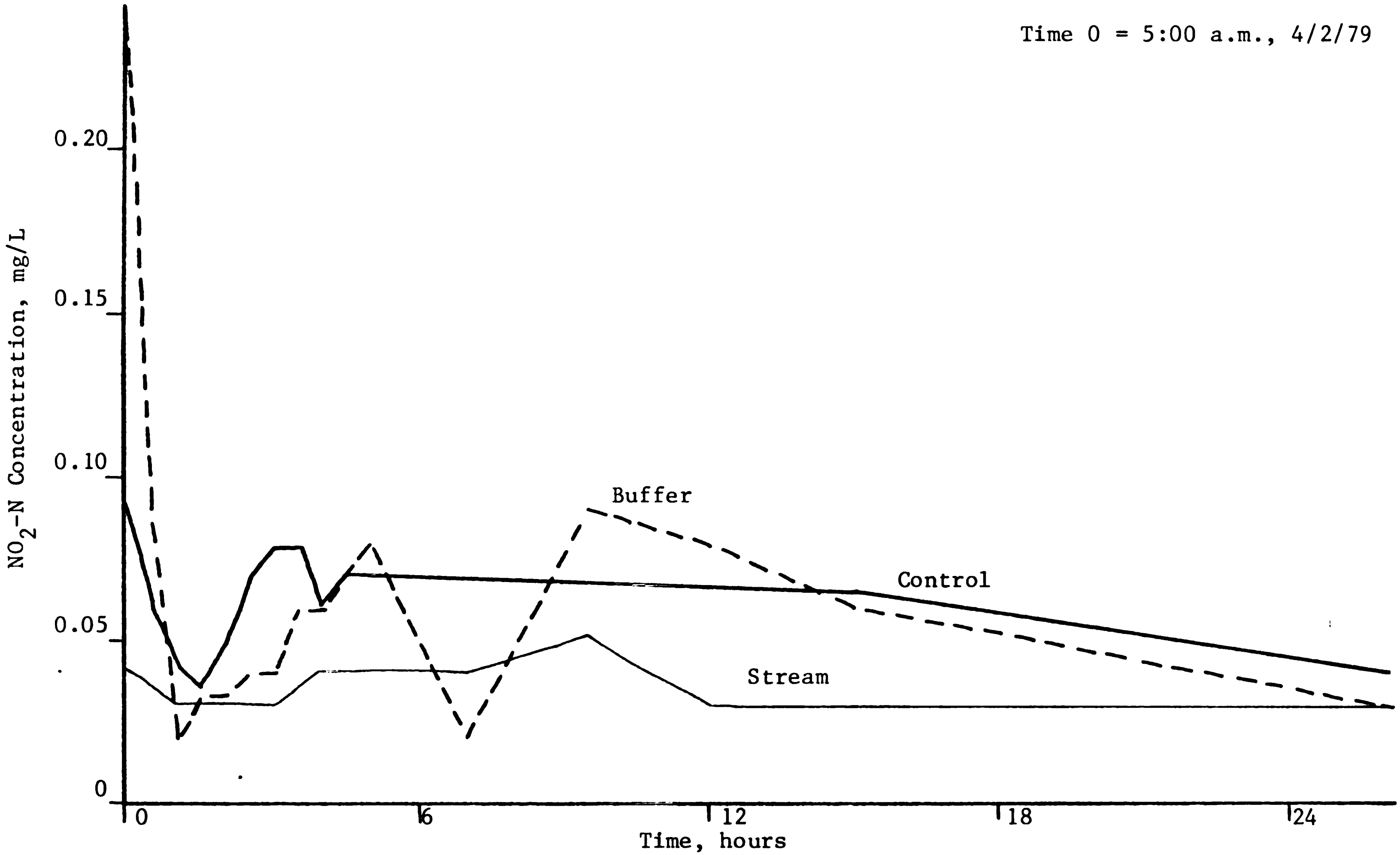

Figure 54. Nitrite-Nitrogen Concentration vs. Time, Event 3

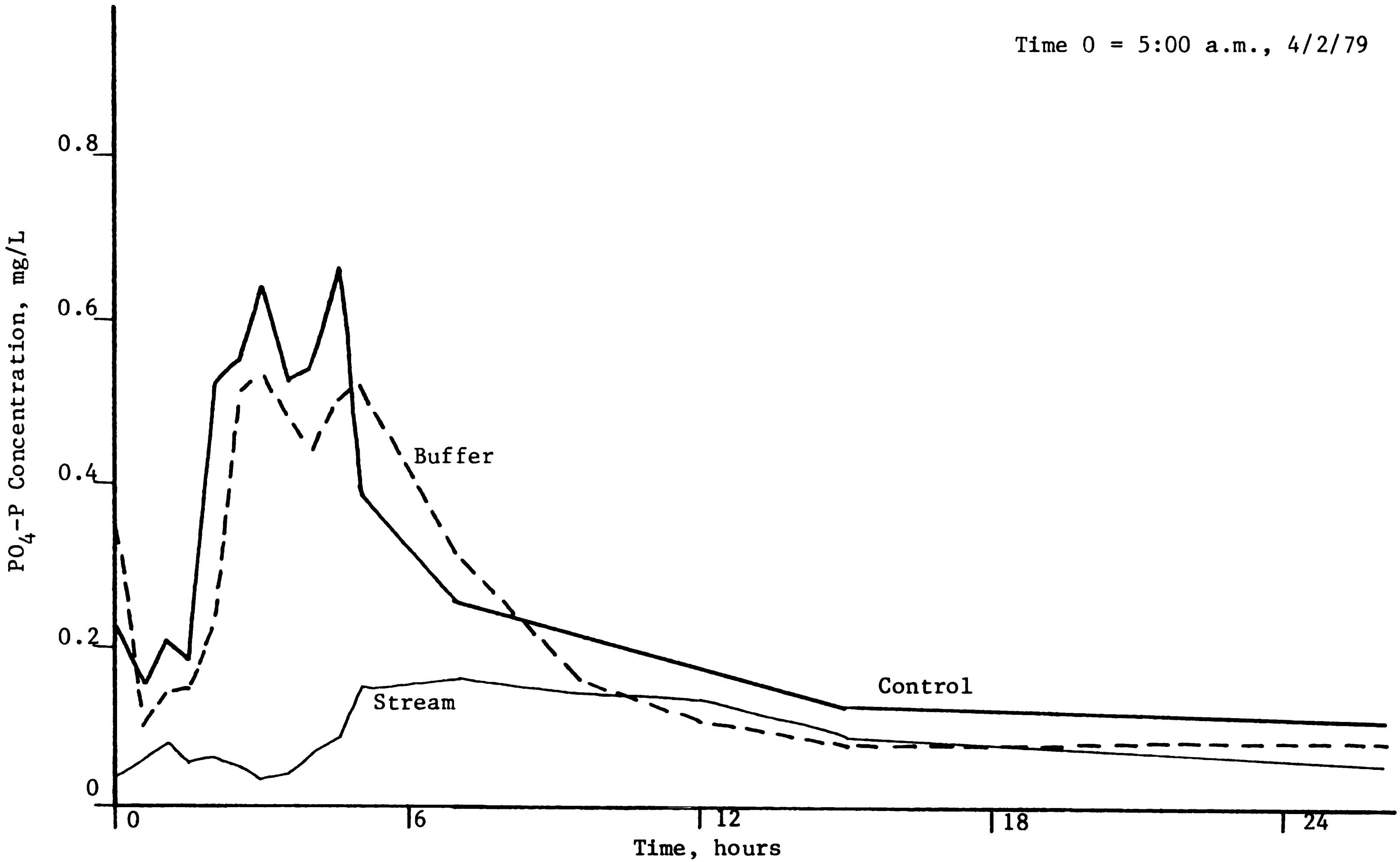

Figure 55. Total Phosphate Concentration vs. Time, Event 3

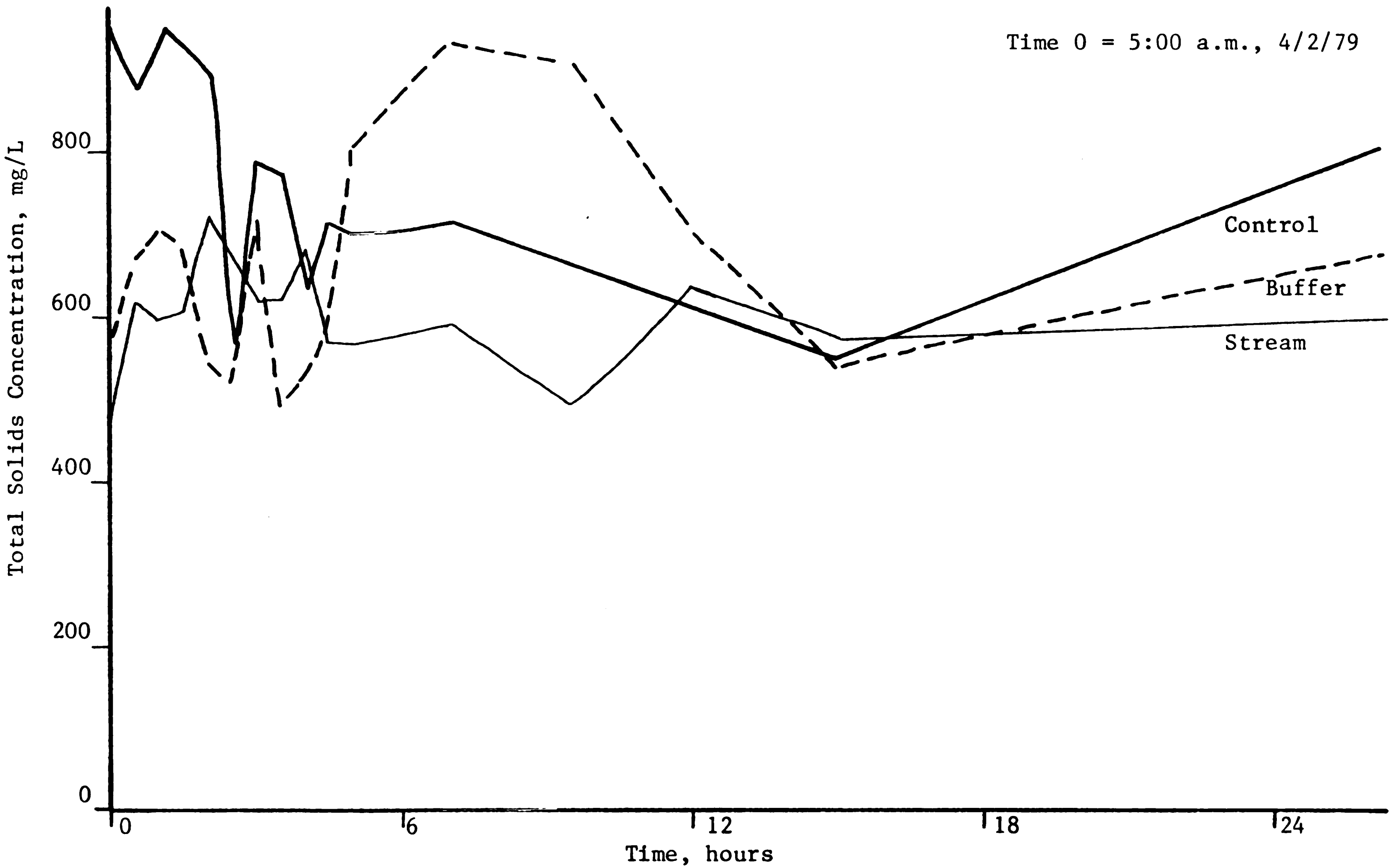

Figure 56. Total Solids Concentration vs. Time

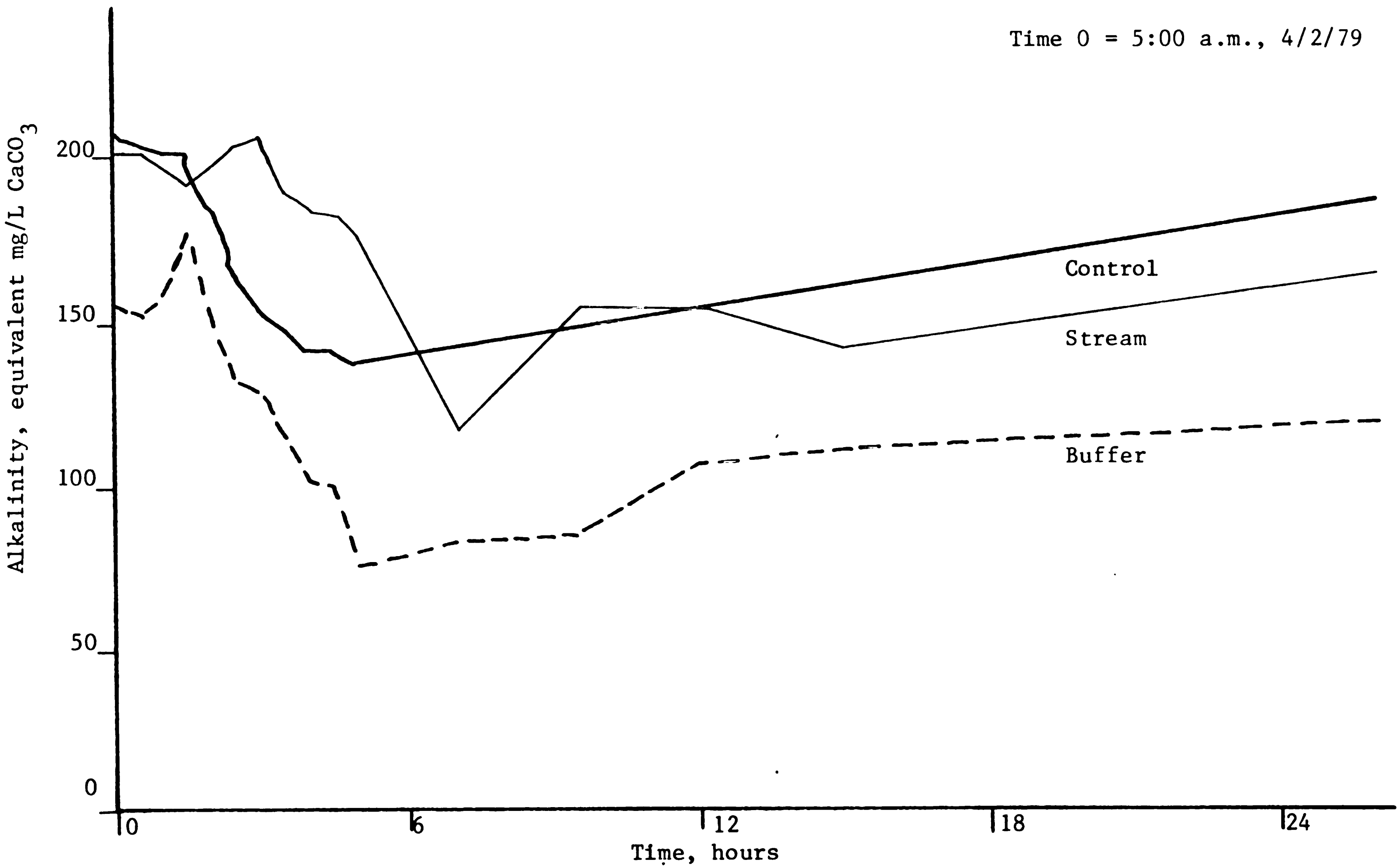

Figure 57. Alkalinity vs. Time, Event 3

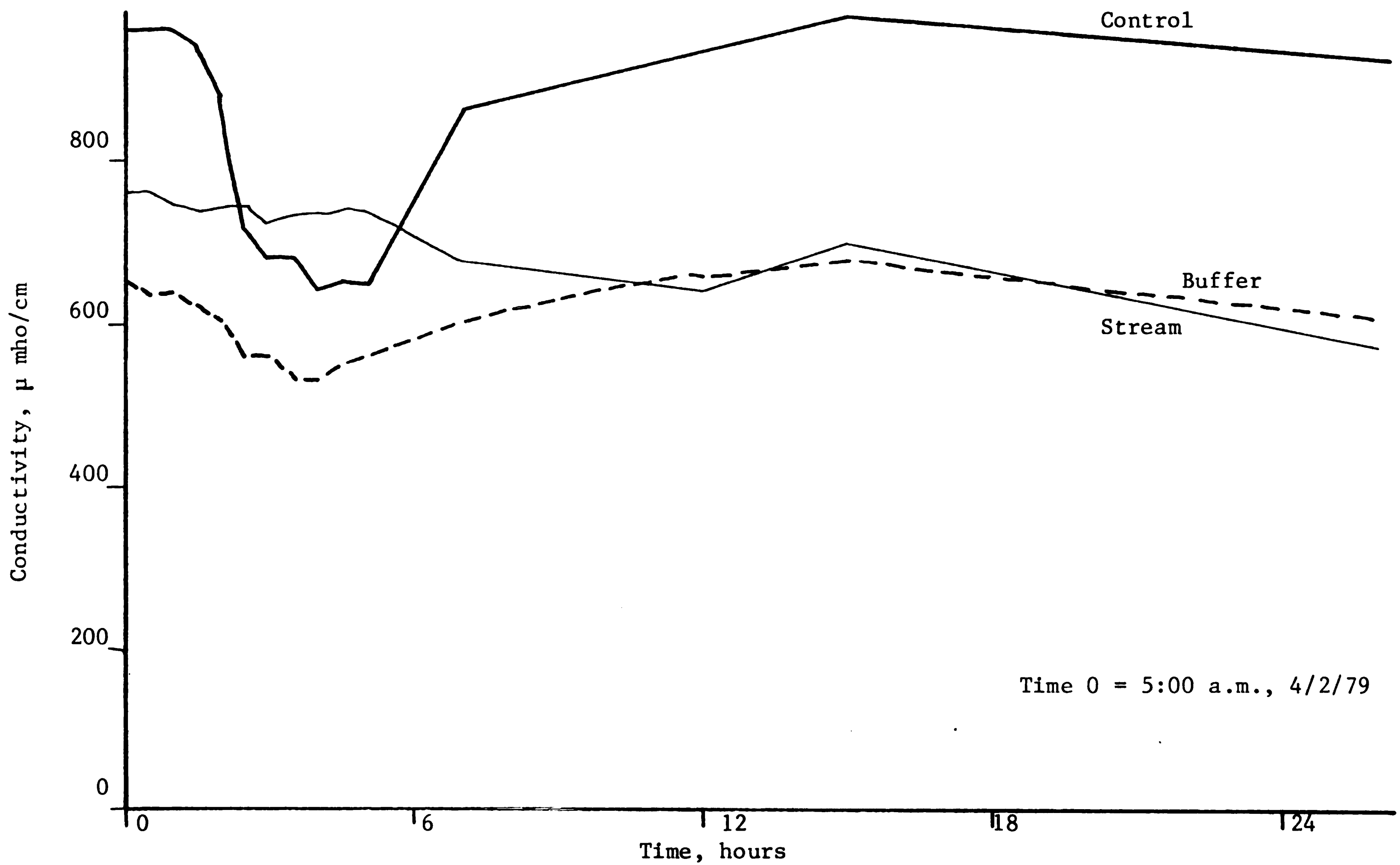

Figure 58. Conductivity vs. Time, Event 3

for the most part, as those measured in the runoff flows.

3.4.5. Runoff Event Four

Event four began at 4:00 p.m. on April 5, 1979. A light rain began shortly before 4:00 p.m., and the soil of the two fields was so saturated that runoff occurred almost immediately. Precipitation continued for 6 hours and runoff continued for about 12 hours. The sampling process was automatically initiated at 4:00 p.m. on April 5, and continued for the duration of the event. Data gathered during runoff event four are presented as Figures 59 through 71. The time designated as hour 0 for this event is 4:00 p.m. on April 5, 1979.

Stream concentrations of the various water quality parameters estimated are quite comparable with those of the runoff flows in most cases. Values of alkalinity and chemical oxygen demand were somewhat lower in the fields' runoff than in the stream through much of this event.

The two runoff hydrographs are of the same general shape, though the periods of peak flow occur at different times. Rainfall may well have varied in timing and intensity between the two fields. Amounts of both rainfall and runoff are quite minor. Only a slight increase in stream flow is seen as a result of this light rain.

In this runoff event, measured values of total Kjeldahl nitrogen concentration, ammonia-nitrogen concentration, nitrate-nitrogen concentration, total phosphate concentration, conductivity, and alkalinity are generally greater in samples from the control field than from the buffer. Buffered field nitrite-nitrogen concentrations, however, are consistently higher than those of the control. The concentrations of total solids, as well as the values of both chemical and biochemical oxygen demand, were quite similar in the runoff from both of the cropland areas.

