APPLICATION OF GIS IN ENVIRONMENTAL POLICY ANALYSIS

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Role of Analysis in Policy Deliberation

In 1996, the National Research Council published an important prescription for how environmental risk-based policy should be formulated (Stern and Fineberg 1996). This publication redefines the relationship between policy analysis and policy deliberation.

In its previous prescription (NRC 1983), the NRC defined a process of environmental decision-making that has shaped the way that many federal and state environmental regulatory agencies implement risk-based programs. This paradigm embraced a linear process that attempts to separate facts and values. In risk assessment, scientists were asked to conduct value-neutral analysis of risk using the best data and risk models available. This assessment was then fed into the risk management process in which tradeoffs among competing values were made in selecting a risk reduction strategy. While the 1983 paradigm acknowledged that stakeholders have a legitimate role in risk management, their involvement in risk assessment was less important by virtue of the expert scientific nature of the enterprise.

In 1996, the NRC re-examined the risk analysis paradigm and derived a remarkably different approach (Stern and Fineberg 1996). In the new paradigm, risk-based decision-making is prescribed as an integrated and recursive process of technical analysis and political deliberation. The arbitrary separations of fact and value, expertise and dialogue, and assessment and management were abandoned in favor of a holistic integration. This new approach increases the trustworthiness of decision-making and better resolves controversies than does the former. Despite this (r)evolutionary change in thinking, there is little evidence that environmental agencies have abandoned the earlier paradigm. This may be due to the heavy emphasis on natural science and engineering training of decision-makers.

In the 1996 prescription, the interplay of analysis and deliberation takes place in both risk assessment and risk management. Analysis is used to inform policy deliberation so that the best information is brought to bear upon the problem to be solved ("getting the science right"). This role of analysis is not so different from that under the 1983 paradigm. The novel change is that deliberation is used not only to make a decision, but also to frame the analysis and to empower participants in understanding analytic findings ("getting the right science"). Thus, it is not solely within the discretion of the analyst to decide what information should be considered in the analysis, what models should be used to predict impacts, and how to evaluate alternative impact management schemes. Non-technical stakeholders should also participate in framing the issues that are salient to the decision problem. Such issues include deciding what information should be considered, what further studies should be performed to reduce uncertainty, what models should be used to predict impacts and to evaluate alternatives, what assumptions and defaults should be used in these models, and so on. New information, once provided to the deliberants, may stimulate another round of analyses to further inform deliberation. The careful integration of analysis and deliberation in a recursive manner is the most important element of the new paradigm.

This paper examines the role that GIS can play in informing policy deliberations while at the same time stimulating further analyses. As will be demonstrated, the graphical display capability of GIS, coupled with its powerful analytical capacity inherent in its underlying database, is well situated to facilitate the integration of environmental policy analysis and deliberation.

Use of GIS in Environmental Policy Analysis

Geographic Information Systems (GIS) is an important and increasingly useful tool in environmental policy analysis. GIS not only allows the visualization of spatial data to aid policy decision-making, but also allows scenario testing that can explore the anticipated outcomes of policy alternatives. We will use GIS to analyze the environmental threat to an amphibian population in Norman, Oklahoma and then discuss how the GIS-based analysis can inform policy designed to reduce this threat. The paper concludes with a discussion of issues raised by the analysis, which illustrates how policy deliberation can frame further analysis.

A GIS Case Study: Declining Amphibian Population

The decline in amphibian population in many parts of the world (Blaustein and Wake 1990; Fellers and Dorst 1993; Phillips 1990; Tyler 1991) deserves attention not only because it is disturbing in its own right but also because amphibians serve as potential indicators of the overall health of the environment. Several factors are hypothesized to contribute to population declines. Anthropogenic factors leading to habitat destruction and degradation clearly remain the most significant causes of amphibian disappearance (McNeely *et al.* 1990; Wilson 1988). For example, increased UV radiation from the depletion of stratospheric ozone has been suggested as one cause (Blaustein *et al.* 1994). However, lethal and sub-lethal concentrations of environmental toxicants such as pesticides, trace metals, and industrial organic chemicals can also trigger population declines (Carey and Bryant 1995). It is important to understand the causes of amphibian population declines in particular environmental settings in order to formulate appropriate policies that can restore the population.

Since environmental factors have a strong spatial component, GIS is ideally suited to investigating stressors that might be responsible and hence is a powerful analytical and planning tool to inform environmental policy deliberation.

Study Site

The study site (Figure 1)[1] is a landfill located south of the city of Norman in central Oklahoma on alluvium deposited by the Canadian River, which has been designated as a national toxicology study site by the U.S. Geological Survey (USGS). The landfill was operational from 1922 to 1985 with no restrictions on the type of wastes deposited. More than 40 semi-volatile and non-volatile compounds are found in the groundwater downgradient of the landfill (Dunlap *et al.* 1976). Many of these compounds are known xenobiotics and carcinogens. A reference site (Figure 2), approximately 5 miles upstream of the river, serves as a control area. GIS-related studies undertaken at the study site include environmental toxicity, amphibian biomonitoring, and ultra-violet radiation.

Environmental Toxicity Study

Toxicological assays such as FETAX (Frog Embryo Teratogenesis Assay – *Xenopus*) can be used to study the effects of environmental toxicants on amphibians. FETAX is a four-day, whole embryo, developmental toxicity test using the South African clawed frog (*Xenopus laevis*). The assay was initially developed as an indicator of potential human developmental health hazards (Dumont *et al.* 1982) and has found wide application in aquatic toxicological assessments (Dawson *et al.* 1985; Bantle *et al.* 1994; Fort *et al.* 1995). Surface and groundwater samples collected between January and April 1997 from the landfill and reference sites were tested using FETAX.

Most of the toxicity at the landfill site exists downstream of the landfill (Figure 3). Toxicity is particularly high at location NL4, a groundwater seep, at which 100% mortality was observed. At the reference site (Figure 4), only sporadic instances of higher than normal toxicity and malformation are found. This suggests that a leachate plume is emanating from the landfill.

