THE EFFECT OF LAND USE ON WATER QUALITY

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ABSTRACT

Stream water quality in southern Illinois was shown to be related to predominant land use within three adjacent watersheds having basically different land uses. The streams of the three watersheds, predominantly "forested", "pasture", and "cropland", respectively, were monitored on a weekly basis (on-site, grab, and continuous samples) for one year and data obtained on levels of pH, specific conductance, suspended solids, calcium, and nitrate-nitrogen. Variations in the levels of these parameters within a given stream could generally be related to identifiable events such as intense storms and associated high stream flow. Suspended solids were found to be quite high: 51.7 tons/acre/year from the "pasture" watershed--primarily due to the presence of cattle in the stream channel; sediments from the "cropland" and "forested" watersheds were calculated to be 13.0 and 8.8 tons/acre/year, respectively. Highest nitrate-nitrogen values for the stream draining the "cropland" watershed were generally related to tillage operations while the nitrate-nitrogen values in the stream of the "pasture" and "forested" watersheds were generally associated with livestock activity and leaffall, respectively. Specific conductance, calcium and pH levels were highest in the stream of the "cropland" watershed and lowest in the stream draining the "forested" watershed.

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Introduction:

In the past, little attention was given to the fact that stream water quality was being degraded by land use activities. Early settlers observed that all streams carried sediments which resulted from natural or geologic erosion. Streams draining areas under cultivation were observed to usually contain more sediments than similar streams draining forested areas, but this was considered normal and an unavoidable consequence of maintaining an area under cultivation.

Today we know that various land use activities may influence the quality of water coming from the land. One can expect poorer quality water to be associated with land uses that result in a disturbance of the soil and vegetation within a watershed, while better quality water usually can be associated with land use activities which maintain the area in a relatively undisturbed condition.

This has major implications for the future. Public Law 92-500, the Federal Water Pollution Control Act Amendments of 1972, has as its objective the goal of restoring and maintaining the chemical, physical, and biological integrity of the Nation's waters. Sections 208 and 304 of P. L. 92-500 address land use activities which are, or may result in, non-point sources of pollution. Under P. L. 92-500 attention will focus on identifying, evaluating, and controlling non-point sources of pollution.

A major problem exists in the lack of data relating stream water quality to land use activities. With this in mind, a study was conducted in southern Illinois to assess the quality of water draining three adjacent watersheds having different land uses. Specifically, the quality of water from a predominantly forested watershed was monitored and compared to the

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quality of water coming from the streams draining more agriculturally oriented watersheds.

Study Area and Procedures:

The study was conducted in the headwater region of the Little Saline River basin, located in Johnson County, Illinois. The area is typical of the unglaciated area of the Shawnee Hills physiographical division. The soils (Grantsburg-Zanesville association) are derived from loess overlying alternating layers of sandstone and shale over limestone. Precipitation averages 42.5 inches annually.

The Clifty Creek Watershed (forested), containing about 500 hectares, is 70% forested (natural upland hardwoods and abandoned farmland reverting back to forests), 20% pastureland and 10% field cropland and orchards. The orchards, pasture and cropland are restricted to the more level ridge top areas. The stream totals 5.7 miles in length with only about 8% of the channel passing through pastureland near the upper reach of the main channel. Topography is generally steep, with slopes of up to 70% common. The stream flows across and has cut through the bedding plane of numerous alternating layers of sandstone and shale. Some limestone is present in the stream bed. Coarse gravel and large rocks fill the stream channel and are moved by high flows.

The Dry Fork Watershed (pastureland), containing about 300 hectares, is 42% pastureland, 13% cropland and 45% forested (generally used as wooded pasture). Most of the stream channel passes through forested areas or narrow forested strips extending along both sides of the channel. Only about 6% and 5% of the 3.1 miles of stream pass directly through crop and pasture land, respectively. However, cattle are not excluded from most of the forested area and generally they have direct access to the stream throughout its length. Croplands are generally restricted to the upper portion of the watershed and the level areas near the ridges. Topography is generally moderately to steeply rolling. The stream generally flows along the bedding plane of sandstone layer. The stream channel generally is free of gravel and rocks with flow occurring on sandstone bedrock.

