

# **MONITORING IMPACTS OF ANIMAL RESEARCH CENTER ON SURFACE AND GROUNDWATER QUALITY**

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## **Brief Project Summary**

The Animal Research Center (ARC), a facility designed to meet the research goals of the College of Agriculture, must meet the requirements of the Agricultural Water Quality Authority as established by SB 241. Intelligent hydrologic planning is incumbent upon a detailed knowledge of the hydrologic system as well as of the influences upon that system. An ongoing water quality monitoring program was instituted in October of 1996 to determine the impact of ARC operations on surface water and ground water quality.

All relevant water quality, flow, well, and spatial data have been archived on BAE computer systems. The data is readily available for teaching, research, and planning use and have been utilized by several researchers and departments with interests at the ARC.

By October 1, 2000, three years of water quality data have been gathered for the ARC prior to the population of the new animal research facilities. In addition, 2 years of storm water quality has also been collected. An initial assessment of the surface water quality monitoring strategy of the stream solute mass load error and bias, when compared to “true water quality”, was completed utilizing the surface water quality and water flow data, collected at 10 minute intervals, at ARC watershed discharge monitoring site (ST-1). The error and bias of the estimated stream solute mass load, when compared to “true mass load”, was determined. The results of this assessment would be applicable to the other surface monitoring sites on the ARC where water quality data was collected biweekly with flow rate determined every 10 minutes.

Surface water concentrations of nitrate-N, temperature, pH, and EC were found to exhibit diurnal (daily) variations throughout the year. The minimum error and bias, when compared to “true mass load” or daily average concentration, occurred if water samples were taken at mid-morning. The error and bias of the estimated stream solute mass load was found to be less than 10% for water sampling frequencies of 1 week, 2 weeks and 4 weeks with no storm chasing sampling.

Significant differences in surface water nitrate-N and o-phosphate concentrations were found for watersheds with different agricultural land uses. Surface water sampling sites were found to have higher concentrations for predominately row crop land use than for pasture land use. The ARC stream loads for Total N and o-phosphate were greater than US EPA maximum guidance values except for Total N for a pasture watershed.