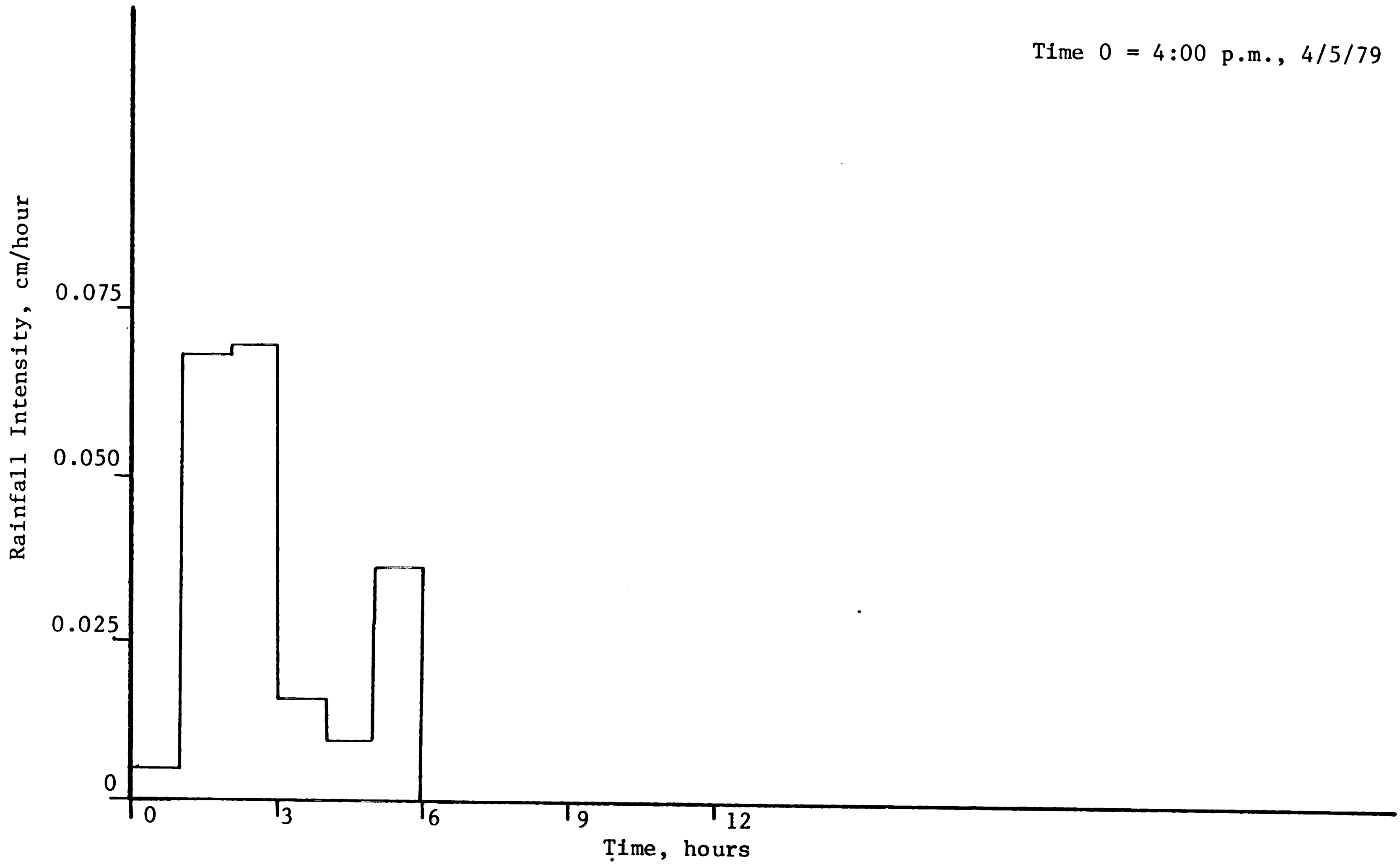

Figure 59. Rainfall Intensity vs. Time, Event 4

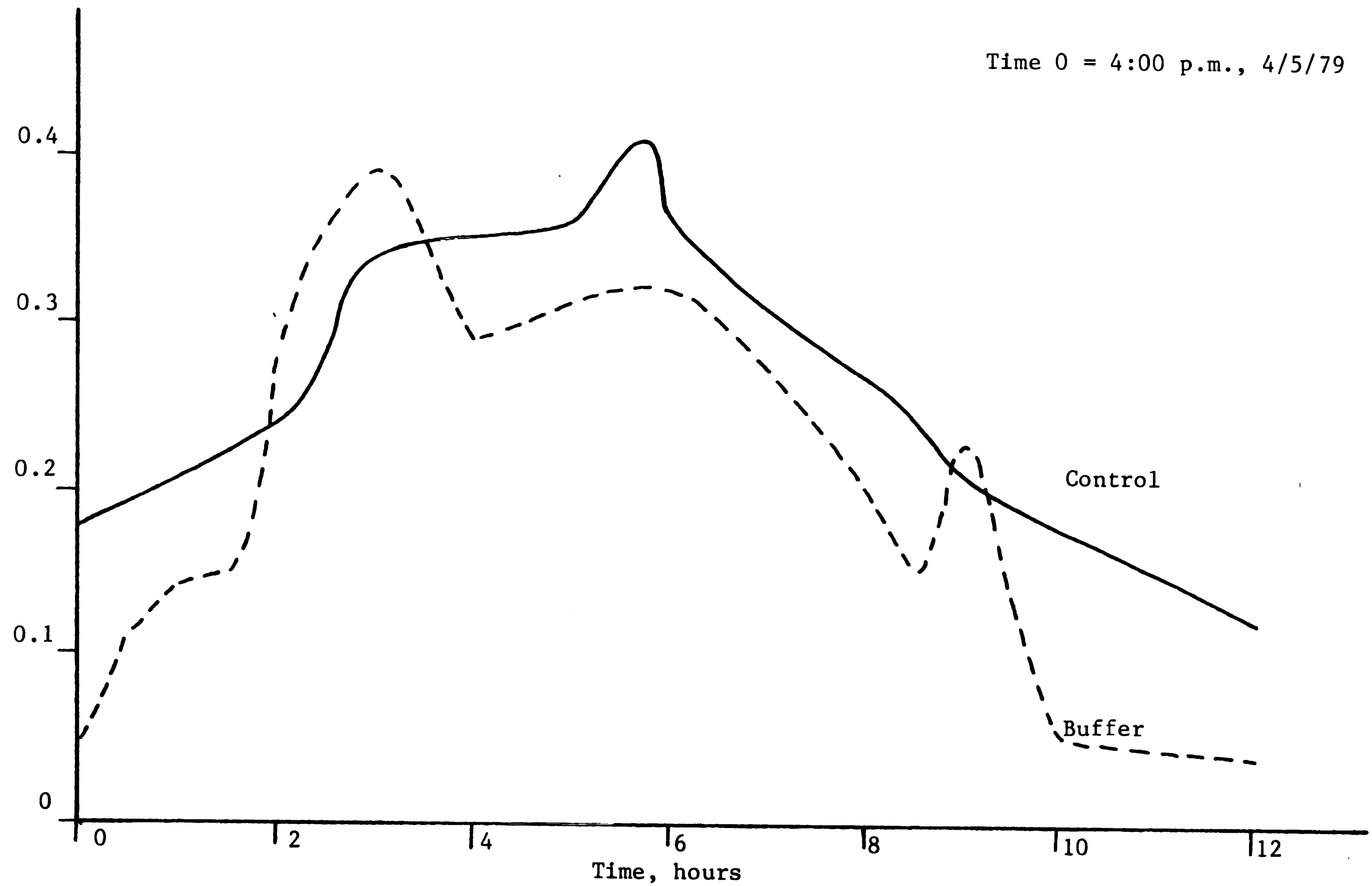

Figure 60. Runoff Flow vs. Time, Event 4

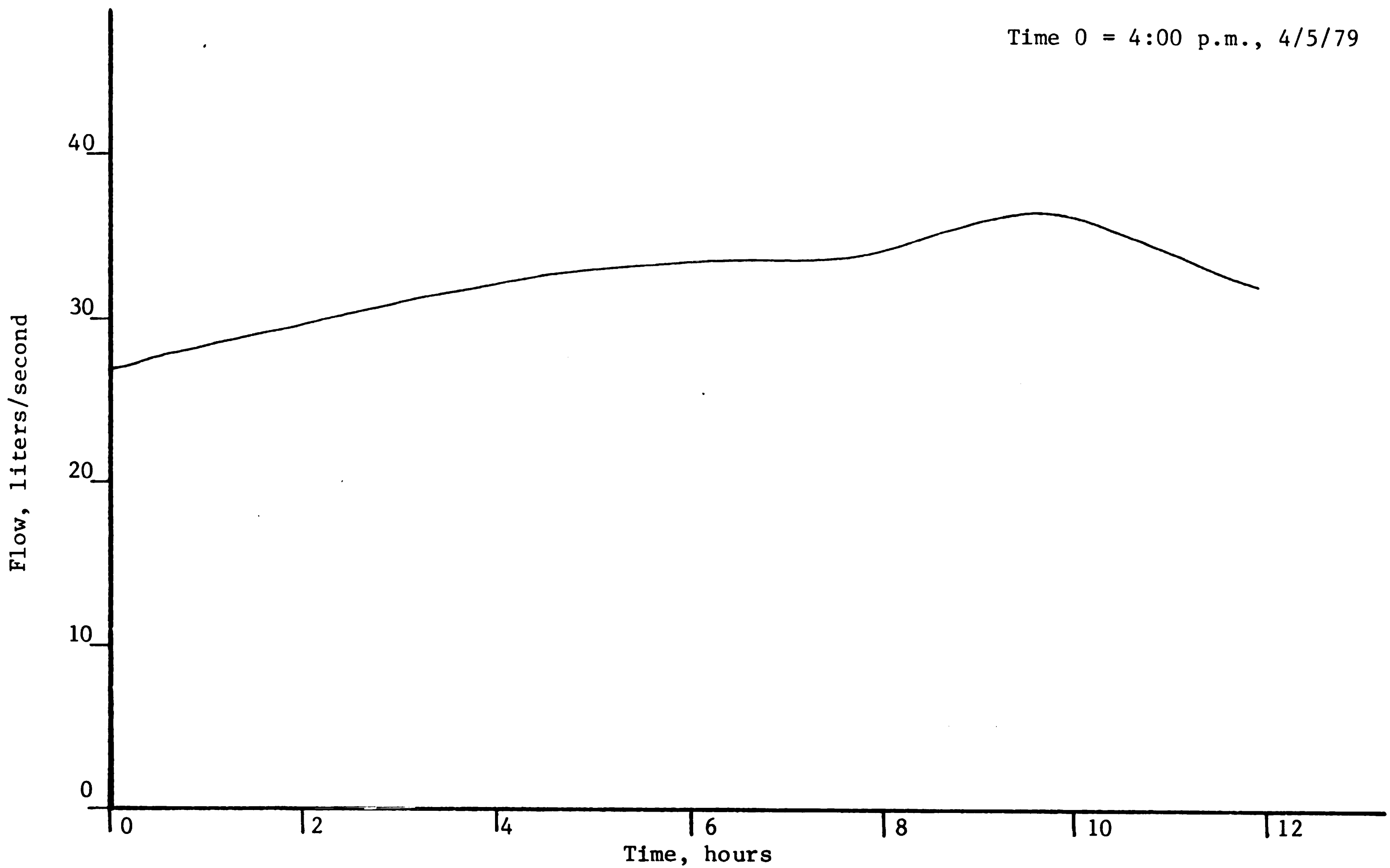

Figure 61. Stream Flow vs. Time, Event 4

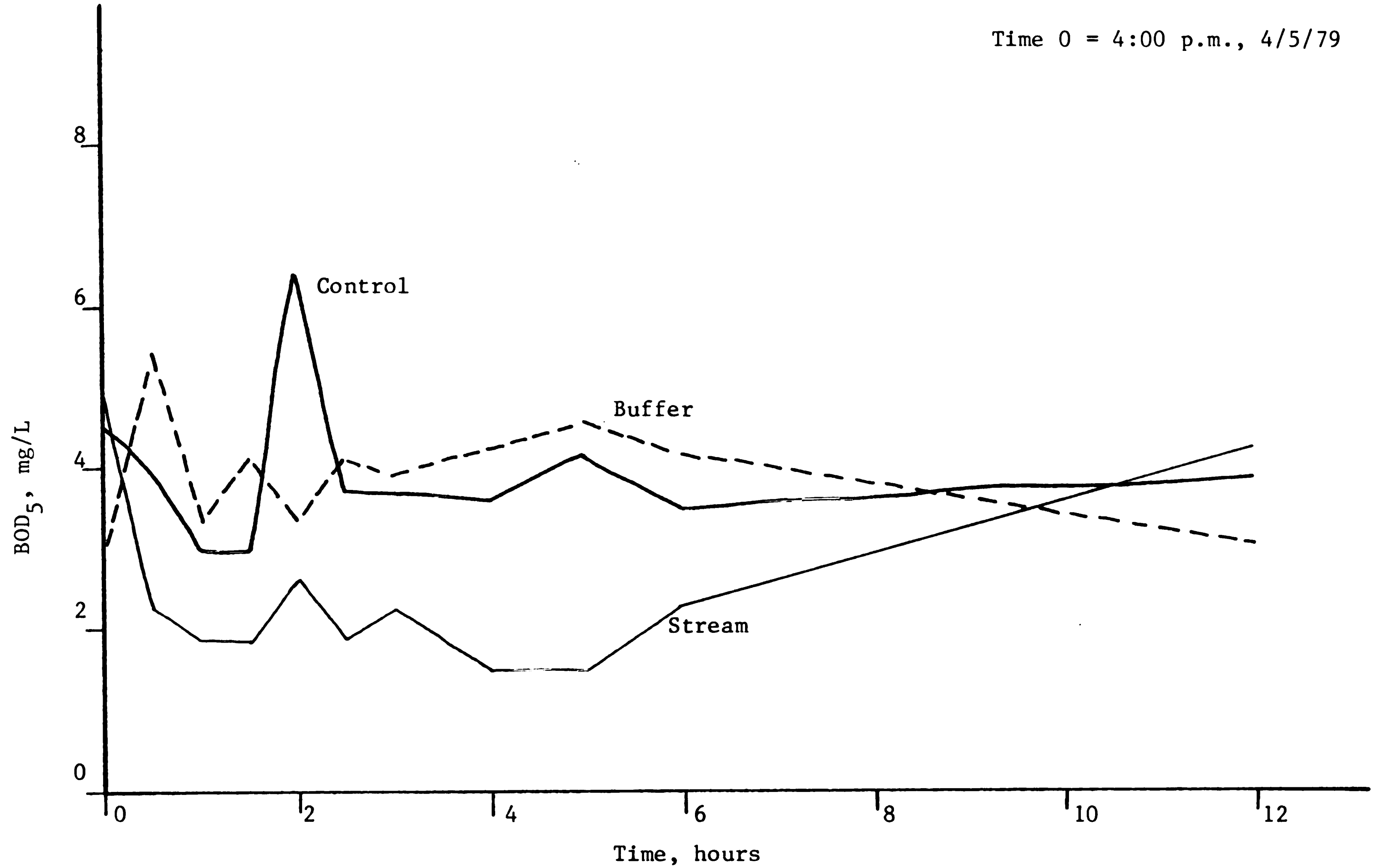

Figure 62. 5-day Biochemical Oxygen Demand vs. Time, Event 4

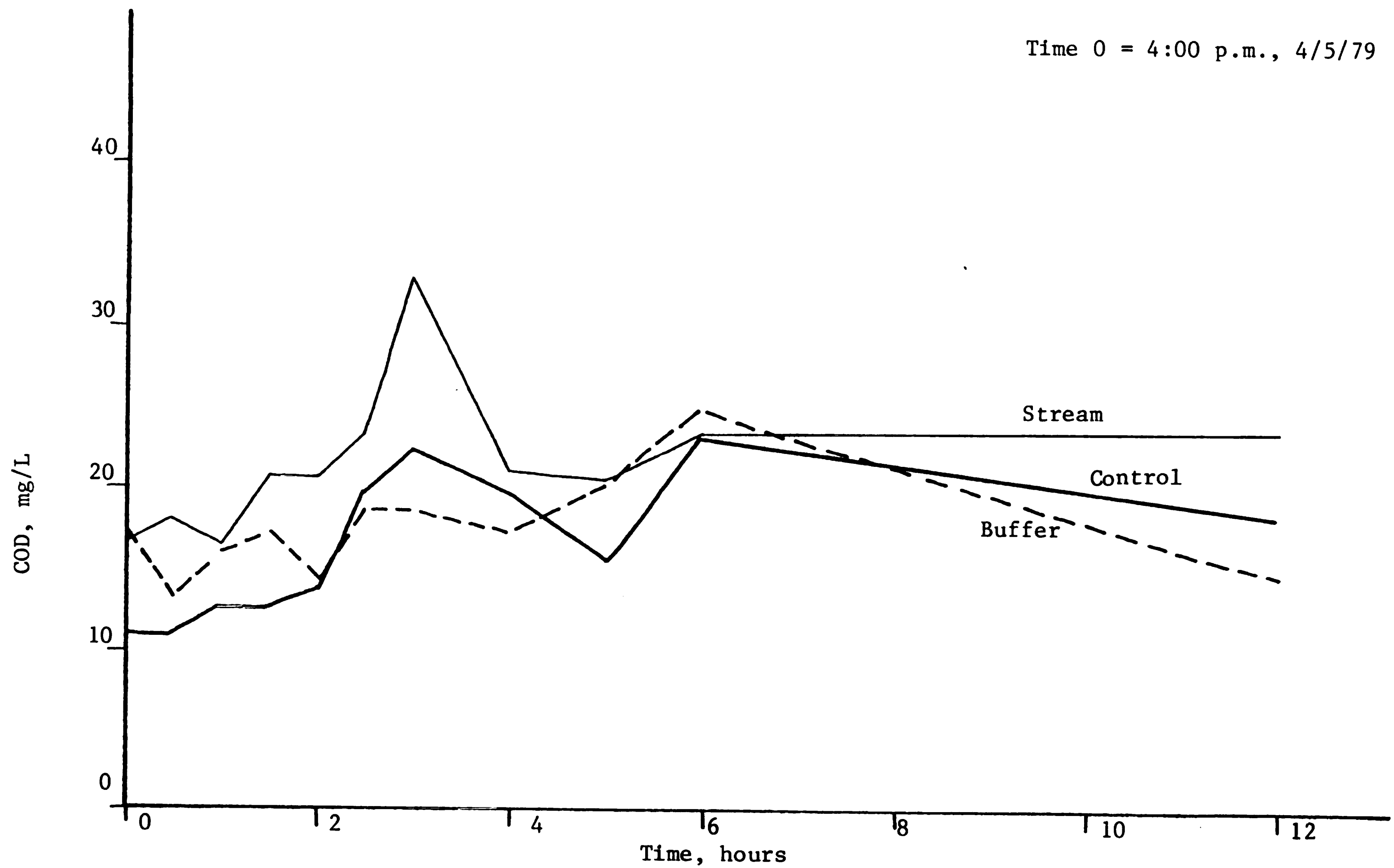

Figure 63. Chemical Oxygen Demand vs. Time, Event 4

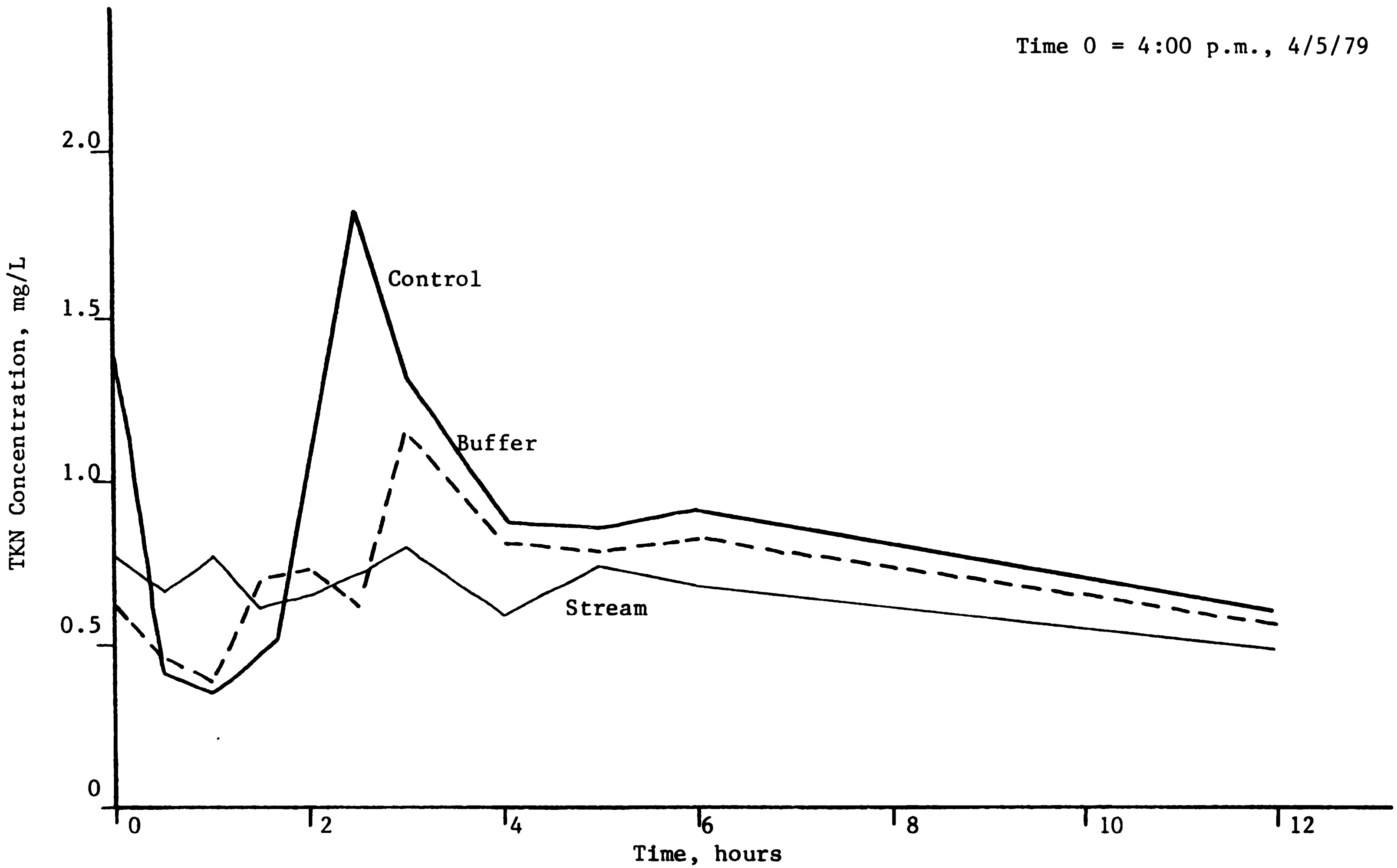

Figure 64. Total Kjeldahl Nitrogen Concentration vs. Time, Event 4

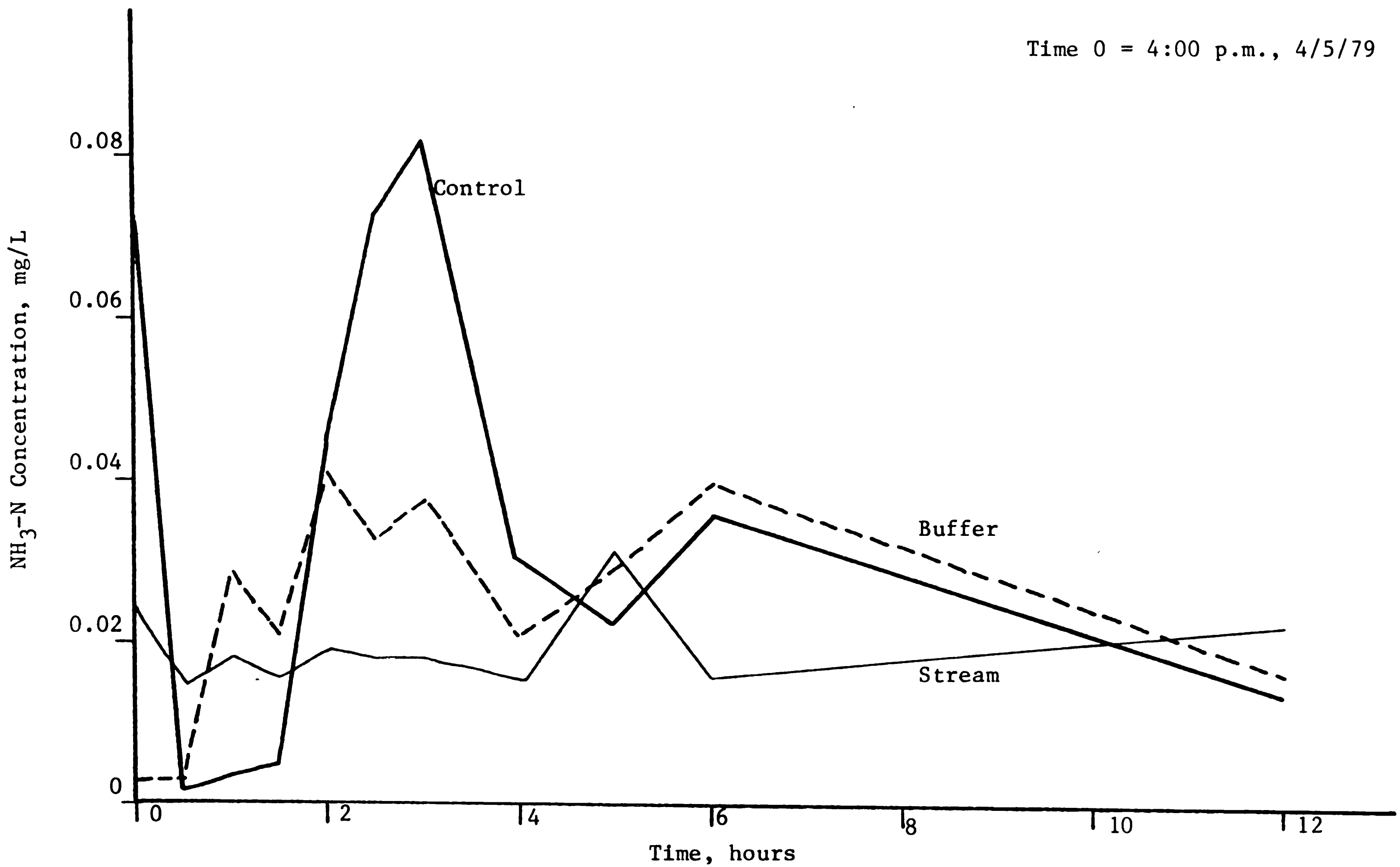

Figure 65. Ammonia-Nitrogen Concentration vs. Time, Event 4

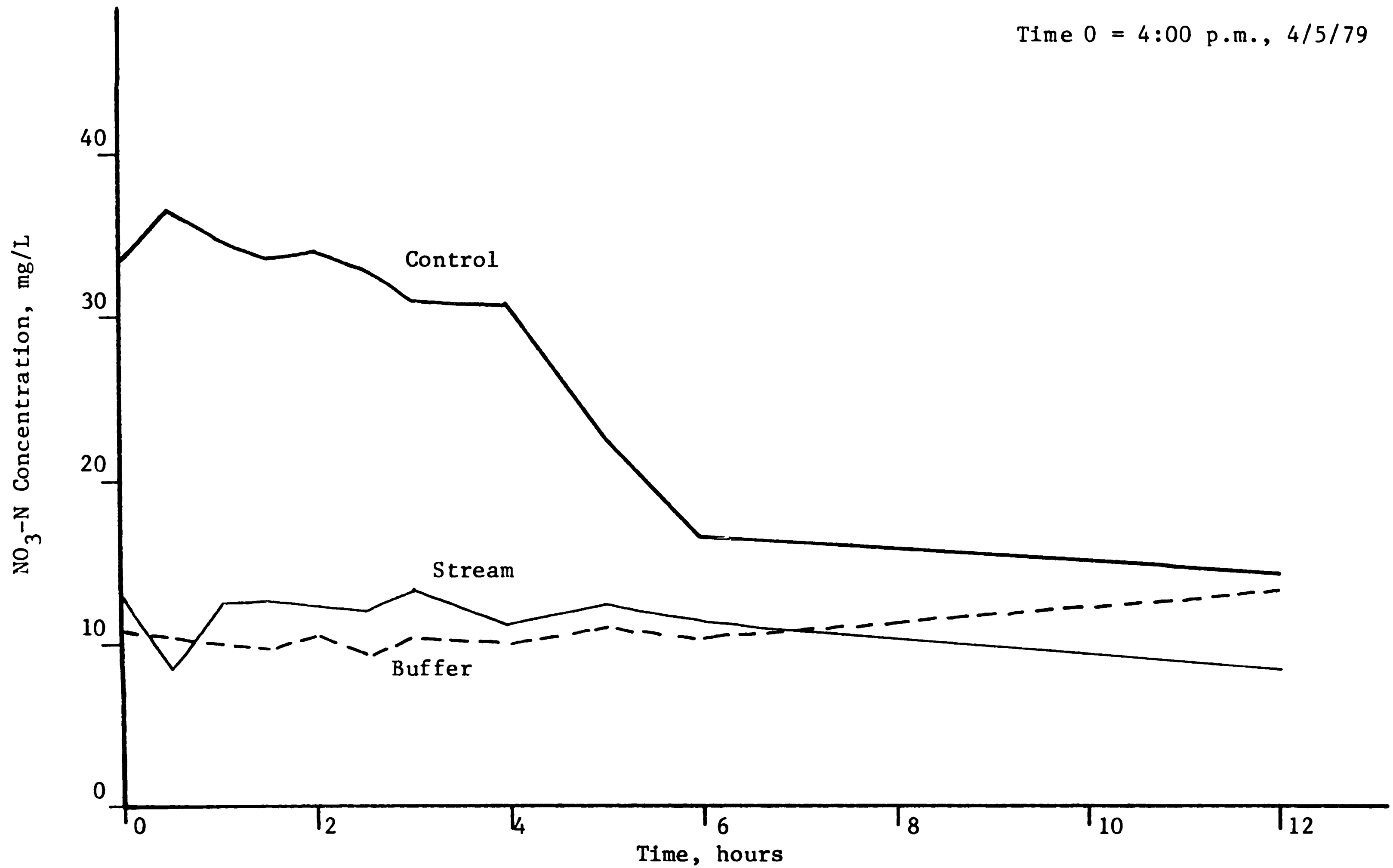

Figure 66. Nitrate-Nitrogen Concentration vs. Time, Event 4

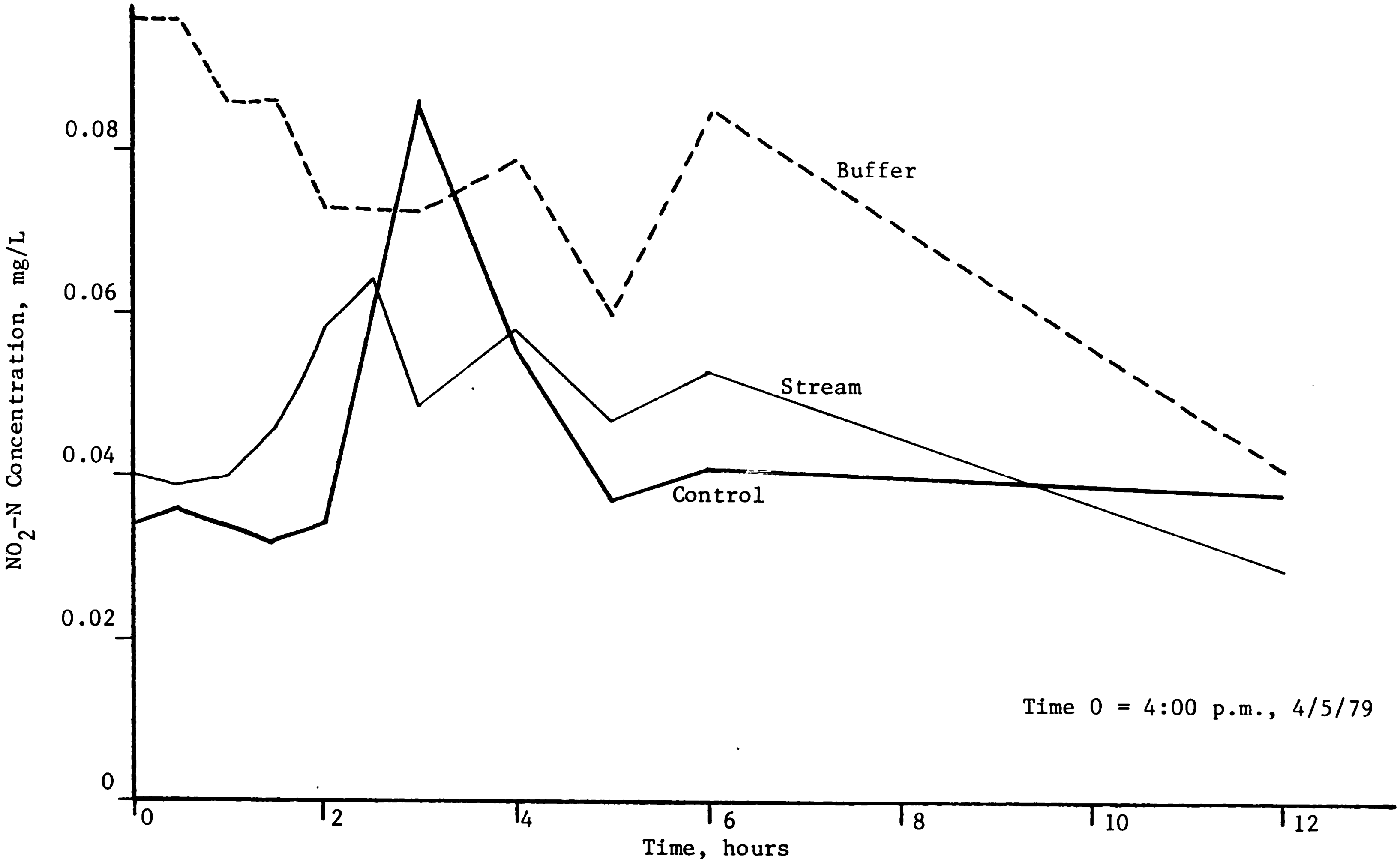

Figure 67. Nitrite-Nitrogen Concentration vs. Time, Event 4

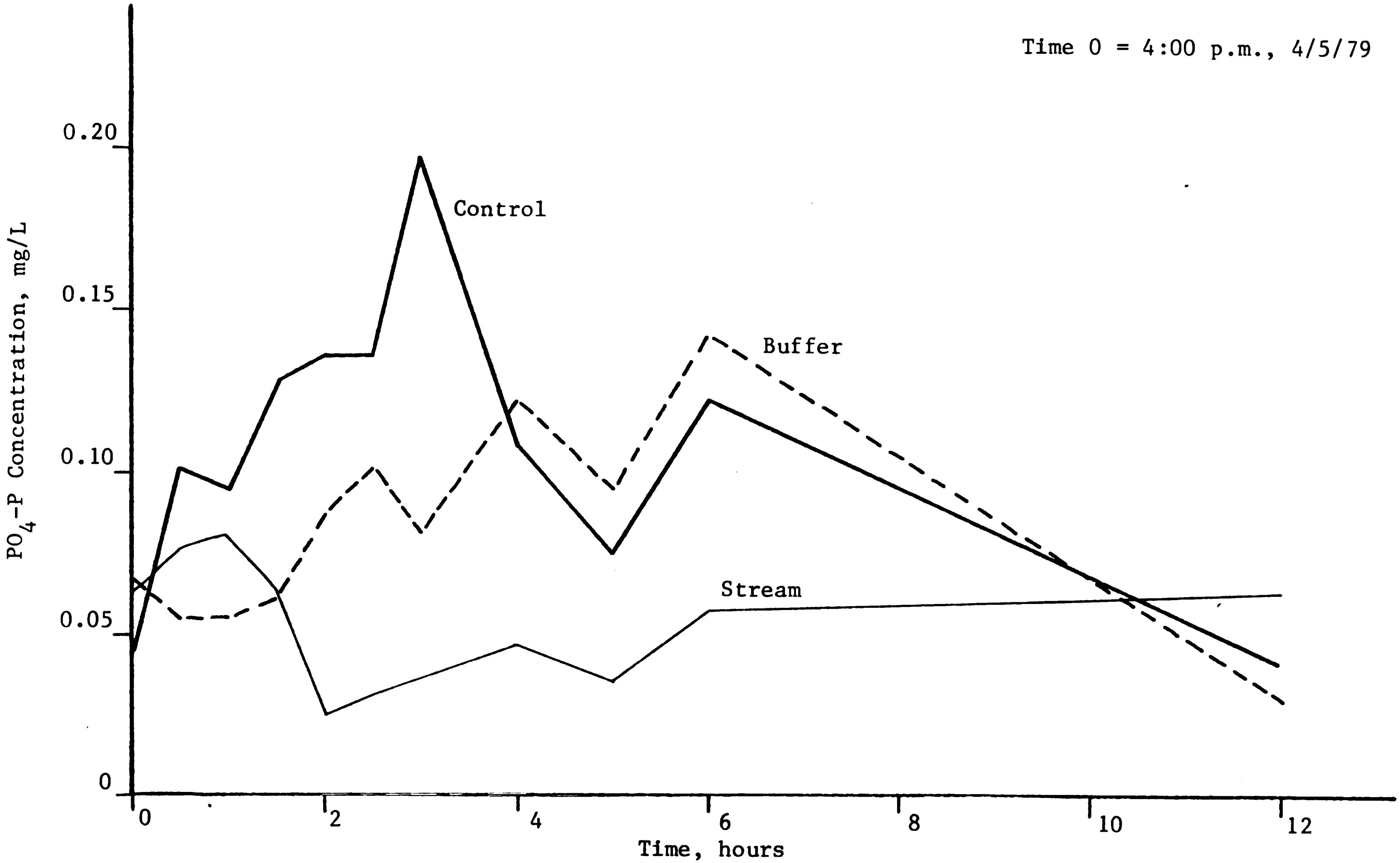

Figure 68. Total Phosphate Concentration vs. Time, Event 4

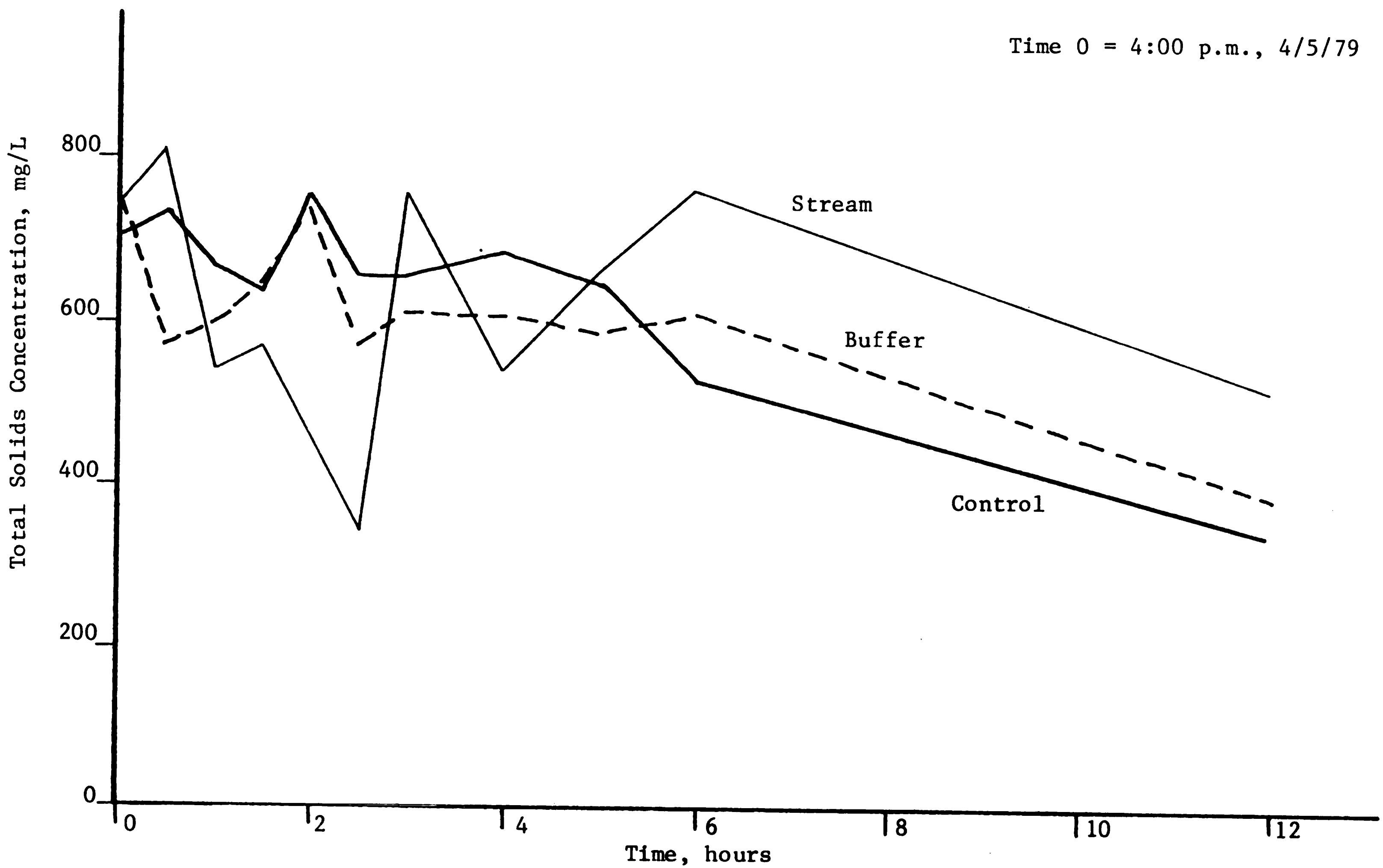

Figure 69. Total Solids Concentration vs. Time, Event 4

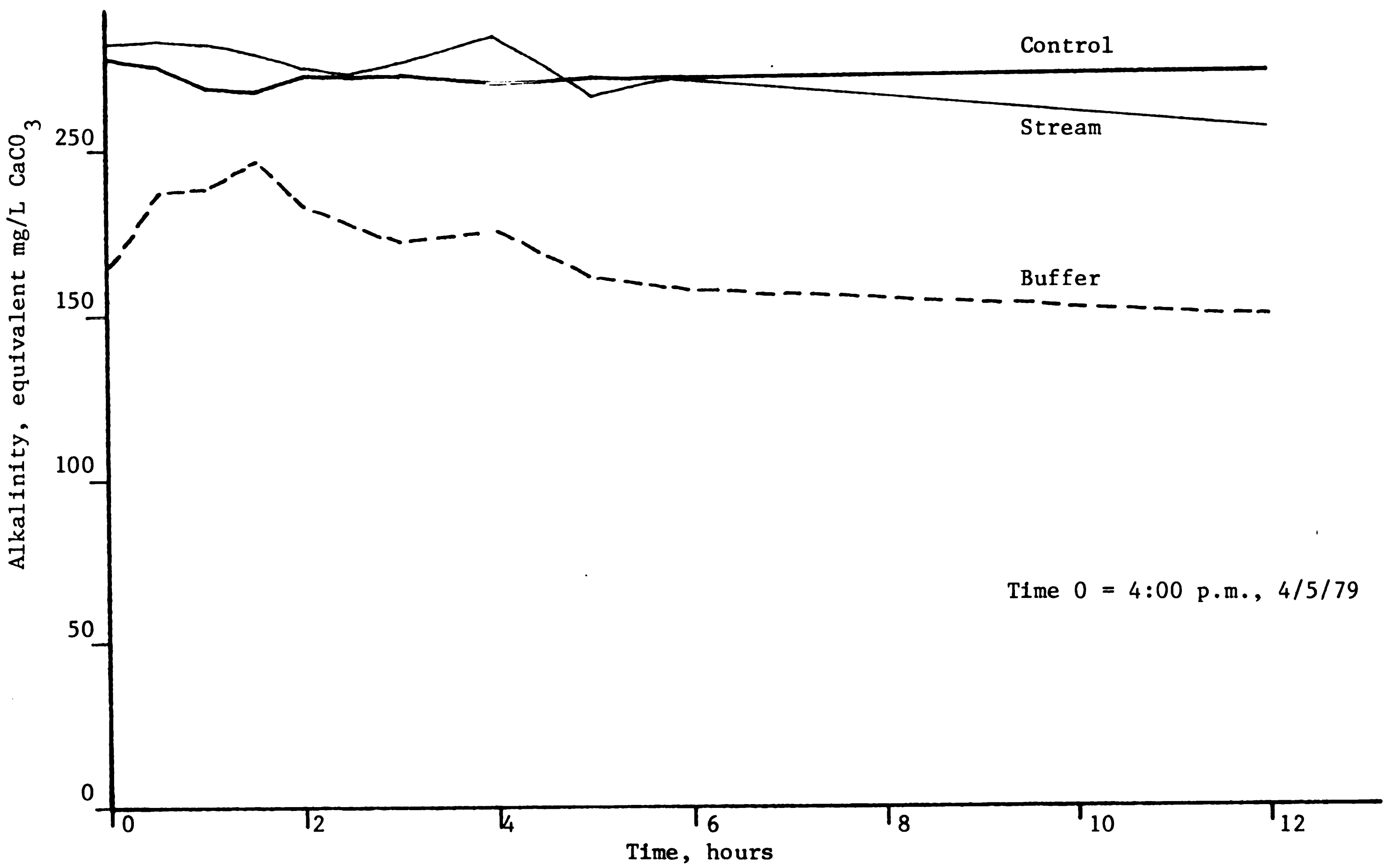

Figure 70. Alkalinity vs. Time, Event 4

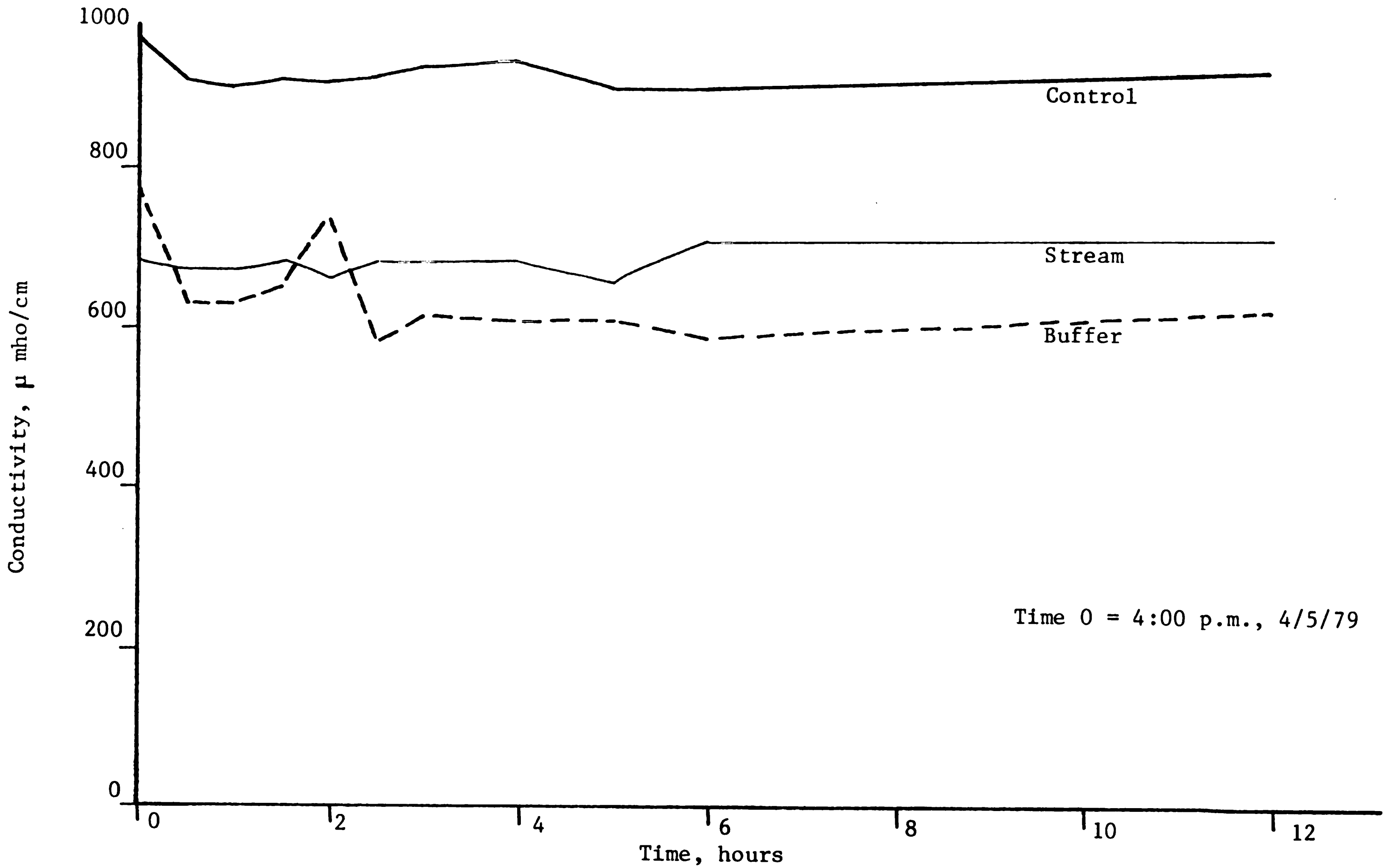

Figure 71. Conductivity vs. Time, Event 4

3.4.6. Runoff Event Five

The fifth major runoff event of the study occurred on April 8, 1979. An intermittent rainfall began at about 9:10 a.m., and runoff flows from both the buffered and control fields were first detected some 5 hours later. The storm continued in a sporadic manner until just after noon on April 9. Maximum average hourly intensities of rainfall were 0.12 centimeters per hour. Runoff subsided slowly, with the event ending at about 8:30 a.m. on April 11.

The first water samples were collected at 2:15 p.m. on April 8, as the rising flow tripped one of the float-loaded microswitch assemblies. A sampling interval of thirty minutes was maintained. As with other events, all samples gathered on the rising hydrograph were subjected to laboratory analysis. Samples collected during periods of low or subsiding flow were selectively analyzed at intervals of from one to several hours. Data from this event are presented in Figures 72 through 84. The time designated as hour 0 for this event is 2:15 p.m. on April 8, 1979.

The hydrographs of runoff from the buffered and control field are of similar shape, with the exception of the initial peak. The flow chart from the control field monitoring station indicates an abrupt reduction in flow rate at about hour 3 of this event. This is not considered likely when viewed in relation to the buffered field's hydrograph and the rainfall data. The flow recorder utilizes a beaded wire, fastened between a float and a weight, to rotate the notched wheel which controls the rotating drum and chart. It appears that the beaded wire may have slipped a notch or two to cause the apparent flow reduction. The flow is reported as recorded, though the malfunction described above is suspected and an error is probable.