The Little Saline Watershed (cropland), containing about 550 hectares, is 38% cropland and orchards, 16% pastureland, and 46% forests and abandoned farmland reverting back to forests. Approximately 42% of the 4.8 miles of stream passes

either directly through or along one side of cropland or pasture land areas. The forested area is predominantly located in the lower one-tenth of the watershed and in two relatively large tracts at approximately the middle and in the lower portion of the upper one-third of the watershed, respectively. A narrow band of forest, bordering the stream on both sides, connects the lower, middle, and upper tracts. The topography generally is gently to moderately rolling. The stream generally flows along the bedding plane of a sandstone layer. Most of the stream channel is free of rock and gravel. Considerable amounts of fine-textured sediments are to be found in the bottom of pools and in sediment bars which occur in the middle portion of the watershed.

The streams draining the three watersheds were sampled near the mouth of each watershed. The Little Saline and Clifty Creek were sampled above a gravel road which runs across the lower portion of the watersheds. The Dry Fork was sampled both above and below the road in order to ascertain the effect of the road on water quality.

Sampling extended from April 15, 1977 through April 24, 1978. Three types of samples were collected: 1) grab samples were obtained on a weekly basis, 2) continuous composite samples, proportional to flow, were collected weekly, and 3) stage samples were collected after high flow. All samples were returned to the laboratory for analyses of suspended sediments, nitrate-nitrogen, alkalinity, and calcium levels. Specific conductance, pH, and flow rates were determined on-site each week.

Land uses were determined from high altitude, color infrared aerial photos, LANDSAT imagery and on-the-ground reconnaissance.

Results and Discussion:

Suspended solid levels were quite variable. Concentrations ranged from less than 0.1 to 7,975 mg/l. Highest values were associated with high flows and stage samples. The values obtained throughout the study via grab samples are shown in Figure 1. Evaluation of these data reveals several trends which appeared to be related to land use.

The high value recorded on March 23 for Clifty Creek is known to have been caused by a portion of the streambank slumping into the stream channel. We suspect that the high values