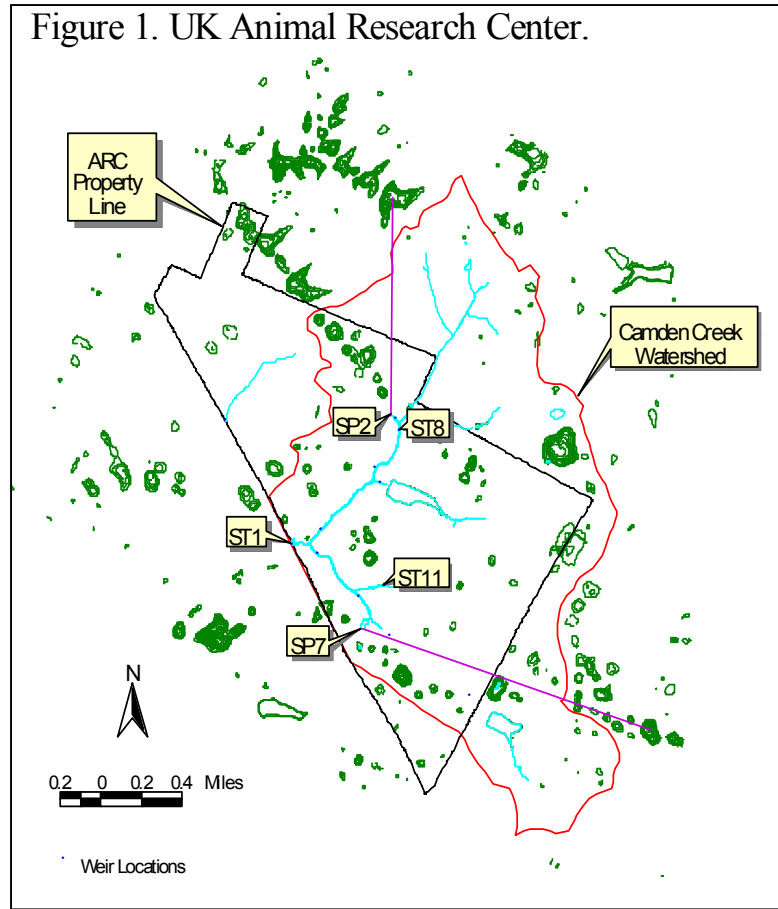
### **Project Objectives**

- 1.** Assess the net impact of an integrated animal production on surface water leaving the farm.
- 2.** Assess groundwater quality at established well nests.
- 3.** Determine the relative levels of contribution of the row crop and the pasture areas of the integrated animal production system to water quality constituents.
- 4.** Support water quality research efforts at the Center by maintaining a minimum, ongoing monitoring program.
- 5.** Maintain a GIS historical landuse activity database.
- 6.** Maintain a hydrology teaching field laboratory for Biosystems and Agricultural Engineering, Agronomy, and Forestry departments.

## Methods

The University of Kentucky Animal Research Center (ARC; Figure 1) lies within the Inner Blue Grass physiographic region of Kentucky and is characterized by broad, shallow sinkholes with caverns and underground drainage ways, low relief, broad valleys and ridges, sparse rock outcrops and thick, fertile, limestone and shale residual soils (Keagy et al., 1993). The geology of the area is characterized as Lexington

Figure 1. UK Animal Research Center.



Limestone, high in phosphorus content, with most member units having minor shale bedding with one significant upper member interbedded with shale. Soils are moderate to well-drained silt loams derived from the high phosphatic limestone. Maury soils are found on broad ridgetops and cover 70% of the area. They are fertile and deep (10-15 ft. over bedrock) with a silty-clay subsoil. McAfee soils cover 15% of the area and are located on moderately steep slopes. They are shallow (< 3 ft. over bedrock) with a silty-clay subsoil. Parts of the ARC are used for precision agriculture operations and include tobacco, row crops, small grains, and animal research grazing plots. The predominant land use outside the ARC boundary is pasture for horse and cattle farms.

A water-monitoring network was established at the ARC in October 1996 that has provided background data for comparing post-BMP implementation results with pre-BMP water quality values. Implementation of the nutrient management program at the ARC begins during 2002 as the Beef and Swine Research Units populate their facilities with animals. The water-monitoring network, established at the ARC, is to provide sufficient data suitable for assessing the impact of ARC activities on water quality and quantity. One important justification for the network is that much of the water that flows through the ARC originates from land outside the ARC.

Surface water and ground water quality data will have been collected for nearly three years by the end of the 2000 water year (October 1). In addition, two years of storm flow data will have been collected. This data is the background on which an assessment the impact of the ARC animal waste nutrient management program BMPs on water resources over the next three to five years is based. Preliminary analysis of the water quality data has shown that sampling strategies can introduce statistical error or bias into a data set due to the existence of diurnal variations in stream water quality parameters. Implications of this analysis are that an unacceptable level of Type I and Type II statistical errors can be introduced to the watershed assessments of the nutrient management BMPs. The water quality database, containing both pre-BMP implementation data, was used to evaluate sampling strategies and methods for use in karst terrains and small watersheds that reduce error and optimize the utility of data gathered for determining agricultural watershed TMDLs, nutrient loads and water concentrations.

The introduction of BMP practices, such as injecting swine manure into ARC cropland, composting solids wastes before surface land application, and the establishment of riparian zones, is hypothesized to maintain or improve surface water quality that exits the ARC. Errors

associated with the sampling protocols need to be minimized to avoid the masking of statistically significant positive or negative impacts.