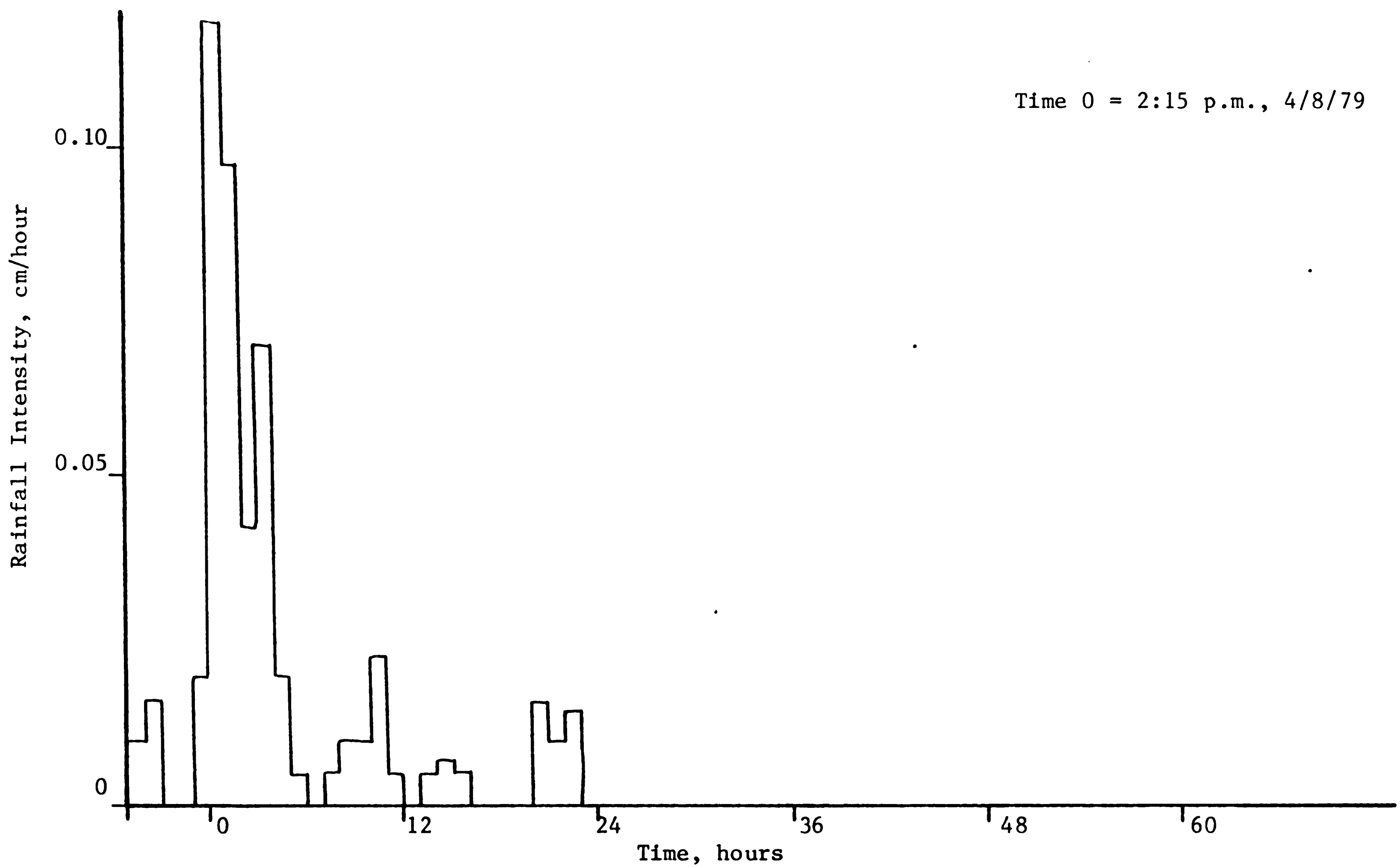

Figure 72. Rainfall Intensity vs. Time, Event 5

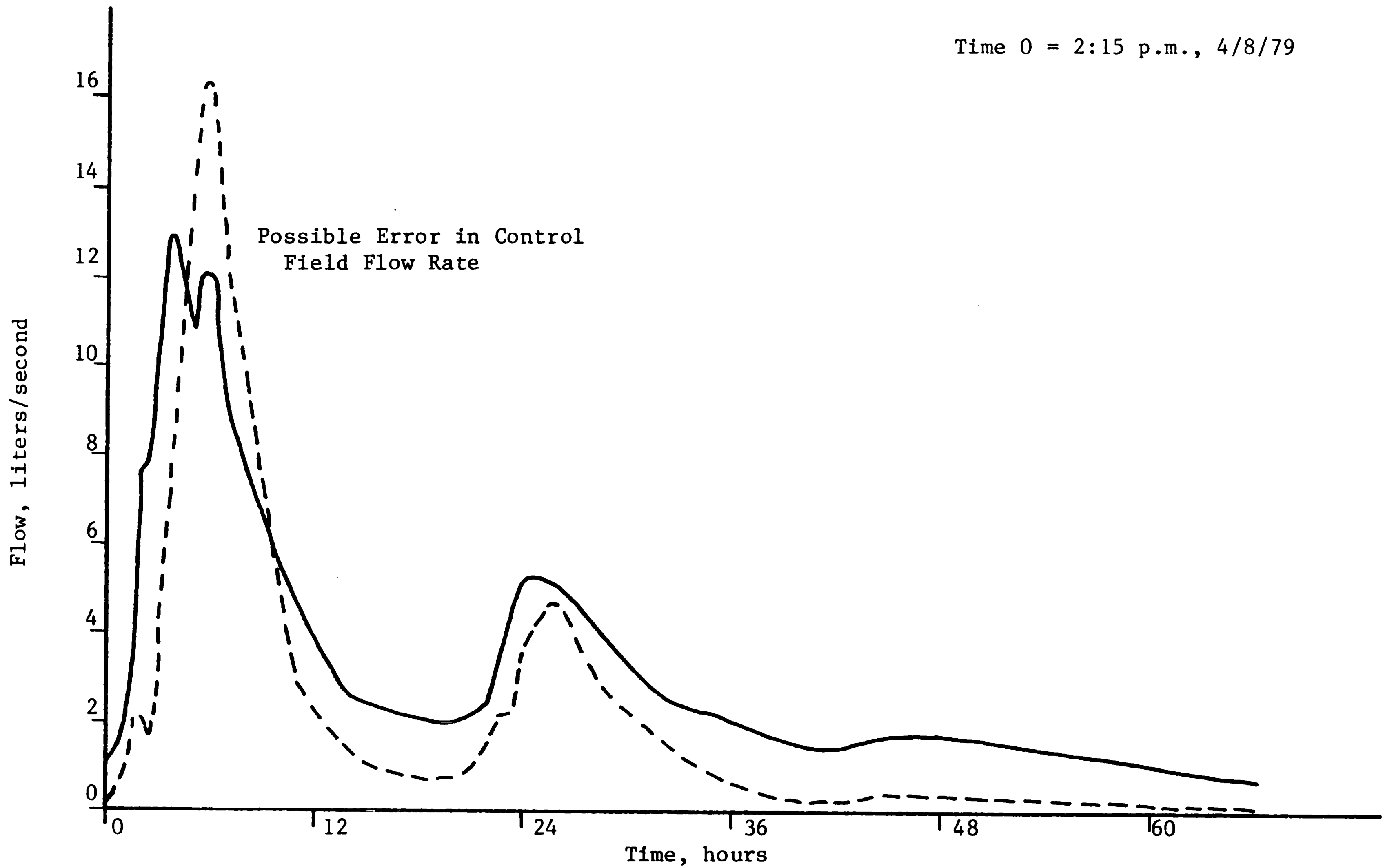

Figure 73. Runoff Flow vs. Time, Event 5

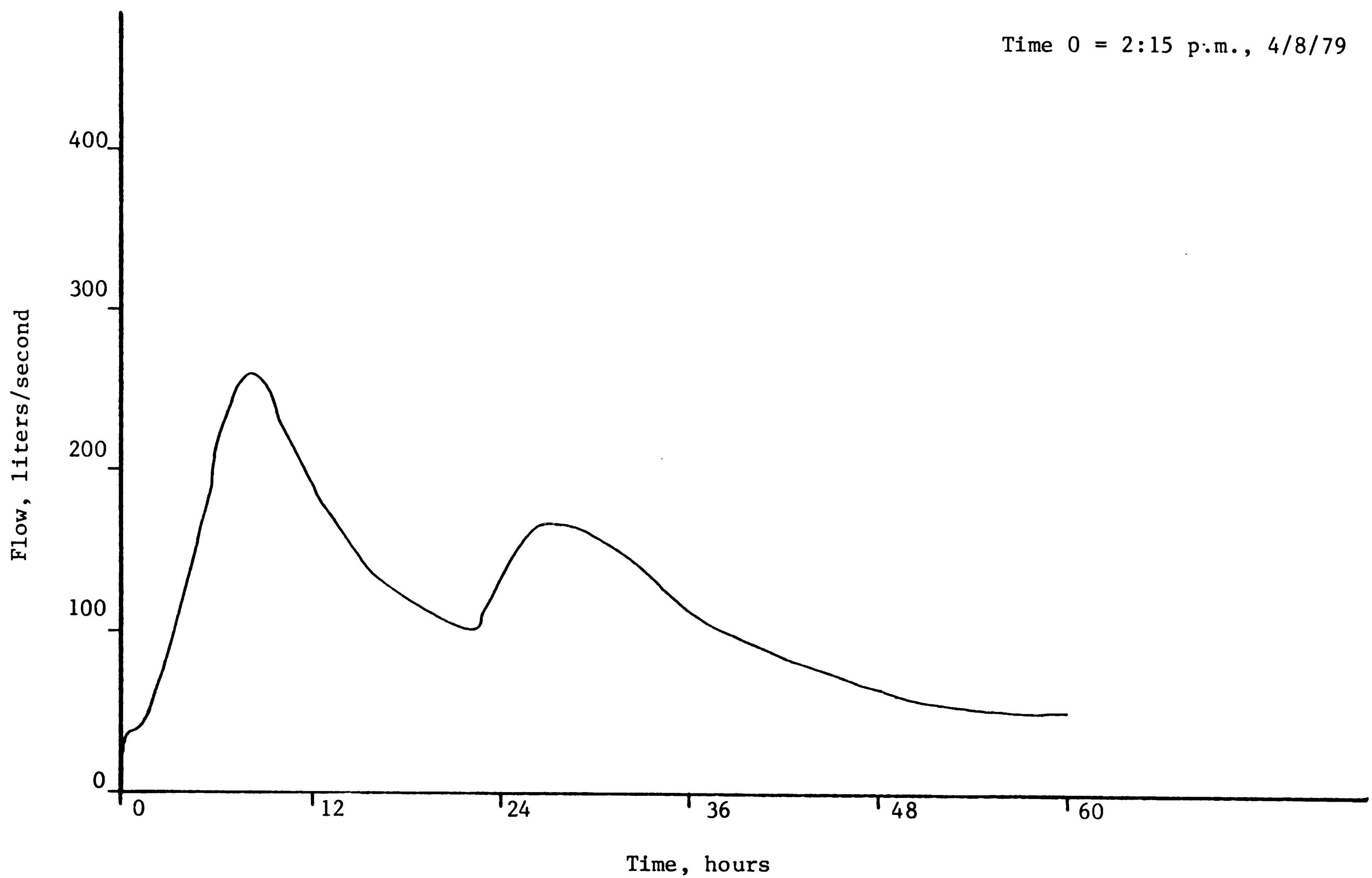

Figure 74. Stream Flow vs. Time, Event 5

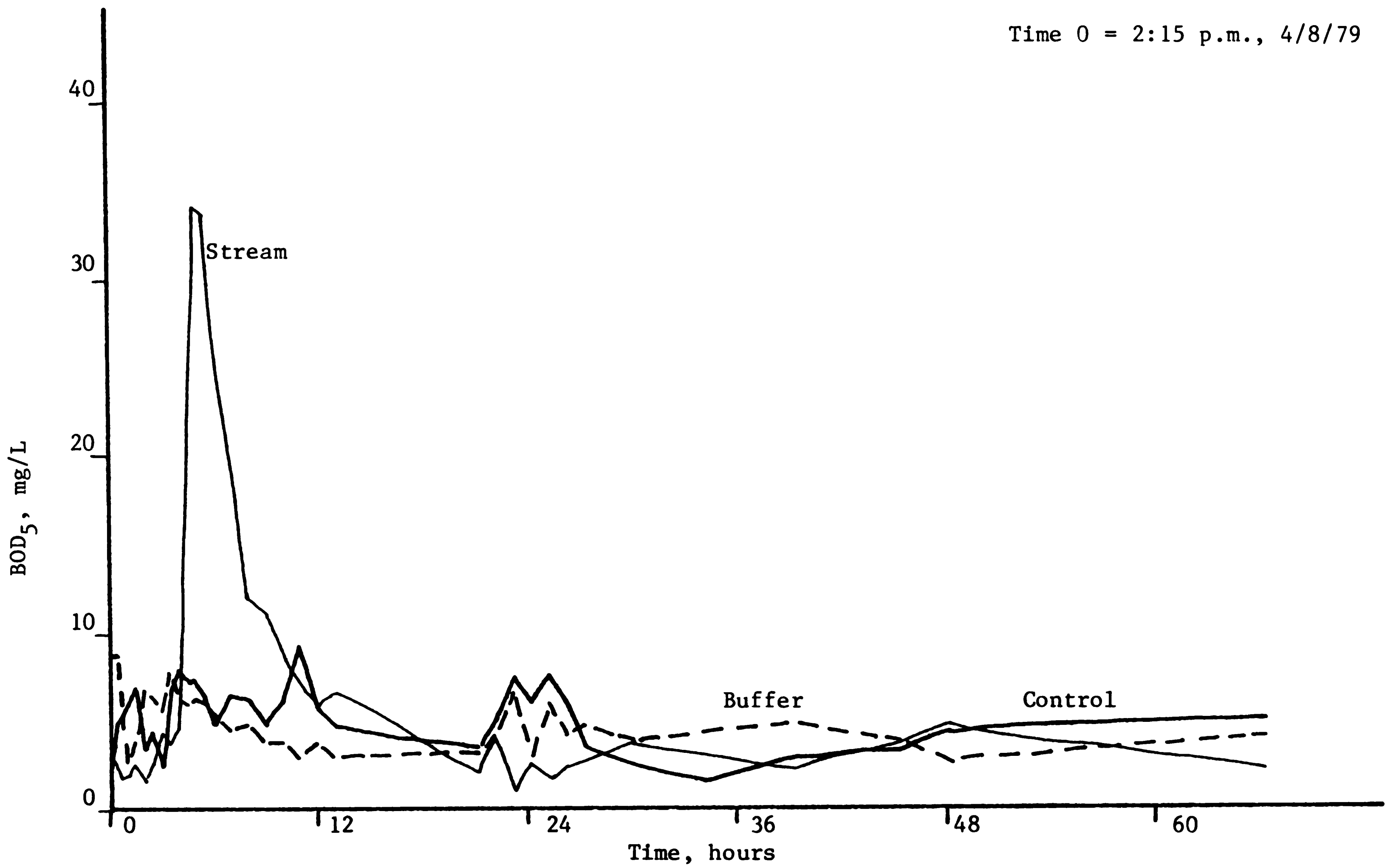

Figure 75. 5-day Biochemical Oxygen Demand vs. Time, Event 5

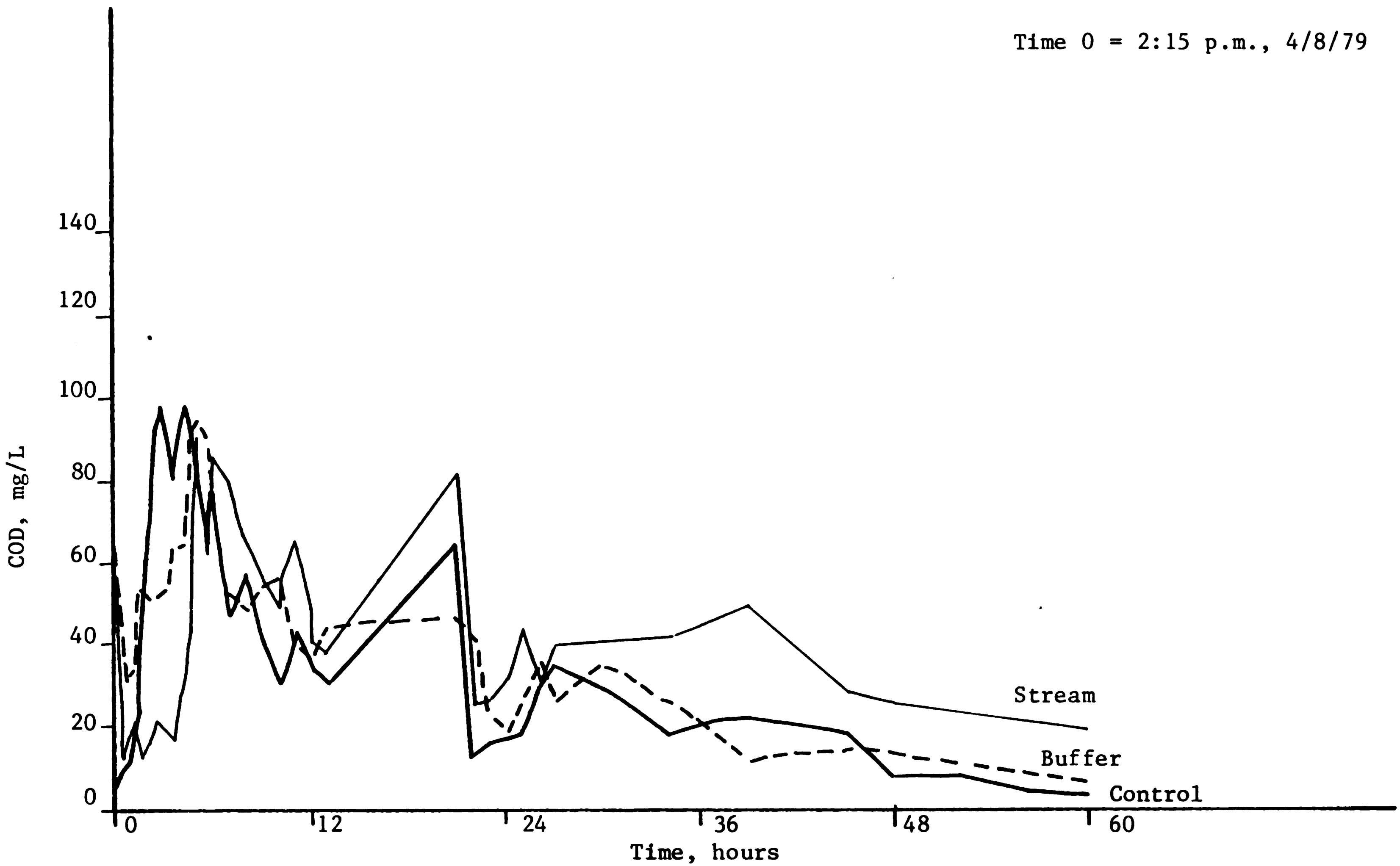

Figure 76. Chemical Oxygen Demand vs. Time, Event 5

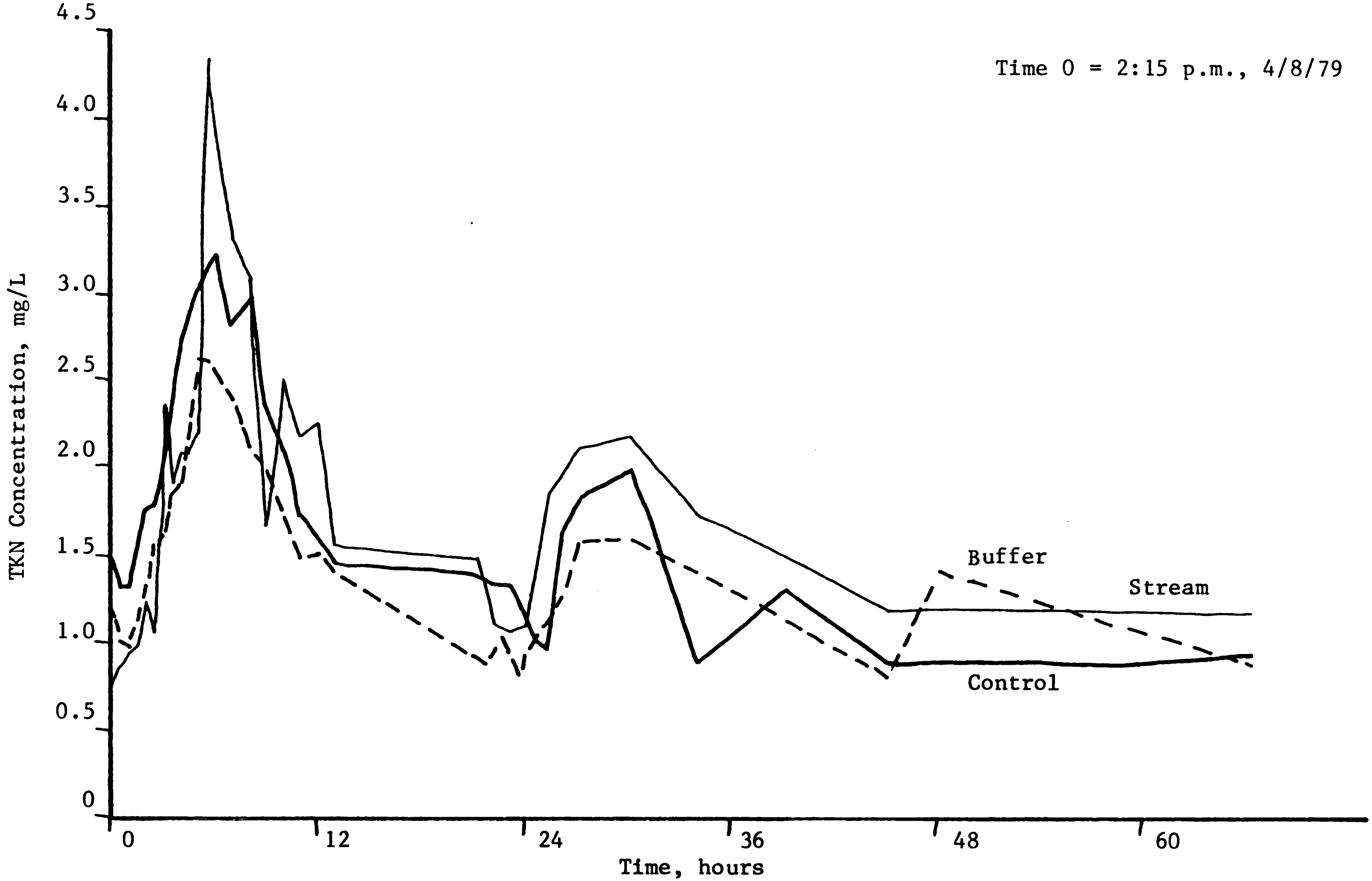

Figure 77. Total Kjeldahl Nitrogen Concentration vs. Time, Event 5

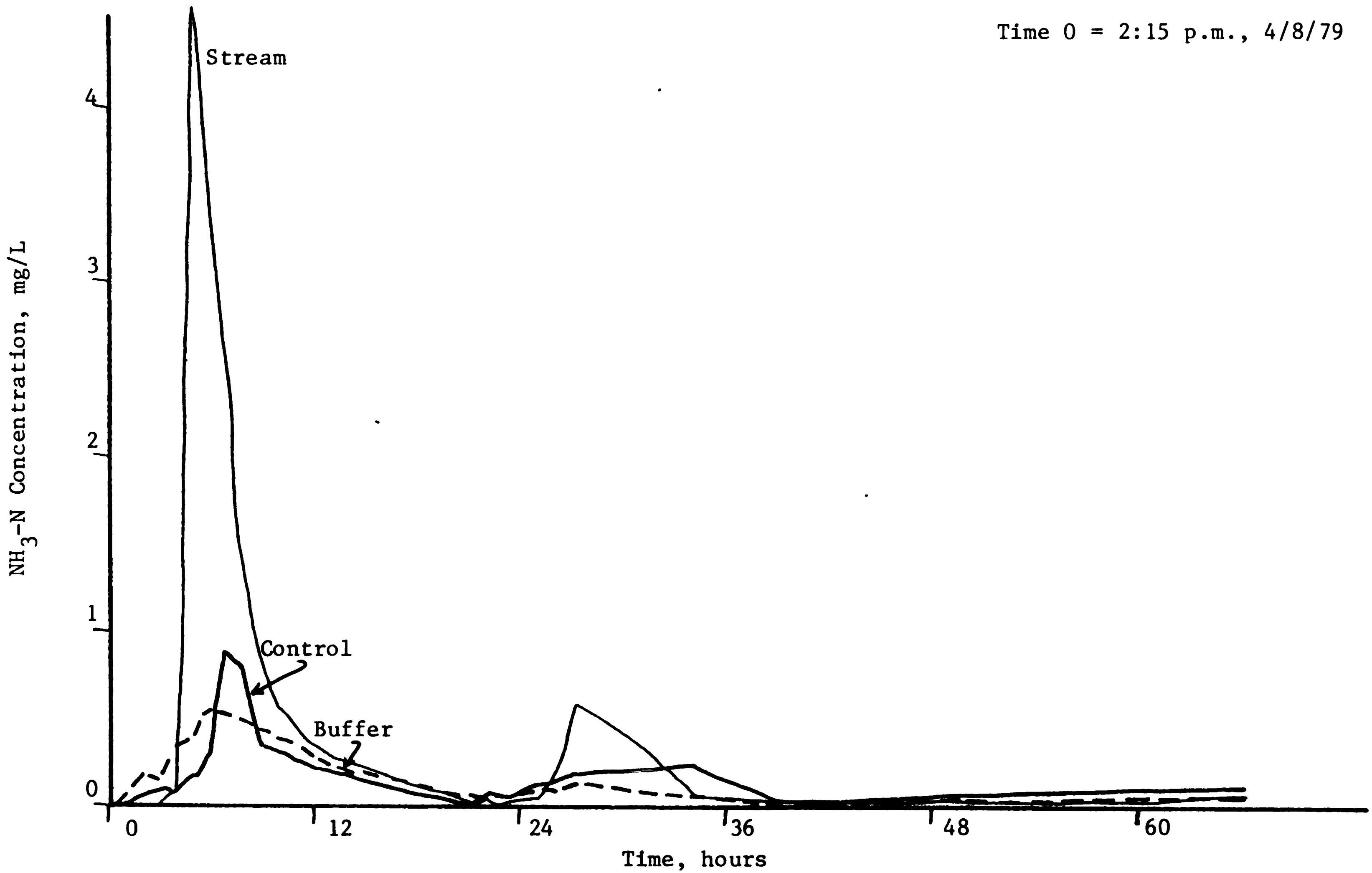

Figure 78. Ammonia-Nitrogen Concentration vs. Time, Event 5

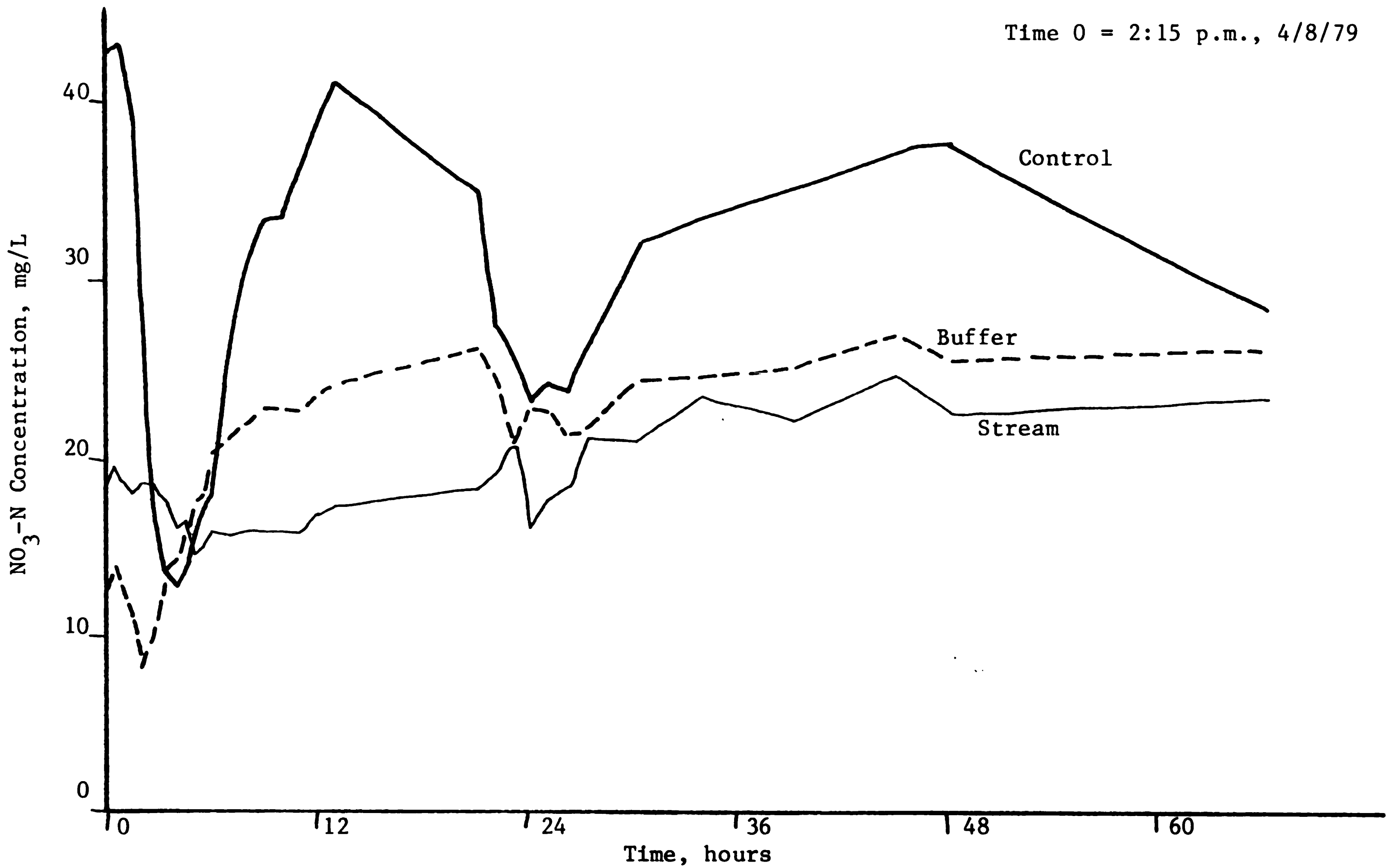

Figure 79. Nitrate-Nitrogen Concentration vs. Time Event 5

Figure 80. Nitrate-Nitrogen Concentration vs. Time, Event 5

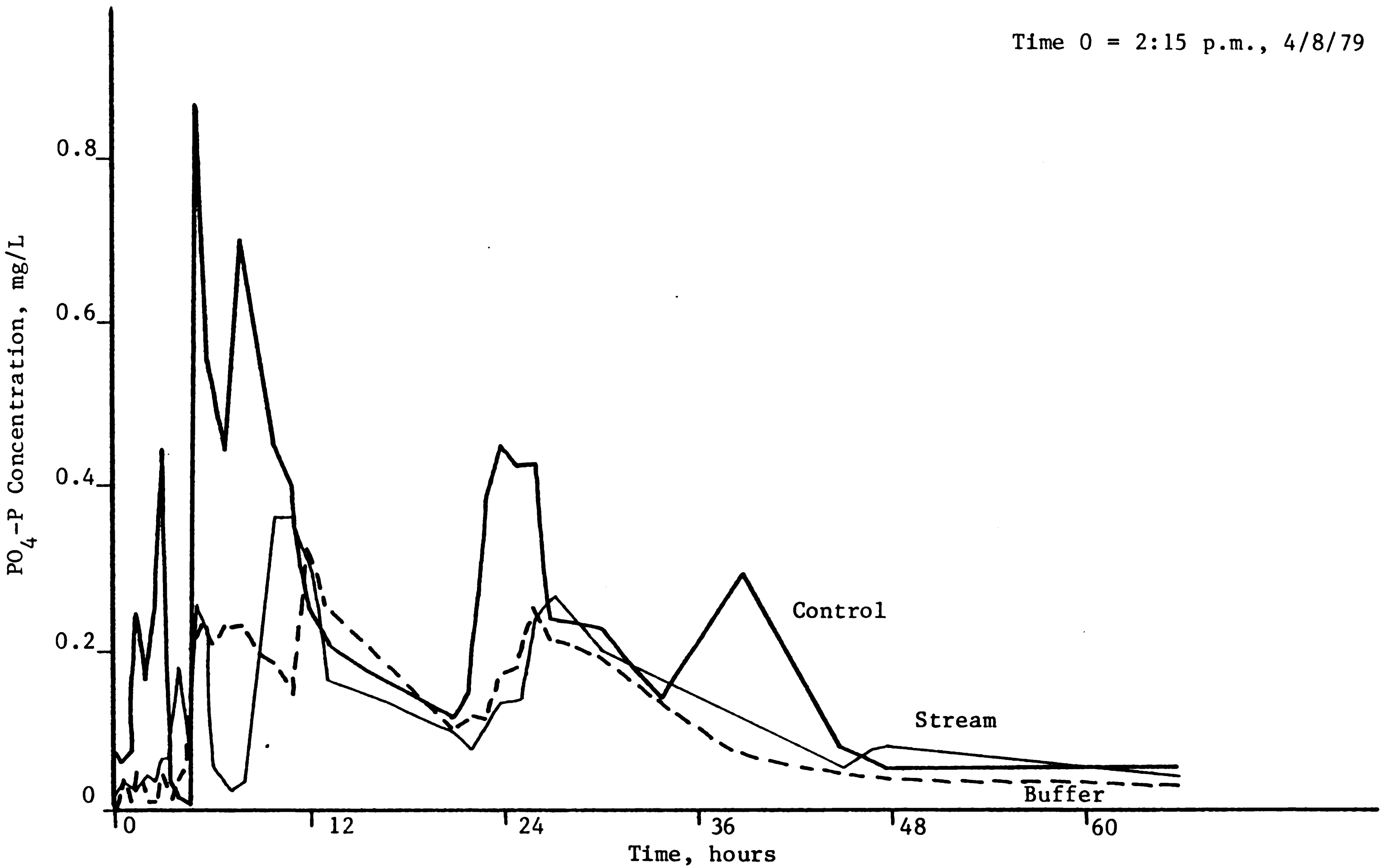

Figure 81. Total Phosphate Concentration vs. Time, Event 5

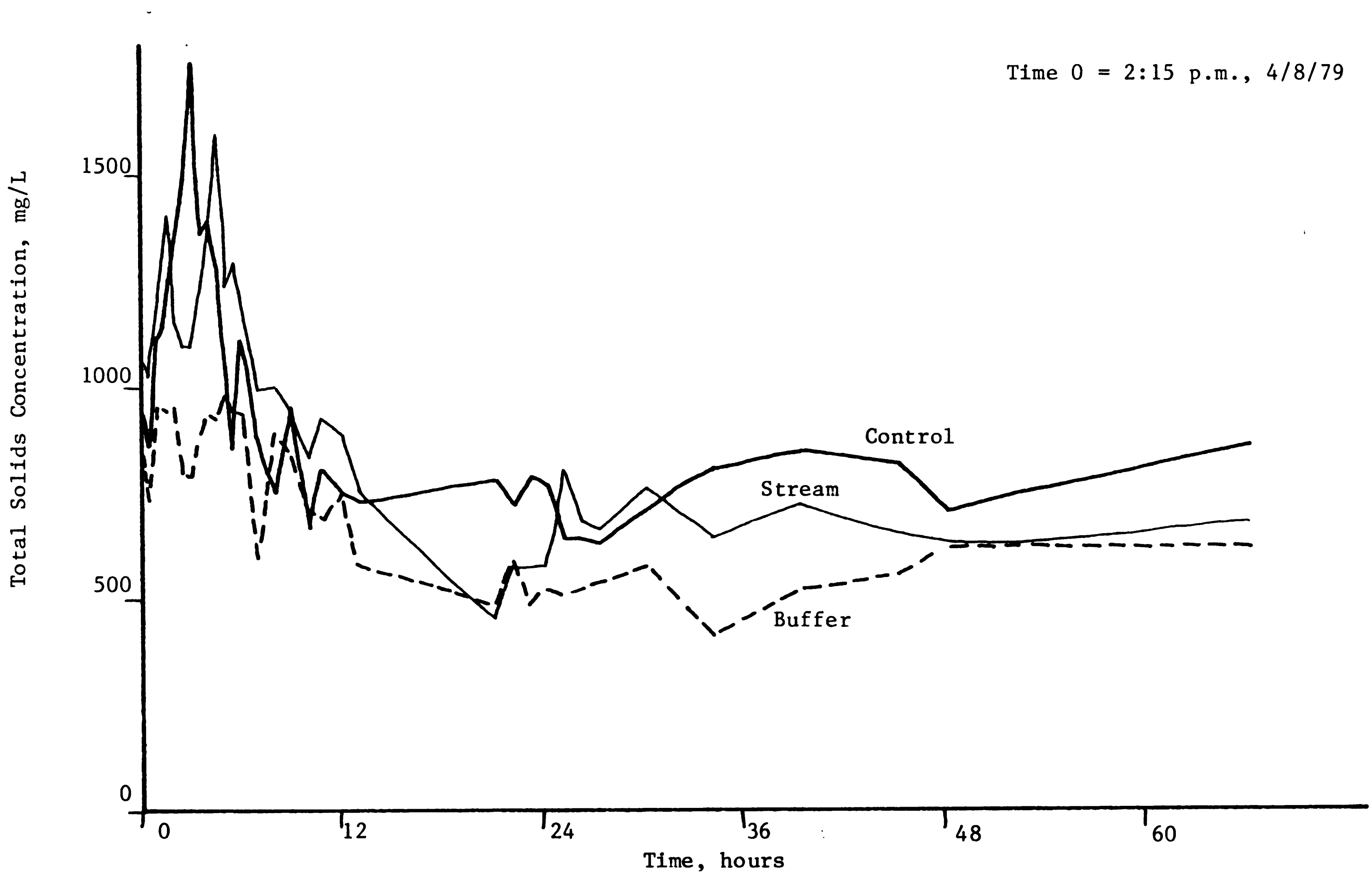

Figure 82. Total Solids Concentration vs. Time, Event 5

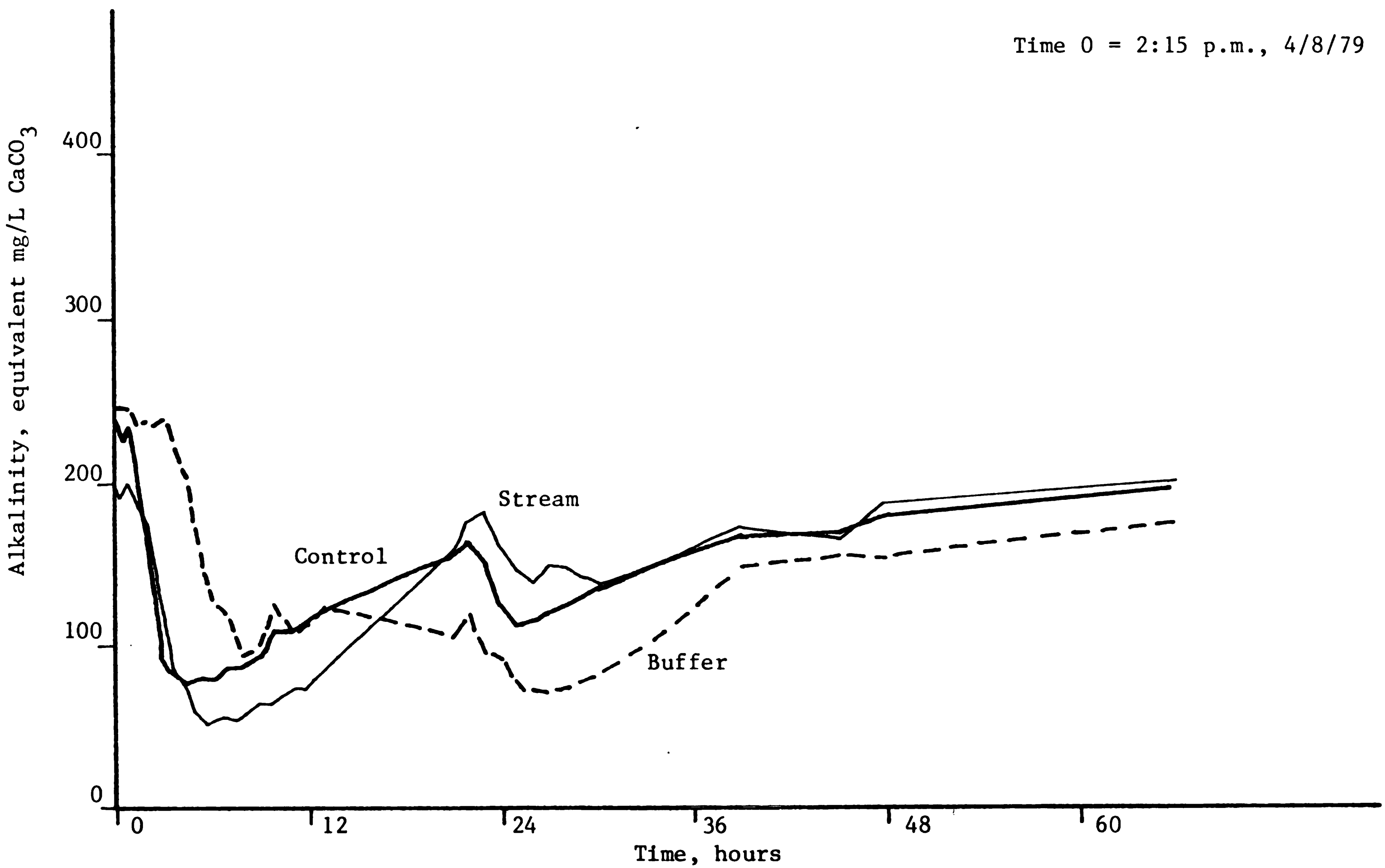

Figure 83. Alkalinity vs. Time, Event 5

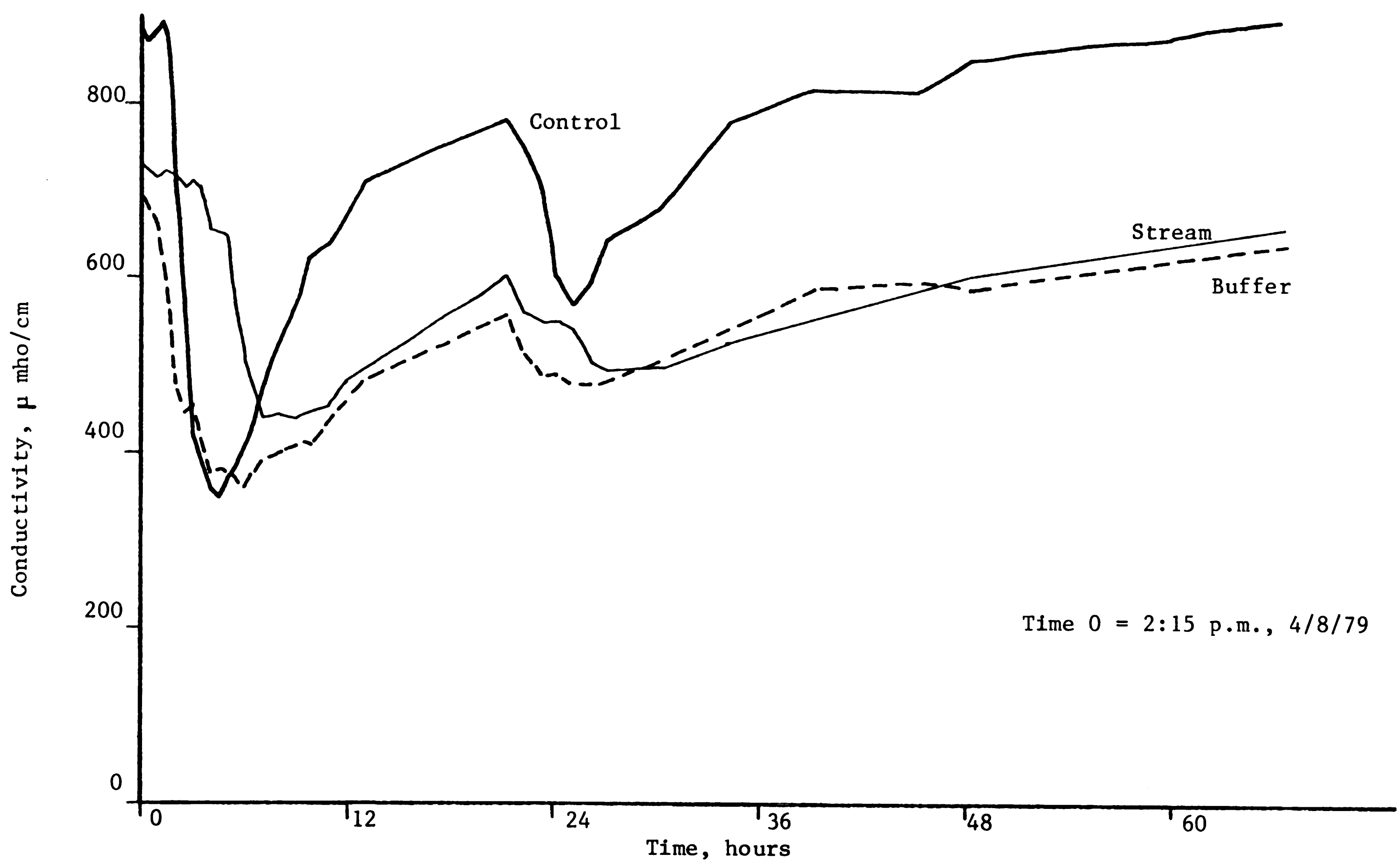

Figure 84. Conductivity vs. Time, Event 5

The runoff samples analyzed from the control field indicate generally higher concentrations of total Kjeldahl nitrogen, nitrate-nitrogen, total solids, and total phosphate than in the runoff from the buffered field. Conductivity values are also greater in the control, whereas 5-day biochemical oxygen demand, chemical oxygen demand, ammonia-nitrogen, and alkalinity values from the two fields' runoff are similar. During the period of peak runoff flow, concentrations of 5-day biochemical oxygen demand, total Kjeldahl nitrogen, and ammonia-nitrogen are greater for the stream samples than for either set of runoff samples. The estimates of the other water quality parameters for the stream are quite comparable to those corresponding estimates for the two runoff flows.

3.4.7. Runoff Event Six

Runoff event six closely followed event five. The event began at about 12:15 p.m. on April 11, 1979, when runoff flows were first measured. The time designated as hour 0 of event six is synynomous with what would be the time designated as hour 70 of event five, were the abcissa extended. The cause of runoff, as with the several previous events, was light and sporadic precipitation falling on saturated soils. Runoff followed the time of first rainfall with only a slight lag, and the storm continued intermittently for 14 hours. Maximum hourly rainfall intensities of 0.13 centimeters per hour were measured. Flows of runoff subsided on the afternoon of April 12, and the event ended at about 6:00 p.m. on that date.

The three automatic water samplers began operation at 12:15 p.m. on April 11, as the event commenced, and continued to operate through the 30-hour duration of runoff. A sampling and analysis interval of 30 minutes was maintained through the peak of the runoff hydrograph, and was lengthened as flows subsided. Figures 85 through 97 present data gathered from this runoff occurrence. The time designated as hour 0 in these figures is 12:15 p.m. on April 11, 1979.

The shape of the two runoff hydrographs is similar, as with the previous events, and the water yield of the buffered field is somewhat less than that of the control. No time lag is apparent between fields as to the initiation of runoff. The stream flow peak lags the runoff flows' peak by about two hours.

Laboratory analysis of the water samples indicates that the buffered field runoff contains lower levels of chemical oxygen demand, ammonia-nitrogen, nitrate-nitrogen, total solids, conductivity, and alkalinity than does runoff from the control field. Concentrations of 5-day biochemical oxygen demand, total Kjeldahl nitrogen, nitrite-nitrogen, and total phosphate from the two runoff streams are quite comparable. Values of the various water quality constituents obtained from analysis of stream samples are in the same range as those of the runoff samples. Nitrate-nitrogen concentrations, particularly in the control field's runoff, were substantially higher in runoff event six than in the other five events.