The toxicity assessment results obtained from groundwater samples collected during November 1995 are summarized in Figure 5. This map clearly shows an inverse relationship between distance from the landfill and toxicity. This relationship suggests that the landfill is the source of the toxicity. Three mechanisms can account for the decrease of toxicity with distance. First, vertical and lateral dispersion

[1] All figures and tables are located in an appendix at the end of this paper.

reduces contaminant concentration as the plume migrates away from the landfill. Second, the stream that flows across the groundwater plume migration route can lose water to the aquifer and dilute the contaminants. Third, the stream can intercept groundwater contaminants whenever it gains water from the aquifer as during times of high groundwater elevation. In either of these last two cases, the stream-groundwater interaction can decrease contaminant concentrations. The decreasing rate of toxicity with distance from the landfill provides valuable clues to the status of the plume of toxicants leaching from the landfill.

Figure 6 shows the typical malformations that were observed, including dorsal curvature of the tail, lack of gut development, and stunted growth. These malformations are consistent across sampling locations at the site.[2] Interestingly, we found that teratogenicity *increases* with distance, which suggests that the concentration of teratogens must also be increasing with distance – but this is not the case. The best explanation is that loss of toxicity allows more embryos to survive to be malformed.

Biomonitoring-Weather Study

Biomonitoring and weather data can be correlated and compared at Norman Landfill and reference sites to provide additional information on amphibian toxicity. Amphibian biomonitoring was conducted using drift fence arrays at both sites (Figures 7 and 8). This technique employs the use of pitfall and funnel traps placed at strategic points along an artificial barrier (drift fence). The barrier intercepts animals moving through the habitat and directs them toward the traps. Figure 9 depicts the total number of animals observed during the survey period. The biomonitoring data were then correlated with prevailing weather conditions (Table 1). Oklahoma Mesonet weather stations provide weather data at a 5-minute temporal scale. We found that the amphibian population correlates positively with rainfall and relative humidity, whereas the reptilian population, which is not declining, does not correlate with these variables. This suggests that amphibians are uniquely sensitive to moisture variation, thus providing another clue as to their decline.[3]

Utility of GIS to Inform Policy Deliberation

The correlation between distance from the Norman Landfill and frog embryo toxicity and teratogenicity provides strong evidence that the amphibian decline is due exposure to contaminants emanating from the landfill. In addition, the unique sensitivity of amphibians to rainfall and humidity and the positive correlation of these variables with population suggest that contaminant exposure is occurring through water. However, amphibian sensitivity to humidity is most at the contaminated site whereas sensitivity to rainfall is apparent at both the contaminated and reference sites. Finally, the relationship between groundwater and surface water contamination through their hydrologic connection suggests that surface water contamination is occurring from the migration of contaminants to surface water from groundwater during wet periods.

Tying these findings together, the following tentative explanations emerge. Amphibian decline near the Norman Landfill may be due, at least in part, to surface water contamination by the migration of leachate through groundwater to surface water. Dilution of the contamination occurs during rainfall periods when surface water runoff and stream flow are high and thus adverse effects are not manifest. However, contaminant concentrations in surface water may rise after stream flow subsides if groundwater elevations remain high. However, it is still possible that contamination carried to streams by surface runoff is also responsible. Moreover, it is still possible that weather itself – especially humidity – is also contributing to the decline since declines in population with lowered humidity was also noted at the reference site.

Though additional studies are underway to investigate this and other possible causes of decline, if the hypothesized cause is proven correct, then effective mitigation must include groundwater remediation.

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[2] The reader is referred to Bruner *et al.* (1998) for a detailed description of the surface and groundwater toxicity analysis of the landfill and reference sites.

[3] A three-year ultraviolet radiation field study is currently underway to investigate more closely the possible effects of UV on amphibian populations. These results are not yet available.

This was not immediately evident. Without the GIS study, it is possible that a policy that focused only on surface runoff contamination would have been pursued, which would likely have failed to reverse the amphibian population decline.

Utility of GIS to Frame Further Policy Analysis

Based on the spatial variations of toxicity in groundwater and surface water near the landfill, both landfill leachate and surface water runoff may be contributing factors to the observed decreases in amphibian populations. The short-term study indicates that weather may also play an important role in the population fluctuations. Since ecological studies require long-term evaluation, there is a strong need for sustained data collection and analysis. The resolution of this matter will depend on further GIS analysis of toxicity assessments from such long-term studies. Moreover, based on these preliminary results, additional studies should be undertaken to address the biogeochemical characteristics of the landfill. The USGS is already conducting extensive studies aimed at characterizing the subsurface flow characteristics of the site as part of the Toxic Substance Hydrology program. These studies, undertaken in conjunction with the toxicity tests of the surface waters and ground waters, will provide valuable information on the toxicity of the site. Evaluating these studies in the framework of a GIS will provide valuable insights in the spatial and temporal variation of the toxicity at the site.

Future Research

An important study that will be implemented soon involves amphibian habitat. A GIS-based habitat map will be generated using Landsat TM satellite data. This effort will provide valuable input to any indication of the habitat being a limiting factor to the amphibians.

Another needed study indicated by the preliminary analysis of toxicity is *in situ* toxicity experimentation. The preliminary results were based on lab analysis of the samples. Moreover, the significant toxicity observed at the lower stretches of the slough needs further validation. Conducting the FETAX test under ambient field conditions at selected sites will provide the necessary validation of the lab results. Further screening of the toxicity could be conducted by coupling the field-based FETAX tests with the Toxicity Identification and Evaluation (TIE). TIE tests can be used to identify the individual chemical stressors most responsible for population declines.

Conclusion

This paper demonstrates the application of GIS to integrate spatial environmental data from diverse sources to analyze impacts and identify sources of threats to ecological receptors. The data sources included surface water and groundwater toxicity analyses, amphibian biomonitoring results, and weather information gathered from Mesonet stations. The use of GIS in this case study facilitated the creation and use of a comprehensive risk database not only to explore causes of, and potential solutions to, amphibian population declines. This is of particular importance in judging the significance of competing causes of toxicity. Furthermore, the results of this preliminary study highlights the importance of spatial technology in creating an context conducive to dialog and consensus-building among stakeholders and policymakers by providing an impetus for further study and sustained monitoring. Use of the visual displays and analytical results of this project presented at public and professional meetings have resulted in continued funding of *in situ* experiments and monitoring efforts. Though we did not sponsor actual policy deliberations as part of this research, we hope that this paper demonstrates how GIS can be used to both inform policy deliberation and frame further analysis.