### Sampling Strategies

The USEPA Protocol for Developing Nutrient TMDLs does not provide guidance for a stream sampling strategy to obtain stream nutrient loads. Stream sampling strategies have varied widely and each has its associated error and bias. Robertson and Roerish (1999), in a study utilizing subsampling to represent different sampling strategies, found that the most effective sampling strategy to estimate loads in small streams depended on the length of the study. Fixed-period monthly sampling with storm chasing appeared to be the most effective and resulted in the most precise annual loads but still resulted in overestimations of 25-50%. For longer studies, Robertson and Roerish found semimonthly sampling provided the least biased and most precise estimates of constituent loads. Our baseline data at ST-1 can be used as the basis for “true” nutrient flux to compare sampling strategies (subsamples created from database). Richards and Holloway (1987) found that flow stratified sampling and load calculation utilizing the Beale Ratio Estimator provided the most precise load estimations. They noted that bias was strongly related to sampling frequency and decreased fairly rapidly with increased sampling frequency. Also, Richards and Holloway (1987) stated that sampling strategies based upon sampling theory tended to overestimate the number of samples required to achieve a given precision. Currens (1997), studying a karst spring in southwestern Kentucky, recommended biweekly sampling supplemented by bihourly samples from storm flows.

Another problem that has not been adequately addressed in the literature is the effect of diurnal variations on sample error and bias. Research has gone into the study of diurnal variations in temperature (e.g. Jacobs, et al., 1997; Lowney, 2000; Younus, et al., 2000;

Constanz, et al., 1994), dissolved oxygen (e.g. Guasch, et al., 1998), electroconductivity (e.g. Kobayashi, et al., 1990) and NO<sub>3</sub>-N (e.g. Hessen, et al., 1997; Christensen, et al, 1990; and Jordan, et al., 1997). Work has also been done on the design of sampling strategies to determine mass loads (e.g. Robertson and Roerish, 1999; Richards and Holloway, 1987; Preston, et al.,1989; and Cohn, et al., 1989). However, nothing could be located in the literature that dealt with the possibility of the introduction of error and bias into a dataset due to diurnal variations.

### Results and Discussion

Table 1 is a comparison of randomly selected daily water variables and their “true” daily means. The “true” daily means were determined from data collected at 10 minute intervals at ST-1 with a YSI 6000 Water Quality Datalogger by averaging the 144 data points collected each day. Random values were selected from the data record within given periods of the day, such 8 am to 5 pm, or noon to 5 pm. Table 1 contains the means, standard

Variable	No. of Days in Data Record	Sampling Period	mean	standard deviation	RMSE
Temp	1066	24 hour	-0.090	2.453	2.455
		8 am - 5 pm	0.949	2.406	2.586
		8 am - noon	-0.858	1.655	1.864
		noon - 5 pm	2.527	1.752	3.075
		max - min	0.326	0.412	0.525
pH	1066	24 hour	-0.004	0.294	0.294
		8 am - 5 pm	0.158	0.264	0.308
		8 am - noon	0.012	0.192	0.192
		noon - 5 pm	0.286	0.255	0.383
		max - min	0.063	0.056	0.084
NO <sub>3</sub> -N	786	24 hour	0.005	0.437	0.437
		8 am - 5 pm	0.056	0.352	0.357
		8 am - noon	0.087	0.309	0.321
		noon - 5 pm	0.035	0.449	0.450
		max - min	0.050	0.272	0.276
E.C.	1003	24 hour	0.000	0.025	0.025
		8 am - 5 pm	0.000	0.024	0.024
		8 am - noon	0.009	0.020	0.022
		noon - 5 pm	-0.008	0.022	0.024
		max - min	-0.003	0.013	0.013

deviations, and root mean square errors (RMSE) of the differences between the random sample and the daily mean. Samples collected between noon and 5 pm were the worst at estimating the daily mean for temperature, pH, and NO<sub>3</sub>-N. The largest error was produced for E.C. by sampling between 8 am and noon. Averaging the daily minimum and maximum values produced the best estimates of the daily means. In a long term study, with a goal of estimating average annual loads

or concentrations emanating from a watershed, it would seem reasonable that collecting data that was sampled as near the daily mean as possible would produce better results. Conversely, it would seem that consistently collecting data near maximum or minimum values could produce bias in the data.