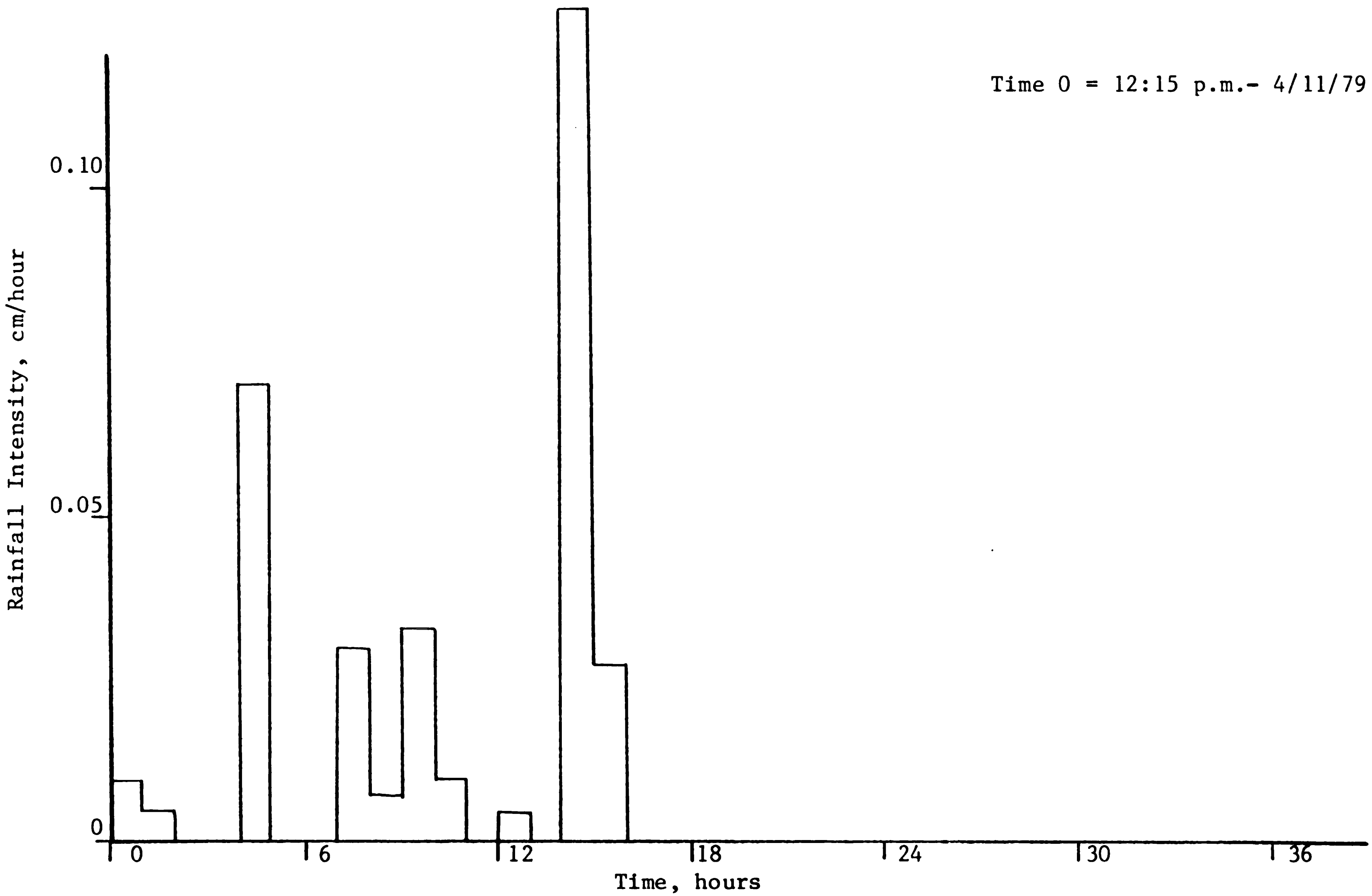

Figure 85. Rainfall Intensity vs. Time, Event 6

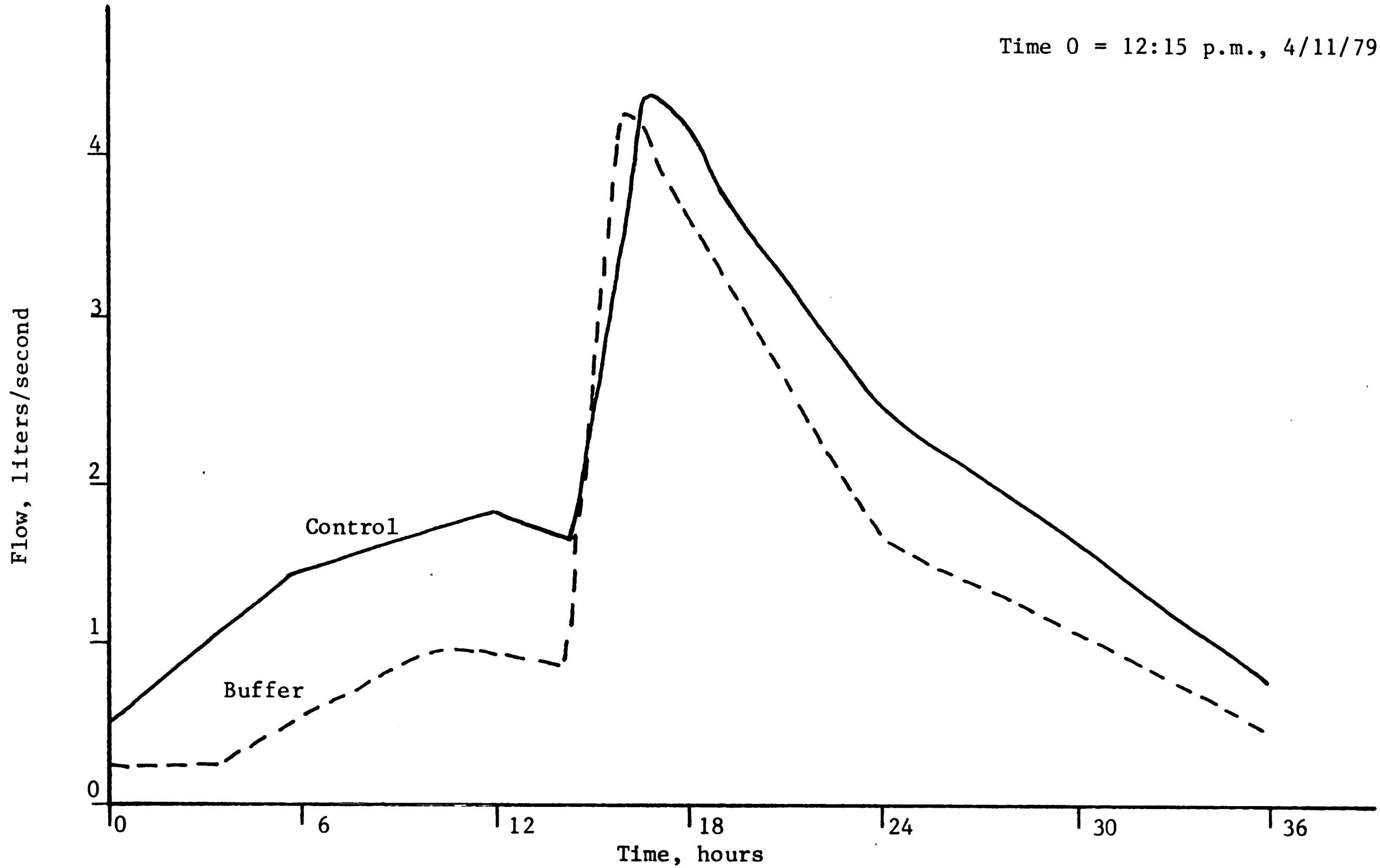

Figure 86. Runoff Flow vs. Time, Event 6

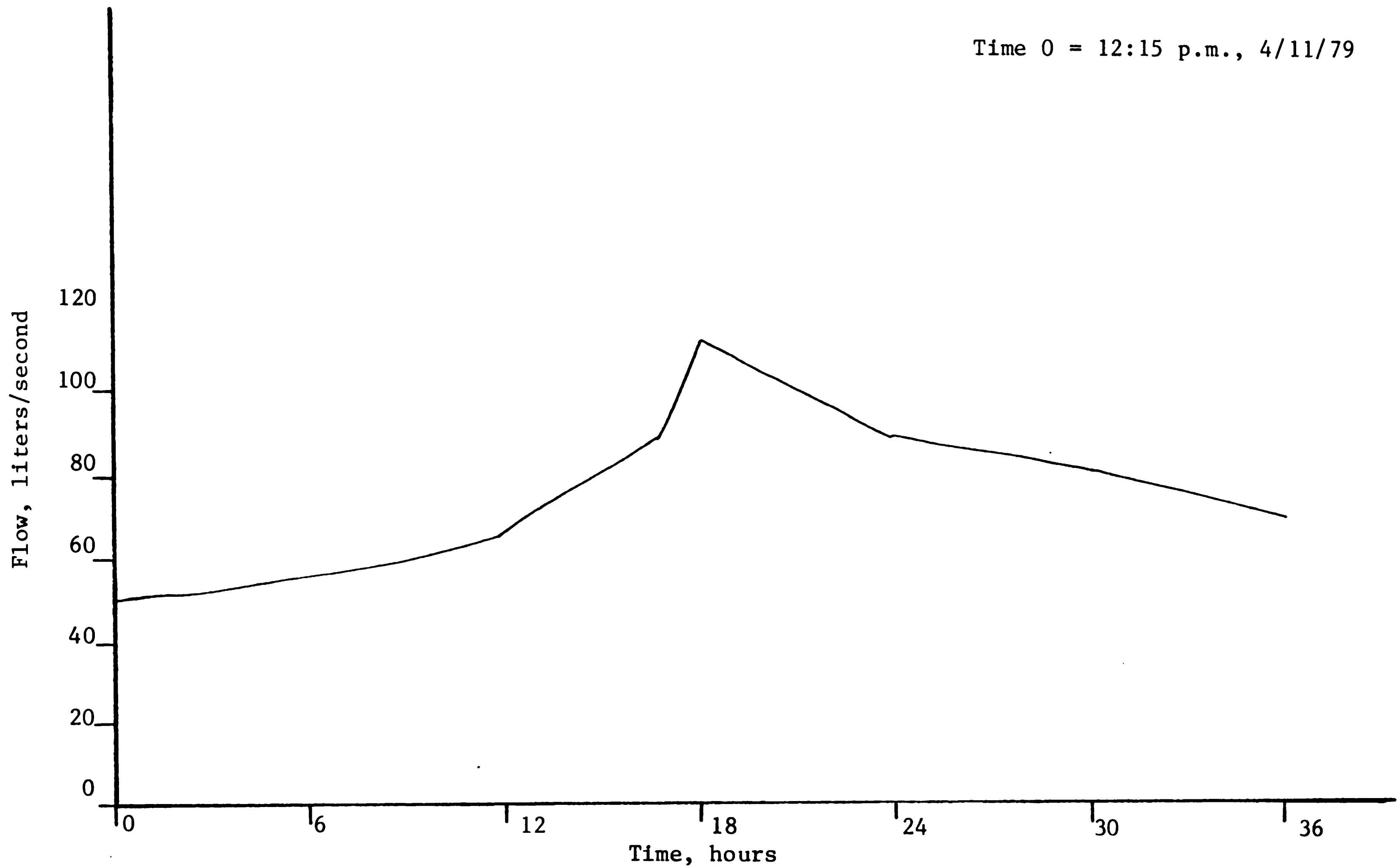

Figure 87. Stream Flow vs. Time, Event 6

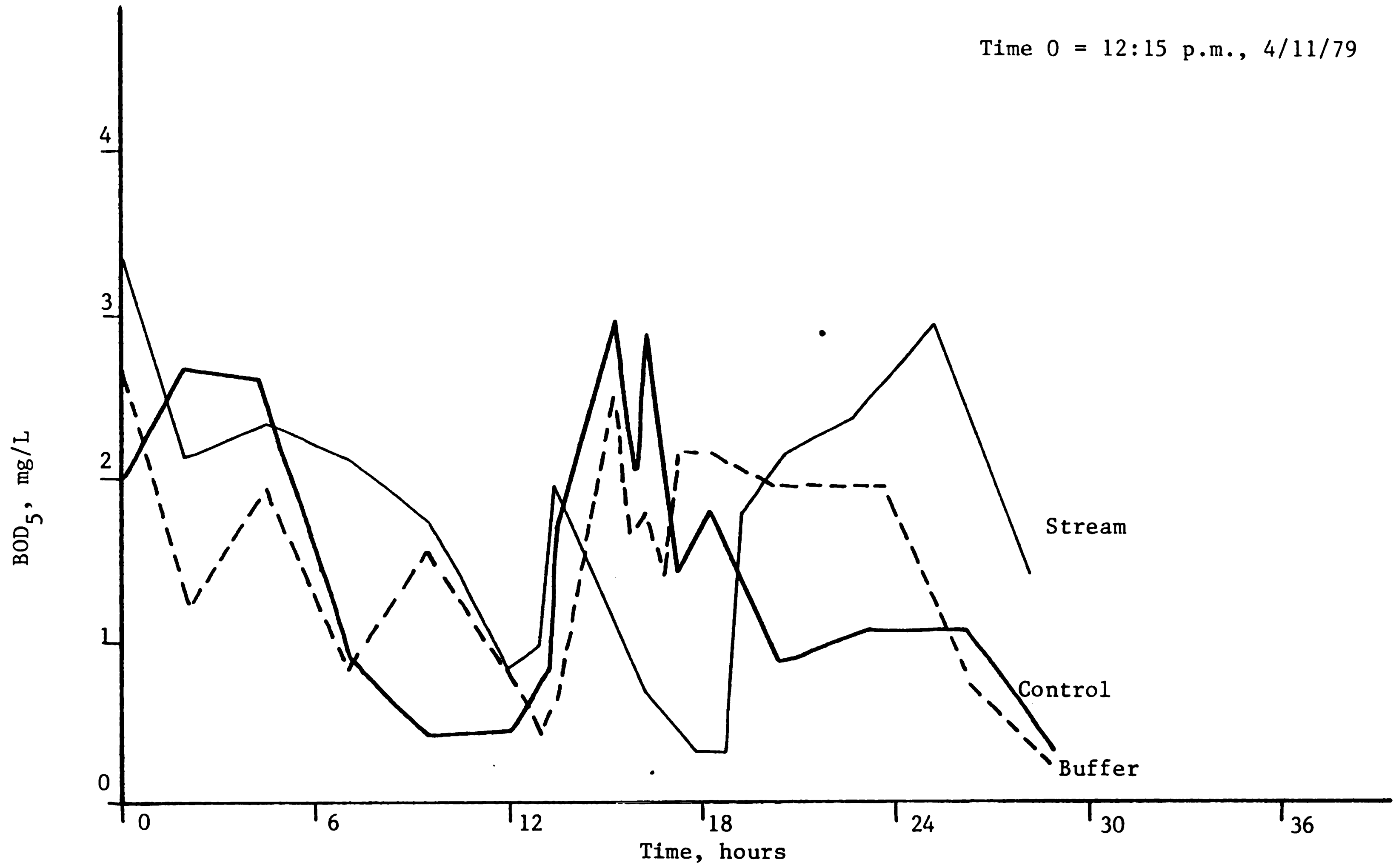

Figure 88. 5-day Biochemical Oxygen Demand vs. Time, Event 6

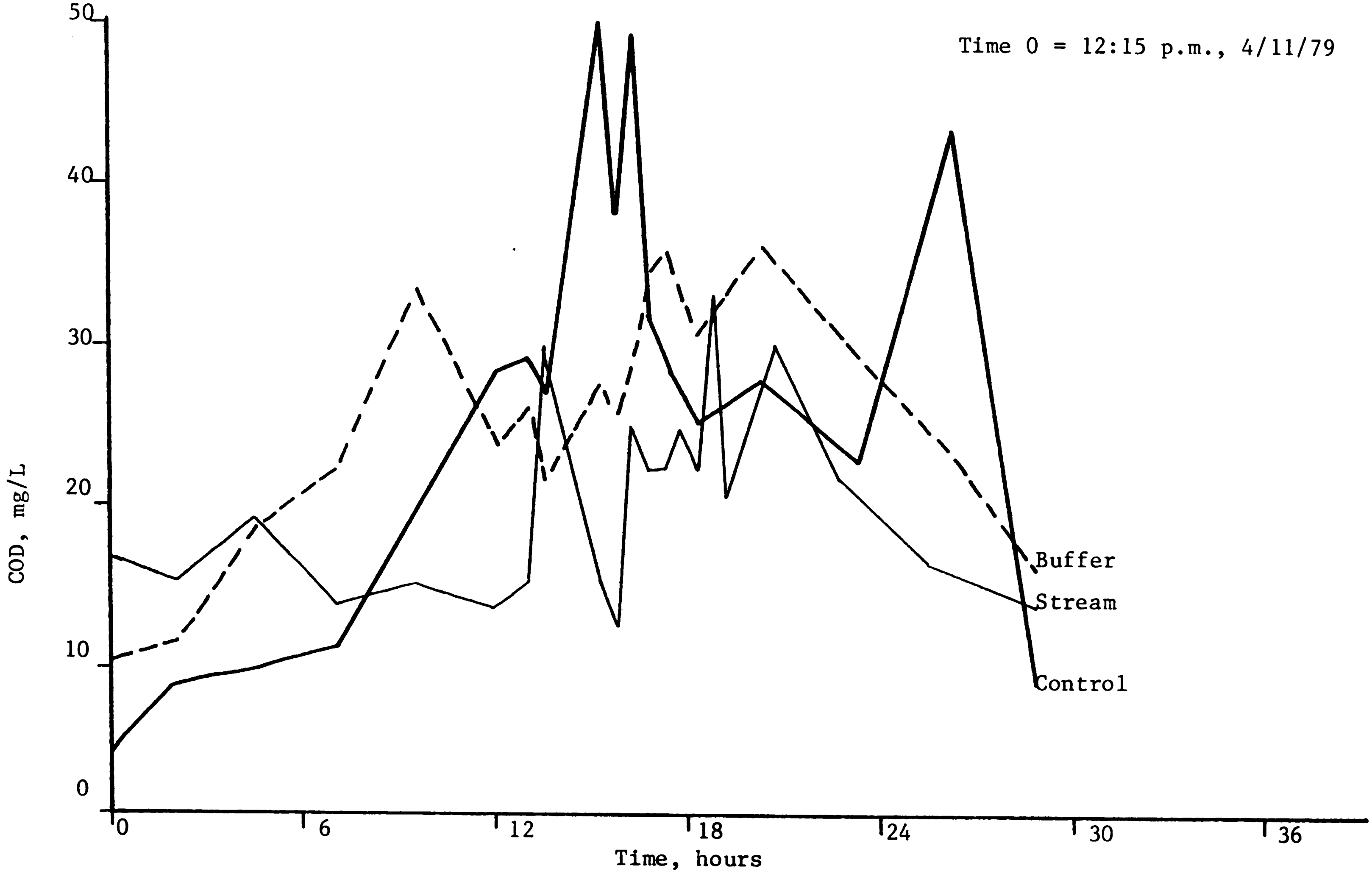

Figure 89. Chemical Oxygen Demand vs. Time, Event 6

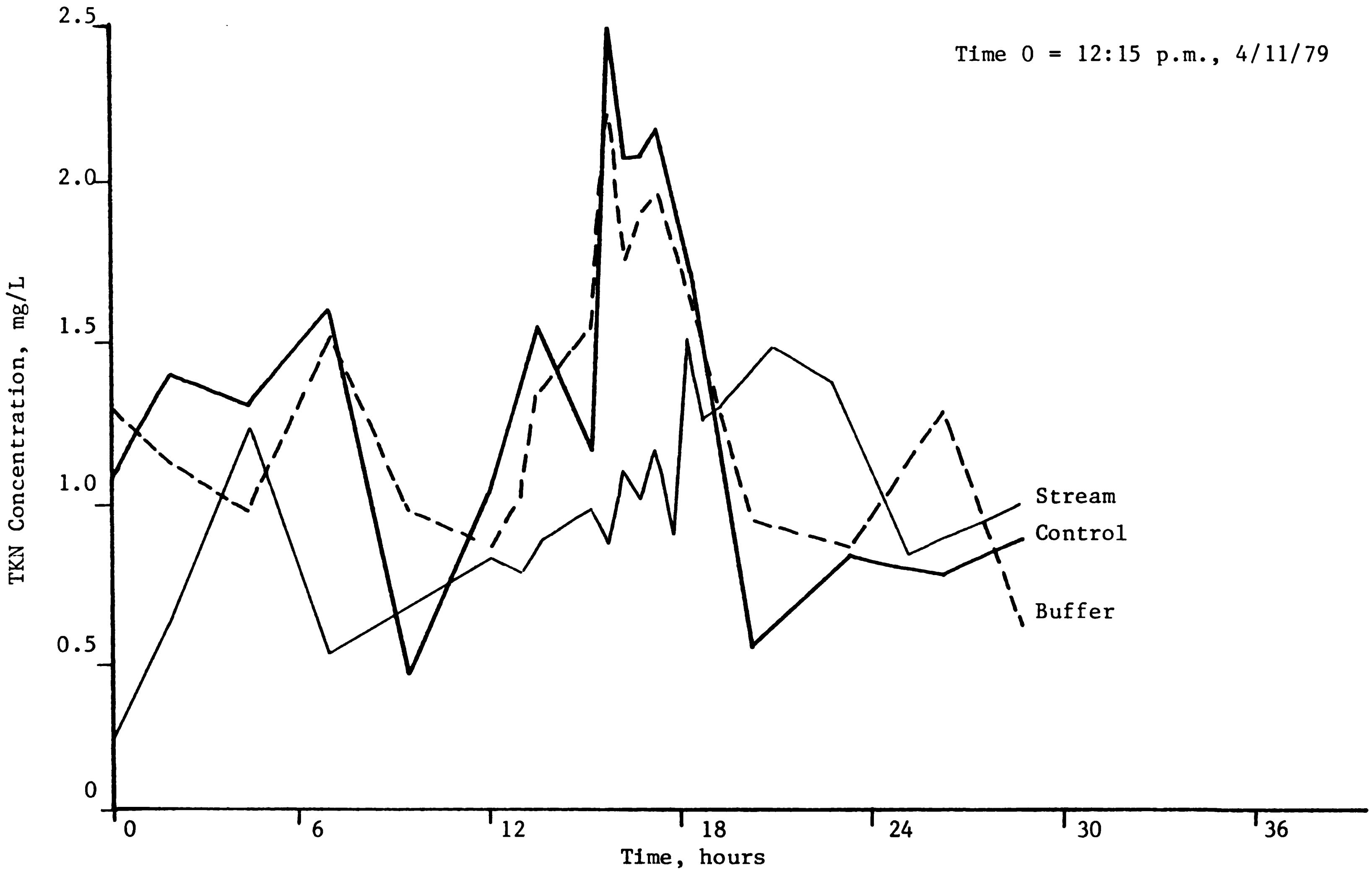

Figure 90. Total Kjaldahl Nitrogen Concentration vs. Time, Event 6

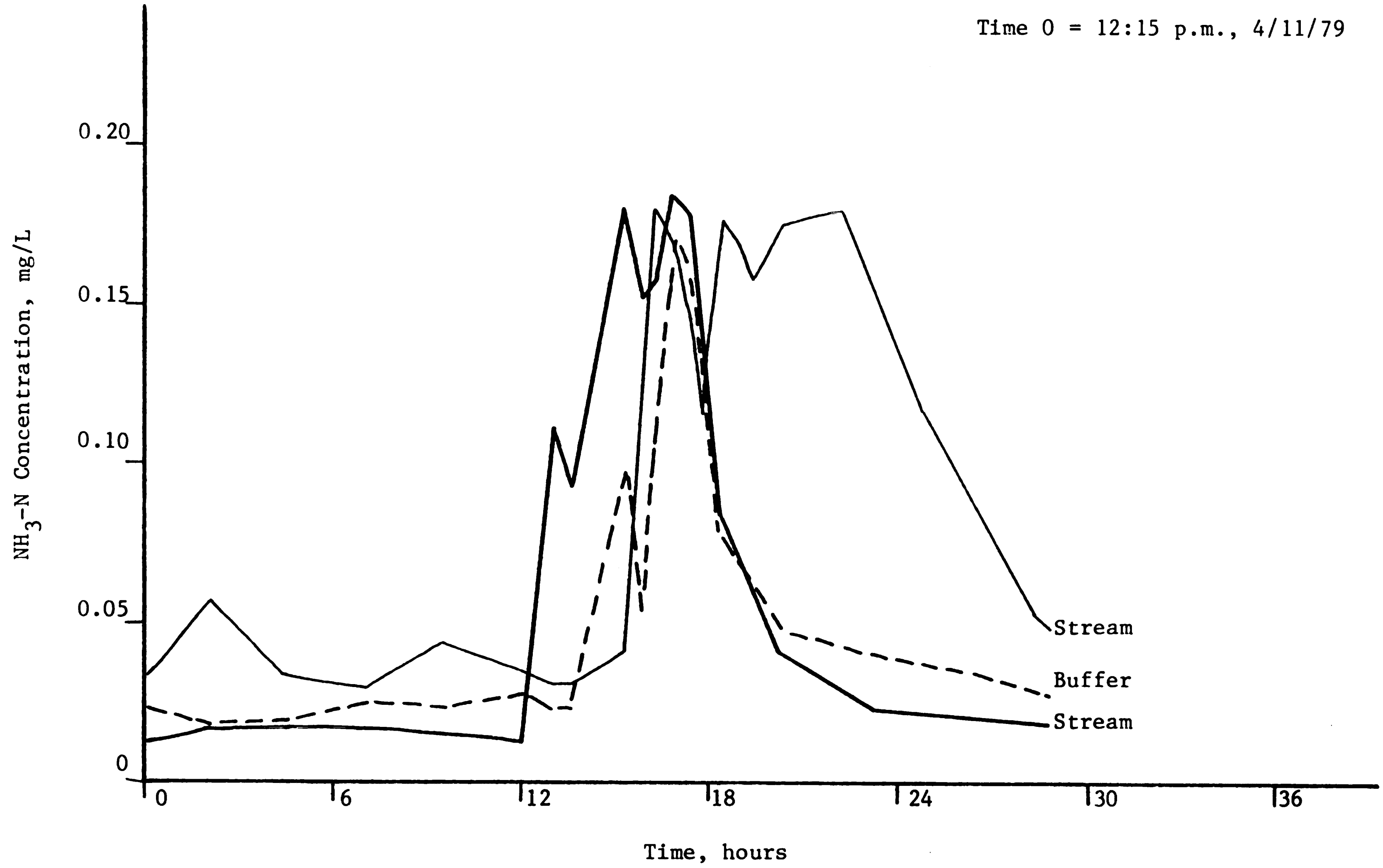

Figure 91. Ammonia-Nitrogen Concentration vs. Time, Event 6

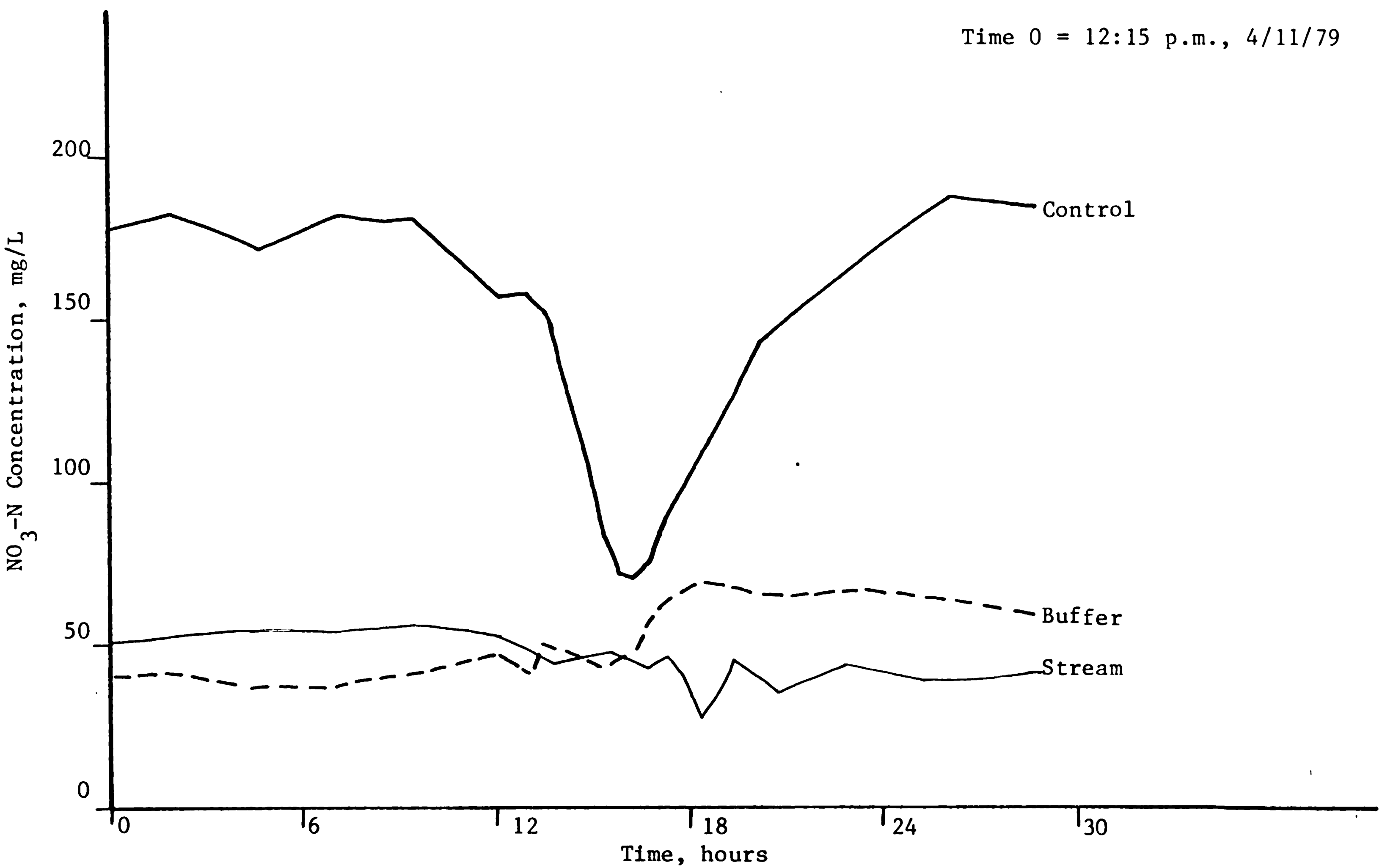

Figure 92. Nitrate-Nitrogen Concentration vs. Time, Event 6

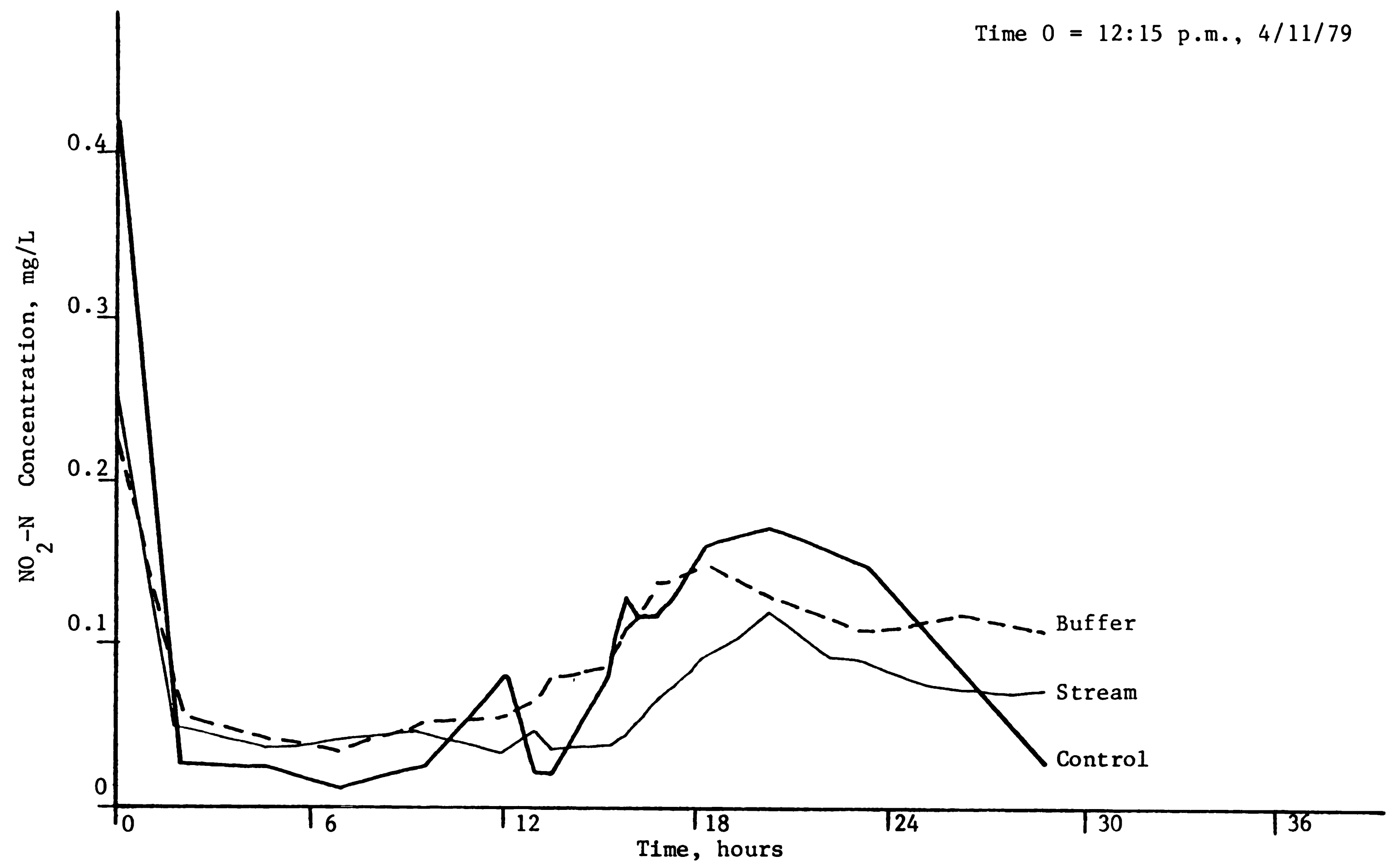