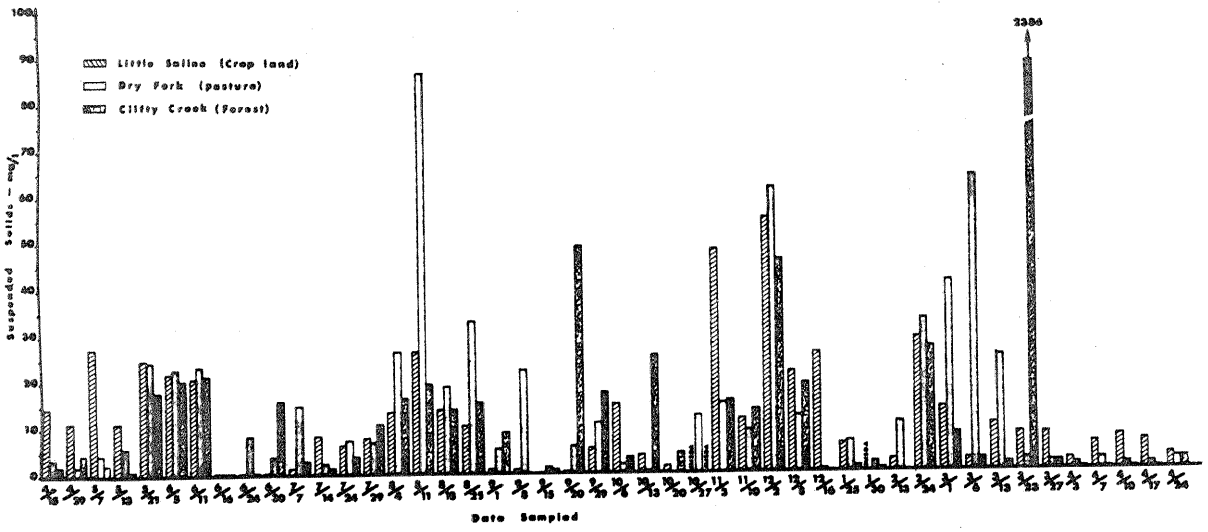

Figure 1. Suspended solids levels in grab samples obtained from the streams draining the Little Saline (cropland), the Dry Fork (pasture) and the Clifty Creek (forested) watersheds. Samples obtained on dates indicated.

for Clifty Creek on September 20 and 29 were also due to mass wasting, although at the time, the stream was not walked to verify the fact. We do know that an intense storm had occurred the preceding afternoon which moved a substantial amount of rubble within the stream channel. High flow and rubble movement destroyed our continuous proportional and stage samplers, thereby preventing comparison with other samples. The reason for the high value obtained on October 13 is unknown but may be related to high flow washing away more of the slump.

Looking at the suspended solid data in their entirety, we can see that approximately 41% of the time, the Dry Fork stream had the highest sediment load, the Little Saline stream had the highest sediment load approximately 37% of the time, while Clifty Creek had the highest sediment load only 22% of the time. Perhaps more significant is the fact that the Clifty Creek stream contained the lowest sediment load approximately 55% of the time, with the Dry Fork and Little Saline streams having the lowest sediment load 24 and 21% of the time, respectively.

The magnitude of the sediment load is of equal, if not greater, importance than frequency of occurrence. Differences in magnitude can readily be seen in Figure 1. These differences indicate that something is occurring within the watershed with high values, that is not common to the other watersheds. Looking at the entire study, we find that the average sediment load (from grab samples) for the three streams was 11.7, 14.1 and 9.6 mg/l (excluding the value for Clifty Creek on March 23) for the Little Saline, Dry Fork, and Clifty Creek, respectively.

Due to a number of problems, adequate flow measurements were not obtained. Thus it is impossible to accurately quantify the sediment loss from the watershed. However, in order to obtain some idea of sediment discharge from the watersheds, a number of assumptions were made, hydrographs were synthesized from precipitation and watershed data, and a crude, best-guess estimate of sediment discharge was calculated. We estimate that the Dry Fork and Little Saline watersheds are losing soil at the rate of 51.7 and 13.0 tons/acre/year, respectively, while Clifty Creek is losing 8.8 tons/acre/year. This high a sediment yield from a predominantly forested watershed was not expected. However, thinking retrospectively about the amount and type of rubble in the stream channel, we should have anticipated relatively high sediment yields. Throughout the study, high flows in Clifty Creek moved the rubble about quite a bit. Channel and stream bed configurations changed substantially from major storm to major storm, with

rocks, gravel, and sediment forming bars and filling depressions after a storm being moved downstream by the next major storm. Evidence of the stream undercutting its banks was also common.

The data also appear to indicate a time trend which is probably related to land use activities. It can be seen that the Little Saline or "cropland" watershed tended to have higher suspended solids in its stream during the winter and early spring months than did the other watersheds. This probably was due to sediments coming from portions of the watershed which lack a stable vegetative cover. By contrast, highest sediment load in the Dry Fork or "pasture" watershed can be observed during the late spring, summer months, and early fall. This corresponds to the time cattle were on pasture and had access to the stream channel. Highest sediment loads in the "forested" watershed appeared to be mainly storm intensity related.

The effect of land use on sediment production can be more clearly seen in Figure 2. This figure represents the sediment concentration in samples obtained from the continuous, proportional composite samplers. The data from the continuous samplers have the advantage in that they represent more closely the concentrations at the various flow conditions which exist in the stream over time, integrated into a single sample. The marked impact of the cattle in the stream during July, August and September can easily be seen. The impact of activities on the cropland is harder to pinpoint. However, it can readily be seen that substantial sediment is coming from the watershed. The very high value recorded on December 2 for Clifty Creek was associated with quite high flows caused by rain on a substantial snow cover. The high flow moved substantial rubble within the stream channel.