Mean water variable values at each hour of the day, taken from the same data collected to produce Table 1, are plotted in Figure 2. It can be seen in Figure 2 that if one researcher consistently sampled at 6 am and another consistently sampled at 4 pm, they would arrive at different values for pH for the same stream. Can significantly different results be obtained by sampling at different times within the day within a given sampling strategy, such as biweekly or monthly grab sampling? The data was subsampled at biweekly and monthly intervals and the water quality values at 8 am, 10 am, noon, 2 pm, 4 pm, and a random value occurring between 8 am and 4 pm was determined for each subsample. Utilizing the student's t-test, the values obtained at each

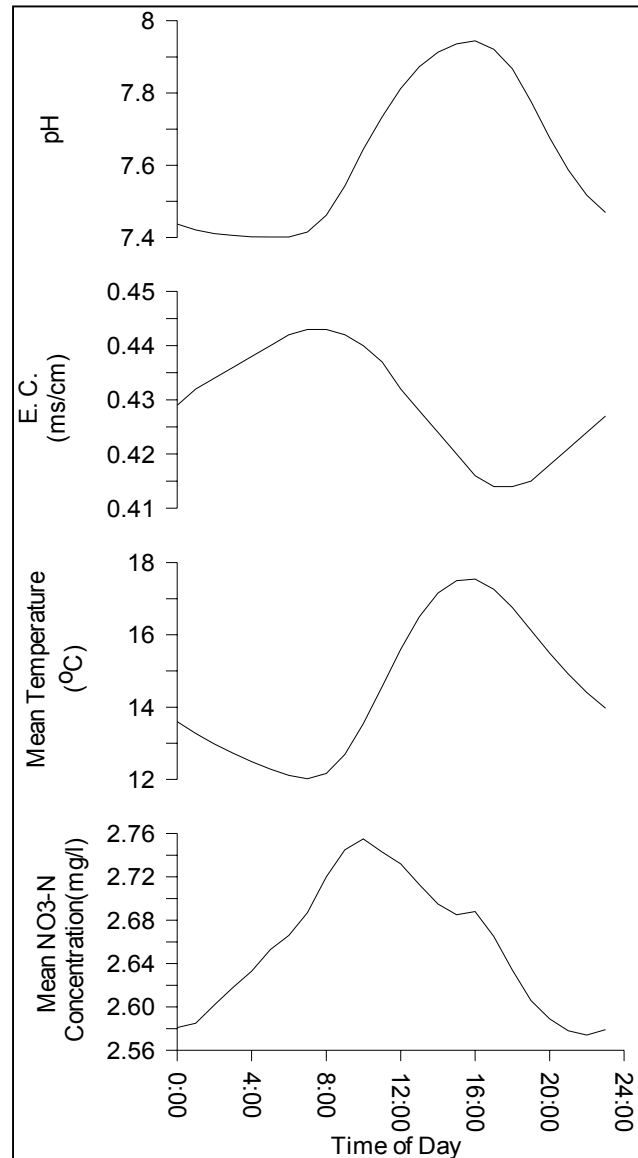


Figure 2. Mean Values at Each Hour.

time were compared to determine if they were significantly different. Table 2 shows that significantly different pH values could be obtained from a biweekly sampling regimen with as