Figure 93. Nitrite-Nitrogen Concentration vs. Time, Event 6

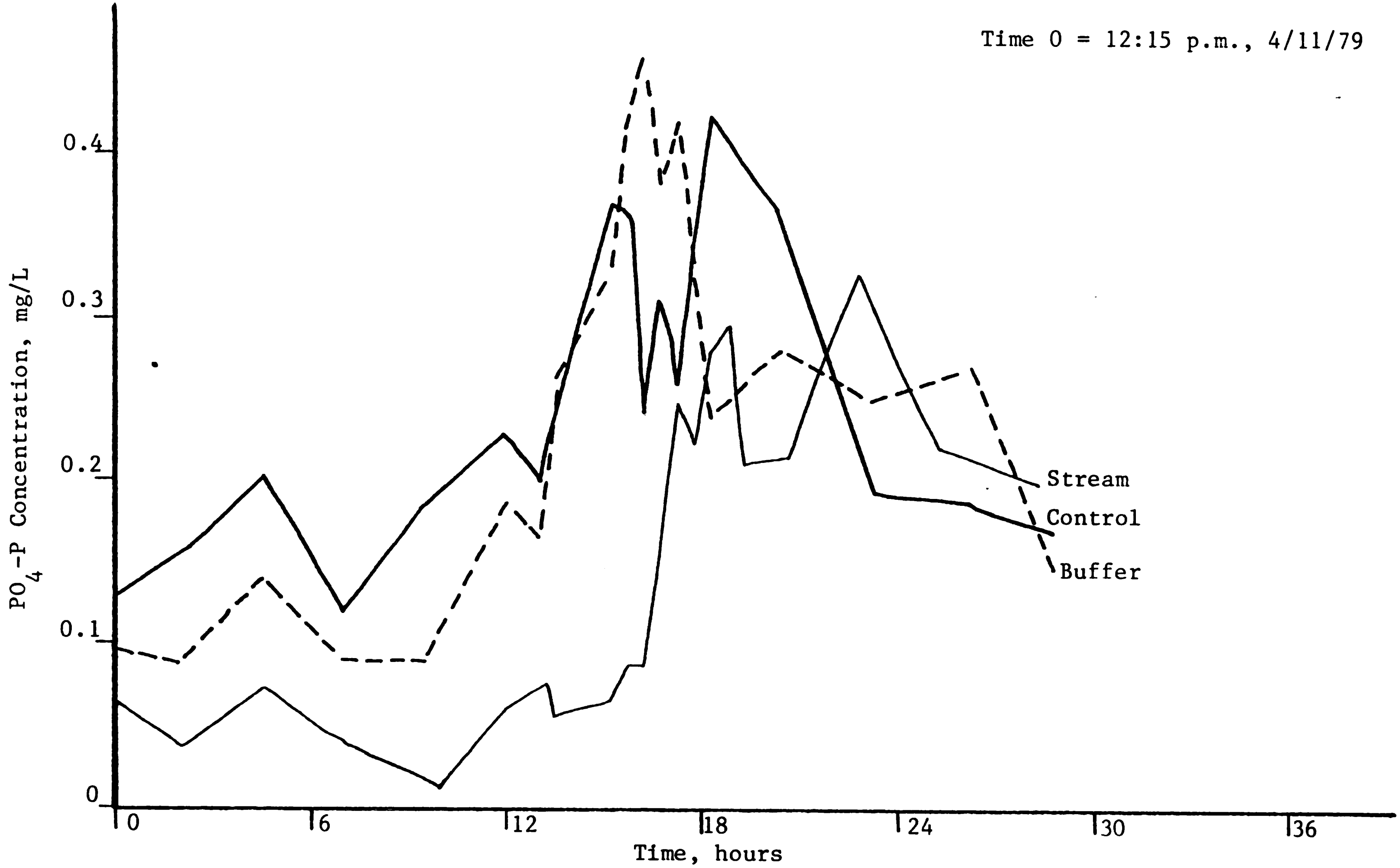

Figure 94. Total Phosphate Concentration vs. Time, Event 6

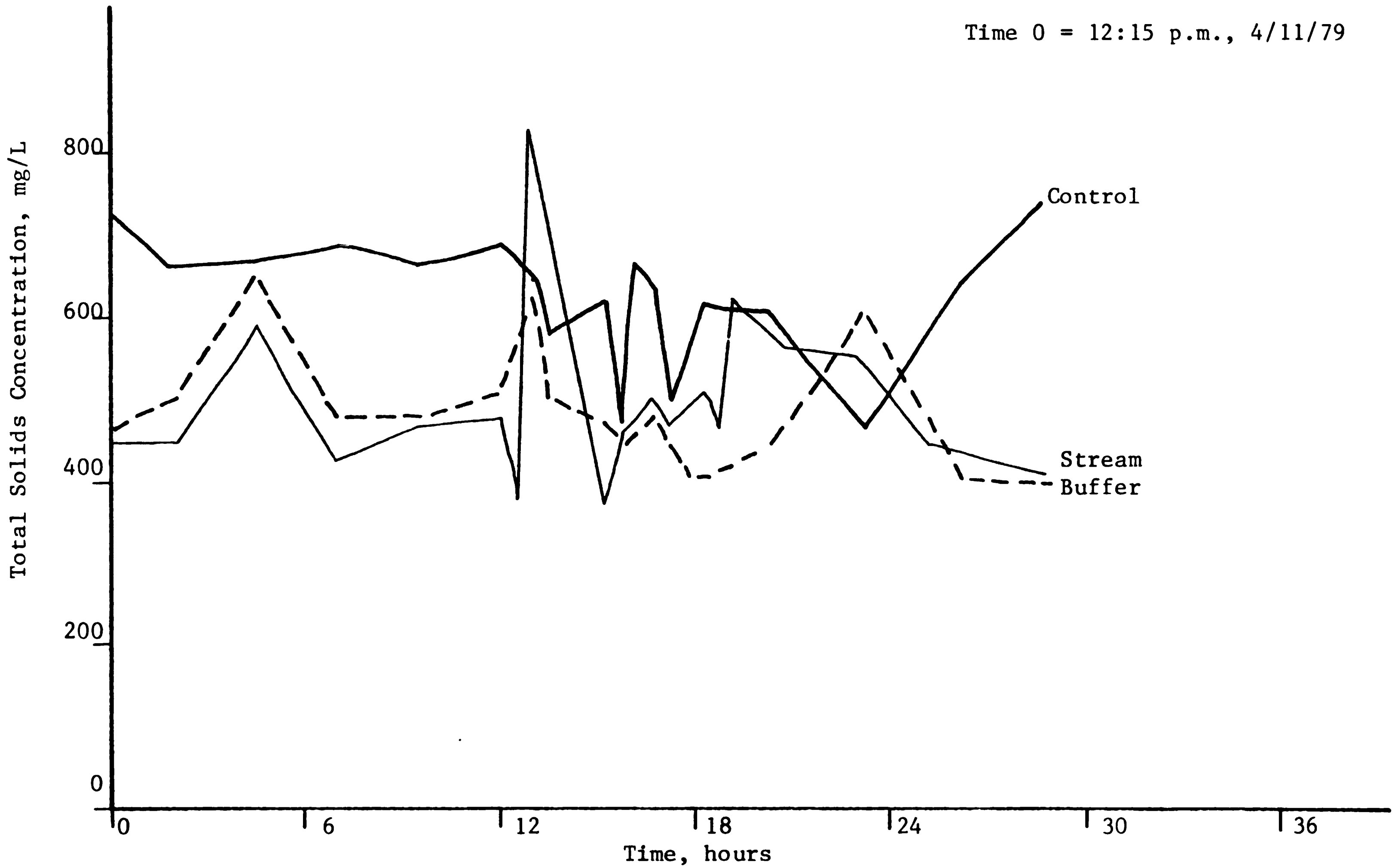

Figure 95. Total Solids Concentration vs. Time, Event 6

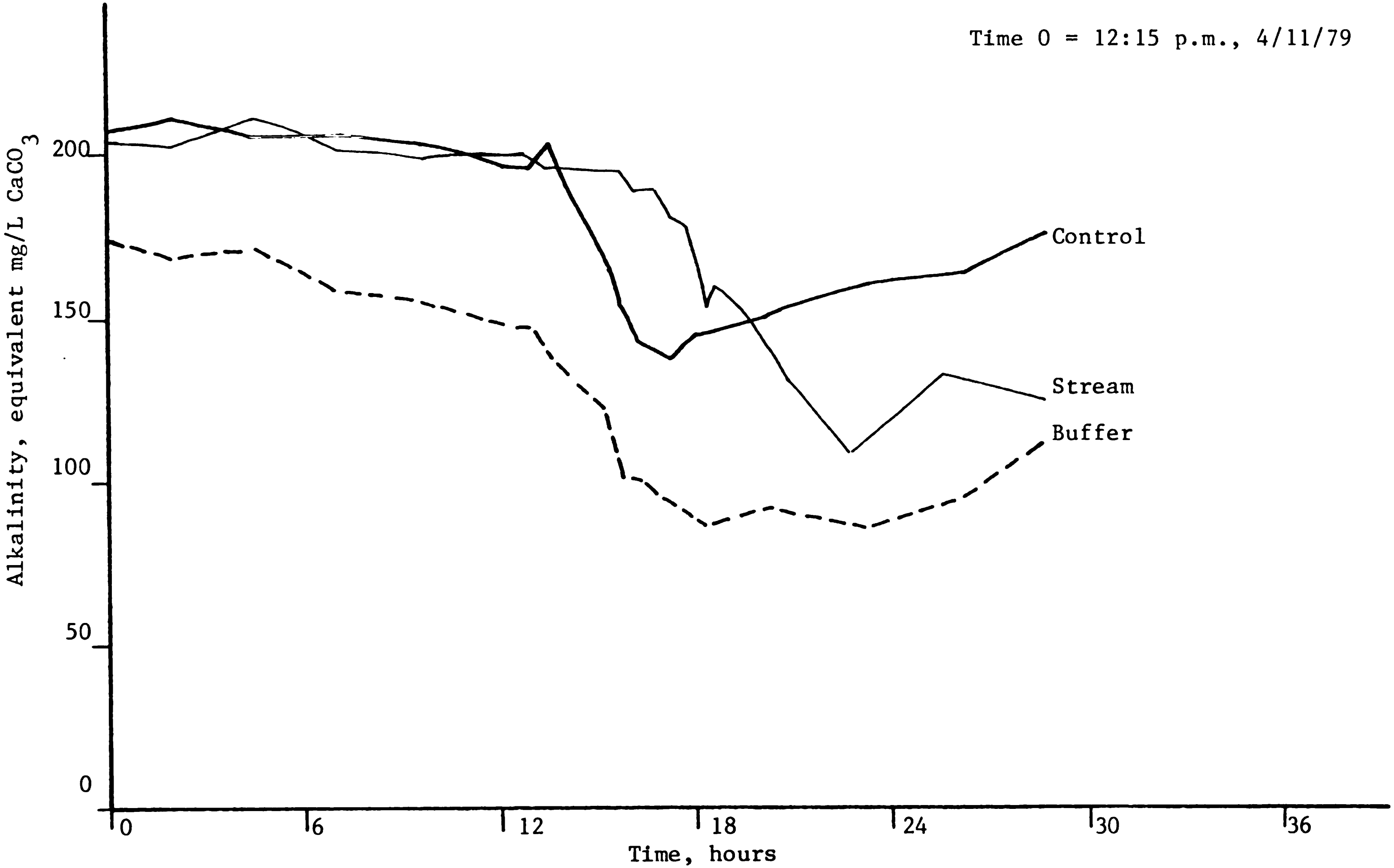

Figure 96. Alkalinity vs. Time, Event 6

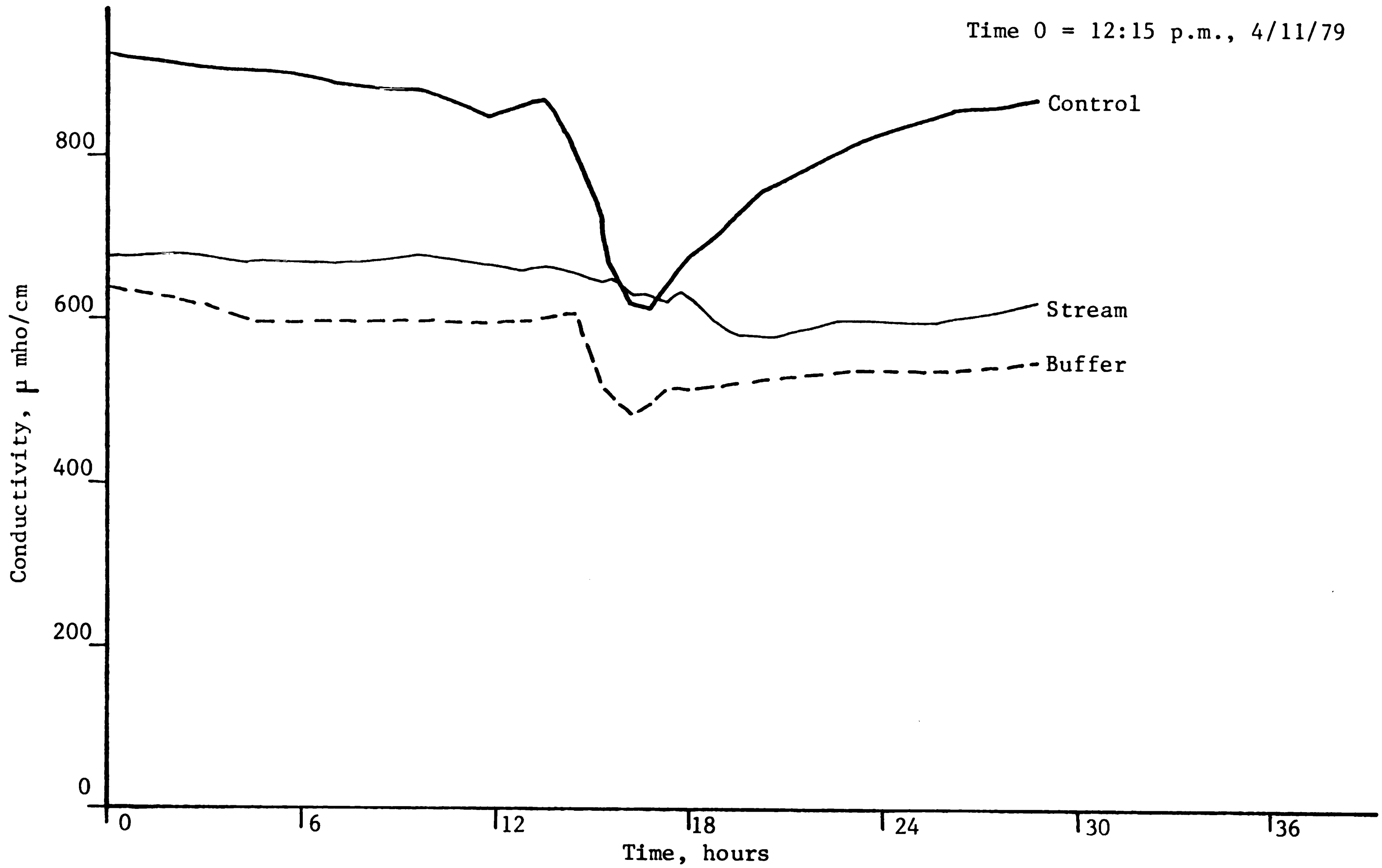

Figure 97. Conductivity vs. Time, Event 6

3.5. Bacteriological and pH Determinations

In addition to the various laboratory analyses performed for the runoff event water samples, the results of which are reported in the previous section, bacteriological and pH determinations were also conducted. Due to their nature, the data from these two laboratory testing programs are presented in tabular form.