Table 1 presents a summary of the means, standard deviations and ranges of the various parameters by site and by sample type where appropriate. It is interesting to note that the Little Saline stream yielded the highest mean values for all parameters (except suspended solids) and that the Clifty Creek stream yielded the lowest mean values for all parameters. The only exception to the pattern involves the suspended solids in the Little Saline stream, which were much lower than we had expected considering the presence of fine sediments at the bottom of pools and in sediment bars in the middle section of the watershed. The largest variation is present in the values from the continuous composite samplers. Part of the explanation can be found in the high values produced by cattle stirring up the sediments in the Dry Fork stream which are subsequently carried off the watershed by high flow. Likewise, the continuous

Table 1. Means, standard deviations and (ranges) for each site.

Parameter Site: Method	In situ pH1/	Sample pH1/ (lab.)	In situ Specific Conductance (mmhos/cm)	Calcium (ppm)
Grab samples				
L.S.	7.5 ± 0.5 (7.0 - 9.7)	7.5 ± 0.4 (7.0 - 8.6)	440 ± 327 (95 - 1300)	52 ± 41a/c/ (4 - 152)
D.F.	7.4 ± 0.4 (7.0 - 8.6)	7.4 ± 0.3 (7.0 - 8.5)	352 ± 189 (80 - 750)	44 ± 30a/b/d/ (1 - 158)
C.C	7.3 ± 0.5 (7.0 - 9.5)	7.2 ± 0.4 (7.0 - 9.1)	202 ± 88 (75 - 360)	17 ± 7a/b/c/d/ (3 - 33)
Composite Proportional Samples				
L.S.		7.7 ± 0.11 (7.4 - 7.9)		81 ± 31a/ (13 - 144)
D.F.		7.4 ± 0.3 (7.0 - 7.9)		73 ± 36b/ (18 - 169)
C.C.		7.2 ± 0.1 (7.0 - 7.4)		21 ± 5a/b/c/d/ (15 - 31)

L.S. = Little Saline; D.F. = Dry Fork; C.C. = Clifty Creek.
1/ Arithmetic mean. 2/ Excluding the value known to have been the result of bank slumpage.
a/b/c/, etc. Means with the same letter are significantly different at the .05 probability level.

Nitrate-Nitrogen (ppm)	Alkalinity (mg/l)	Suspended Solids (mg/l)
.36 ± 0.27g/ (.02 - 1.55)	76.2 ± 39.8 (12.8 - 144.4)	11.7 ± 12.1h/ (0.1 - 54.5)
.27 ± 0.38e/f/ (.01 - 1.60)	72.8 ± 49.8 (8.2 - 182.4)	14.1 ± 18.4h/ (0.1 - 86.5)
.27 ± 0.31e/f/ (.02 - 0.69)	26.6 ± 14.0 (5.3 - 69.0)	9.6 ± 11.6h/2/ (0.1 - 49.0)
.50 ± 0.42e/ (.02 - 1.50)	113.2 ± 23.0 (55.2 - 168.4)	56.1 ± 105.1h/ (0.1 - 513.0)
.38 ± 0.33f/ (.02 - 1.00)	83.4 ± 29.3 (21.6 - 160.8)	490.1 ± 85.2h/ (0.1 - 3661.6)
.11 ± 0.09e/f/g/ (.01 - 0.40)	46.1 ± 30.8 (16.8 - 124.4)	32.1 ± 37.2h/2/ (0.1 - 154.5)