	8 - 10	8 - 12	8 - 2	8 - 4	10 - 12	10 - 2	10 - 4	12 - 2	12 - 4	2 - 4
<b>winter</b>										
mean	-0.166	-0.308	-0.371	-0.340	-0.141	-0.205	-0.174	-0.064	-0.033	0.031
std	0.136	0.229	0.294	0.338	0.102	0.178	0.235	0.094	0.158	0.077
df	15	15	15	15	15	15	15	15	15	15
t statistic	1.220	1.341	1.264	1.005	1.386	1.152	0.740	0.678	0.206	0.405
P = .9	1.753	1.753	1.753	1.753	1.753	1.753	1.753	1.753	1.753	1.753
P = .95	2.131	2.131	2.131	2.131	2.131	2.131	2.131	2.131	2.131	2.131
Sig @ .9	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Sig @ .95	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
<b>spring</b>										
mean	-0.365	-0.655	-0.798	-0.769	-0.290	-0.433	-0.404	-0.143	-0.114	0.029
std	0.157	0.260	0.337	0.430	0.177	0.249	0.326	0.197	0.250	0.197
df	11	11	11	11	11	11	11	11	11	11
t statistic	2.329	2.522	2.369	1.789	1.638	1.739	1.239	0.727	0.457	0.148
P = .9	1.796	1.796	1.796	1.796	1.796	1.796	1.796	1.796	1.796	1.796
P = .95	2.201	2.201	2.201	2.201	2.201	2.201	2.201	2.201	2.201	2.201
Sig @ .9	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Sig @ .95	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
<b>summer</b>										
mean	-0.208	-0.468	-0.614	-0.678	-0.260	-0.406	-0.469	-0.146	-0.209	-0.064
std	0.208	0.384	0.456	0.471	0.237	0.339	0.366	0.125	0.216	0.152
df	15	15	15	15	15	15	15	15	15	15
t statistic	1.001	1.219	1.345	1.439	1.095	1.197	1.281	1.169	0.970	0.419
P = .9	1.753	1.753	1.753	1.753	1.753	1.753	1.753	1.753	1.753	1.753
P = .95	2.131	2.131	2.131	2.131	2.131	2.131	2.131	2.131	2.131	2.131
Sig @ .9	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Sig @ .95	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
<b>fall</b>										
mean	-0.062	-0.159	-0.249	-0.296	-0.097	-0.188	-0.235	-0.091	-0.138	-0.047
std	0.032	0.083	0.170	0.223	0.062	0.153	0.205	0.097	0.151	0.062
df	16	16	16	16	16	16	16	16	16	16
t statistic	1.938	1.924	1.464	1.328	1.578	1.225	1.145	0.933	0.914	0.759
P = .9	1.746	1.746	1.746	1.746	1.746	1.746	1.746	1.746	1.746	1.746
P = .95	2.120	2.120	2.120	2.120	2.120	2.120	2.120	2.120	2.120	2.120
Sig @ .9	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Sig @ .95	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE

little as two hours between sampling times, particularly if the sampling was only conducted during a particular season. Comparison of temperatures also produced significantly different values, whereas NO<sub>3</sub>-N and electroconductivity did not appear to vary significantly with different sampling time. This would imply that a significant difference could be found between two identical watersheds in which no change occurred when sampling at different times, a Type II error. More analysis needs to be done to determine if a sampling protocol should and can be developed that addresses the error and bias by diurnal variation.

Preliminary results from ARC baseline data, collected at ST-1 from June 1997 through 2000, indicate that biweekly, mid-morning sampling with a continuous flow record may provide acceptable estimations of annual load. Table 3 shows the results of comparing two sampling strategies with actual loads of NO<sub>3</sub>-N and Total Solutes. Flow, NO<sub>3</sub>-N and E.C. data was collected continuously (10 minute intervals). Grab samples were also collected biweekly

Load Estimation Method	NO <sub>3</sub> -N						Total Solutes					
	Grab Sample with Grab Flow (kg/ha)			Grab Sample with Total Flow Volume (kg/ha)			Grab Sample with Grab Flow (kmoles/ha)			Grab Sample with Total Flow Volume (kmoles/ha)		
Period	1 week	2 week	4 week	1 week	2 week	4 week	1 week	2 week	4 week	1 week	2 week	4 week
mean	-0.041	-0.021	0.084	-0.014	-0.008	0.002	-0.048	-0.066	-0.078	-0.022	-0.041	-0.015
stdev	0.107	0.429	0.587	0.061	0.135	0.169	0.174	0.343	0.681	0.331	0.443	0.719
median	-0.001	-0.009	-0.004	0.000	0.001	-0.002	0.000	-0.004	-0.017	-0.001	-0.001	0.005
n	37	33	23	37	33	23	51	53	41	51	53	41
RMSE	0.114	0.430	0.593	0.063	0.136	0.169	0.180	0.349	0.686	0.332	0.445	0.720
% diff	-13.11%	-3.19%	13.92%	-4.46%	-1.30%	0.26%	-19.25%	-14.14%	-8.53%	-9.07%	-8.74%	-1.60%
Weeks	37	66	92	37	66	92	51	106	164	51	106	164