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Appendix

[See next pages]

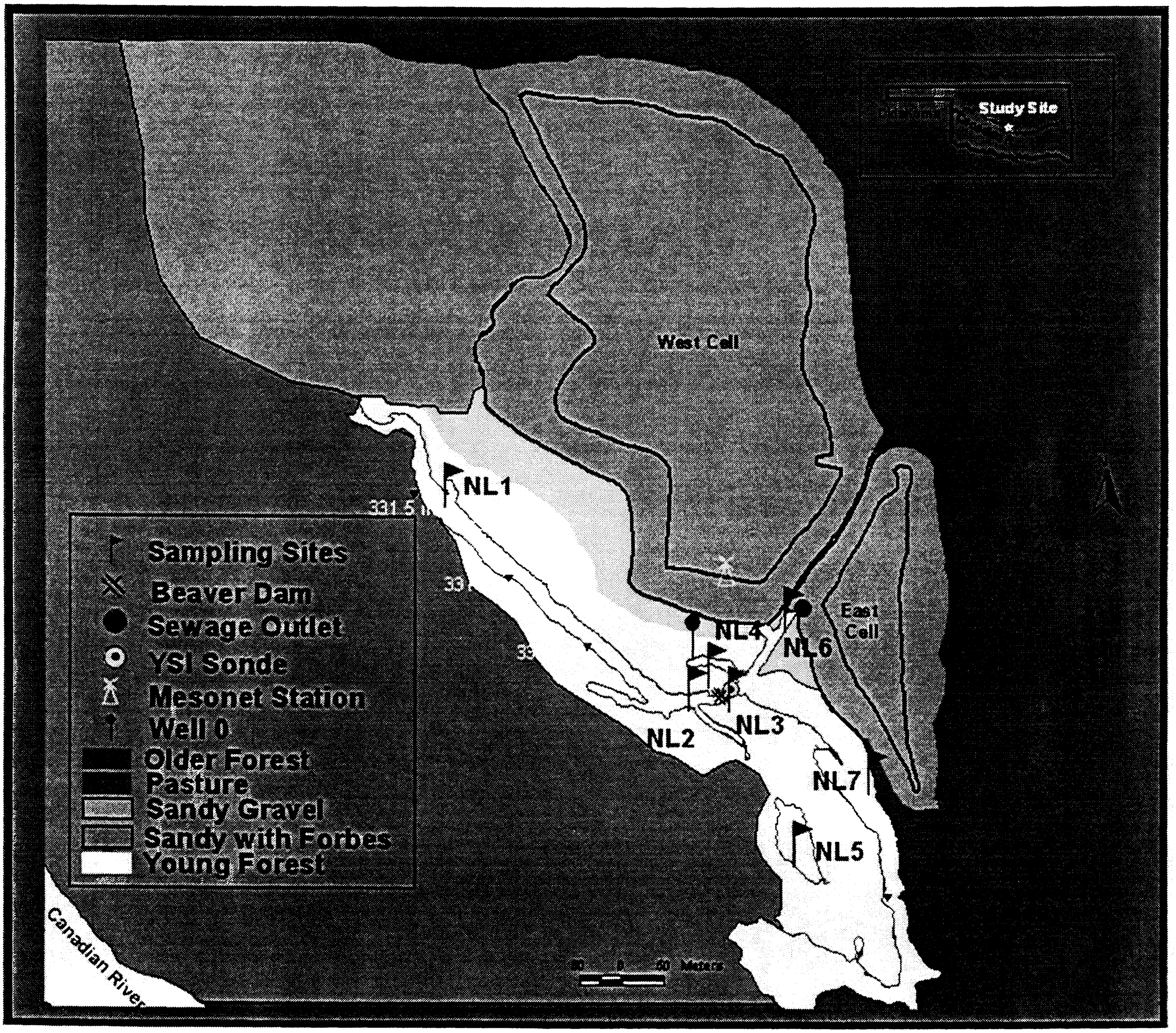

Figure 1. Map of the Norman Landfill Study Site

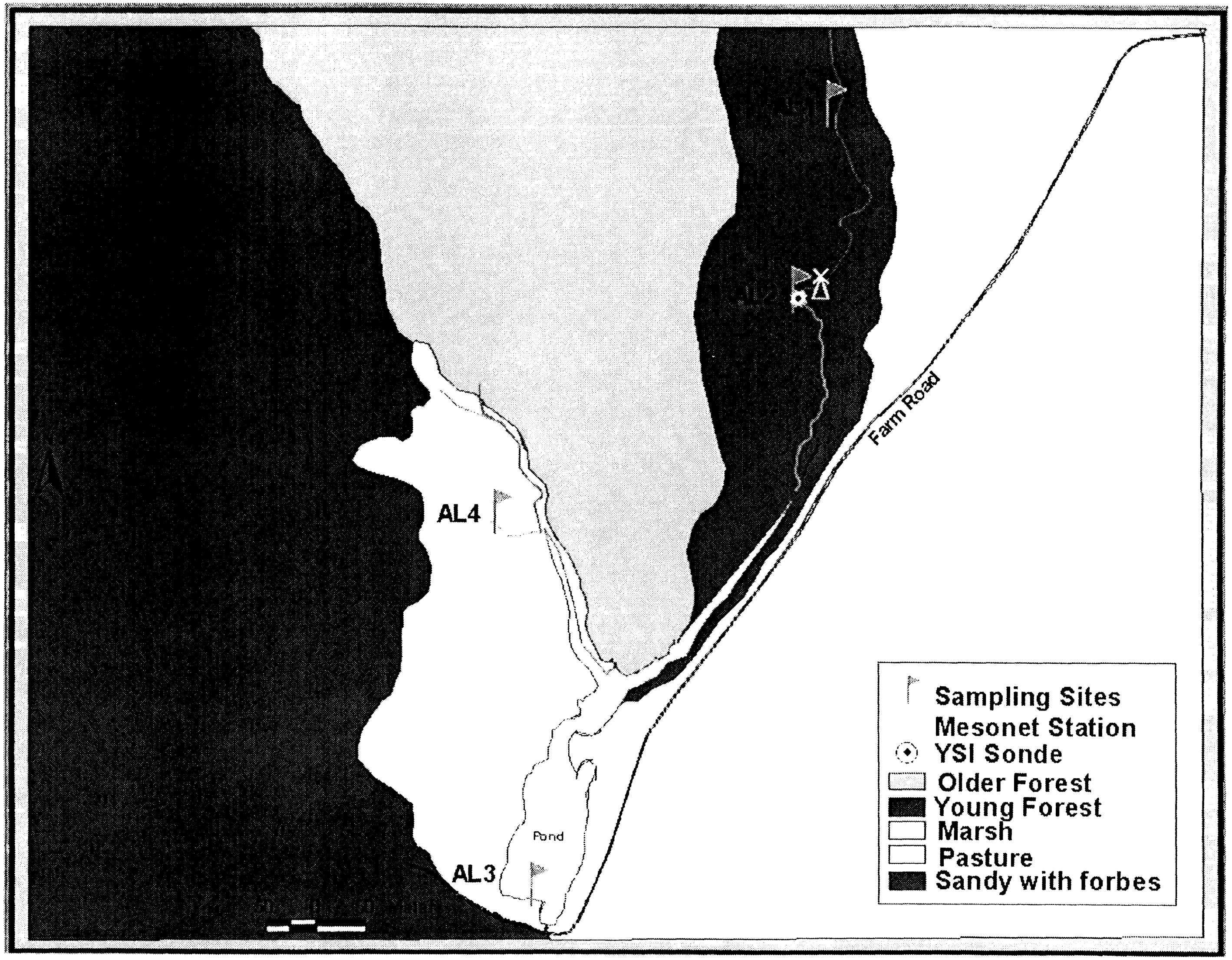

Figure 2. Higher Resolution Map of the Study Site