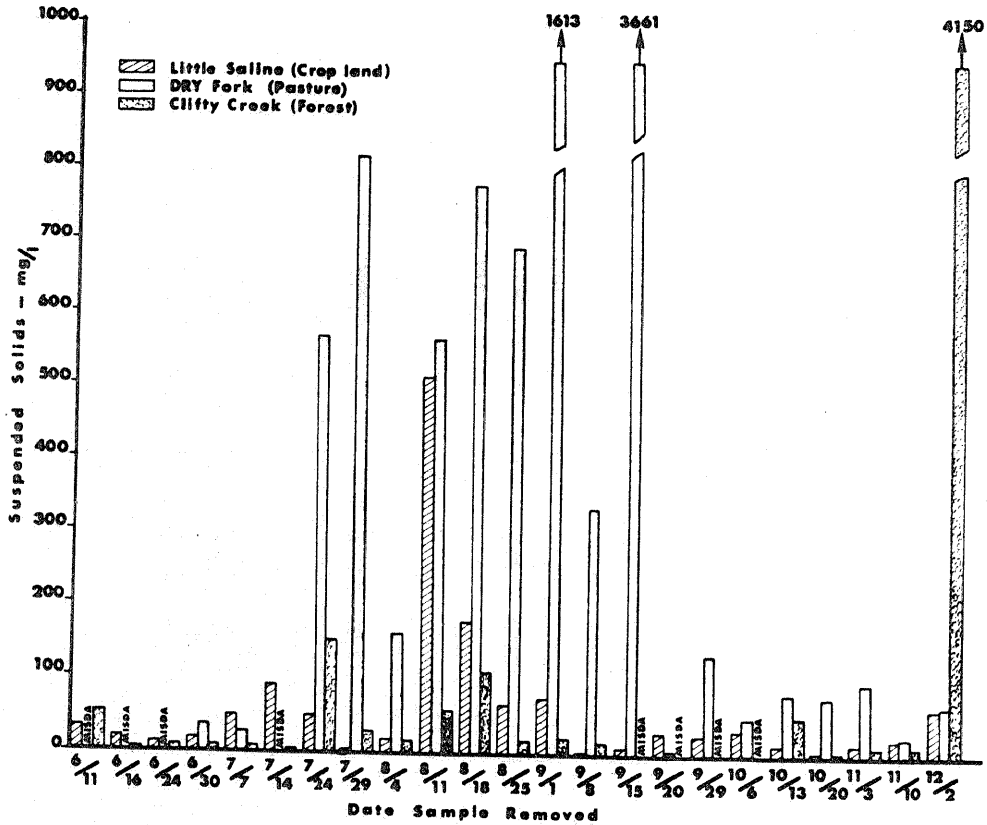

Figure 2. Suspended solids levels in composite samples obtained from the streams draining the Little Saline (cropland), the Dry Fork (pasture) and the Clifty Creek (forested) watershed. Samples removed from the continuous, composite samplers on dates indicated after collection throughout the period from preceding date.

composite sampler in Clifty Creek's stream responded to specific events in the watershed, such as bank slumping, which produced slugs of high sediment load. These slugs were integrated into the sample, leading to high mean values. This illustrates the impact one or two extreme values (or events) may have on the overall mean.

Specific conductance and pH determinations were made on-site whenever grab samples were obtained. PH determinations were also made on all samples in the laboratory using a line-operated, laboratory pH meter. Comparison values generally were in close agreement. The mean on-site pH values of all three streams were quite similar, being 7.5, 7.4 and 7.3 for Little Saline, Dry Fork and Clifty Creek, respectively. Although an obvious trend exists, none of the mean pH values were found to be significantly different. The maximum value of 9.7 measured in the Little Saline on September 15 is highly "suspect" since the laboratory pH made on a grab sample obtained at the same time was only 7.6. Excluding that high value would make the pH range for the Little Saline be 7.0 to 8.6. The pH value of 9.5 measured in Clifty Creek's stream on August 4 also seems out of line although the laboratory pH value was 8.8 for the comparison sample.

Mean specific conductance values, which provide an indication of ionic activity, were 440, 352, and 202 mmhos/cm for the Little Saline, Dry Fork, and Clifty Creek streams, respectively. As can be seen from the standard deviation and range values, specific conductance values were quite variable. This resulted in there being no significant difference between means even though an obvious trend could be observed. In addition, a consistent trend could be observed in that the higher values were generally associated with high flows and the lower values were generally associated with low flows.