A summary of the fecal coliform bacteria counts performed for runoff event water samples is presented as Table 9. Geometric means, the standard bacteriological statistic usually employed, are not shown. This statistic is not reportable as a substantial number of the counts were below the threshold of the test. Alternatively, the results are presented as percentages of total counts within three ranges for the three monitoring station locations. The ranges were determined by two widely recognized fecal coliform bacteria levels originating from government environmental policy. A count of 200/100 mL is the standard set by the U.S. Environmental Protection Agency for the surface water discharge from a secondary sewage treatment plant. A count of 1000/100 mL is a standard often suggested for "secondary body contact" recreational uses of surface waters, and is also the water quality standard imposed on this study's stream by the Michigan Department of Natural Resources. Both standards, properly expressed, are geometric means not to be exceeded. While geometric means are not reportable, the values of these standards are employed to indicate potential pathogen contributions in a somewhat qualitative manner.

As is seen in Table 9, a high percentage of the fecal coliform bacteria counts from all locations are less than or equal to 200/100 mL. A relatively substantial percentage of counts are greater than 200/100 mL and less than 1000/100 mL in both the buffered runoff and the stream, while the percentage of the control counts drops sharply. Percentages of counts in the highest range, 1000/100 mL or more, drop drastically for both runoff flows, while that of the stream samples drops substantially.

A summary of pH results from the runoff water samples collected is presented as Table 10. As the table indicates, pH values were generally greater in the buffered field's runoff than in the control field's runoff. Stream pH values were generally greater than those of either runoff flow. The range of the pH measurements for each runoff event is usually greater for the buffer than the control or stream. Some variation to these generalities is quite apparent. Runoff event one, for example, which is the most significant event in terms of both flow rate and duration, is a notable exception. The control field runoff exhibits a higher mean pH for this event when compared to the buffer, as well as a wider range in pH values recorded. Also in event one, the range of pH values is greater for the stream samples than for the buffer.

Table 9

Runoff Fecal Coliform Bacteria Data [(a)]

Location	Percentage of Determinations			
	$\leq$200/100 mL	201-999/100 mL	$\geq$1000/100 mL	Total
Buffer	66	28	6	100
Control	92	7	1	100
Stream	40	39	21	100

(a) Results from 383 samples from six runoff events of 1979.

Table 10

Runoff pH Data [(a)]

Runoff Event	Location	pH Units		
		Minimum	Maximum	Mean
1	Buffer	6.70	7.10	6.86
	Control	6.50	7.20	6.95
	Stream	6.65	7.40	7.05
2	Buffer	6.70	7.50	6.96
	Control	6.55	6.95	6.83
	Stream	6.90	7.35	7.17
3	Buffer	7.00	7.21	7.11
	Control	6.60	7.25	7.08
	Stream	6.90	7.68	7.50
4	Buffer	7.40	8.20	7.93
	Control	7.40	7.50	7.45
	Stream	7.20	7.80	7.70
5	Buffer	7.20	8.30	7.57
	Control	6.20	7.50	7.06
	Stream	7.00	7.80	7.61
6	Buffer	6.10	8.80	7.48
	Control	7.20	7.35	7.25
	Stream	7.30	7.70	7.59
All Events	Buffer	6.10	8.80	7.18
	Control	6.20	7.50	7.10
	Stream	6.65	7.80	7.32

(a) Results from 547 samples from six runoff events of 1979.

Chapter 4

RESULTS

4.1. Buffer Area Performance

4.1.1 General

The performance of the vegetated buffer area can be evaluated in terms of water pollutant load reduction or water pollutant concentration reduction. Both measures are valid, and the more desired evaluation of the two is determined by the views or purposes of the individual.

Both measures are also important in terms of the resulting water quality of the receiving stream. Pollutant concentration data are needed to assess the instantaneous quality of the water, particularly in relation to some standard based upon the desired continuous use of the receiving waters. Load data are helpful in exploring the future of the receiving stream, and the surface waters to which it later contributes, in terms of the life expectancy of the entire watercourse.

The data collected through laboratory testing of the runoff water samples gathered from the project site were subjected to statistical analyses for the detection of differences in both pollutant concentration and pollutant load. Concentration differences have an instantaneous water quality importance, as stated above, while load differences have a broader significance.

If a certain Best Management Practice reduces pollutant concentration, leaving the pollutant load unchanged, then it is of benefit to the receiving stream. The maximum level of that pollutant in that stream will have been reduced. If another Best Management Practice reduces the pollutant load, while the concentration of that pollutant is not altered, it is also of benefit to the receiving stream. The yearly load placed on that stream will have been reduced. If yet another Best Management Practice reduces both pollutant load and concentration, the potential continuous use of the receiving watercourse and its future are both enhanced. Different types of benefits may result from the installation of any one of the various Best Management Practices. It is important, therefore, to evaluate the practice in terms of both pollutant concentration and pollutant load to insure an adequate assessment of these benefits.

4.1.2. Concentration Analysis

Standard statistical procedures were employed to detect differences in the concentration of the various pollutants monitored in the runoff from the two fields. Each of the parameters estimated from the laboratory analysis of runoff water samples, except for the fecal coliform bacteria counts, were evaluated.

The method of evaluation is illustrated by the example, utilizing 5-day biochemical oxygen demand, presented as Figure 98. As is seen, a one-tailed "t" test was utilized to accept or reject the null hypothesis of equal mean pollutant concentration.

At the five percent level, significant differences were detected for eight of the eleven tests performed. The runoff from the control field was found to have higher total solids concentrations, higher 5-day biochemical oxygen demand, higher chemical oxygen demand, higher total phosphate concentrations, higher nitrate-nitrogen concentrations, and higher values of conductivity and alkalinity, than the runoff from the buffered field. The pH values of the control field runoff samples were found to be lower than those of the buffered field runoff samples. No significant differences between the two fields were found for concentrations of ammonia-nitrogen, Concentration Analysis - BOD_5

Reference: Steel and Torrie (1960)

	Buffer	Control
$\overline{X}$	4.876	5.662
n	166	169
s^2	13.8	20.0
SS	2270	3370

Assume random sample of population $N(u,\sigma^2)$
Significance Level: $\alpha = 0.05$

H_o: $\mu_C = \mu_B$ H_a: $\mu_C > \mu_B$

Test: one-tailed "t" test
Critical Region: reject H_o if $|t_o| > t_{(.05)(333)} = 1.64$

$$t_o = \frac{\overline{X}_B - \overline{X}_C}{\sqrt{s_p^2\left(\frac{1}{n_B} + \frac{1}{n_C}\right)}}$$

$$s_p^2 = \frac{SS_B + SS_C}{n_B + n_C - 2} = \frac{2270 + 3370}{166 + 169 - 2} = \frac{5640}{333} = 16.937$$

$$t_o = \frac{4.876 - 5.662}{\sqrt{16.937\left(\frac{1}{166} + \frac{1}{169}\right)}} = \frac{-0.786}{0.449} = -1.75$$

∴ Reject H_o at the 5 percent level and conclude that BOD_5 concentration is greater for the control than the buffer.

Figure 98. Example Concentration Analysis (Parametric)

total Kjeldahl nitrogen, or nitrite-nitrogen. Pollutant concentration data are presented as Table 11.

The only weakness of this analysis is contained in the assumptions. The samples gathered were not random, in that they resulted from a planned time-series collection procedure. Also, the assumption of a normal distribution may or may not be valid. Variances are quite small and similar for a number of the water quality constituents, but are quite large and different for others. An additional statistical analysis of the concentration data was conducted to minimize these concerns.

This second analysis is nonparametric, negating the distribution problem, and utilizes only one observation per runoff event (for each of the two runoff flows and for each of the eleven constituents), minimizing the problem of independent observations. The median value of concentration was selected as the observation to be utilized due to the extreme variation seen in concentrations of some water quality constituents and to the apparent skewed distributions.

An example of this type of analysis, again using 5-day biochemical oxygen demand, is presented as Figure 99. A one-tailed Wilcoxon test for paired observations was utilized to accept or reject the null hypothesis of equal median concentration. Results from this analysis are also shown in Table 11.

The results from the second series of statistical analyses are quite comparable with the results from the first series. Significant differences were again found for pH, total solids concentration, 5-day biochemical oxygen demand, nitrate-nitrogen concentration, conductivity, and alkalinity. As with the parametric analysis, no differences were noted for ammonia-nitrogen and nitrite-nitrogen concentrations. Conclusions conflict for chemical oxygen demand, total Kjeldahl nitrogen concentration, and total

Table 11

Runoff Pollutant Concentration Comparison

Water Quality Constituent	Location	Mean[a]	Significant Difference[b]	Significant Difference[c]
pH	Buffer	7.18	*	*
	Control	7.01		
Total Solids	Buffer	605 mg/L	*	*
	Control	717 mg/L		
BOD_5	Buffer	4.88 mg/L	*	*
	Control	5.66 mg/L		
COD	Buffer	39.6 mg/L	*	
	Control	44.4 mg/L		
TKN	Buffer	3.86 mg/L		*
	Control	4.32 mg/L		
NH_3-N	Buffer	1.19 mg/L		
	Control	1.39 mg/L		
NO_3-N	Buffer	15.6 mg/L	*	*
	Control	31.0 mg/L		
NO_2-N	Buffer	0.13 mg/L		
	Control	0.15 mg/L		
Total PO_4-P	Buffer	0.65 mg/L	*	
	Control	0.78 mg/L		
Conductivity	Buffer	523 μ mho/cm	*	*
	Control	731 μ mho/cm		
Alkalinity	Buffer	110 eq. mg/L $CaCO_3$	*	*
	Control	142 eq. mg/L $CaCO_3$		

(a) Based on approximately 170 determinations from each location for each water quality constituent.

(b) Based on one-tailed "t" test at 5% significance level, as shown in Figure 98; n=170; * indicates significant difference.

(c) Based on one-tailed Wilcoxon test at 5% significance level, as shown in Figure 99; n=6; * indicates significant difference.

Concentration Analysis - BOD_5

Reference: Walpole and Myers (1972)

Assume random sample of population with unknown distribution
Significance Level: $\alpha = 0.05$

$H_o: \mu_C = \mu_B$ $H_a: \mu_C > \mu_B$

Test: one-tailed Wilcoxon test for paired observations
Critical Region: reject H_o if $w \leq W_{(.05)(6)} = 2$

Pair	1	2	3	4	5	6
$Median_C$	6.45	5.79	4.53	3.85	5.20	1.68
$Median_B$	5.39	4.27	3.41	4.01	4.72	1.62
d_i	1.06	1.52	1.12	-0.16	0.48	0.06
Ranks	4	6	5	2	3	1

$w(+) = 19$, $w(-) = 2$; $\therefore w = 2$

$\therefore$ Reject H_o at the 5 percent level and conclude that BOD_5 concentration is greater for the control than the buffer.

Figure 99. Example Concentration Analysis (Nonparametric)

phosphate concentration, with only one of the tests indicating a significant difference in each case.

4.1.3. Load Analysis

Pollutant load data were obtained through a series of calculations. For the pollutants of interest, the concentration (mg/L) values were multiplied by the appropriate and corresponding flow (L/second) values. This results in a pollutant contribution (mg/second) versus time curve. Pollutant loads were then obtained by approximate integration of these pollutant contribution versus time curves. The values were then corrected for watershed size by dividing them by the contributing land area, yielding area-unitized pollutant loadings with the dimension of kilograms per hectare.

These procedures were utilized in calculating loads of total phosphate, nitrogen, total solids, 5-day biochemical oxygen demand, and chemical oxygen demand for both the control field and buffered field. These five pollutants were of most interest for purposes of load analysis since they represent nutrients, sediment, and degradable organic material. Along with toxic chemicals and pathogens, these three classes of pollutants are generally regarded as the major potential water pollutants of agricultural origin.

Standard statistical techniques were again employed to detect differences in pollutant loads between the two fields. The method of evaluation is illustrated by an example, again utilizing 5-day biochemical oxygen demand, presented as Figure 100. As is seen, a one-tailed Wilcoxon test was utilized, with the naturally paired data, to accept or reject the null hypothesis of no mean difference between observations. The non-parametric analysis was selected due to the kurtosis and skewness of the

Load Analysis - BOD_5

Reference: Walpole and Myers (1972)

Assume random sample of population with unknown distribution
Significance Level: $\alpha = 0.05$

H_o: $\mu_C = \mu_B$ H_a: $\mu_C > \mu_B$

Test: one-tailed Wilcoxon test for paired observations
Critical Region: reject H_o if $w \leq W_{(.05)(6)} = 2$

Pair	1	2	3	4	5	6
$Load_C$	5.10	0.212	0.059	0.0043	0.366	0.028
$Load_B$	3.74	0.207	0.043	0.0042	0.256	0.029
d_i	1.36	0.005	0.016	0.0001	0.110	-0.001
Ranks	6	3	4	1	5	2

$w(+) = 19$, $w(-) = 2$; $\therefore w = 2$

$\therefore$ Reject H_o at the 5 percent level and conclude that BOD_5 load is greater for the control than the buffer.

Figure 100. Example Load Analysis

data, indicating a possibly nonnormal distribution, and to the small number of observations.

At the five percent level, significant differences were detected for each of the five tests performed. The runoff from the control field was found to have contributed higher loads of total phosphate, nitrogen, total solids, 5-day biochemical oxygen demand, and chemical oxygen demand than the runoff from the buffered field. Pollutant load data are presented as Table 12.

Table 12

Runoff Pollutant Load Comparison

Runoff Event	Location	Total Phosphate kg/ha (as P)	Nitrogen[a] kg/ha	Total Solids kg/ha	BOD_5 kg/ha	COD kg/ha
1	Buffer	0.75	4.67	156	3.74	18.3
	Control	0.98	9.84	199	5.10	30.2
2	Buffer	0.027	0.629	26.8	0.207	2.04
	Control	0.031	0.633	30.2	0.212	2.09
3	Buffer	0.003	0.229	8.86	0.043	0.580
	Control	0.005	0.471	11.9	0.059	0.729
4	Buffer	0.0001	0.012	0.621	0.0042	0.021
	Control	0.0002	0.028	0.671	0.0043	0.023
5	Buffer	0.012	1.24	39.5	0.256	2.80
	Control	0.024	2.32	66.1	0.366	3.04
6	Buffer	0.0047	1.03	8.26	0.029	0.50
	Control	0.0054	3.08	12.7	0.028	0.56
All Events	Buffer	0.80	7.81	240	4.30	24.3
	Control	1.05	16.4	321	5.77	36.6
Significant Difference[b]		*	*	*	*	*

(a) Nitrogen = TKN + NO_3-N + NO_2-N
(b) Based on one-tailed Wilcoxon test at 5% significance level, as shown in Figure 100; * indicates significant difference

4.2. Water Quality Impact of Runoff Flows

Probably one of the better ways to judge the water quality impact of a discharge to surface waters is to install sufficient equipment to actually measure it. This is rarely done, probably because of the costs involved. For point source discharges, the estimated stream assimilative capacity at 7Q10 (7-day, 10-year, low flow) is often compared with the anticipated average flow and pollutant contribution of the discharge to assess water quality impact. For nonpoint source discharges, no standard water quality evaluation procedure is generally accepted. The usual procedure utilized for point sources is not applicable, as pollutant contributions from nonpoint sources can be expected to be the greatest at periods of high stream flow. Indeed, at least for the agricultural case, no surface flow from the land would occur during the critical low flow period of the stream.

This difficulty in evaluating the water quality impacts of nonpoint source water pollution has been the source of much discussion among regulatory and planning agencies in Michigan, and similar discussions probably are taking place in many other states as the various regional water quality plans are updated. The difficulties in evaluation and the merits of the several alternative approaches aside, however, the water quality impact of runoff from this study's field site can be readily assessed through the examination of flows and pollutant concentrations.

Of the various water quality constituents measured in this investigation, 5-day biochemical oxygen demand, nitrate, phosphate, and sediment are the pollutants of most environmental concern. The times at which these pollutants can generally be expected to have the most significant impact on the stream are the times of maximum runoff concentrations of these pollutants. These are the times when an increase in stream pollutant concentration, as a result of the cropland runoff, is most likely.

Table 13 presents the resulting instantaneous stream flow and pollutant concentration from addition of the estimated runoff flow and pollutant concentration to the estimated stream flow and pollutant concentration. As is seen, this exercise is repeated for each of the four water quality constituents mentioned above and for each of the six major runoff events occurring during the first year of the study. The times of each of the summations represent the times of "worst-case" instantaneous runoff pollutant concentration recorded within each event. The overall average increase in predicted stream pollutant concentration is calculated as 10.6 percent, though the individual values range from a low of 0.3 percent to a high of 87.0 percent. Due to the extreme variation in percentage increases, the median value of 4.0 percent is more indicative of the impact of runoff on the stream than is the mean value of 10.6 percent.

Another method available for the evaluation of the stream water quality impact of the cropland runoff is a comparison of measured upstream and predicted downstream pollutant loadings. Table 14 presents a comparison of this type. The measured stream loads result from approximate integration of pollutant contribution (flow x concentration) versus time curves for each of the runoff events. The predicted stream loads are a summation of these calculated stream loads and calculated runoff loads, also resulting from approximate integration, from the two cropland areas. This comparison is performed for 5-day biochemical oxygen demand, chemical oxygen demand, nitrogen, total phosphate (as P), and total solids, as was the comparison of the two runoff flows presented previously.

Runoff from the project site is found to have increased the stream loads of these five constituents by an average of about 13 percent during the six periods of record. The greatest percentage increase is seen for

Table 13

Stream Pollutant Concentration Comparison[a]

Runoff Event	Hour	Water Quality Constituent	Measured Stream Values (upstream from runoff)		Predicted Stream Values (downstream from runoff)		Percentage Increase in Concentration
			Flow L/second	Concentration mg/L	Flow L/second	Concentration mg/L	
1	13	BOD_5	310	9.98	383	12.6	26.3
	87	NO_3-N	103	6.60	104	6.90	4.5
	13	PO_4-P	310	0.54	383	1.01	87.0
	4	Total Solids	14	520	15.5	561	7.9
2	20	BOD_5	140	4.52	144	4.62	2.2
	29.5	NO_3-N	110	13.6	117	14.0	2.9
	6	PO_4-P	148	0.35	162	0.42	2.0
	13	Total Solids	180	527	186	537	1.9
3	4.5	BOD_5	76	3.22	82	3.50	8.7
	15	NO_3-N	93	12.7	95	13.0	2.4
	4.5	PO_4-P	76	0.09	82	0.13	30.8
	9.5	Total Solids	108	501	113	512	2.2
4	5	BOD_5	33	1.50	34	1.56	4.0
	3	NO_3-N	31	13.2	32	13.4	1.5
	3	PO_4-P	31	0.036	32	0.037	2.8
	2	Total Solids	29	460	29.5	465	1.1

Table 13 (cont'd).

5	25.5	BOD_5	170	1.72	180	1.86	8.1
	13	NO_3-N	185	0.207	190	0.210	1.4
	5.5	PO_4-P	150	0.28	177	0.35	25.0
	3	Total Solids	48	1095	61	1194	9.1
6	15.5	BOD_5	84	1.10	90	1.21	9.1
	26.5	NO_3-N	88	42.0	91.7	45.9	9.3
	17	PO_4-P	101	0.25	109	0.26	4.0
	4.5	Total Solids	52	591	54	593	0.3
Mean							10.6
Median							4.0

(a) For measured instantaneous "worst case" conditions only

Table 14

Stream Pollutant Load Comparison

Runoff Event	Location[a]	Total Phosphate kg (as P)	Nitrogen[b] kg	Total Solids kg	BOD_5 kg	COD kg
1	Upstream	48.4	989	53,600	781	5630
	Downstream	65.8	1140	57,100	870	6120
2	Upstream	4.61	199	11,200	76.1	705
	Downstream	5.18	212	11,800	80.3	746
3	Upstream	0.83	115	4,780	32.7	254
	Downstream	o.91	122	4,980	33.7	267
4	Upstream	0.075	15.9	866	3.61	33.7
	Downstream	0.078	16.2	880	3.69	34.2
5	Upstream	4.66	553	19,700	160	1130
	Downstream	5.03	589	20,800	166	1186
6	Upstream	1.18	368	3,930	13.9	151
	Downstream	1.29	410	4,140	14.5	162
All Events	Upstream	59.755	2,239.9	94,076	1,067.31	7,903.7
	Downstream	78.288	2,489.2	99,700	1,168.19	8,515.2
Percentage Increase[c]		31.0	11.1	6.0	9.5	7.7

(a) Upstream load = calculated stream load; Downstream load = calculated stream + runoff loads
(b) Nitrogen = TKN + NO_3-N + NO_2-N
(c) Percentage increase in stream load due to runoff contribution from research site

total phosphate, at 31 percent, with the lowest percentage increase, about 6 percent, seen with total solids.

Both the concentration and load comparisons utilize the data collected for the buffered and control fields' runoff. The data are not altered, so the actual predicted stream impact of the research site's runoff is presented. According to the data presented in the previous section, the stream impact of the runoff would be different than predicted if both fields had a vegetated buffer area or if both fields were left "as is", as was the control field.

If the stream was sampled downstream from the confluence of the runoff flows, and these samples subjected to laboratory analysis, the resulting water quality impact of the cropland runoff might well be less than predicted. This could be particularly expected for sediment and sediment-bound nutrients. Some portion of the soil particles transported by the runoff would tend to settle and become a contributor to the stream bedload, rather than the stream suspended load.

4.3. Buffer Area Costs

The costs associated with any particular Best Management Practice may well prove to be a critical factor in influencing the extent to which that particular practice is adopted. Since Best Management Practices are primarily directed at water quality enhancement, as contrasted with the erosion control focus of the more traditional conservation practices, a basic distribution problem is indicated. Most of the benefits of reducing agricultural nonpoint source water pollution may not accrue to the farm where the pollution was reduced. Rather, they will accrue to those whose utility is enhanced by that pollutant reduction.

As is stated by Hamilton (1978), this situation suggests that the adoption of Best Management Practices by farmers, under a strictly voluntary program, might be at a lower level than is deemed necessary by environmental planners. The installation of a vegetated buffer area, for example, is unlikely unless the landowner's utility is increased by the installation. If most of the costs associated with the buffer area must be borne by the landowner, while most of its benefit is realized by others, the buffer area will by perceived as reducing the landowner's utility.

Several alternative institutions are available for increasing the levels of Best Management Practice activity on farms. Some 208 Plans, as was previously mentioned, contain provisions for future regulatory programs. Another method, which appears to be more popular and less volatile than regulatory action, is the payment of subsidies. Many local Soil Conservation Districts are already practicing this technique by including certain Best Management Practices in their traditional "cost-share" programs. Federal Rural Clean Water Act activities, while largely limited to demonstration programs at present, also appear to embrace subsidy payment.

Other possible policies include various taxation plans and the development of marketable pollution rights.

The potential advantages and disadvantages of the various alternative approaches aside, however, it is important to relate the cost of a Best Management Practice to its water quality impact. This is a rational place, if not the best place, to begin the decision process for any of these practices. We are in need of answers to several questions and these questions relate directly to the vegetated buffer area, it being the case at hand.

The costs associated with the vegetated buffer area constructed and maintained during the period of this research project can be readily taken from the project's financial statements and field notes. Unfortunately, it is difficult to separate the costs of developing a buffer area from those of developing a research site which contains a buffer area. Being the object of a research investigation, much more time, care, and attention to detail was taken than would be expected under usual commercial farming conditions.

The capital cost of the vegatated buffer area installed at the research site is estimated at about $4,300.00. Elements of this estimate are shown in Table 15. Design costs are estimated at $1150.00 and construction costs are estimated at $3165.00. Table 16 contains a listing of costs used in preparing the estimate. These rates are not costs of providing the indicated service, but represent reasonable charges which would be billed to the farmer by the firm or firms involved. Again, these costs are not the actual costs incurred while building the research site's buffer area, but represent the costs which could be anticipated if the buffer area had been designed and constructed by commercial concerns.

Other costs which should be considered are loss of income, land

Table 15

Buffer Area Cost Estimate

Task		Amount
Field Inspection and Topographic Survey		
16 hours @ $40.00		$ 640.00
Plotting and Mapping		
5 hours @ $13.50		67.50
Calculations and Design		
10 hours @ $25.00		250.00
Plans and Specifications		
5 hours @ $25.00		125.00
5 hours @ $13.50		67.50
	Design Cost =	$ 1150.00
Clearing and Grubbing		
16 hours @ $70.00		$ 1120.00
Staking, Grade Control, and Layout		
2 hours @ $40.00		80.00
Grading and Smoothing		
16 hours @ $70.00		1120.00
Fertilizing and Seeding		
2 hours @ $70.00		140.00
Fertilizer and Seed		75.00
Construction Inspection		
1 hour @ $40.00		40.00
2 hours @ $25.00		50.00
	Construction Cost =	$ 3165.00
	Total Capital Cost =	$ 4315.00

Table 16

Charges Used for Cost Estimate

Item	Charge
Survey Crew (includes surveyor, rodman, chainman, instrument, and vehicle)	$ 40.00/hour
Engineering Technician or Draftsman	$ 13.50/hour
Design Engineer	$ 25.00/hour
Construction Crew (includes foreman, equipment operator, laborer, D-3 bulldozer, hand tools, and vehicle)	$ 70.00/hour
Grass Seed (3-grass blend)	$ 13.00/Kg
Granular Fertilizer (10-10-10)	$ 0.22/Kg

ownership costs, and yearly maintenance costs. The loss of income associated with the installation of a vegetated buffer area is the net income which would be realized if the buffer area site was maintained as cropland. No such loss existed with the site utilized, since this 0.2 hectare area was not in agricultural production. However, this cost could be substantial under other conditions.

Land ownership costs include the purchase price of the property, interest, and taxes. In most cases, the land on which a vegetated buffer would be installed would already be owned by the agricultural enterprise. With such a situation, no additional ownership costs are incurred. The site of this study's buffer area was owned by the cooperating farmer, so no land ownership costs are assigned. If land purchases were required, however, these costs could also be quite substantial.

Maintenance of the vegetated buffer area has consisted only of mowing the grass several times each summer. The area is relatively small, and a minimal amount of time is required. With six mowings per season, only about 3 hours of labor have been required. With a charge of $5.00 per hour for labor and $5.00 per hour for a mower, the resulting yearly cost is about $30.00.

The capital cost of $4315.00 and the yearly maintenance cost of $30.00 are probably best presented as a average annual equivalent cost. Assuming a fifteen-year life, a negligible salvage value, and an interest rate of ten percent, the average annual equivalent cost of the vegetated buffer area is found to be approximately $600.00. A life of thirty to fifty years is often used for earthen structures. A shorter life is assumed here, as the buffer area is designed to trap sediment, thereby reducing its life. The actual service life of any sedimentation structure, of course, will depend to a great extent on conditions upstream from that structure.