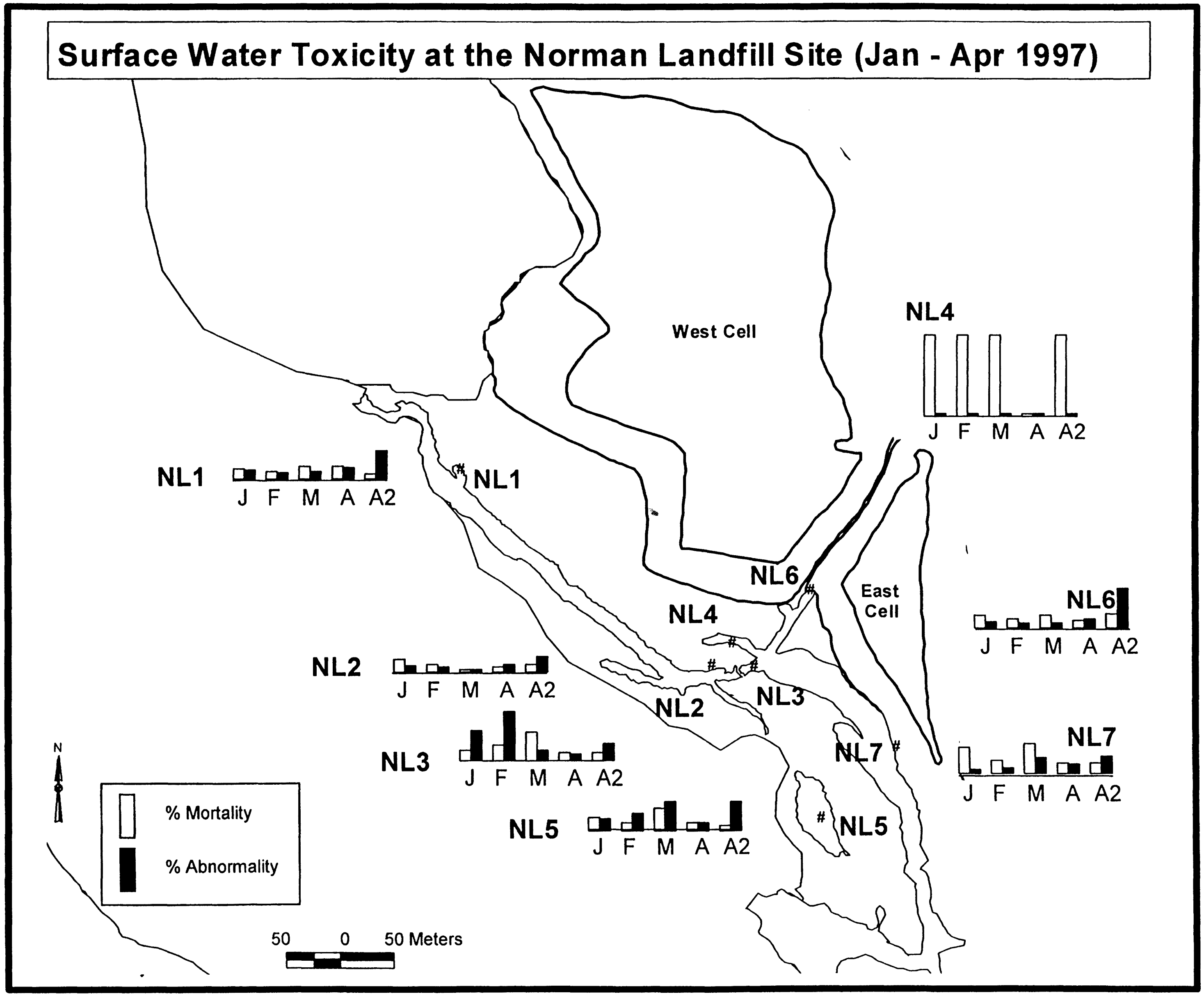

Figure 3. Surface Water Toxicity

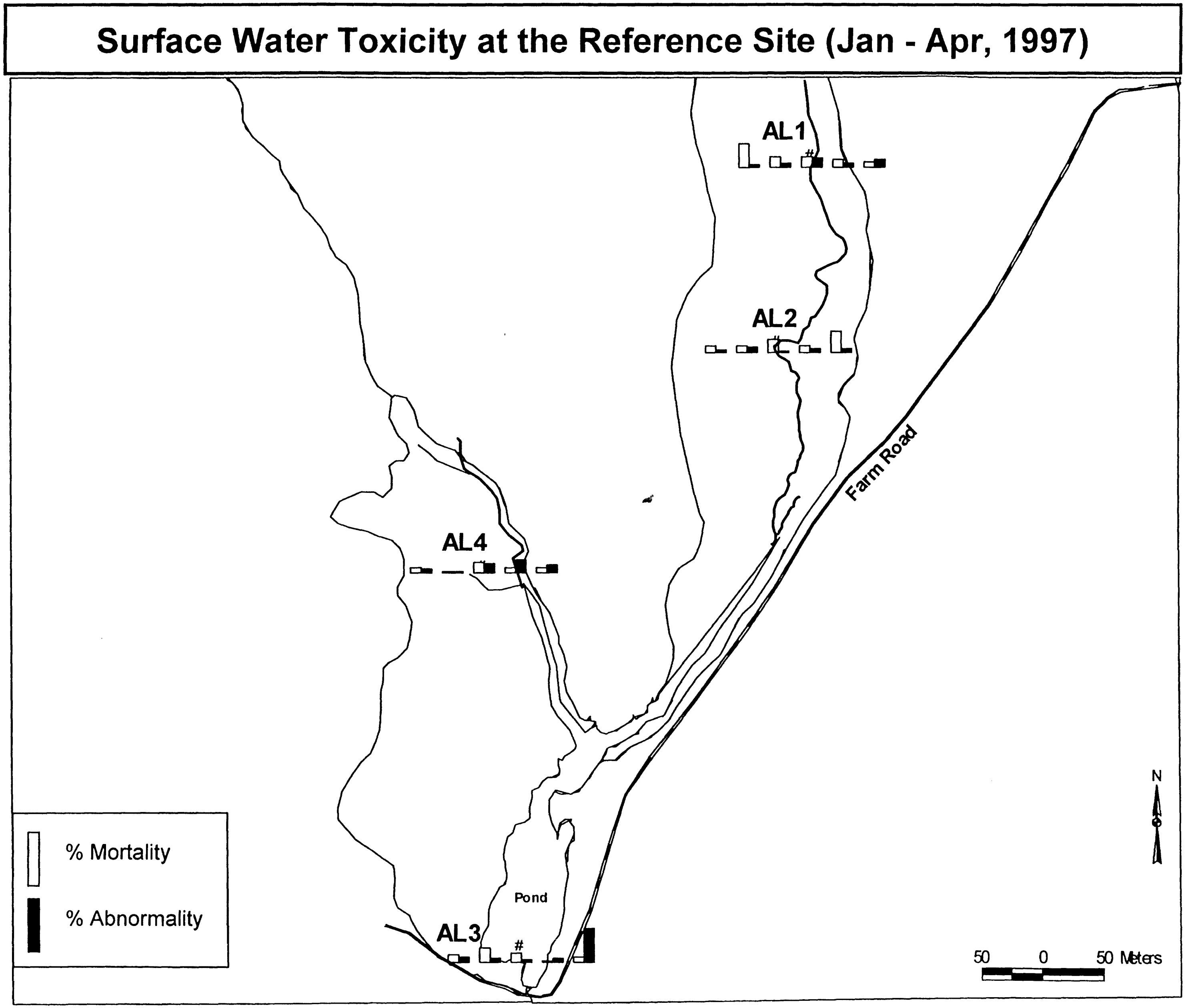

Figure 4. Surface Water Toxicity

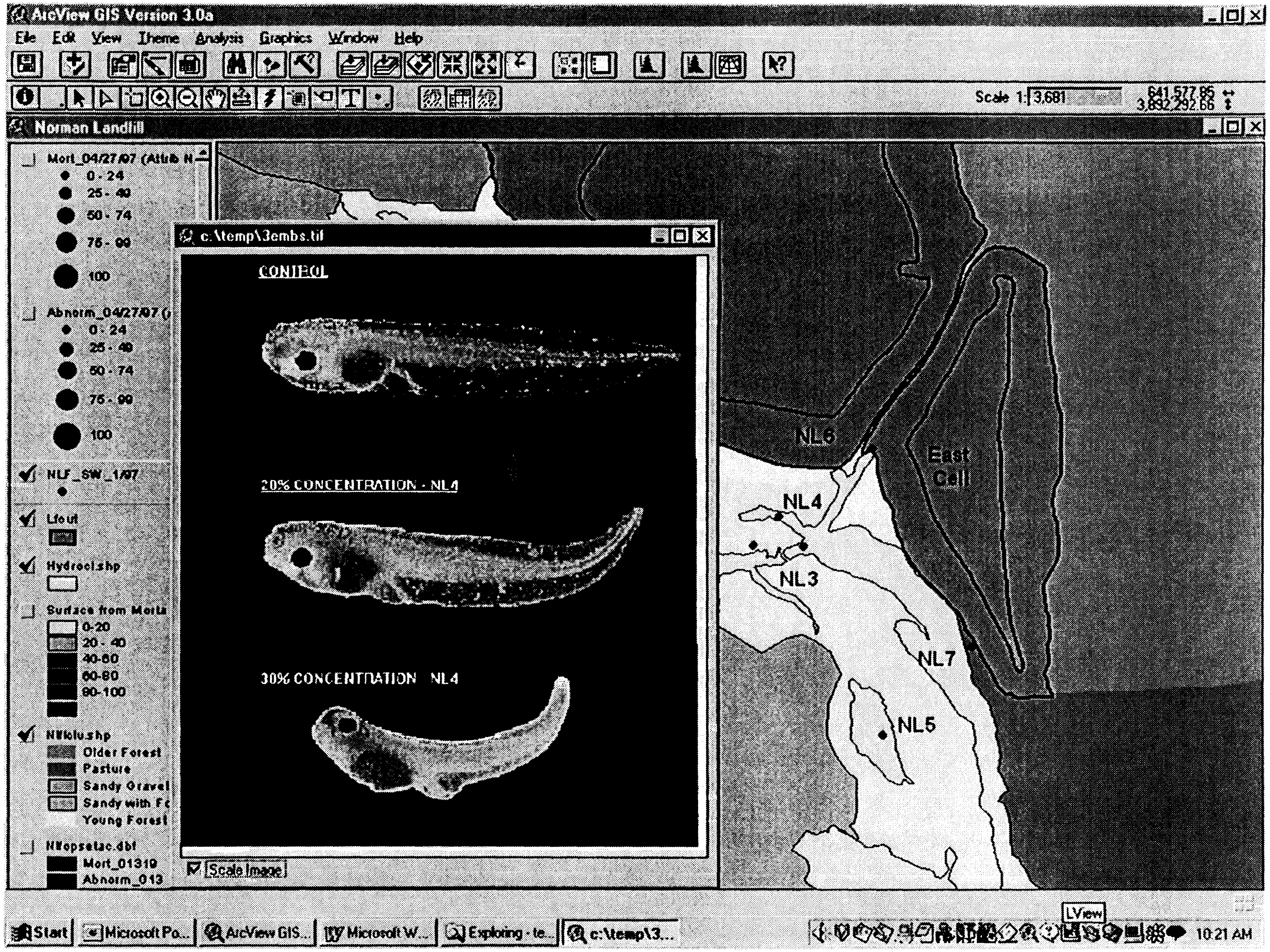

Figure 5. Hotlinked Image Showing Typical Embryo Malformations

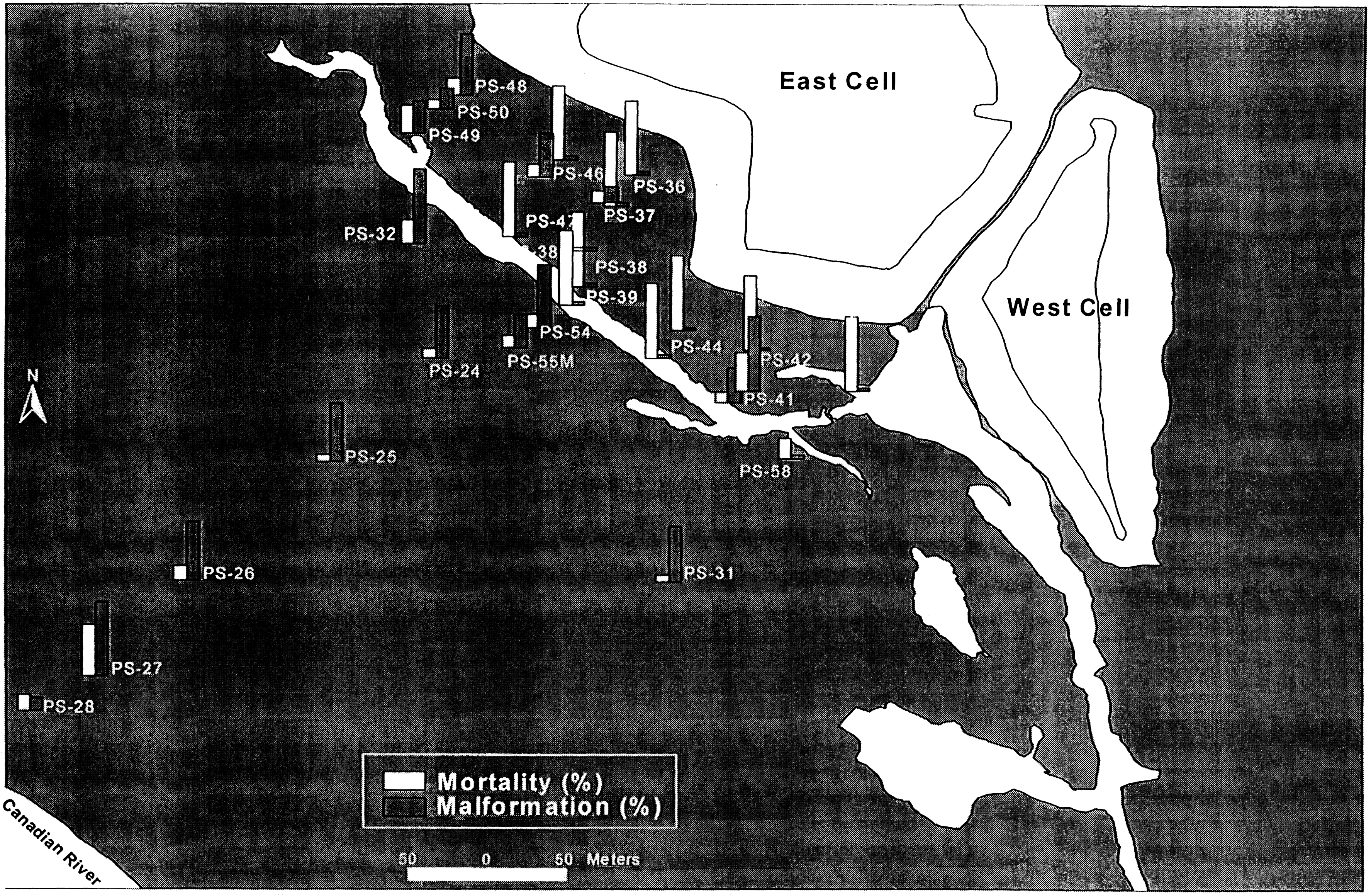