through the period. Loads were calculated three ways: True loads utilizing the continuous flow and concentration data and estimated loads using 1) grab sample concentrations and a “grab flow” and 2) grab sample concentrations and the average flow rate for 1, 2 and 4 week periods. The average flow was determined by using the continuous flow record for 3.5 (1 week), 7 (2 week), and 14 (4 week) days, respectively before and after the grab sample collection time. Wet and dry weather periods were roughly (56% wet, 44% dry) equally represented. As can be seen in Table 3, grab sampling on a weekly or biweekly basis with collection of a continuous flow record appears to be an acceptable method of estimating of annual Nitrate-N loads. Total Solutes appears to be better estimated by utilizing weekly grab samples and flows. More data needs to be collected to determine if this is a viable alternative to supplementing grab sampling with storm chasing or flow stratified sampling strategies, which are more costly.

The ARC stream baseline data has been used to estimate the nutrient concentrations and loads from various land uses. The USEPA Protocol for Developing Nutrient TMDLs present literature stream values for total dissolved inorganic N and ortho-P concentrations, and typical total P and N loading for various agricultural land uses (see Tables 4 and 5). These values are recommended when no watershed data is available. The USEPA values for pasture are 1/3 the values found for the ARC pasture areas, but the USEPA values do not account for high P soils. The high inorganic-N in the ~ 60% row crop land use watershed is associated with a tobacco, corn, wheat, and soybean rotation. The ARC stream flow nutrient loads from row crop areas for Total N and ortho-P exceed the maximum USEPA guidance values. For the pasture watershed, the ortho-P nutrient load exceeds the USEPA maximum guidance value while Total N load is slightly above the USEPA median guidance value.

Land Use	ARC Watershed Mean (mg/l) **		USEPA Central USA Mean (mg/l)	
	Total Inorganic N	Total Ortho-P	Total Inorganic N	Total Ortho-P
> 90% Agriculture with ~ 20% row crop (ST-1)	2.88 A	0.21 A		
> 90% Agriculture with ~ 0% row crop (ST-8)	2.86 A	0.21 A		
> 90% Agriculture with ~ 60% row crop (ST-11)	9.56 B	0.38 B		
> 90% Agriculture			0.77	0.085

\*\* Means in column with different letters are significantly different at  $\alpha=0.05$ .

Land Use	Nutrient	ARC Watershed (kg/ha-yr)	USEPA (kg/ha-yr)					
			Min.	Max.	Median			
>90% Agriculture with >20% Row Crop (ST-1) (10/1996-6/2000)	Total N	13.01						
	Ortho-P	0.85						
>90% Agriculture with >60% Row Crop (ST-11) (4/1999-6/2000)	Total N	18.06						
	Ortho-P	0.59						
> 90% Agriculture with >0% Row Crop (ST-8) (4/1999-6/2000)	Total N	4.52						
	Ortho-P	0.28						
UKARC (4/1999-6/2000)	Total N	14.18						
	Ortho-P	0.38						
Pasture	Total N					1.2	7.1	4.2
	Ortho-P					0.01	0.25	0.13

## Conclusions

- Diurnal variation was found at the ARC surface water discharge point (ST-1) for temperature, E.C., nitrate-N, and pH at levels that could contribute significant error and bias when calculating stream daily averages and stream nutrient loading.
- Mid-morning surface water sampling was found to produce the least error and bias when estimating daily averages and daily stream load.
- Grab sampling on a weekly, biweekly, or monthly basis with collection of a continuous flow record appears to be an acceptable method of estimating of annual stream nitrate-N and total solute loads.
- Surface water sampling sites were found to have significantly higher surface water nitrate-N and o-phosphate concentrations in a watershed with predominately row crop land use than watersheds with pasture land uses.
- The ARC stream loads for Total N and o-phosphate were greater than US EPA maximum guidance values except for Total N for a pasture watershed.

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