A vegetated buffer area similar to the one investigated could be installed for less than the estimated $4315.00. Sufficient labor and proper equipment for such a task are present on many farms, and buffer areas could be constructed without the assistance of a land improvement contractor. Many farmers, if made aware of the practice, would probably be able to locate an effective site and perform a rough design and layout of a buffer. Thus, a numer of buffer areas could conceivable be installed without the assistance of an engineer or a contractor. It can probably be argued with some justification that a commercially designed and constructed buffer would tend to be superior to a "home-made" version, though insufficient data exist to provide much insight in this area. The direct participation of the farmer in the design and installation of a vegetated buffer, however, does have the potential of lowering costs.

The average annual equivalent cost of many agricultural expenditures is often converted so it can be expressed in terms of crop yield. The land area contributing runoff flow to the vegetated buffer area is about 9.3 hectares. Corn yield from this area was estimated at about 6000 kilograms per hectare (96 bushels per acre) for the 1978 crop. With a corn price of $0.079 per kilogram ($2.00 per bushel), the average annual equivalent cost of $600.00 estimated for the buffer area represents 817 kilograms per hectare (13 bushels per acre) of corn. Thus, the annual cost associated with the vegetated buffer area is equivalent to a corn production loss of 817 kilograms per hectare (13 bushels per acre) for the contributing land area. This figure, of course, can be expected to vary widely and may only be applicable to the particular situation of this study.

Chapter 5

CONCLUSIONS

5.1. Pollutant Reduction Due to the Buffer Area

The vegetated buffer area which was constructed and tested is capable of reducing both concentrations and loads of some of the pollutants monitored in the cropland runoff. Utilizing data gathered from the six runoff occurrences of the project's first year, statistically significant differences in instantaneous total solids concentrations, 5-day biochemical oxygen demand values, chemical oxygen demand values, nitrate-nitrogen concentrations, and total phosphate concentrations were found by comparing the buffer area's runoff with runoff from the control field. Utilizing medians of these same data, and a nonparametric test, statistically significant differences in total solids concentrations, 5-day biochemical oxygen demand, total Kjeldahl nitrogen concentrations, and nitrate-nitrogen concentrations were found. These same data, when converted to pollutant loads, were subjected to another nonparametric test. Statistically significant differences in total runoff loads of total phosphate, nitrogen, total solids, 5-day biochemical oxygen demand, and chemical oxygen demand were found for the two fields.

The differences found in runoff concentrations of total solids, 5-day biochemical oxygen demand, and chemical oxygen demand are believed to be primarily due to the sedimentation activity facilitated by the vegetated buffer area, though the filtering of the water flows by the grassed media surely also contributes to these differences. Some small portion of the oxygen demand may also be reduced by biological activity. The significantly lower total solids load from the buffer, as compared to the control field, is also believed due to sedimentation and filtration.

The statistically significant difference in nitrogen loads in the two fields' runoff is cause for both optimism and concern. Of the four nitrogenous compounds measured, the only significant concentration difference detected in the runoff flows by both concentration analyses was for nitrate-nitrogen. No significant concentration differences were detected for ammonia-nitrogen or nitrite-nitrogen concentrations. This nitrate difference is quite substantial, and is certainly responsible for the large difference in calculated nitrogen loads. These facts tend to suggest that substantial denitrification took place within the vegetated buffer area, apparently reducing about 64 kilograms of nitrate-nitrogen to gaseous nitrogen during the first year of the study.

It was anticipated that some denitrification might occur in the buffer area, but an average nitrate concentration reduction of fifty percent was totally unexpected. The relatively light loads of oxygen demand, somewhat indicative of only modest amounts of carbon compounds available for oxidation, tends to cast doubts on such a high level of denitrifier activity. Other conditions favoring denitrification, such as a sufficient microbial population, an anaerobic environment, and a near neutral pH, however, may well be present within the buffer area during runoff occurrences. The neutral pH condition is verified by the data. Further complicating this issue are the extreme variations in nitrate values obtained from the analysis of soil samples gathered at the research site, as the confidence interval increments are often greater than the sample mean.

It has been shown that nitrogen loads and nitrate concentrations were significantly lower in the buffered field runoff than in the control field runoff. Conclusions concerning the source of these differences, however, cannot be reached without the collection of additional data. The differences may be due to field nitrate differences, to denitrification within the vegetated buffer area, or to a combination of the above. It appears unlikely, though not impossible,that nitrate levels in the control field would be several times greater than that of the buffered field or that denitrification would reduce runoff nitrate levels by half. Therefore, a combination of these two factors is the most likely cause of the measured differences.

The significant differences in total phosphate loads, resulting from the nonparametric load analysis, and in total phosphate concentrations, resulting from the parametric concentration analysis, is attributable to two separate types of causes. For the runoff events resulting from rainfall, sedimentation and filtration probably account for most of the phosphate loss within the buffer area, as most of the phosphate can be expected to be associated with soil particles. As these particles are retained by the buffer area, so is the phosphate. As was previously mentioned, snowmelt runoff from agricultural cropland has been shown to have disproportionately high percentages of its phosphorus content in soluble form. Chemical fixation, or adsorption, could then be expected to play a larger role in reducing phosphate levels for snowmelt events. It is difficult to determine, however, what portion of the phosphate loss occurring within the buffer area is attributable to chemical fixation at surfaces of soil or vegetation and what portion is attributable to the sedimentation of soil particles enriched by phosphates in the runoff flow just prior to sedimentation.

The statistical differences detected for total phosphate concentrations, instantaneous values of chemical oxygen demand, and total Kjeldahl nitrogen concentrations were detected in only one of the two concentration analyses for these three water quality constituents. The buffer area may well have reduced the concentration of these pollutants, as loads of total phosphate, chemical oxygen demand, and nitrogen were significantly different. Apparent reductions in concentration were either of less magnitude or were more variable for these parameters than for the parameters exhibiting significant differences for both concentration analyses. This situation of a significant concentration difference by one method, and an insignificant concentration difference by the other, is brought about through the limitations of the two methods used for statistical analysis of the concentration data. The parametric procedure maximizes use of the large number of individual observations, but the assumptions necessary for the use of this test are somewhat invalid. The nonparametric procedure is unable to take full advantage of the collected data, though the assumptions are quite proper. The parametric procedure could be used if the effective number of observations was determined. Serial correlation techniques could be employed in this task, but the time and cost of such are prohibitive at this time. Serial correlations may be performed, however, at the conclusion of this study.

The vegetated buffer area appears to have had little net effect on concentrations of ammonia-nitrogen or nitrite-nitrogen. Mean concentrations of these water quality constituents are lower for buffer area runoff than for runoff from the control field, but the differences are not statistically significant. Total Kjeldahl nitrogen concentrations, as mentioned before, were found to be significantly different for one of the two analyses. The data indicate that nitrification probably is not occurring within the buffer area, as an increase in nitrite-nitrogen concentration would normally be expected as a result of nitrification. Other indications of nitrification within the vegetated buffer would be lower runoff levels of both ammonia and organic nitrogen, and higher levels of nitrate, when compared with the levels of these compounds in the runoff from the control field. While the ammonia-nitrogen and total Kjeldahl nitrogen data offer some support to the conclusion that a moderate amount of nitrification may be occurring within the buffer, the nitrate and nitrite data contradict such a conclusion. Any differences in ammonia-nitrogen and total Kjeldahl nitrogen concentrations could also be due to volatilization and sedimentation, respectively.

Fecal coliform bacteria counts in buffer area runoff samples were generally higher than those from the control field's runoff. Counts for both runoff flows, however, were below the standard set by the U. S. Environmental Protection Agency for fecal coliform organisms in effluents from sewage treatment plants providing secondary treatment. Reasons for differences in the fecal coliform counts for the runoff flows are not certain. While "blooms" of fecal coliform bacteria can occur, the buffer area would appear to lack the retention time, salinity, and temperature for such an occurrence. The last prior application of swine manure took place six weeks before the first runoff event, and eleven weeks before the sixth runoff event. Thus, natural die-off would generally prevent many of these organisms from appearing in the runoff. A previous study, however, reports high levels of fecal coliform organisms in runoff from agricultural land to which no manure had been applied (Dornbush et al., 1974).

Lacking a better explanation for the differences measured in the fecal coliform counts for the runoff flows, this difference could be attributed to wildlife. Shortly after the construction of the buffer area, signs of many wild species were discovered in the area. This may be due to the buffer area itself, but the major cause is probably the small earth and culvert bridge over the stream. This bridge is immediately adjacent to the buffer area and appears to serve as a major stream crossing for wildlife. Deer, moles, muskrats, squirrels, rabbits, raccoons, one opposum, one skunk, and numerous field mice were seen in the buffer area, and tracks and droppings were apparent in the winter snow pack. While the true cause of the differences in the fecal coliform counts remains uncertain, the problems associated with using an indicator bacteria in water quality standards or environmental research is well illustrated.

Instantaneous values of both conductivity and alkalinity from the two fields' runoff were found to be significantly different with both concentration analyses. These parameters are measures of gross properties of a water sample. Runoff samples from the buffer area averaged about 29 percent lower conductivity and about 23 percent lower alkalinity than samples of the control field's runoff.

The conductivity curves for each of the runoff events are somewhat inversely related to flow rate, in that the highest values generally occur at periods of low flow and lower values generally occur during high flow periods. Values were consistently higher for control field samples. Also, less variation in conductivity during runoff events is seen with buffer samples than with the samples of the control field's runoff. This indicates that the vegatated buffer area is effective in both reducing the concentrations and the variability of the concentrations of some of the various inorganic compounds present in cropland runoff.

The alkalinity curves also exhibit a somewhat inverse relationship to runoff flow, as is seen with the conductivity curves. Unlike the conductivity curves, however, the variations in values measured are similar for the two runoff flows. Alkalinity is primarily a function of carbonate, bicarbonate, and hydroxide content, though it is also influenced by borates, silicates, and phosphates. Lower alkalinity values are indicative of lower concentrations of the above, so it can be concluded that some of these compounds remained in the vegetated buffer area.

An extremely interesting difference seen in the runoff from the two fields is that of pH. The pH of control field runoff water samples averaged 7.01 and the average from the buffered field determinations was 7.18. This difference is statistically significant, as was seen in Chapter 4. In contrast to the runoff pH measurements, the soils analyses indicate that the control field's soil was slightly more basic than the buffered field's soil. Thus, the runoff data do not support the reasonable expectation of slightly more acidic runoff water from the buffered field than from the control.

There are two possible explanations for the higher pH of the buffer area runoff samples. Cation exchange processes at the soil surface of the buffer may have removed positive ions from the runoff flow. This would have the effect of raising the pH of the runoff water. Denitrification would also cause runoff water to become more basic. The denitrification process utilizes hydrogen ions, thus reducing their concentration, in the reduction of nitrate-nitrogen to nitrogen gas.

A review of the data summaries from the first year of this study indicates that the vegetated buffer area did improve the quality of cropland runoff. Concentration means, pollutant loads, and percentage differences for sediment, nutrients, and oxygen demand are presented in Tables 17 and 18. Not all of these differences are statistically significant, and some questions remain, but these tables do represent the best estimate available at this time of the water quality benefit of the vegetated buffer area.

Table 17

Runoff Pollutant Concentration Summary [a]

Water Quality Constituent	Mean Concentration Control Field mg/L	Mean Concentration Buffered Field mg/L	Percentage Difference [b]
Total Phosphate (as P)	0.78	0.65	16.7
Nitrogen [c]	35.5	19.6	44.8
Total Solids	717	605	15.6
5-day Biochemical Oxygen Demand	5.66	4.88	13.8
Chemical Oxygen Demand	44.4	39.6	10.8
		Mean	20.3

(a) Based on data collected 3/3/79 through 4/12/79
(b) (Control Concentration - Buffer Concentration) ÷ Control Concentration X 100%
(c) Nitrogen = TKN + NO_3-N + NO_2-N

Table 18

Runoff Pollutant Load Summary[a]

Water Quality Constituent	Control Field Load[b] kg/ha[c]	Buffered Field Load[b] kg/ha[c]	Percentage Difference[d]
Total Phosphate (as P)	1.05	0.80	23.8
Nitrogen[e]	16.4	7.81	52.4
Total Solids	321	240	25.2
5-day Biochemical Oxygen Demand	5.77	4.30	25.5
Chemical Oxygen Demand	36.6	24.3	33.6
		Mean	32.1

(a) Based on data collected 3/3/79 through 4/12/79
(b) Determined by approximate integration of mass flow vs. time curves for total load and correcting for size of watershed
(c) 1.0 kg/ha = 0.89 lb/ac
(d) (Control Load - Buffer Load) - Control Load X 100%
(e) Nitrogen = TKN + NO_3-N + NO_2-N

5.2. Stream Water Quality

Water quality standards for surface waterways within Michigan are set by the Michigan Department of Natural Resources. No standards are specifically available for the stream sampled during this research study. The standards for Deer Creek, however, of which the stream is an unnamed tributary, apply to its contributing branches. These water quality standards were found by examination of Michigan Department of Natural Resources documents and through personal communication with Mr. Kent Mottinger, a Water Quality Investigator with that agency.

Deer Creek is currently protected for agricultural, navigational, industrial water supply, warmwater fishery, and partial body contact recreational uses. When translated into quality standards, these uses represent a minimum dissolved oxygen concentration, a maximum concentration of total dissolved solids, maximum counts of fecal coliform bacteria, and a pH range that are allowable for the stream's waters. The standards for Deer Creek and its tributaries are shown in Table 19.

In addition to these stated standards, levels of certain other water quality constituents are indications of potential environmental problems within a watershed and are considered as general water quality guidelines. Eutrophication is of major concern, and the often quoted values of soluble inorganic nitrogen and phosphorus limiting algal growth have become a somewhat unofficial standard. These concentrations are 0.1 mg/L and 0.05 mg/L, respectively, though the values of 0.5 mg/L of ammonia-nitrogen and 0.1 mg/L of total phosphate-phosphorus are also widely quoted as lower limits favorable for profuse algal growth in impoundments. Another nutrient of concern is nitrate-nitrogen, and particularly so at concentrations of 10 mg/L or more. This concentration

Table 19

Water Quality Standards for Deer Creek

Parameter	Limits
Total Dissolved Solids Concentration	maximum of 500 mg/L (monthly average) maximum of 750 mg/L (instantaneous)
pH	6.5 to 8.8 pH units (instantaneous)
Dissolved Oxygen Concentration	minimum of 5.0 mg/L (instantaneous)
Fecal Coliform Bacteria Count	maximum of 1000/100 mL (geometric mean of a series of 5 or more samples within a 30-day period)

of nitrate is the maximum limit set by the U. S. Environmental Protection Agency for public water supplies, primarily due to the relationship between methomoglobinemia in mammals and high nitrate levels. The ratio of a stream's 5-day biochemical oxygen demand and dissolved oxygen concentration is an additional quick indication of a stream's general condition. A ratio of 0.5 or greater generally indicates a stream under stress and in sore need of reaeration or dilution.

A comparison of the water quality standards and the data gathered from the weekly stream water samples indicates some minor problems within the watershed. Several water quality violations were recorded during the first year of this study. Seven separate samples contained dissolved oxygen concentrations of less than 5.0 mg/L. No violations in the expressed fecal coliform bacteria standard were noted, though several samples did contain counts of greater than 1000/100 mL. The pH of all samples gathered was within the allowable range. Total dissolved solids determinations,more often expressed as filterable residue, were not performed. Total solids, or total residue, tests were conducted for the stream samples. The mean total solids concentration was only slightly greater than the monthly total dissolved solids standard, and maximum concentrations of total solids exceeded the instantaneous dissolved solids standard in only two of the samples analyzed.

A comparison of the weekly stream data and the general water quality guidelines stated earlier indicate some additional problems. Mean levels of nitrogen compounds and total phosphate are in the range of the generally accepted concentrations favorable to algal growth, indicating that eutrophic conditions may exist in downstream impoundments. Maximum nitrate-nitrogen concentrations observed were four times higher than the drinking water standard of 10 mg/L, and the mean concentration was about 11.2 mg/L. The ratios of 5-day biochemical oxygen demand to dissolved oxygen concentration were quite high. Values of this ratio were greater than 1.0 in several instances, and the mean of the ratios from all samples is calculated at about 0.52. These ratios and their yearly variation are generally indicative of a eutrophic stream, as explained by Melvin and Gardner (1960).

Data gathered from weekly samples reveal that the stream may well contribute to downstream water quality problems, but that very few violations of the water quality standards occurred. The same can be said of the numerous stream samples gathered during runoff events. The concentrations of the various water quality constituents monitored during periods of high flow were greater than or comparable with the concentrations recorded for the weekly samples. Again, though few water quality violations were observed, the stream was of marginal quality during periods of high flow.

5.3. Impact of Runoff Flows

Runoff pollutant concentrations were sometimes less than stream pollutant concentrations, as measured from samples gathered during the six reported runoff occurrences. This situation is an exception, however, to the general case observed. In the vast majority of instances, runoff pollutant concentrations were greater than stream concentrations.

The runoff flows from the project site have a substantial impact on the water quality of the stream in terms of pollutant loads. Runoff from this approximately 20-hectare cropland area increased the average pollutant load of the stream by about 13 percent during periods of high flow. Stream pollutant concentration effects of the cropland runoff, however, varied widely. Addition of flows and instantaneous loadings at times of maximum runoff pollutant concentration resulted in an overall average stream concentration increase of about 10.6 percent. The maximum estimated increase in instantaneous stream concentration, as a result of runoff contribution, was an 87 percent increase in total phosphate concentration at hour 13 of event 1. During periods when runoff pollutant concentration was less than that of the stream, however, the runoff flow reduced the stream pollutant concentration by dilution. Such occurrences as those above were seldom, but the extreme variation seen is illustrated.

The stream water quality impact of the runoff flows would have been even more substantial if the vegetated buffer area had not been established. Similarly, if buffer areas were established in both fields, less stream impact would be expected. Based on the average load reduction within the buffer of 32 percent, as calculated for total phosphate, nitrogen, total solids, 5-day biochemical oxygen demand, and chemical oxygen demand, an average stream pollutant load increase of about 17 percent would be anticipated if the buffer area had not been installed. An increase in load of only about 9 percent would be expected with vegetated buffer areas in each field.

5.4. Viability of the Buffer Area Concept

A viable Best Management Practice should probably possess three principal attributes in relation to other available alternatives. These attributes are a low cost, a high pollutant reduction, and a good measure of the somewhat intangible quality best described as appropriate technology. The vegetated buffer area exhibits one of these qualities without doubt, though the existence of the other two is certainly subject to interpretation. Little information on alternative practices is available for comparison.

No problem exists with the vegetated buffer area from the standpoint of appropriate technology. In general application, it should have good conceptual acceptance from farmers in that it is not an unfamiliar type of land improvement. Most agricultural producers have seen sod or grass waterways, and the buffer area is similar in purpose and appearance. The vegetated buffer area deals with soil, plants, and water; the practical and familiar elements of agriculture. Finally, its ideal site would be the "old bog at the edge of the field" in many instances, thus providing both enhanced surface drainage and minimal disruption of normal farming activities.

Whether any agricultural producers will actually install vegetated buffer areas is another question. Conceptual acceptance, while an important first step, does very little to promote implementation. The installation of most Best Management Practices, including buffer areas, must be brought about through policy. Several legal and economic alternatives are available, as was previously mentioned. The favored alternative at this time appears to be subsidy payment. While the existence of a buffer area may increase the utility of some farmers, such increases will probably be minor. The payment of subsidies (or whatever other alternative institution may be adopted) will probably need to approach the magnitude of the buffer area's cost to insure implementation.

The desired attributes of low cost and high pollutant reduction may or may not be present, depending upon the views of the observer. Interpersonally valid welfare measures are often quite difficult to obtain for pollution control topics, and the vegetated buffer area should be no exception. These two desired attributes are also quite relative and their existence can only be determined in relation to alternatives. Some other practice might be capable of greater reductions in runoff pollutants at a lower cost. This is a major problem for those making decisions concerning Best Management Practices. As stated previously, very little information relating particular practices, their cost, and their water quality benefit is presently available.

At least an estimate of cost and water quality benefit for a vegetated buffer area, though based on only one year's data consisting of only six runoff occurrences, now exists. It is believed that the vegetated buffer area installed and tested during this study has an average annual equivalent cost of about $600.00. It is also believed that the buffer area is capable of reducing average concentrations and total loads of sediment, plant nutrients, and oxygen demand in the surface runoff from the 9.3-hectare area of cropland by about 25 percent. These beliefs will surely be refined as the project continues and as more data are collected.

This estimated 25 percent reduction represents a calculated 20.3 percent average difference in mean pollutant concentrations between the two cropland areas and the 32.1 percent average calculated difference in the area-unitized pollutant loadings. The load differences represent about 2.3 Kg of total phosphate (as P), 80 Kg of nitrogen, 753 Kg of total solids, 14 Kg of 5-day biochemical oxygen demand, and 114 Kg of chemical oxygen demand which were retained by the buffer area during the first year of the study. Neglecting chemical oxygen demand, which has a limited meaning in natural systems, a total load difference of about 850 Kg of nutrients, sediment, and oxygen demand is calculated. With an estimated annual equivalent cost of $600.00 and an apparent reduction of 850 Kg of four water pollutants, a removal cost of about $0.71/Kg is calculated.

The value of this reduction is difficult to estimate. No inter-personally valid welfare measure is known for pollutant reduction in the unnamed branch of Deer Creek. It may well be impossible to establish such a value, or the cost of establishing that value may be prohibitive. To some individuals, this cost may seem excessive. For these people, the vegetated buffer area is yet to considered as viable. Others may consider a price of $0.71 per kilogram for runoff pollutant reduction a bargain. To them, the practice is quite viable.

The decision of viability, at this time, can only be made according to personal preference. In the future, it is hoped that it can be made through comparison with alternatives. The possibility of such a comparison, however, is dependent upon future research on those alternatives.

Chapter 6

RECOMMENDATIONS

6.1. Pollutant Source Classification

Someone once said that the success of a bureaucracy is measured by the bureaucrats according to the number of new phrases invented. While some new phrases can be quite useful, particularly when dealing with new concepts, progress may occasionally be hindered by new phrases. A relatively new phrase which appears to be a hindrance is "agricultural nonpoint source water pollution". When first introduced, the phrase was not readily understood. Topic areas represented by this phrase, however, such as agricultural runoff, the pollution of rural underground and surface waters, and soil erosion, are all concepts which were already understood. The new phrase appears to have interjected some unnecessary confusion.

Another problem with "agricultural nonpoint source water pollution", both as a phrase and as a concept, is that it tends to suggest that these sources are just about everywhere and can hardly be individually defined. This impression probably helps to maintain the regional scale of the environmental planner, and may tend to favor the proposal of widespread solutions. When the scale of the observer is reduced, say from an entire river basin to a single branch of a rural stream, the new phrase acquires some tarnish. Underground aquifers are not replenished everywhere. Rather, their replenishment generally occurs within relatively confined recharge areas. Runoff does not enter surface watercourses at all locations. Instead, runoff generally travels in identifiable paths according to topographic features.

It is certainly important to consider entire drainage basins in water quality planning. In the case of most agricultural water pollution problems, however, any needed improvement will surely be at the farm or field scale. At this small scale, the sources are individually identifiable. This point is illustrated by the vegetated buffer area. Rather than planting the borders of the watercourse with grass, the runoff path was identified and the buffer area was established in that path.

Agricultural water pollution, when viewed at the farm scale, may be inappropriately described as "nonpoint source" pollution. The vast majority of agricultural water pollution sources can be individually identified and, since greatly influenced by climate, are quite intermittent in nature. This is certainly the case with cropland runoff, which may contribute heavy pollutant loads to surface waters when improperly managed. At the farm scale, agricultural pollution can be more correctly described as "intermittent point source" pollution, to use another new phrase from the U. S. Environmental Protection Agency. The need for categorizing agricultural water pollution is not immediately obvious. If such a categorization is required, however, the label of "intermittent point source" is preferred.

6.2. Environmental and Agricultural Policy

Several choices are available concerning alternative institutional mechanisms which could be adopted in the area of agricultural nonpoint source water pollution. The majority of the present activity of the existing programs appears to be associated with pilot and demonstration projects. The institutional arrangements typically involve federal funding and approval, with a local entity responsible for implementation and management. The mechanism generally employed to achieve compliance is a financial incentive, usually a subsidy payment or a "cost-share" agreement. Other mechanisms, as was previously mentioned, could also be employed to encourage adoption of the various Best Management Practices.

The immediate policy problem involving institutional mechanisms, however, is not directly related to the merits of the alternative institutions. The policy process appears to be in sore need of empirical evidence as to the value of the various Best Management Practices. What a practice costs and which institution will motivate agricultural producers to bear (either directly or indirectly) those costs are quite simple problems when compared to the question of the worth of a practice. Information is needed comparing the performance of various practices, relating a particular practice to its incremental benefit, and relating that benefit to its incremental value before sound institutional policy can be formulated.

Choices are also available in the area of alternative technical approaches which might be pursued. The various Best Management Practices can be divided into three general types. These categories are cultural techniques, management techniques, and structural techniques. A different technical approach is embraced by each of these three categories.

Management techniques are generally directed toward minimizing the input of potential water pollutants or toward minimizing the probability of pollutant loss. Examples are biological pest controls and the timing of manure application to coincide with periods of low historic runoff potential. Cultural techniques are generally directed toward keeping water pollutants in place on the land. An example of a cultural technique is maintaining a winter cover crop. Structural techniques are generally directed toward keeping water pollutants out of surface watercourses. An example is the vegetated buffer area. Choices are available concerning which of these technologies should be developed and should be supported.

The immediate policy problem here is more basic than simply the relative merits of the alternative technologies. The difficulty arises due to the lack of empirical evidence available to compare, much less to judge, the performance of the various types of practices. The need of the decision maker is quite similar for alternative technical approaches as it is for alternative institutional mechanisms. Additional research is required in terms of the performance of the various Best Management Practices.

6.3. Future Research

The obvious recommendation for future research is that this study should continue for at least the planned three-year project period. This minimum length of time was initially believed to be necessary for a comprehensive evaluation of the vegetated buffer area and that belief remains unaltered. Besides providing additional and needed data on runoff pollutant concentration and load, additional experience and insight regarding the buffer area's performance under more and different climatic conditions would be obtained.

A change in the physical layout of the project is also recommended, in the form of an additional runoff monitoring station. This new station, consisting of a flume and automatic water sampler, is already being installed at the upstream edge of the vegetated buffer area. With this arrangement, both a portion of the buffer's influent and its effluent can be sampled. The addition of two more laboratory tests for runoff water samples would also be of benefit. A chlorides determination would provide a further check on the similarity of the fields. A nitrogen gas determination, conducted with gasses from the air space above runoff samples stored in tightly capped containers, is also desired for at least some portion of the buffer area's effluent samples. Concentrations of greater magnitude than that of atmospheric equilibrium would be indicative of denitrification taking place within the buffer area.

Other research recommendations deal with all Best Management Practices and the Rural Clean Water Program in general. As was previously stated, very few research studies exist which relate a specific Best Management Practice, its cost, and its incremental water quality impact. The research effort represented in part by this dissertation stands with little company in this regard. Projects which relate a practice, its cost, and its impact are sorely needed before such practices are recommended, and much more so before they are required.

The Rural Clean Water Program, at last report, has officially begun its first full year of operation. Initial funding, some fifty million dollars, is quite modest when compared with many other federal programs. Of major concern is the apparent tendency to allocate these funds for demonstration, rather than for research. These Rural Clean Water Program monies, if spent on the type of research described earlier, could be of great assistance in determining potential benefits, probable benefits, values, and costs of the truly comprehensive national program in rural water quality enhancement envisioned by some. A regular demonstration program, on the other hand, would only provide for the demonstrative installation of practices of predominantly unknown water quality benefit. These benefits, if any, may remain largely unknown without adequate financial support for research and monitoring.

Investigating these potential water quality benefits in a field setting is both expensive and difficult. The work is also quite demanding, in both the physical and mental senses. This may well be the reason that so few of these studies are being performed. A laborer employed by this project's cooperating farmer greatly lifted the morale of the investigator and also defined the scope and the spirit of this type of research. He did so with a simple comment spoken before daylight on a cold and rainy spring morning at the edge of the field of mud, melting snow, and corn stubble: "You damn guys'll measure anything." He was right, and this sort of work should continue.

"When you make a thing, a thing that is new, it is so complicated making it that it is bound to be ugly. But those that make it after you, they don't have to worry about making it. And they can make it pretty, and so everybody can like it when the others make it after you."

-Picasso

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