Figure 6. Groundwater Toxicity

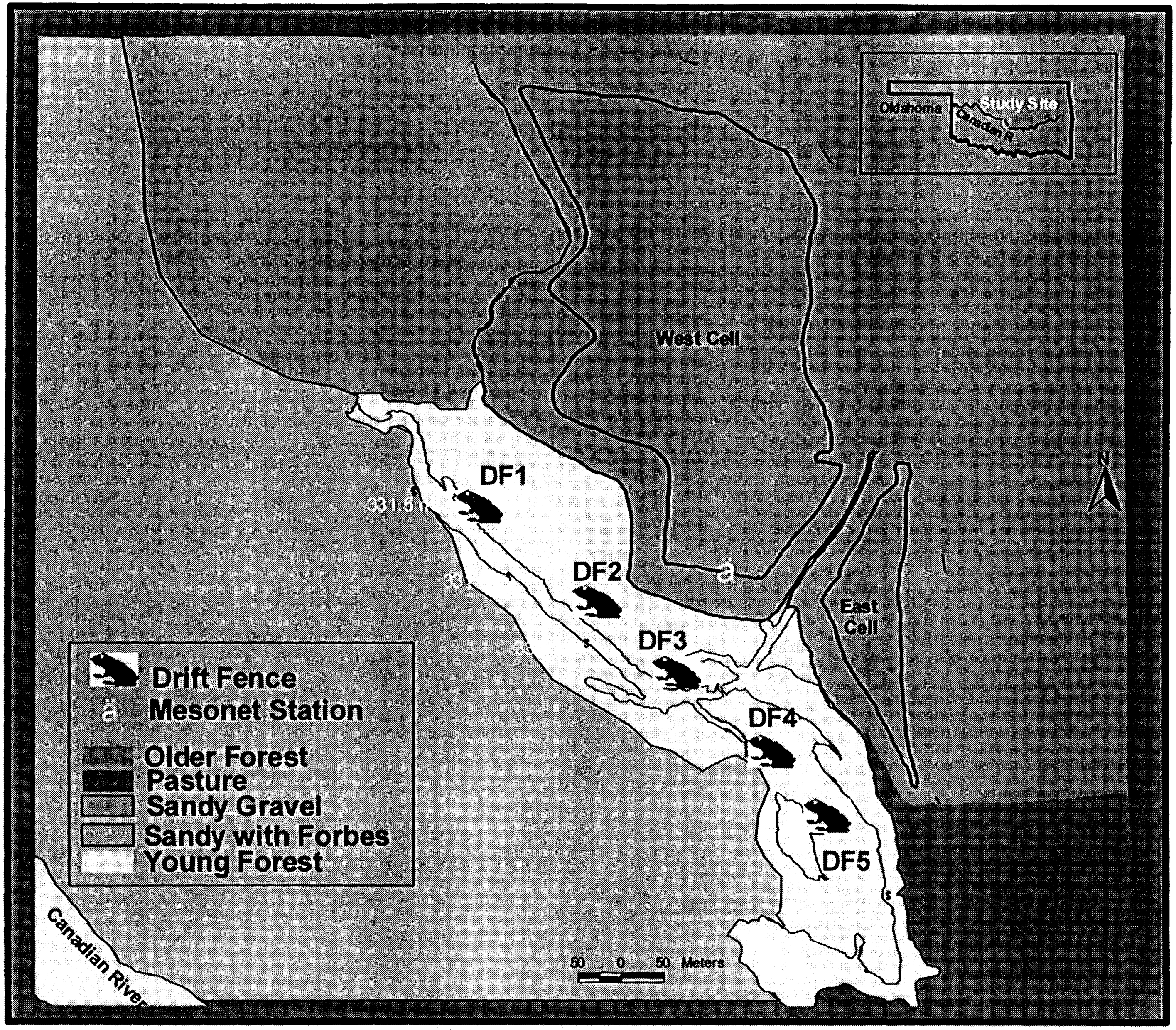

Figure 7. Drift Fence Locations at the Landfill Site

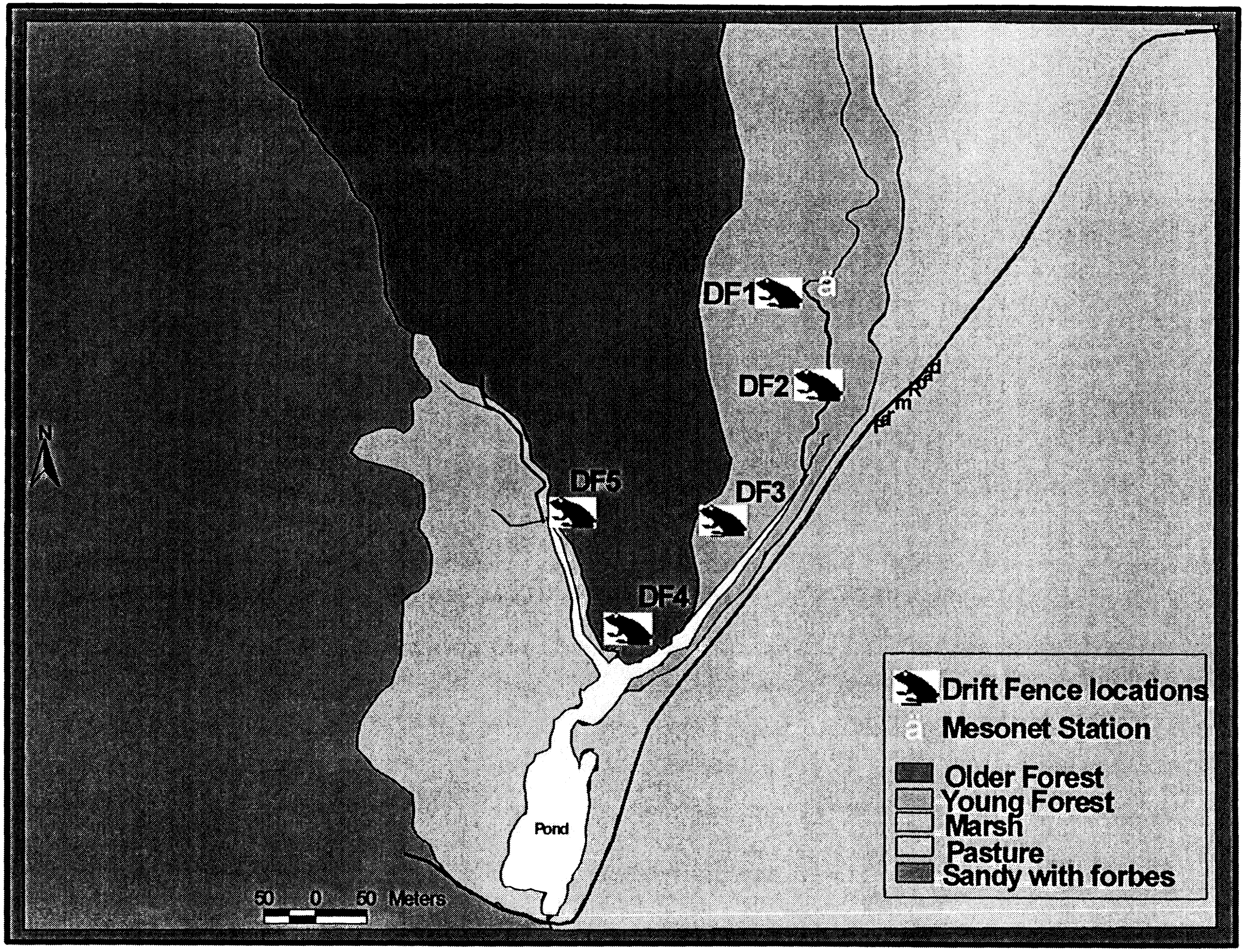

Figure 8. Drift Fence Locations

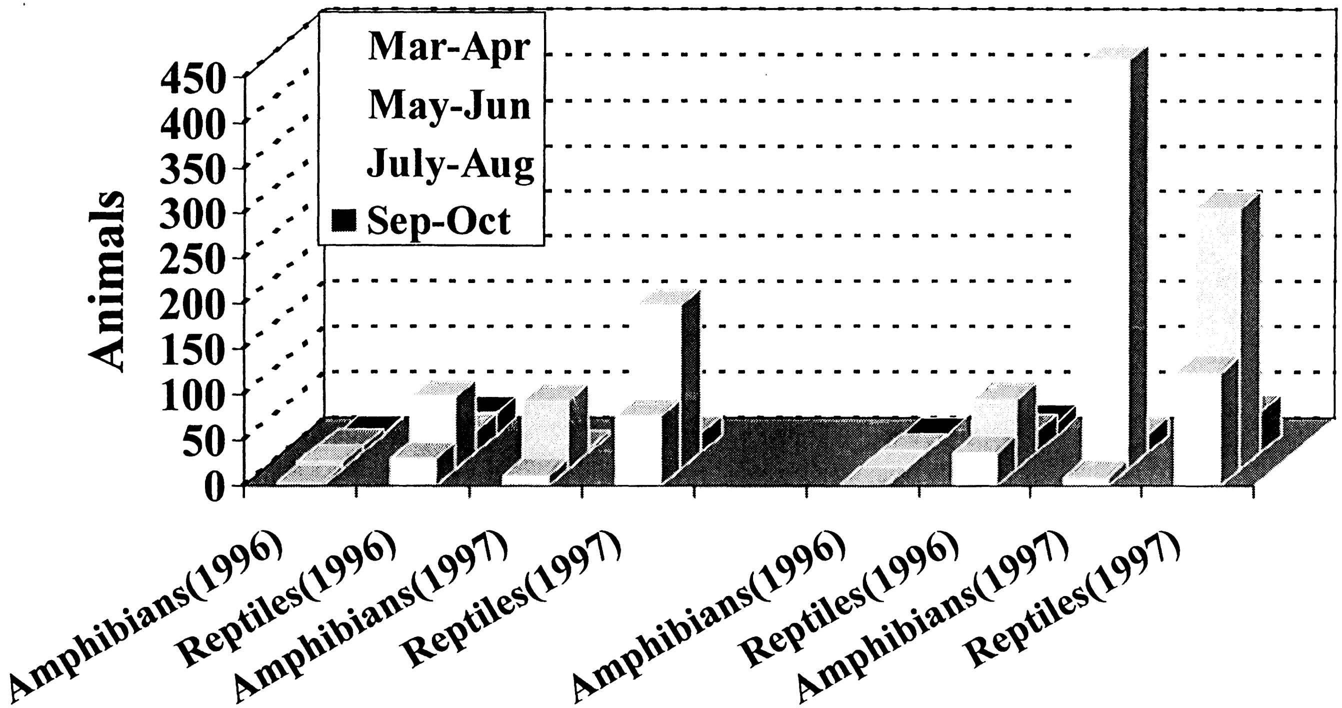

Figure 9. Total Number of Amphibians and Reptiles Observed at the Landfill and Reference Sites

Table 1
Correlation Coefficients (Pearson's *r*) of Biomonitoring Data vs. Weather Variables for the Landfill (NLF) and Reference Sites (REF)

YEAR	SITE	SPECIES	RELATIVE HUMIDITY	AIR TEMP	WIND SPEED	RAIN	SOLAR RADIATION	NET RADIATION
1996	NLF	Amphibians	0.06	0.26	-0.21	**0.38***	0.24	0.00
		Reptiles	-0.16	0.23	0.08	0.12	**0.46***	**0.79***
	REF	Amphibians	0.13	0.27	-0.05	**0.51***	0.16	#
		Reptiles	0.04	**0.55***	-0.24	-0.11	**0.41***	#
1997	NLF	Amphibians	**0.35***	**0.19***	**-0.18***	0.02	-0.06	-0.12
		Reptiles	-0.04	**0.23***	-0.15	-0.14	**0.44***	**0.38***
	REF	Amphibians	**0.32***	**0.18***	-0.10	**0.42***	-0.02	#
		Reptiles	-0.07	**0.27***	-0.13	-0.02	**0.47***	#

* $p < 0.05$ significance

Net Radiation not recorded at reference site.