The specific conductance relationship between watersheds is reflected in the calcium, nitrate-nitrogen and alkalinity data. All means are ranked highest for the Little Saline stream and lowest for the Clifty Creek stream. And except for the nitrate-nitrogen values for Clifty Creek, all composite samples means were higher than grab sample means.

The nitrate-nitrogen data are presented in Figure 3 with the values from grab samples shown on the bottom. The impact of farming activities on the nitrate concentration in the stream can be seen in the data for the Little Saline stream. The high values in the spring and early summer months are assumed to be related to tillage and fertilizing activities, while the

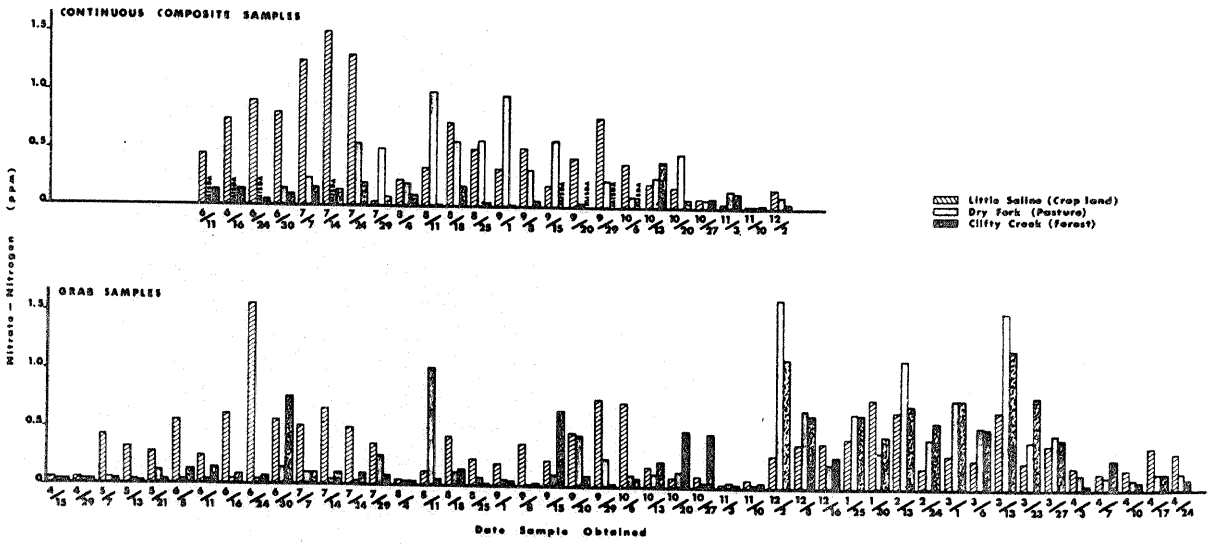

Figure 3. Nitrate-nitrogen levels in grab samples and continuous composite samples obtained from the streams draining the Little Saline (cropland), the Dry Fork (pasture) and the Clifty Creek (forested) watersheds. Grab samples obtained and composite samples removed from the samplers on dates indicated.

relatively high values in late September and early October are assumed to be related to harvest activities. The high nitrate-nitrogen concentrations in the stream draining the Dry Fork (especially evident in the continuous sampler data) during the summer months is assumed to be related to the release of wastes by the cattle directly into the stream or onto the stream banks. The reason for the high values for the forested watershed in June and September is unknown. The relatively high values from the forested watershed in October are associated with leaf fall.

An increase in nitrate-nitrogen levels in the streams during the winter and early spring months can readily be seen in Figure 3. Obviously, something was taking place in the watersheds (especially the Dry Fork and Clifty Creek watersheds) which was influencing the nitrate-nitrogen levels in their streams during December through March. Since freezing and thawing of soils may promote nitrification and the mobilization of nitrates, it is possible that the high values observed during the period were associated with increased nitrification and subsequent leaching of nitrates to the streams. We know that during the period, temperatures were quite low and a considerable amount of snow covered the ground most of the time; ice generally was present in or covered the stream. The general reversal in order appears to indicate that more nitrification was occurring in the "pasture" and "forested" watersheds than in the "cropland" watershed. This probably is related to the greater amount of organic matter present in these watersheds.

A point that should not be overlooked is that although nitrate-nitrogen concentrations can be shown to be related to land use activities, all values observed are way below the Public Health standards of 10 ppm for nitrate-nitrogen in drinking water. What effect the nitrogen levels have on eutrophication is not clear. Some filimentous algae were observed in all three streams.

The impact of the road on water quality could not be assessed. Either there was little or no impact or the impact was masked by the overriding influence of the cattle within the Dry Fork watershed.

Summary:

Evaluation of grab and composite samples from the streams of three adjacent watersheds, having basically different land uses, has shown that stream water quality can be related to the predominant land use within the watershed. Levels of pH, specific conductance, suspended solids, calcium and nitrate-nitrogen were monitored on a weekly basis in streams draining mostly forested, pasture, and cropland watersheds from April 15, 1977 through April 24, 1978. Considerable variation in concentrations was observed. These variations generally were related to identifiable events, such as intense storms and associated high stream flow. In general, corresponding variations occurred simultaneously in the three watersheds.

Suspended solids levels were strongly influenced by land use activities and storm events. The Dry Fork, or pasture, watershed was found to yield about four times the sediment as did the Little Saline, or cropland, watershed. Values were 51.7 and 13.0 tons/acre/year, respectively. This large sediment yield can be attributed to livestock having direct access to the stream channel where they churned up the stream bottom and broke down the stream banks. Sediment yield from the Clifty Creek, or forested, watershed was calculated to be 8.8 tons/acre/year. This high yield can be attributed to the relatively steep gradient stream actively cutting and reshaping its stream channel.

Nitrate-nitrogen values up to 1.5 ppm were observed in the Little Saline "cropland" stream during the spring and early summer months which corresponded to tillage activities. Nitrate-nitrogen values of up to about 1.0 ppm were observed in the Dry Fork "pasture" stream during the summer and early fall months which corresponded to the period of active use of the stream by cattle. Nitrate-nitrogen values for the Clifty Creek "forested" stream were generally low. An increase from generally less than 0.1 ppm to about 0.5 ppm could be associated with leaffall in October. A marked increase in nitrate-nitrogen values for the "pasture" and "forested" watersheds occurred in December and lasted through March. Values jumped from less than 0.1 ppm to as high as 1.5 ppm and generally stayed around 0.5 to 0.7 ppm for the period.

Specific conductance, calcium and pH levels were highest in the stream of the "cropland" watershed and lowest in the stream draining the "forested" watershed.

Comparisons between values obtained from grab samples and those from samples collected by continuous, proportional, composite samplers show substantial differences and point out the need for a continuous sampling program which will integrate all levels of flow and concentration levels.

This study produced several bits of information which may be useful in "208" planning as prescribed by PL 92-500. The impact of cattle having direct access to the stream is very clear. Their presence in and near the stream had a major degrading impact on water quality. Farming activities may have somewhat of a degrading impact on water quality which appears to be seasonal in nature. As could be expected, the stream draining the basically undisturbed forested watershed had the best quality water. Even here, sediment discharge, produced by natural weathering processes, can be relatively high due to the specific conditions within the watershed. In our case, the stream draining the forested watershed had a steep gradient and was actively changing its channel characteristics by bank undercutting and movement of substantial rubble within the stream channel.

The implication derived from this study is that water quality is more directly related to the amount of site disturbance than to a specific land use. This study also points out the necessity of considering natural water quality levels, associated with undisturbed areas, prior to establishing stream standards which may be unrealistic for a particular area.